Super Truck Program: Engine Project Review

Recovery Act – Class 8 Truck Freight Efficiency Improvement Project

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Overview

Timeline

• Project start: April 2010
• Project end: March 2015
• Percent complete: 20%

Budget

• Total project: $79,119,736
  • DOE: $39,559,868
  • Daimler: $39,559,868
• Budget is split between engine and vehicle projects (DDC & DTNA)
• 2010 engine budget $5,126,628
  • DOE: $2,563,314
  • Detroit Diesel: $2,563,314

Barriers

• Rankine engine has significant technical hurdles

Partners

• Department of Energy
• Oak Ridge National Laboratory
• Massachusetts Institute of Technology
• Atkinson LLC
• Daimler Trucks North America
• Daimler Advanced Engineering
Program Objective

- Super Truck (ST) program goal: 50% improvement in freight efficiency
  - Measured in ton-miles/gallon over typical heavy truck drive cycle
  - Baseline is production 2009 Cascadia with DD15 Engine
- Super Truck engine goal: 50% brake thermal efficiency at a condition representative of over the road operation
  - Base engine – 47%
  - Parasitic reduction – 48%
  - Waste heat recovery – 50%

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\text{BSFC (kg/kWhr)} \\
\begin{array}{cccccc}
0.140 & 0.150 & 0.160 & 0.170 & 0.180 & 0.190 \\
35.0 & 40.0 & 45.0 & 50.0 & 55.0 & 60.0 \\
\end{array}
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50% eff = 0.167 kg/kWhr
55% eff = 0.152 kg/kWhr

![Graph: Engine Thermal Efficiency vs BSFC]
Super Truck Program: 8 Cross-Functional Workstreams

- Engine Downsizing & Hybrid
- Powertrain Integration
- Energy Management
- Parasitic Losses
- Aerodynamics
- Weight Reduction
- Waste heat Recovery
- Predictive Technologies

50% Improvement in Freight Efficiency
Engine Down Sizing

In the early 1990’s, 11-13L engines dominated

Today, 13-15L engines dominate

- Some reasons technical, some user based

Where is engine size headed?

- Drivability
- CO2/fuel economy
- Weight
- Cost
- Hybrids
Horsepower Rating and Operating Speed Analysis

Drivability studies have been performed.

Over the past 20 years, engine ratings have drifted higher, resulting in higher speeds on hills, fewer shifts and increased driver satisfaction. Downside is fuel economy.

Balancing driver satisfaction vs. fuel economy is an interesting challenge.
Combustion System Update

Objective: Evaluate 2-step piston bowl; showed improved bsfc on single cylinder.

Results varied for the different bowl shapes, but baseline bowl bsfc remained competitive. However, significant (>30%) reductions in engine smoke levels were seen with 2-step bowl.

Follow-on activity: heads with higher swirl level are being procured as this is expected to be an important factor in effecting 2-step bowl bsfc based on single cylinder testing.
Engine Performance vs. NOx

- BSFC [kg/kWhr]
- EGR_PCT [%]
- SMK_FSN [FSN]
- TPI [kPa]

Graphs showing engine performance metrics against NOx, including in-cylinder volume, pressure, and other performance indicators.
Pumping Loss vs. NOx

Simulation shows higher bsfc with today’s air system at increased NOx levels

- Also shows significant bsfc improvement with air system re-matched for lower EGR rates at higher NOx

For Super Truck, air/EGR system must be re-matched to reduce pumping loss at lower EGR flow rates
Super Truck Engine Controls – Objectives

- Develop a **predictive** engine controller
- Include a fuel efficiency optimizer
- Integrate predictive vehicle information
- Reduce calibration complexity

Extensive engine mapping is used in neural network model training

Emissions & fuel economy models enable on-board BSFC optimization

Calibration Constraints
- Drivability
- Durability
- Fuel economy
- Life-cycle cost
- NOx / PM / NMHC / CO₂
- OBD
- Exhaust temperature
- GPS / Route / Traffic info.

Predictive route information enables enhanced use of engine optimization.
Super Truck Engine Controls – Test Results

Implemented controller logic on engine in transient test cell

The controller provide significant CO₂ vs. NOx flexibility

Preliminary tests completed on heavy duty truck

Controller response under road load conditions (1500 RPM / 1500 N.m)
Parasitic Reduction: Targeting >4% bsfc Improvement

Multiple systems being optimized.

- Kit friction, overall engine friction, and accessory loads

Smarter use accessories and pumps

- Increased electronic control/optimization

2010 progress

- 1.5% improvement demonstrated in test cell and on vehicle.
- Parts on order to allow demonstration of an additional 1.5% (anticipated) improvement.
- Feasibility evaluation underway for further improvements of >1%. Verifying risk to engine and required enabling technologies.
  - Partnered with Massachusetts Institute of Technology (MIT)
Aftertreatment

- Aftertreatment program focused on next generation materials
  - Objective is lower dP for improved engine operating efficiency and improved DEF-SCR efficiency to allow for higher engine out NOx
    - New DOC material for reduced back pressure
    - New material DPF for lower back pressure while maintaining soot storage capability
    - New DEF-SCR with focus on higher NOx conversion efficiency
  - Sizing and design work complete
    - Part procurement underway
    - Scheduled arrival at DDC: July 2011
Waste Heat Recovery

Approximately 55% of fuel energy is “waste heat”

Waste heat recovery

- Turbocompound – will be fitted to ST engine
- Rankine cycle – recover energy from EGR and/or exhaust gases
  - 5% BSFC improvement expected
  - Significant technical challenges
    - Heat exchangers, expander, compressor, packaging, engine integration, etc
- Status – system sizing and significant component level testing underway

Development Partners

- Oak Ridge National Laboratory
- Daimler Advanced Engineering Group
Simulation and Packaging

- Multiple simulation tools being used
  - Thermodynamic calculator to GT-Power
  - Being performed at ORNL and Detroit
- Component testing @ Daimler Research
- Packaging studies underway
Rankine Major Components

- **Evaporator**: High efficiency heat exchanger located at ATD outlet. Transfer exhaust energy to working fluid.
- **Expander**: Handle 2-phase flow. Withstand high pressure ratio. High speed for electricity generation.
- **Working Fluid**: Ethanol. Low environmental impact. Thermodynamic properties suitable for Rankine cycle.
- **Condenser**: Handle 2-phase flow. Rejected heat will be released back to environment under hood.
- **Pump**: Hermetically sealed Diaphragm pump.
Collaboration and Support

• Department of Energy Head Quarters
  • Gurpreet Singh
  • Roland Gravel

• National Energy Technology Laboratory
  • Carl Maronde

• Oak Ridge National Laboratory
  • Waste heat recovery modeling and testing

• Massachusetts Institute of Technology
  • Low friction technologies

• Atkinson LLC
  • Advanced engine controls
Summary and Future Work

- First year of Super Truck program complete
- Engine displacement and rating have been selected
- Base engine performance:
  - 2-step piston bowl showed significant smoke improvement, but at slight expense of bsfc. Higher swirl heads being investigated.
  - BSFC benefit of higher engine out NOx is feasible with re-matched air system
- Over 1% bsfc already demonstrated via reduced parasitics with more on the way
  - Partnered with MIT for studies into new oils, additives, and material coatings.
- Next generation engine optimizing controller functioning well in lab and (limited) vehicle tests
- Aftertreatment system re-design complete and prototypes due in July 2011
- Waste heat recovery system being extensively modeled, component level testing underway, and system procurement to begin in summer 2011.