Super Truck Program: Vehicle Project Review

Recovery Act – Class 8 Truck Freight Efficiency Improvement Project

Derek Rotz (PI & Presenter)
Dr. Maik Ziegler
Daimler Truck North America LLC
June 19th, 2014

Project ID: ARRAVT080
Overview

Timeline

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

Budget

- Total project $79,119,736
- Vehicle budget $47,486,735
  - DOE share(*) $15,526,639
  - DTNA share (*) $15,526,639

Barriers

- Resolve thermal & fluid dynamics tradeoffs between aero & cooling
- Rejecting more heat in a smaller, aerodynamic hood & engine compartment
- Development of safe and efficient high voltage power distribution, integrating multiple HV energy sources
- Making tradeoffs between efficiency, cost and weight
- Vehicle controls integration (aux, hybrid, powertrain, waste heat, predictive)

Partners

- Detroit Diesel
- Schneider National, Walmart
- National Renewable Energy Lab
- Oregon State University
- Strick Trailer
- Michelin
- ...
# Objectives and Milestones

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

- At least 20% improvement through a heavy-duty diesel engine capable of achieving a 50% brake-thermal efficiency
- Identify key pathways towards achieving 55% through modeling and analysis

<table>
<thead>
<tr>
<th>Timeline</th>
<th>Phase Description</th>
<th>Milestones</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/10–3/11</td>
<td><strong>Analysis:</strong> (1) Technology Modeling/Analysis and Initial Component Development</td>
<td>Develop analytical roadmap:</td>
</tr>
<tr>
<td></td>
<td>and Demonstration</td>
<td>• 50% vehicle freight efficiency improvement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 50% engine brake thermal efficiency</td>
</tr>
<tr>
<td>4/11–3/12</td>
<td><strong>Specification:</strong> (2) Experimental Demonstration of Technology Building Blocks</td>
<td>Experimentally demonstrate technology building blocks:</td>
</tr>
<tr>
<td></td>
<td>for Intermediate Goals</td>
<td>• 25% vehicle freight efficiency improvement (system level test)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 46% engine brake thermal efficiency</td>
</tr>
<tr>
<td>4/12–5/13</td>
<td><strong>Design:</strong> (3) Technology Identifications and Final Component Development and</td>
<td>Identify and initially develop technology building blocks:</td>
</tr>
<tr>
<td></td>
<td>Demonstration</td>
<td>• 50% vehicle freight efficiency improvement (system level test &amp; analysis)</td>
</tr>
<tr>
<td></td>
<td>(4) Experimental Demonstration of Technology Building Blocks for 50% Engine Thermal</td>
<td>• 50% engine brake thermal efficiency</td>
</tr>
<tr>
<td></td>
<td>Efficiency and 50% Vehicle Efficiency</td>
<td></td>
</tr>
<tr>
<td>6/13–6/14</td>
<td><strong>Build:</strong> (4) Experimental Demonstration of Technology Building Blocks for 50%</td>
<td>Experimentally demonstrate technology building blocks:</td>
</tr>
<tr>
<td></td>
<td>Engine Thermal Efficiency and 50% Vehicle Efficiency</td>
<td>• 50% vehicle freight efficiency improvement (system level test)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 50% engine brake thermal efficiency</td>
</tr>
<tr>
<td>7/14–3/15</td>
<td><strong>Test:</strong> (5) Final System Integration and Demonstration</td>
<td>Experimental demonstration:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 50% vehicle freight efficiency improvement (entire vehicle test)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 50% engine brake thermal efficiency (engine test)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 55% engine brake thermal efficiency (engine analysis)</td>
</tr>
</tbody>
</table>
Phase I Milestone Completed

Analytical roadmap development to 50% vehicle FEI & 50% engine BTE

Baseline Tractor
- 2009 Cascadia 125”BBC, 72”RR
- DD15 Engine 455hp/1550 lb-ft

Vehicle Test
- Baseline Performance Measurements
- Highway Cycle (55 & 65 mph)
- Idle Cycle (summer, winter)
- City Cycle

SuperTruck
- Establish System Level Technical Targets

Modeling & Analysis

Roadmap: Vehicle

Roadmap: Engine

(Engine topics covered in separate session)
Phase 2 & 3 Milestone Status

Experimental testing to 25% & 50% vehicle freight efficiency*

Freight Efficiency Improvement % - (system level measurements)

- Aerodynamics (Scale WT): 16.0%
- Powertrain Drivetrain (incl. hybrid): 16.5%
- Lightweight: 5.0%
- Energy Management (incl. idle reduction): 3.5%
- Parasitic Losses: 1.0%

Engine (to 48.1% BTE): 14.5%

* Technical Accomplishments covered in the 2012-2013 Annual Merit Reviews
Phase 4: Road to 50%

A-Sample
- Aero hood, bumper, grille
- Downsized Engine, Automated Manual Trans. + eCoast
- Waste Heat Recovery (electrical expander & vehicle cooling)
- 6x2 Axle Tall RAR + oil management
- Hybrid Electric Powertrain (120kw eMotor, 360v, 2.4 kw-hr usable Li-Ion Bat)
- eHVAC (HV compressor, remote condensor, electrical fan)
- eMotor engine start
- Cab insulation package
- Clutched air compressor
- Electronic air control
- AccuSteer
- Low RR wide based single tires
- Thermal management
- Trailer aero., lightweighting and solar

Final Demonstrator

2009 Baseline Cascadia
A-sample SuperTruck Build

Purpose: to prototype a functional chassis to integrate vehicle systems:

- Downsized Engine, Waste Heat, Hybrid, Cooling
- High Voltage Power Distribution
- Powertrain/Drivetrain Integration
- Software integration e.g. Shift optimization
- Packaging, Routing & Plumbing etc.

Testing completed to date:

- Full Scale Wind Tunnel (underhood airflow)
- eMotor cold start
- Thermal tunnel test
- eHVAC test & calibration
- Vehicle Performance Testing
Waste Heat Recovery Status

Accomplishments

• Successful Key-on workshop in November including HV electrical components

• 6kw peak exhaust energy recovered under high load, steady state conditions

Current Tasks

• Develop de-aeration strategy

• Improve control stability during transient operation
A-Sample Thermal Tunnel Testing

Vehicle Measurements

Ambient Capability *Engine* + *Waste Heat*
- 113°F (45°C) reached

Engine Air Intake
- Stayed below temperature rise limits
- Pressure measurements noisy

Fan Speed Characterization
- Swept temperatures (25-40°C)
- Swept wind speeds (20-40mph)
- Grille open & closed positions
- Fan speed remained below 1000 RPM
A-Sample Air Flow Study in Wind Tunnel

Vehicle Measurements

<table>
<thead>
<tr>
<th>Cruise Speed (58mph)</th>
<th>Air Flow (kg/s)</th>
<th>Drag</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A-sample configuration</strong></td>
<td>Eng, WHR, CAC</td>
<td>$\Delta C_d$ $\left(0^\circ \text{Yaw}\right)$</td>
</tr>
<tr>
<td>Nominal</td>
<td>baseline</td>
<td>baseline</td>
</tr>
<tr>
<td>Cooling optimized grille</td>
<td>+3%</td>
<td>0%</td>
</tr>
<tr>
<td>Aero optimized grille</td>
<td>-57%</td>
<td>-6%</td>
</tr>
</tbody>
</table>
eMotor Cold Start Test

Vehicle Measurements

Test Procedure

- 24 hour cold soak
- 0 to -15°C by 5° incr.

Observations

- No eMotor torque increase at lower temps.
- Peak Li-ion battery current at 112A

Conclusions

- Temperatures of -15°C easily achievable
- Data indicate -20 to -25°C starting possible
- >1% Freight Efficiency gained
  - Omit starter and Pb-Acid starting batteries
Vehicle Level Performance Test ✓
March-April, 2014: On Highway Fuel Economy Test

### Technical Accomplishments A-Sample Truck

#### Gross Vehicle Weight (lb)

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Tare</th>
<th>Payload</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Cascadia</td>
<td>65,000</td>
<td>34,000</td>
<td>31,000</td>
</tr>
<tr>
<td>A-Sample Test Vehicle</td>
<td>65,000</td>
<td>32,450</td>
<td>32,550</td>
</tr>
</tbody>
</table>

1550 lbs. additional freight on A-Sample ➔ 5% Freight Efficiency Improvement

#### Grade Profile

- **San Antonio Dallas (SDS)**: 65 mph
- **Portland Canyonville (PCP)**: 55 mph

#### Daily Fuel Economy

<table>
<thead>
<tr>
<th>Date</th>
<th>A-Sample (ton-mpg)</th>
<th>Baseline (ton-mpg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/26</td>
<td>5.0%</td>
<td>52.0%</td>
</tr>
<tr>
<td>3/27</td>
<td>5.0%</td>
<td>61.6%</td>
</tr>
<tr>
<td>3/31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4/1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4/8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4/9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4/10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Grade Profile

- **San Antonio Dallas (SDS)**: 65 mph
- **Portland Canyonville (PCP)**: 55 mph

#### Fuel Weight Improvement

- **A-Sample % improvement**
  - PCP: 57%
  - SDS: 66%
Phase 4: Road to 50%

Final Demonstrator

A-Sample Technologies, plus…
- Full Tractor Aero
- 50% BTE Engine + WHR
- Predictive hybrid & engine controllers
- Axle - Active oil management with FE gear oil
- Lightweight Aluminum Frame and cross members
- Ultra Lightweight Air Suspension
- Smart 6x2
- Solar reflective paint
- Enhanced Trailer aerodynamics

2009 Baseline Cascadia

A-Sample

Final Demonstrator
Aerodynamics Validation in Scale Model Wind Tunnel

SuperTruck vs. Baseline

Drag Reduction Contribution

- Tractor \( \Delta C_d = -15\% \)
- Trailer \( \Delta C_d = -39\% \)

Percentage of Test Runs

- Tractor 67%
- Trailer 33%
Final Demonstrator Build

**Chassis**
- Frame, Suspension, Axles complete
- Powertrain & cooling Installed
- Wiring & plumbing on-going

**Cab Exterior**
- Design release complete incl. A&B side parts
- Molds & exterior parts 80% complete
- Pre-fit completed by June

**Cab Interior**
- Sleeper design complete
- Components & assy. ongoing
- Ship to Portland in June

Build progressing for Sept 1st FE test start
Super Truck Partnerships and Collaborations

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

<table>
<thead>
<tr>
<th>Energy Management</th>
<th>Hybrid</th>
<th>Aero/Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>NREL</td>
<td>MBtech</td>
<td>ARC Auto Research Center</td>
</tr>
<tr>
<td>DELPHI</td>
<td>FUSO</td>
<td>CD-adapco</td>
</tr>
<tr>
<td>OSU</td>
<td>Eaton</td>
<td>TITANX</td>
</tr>
<tr>
<td>Telogis</td>
<td>MiaSolé</td>
<td>Mekra Lang</td>
</tr>
<tr>
<td></td>
<td>US Hybrid</td>
<td>Modine</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Freight WING</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lightweighting</th>
<th>Powertrain/Parasitics</th>
<th>Fleet</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSU</td>
<td>DETROIT</td>
<td>SCHNEIDER</td>
</tr>
<tr>
<td>‘TORAY’</td>
<td>CON-MET</td>
<td>Pointing the Way</td>
</tr>
<tr>
<td>STRICK</td>
<td>MICHELIN</td>
<td>RAW</td>
</tr>
<tr>
<td></td>
<td>ACCURIDE</td>
<td>Save money. Live better.</td>
</tr>
<tr>
<td></td>
<td>Parker</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bendix</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ASHLAND</td>
<td></td>
</tr>
</tbody>
</table>
Summary and Future Work

Successful completion of phases 1-3; Phase 4 targets met

- 50% Vehicle Freight Efficiency target exceeded on A-Sample vehicle through testing on Portland-Canyonville and San Antonio-Dallas routes
- 50% Engine Brake Thermal Efficiency target exceeded in engine test cell

Next Steps

- Complete buildup of 2 final demonstrator vehicles
- Conduct fuel economy testing
Backup
Project Year 4 (PY4) Engine BTE Improvement \( \rightarrow \) 2.1% points

- **PY4 Enablers**
  - Further increase in compression ratio (CR), piston bowl and matching injector profile optimization.
  - 3rd Iteration of turbo-charger.
  - Optimized liner cooling.
  - EGR waste heat recovery.
  - WHR component and calibration optimization.