SuperTruck

Powertrain Technologies for Efficiency Improvement

2015 Annual Merit Review
Washington, DC
June 12, 2015

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Volvo Group Trucks Technology

Principal Investigator: Pascal Amar
Volvo Technology of America

ACE060

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# Project Overview

## Timeline

<table>
<thead>
<tr>
<th>Project Stage</th>
<th>Percentage Complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 2011 - June 2016</td>
<td>75%</td>
</tr>
</tbody>
</table>

complete to date

## Barriers

- Cost effective & timely evaluation of complex technologies and systems
- Added weight and packaging of technologies
- Integration of interdependent technologies
- Development of robust solutions with broad application and customer acceptance

## Budget

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Project Cost:</td>
<td>$38M</td>
</tr>
<tr>
<td>DOE Funding:</td>
<td>$19M</td>
</tr>
<tr>
<td>Funding received to date</td>
<td>$12.3M</td>
</tr>
<tr>
<td>Total project cost to date</td>
<td>$25.9M</td>
</tr>
</tbody>
</table>

## Project Partners:

- Volvo
- Grote
- FreightWing
- PennState
Relevance to Program Goals

Bring technologies that enable lower customer operational cost and reduced environmental impact to market ahead of normal product development time cycle.

Develop more efficient highway transportation technologies to reduce petroleum consumption.

Project Objectives

Objective 1:
Develop powertrain technologies to contribute to **50% freight efficiency improvement** in vehicle testing.

Objective 1a:
Develop powertrain technologies capable of **50% engine BTE** in vehicle environment.

Objective 2:
Investigate engine technologies capable of **55% BTE** through simulation and scoping studies.

Reporting Period Project Objectives

Objective 1:
Test **48% BTE powertrain** in concept vehicle.

Objective 1a:
Develop **50% BTE technologies**.

Objective 2:
Simulate technologies to achieve **55% BTE**.
Projects supporting the objective to develop more efficient highway transportation technologies to reduce petroleum consumption, operating cost, fuel consumption, environmental impact, and time to market for high risk high complexity items are as follows:

- DOE & NETL under Award Number DE-EE0004232
- DOE & NETL under Award Number DE-FC26-07NT43222

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Total Powertrain Workflow Approach

55% BTE Combustion Technologies (Objective 2)
- Innovative engine architectures
- Fueling Optimization
- Alternative combustion cycles
- Demonstrate in Simulation and Single Cylinder Scoping

50% BTE Powertrain Technologies (Objective 1a)
- Engine System(s)
  - Combustion
  - WHR
  - Air Handling
  - …
  - Aftertreatment
  - Driveline
- Demonstrate in test cell

50% Freight Efficiency Improvement Technologies (Objective 1)
- Powertrain Improvements
- Aerodynamics
- Light weighting
- Rolling Resistance
- Driver Aides
- Auxiliaries
- …
- Chassis Test

Requirements and Feedback

Technology to Customer

Requirements and Feedback

Requirements

+ New Technology

Transfer Technology

Transfer Technology
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Requirements and Feedback

Technology to Customer

+ New Technology
Strategy for Brake Thermal Efficiency
(Objective 1a and 2)

- Develop and verify powertrain components that enable 50% engine BTE.

- Each family displayed represents many subsets of technologies.

- Integrate systems into concept vehicles and verify on customer duty cycles.

- Provide pathway to 55% BTE engine.
Accomplishments towards 50% BTE (Objective 1a)

The 50% BTE engine component development is complete.
System integration & test is ongoing.

Engine program has run the equivalent of 1,600,000 miles (to the moon and back >3 times)

New engine is as good without WHR as previous engine with WHR, measuring 48% BTE.
Accomplishments towards 50% BTE (Objective 1a)

Improvements in advanced concepts:

Testing initiated with Volvo-designed WHR expansion machine, a 5 stage axial turbine.

An elegant solution with significant reductions in weight and size compared to alternatives.

Realized project benefit to customers:

The SuperTruck first demonstrator propshaft, combustion system, axles, down-speeding technology (and more) will be in production soon, some are already available for purchase.
Total Powertrain Workflow Approach

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+ New Technology

Requirements and Feedback

Technology to Customer

Requirements and Feedback

Requirements and Feedback
Approach to Freight Efficiency Improvement

Two phases of development

✔ Phase 1 complete, test concepts early in concept truck to assist final design
  - Phase 2 ongoing, deliver 50% BTE engine to demo truck
Powertrain Accomplishments towards 50% Freight Efficiency Improvement (Objective 1)

First Concept / Mule Chassis

Test Complete.

Technology Commercialized from First Concept Chassis:

Aforementioned Powertrain Components plus:
- Improved Roof
- Improved Bumper
- Flared Chassis Faring
- LED Headlamps
- LED Interior Lighting
- New Tail Fairing

Production Truck

Technology to Customer

FUEL ECONOMY IMPROVEMENTS DELIVERED TO CUSTOMER!
Powertrain Accomplishments towards 50% Freight Efficiency Improvement (Objective 1)

Powertrain delivered to final demonstrator chassis, vehicle is in build phase

*Test cell results indicate road cycle fuel economy exceeds initial expectations*

*Engine designed for lighter loads resulting from an aerodynamic and low rolling resistance vehicle*
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Technology to Customer

Requirements and Feedback

Requirements and Feedback

Requirements
**Approach for 55% BTE Engine** (Objective 2)

**Phase I - Tools & Method Development**
- Penn State - CFD Development
- PDF Diesel Development
- PDF PPC Validation
- GT Power modelling & Eff. Calculations

**Phase II - Concept Development**
- Concept 55 CFD Simulations
- Concept 55 model validation
- Concept 55 GT Power
- Fuel Mechanism Research
- Concept 55 prototype

**Goal:**
Define a powertrain system capable of 55% engine BTE using an integrated computational method.

Verify assumptions for robustness.
Approach for 55% BTE Engine (Objective 2)

Goal: simulate a powertrain system capable of 55% engine BTE using an integrated computational method. Verify assumptions for robustness.

- PDF Model
- Chemical Mechanism Model
- Fuel Spray Model
- Gas Exchange Simulations
- 3D Combustion Simulations
- GT Power Engine Model / Fundamental Engine Design
- Tests to support simulation

Characterization of Fuel Injection
Combustion Analysis
Engine Tests
Accomplishments toward 55% BTE Engine (Objective 2)

Inter-dependent simulation tools have improved the combustion system design. Tests have been initiated to validate the simulations.
Accomplishments towards 55% BTE Engine (Objective 2)

- Parasitic Reduction
- Waste Heat Recovery
- Improved Gas Exchange
- Heat Loss Reductions
- Combustion Improvements
- Over-Expansion

☑ 56.2% BTE engine simulated

48% BTE engine baseline
Collaborators / Partners

Suppliers and development partners have developed methods to integrate all new technologies in simulation and test phase, striving to deliver an optimized powertrain and chassis for maximum return on investment. Academic partners are assisting in simulations.

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<tr>
<td>The Customer</td>
<td>Log vehicle data used from thousands of highway vehicles on the market is to define drive cycles and requirements</td>
</tr>
<tr>
<td>Volvo Technology of America</td>
<td>Contract Management and Collaborator Integration</td>
</tr>
<tr>
<td>Volvo Group Trucks Technology</td>
<td>Engine, Transmission, Axles, Light weighting, Chassis Auxiliaries, Integration, Chassis Aerodynamics, …</td>
</tr>
<tr>
<td>FreightWing/Ridge Corp.</td>
<td>Trailer Aerodynamic Devices</td>
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<tr>
<td>Grote Industries</td>
<td>Advanced Lighting</td>
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<tr>
<td>Ricardo, Inc.</td>
<td>Rankine WHR Generation 1 Development</td>
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<td>University of Michigan</td>
<td>55% BTE Simulation and Testing</td>
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<tr>
<td>Drexel University</td>
<td>WHR Topology Simulation</td>
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<tr>
<td>Pennsylvania State University</td>
<td>55% BTE Simulation and Testing</td>
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<tr>
<td>Chalmers University of Technology</td>
<td>55% BTE Testing</td>
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<tr>
<td>Exxon Mobil</td>
<td>Advanced Fuels and Lubrications</td>
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Future Plans for Powertrain Development

• 55% BTE (Objective 2)
  – Continue to refine tools and validate models with test data
  – Progress in engine design

• 50% BTE (Objective 1a)
  – Prepare technology transfers from SuperTruck to customer
  – Refine WHR system for optimal road cycle operation

• 50% Freight Efficiency (Objective 1)
  – Support Vehicle test of 50% BTE powertrain
  – Use data from vehicle test to guide future product development
Summary of Volvo Supertruck Project Status

- **Timeline**: Project is 75% complete to date
- **Budget**: On track
- **Relevance**: Develop more efficient highway transportation technologies to reduce petroleum consumption, reducing operating cost, fuel consumption, environmental impact, and time to market for high risk high complexity items
- **Approach**: Through simulation and testing, develop technologies that meet or exceed 55% BTE scoping, 50% BTE powertrain system in chassis, and 50% Freight Efficiency improvement.
- **Technical Accomplishments**: In 2013/14 Volvo verified combustion simulation for PPC and simulated a 56.2% BTE capable engine. The 50% BTE powertrain is under development, with 48% BTE realized without WHR (previously 48% with WHR). The first concept vehicle achieved a 45% Freight Efficiency Improvement.
- **Collaborations**: Suppliers and partners have developed methods to integrate all new technologies in simulation and test phase, striving to deliver an optimized powertrain and chassis for maximum return on investment. Academic partners are assisting in simulations with great success and collaboration.
- **Future Plans**: In 2015-2016 the 50% BTE capable powertrain will be demonstrated in vehicle. Simulation 55% components will progress through upcoming funding year. Technologies considered viable will be prepared for transfer to customer.
End of presentation.

Thank you for your attention.