Argonne NATIONAL LABORATORY

... for a brighter future

U.S. Department of Energy

UChicago ▶ Argonne LLC

Office of Science U.S. DEPARTMENT OF ENERGY

A U.S. Department of Energy laboratory managed by UChicago Argonne, LLC

Vehicle Model Validation

Project ID # vssp_17_rousseau

2009 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review

May 19, 2009

Aymeric Rousseau, Namdoo Kim,
Jason Kwon, Antoine Delorme
Argonne National Laboratory

Sponsored by Lee Slezak

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 – July 2007
- End – September 2010
- 60% Complete

Budget

- DOE
  - FY08 $ 200K
  - FY09 $ 250K

Barriers

- Understand latest control strategies
- Compare with internal controls

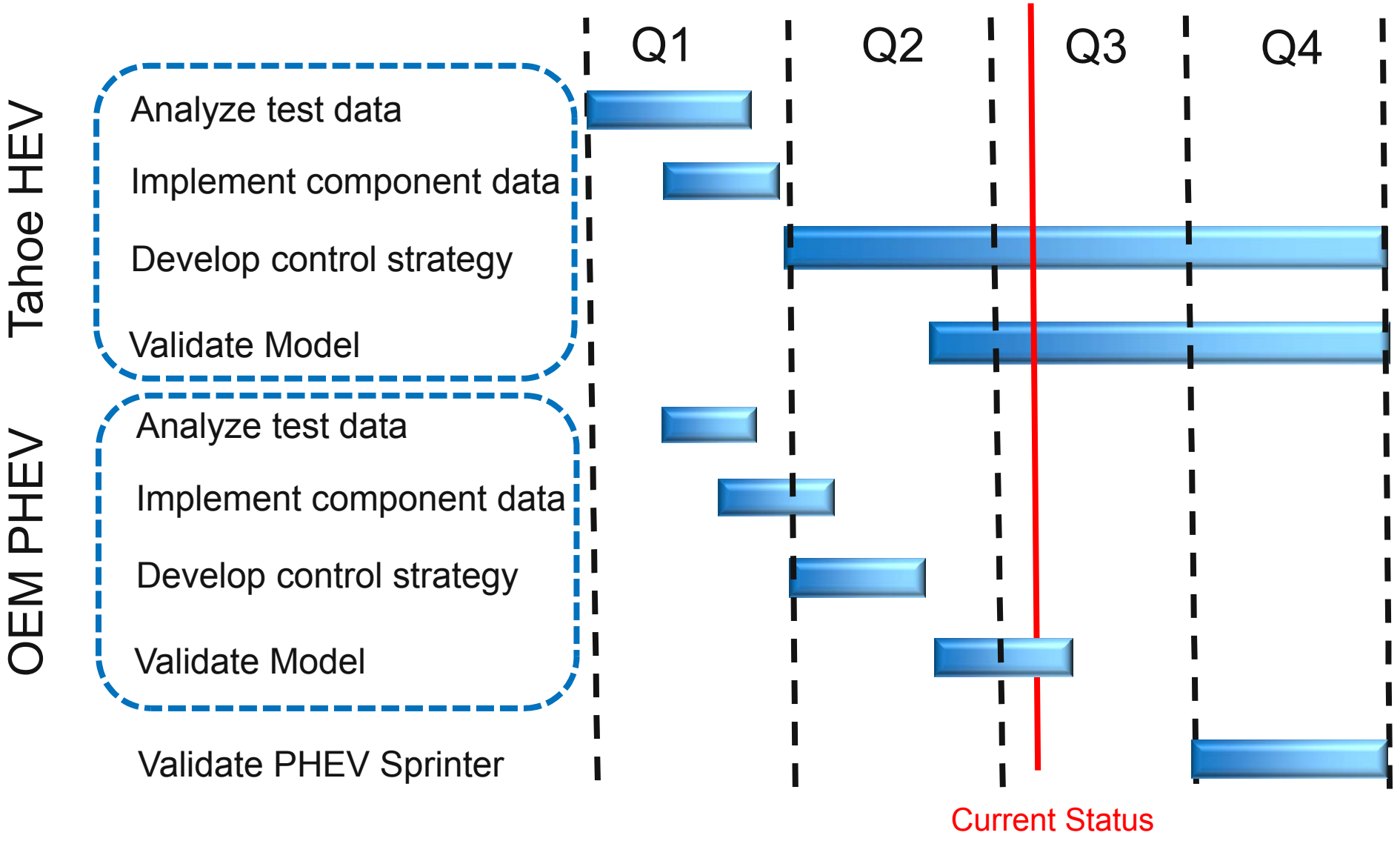
Partners

- ANL's APRF
- INL vehicles
- HIL activities

Main Objectives

- Evaluate the state-of-the-art in control strategies.
- Compare OEM's controls with ones developed internally using rule-based or optimization techniques.
- Provide validity to the simulation studies performed for DOE.

Milestones


Q1
Q2
Q3
Q4
Tahoe HEV
Analyze test data
Implement component data
Develop control strategy
Validate Model
OEM PHEV
Analyze test data
Implement component data
Develop control strategy
Validate Model
Validate PHEV Sprinter
Current Status

Generic Approach: From Test to Validation

1- Import Test Data into PSAT

2- Individual Sensor Evaluation

3- Sensor Comparison

4- Calculate Effort/Flow From Sensors

5- Sensor & Calculation Comparison

Quality Analysis (QA)

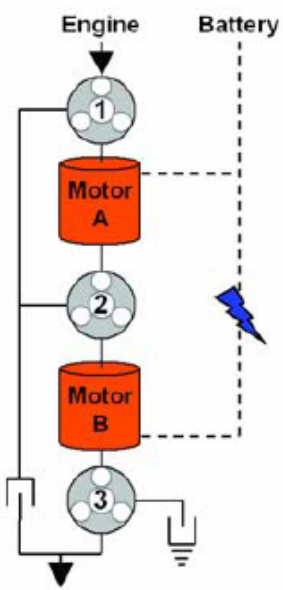
6- Control Strategy

7- Model Validation

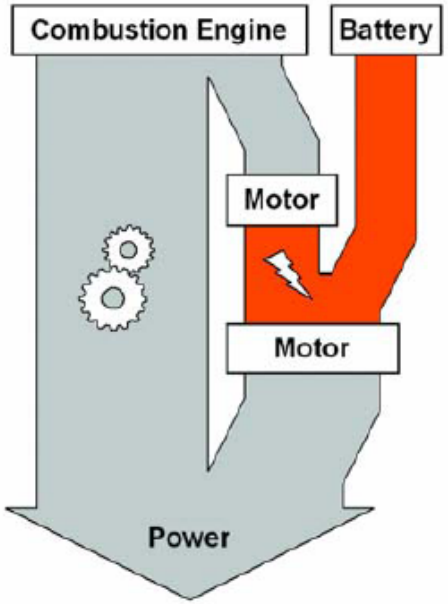
Analysis & Validation

Two-Mode Description

- A two-mode is composed of input split (equivalent to one-mode) and compound split
- Three mechanical points instead of one
    - one from the input split
    - two from the compound mode (one can be used for acceleration, the other for high speed cruising)
- The objective is to minimize the electrical path, leading to smaller electric machines

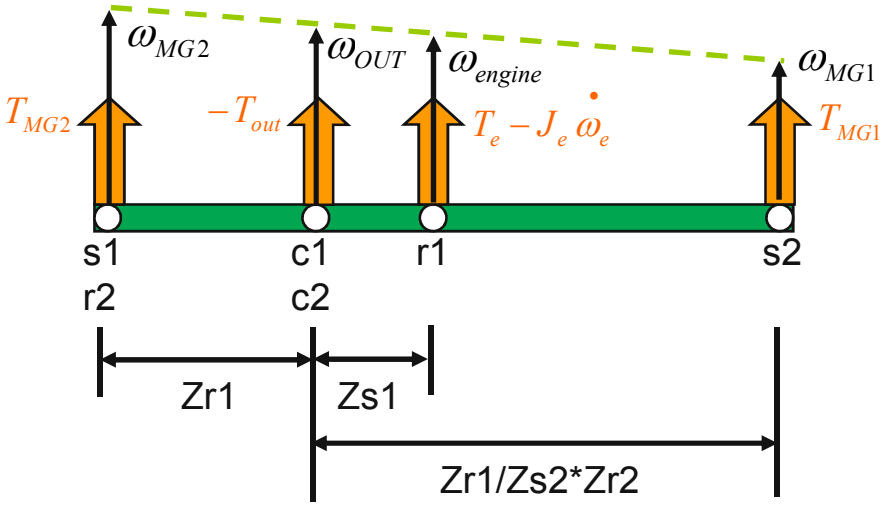


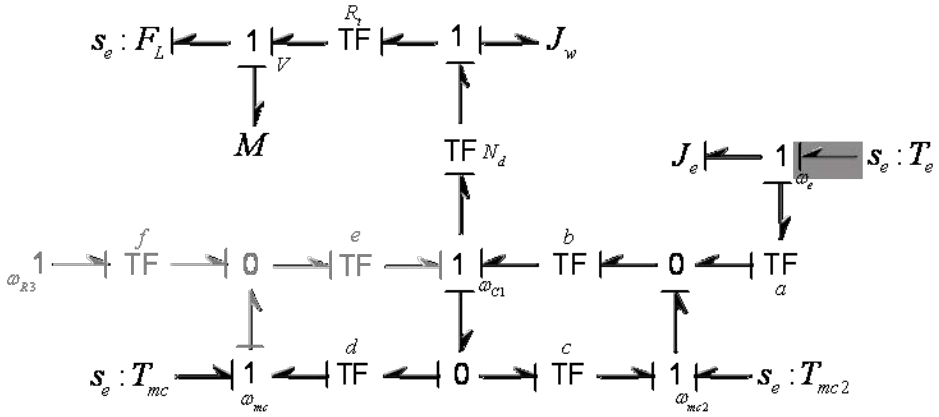
- Planetary gears split engine power and can multiply all torque
- Clutches change EVT modes smoothly
- Combined motor power requirement is much improved with two modes



Equations for Gearbox Model

Mode 2 (Compound Mode) – Process for Equations





Option 1 – Lever Diagram

$$J_{engine}\dot{\omega}_{engine} = T_{engine} - \frac{Z_{r1}}{Z_{s1}}T_{MG2} + \frac{Z_{r1}\times Z_{r2}}{Z_{s1}\times Z_{s2}}T_{MG1}$$

$$T_{OUT} = (1+\frac{Z_{r1}}{Z_{s1}})T_{MG2} + (1-\frac{Z_{r1}Z_{r2}}{Z_{s1}Z_{s2}})T_{MG1}$$

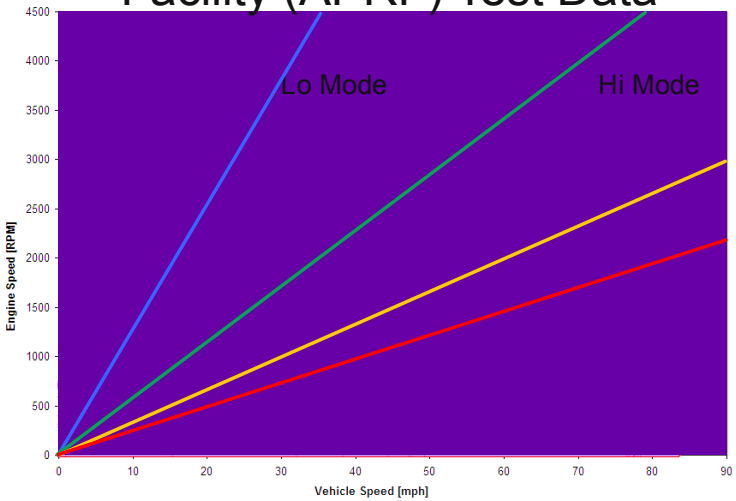
Option 2 – Bond Graph

$$\omega_{MG1} = (1-\frac{Z_{r1}Z_{r2}}{Z_{s1}Z_{s2}})\omega_{OUT} + \frac{Z_{r1}Z_{r2}}{Z_{s1}Z_{s2}}\omega_{engine}$$

$$\omega_{MG2} = (1+\frac{Z_{r1}}{Z_{s1}})\omega_{OUT} - \frac{Z_{r1}}{Z_{s1}}\omega_{engine}$$

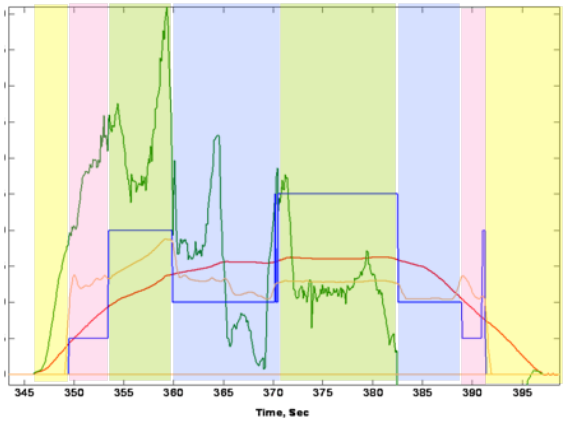
Control Strategy Development
Mode Selection – Rule Based (Option #1)

Advanced Powertrain Research Facility (APRF) Test Data



Rules

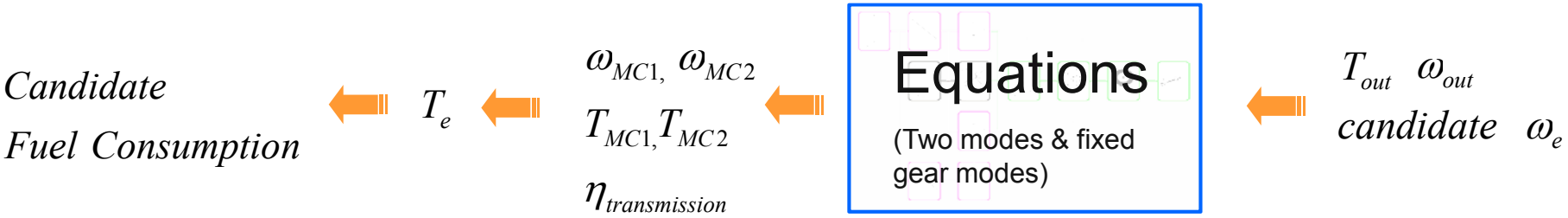
Mode selection based on:
- State of Charge (SOC)
- Vehicle speed
- Wheel power
- …



Vehicle speed
Wheel power
Mode
Engine speed

EV mode
1 Mode
2 Mode
Fixed Gear (2nd,3rd)

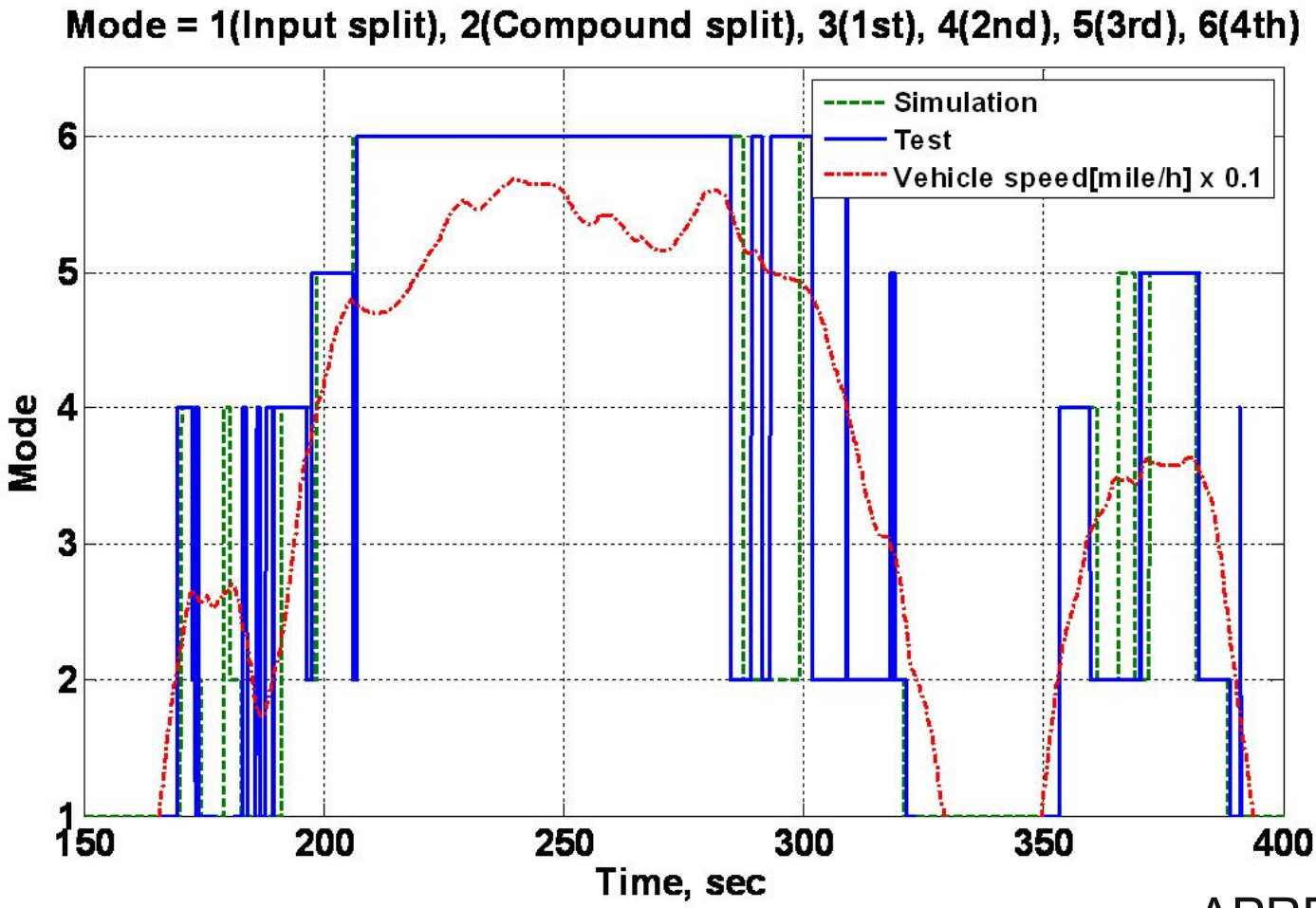
Control Strategy Development
Mode Selection – Optimization (Option #2)



- A candidate fuel consumption set can be generated for a candidate set of inputs (T_{out}, ω_{out}, ω_e).
- Instantaneous optimization is used to minimize the powertrain losses. The algorithm selects the modes and the operating conditions of each components.
- The main issue is to define a cost function to ensure SOC regulation.

Mode Selection Comparison

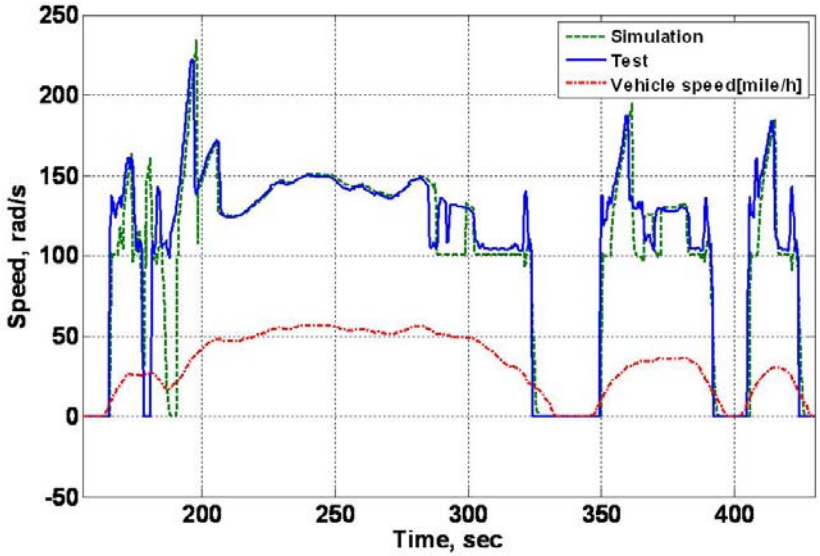
Control Strategy Option #1 Versus Test Data



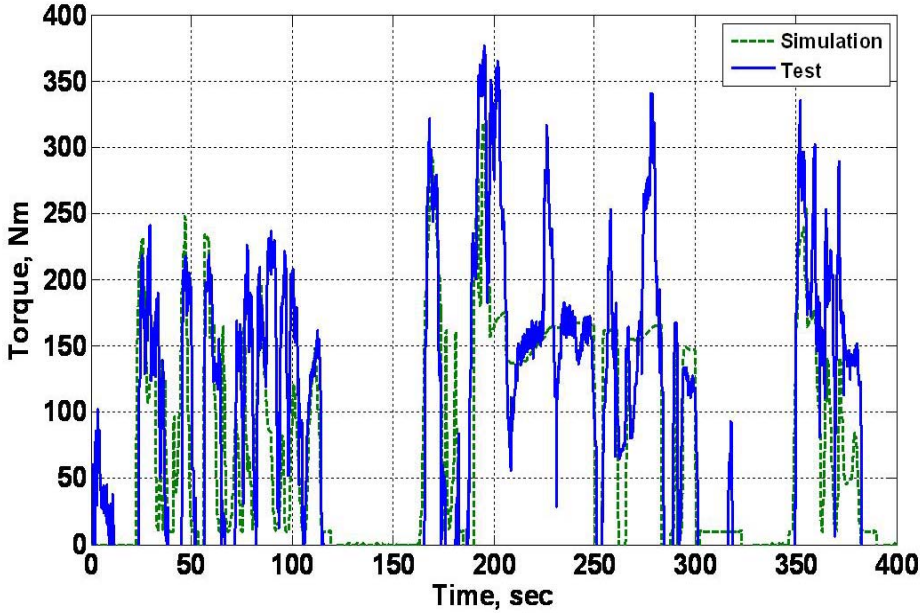
APRF Test Data

Engine Operation Comparison

Engine Speed



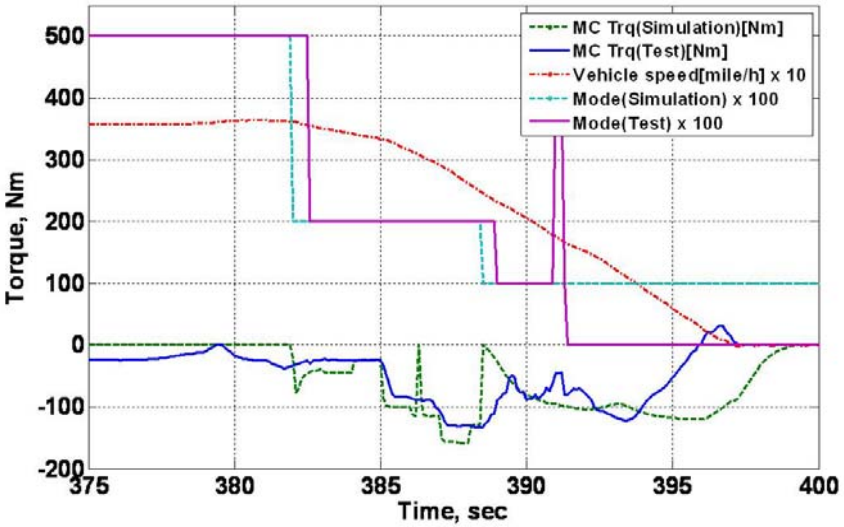
Engine Torque



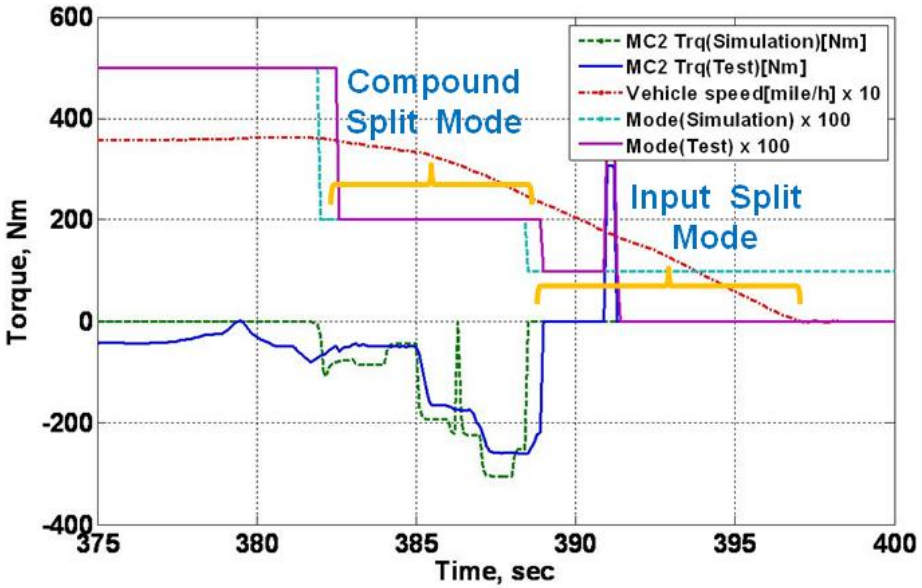
APRF Test Data

Regenerative Braking Comparison

Motor 1 - UDDS

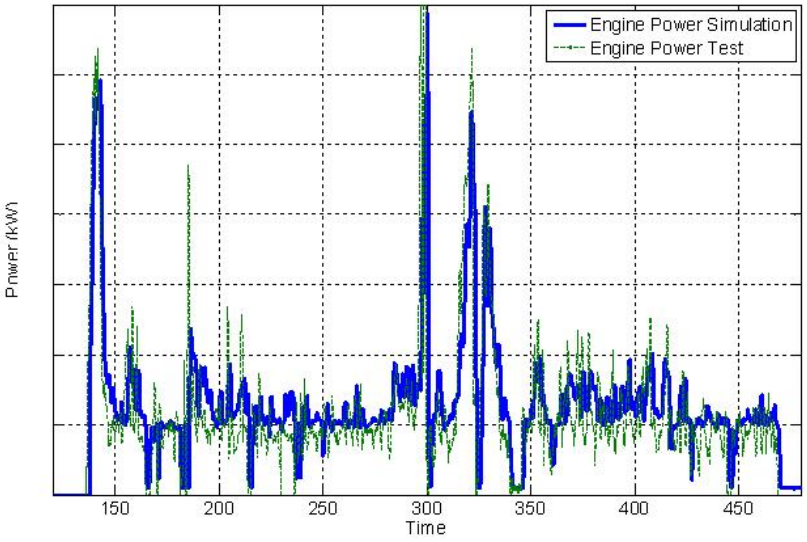


Motor 2 - UDDS



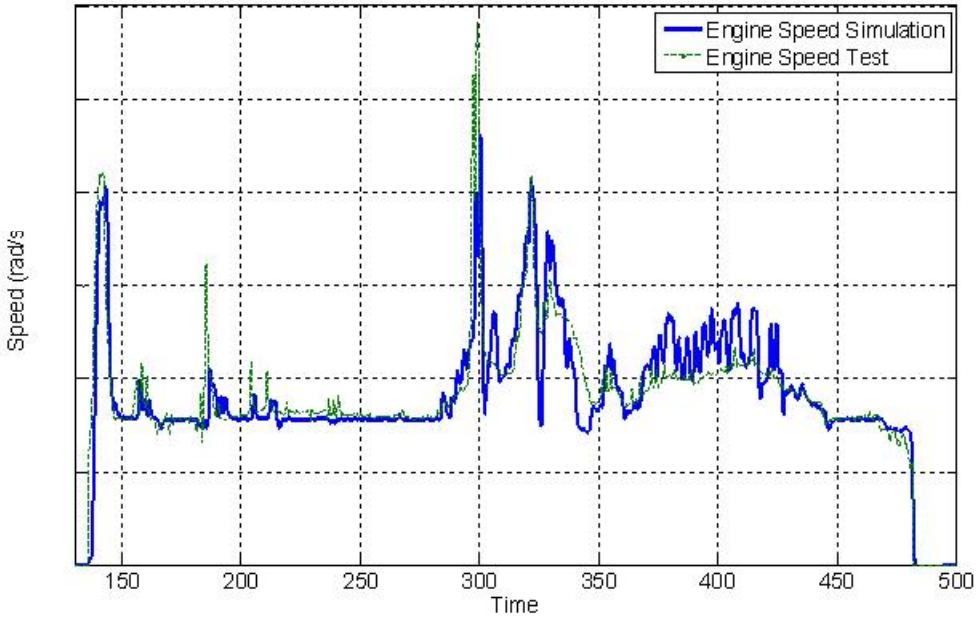
APRF Test Data

OEM PHEV Model Validated



Engine Power

Engine Speed



APRF Test Data

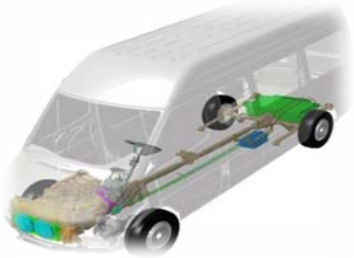
Future Activities

- Complete the integration of the physical transmission model (Simscape / Simdriveline)
- Complete the validation using optimization algorithm
- Validate vehicles tested at APRF

Source: Toyota

Source: GM

Source: Ford



Source: Daimler

Source: Honda

Summary

- Two different transmission models were developed for the Tahoe HEV, based on (a) dynamic equations and (b) physical modeling.
- Two control strategies were developed as well for (a) rule based control and (b) instantaneous optimization.
- Preliminary validation of the Tahoe HEV model showed good correlation.
- OEM PHEV model validated. Fuel efficiency of current control strategy will be compared with one developed in-house on the EPA Real World Drive Cycles.

References

- N. Kim, A. Rousseau, R. Carlson, F. Jehlik, “Tahoe HEV Model Development in PSAT”, SAE 2009-01-1307, World Congress, April 2009
- B. Carlson, J. Kim, A. Rousseau, “GM Tahoe 2 Mode System”, DOE Presentation, June 2008, Washington DC