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Vehicle Model Validation

Project ID # 17

**2009 DOE Hydrogen Program and Vehicle Technologies
Annual Merit Review**

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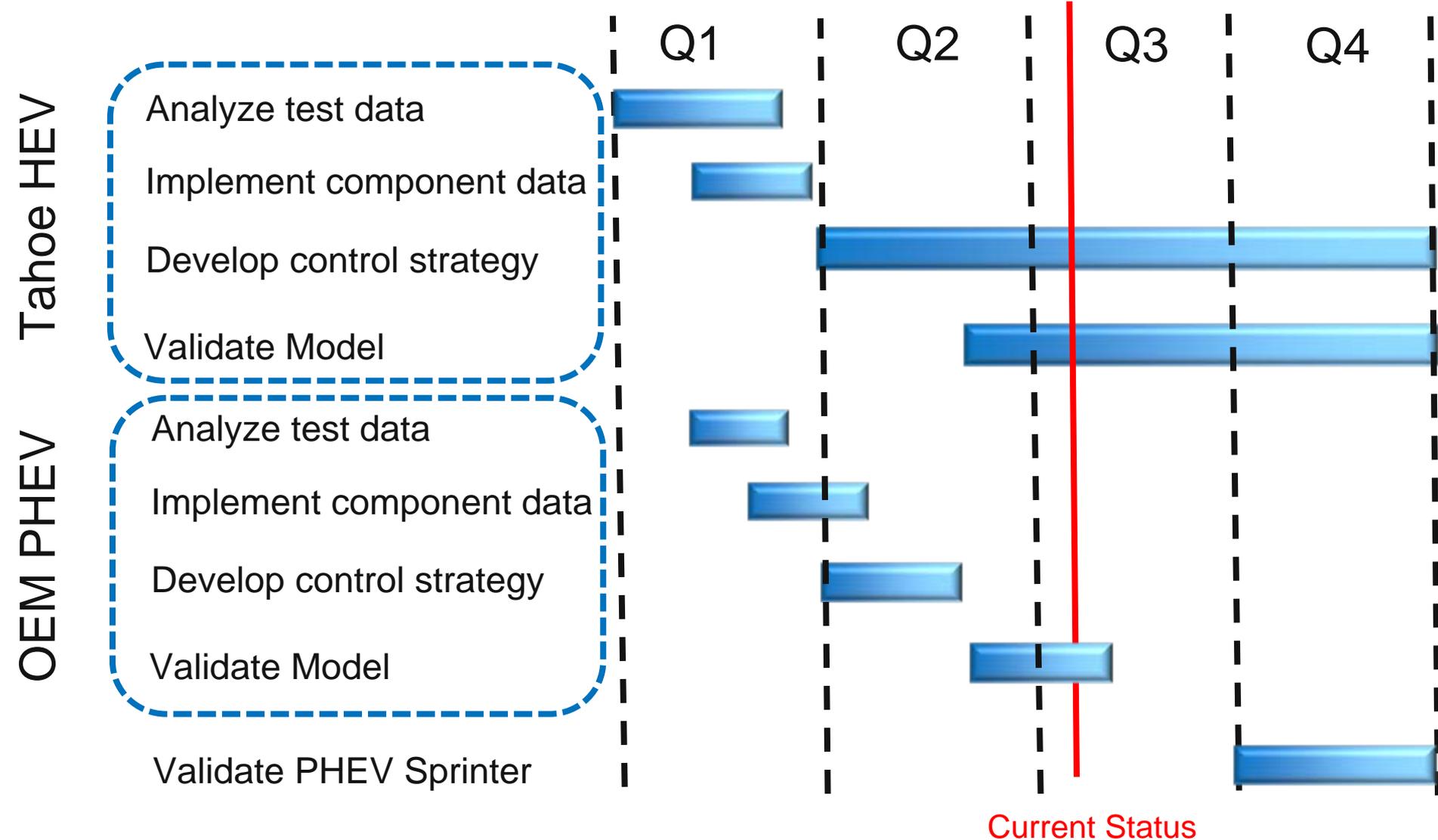
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Main Objectives

- 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

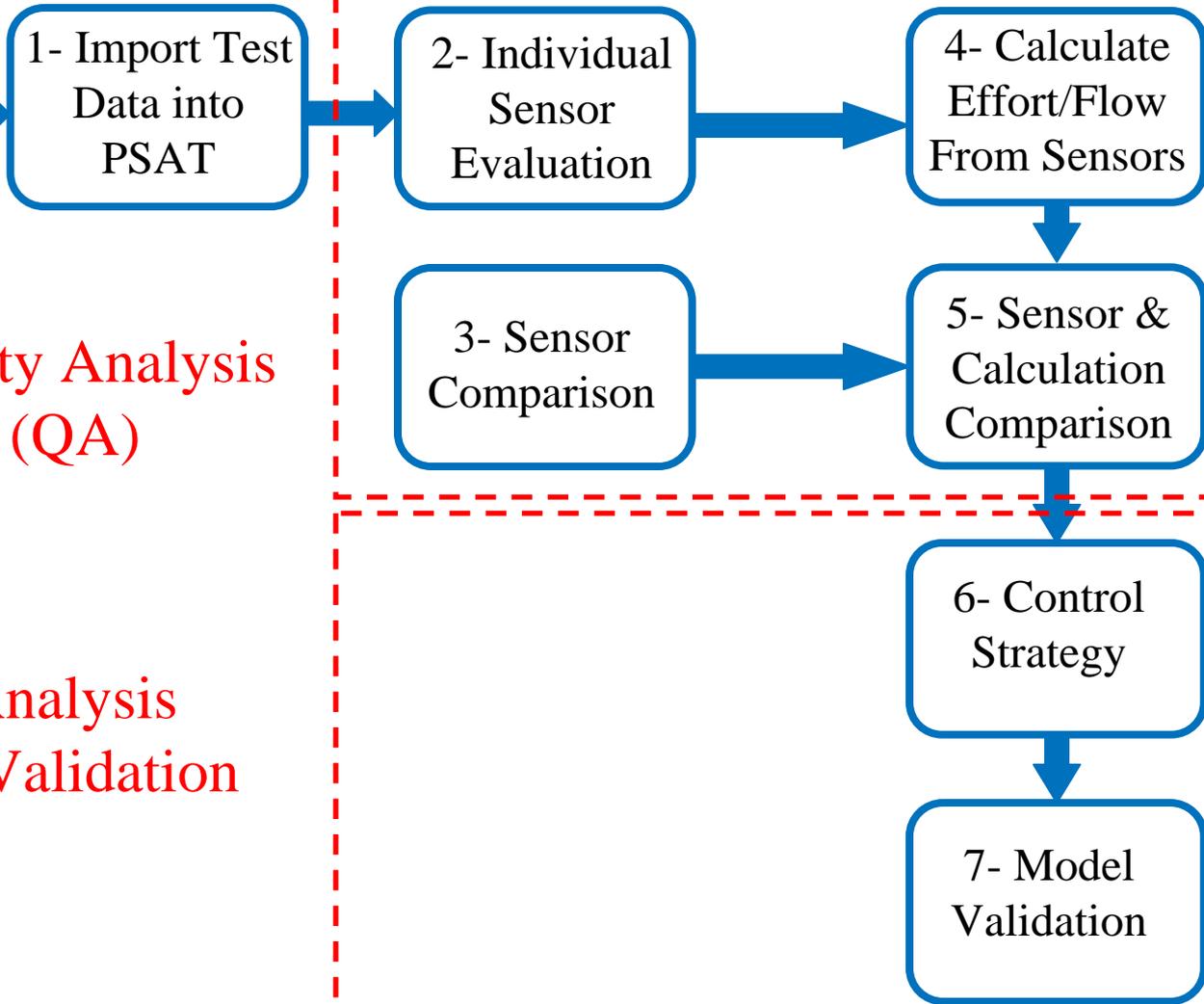


Generic Approach: From Test to Validation



Quality Analysis
(QA)

Analysis
& Validation

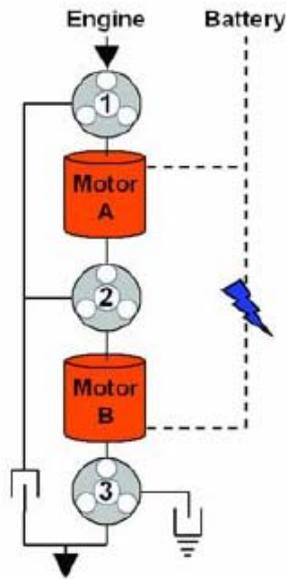




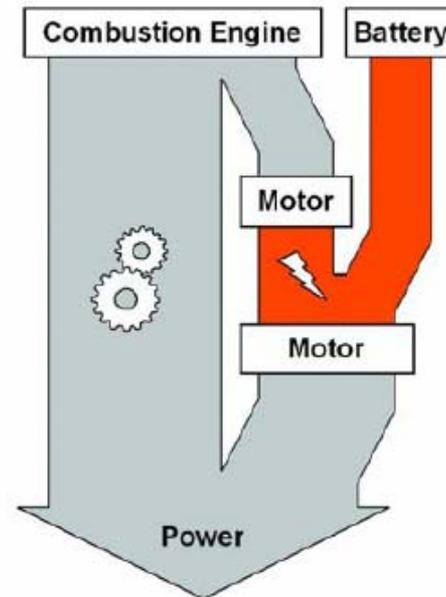
Two-Mode Description



- 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

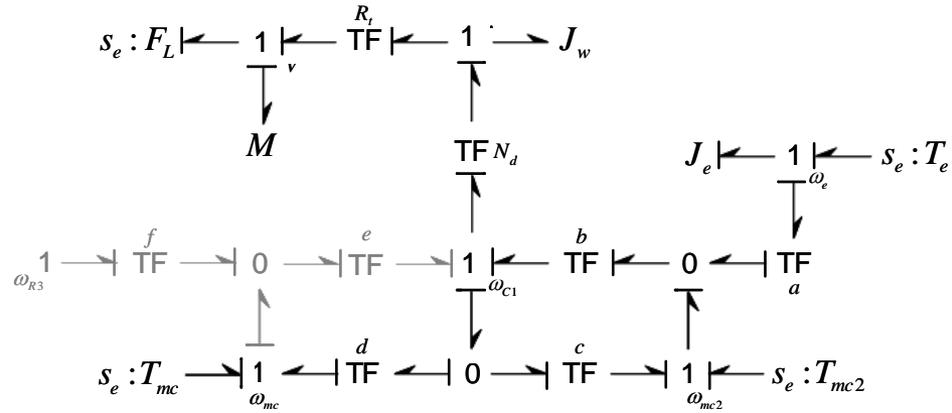
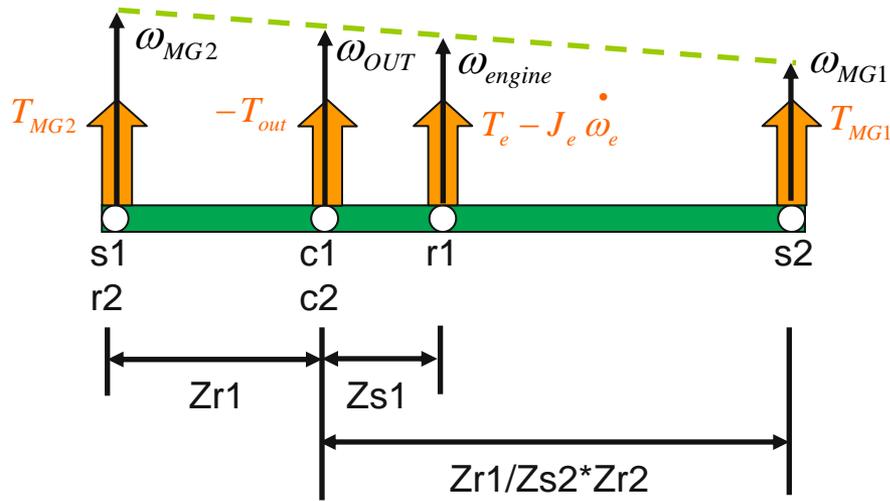


- Planetary gears split engine power and can multiply all torque
- Clutches change EVT modes smoothly
- Combined motor power requirement is much improved with two modes



Equations for Gearbox Model

Mode 2 (Compound Mode) – Process for Equations



Option 1 – Lever Diagram

Option 2 – Bond Graph

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

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

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

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

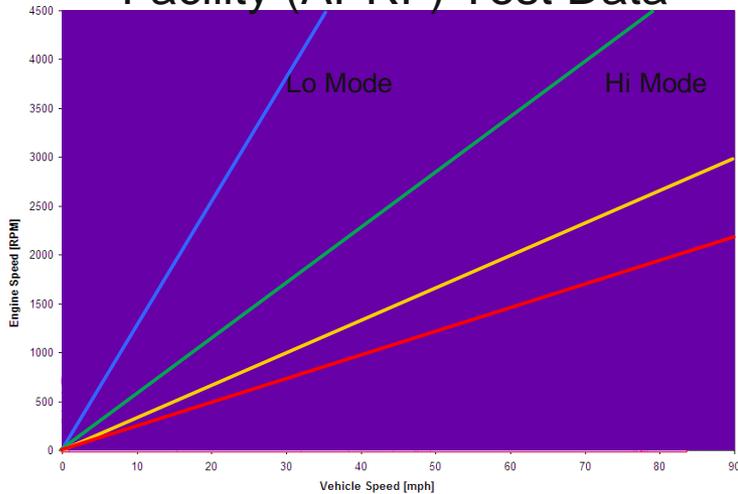


Control Strategy Development

Mode Selection – Rule Based (Option #1)



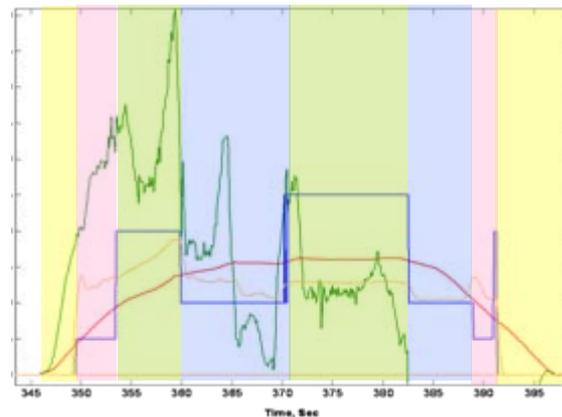
Advanced Powertrain Research
Facility (APRF) Test Data



Rules

Mode selection based on:

- State of Charge (SOC)
- Vehicle speed
- Wheel power
- ...

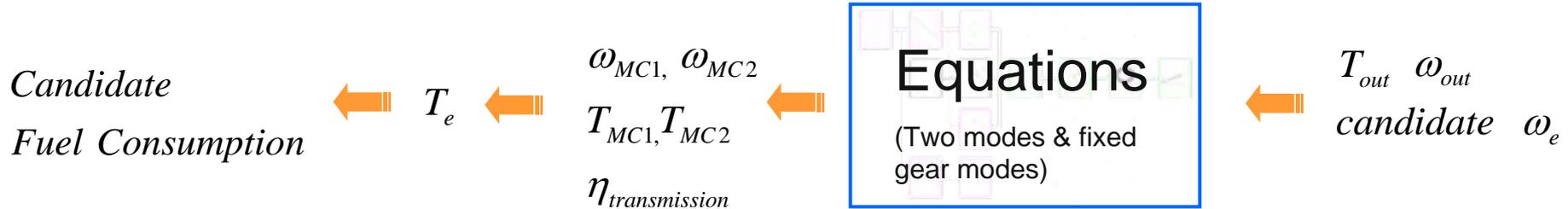


- Vehicle speed
- Wheel power
- Mode
- Engine speed
- EV mode
- 1 Mode
- 2 Mode
- Fixed Gear (2nd, 3rd)



Control Strategy Development

Mode Selection – Optimization (Option #2)



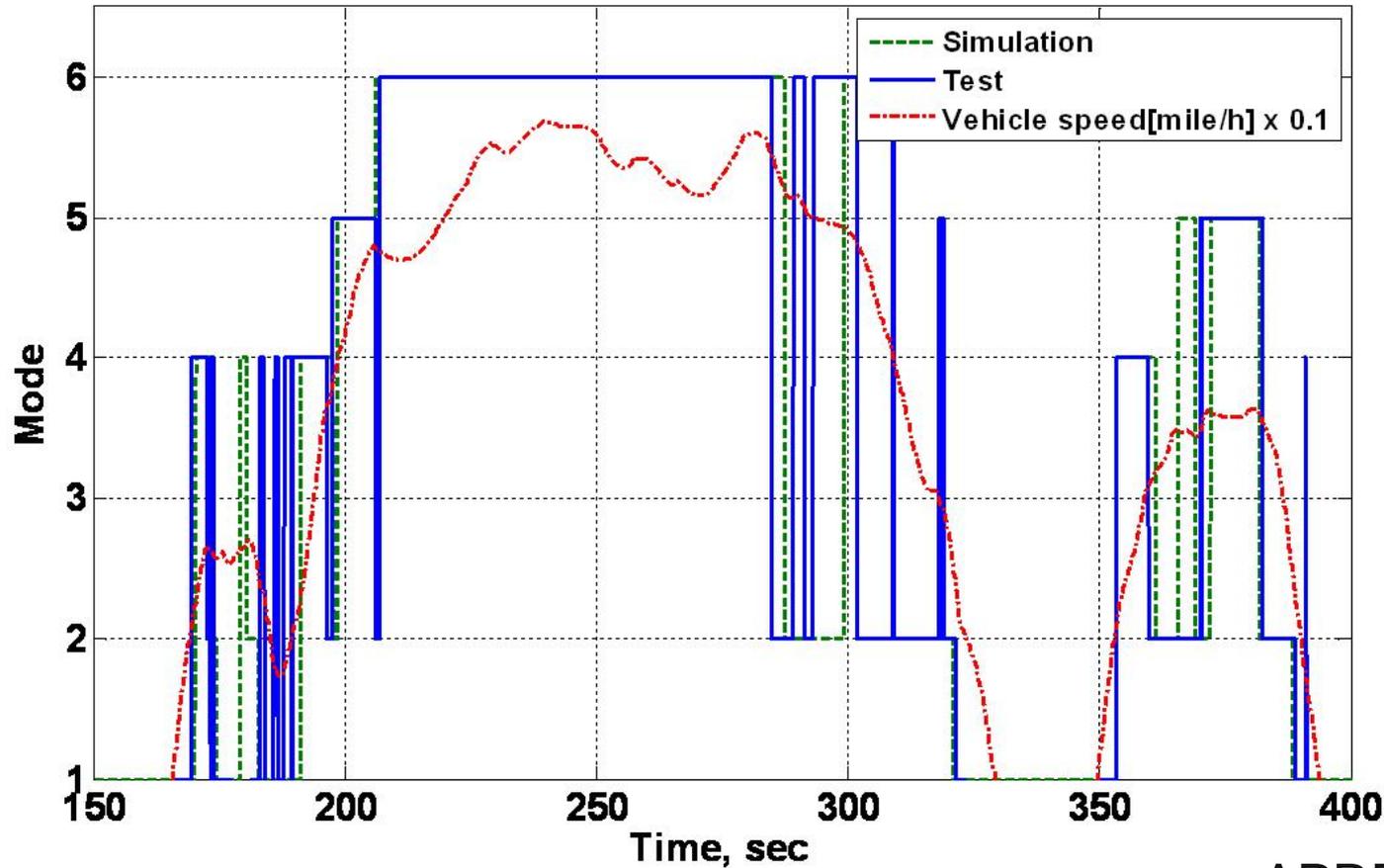
- A candidate fuel consumption set can be generated for a candidate set of inputs ($T_{out}, \omega_{out}, \omega_e$).
- Instantaneous optimization is used to minimize the powertrain losses. The algorithm selects the modes and the operating conditions of each components.
- The main issue is to define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

Mode Selection Comparison

Control Strategy Option #1 Versus Test Data



Mode = 1(Input split), 2(Compound split), 3(1st), 4(2nd), 5(3rd), 6(4th)

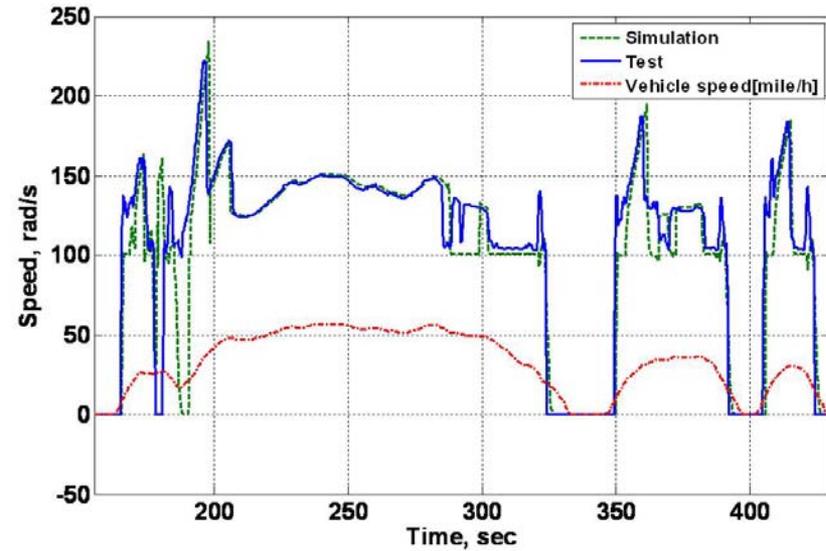


APRF Test Data

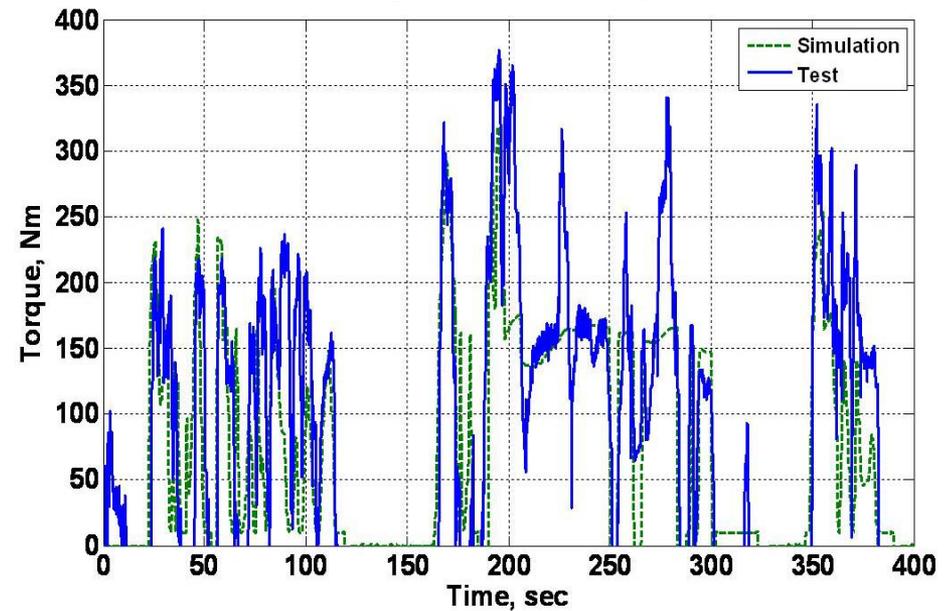
Engine Operation Comparison



Engine Speed



Engine Torque

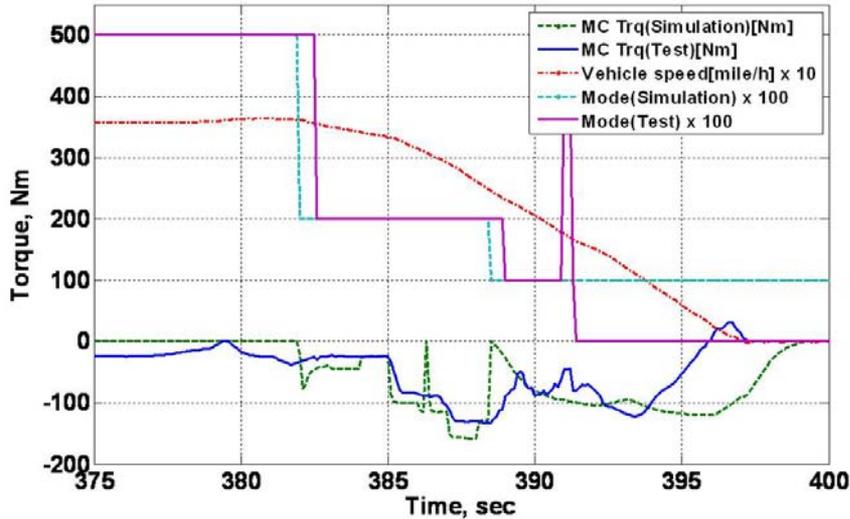


APRF Test Data

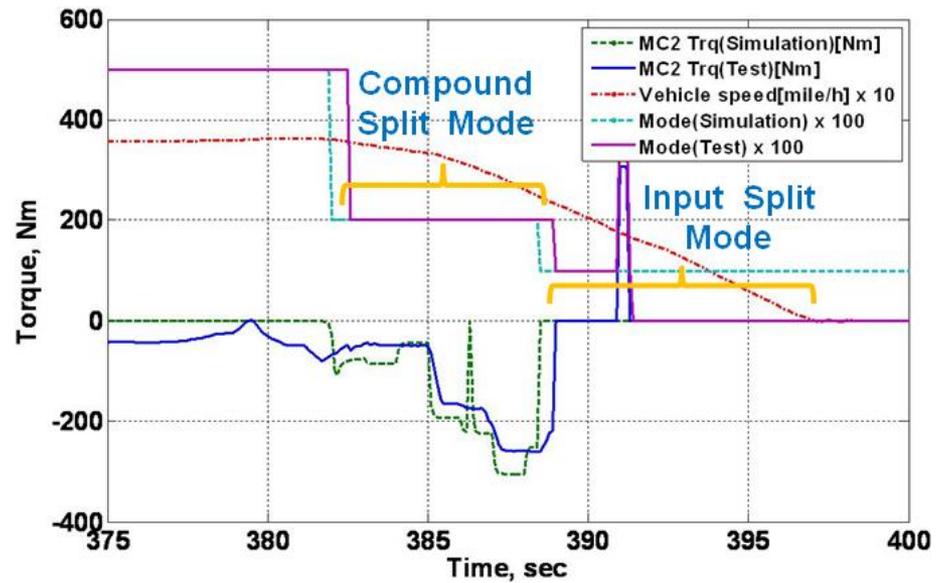
Regenerative Braking Comparison



Motor 1 - UDDS

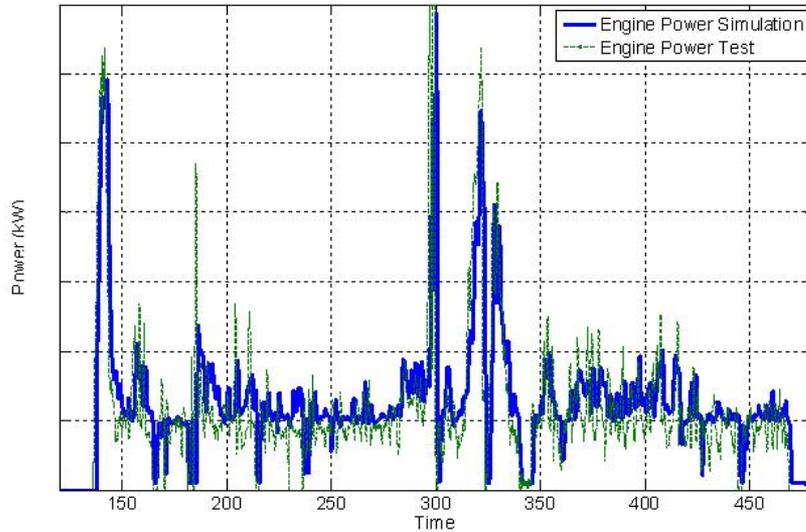


Motor 2 - UDDS



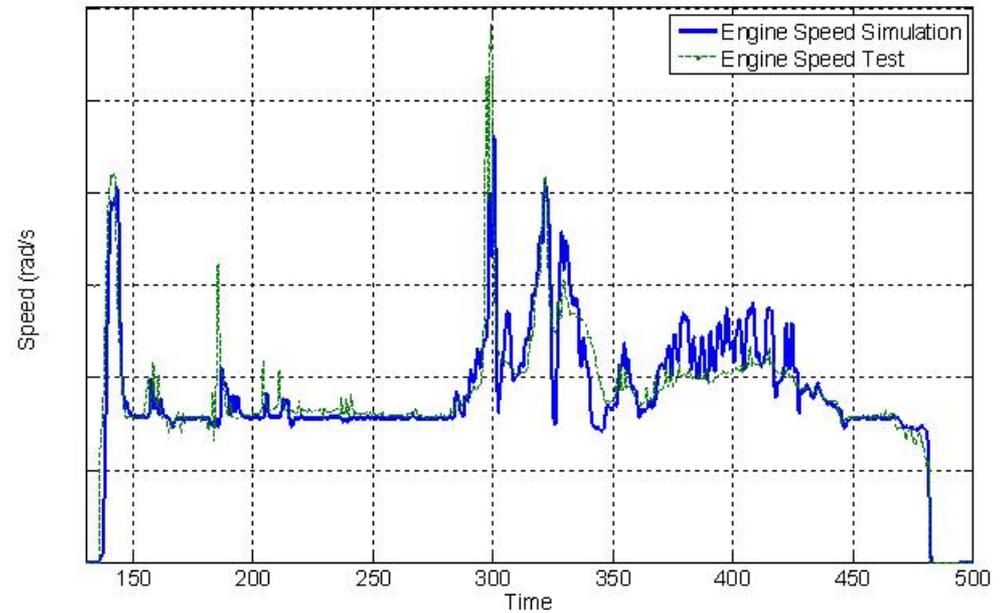
APRF Test Data

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



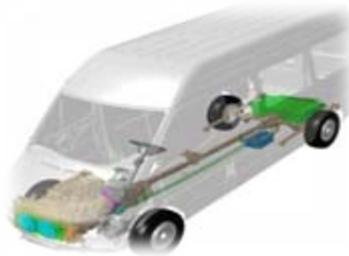
Source: Toyota



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