Heavy Duty Vehicle Modeling and Simulation

2009 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review

June 08, 2010

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Sponsored by Lee Slezak

Project ID #VSS020

U.S. Department of Energy

Energy Efficiency and Renewable Energy

Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Project Overview

Timeline

- Start October 2009
- Finish September 2010
- 80% Complete

Barriers

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

Budget

- FY08 - $200K
- FY09 - $200K
- FY10 - $300K

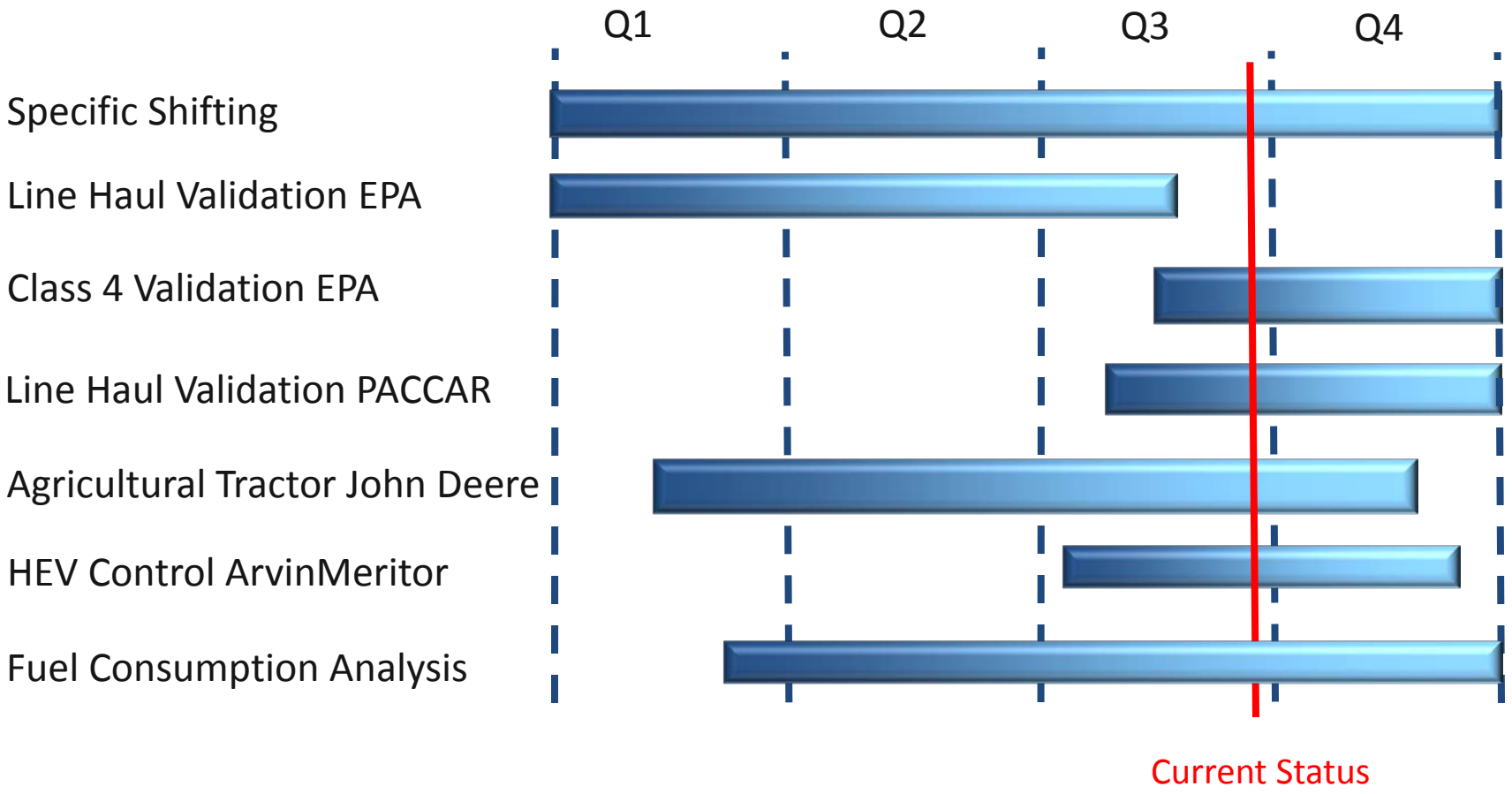
Partners

- Allison
- ArvinMeritor
- Cummins
- John Deere
- PACCAR
- U.S. EPA

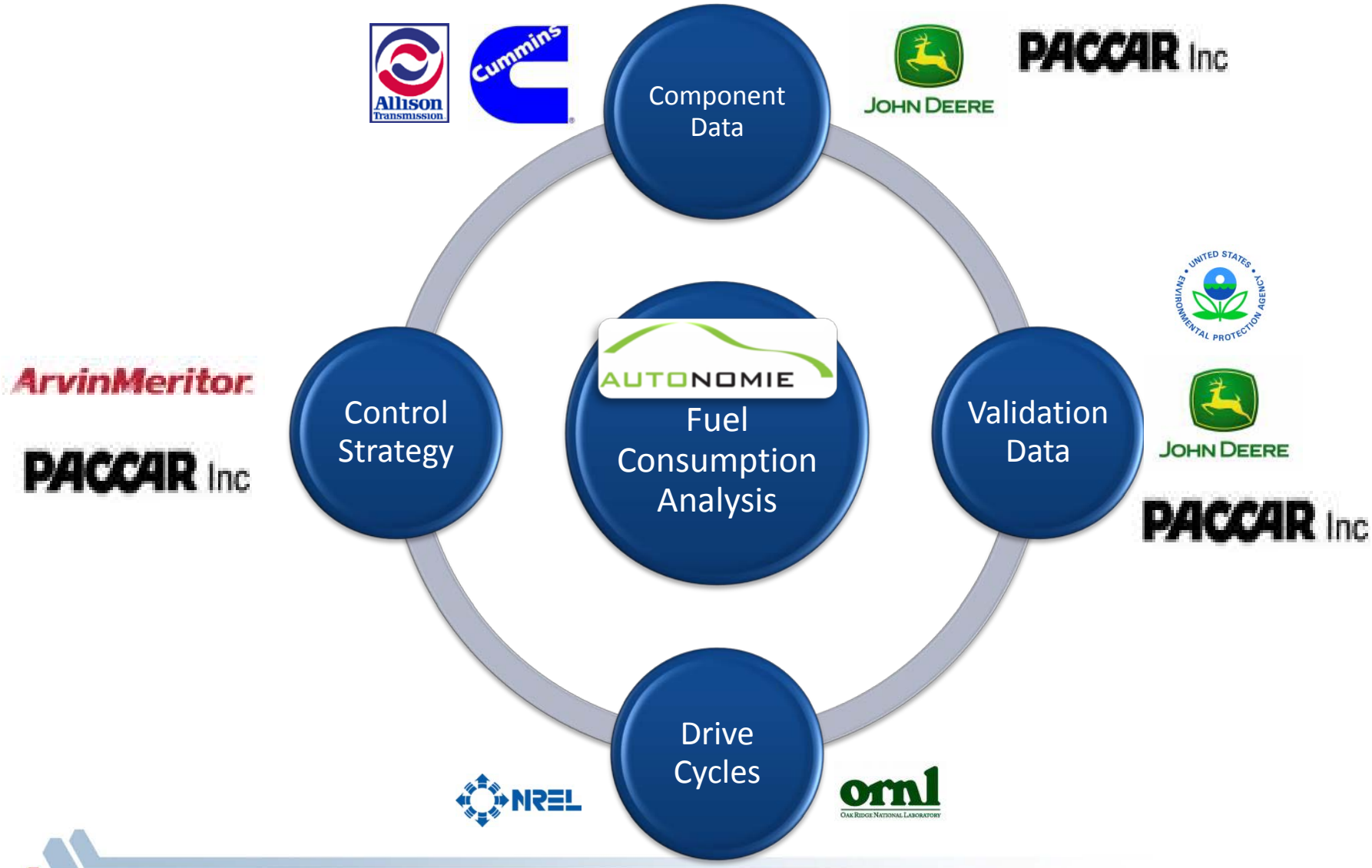
Objectives

- Evaluate benefits of DOE technology on medium and heavy duty vehicles
- Develop heavy duty version of 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

Milestones


Q1
Q2
Q3
Q4
Specific Shifting
Line Haul Validation EPA
Class 4 Validation EPA
Line Haul Validation PACCAR
Agricultural Tractor John Deere
HEV Control ArvinMeritor
Fuel Consumption Analysis
Current Status

Approach
Work Directly with Companies



Technical Accomplishments

Reference Vehicles for Different Applications

Pickup Class 2b

Parcel and
Delivery Class 4

Utility Class 6

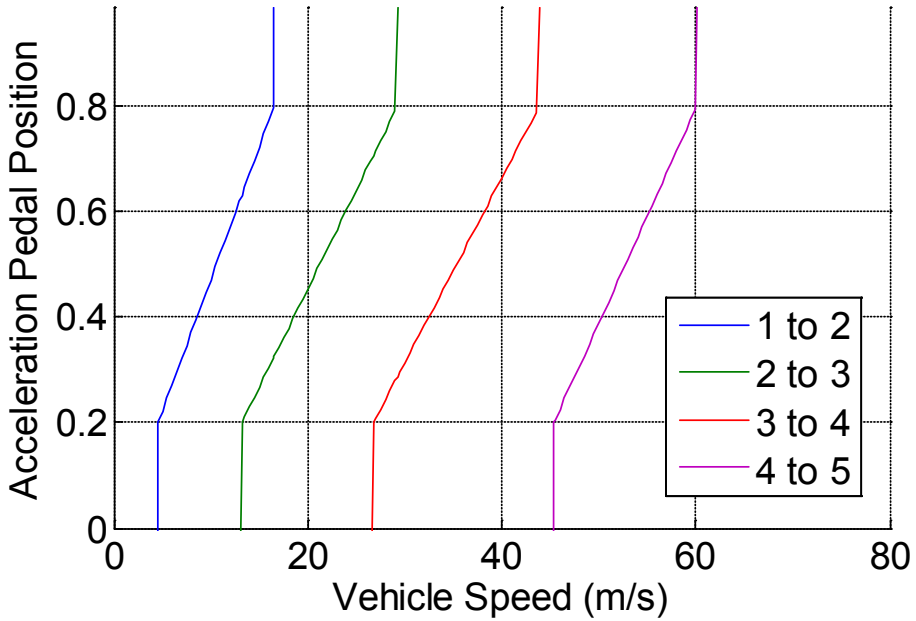
Line Haul Class 8

Transit Bus

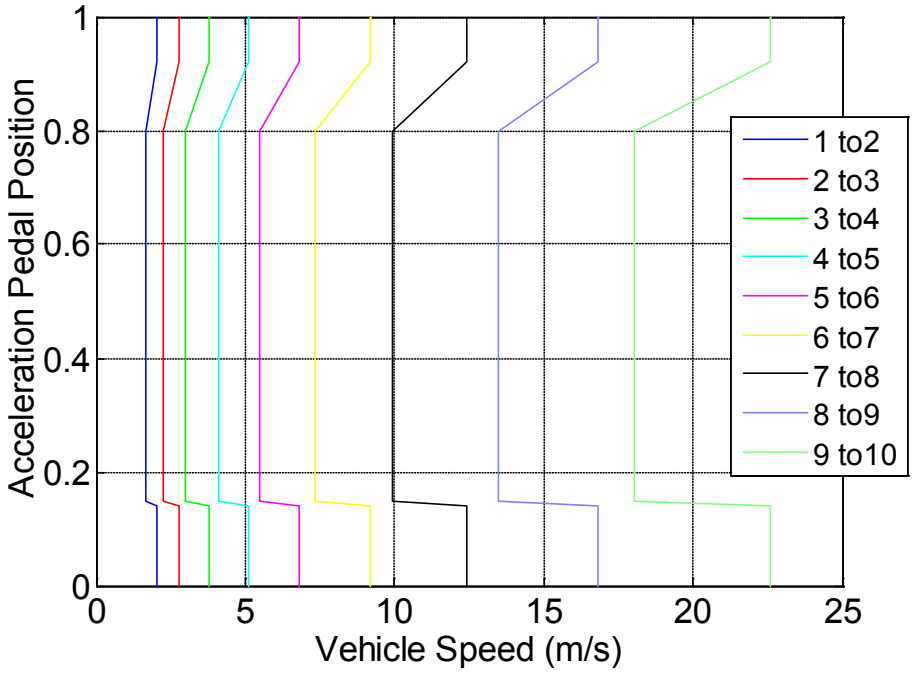
Refuse Truck

Technical Accomplishments
Specific Shifting Algorithms Defined

- A generic shifting schedule algorithm was developed based on Allison's inputs
- Specific torque converter lockup logic was also developed



Light Duty



Heavy Duty

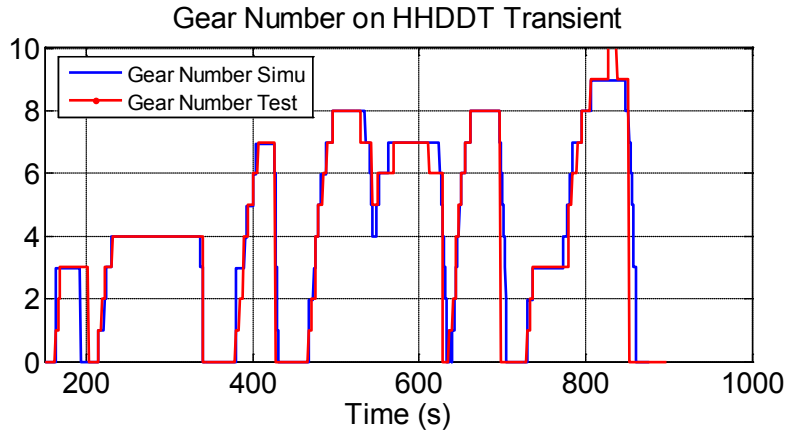
"samples"

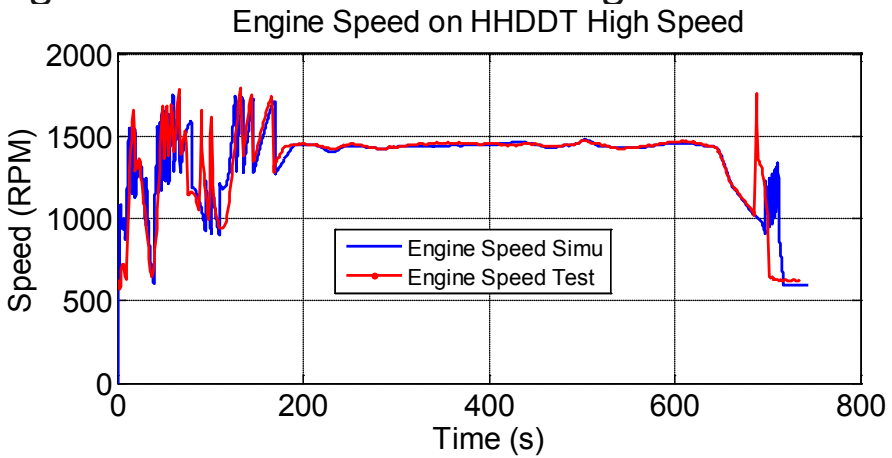
Technical Accomplishments
Line Haul Conventional Validation with EPA

- The Truck considered was a 2008 Navistar Prostar with the following specifications:

Engine	Cummins ISX 14.9L, 321kW
Transmission	Manual 10 Speed FRM-15210B Final Drive Ratio: 2.64
Tractor + Trailer Mass	31203 kg
Wheel	Total of 18 wheels (10 for tractor and 8 for trailer) Loaded Radius = 0.48 m

- Gear number not recorded in test -> Had to be reconstructed
- Algorithm was developed to select the best gear when the truck is starting in simulation





- Signals comparison showed very close shifting behaviors and engine speeds. Minor differences were seen in vehicle speed.

Technical Accomplishments
Line Haul Conventional Validation with EPA

- Several assumptions had to be made since the sample rate and list of sensors were not appropriate for validation exercise.

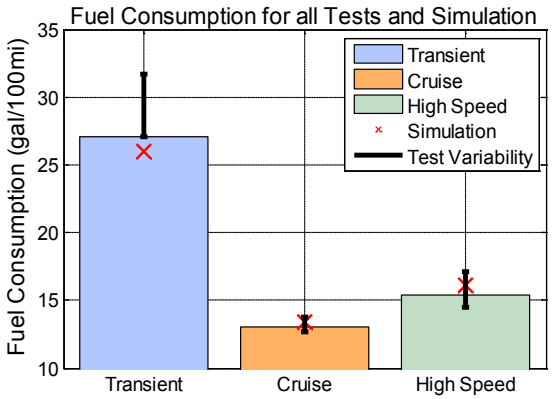
Test-to-test Uncertainty Showed High Variations

(Consumption in gal/100mi)	Transient	Cruise	High Speed
Lower Test Consumption	27.04	12.66	14.47
Higher Test Consumption	31.94	13.74	17.12
Difference (%)	**17.4%**	**8.6%**	**18.3%**

Fuel Consumption Results Comparison

(Consumption in gal/100mi)	Transient	Cruise	High Speed
Main Test Iteration Fuel Consumption	27.04	13.04	15.42
Simu Fuel Consumption	25.95	13.40	16.14
Difference (%)	**-4.03%**	**+2.75%**	**+4.68%**

Simulation within Test-to-Test Uncertainty



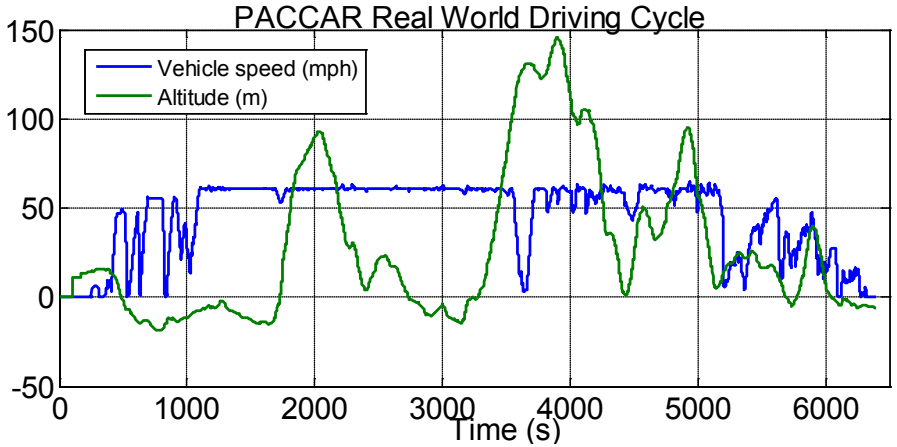
Technical Accomplishments

Line Haul Conventional Validation with PACCAR

- Validation of a Kenworth T660 Line Haul Truck with the following specifications:

Engine	Cummins ISX 14.9L, 317kW
Transmission	Manual 18 Speed Fuller RTLO-18918B Final Drive Ratio: 3.55
Tractor + Trailer Mass	29800 kg
Wheel	Total of 18 wheels (10 for tractor and 8 for trailer) Loaded Radius = 0.477 m

- Various 10 Hz test data available
  - Real World driving with grade in the Seattle area
  - Test Track driving

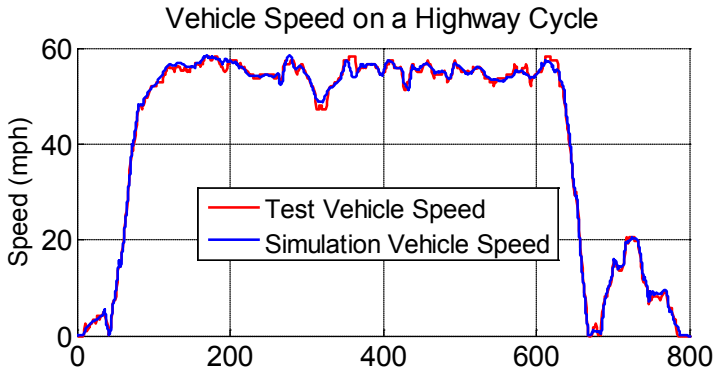


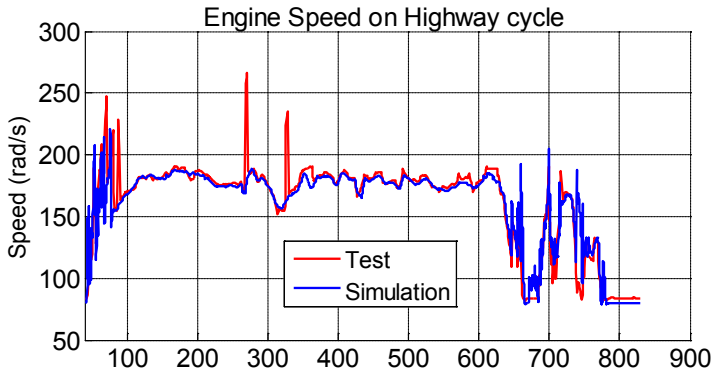
- Special attention given to
  - Accurately model shifting behavior, especially gear skipping
  - PACCAR has already developed a successful **distance-based driver** model which they will share with ANL for development in Autonomie. The drive cycle will be speed vs. distance when the truck is moving and time-based when the truck is stopped.

Technical Accomplishments
Class 4 P&D Validation with EPA

- The FedEx Truck is a 2008 Freightliner MT45 Chassis with a Ford Utilimaster Body

Engine	Cummins ISB 6.7L, 149kW
Transmission	Automatic 5 Speed Allison 1000 Series Final Drive Ratio: 4.1
Vehicle Mass	5883 kg
Wheel	Loaded Radius = 0.4 m





Highway Cycle	Test	Simulation
Fuel Economy (mpg)	13.8	14.3
Fuel Consumption (gal/100miles)	7.2	6.9
Delta Fuel Consumption (%)		**-3.5%**

Preliminary results

Technical Accomplishments

Agricultural Tractor Study with John Deere

- Model Development of a Conventional John Deere 7530 tractor and a Hybrid version

Engine	Diesel John Deere 6.8L, 154kW
Transmission	Manual 20 Speed split in 5 different groups
Vehicle Mass	8000 kg
Wheel	Loaded Radius Front = 0.7 m Loaded Radius Rear = 0.9 m

- The gearbox is split in 5 groups of 4 gear ratios, each specific to a vehicle application
- PTO and accessory loads are time varying and can request high amounts of torque
- Engine operations are governed by PTO device (Specific engine speed has to be used for PTO work, e.g. 2100 RPM)
- The Hybrid main goal is to assist the engine in transient operations (other than PTO)
- Modeling work was done to build the two configurations in Autonomie, include varying high torque mechanical accessory, and develop a generic hybrid model before more data is available.
- No Test data and drive cycle available yet. Thus no validation has been achieved.

Technical Accomplishments

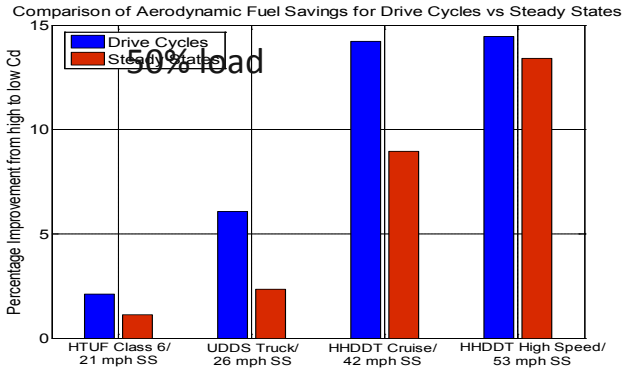
Line Haul Hybrid Control Development with ArvinMeritor

- ArvinMeritor has been developing a hybrid transmission for Class 8 Line-Haul trucks ("Dual-Mode Hybrid Drivetrain")
- ArvinMeritor provided:
  - Configuration type
  - Ratios and component efficiencies
- Argonne implemented:
  - Implemented specific configuration in Autonomie
  - Implemented high- and low- level hybrid control
  - Provided ArvinMeritor with complete vehicle model
- ArvinMeritor is going to use Autonomie for their vehicle simulations to support future design and control

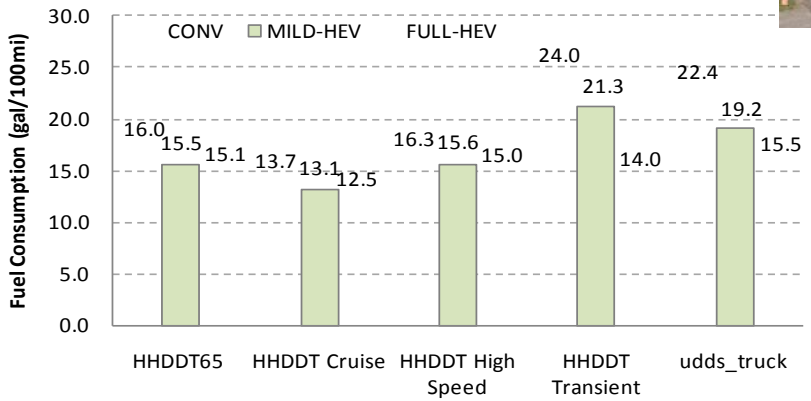
Technical Accomplishments

Evaluating Fuel Consumption of Advanced Technologies

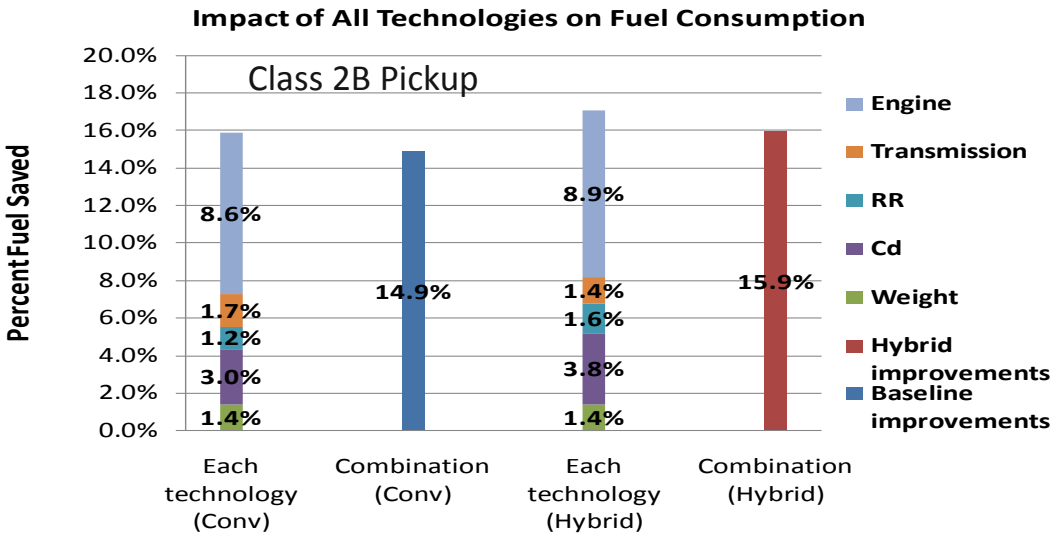
Impact of Aerodynamics for Different Line Haul Applications



Impact of Mild and Full HEV for Line Haul Applications



The Sum of the Combined Technologies < The Sum of Each Technology



Collaborations

- Collaboration with OEMs critical in
  - Accelerating the development of the control code (e.g., shifting logic, torque converter lock up…)
  - Gathering state of the art component data
  - Gathering state of the art vehicle data
- Value of data obtained through partnerships valued at several million dollars

Future Activities

- Complete on-going activities
  - Validation of conventional vehicles for Class 4 (EPA) and Line Haul (PACCAR).
  - Development of HEV control strategies
- Expand collaborations
  - Validate additional classes (e.g., bus) and configurations (e.g., HEVs) working with OEMs, government agencies and ANL's APRF (testing of Class 4 with several powertrain)
  - Continue to develop specific heavy duty features, including driver, shifting, accessories
  - Evaluate fuel consumption benefits of advanced technologies on both standard and real world drive cycles
- Support future Medium and Heavy Duty regulations

Summary

- Requirements were added to Autonomie to ensure specific needs of Heavy Duty Trucks
- Features were implemented:
  - Models and data
  - Control strategies…
- Several vehicle classes correlated using proprietary OEM's data.
- Evaluation of advanced technologies on-going.
- Leveraged several millions of dollars of proprietary OEM data (both component and vehicle testing)