Project Overview

Timeline
- Start – September 2008
- End – September 2009
- 60% Complete

Budget
- DOE
  - FY08 $ 200k
  - FY09 $ 200k

Barriers
- Evaluate the potential fuel efficiency gains for Medium & Heavy Duty
- Provide DOE R&D guidance

Partners
- Cummins
- Allison
- West Virginia University
- ORNL
Main Objectives

- Evaluate benefits of DOE research on medium and heavy duty vehicles
- Develop heavy duty version of PSAT/Autonomie to support DOE R&D activities
- Integrate specific data, models, controls for heavy duty
- Validate several heavy duty vehicle classes
- Integrate specific features for heavy duty
- Support future regulatory needs
- Support EPA SmartWay activities
Milestones

Q1
Integrate component data
Validate vehicle classes
List technology options

Q2
Evaluate regulatory options
Run Simulations

Q3

Q4
Write report

Current Status
**Approach**

Work directly with companies / academia to gather Medium & Heavy Duty data
**PSAT Validation: Details of Tractor Truck**

Data from Chassis Dynamometer Tests and On-Road Tests

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Model Year</td>
<td>1996</td>
</tr>
<tr>
<td>Test weight (lb.)</td>
<td>56000</td>
</tr>
<tr>
<td>Odometer Reading</td>
<td>441097</td>
</tr>
<tr>
<td>Transmission Type</td>
<td>Manual</td>
</tr>
<tr>
<td>Transmission Model</td>
<td>RTLO 20918, 18 speed</td>
</tr>
<tr>
<td>Engine Type</td>
<td>Caterpillar 3406E</td>
</tr>
<tr>
<td>Engine Model Year</td>
<td>1996</td>
</tr>
<tr>
<td>Engine Disp. (Liter)</td>
<td>14.6</td>
</tr>
<tr>
<td>Number of Cylinders</td>
<td>6</td>
</tr>
</tbody>
</table>

![Graph showing speed (mph) over time (s)](UDDS Used for Chassis Dynamometer Testing)
Modeling and Validation of Peterbilt Truck

Component data development

- Engine map
- Auxiliary loads, including fan load.
- Vehicle losses developed to match chassis dynamometer.
- The transmission ratios and efficiencies were documented.

* This vehicle was also simulated on a road route, PA43, as well as chassis dynamometer cycles.
Comparison of Actual and Predicted Results

On-road result variability can be attributed in part to lack of knowledge of real rolling resistance and aerodynamic factors. For the chassis UDDS these factors were known.

PSAT Validation With Chassis (Test weight 56000 lb)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Measured</th>
<th>PSAT Simu.</th>
<th>Relative % Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>UDDS Cycle (mile)</td>
<td>5.44</td>
<td>5.37</td>
<td>1.29</td>
</tr>
<tr>
<td>Fuel Econ. (MPG)</td>
<td>3.82</td>
<td>3.82</td>
<td>0.00</td>
</tr>
<tr>
<td>Fuel Mass (kg)</td>
<td>4.58</td>
<td>4.52</td>
<td>1.31</td>
</tr>
<tr>
<td>Eng. Fuel Rate (g/s)</td>
<td>4.40</td>
<td>4.30</td>
<td>1.27</td>
</tr>
<tr>
<td>CO₂ (g/mile)</td>
<td>2639.8</td>
<td>2685.5</td>
<td>-1.73</td>
</tr>
</tbody>
</table>

PSAT On-road Test Results (Test weight 79700 lb)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Measured</th>
<th>PSAT Simu.</th>
<th>Relative % Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>P 43 Route (mile)</td>
<td>19.54</td>
<td>19.44</td>
<td>0.61</td>
</tr>
<tr>
<td>Fuel Econ. (MPG)</td>
<td>4.26</td>
<td>4.20</td>
<td>1.41</td>
</tr>
<tr>
<td>Fuel Mass (kg)</td>
<td>14.42</td>
<td>14.88</td>
<td>-3.19</td>
</tr>
<tr>
<td>Eng. Fuel Rate (g/s)</td>
<td>9.40</td>
<td>9.80</td>
<td>-4.26</td>
</tr>
<tr>
<td>CO₂ (g/mile)</td>
<td>2180.7</td>
<td>2445.4</td>
<td>-12.13</td>
</tr>
</tbody>
</table>

*Note: Engine fuel rate, engine torque, engine speed, engine power and vehicle speed are all average values

![Measured vs PSAT Engine Fuel Rate](image1)

![PSAT Simulated vs Measured Fuel Rate](image2)

$R^2 = 0.9268$
PSAT Has Been Correlated for Several Additional Vehicle Classes

Other correlated vehicle classes include, but not limited to:

- NABI 60LFW*
- New Flyer DE60LF, BRT*

* Data provided by Herbert Fox (NYIT)
Study Performed to Update Class 8 Energy Balance for 21CTP

Total Fuel Energy Consumption Rate
(65 mph, 80000 lbs)
440 kW

Aerodynamic losses
93 kW

Rolling Resistance
70 kW

Drivetrain
9 kW

Auxiliary Loads
10 kW

• Engine Power Required
183 kW
• Engine Efficiency
41.3 %
• Engine Losses
257 kW
Powershifting Automatic Transmission Follows the Trace Better…

Performance Comparison

Drive Cycle Comparison

Conventional City Bus
Same engine used
But Achieves Lower Fuel Economy

<table>
<thead>
<tr>
<th></th>
<th>Distance (miles)</th>
<th>Average Vehicle Speed (mph)</th>
<th>Fuel Consumption (mpg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic</td>
<td>1.99</td>
<td>12.6</td>
<td>3.89</td>
</tr>
<tr>
<td>Manual</td>
<td>1.66</td>
<td>10.5</td>
<td>3.99</td>
</tr>
</tbody>
</table>

The manual does not follow the drive cycle!

- The manual produces a lower average vehicle speed, which means the manual does less work.
- Fuel Efficiency is the ratio of work to fuel, which fuel economy (mpg) alone does not measure.

Fuel Economy alone is a NOT good metric for trucks

=> Need to evaluate different cycles and metric options
PSAT Has Been Successfully Used to Assess Heavy Duty Vehicle Fuel Efficiency

Impact of Advanced Technologies for Class 2B

- Additional Studies Performed with Companies Include:
  - Drivetrain configuration comparison
  - Control strategy development
  - Performance during acceleration and grade
  - Drive cycle impact
Assessing Options for Fuel Efficiency Regulations

Too many vehicle options => Combination of model & test should be used

Maturity of technology and model will define what process should be used (MIL, SIL, HIL, RCP, vehicle testing…)

V&V Model Applied to Software
Heavy Duty Vehicle Simulation Challenges

- How do we manage hundreds or thousands of possible options? (e.g., powertrain options, auxiliaries…)
- How do we ensure common definition of processes (e.g., what does validation mean?)
- How do we decide appropriate level of modeling?
  - Should drive quality be included since it influences fuel efficiency?
  - Should steady-state, zero-dimensional or 1D plant models be used?
  - Does the level of modeling different for each Class?
- How do we allow model reusability and sharing?
- How do we manage information from so many different sources?
  - What type of database management?
  - How do we handle proprietary information?
- How do we ensure that we can seamlessly perform MIL, SIL, HIL, RCP?
- How can we minimize number of drive cycles?
- How do we compare dynamometer and real world results?
Future Activities

- Continue collaboration with Medium & Heavy Duty companies to accelerate validation of considered vehicle classes.
- Define list of component and powertrain technologies to be considered for each classes.
- Define the drive cycles for each application.
- Analyze the efficiency benefits of different technologies.
Summary

- Several vehicle classes correlated using company’s test data.
- Specifics of heavy duty application assessed:
  - Model requirements
  - Fuel efficiency...
- Evaluation of advanced technologies on-going.
- Consider options to fairly compare efficiency when vehicles do not follow drive cycles.
- Evaluation of different metric options.
- Requirements were added to Autonomie to ensure specific needs of Heavy Duty Trucks are better