Super Truck Program: Vehicle Project Review

Recovery Act – Class 8 Truck Freight Efficiency Improvement Project

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Project ID: ARRAVT080
Overview

Timeline

- Project start: April 2010
- Project end: March 2015
- Percent complete: 40%

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)

Budget

- Total project $79,119,736
- Vehicle Budget $47,486,735
  - DOE Share(*) $6,100,000
  - DTNA Share (*) $6,100,000

Partners

- Detroit Diesel
- Schneider National, Walmart
- National Renewable Energy Lab
- Oregon State University
- Strick Trailer
- Michelin
- …

(*) through Feb, 2012 for vehicle R&D expenses only, engine R&D expenses reported separately
# Objectives and Milestone

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

Modeling & Analysis

• Establish System Level Technical Targets

Roadmap: Vehicle

Roadmap: Engine
Phase 2 Milestone Status

Experimental testing to 25% vehicle freight efficiency

Freight Efficiency Improvement % - (system level measurements)

- Aerodynamics (Scale WT) 10.0%
- Powertrain Drivetrain 7.5%
- Lightweight 5.0%
- Energy Management (incl. idle reduction) 3.5%
- Parasitic Losses 1.0%
- Hybrid (FE test Q3, 2012) 9.0%
- Engine (to 46% BTE) 25.0%

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Experimental Tests Conducted on ‘Tinker’ Trucks

Hybrid ‘Tinker’ Truck

SAE Hybrid Committee
Standards development for electrification of Powertrain and Accessories

HEV / Engine controls Integration

HV Power Distn.

eMotor Starter

Rear Axle Config/ Ratio

Direct Drive AMT w/ optimized shifting

Powertrain & Parasitics ‘Tinker’ Truck

Predictive Torque Mgt.
AccuSteer
Clutched Air Comp.
Electronic Air Control

Anti-Idle
eHVAC
Cooling Package

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

30% drag reduction target exceeded in CFD and Scale Wind Tunnel Tests

Trailer Aerodynamics

- Run 1a
- Run 1b
- Run 2
- Run 5b
- Run 3a
- Run 3b
- Run 4a
- Run 4b
- Run 5a

Tractor – Basic Shape Analysis

- Notional 1
- Notional 3

CFD and Scale Wind Tunnel Testing
- Conducted steady state, closed grill simulation & testing
- Conducted transient, open grill simulation & testing
- Results correlate

Trailer Aerodynamics Test Results

ΔCd Measured
- 15% reduction
Thermal Management / Cooling

Cooling concept developed to meet add’l heat rejection while maintaining aero.

3D CFD Thermal Analysis

1D Thermal Analysis

SuperTruck Cooling Requirements

Analysis Study Complete
• WHR cooling circuit analysis
• Hybrid cooling circuit analysis
• Alternative layouts and packaging
• Cooling Performance analysis

Pressure Drop Analysis

Load Sweep Analysis

Full Load Analysis

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Lightweighting

Chassis analysis and tests to 4.5 – 5.8% FEI reduction, Cab analysis on-going

Cab Exterior
- Target floor, side/backwall, roof, hood systems
- Evaluate & test lightweight, low cost sandwich structures
  - Cores - foams, honeycomb
  - Faces – Al, FRP

Frame Rails
- Composite designed, installed & tested
- Low Cost Aluminum designed & installed

Next Steps
- Cross member development
- Complete Load-Optimized frame design in conjunction with lightweight suspension

Technical Accomplishments and Progress

<table>
<thead>
<tr>
<th>Mechanical Property</th>
<th>Symbol</th>
<th>Day Cab Reqs.</th>
<th>Sleeper Cab Reqs.</th>
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<tbody>
<tr>
<td>Vertical Bending Stiffness</td>
<td>(E_{lv})</td>
<td>Exceeds</td>
<td>Meets</td>
</tr>
<tr>
<td>Lateral Bending Stiffness</td>
<td>(E_{lz})</td>
<td>Falls Between</td>
<td>Falls Between</td>
</tr>
<tr>
<td>Torsional Stiffness</td>
<td>(G_{T})</td>
<td>Exceeds</td>
<td>Meets</td>
</tr>
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Powertrain Drivetrain Integration

7.5% FEI measured with further tests scheduled

Engine Downspeeding

Modeling & Analysis
- Gear ratio Optimization on Transmission/Axle
- Shift strategy Optimization
- Gradeability / Startability

Testing
- Transmission/Axle Ratio Performance Q2, 2012

Tires/Wheels/Hubs

- Reduced Rolling Resistance
- Lightweight Wheels/Hubs
- Aero. Enhancements

Testing
- 1st Round of Testing Complete
- 2nd Round of Testing Q4, 2012

Axles

- Gear Oil Temperature Management
- Gear Oil Formulations
- Axle Configurations (traction enhanced 6x2)
Hybrid A-Sample

Analysis complete for sizing & performance, tests scheduled in Q3 2012

Modeling & Analysis
- Fuel Economy Estimation
- Component Sizing

(e.g. Battery SoC Analysis)

Digital Mockup

Cascadia HEV Component Location
A-Sample Hybrid Parts Layout

Hardware & Testing
- A-sample hardware installed
- Controls logic & EE integration (Hybrid + eHVAC)
- Functional testing on-going

Vehicle Testing
- eHVAC Q1, 2012
- Highway /City FE test scheduled Q3, 2012
Parasitic Losses

*Testing & Analysis show up to combined 1.5% FEI potential*

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**Power Steering**
Closed Center Steering Gear  
*(constant pressure, variable flow)*

Modeling & Analysis Complete
- Performance Estimate
- Component sizing, controls developed
- Hardware procured
- Installation and Test scheduled for Q2, 2012

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**Air System**
Clutched Air Compressor + Electronic Air Dryer

Air System Testing Complete
- Significant reduction in purge cycles
- Lower average compressor power
Energy Management

Predictive Torque Management
Limits torque based on vehicle mass and road grade to limit excessive accelerations, via J1939 TSC1

Vehicle Testing Complete
• City Cycle route – up to 2.4% savings measured
• Customer Field Test: 5 tractors, 3 mo, >100,000 miles
• Driver Survey

Eco-Driver Feedback
Development Status
• A-Sample application complete, based on 4 criteria
• Fuel & Fleet Test Scheduled
• Customer field Test

Predictive Auxiliary Load Mgt.
Intelligently controls thermostatic valve, coolant pump & fan based on predictive engine load, and 3D Digital Maps.

Development Status
• 2 state coolant Pump successfully tested
• Controls developed, hardware installed & functionally tested
• Fuel Economy Test for thermostat & full variable pump scheduled for Q2, 2012
Energy Management Anti-Idling

Completed testing indicates program on track to meet 4% FEI targets

固体氧化物燃料电池测试
- SOFC空转燃料消耗期间的夜间
- 功率输出扫描
- SOFC最大功率输出时间
- 启动和关闭测量。

货车隔热测试
- 热浸
- 热转换
- 热成像
- 空气交换
- 保温/辐射屏障

混合动力和静止eHVAC
- 控制开发完成
- e-fan
- e-compressor
- 发动机启停

eHVAC测试计划在Q1, 2012结束
SuperTruck Partnerships and Collaborations

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

Energy Management
- NREL
- DELPHI
- OSU
- Telogis

Hybrid
- FUSO
- MBtech
- Mercedes-Benz
- itk

Aero/Cooling
- ARC
- CD-adapco
- SILVER EAGLE
- MODINE

Lightweighting
- OSU
- TORAY
- TRUCK
- INMAGUSA

Powertrain/Parasitics
- DETROIT Engine
- MET
- Michelin
- Accuride
- Bendix
- Ashland

Fleet
- SCHNEIDER
- Walmart

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Vehicle Summary and Future Work

Successful completion of phase 1 & phase 2 targets on schedule

Technology Building blocks to 25% FEI measured

- Aerodynamics / Cooling
- Powertrain / Parasitics
- Anti-idling
- Lightweighting
- ...

Next Steps

- Continued System Level Testing
- Complete Full-Scale Cab Exterior Model for Aero
- Buildup of preliminary ST Chassis for System Integration
- Complete Integrated Tractor/Trailer Development for Lightweighting & Aero
Technical Backup Slides
Energy Management

Solar

Modeling & Analysis
- Freight Efficiency potential identified
- high-variability in performance

Vehicle Testing
- Scheduled Q2, 2012

Efficient Operations

Algorithm Development Complete
- Routing based on fuel consumption

Verification/Validation & Tests
- Simulation-Routing Verification work on-going
- Fleet Analysis, Q2 2012
Engine Summary and Future Work

- Engine has demonstrated 46.2% brake thermal efficiency
- Plans firmly in place for next level of performance improvement:
  - Higher compression ratio including new piston bowl and injector tip
  - Iterate SCR design for lower pressure drop
  - Reduced engine parasitics
  - Continue controls development and refinement
  - Waste heat regeneration development
    - Expander and generator
    - Add EGR waste heat recovery
    - Integrate onto vehicle