PNGV System Analysis Toolkit

Developed by Argonne National Laboratory
with Ford, General Motors, and DaimlerChrysler
Funded by the U.S. Department of Energy

Outline

- PSAT Introduction
- PSAT Capabilities
- Examples of Validation
- PSAT Users
- Conclusions

ANL System's Analysis Program

ANL PSAT

MODELING (PSAT):

- Choose the appropriate powertrain
- Choose component size
- Develop the best strategy

PROTOTYPING (PSAT-PRO):

- Develop the control command system
- Create the physical system
- Simulate test procedures

ASAP

TESTING (APTF):

- Test and map components
- Perform the simulated tests
- Test hybrid vehicles

What is the PNGV System Analysis Toolkit?

ANL PSAT

- Developed by Argonne 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 users to realistically simulate
  - Fuel consumption and exhaust emissions (e.g., Federal Test Procedure, highway, all other cycles)
  - Performance (e.g., 0-30 mph, 0-60 mph, 40-60 mph, distance in 5 sec, maximum launch grade, maximum continuous speed, 55 mph at 6% grade)

Forward-Looking Modeling

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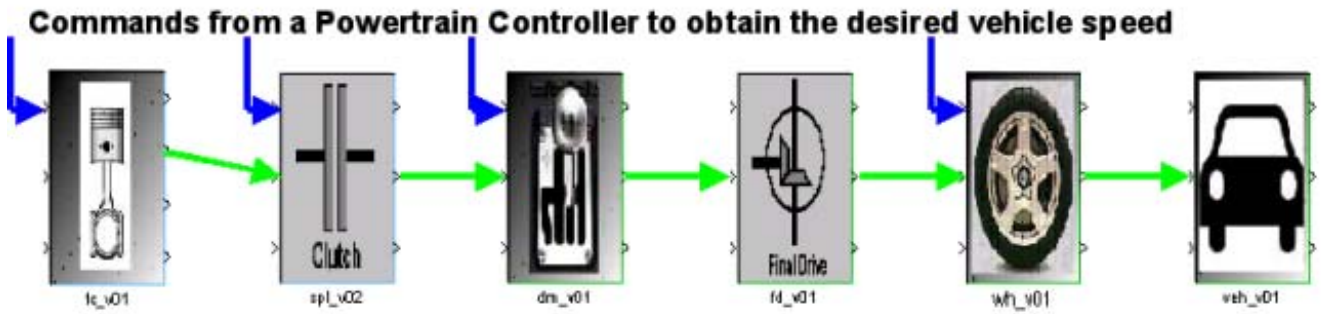
- Forward looking models (PSAT) represent how systems respond in reality
- In a vehicle, the driver input creates the vehicle response



- 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., 1-D engine model to characterize emissions…)
- Develop control strategies that can be later tested on a bench or in a vehicle
- Small time step

PSAT Is Reusable and Flexible

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- Each drivetrain is built according to user choices
- Unrivaled number of configurations
- Component model format is generic (3 ins/3 outs)
- Can use the same component model several times
- Can compare several strategies within the same model using switches
- Each drivetrain controller is composed of three blocks (constraints, strategy, transients)
- Software highly parameterized (flexible, reusable)

More than 80 new 4WD configurations have been integrated in less than a month !!

PSAT Single-Shaft Parallel Hybrid

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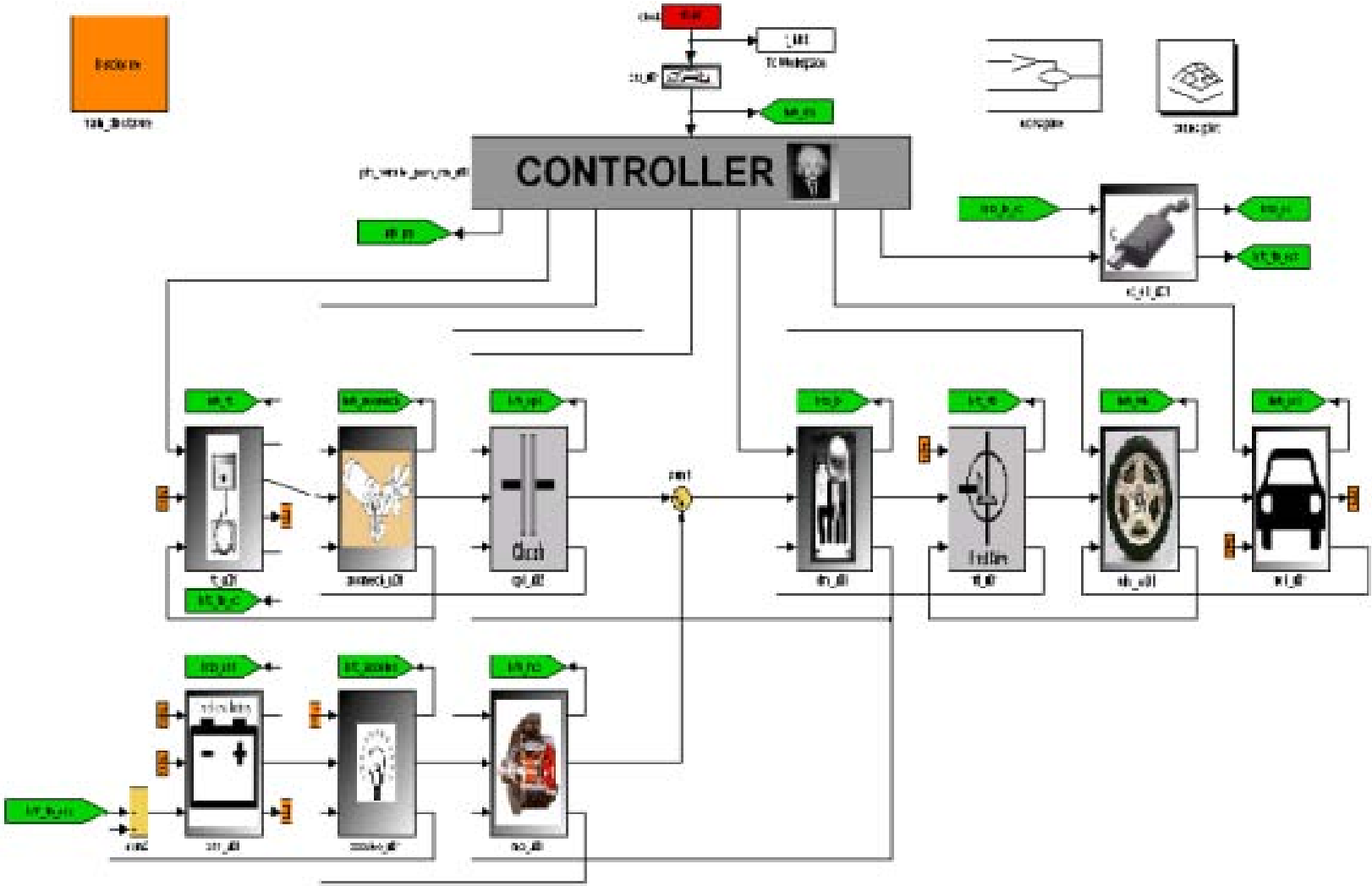

PSAT Structure Flows Intuitively

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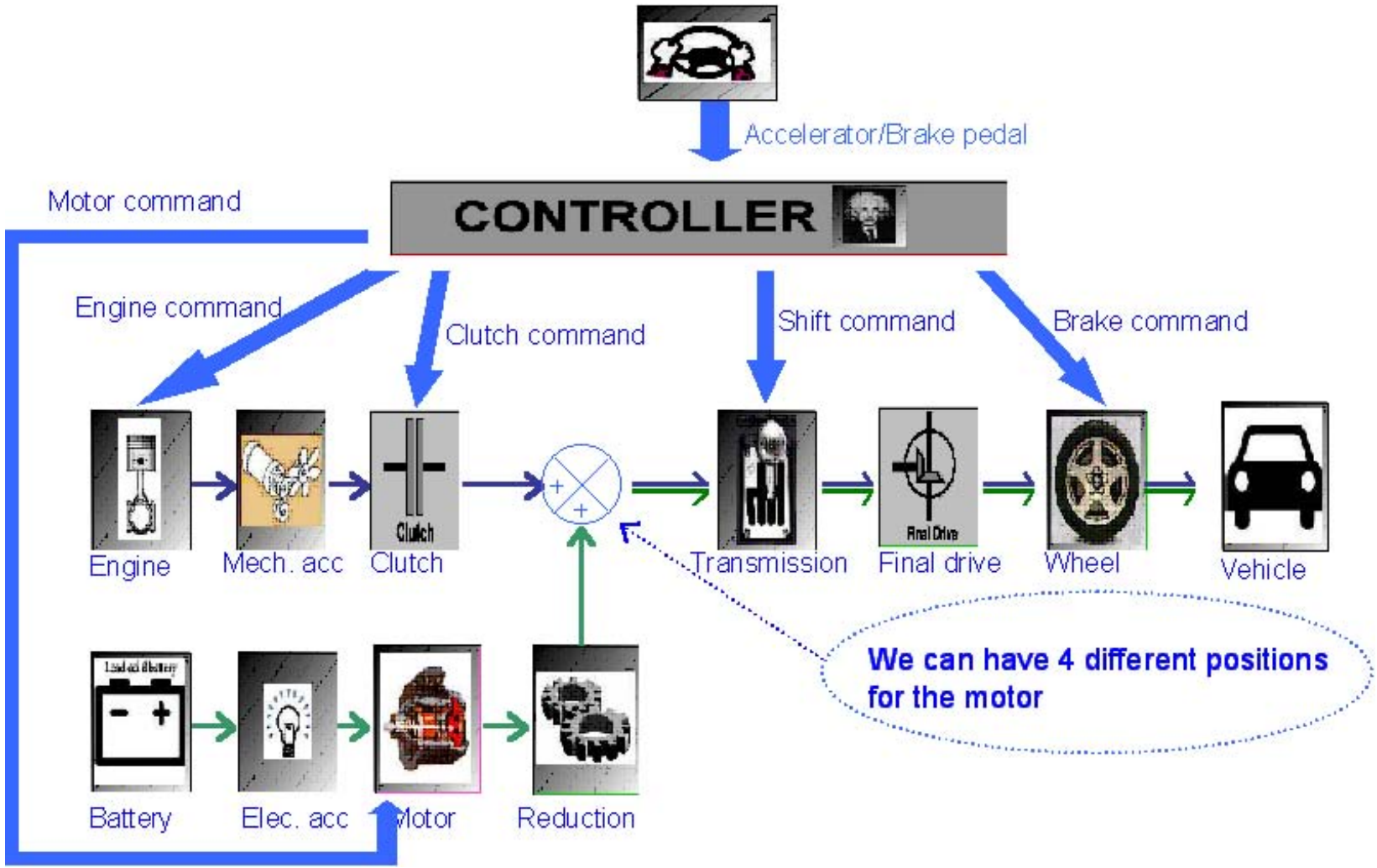
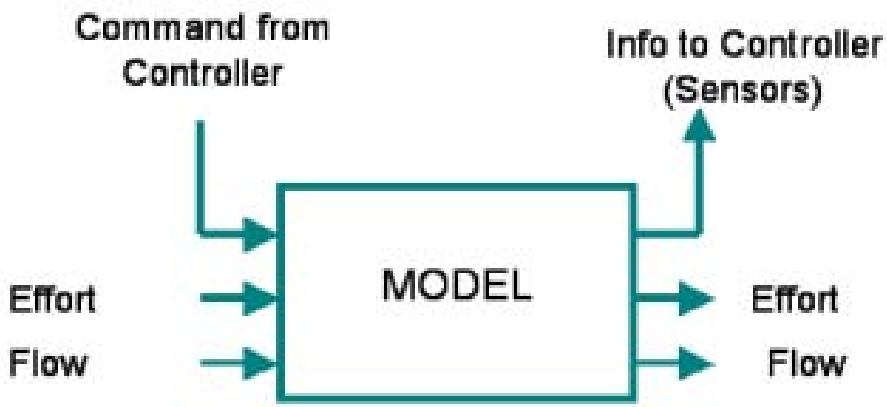


Different Levels of Modeling Can Be Used



	Effort	Flow
Engine	Torque	Speed
Motor	Voltage	Current

All the component models have the same number of inputs (3) and outputs (3)

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Each Model Can Be Used Several Times

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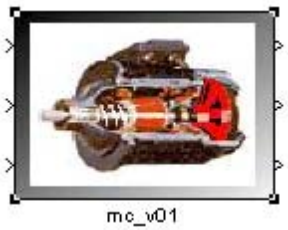
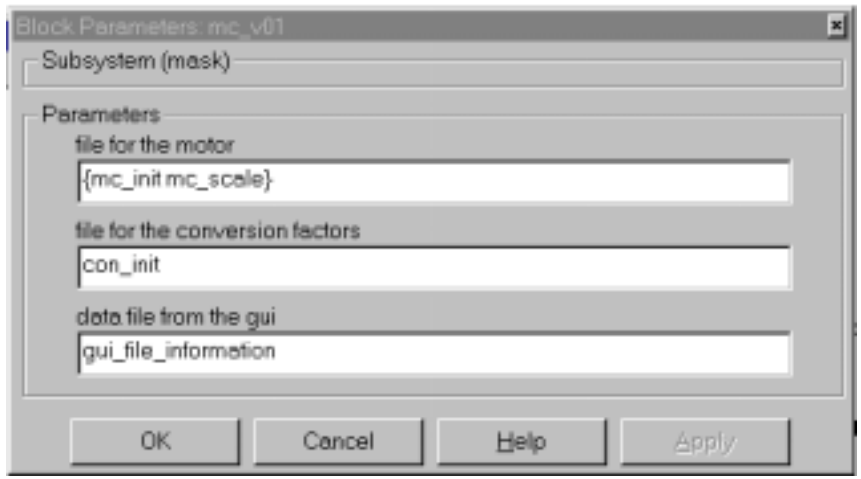
Use of mask
All the variables are locals

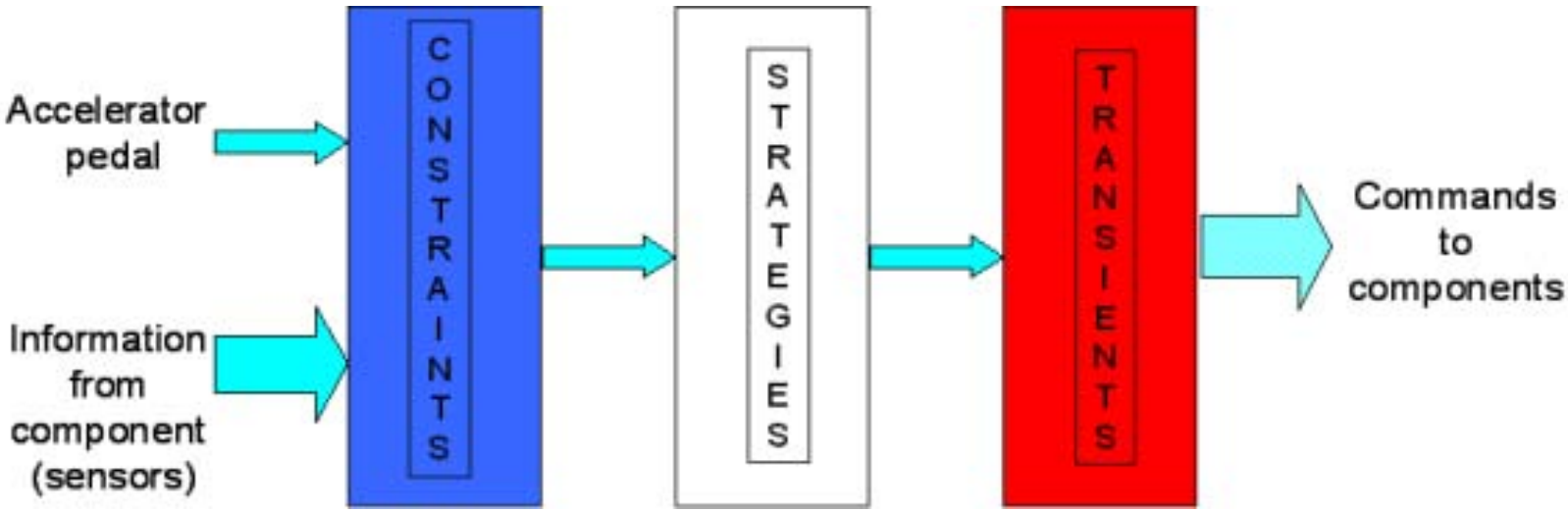




The same model can be used for different components

Controllers Organization Is Generic

A generic organization common to all powertrains



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Control Strategies Comparison Is Easy

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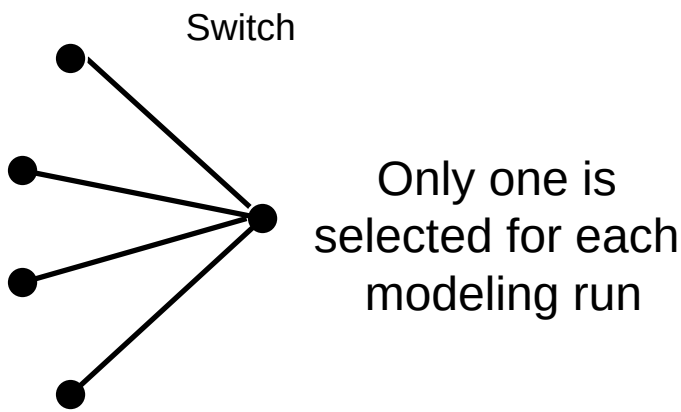
Within the same model, we can switch between different strategies. For example, the engine start can be based on

Strategy 1: a vehicle speed

Strategy 2: a power demand

Strategy 3: a torque demand

Strategy 4: a level of SOC



We compare ONLY separate strategies
We can EASILY implement new ones

PSAT Characteristics

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- Ability to use PSAT for any research project because models are generic and reusable
- Easy integration of initialization files, component models, or control strategies
- Can easily compare different levels of modeling or different control strategies
- Use of a voltage bus rather than power bus
- Realistic transient behavior (clutching, shifting…)
- Common naming nomenclature for files, parameters, and variables
- Multiple-user capabilities

PSAT Characteristics (cont.)

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- Can choose any Matlab solving algorithm
- Can run many simulations in a row (different cycles, parametric study, SOC equalization…)
- Speed up the simulation time (>6) using a compiled version with the possibility to change a parameter or a cycle without recompiling
- Extensive post-processing, including four phases (accel/decel, charge/discharge) and display of energy, power, torque, voltage, current, speed, and efficiencies
- Procedure to save simulation results
- Can create your own cycle
- HTML documentation

PSAT Graphical User Interface

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- PSAT GUI is based on 4 main windows:
  - Initialization – Choose the configuration and the components
  - Test choice – Choose the type of test(s) to be realized
  - Results – Access to the final results and plots
  - Post-processing – Display the energy, power… of the different components
- Several other windows are then used to
  - Integrate new data or models
  - List the initialization files of each model
  - List the parameters of each control strategy
  - Run multicycles or create a trip
  - Save the simulation(s)

PSAT GUI – Initialization Window

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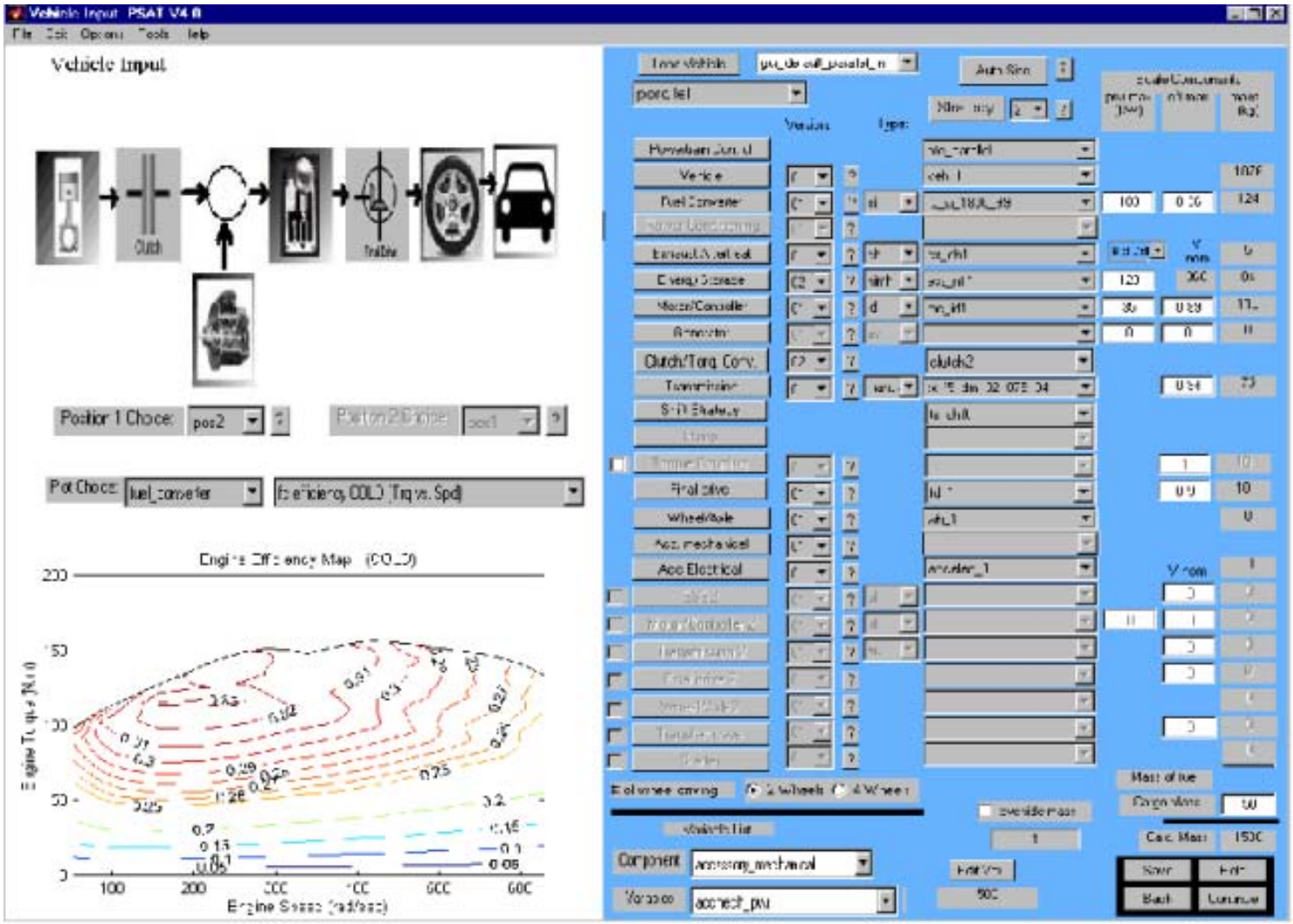
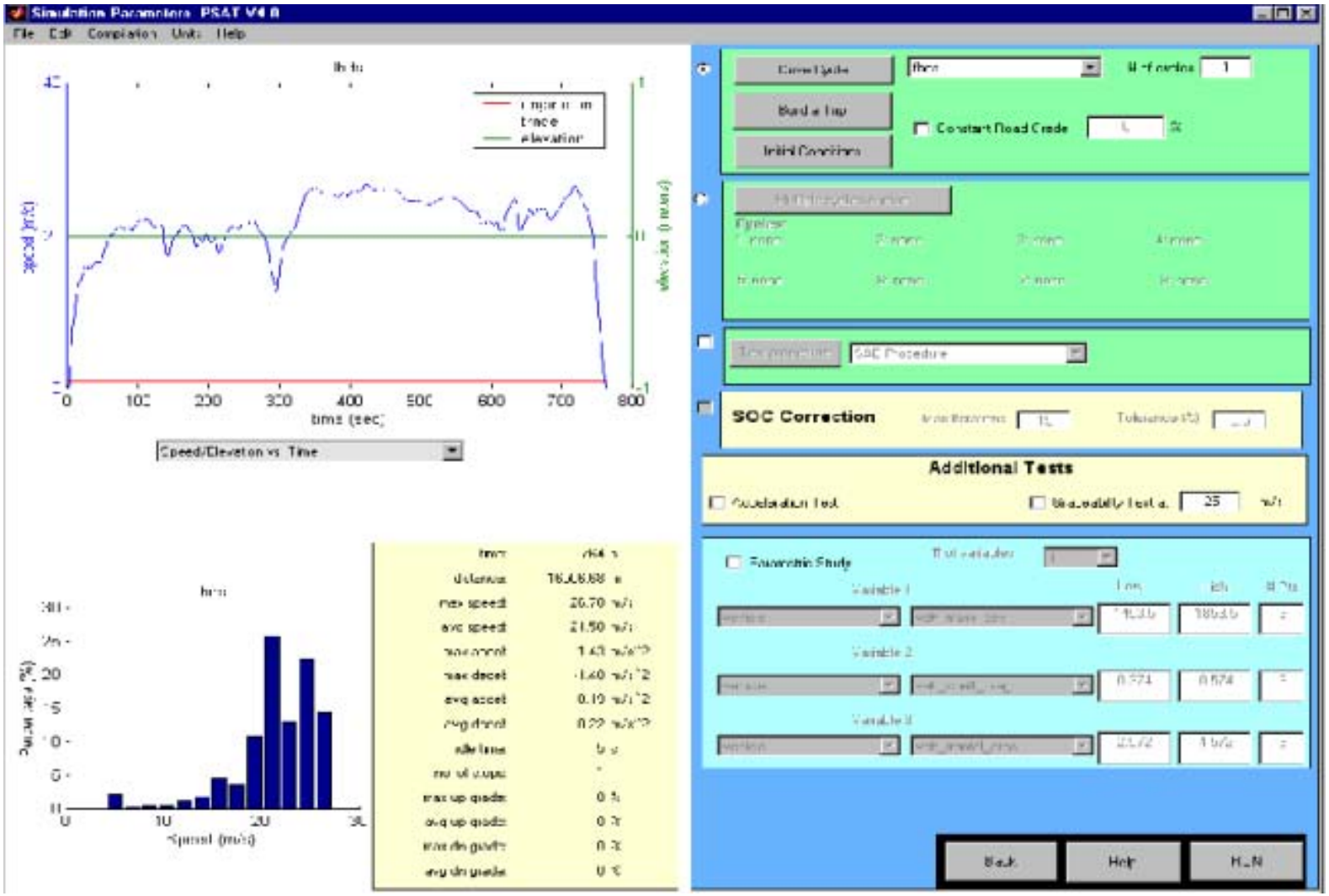


PSAT GUI – Test Choice Window



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PSAT GUI – Multi Cycle Choice

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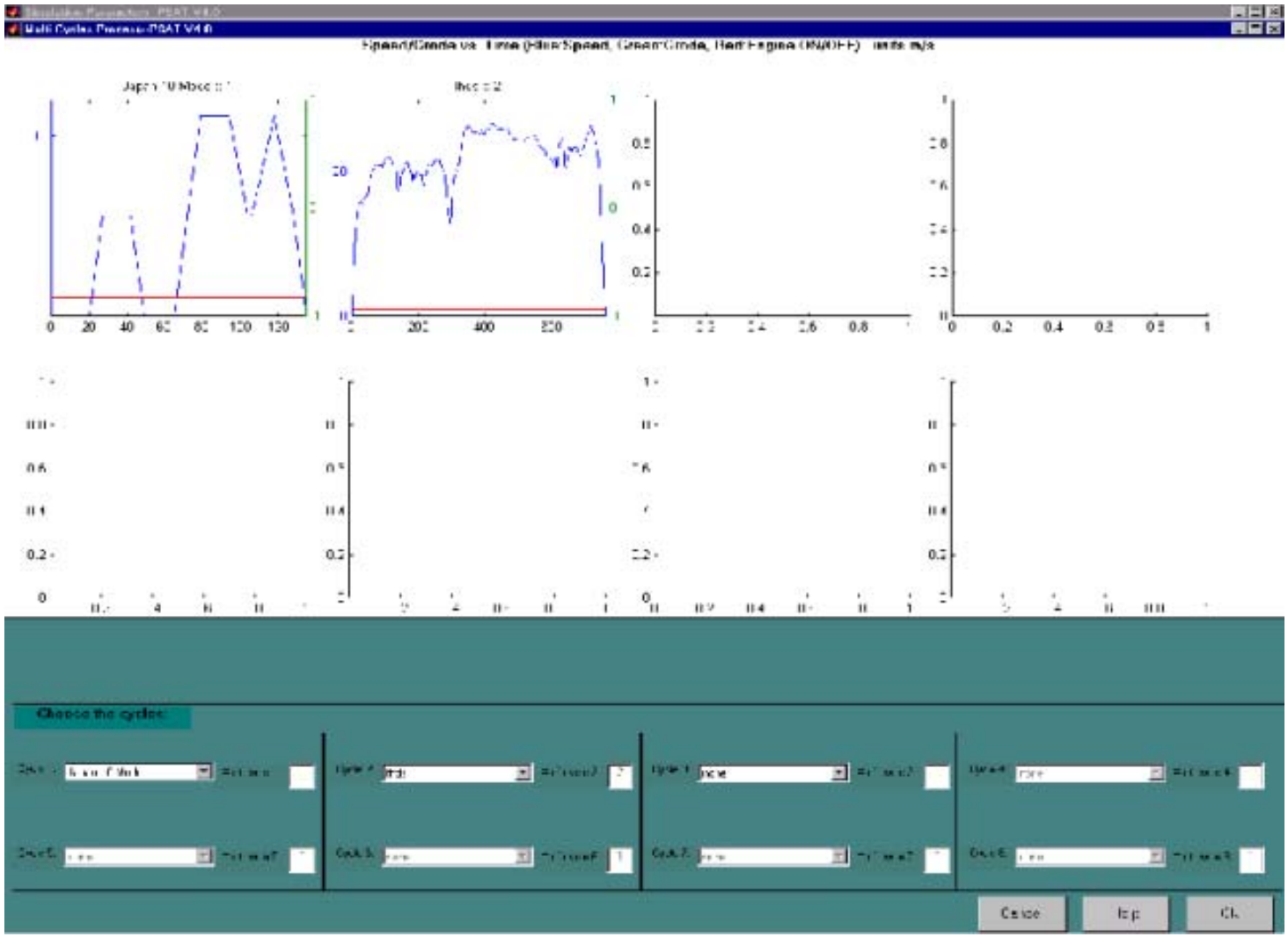
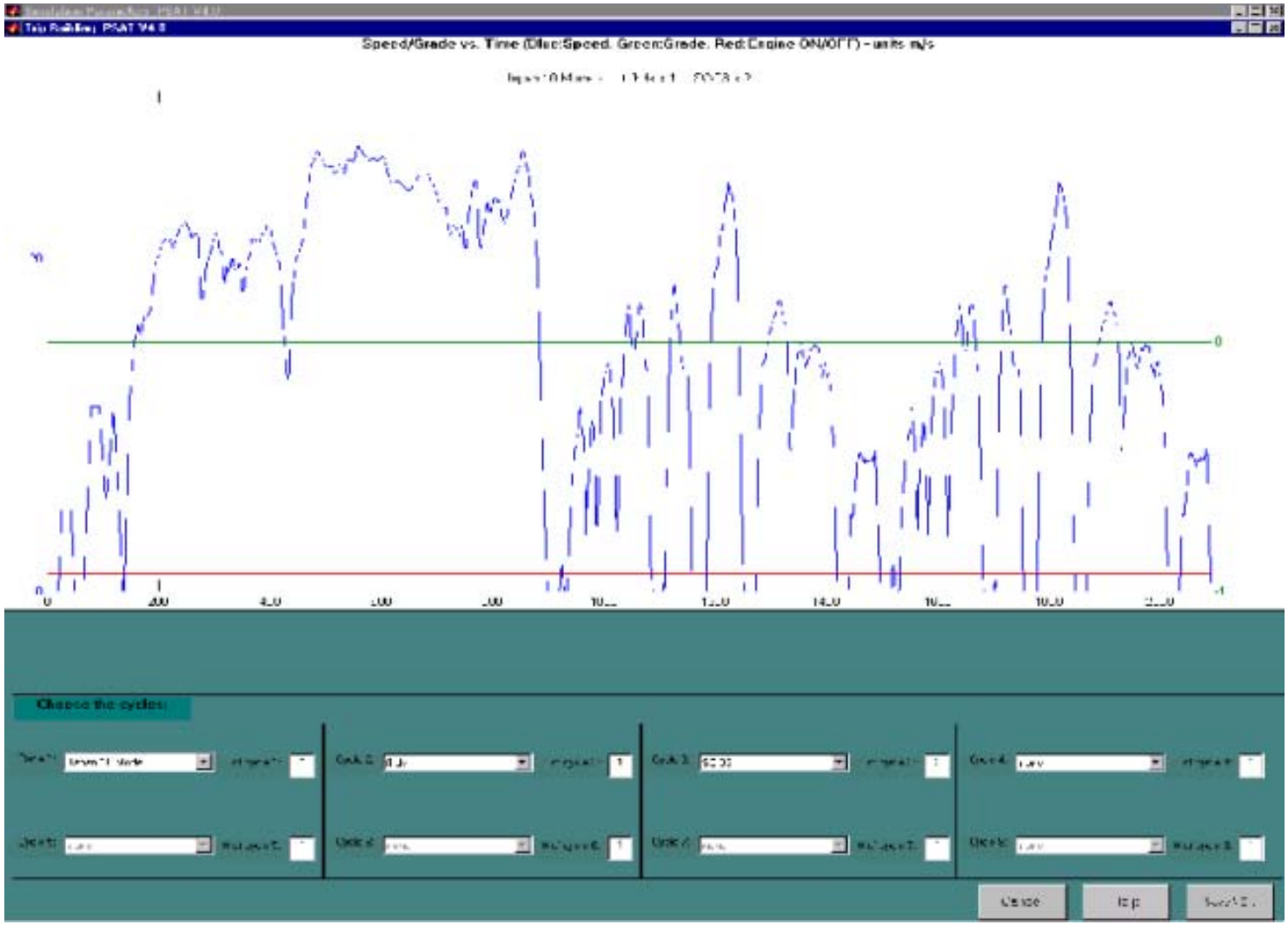


PSAT GUI – Creation of a Trip



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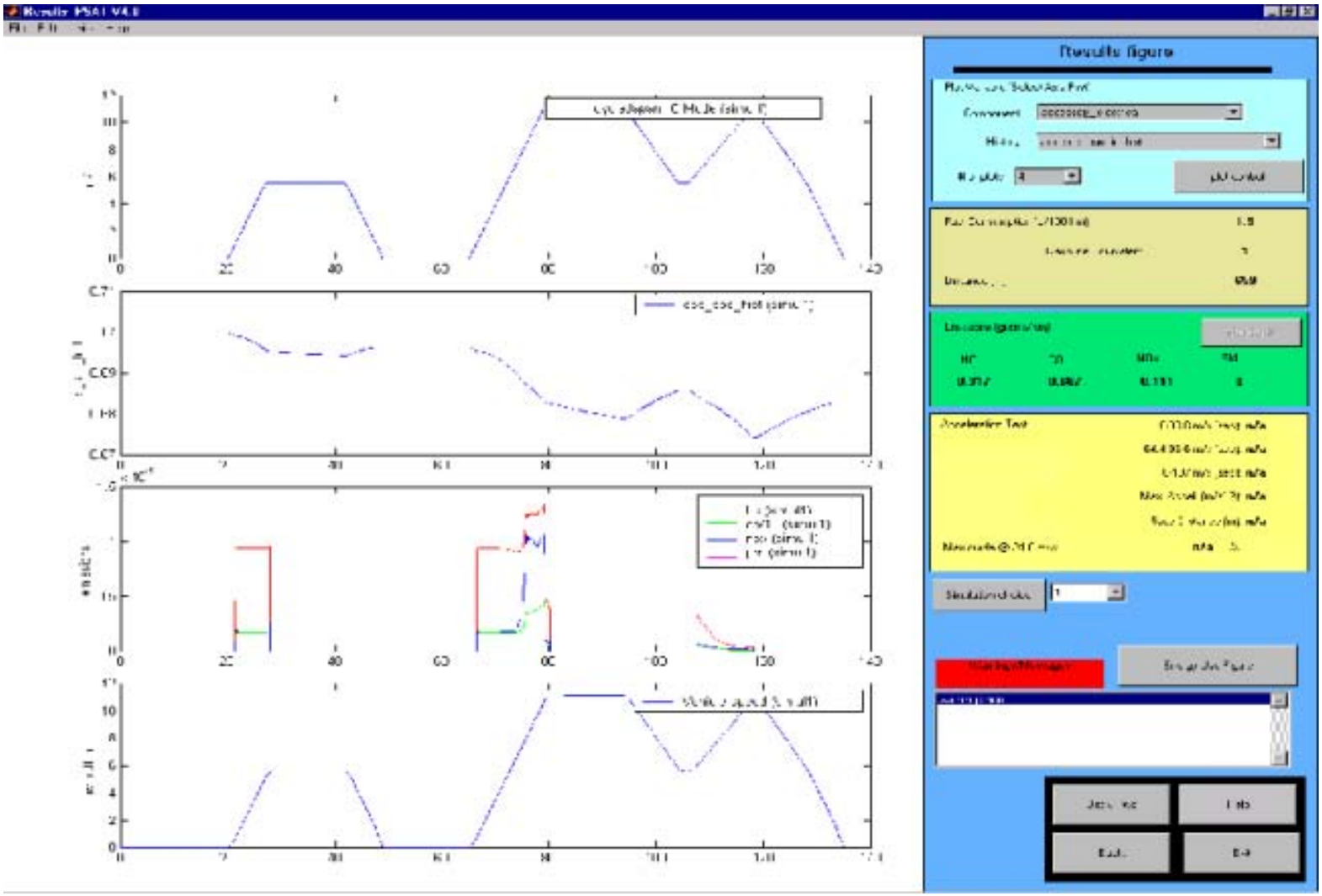
PSAT GUI – Results Window



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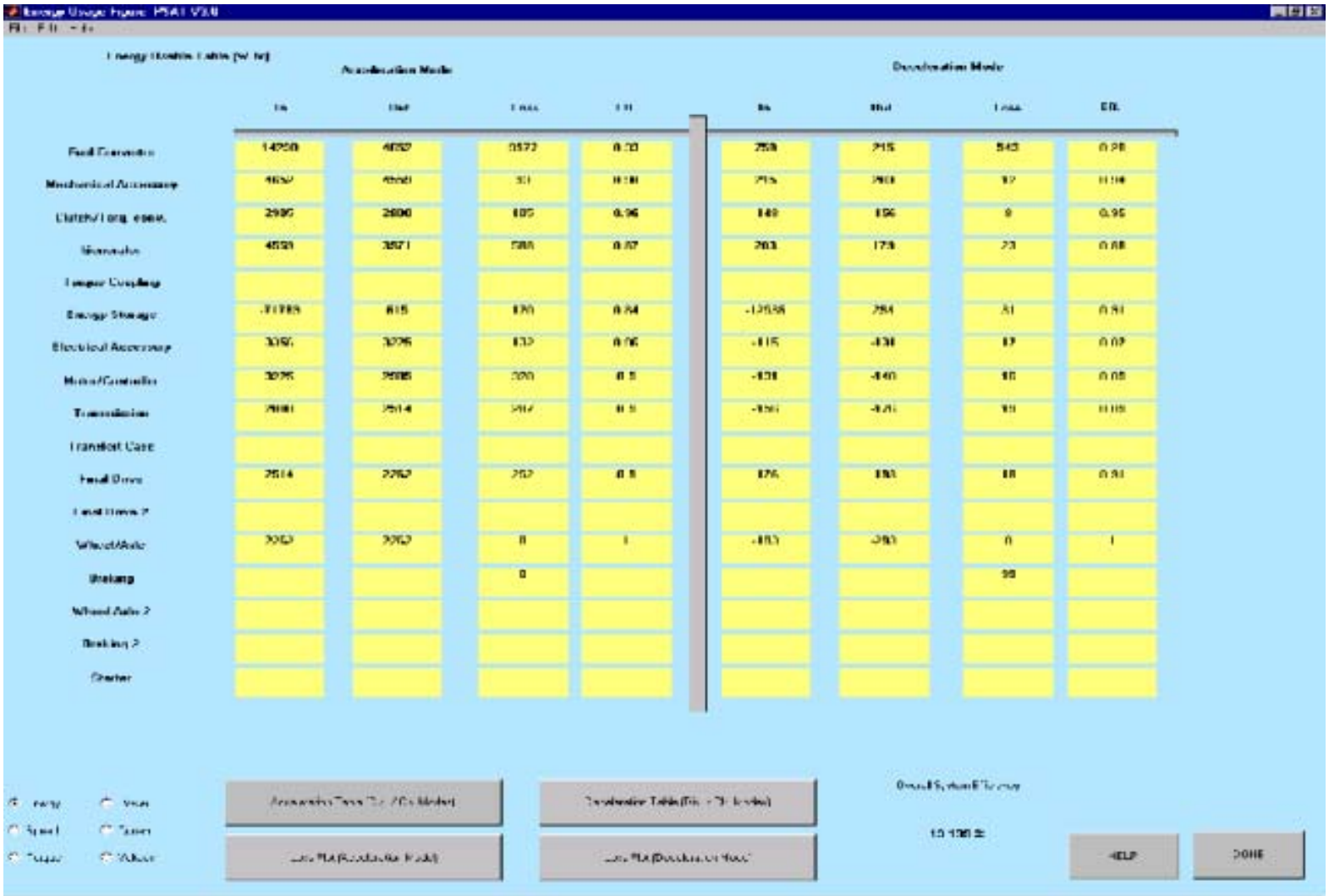
PSAT GUI – Energy Window



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Conventional Vehicle Validation - Taurus

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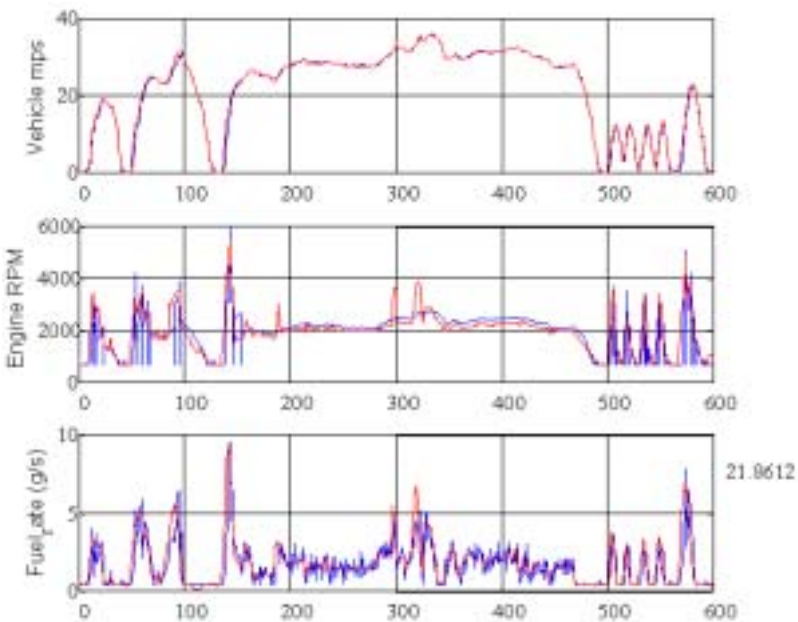

US06 Cycle

Test/Simulated Consumptions: 22.9/22.6 mpg

Blue = modeling
Red = testing

MEEM model has been used

Conventional Vehicle Validation - Taurus

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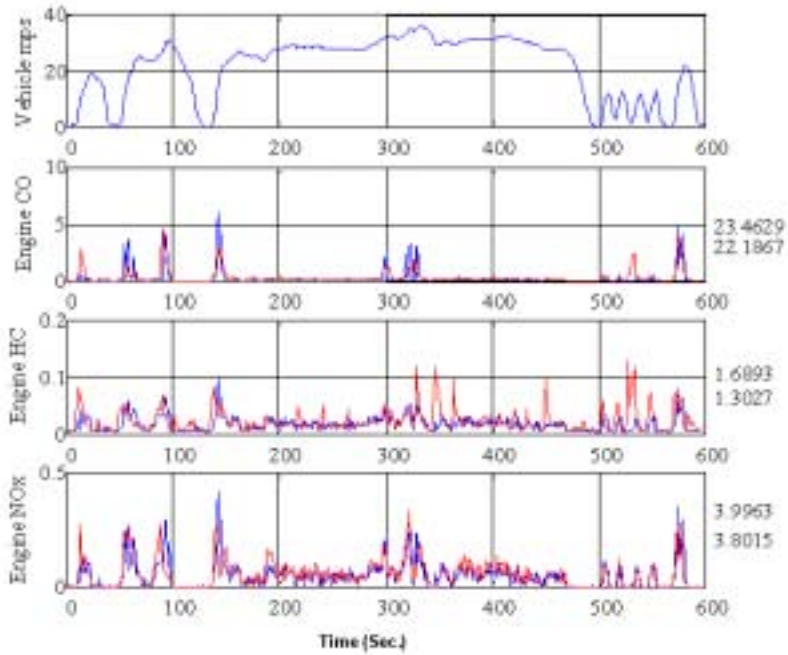

US06 Cycle

Pre-catalyst emissions

Blue = modeling
Red = testing

MEEM model has been used

Conventional Vehicle Validation - Taurus

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MY97 Taurus		FUDS			US06	
155 hp	Tested	Modeled	Diff.	Tested	Modeled	Diff.
MPG	22.1	22.5	-1.9%	23.2	23.0	0.8%
Pre-Catalyst						
CO (g/mi)	13.5	13.8	-2.6%	23.5	23.5	-0.1%
HC (g/mi)	2.2	2.0	10.1%	1.7	1.6	8.4%
NOx (g/mi)	2.1	2.1	-1.4%	4.0	4.0	0.8%
Post-Catalyst						
CO (g/mi)	1.1	1.1	1.8%	6.8	7.0	-2.1%
HC (g/mi)	0.10	0.09	6.6%	0.03	0.04	-8.3%
NOx (g/mi)	0.33	0.32	3.1%	0.105	0.114	-7.9%

HEV Vehicle Validation – Japanese Prius

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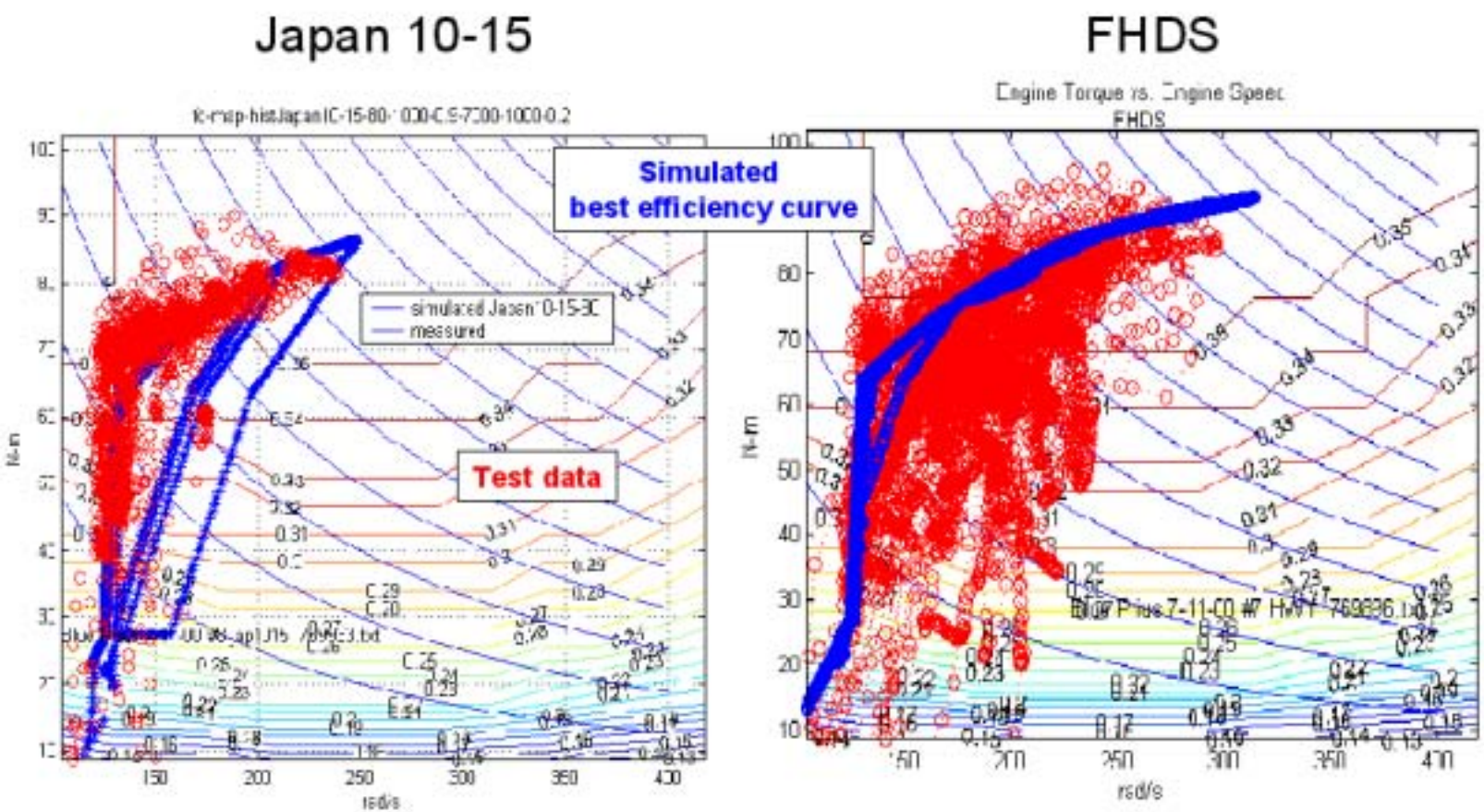
Engine Torque vs. Engine Speed



Specific Tools Are Necessary To Understand HEVs Control Strategies

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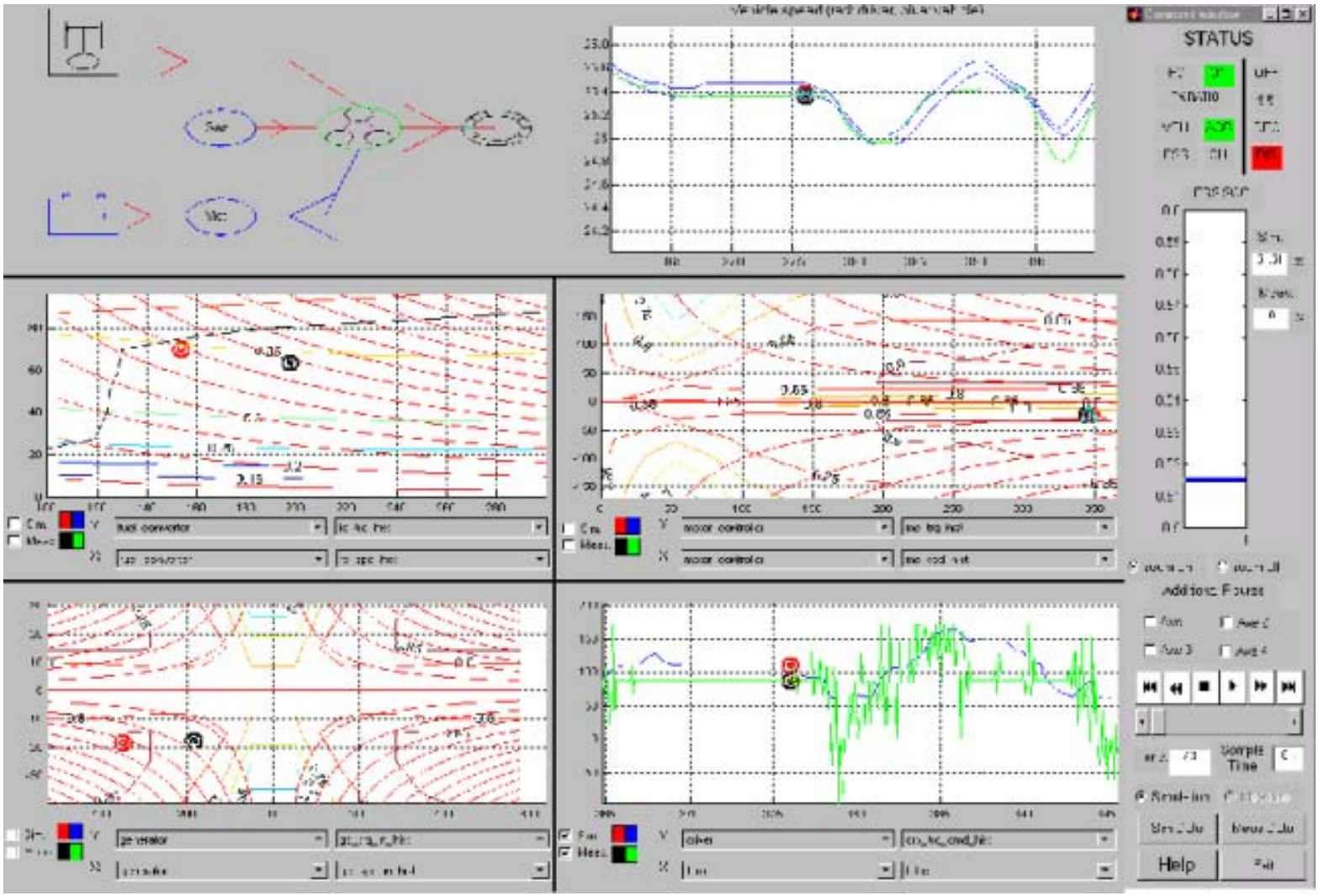
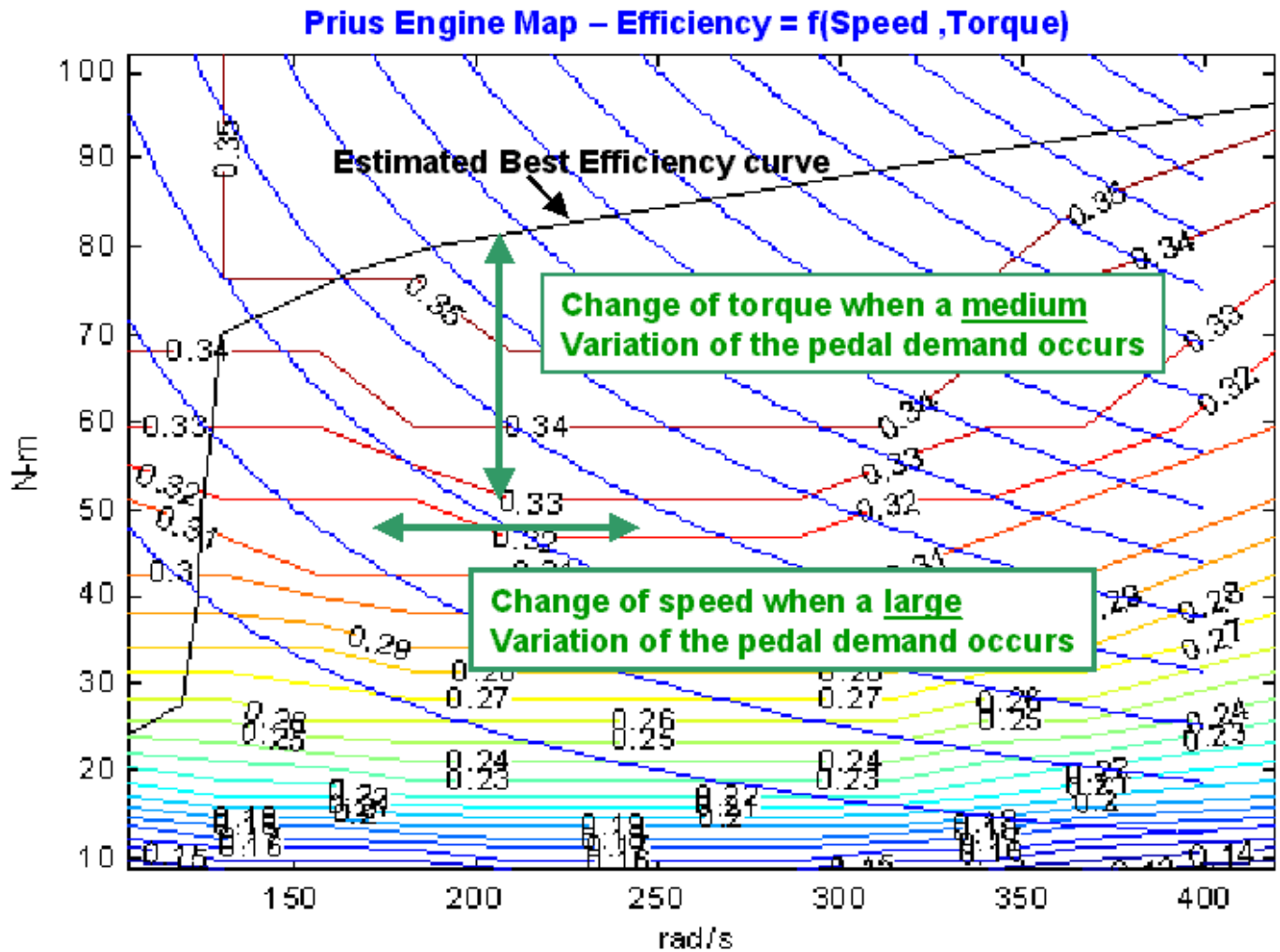


The Japanese Prius Doesn't Always Follow The Best Efficiency Curve



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PSAT Prius Validation Is Within 5%

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Cycle	Cons test mpg	Cons simul mpg	Diff in %	SOC init	SOCf test	SOCf simul	Diff in %
Japan 10-15	44.9	45.1	0.4	0.600	0.580	0.583	0.5
Japan 10-15	48.8	50.7	3.9	0.610	0.575	0.561	2.3
EUDC	44.0	43.8	0.4	0.610	0.605	0.593	2.0
FHDS	48.2	46.7	3.2	0.550	0.571	0.573	0.3
UDDS	42.3	39.9	5.9	0.550	0.530	0.570	8.7

Component Behavior Is Validated

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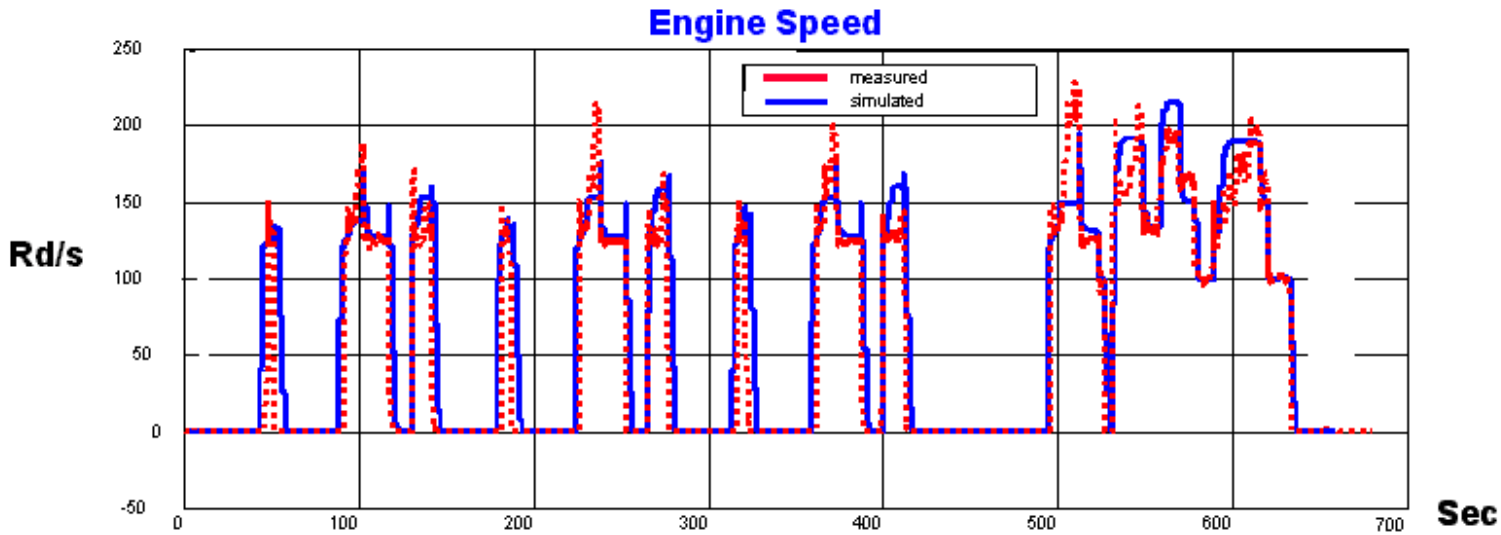

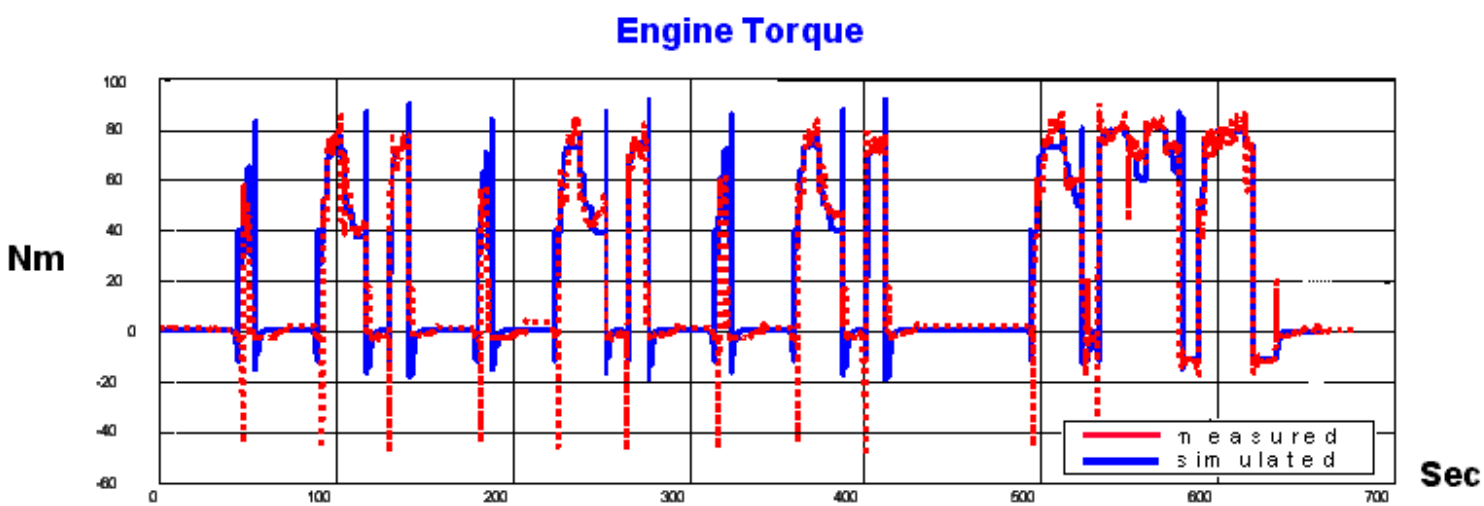

HEV GM Precept Correlation

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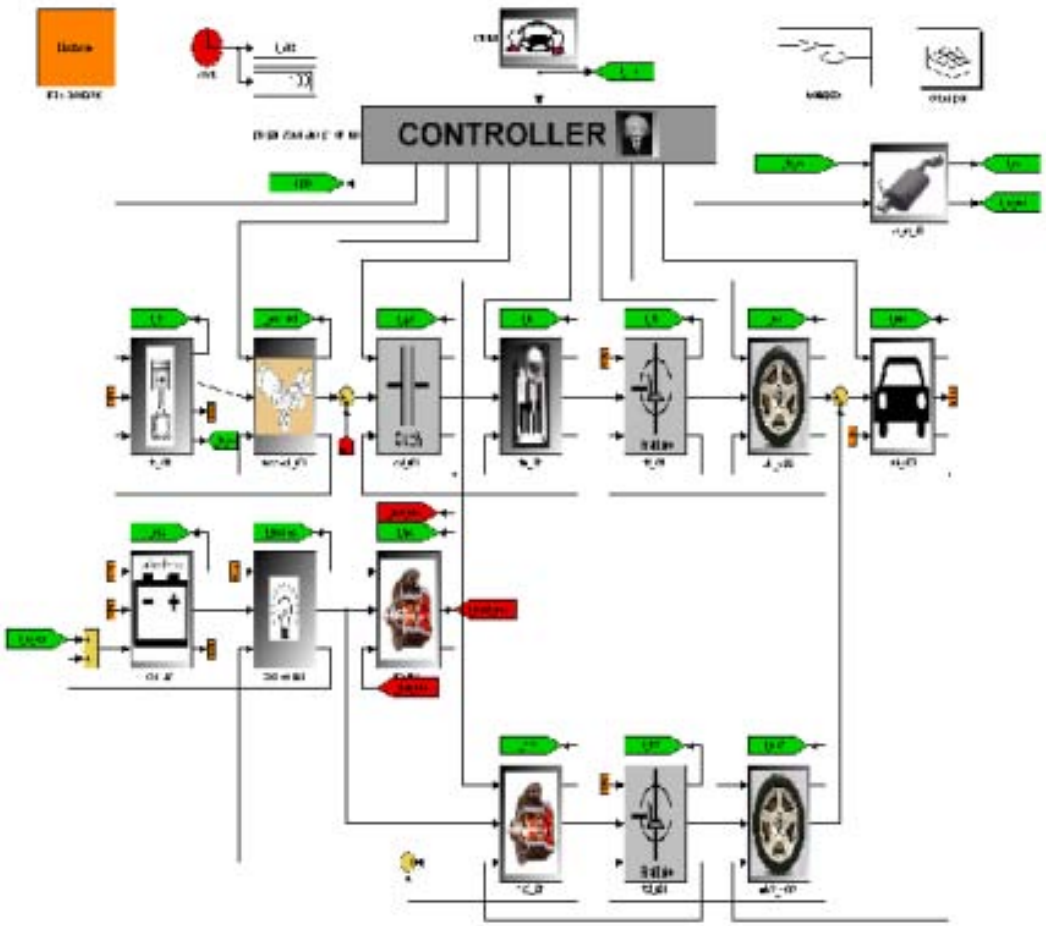

Combined

Test/Simulated Consumptions: 79.6/76 mpg

Small SOC difference in simulation

PSAT Users Group

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- Ford, General Motors, DaimlerChrysler, and PNGV partners (DOE, National Laboratories, universities, companies…) use PSAT for modeling purposes (e.g., HEV Durango, Precept…)
- Since June 2000, a nonproprietary version has been available. As of today, more than 20 universities use PSAT for modeling and development.
- The PNGV System Analysis Team plans to increase PSAT group by selecting new users.
- Our goal is to share information between users to allow PSAT to become a standard.
- Because of DOE and USCAR policy, PSAT is a freeware.

Conclusions

ANL PSAT

- PSAT, developed originally by USCAR for PNGV purposes, is a powerful modeling tool for both fuel consumption and performance.
- Because of its flexibility and reusability, PSAT can be used for any study or development:
  - Configuration comparison
  - Control purposes
  - New component behavior in a system…
- In a near future, Argonne plans to extend PSAT users number to later become a standard.