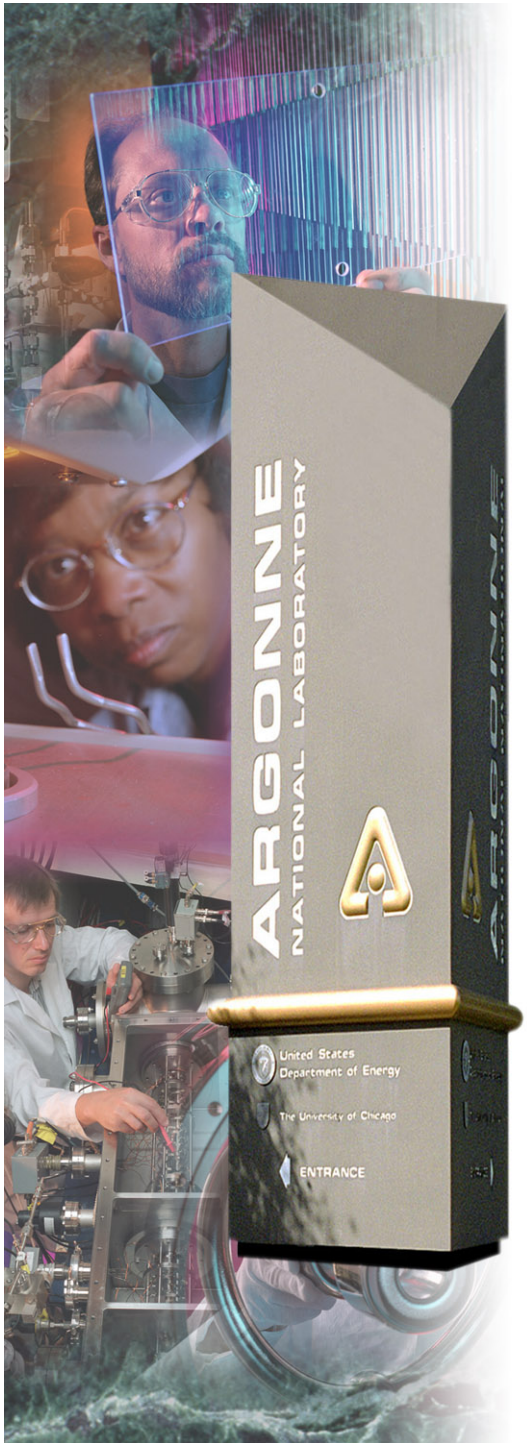

Validation Process of a HEV System Analysis Model: PSAT

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Office of Science Laboratory
Operated by The University of Chicago

Outline

PSAT Introduction

Vehicle testing

Component Validation

Control Strategy Understanding

Drivetrain Validation

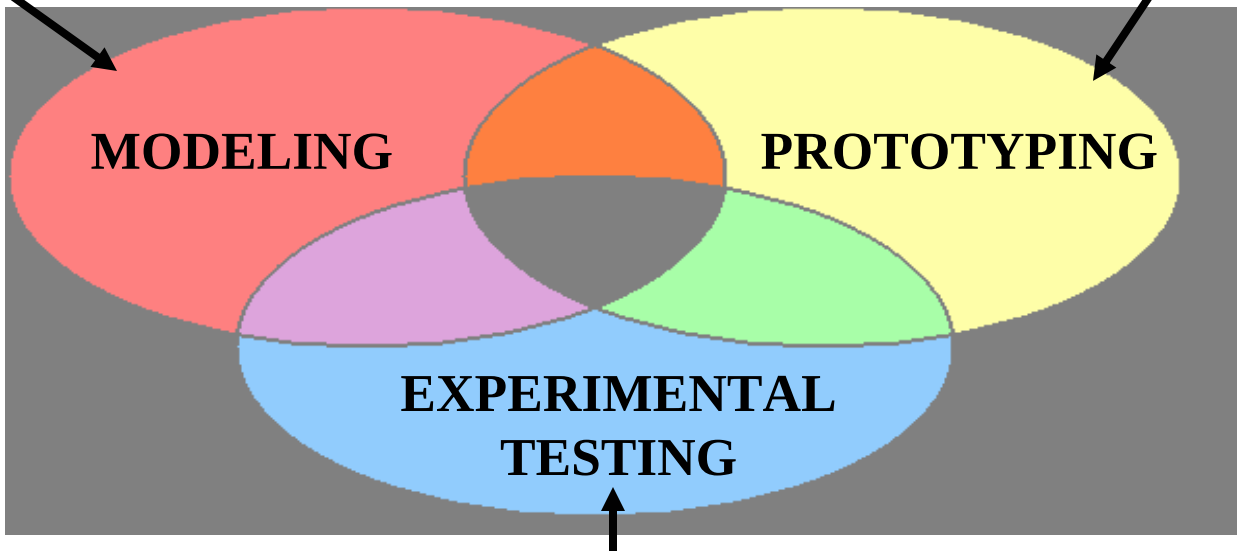
Conclusion

ANL System Analysis Program

Modeling, testing, and hardware control used to investigate various technologies of advanced vehicles (diesel emissions, CVTs…)

1. Modeling software: PSAT
2. Development/integration of new models/data into PSAT
3. Control strategy development

1. Control software: PSAT-PRO
2. Rapid Prototyping (RP)
3. Hardware In the Loop (HIL)



1. Instrumentation
2. Emissions equipment
3. Data processing

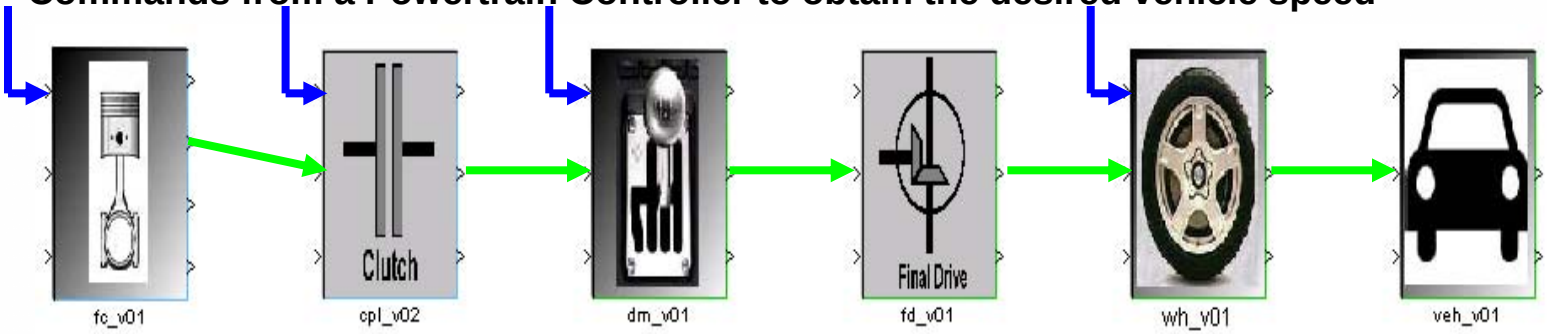
What is PSAT?

- Developed by ANL under the direction and with the contribution of Ford, General Motors and DaimlerChrysler for the Partnership for New Generation of Vehicle (PNGV)
- Funded by USCAR and now by DOE
- A powerful forward-looking modeling tool that allows the user to realistically simulate:
  - Fuel consumption and exhaust emissions (e.g. Federal Test Procedure, highway, all other cycles)
  - Performance (e.g. 0-30mph, 0-60 mph, 40-60 mph, distance in 5 sec., maximum launch grade, maximum continuous speed, 55mph at 6% grade)

Forward Looking Modeling

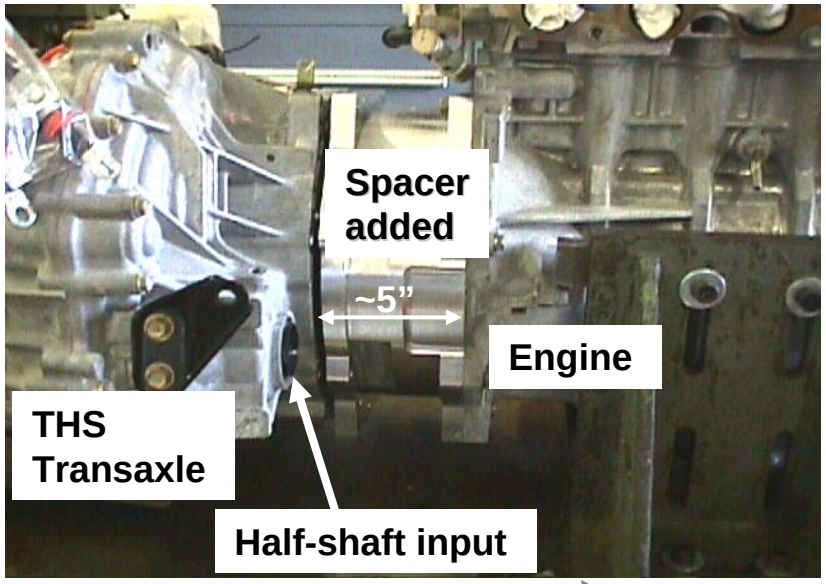
Forward looking models (PSAT) represent how systems respond in reality
In a vehicle, the driver input creates the vehicle response

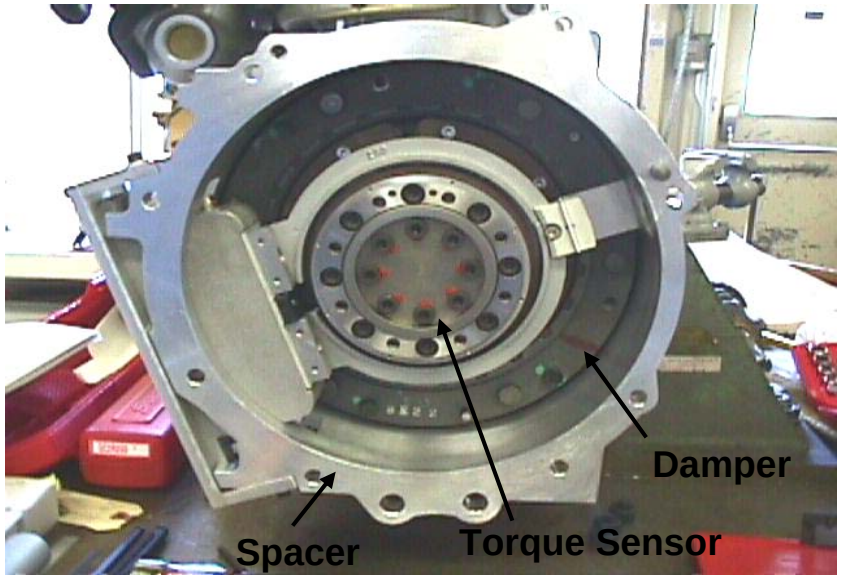
Commands from a Powertrain Controller to obtain the desired vehicle speed



- **Forward looking modeling is consistent with industry practice for vehicle design**
- **Accurate representation of a dynamic system (e.g. engine starting, shifting, clutch engagement / disengagement…)**
- **Possibility to implement advanced component models (e.g. 1D engine model to characterize emissions…)**
- **Develop control strategies that can be later tested on a bench or in a vehicle**
- **Small time step**

Extensive Data Collection With Torque Sensors



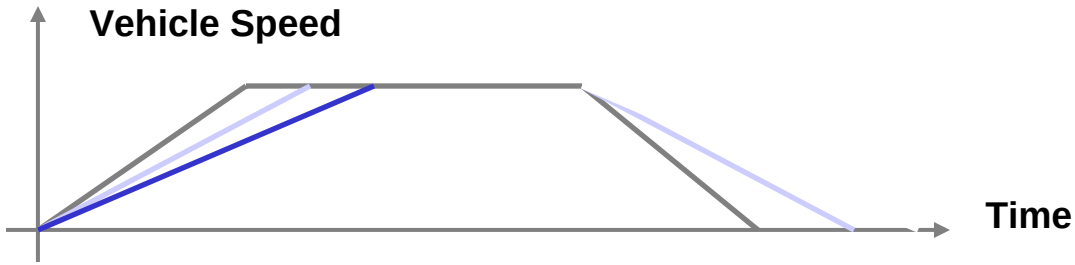


Prius engine torque sensor

Insight axle torque sensor

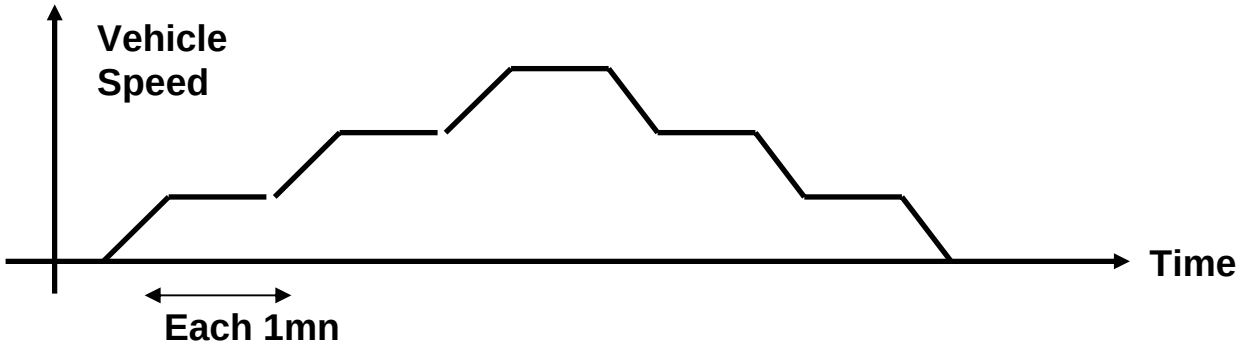
Different Types of Tests Are Needed

Steady-state speeds

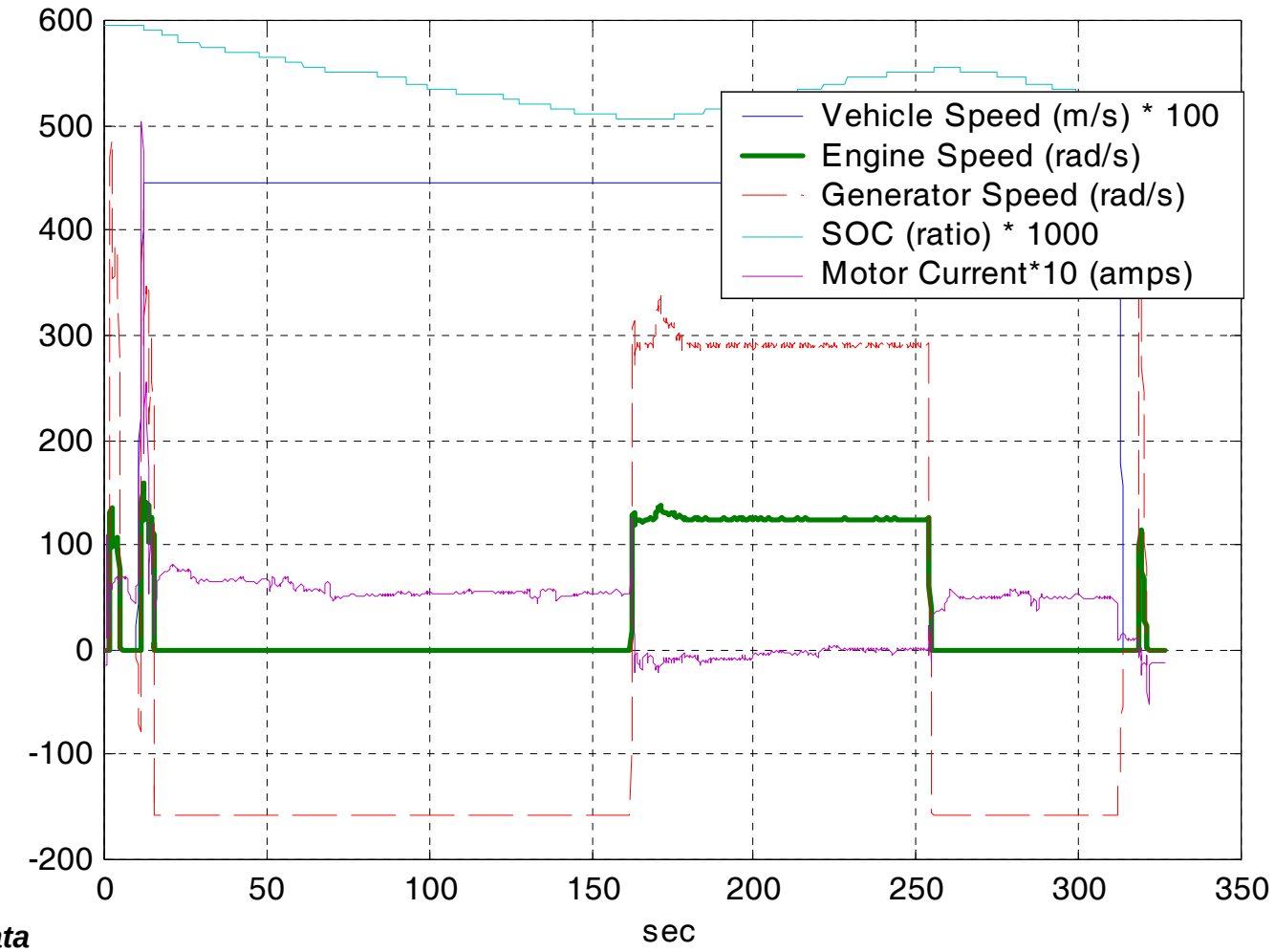


Succession of accelerations and decelerations at different speeds

Standard cycles (EUDC, Japan…)

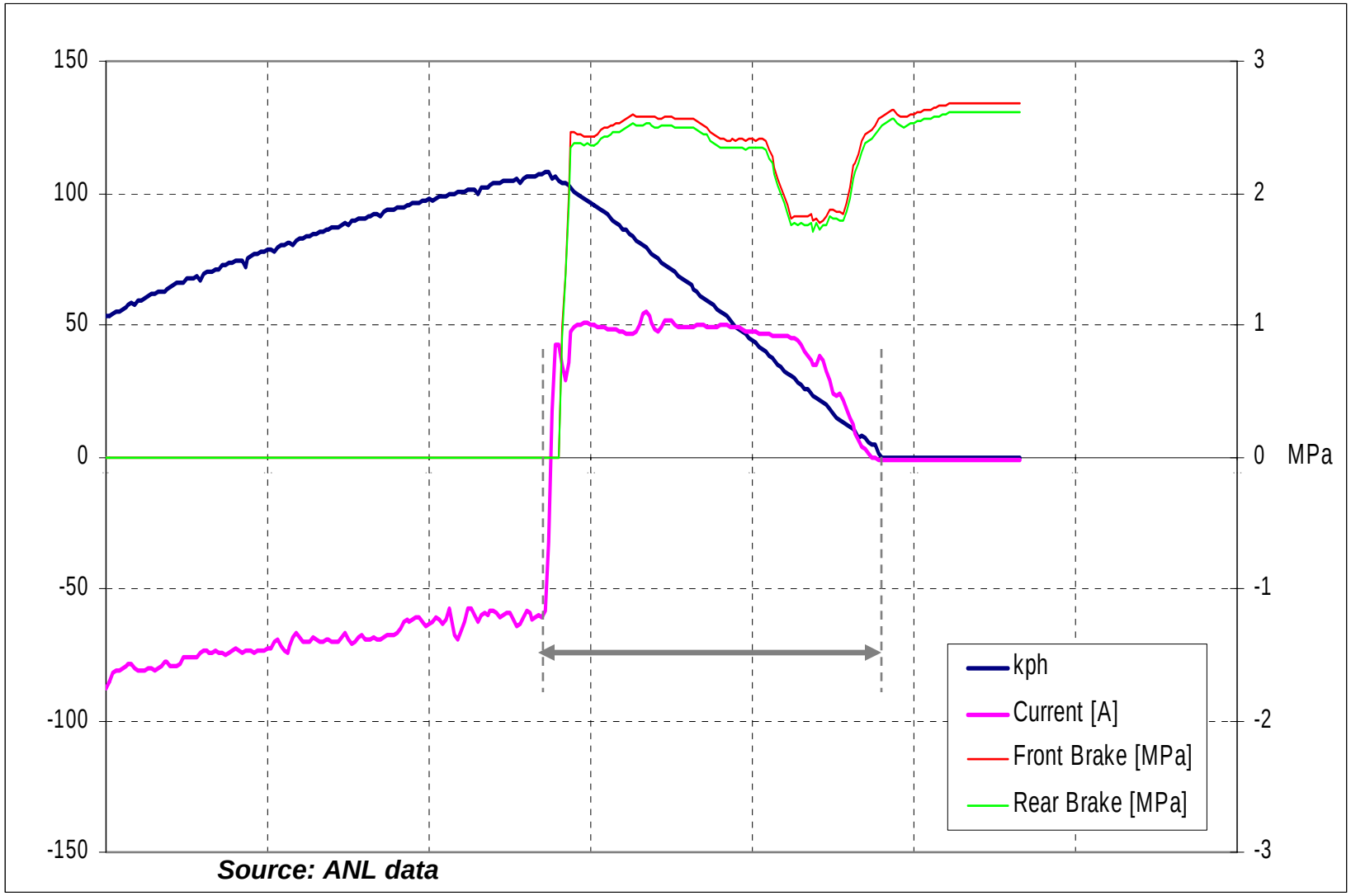


Control Strategy Understanding



Source: ANL data

Acceleration / Deceleration Tests



Source: ANL data

What is the Uncertainty of Each Model?

Physical Vehicle

Simulated Component

Measured Current

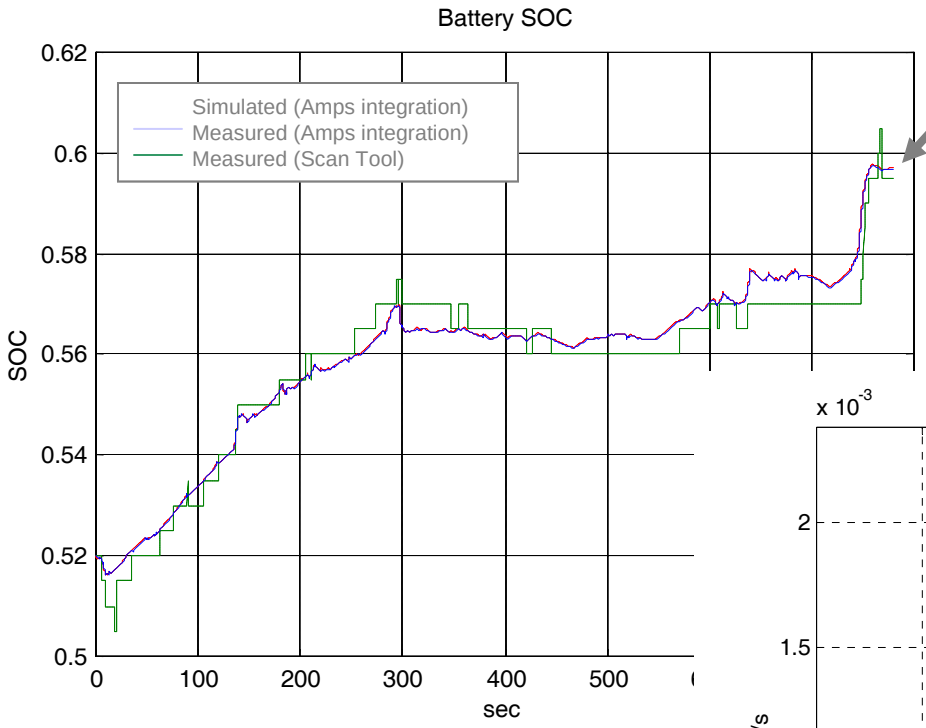
Simulated SOC

Measured Voltage = Simulated Voltage ✓

Measured SOC = Simulated SOC ✓

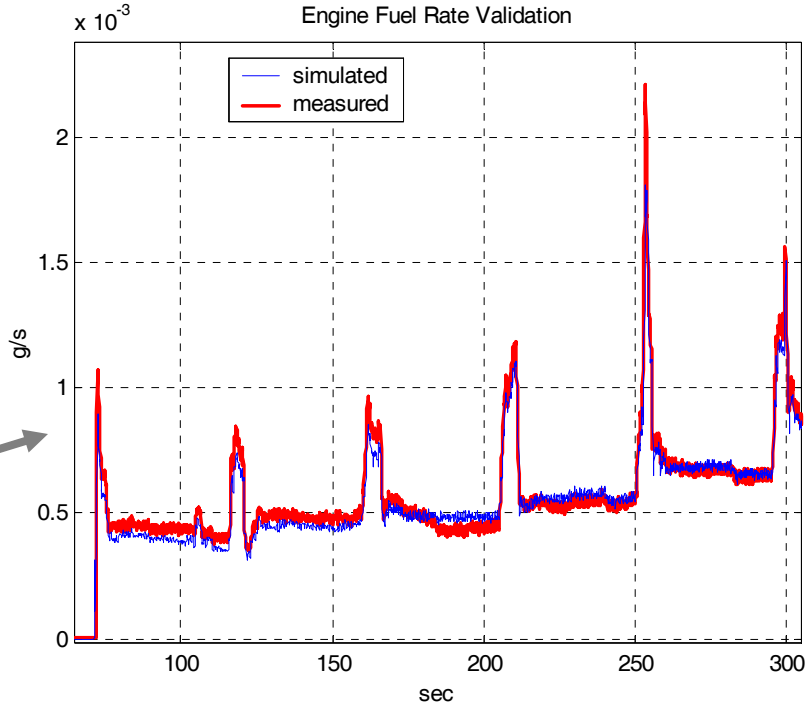
Valid Battery Model ✓

Battery and Engine Validation



Battery Validation

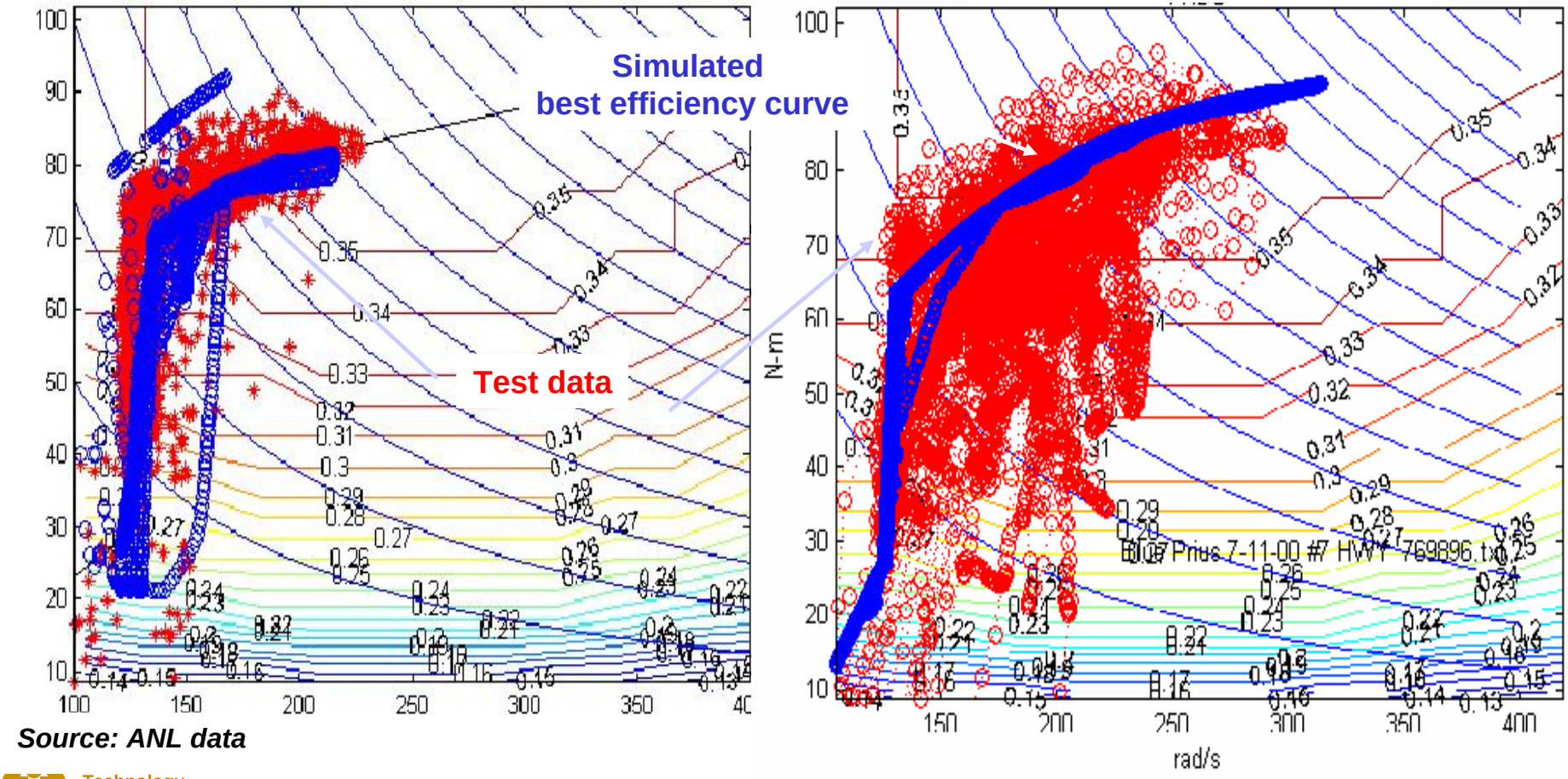
Engine Validation



Control Strategy May Differ From One Cycle to Another One

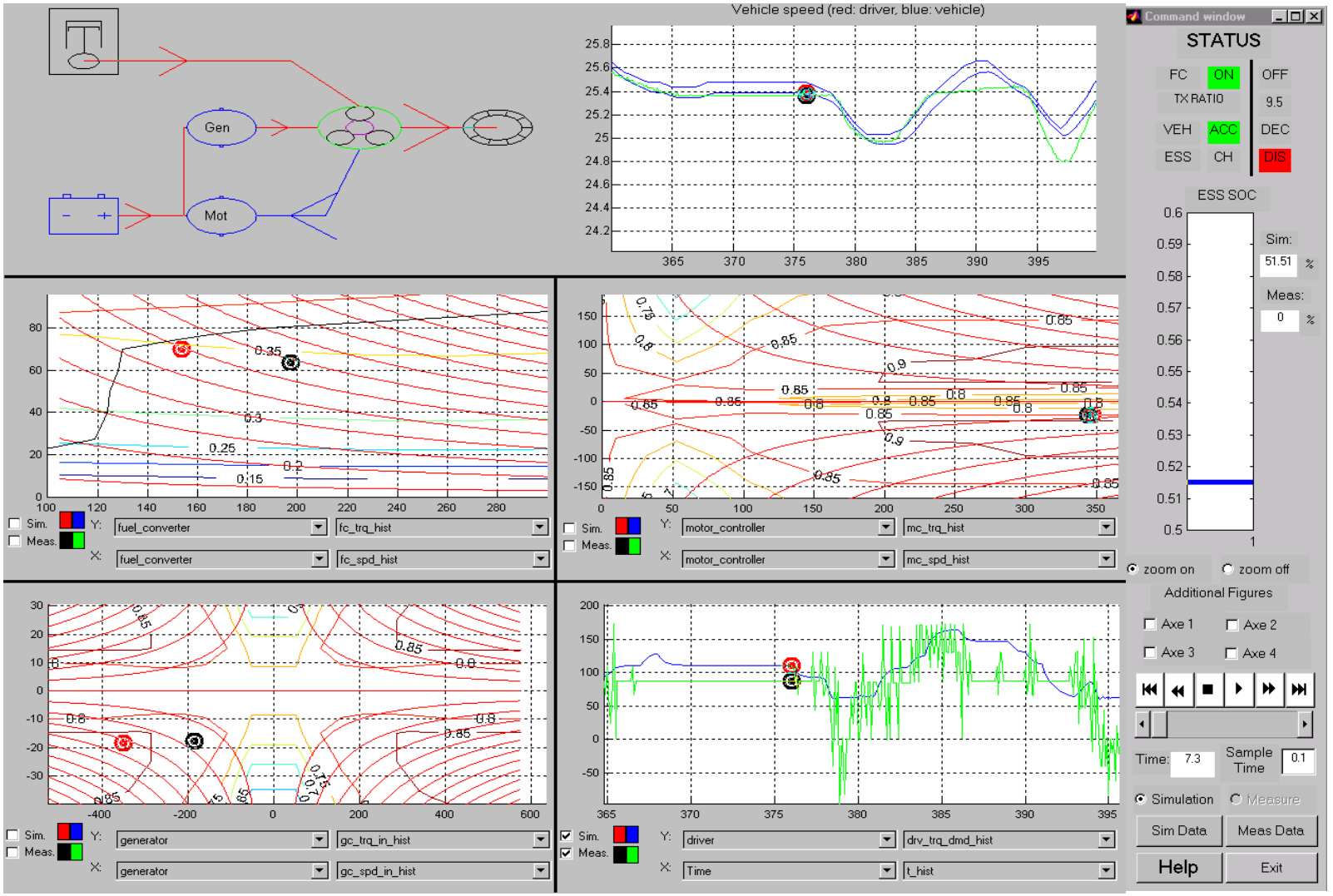
Engine torque vs. Engine Speed

Japan 10-15 Highway Cycle

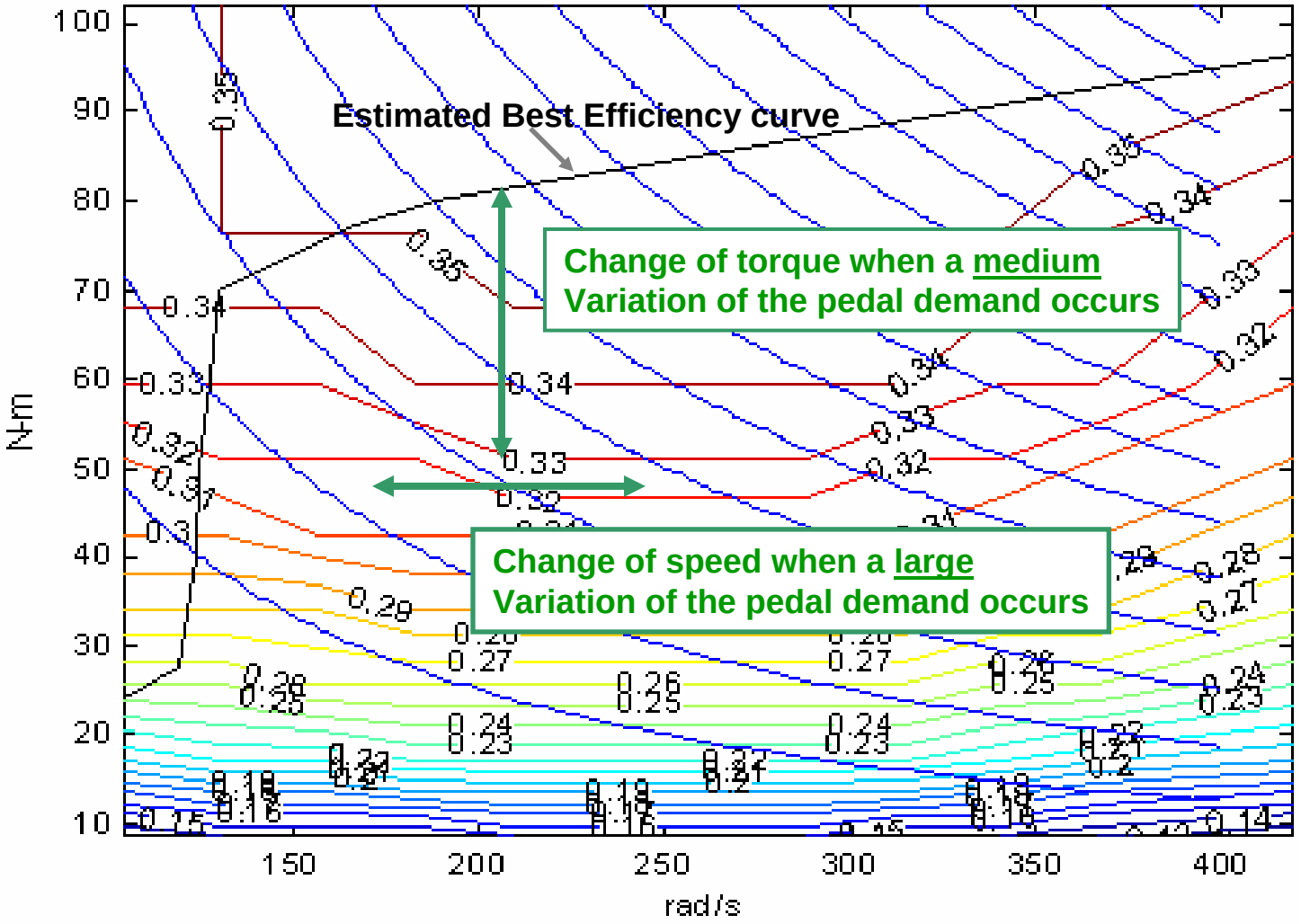


Source: ANL data

Specific Tools Are Necessary to Understand HEV Control Strategies



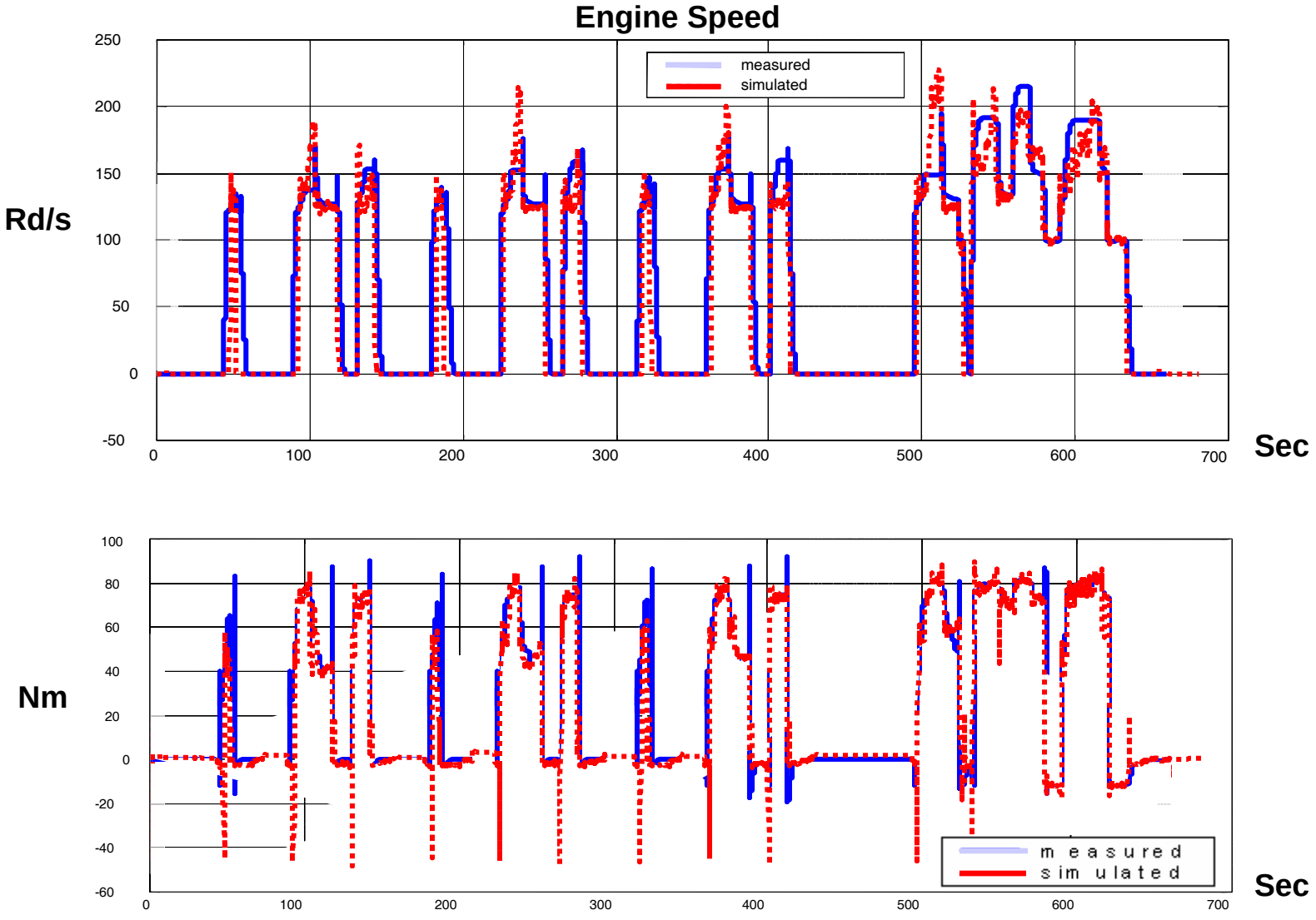
The Japanese Prius Does Not always Follow the Best Efficiency Curve



PSAT Prius Validation is Within 5%

Cycle	Cons test mpg	Cons simul mpg	Diff in %	SOC init	SOCf test	SOCf simul	Diff in %
Japan 10-15		**45.1**	0.4			**0.583**	0.5
Japan 10-15		**50.7**	3.9			**0.561**	2.3
EUDC		**43.8**	0.4			**0.593**	2.0
FHDS		**46.7**	3.2			**0.573**	0.3
UDDS		**39.9**	5.9			**0.570**	8.7

Component Behavior is Validated



Conclusions

HEVs require new approach for validation

- **A validation methodology has been developed for HEV validation**
  - **Specific tests have been defined**
  - **Specific tools have been developed**
- **The Japan Toyota Prius has been validated within 5% on different cycles with different SOC using PSAT**
- **The generic methodology and tools developed can be applied to any HEV validation process**