SuperTruck – Development and Demonstration of a Fuel-Efficient Class 8 Tractor & Trailer Vehicle

DOE Contract: DE-EE0003303
Project Officer: Ralph Nine
Navistar Principal Investigator: Russ Zukouski

DOE MERIT REVIEW

12 June, 2015

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Program Overview

### Timeline

- **Project Start:** October 2010
- **Project End:** Sept 2016
- **% Complete:** 62%

### Barriers

- Achieving 50% freight efficiency while balancing Voice of Customer Needs
- Alignment with business needs
- Reducing tractor weight while adding new systems

### Partners

- **Navistar**
  - Principal Investigator, Vehicle Systems
  - Integrator Controls Systems, Engine & Vehicle Testing
- **Bosch**
  - Fuel Systems
- **Wabash**
  - Trailer Technologies
- **Argonne ANL**
  - Dual Fuel Engine testing, simulation & evaluation
- **Lawrence LLNL**
  - Aerodynamic CFD

### Budget

- **Total Funding:** $76,178,386
- **DOE:** $35,754,460
- **Prime:** $40,423,926
- **Funding FY2014:** $6,025,644
- **Funding for FY2015:** $8,965,646
Goals & Objectives - Relevance

• **Project Goal**
  • Demonstrate 50% improvement in freight efficiency of a combination Tractor-Trailer
  • Attain 50% BTE Engine
  • Demonstrate path towards 55% BTE Engine

• **March 2014 to March 2015 Goals**
  ✔ – Restart / ramp up program after “Pause” period
  ✔ – Re-evaluate technology concepts in lieu of original dual mode hybridization concept for vehicle
  ✔ – Build & evaluate mule truck
  ✔ – Complete Phase 2 (*concept phase/ technology roadmap*)
# Program Timing

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>2014</td>
<td></td>
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<tr>
<td></td>
<td>PHASE 2 (Technology Development)</td>
<td>PHASE 3 (Detail Design)</td>
<td>PHASE 5 (Verification Testing)</td>
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<tr>
<td>2015</td>
<td></td>
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<tr>
<td></td>
<td>START: 4/1</td>
<td>START: 5/21</td>
<td>START: 11/4</td>
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<tr>
<td></td>
<td>Dev Veh</td>
<td>CV (mule)</td>
<td>DV (final demo)</td>
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<td>2016</td>
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<td>DOE Demo</td>
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<td>Date: 9/2/16</td>
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Vehicle Partnerships and Completed tasks

**Navistar**
- Vehicle systems integrator
- Control Systems
- Base Engine

**Wabash National**
- Trailer Technologies

**BOSCH**
- Fuel Systems

**LLNL**
- Computational Fluid Dynamics

**ANL**
- Engine Design
- Controls deployment
- Fuel Reactivity testing

**Phase II**
- Concept technologies chosen
- 48.3% BTE achieved
- Load biasing dev truck built & evaluated
- Material procured for Mule build
- Engine Design
- Controls deployment

**Phase III-V**
- **50% + FE**
  - 50% FE
  - 50+ BTE Path 55% BTE

**PAUSE**

**Apr-12**

**Oct-12**

**Apr-14**

**Apr-15**

**Apr-16**

FE = Freight Efficiency (ton-miles/gal)
Vehicle Collaborators & Completed tasks

Oct-12  Apr-14

PAUSE

Phase II

Eaton ✓ Transmissions ✓ Concept technologies chosen

Dana ✓ Axles ✓ Concept technologies chosen

Hendrickson ✓ Suspensions ✓ Concept technologies chosen

Apr-15  Apr-16

Phase III-V

50% BTE

50% BTE

50% BTE
Technical Approach
Four Distinct Areas of Development

**Lightweighting**
- Lightweight Frame
- Composite Materials
- Lightweight Trailer

**Rolling Resistance**
- Energy Recovery
- Reduced Parasitic

**Aerodynamic Improvement**
- Tractor
- Trailer

**Powertrain Technologies**
- High Efficiency Drivetrain
- Stop/Start Idle Reduction
- Waste Heat Recovery
eTurbo
- Adv. After treatment
- Friction Reduction

Total Est. FE Improvement 50% +
Approach - Lightweighting

- Frame System (~0.5-1% FE$^1$)
  - Frame w/ Lightening Holes
  - Aluminum Cross Members

- Wabash National Trailer (~4-5% FE$^1$)

- Hybrid Front Suspension (~0.5-1% FE$^1$)
  - Aluminum Components
  - Composite Leaf Springs

- Lightweight IROS Rear Suspension (~0.5-1% FE$^1$)
  - Redesign
  - Aluminum Cross members
  - Composite Springs

1. Calculated, simulation or test data
2. Improvements shown relative to SuperTruck mule vehicle

FE = Freight Efficiency (ton-miles/gal)
Approach - Lightweighting

**Tire & Wheel Equipment (~1-2% FE\(^1\))**
- Wide Base Single Rear Tires
- Aluminum Rims/Hubs
- Steel Shell Brake Drums

**Lightweight Driveshafts and Axles (~1-2% FE\(^1\))**
- 6x2 Configuration
- “Diamond Series” Aluminum Driveshaft

\(^1\) Calculated, simulation, or test data

2. Improvements shown relative to SuperTruck mule vehicle

**FE = Freight Efficiency (ton-miles/gal)**
• Development truck was configured to evaluate new suspension technologies:
  - 6x2 configuration with axle load control
  - Liftable dead axle

• Tests were performed on a closed loop track

• Fuel economy was demonstrated due to reduced rolling resistance using load biasing
Approach - Rolling Resistance

- **Rolling Resistance (~7-8% FE\(^1\))**
  - Wide-Base Single Tires
  - Timken PDFE high efficiency bearings

- **“Smart” Subsystems (~6-7% FE\(^1\))**
  - Cruise Control
  - High Temperature engine cooling
  - Air Compressor
  - Alternator /Generator
  - A/C compressor

FE = Freight Efficiency (ton-miles/gal)

1. Calculated, simulation, or test data
2. Improvements shown relative to SuperTruck mule vehicle

Single 4% downhill: 6.86% fuel saving, and 0.1% travel time increasing.
Approach - Aerodynamic Improvements

- Wind tunnel results
- Re-designed Cab and Aerodynamics
  - (10-12% FE$^1$)
- Aerodynamic Improvements
- Weight Reduction

$FE = \text{Freight Efficiency (ton-miles/gal)}$

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Approach - Aerodynamics Improvements

- Wind tunnel results
- Trailer Systems (~17-19% FE\textsuperscript{1})
  - Trailer Boat Tail
  - Trailer Skirts
  - Trailer Bogie Treatment
  - Trailer Wheel Covers
  - Drive Wheel Covers

- Dynamic Pitch Control (~2-3% FE\textsuperscript{1})
  - Trailer Bogie Height Reduction
  - Front Axle Height Reduction

\textbf{FE = Freight Efficiency (ton-miles/gal)}

1. Calculated, simulation, or test data
2. Improvements shown relative to SuperTruck mule vehicle

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\textsuperscript{1}
Development truck results
- 6x2 Drivetrain ( ~2-3.0% FE$^1$)
  - 6x2 Configuration
  - Direct-Drive Eaton UltraShift
  - Load Biasing Suspension

50% BTE engine development work
- Currently at 48.3% in dyno cell
- See engine presentation
  (ace059_zukouski_2015_o) for in-depth work on:
  - Combustion
  - Air System
  - Friction Accessories
  - Aftertreatment
  - WHR

1. Calculated, simulation, or test data
2. Improvements shown relative to SuperTruck mule vehicle

FE = Freight Efficiency (ton-miles/gal)
Approach - Powertrain Technologies

- Stop / Start technology includes
  - Long life starter
  - Software strategy
  - NiZn Batteries
  - Simulation shows

- WHR
  - Estimated ~3-4% FE¹

**Route \ Metric | Weighted Impact**

<table>
<thead>
<tr>
<th>Route</th>
<th>Weighted Impact</th>
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<tbody>
<tr>
<td>Kentucky</td>
<td>0.20%</td>
</tr>
<tr>
<td>Illinois</td>
<td>0.65%</td>
</tr>
<tr>
<td>Illinois City</td>
<td>0.71%</td>
</tr>
<tr>
<td>Total</td>
<td>1.56%</td>
</tr>
</tbody>
</table>

**FE = Freight Efficiency (ton-miles/gal)**

1. Calculated, simulation, or test data
2. Improvements shown relative to SuperTruck mule vehicle

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2014-15 Accomplishments
Four Distinct Areas of Progress

Lightweighting
- Lightweight Frame
- Composite Materials
- Lightweight Trailer

Rolling Resistance
- Energy Recovery
- Reduced Parasitic

Aerodynamic Improvement
- Tractor
- Trailer

Powertrain Technologies
- High Efficiency Drivetrain
- Stop/Start Idle Reduction
- Waste Heat Recovery
- eTurbo
- Adv. After treatment
- Friction Reduction

Technology road map developed

Recuperative Electric Charge:
- “Smart Charging”
- 48V Motor/Generator
- 48V NiZn Battery Storage
- Multi-Bus Battery Equalizer

New Cab
48V Electric HVAC

48.3 BTE Engine

High Temp Cooling,
“Smart Cooling”
WVP
VOP
E-Thermostat
3-Speed Fan
Boiling Protection

Aluminum Drive Shaft
Bendix IAC
Clutched Compressor
Timken Low Friction Bearings
Downsped 6x2 Axle
Drive Wheel Covers
Dynamic Load Biasing
Updated Wabash (2015) slotted skirts
Navistar Designed Trailer Bogie Faring

2012 Lightweight (-1525 lbs)
Wabash trailer

Pitch Control

Navistar Designed Wake Convergence Device

Wide-Base Single Tires

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Future Work

- 2015
  - Target completion of development truck – April / 2015
    - Validation plan: 2 months control development for axle Load Biasing and dynamic ride Height Control
  - Target completion of development truck – June / 2015
    - Enhanced Charging
    - Smart Cooling
    - Smart Cruise
    - 50% +BTE engine
    - Electric HVAC
  - Increasing collaborations
- 2016
  - Build, final testing, & optimizing of demo vehicle
  - Presentation to DOE

Navistar SuperTruck Freight Efficiency Plan

Freight Efficiency (Ton-MPG)

- Trailer aero improvements
- Lightweighting
- Powertrain Technologies
- Rolling Resistance
- 2009 ProStar Long Sleeper

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Project Summary

1. Several aerodynamic scale-models have been developed and evaluated in the wind tunnel. Significant improvement over the baseline vehicle has been observed which will be incorporated in final design
2. Initial load biasing evaluation completed
3. Concept material has been procured for mule vehicle test
4. Current engine tested at a BTE of 48.3% with additional technologies still to deploy
5. Technology concepts & targets established to move forward to Phase 3 (Design)

FE = Freight Efficiency (ton-miles/gal)

1. Calculated, simulation, or test data
2. Improvements shown relative to SuperTruck mule vehicle

<table>
<thead>
<tr>
<th>Development Area</th>
<th>Freight Efficiency Target</th>
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<tbody>
<tr>
<td>Weight</td>
<td>80+</td>
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<tr>
<td>Rolling/Parasitic</td>
<td></td>
</tr>
<tr>
<td>Aerodynamics</td>
<td></td>
</tr>
<tr>
<td>Engine</td>
<td></td>
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