Super Truck Program: Vehicle Project Review

Recovery Act – Class 8 Truck Freight Efficiency Improvement Project

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Project ID: ARRAVT080

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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 DTNA direct hrs + material
- Total: $2,707,000
- DOE: $1,354,000
- DTNA: $1,354,000

Barriers
- Risk: aggressive freight efficiency target
- Complexity of vehicle integration

Partners
- Oregon State University
- Detroit Diesel, Daimler Research
- Schneider National, Walmart
- Great Dane
- ARC
- Solar World Industries America Inc.
- Department of Energy
**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
Eight Cross-Functional Workstreams

- Engine Downsizing & Hybrid
- Powertrain Integration
- Energy Management
- Parasitic Losses
- Aerodynamics
- Weight Reduction
- Waste heat Recovery
- 50% Improvement in Freight Efficiency
- Predictive Technologies
# Baseline Evaluation

## Highway Cycle (58 mph)
- **Distance:** 401 miles
- **Tests completed:** 5 x round trip
- **2 x tractors**
- **Data Collected:** 1.7 GB
- **Channels:** 126

## Highway Cycle (65 mph)
- **Distance:** 438 miles
- **Test completed:** 5 x round trip
- **2 x tractors**
- **Data Collected:** 1.7 GB
- **Channels:** 126

## Urban Cycle (30 – 45 mph)
- **Distance:** 25 miles
- **Test completed:** 15 x round trip
- **2 x tractors**
- **Data Collected:** 0.7 GB
- **Data Collected:** 0.7 GB
- **Channels:** 126

## Idle Cycle
- **Cycle:** 10 hour idling
- **Duration:** 5 hours *(summer mode)*
- **Duration:** 5 hours *(winter mode)*
- **Test completed:** 4 x tractors
- **Data Collected:** 0.4 GB
- **Channels:** 126
# Vehicle Simulation Scenarios

## Baseline Truck
- **Coefficient of Drag & Frontal Area (Cd*A):** Cascadia 125" BBC 72" RR
- **Coefficient of Rolling Resistance (Crr):** Baseline
- **Transmission & Axle Ratios:** Overdrive std. rear axle ratio
- **Axle Efficiency (η):** Baseline Axles
- **Auxiliary Loads {off, on}:** on
- **Freight Mass:** 15.6 t
- **Regeneration:** No Regeneration
- **Idling:** Main Engine
- **Intelligent Controls:** Baseline

## Target Truck 1
- **Coefficient of Drag & Frontal Area (Cd*A):** Cascadia with Component upgrade
- **Coefficient of Rolling Resistance (Crr):** Low RR Dual Tires
- **Transmission & Axle Ratios:** Direct Drive Faster rear axle ratio
- **Axle Efficiency (η):** Conventional Axle Upgrades
- **Auxiliary Loads {off, on}:** on
- **Freight Mass:** 15.4 t
- **Regeneration:** Partial EB
- **Idling:** Current APU
- **Intelligent Controls:** Controllable Systems + Predictive Cruise

## Target Truck 2
- **Coefficient of Drag & Frontal Area (Cd*A):** Cascadia-based Full exterior upgrade
- **Coefficient of Rolling Resistance (Crr):** Low RR Super-Single
- **Transmission & Axle Ratios:** + optimized control strategy
- **Axle Efficiency (η):** 0.975
- **Auxiliary Loads {off, on}:** off
- **Freight Mass:** 15.8 t
- **Regeneration:** Partial EB + SB
- **Idling:** SOFC /Hybrid
- **Intelligent Controls:** + Additional Predictive Technologies

## Target Truck 3
- **Coefficient of Drag & Frontal Area (Cd*A):** “Bullet” Truck
- **Coefficient of Rolling Resistance (Crr):** Advanced Tire Technologies
- **Transmission & Axle Ratios:** Advanced Powertrain Technologies
- **Axle Efficiency (η):** Advanced Axle Technologies
- **Auxiliary Loads {off, on}:** off
- **Freight Mass:** 16.3 t
- **Regeneration:** Full EB + SB
- **Idling:** Advanced APU Technologies
- **Intelligent Controls:** Advanced Controls

## Fixed Parameters
- **Engine:** 15 liter 455/1550
- **GCVW:** 65000 lbs

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Increasingly aggressive targets
Vehicle Simulation Results-Energy Consumption

- Baseline Truck
- Target Truck 1
- Target Truck 2
- Target Truck 3

- Idle Losses
- Braking Losses
- Vehicle Losses
- Powertrain & Parasitics
- Engine Losses

Mass-Adjusted Energy Losses (kw-hr)
Roadmap: Vehicle-Side Technologies

Freight Efficiency Improvement (FEI)

- Aerodynamic Drag reduction
- Rolling Resistance Reduction
- Coaching
- Intelligent Controls
- Weight Savings
- Other Regen.
- Braking Regen.

Technologies:
- External Aerodynamics
- Tires
- Energy Mgt.
- Powertrain Integration
- Materials
- Hybrid
- Idle Reduction
- Parasitic Losses
External Aerodynamic Analysis

Scale Wind Tunnel Testing

Objective: 30% aero. drag reduction over baseline

Results to Date

- 268 hrs of wind tunnel tests
- Identification of significant parameters

Computational Fluid Dynamics

50+ full vehicle simulations (30,000 CPU-hrs)
- Drag Development
- Visualization

NEXT STEPS: lock-in macro tractor-trailer design features, investigate underhood thermal management
Hybrid Electric Architecture

Proposed Hybrid Architecture

- Parallel hybrid configuration
- Weight advantage
- Enabler for additional features (e.g. anti-idle)

Weight Impact Analysis

Results To Date

- Analysis of various architectures complete
- Simulation on Portland Route indicate sufficient fuel savings to meet target

NEXT STEPS: Further analysis to size components (E-motor, Battery) and buildup of hybrid system
Parasitic Losses

Objective: 2% Freight Efficiency Improvement through auxiliary optimization

Air Conditioning System
- Investigation of Single Circuit Layout

Target: Optimization of power consumer operation (fan, compressor)

Power Steering System
- Evaluation of efficient concepts

Open Center
- Constant Flow
- Variable Pressure

Closed Center
- Variable Flow
- Variable Pressure

Target: Minimization of Pump Power & Duty Cycle

NEXT STEPS: Evaluation / Selection of preferred concept sizing of system components
Idle Reduction Technologies

**Objective:** 4% Freight Efficiency Improvement over baseline (*main engine idling*)

### Solid-Oxide Fuel Cell APU

**Results:** SOFC-APU installed & tested on Cascadia, fuel measurement

**Characteristics:**
- Enables full-engine off Operations

### Hybrid System

**Results:** concept defined, preliminary energy calculations completed

**Characteristics:**
- Fast on/off time
- No dedicated added weight

➤ **NEXT STEPS:** evaluation / selection of preferred SuperTruck concept based on representative test cycles
Investigation Phase – Portfolio Analysis

- A portfolio analysis was performed to identify potential weight reduction concepts.
- Concepts were discussed and grouped according to short / medium / long term.
- Certain concepts were further investigated by a feasibility analysis.

Some of the proposed concepts include:

<table>
<thead>
<tr>
<th>Aluminum Frame Rails</th>
<th>Lightweight MMC components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal tailpipe</td>
<td>One-piece driveshaft</td>
</tr>
<tr>
<td>Load optimized frame rail</td>
<td>Multi-link suspension</td>
</tr>
<tr>
<td>Composite fuel tanks</td>
<td>Integrated suspension/ airbag system</td>
</tr>
<tr>
<td>Load optimized 5th wheel approach</td>
<td>Spaceframe chassis concept</td>
</tr>
</tbody>
</table>
Chassis – Load Sensitivity / Optimization Study

**Objective:** to save 1000 lbs while meeting loading criteria using innovative chassis design and new materials

**Conventional Frame**

**NEXT STEPS:** Evaluate cross-sectional geometries to meet deflection criteria with standard 5th wheel position

**Load-Optimized Frame**

**NEXT STEPS:** Concept development and load path analysis based on Topology Optimization.
Energy Management

Predictive Torque Management

• Limits torque based on vehicle mass and road grade to limit excessive accelerations.
• Torque Limit applied using J1939 TSC1 message.

Results To Date

• Simulations shows fuel saving based on limiting factor, terrain & driving behavior
• Prototype hardware installed and functional in vehicle

➔ NEXT STEPS: Conduct a fleet trial to evaluate ‘real-world’ performance and driver feedback, define calibration levels
Summary and Future Work

First Year of SuperTruck Complete

- Baseline vehicle & route specified
- Completed baseline testing
- Definition of technical measures on a system basis
- Vehicle improvement targets defined based on simulation
- Key accomplishments for concept development
  - Hybrid & Energy Management Simulation
  - FEA of Lightweight Frame
  - Aerodynamic and CFD Analysis

Future Work for 2011

- Complete high-level SuperTruck vehicle specification,
- Resolving technology conflicts
- Complete digital mockup
- Build up prototype systems for performance evaluation on 3 ‘tinker’ trucks
  - Hybrid, powertrain, chassis, aerodynamics
Collaboration and Support

Oregon State University
- Composite Frame Analysis
- Fuel Efficient Routing

Schneider National / Walmart
- Fleet Partner – Technology Evaluation

Great Dane
- Trailer Lightweighting & Aerodynamics

ARC
- Aerodynamics

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