PSAT Training
Part 2: Capabilities

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Operated by The University of Chicago
for the U.S. Department of Energy

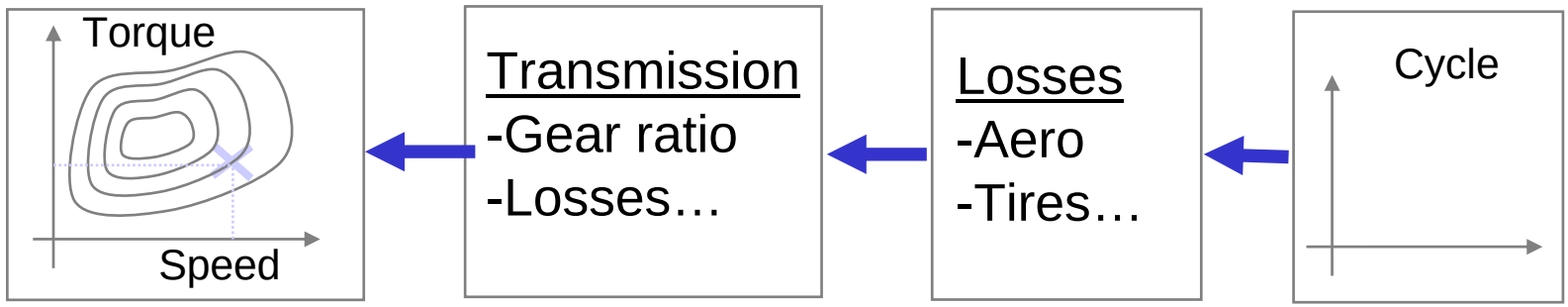
Outline

- **ANL Philosophy**
- PSAT Overview
- Validation
- Example of Work Done at ANL
- Perspectives

Backward Models

Backward-looking models (SIMPLEV, ADVISOR) are static system models that infer drivetrain operation from a speed vs time trace.

No commands: The desired speed is used to go back from one component to the next.

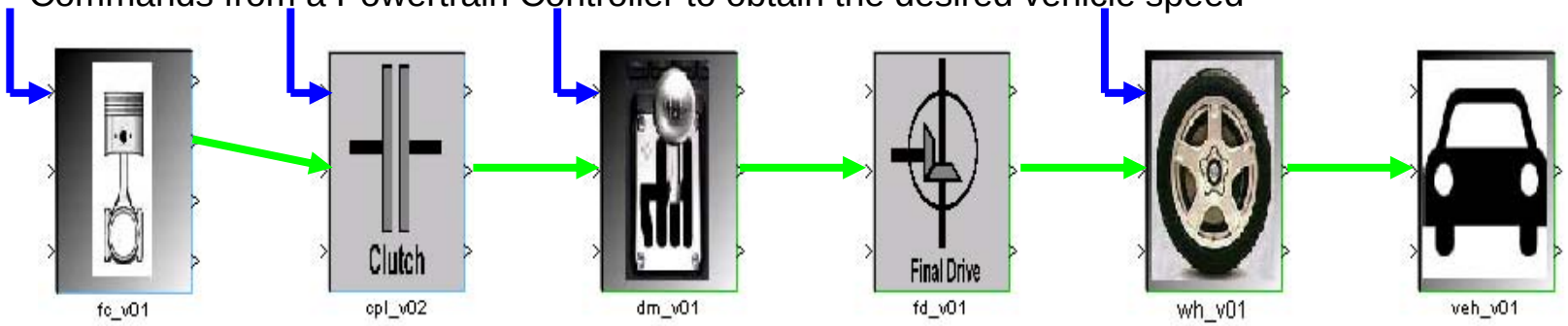


- **Quasi-steady models**
- **Transient effects on fuel economy and emissions not accounted for realistically**
- **Not suited for hybrid control strategy development**
- **Fast run-time (1 calculation per second in ADVISOR)**

PSAT Looks Forward

Forward modeling (driver-to-wheels) more realistically predicts system dynamics, transient component behavior and vehicle response.

Commands from a Powertrain Controller to obtain the desired vehicle speed



- **Consistent with industry design practice**
- **More accurately represents component dynamics (e.g., engine starting and warm-up, shifting, clutch engagement ...)**
- **Allows for advanced (e.g., physiological) component models**
- **Allows for the development of control strategies that can be utilized in hardware-in-the-loop or vehicle testing**
- **Small time steps enhance accuracy**

To Satisfy Goals and Objectives: Two Different Models for Two Different Uses

ADVISOR

1. Backward-looking (static model)
2. Advantages
   - Run fast
   - Simple models
3. Capabilities
   - Components sizing
   - Sensitivity analysis
   - Efficiency vs hybridization
   - Generic cost

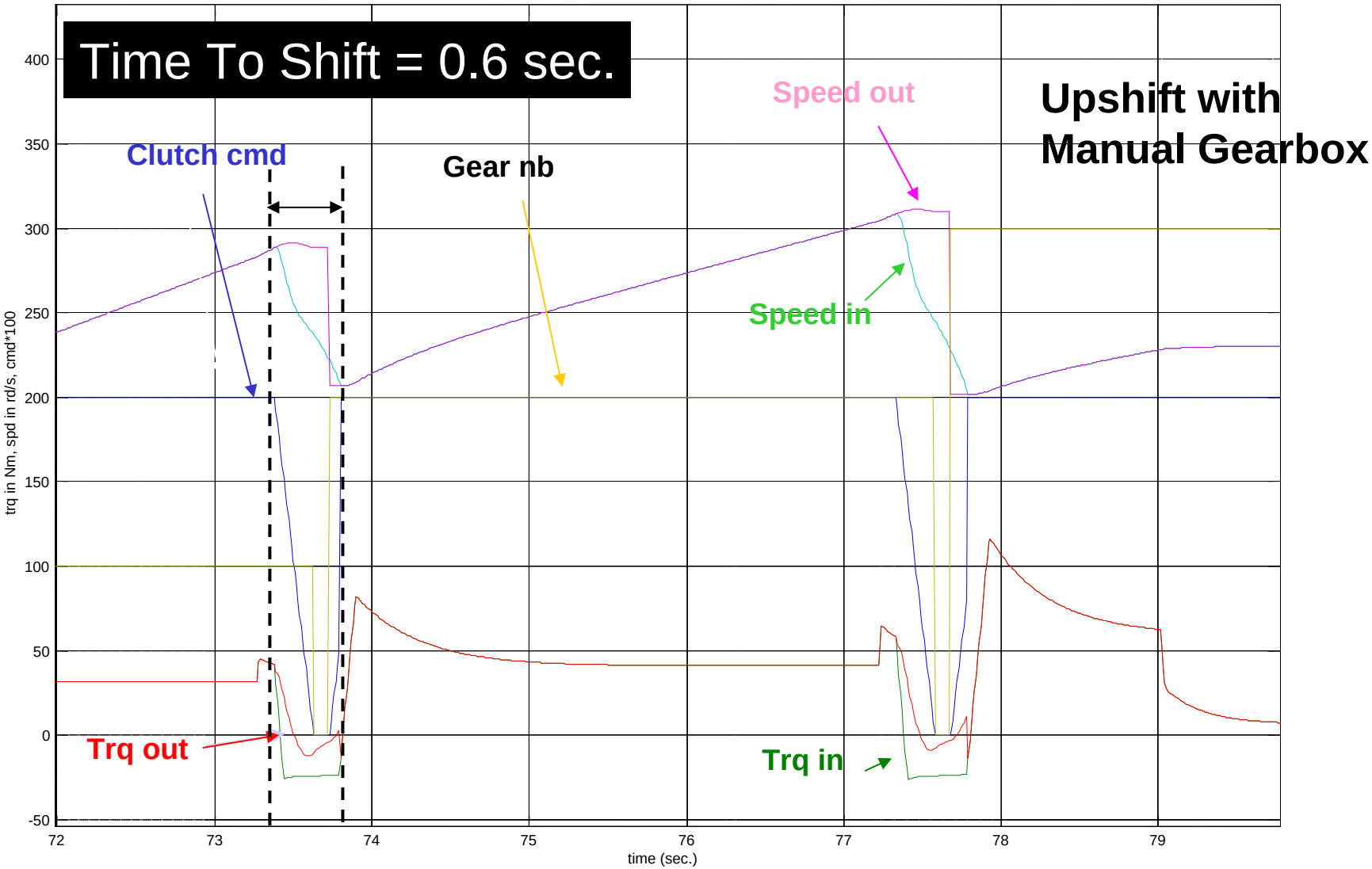
Provide Trends

PSAT

1. Forward-looking (dynamic model)
2. Advantages
   - Representative of dynamic systems
   - Highly advanced component models
   - Take transients into account
3. Capabilities
   - Component technology evaluation
   - Control strategy development
   - Optimization routines
   - Sensitivity analysis
   - Specific cost

Provide Decisions

Transients Are Accurately Represented



What Can Be Done with PSAT?

Yes

1. Study fuel economy & emission
2. Simulate Performance
3. Size Components
4. Simulate Gradeability
5. Perform parametric study
6. Compare drivetrain configurations
7. Compare drive cycles
8. Build drive cycles
9. Develop & integrate
   - Data
   - Component models
   - Control strategy
10. Optimization

No

1. Component calibration
2. Study driveability
3. Run with a too large sample time

Model Needed for FE & Performance

- **Map based (for efficiency & max/min characteristics)**
- **Take into account vehicle transient effects**
- **Take into account component response time (transfer function)**
- **Inertia effect is only taken into account in vehicle (not to slow simulation too much)**
- **No stiffness taken into account**
- **Physiological/NN models needed for emission & further vehicle/component transient effects**

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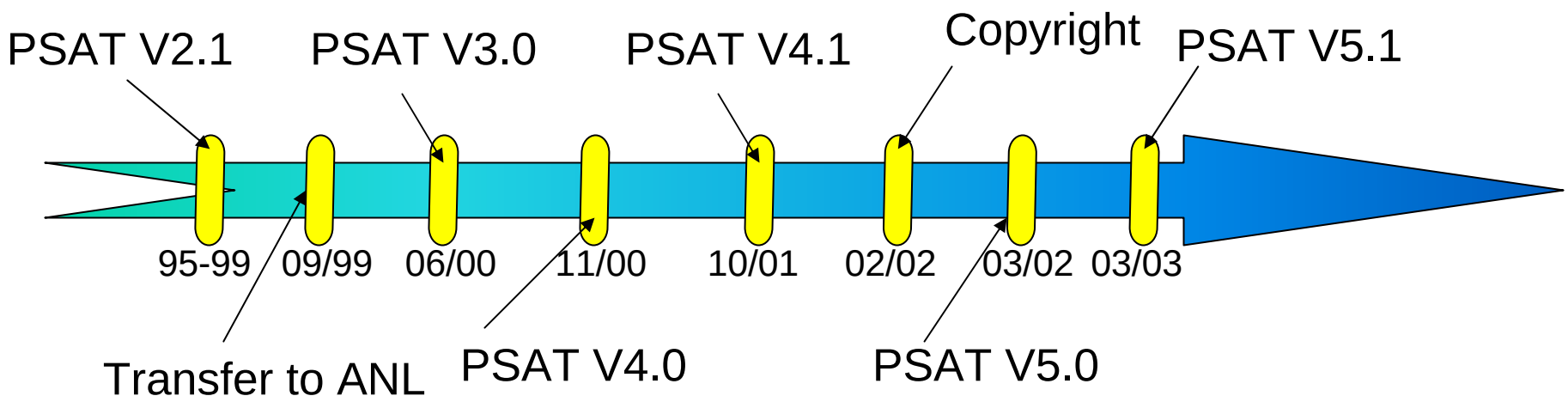
PSAT Has a Long History

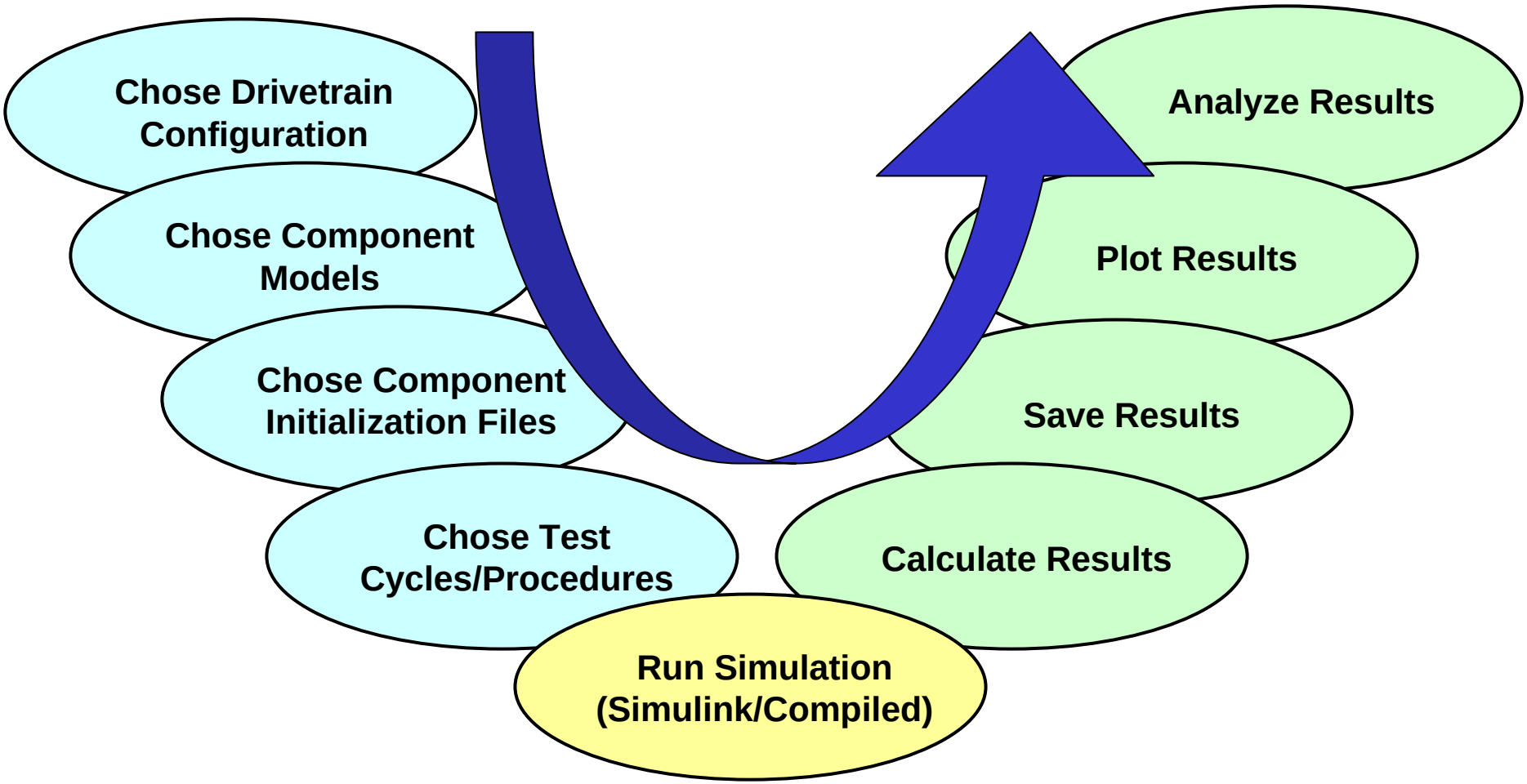
- **PSAT was initiated in 1995 by USCAR (contract to TASC and SwRI).**
- **Redesigned by ANL since 1999 to meet the needs of DOE's integrated analysis, hardware-in-the-loop and validation activities.**



PSAT Needs

- **PIII 750 MHz – 256 Ram min (The more the better)**
- **Matlab R12 or R13**
- **Optional:**
  - RTW Toolbox to compile code
  - Fuzzy Logic Toolbox to use fuzzy control strategy
  - Neural Network Toolbox for engine model

PSAT Simulation Process



Hybrids: A Wide Variety of Configurations

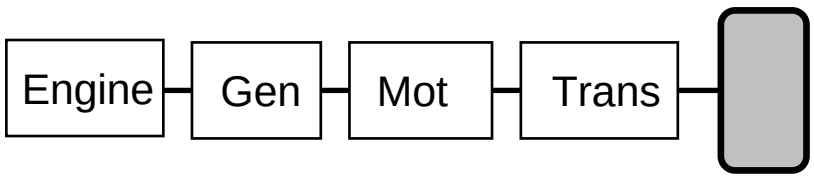


Figure 1: Series

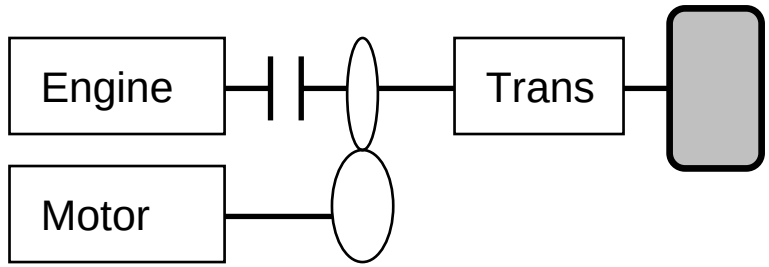


Figure 2: Single shaft parallel

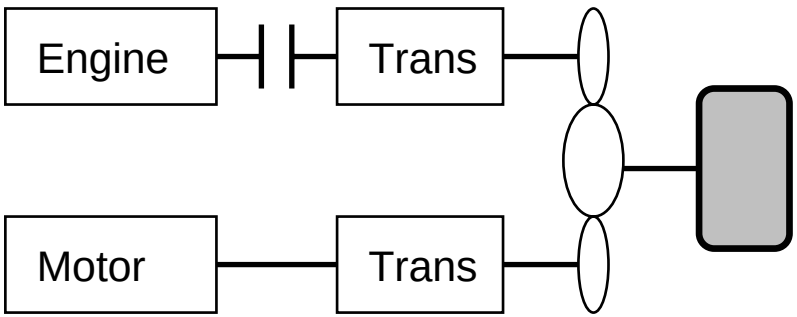


Figure 3: Double shaft parallel

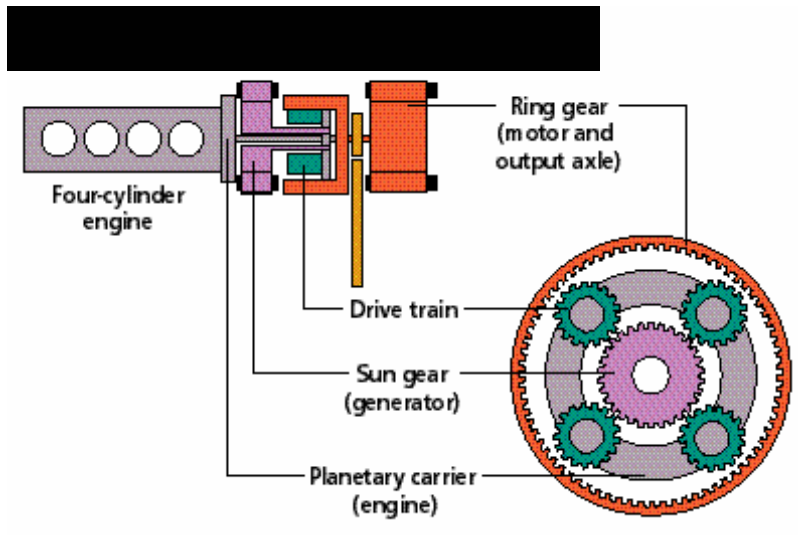
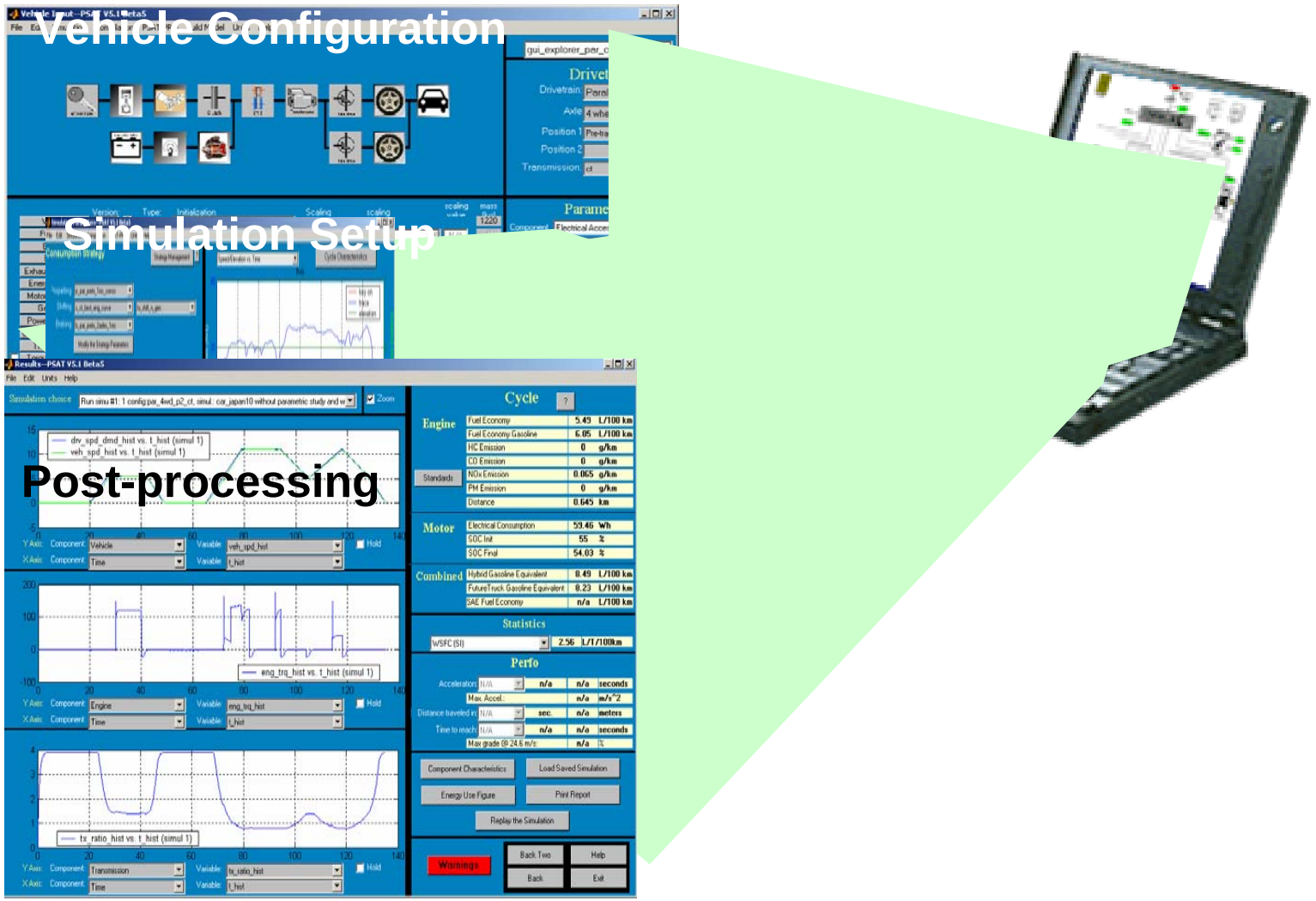
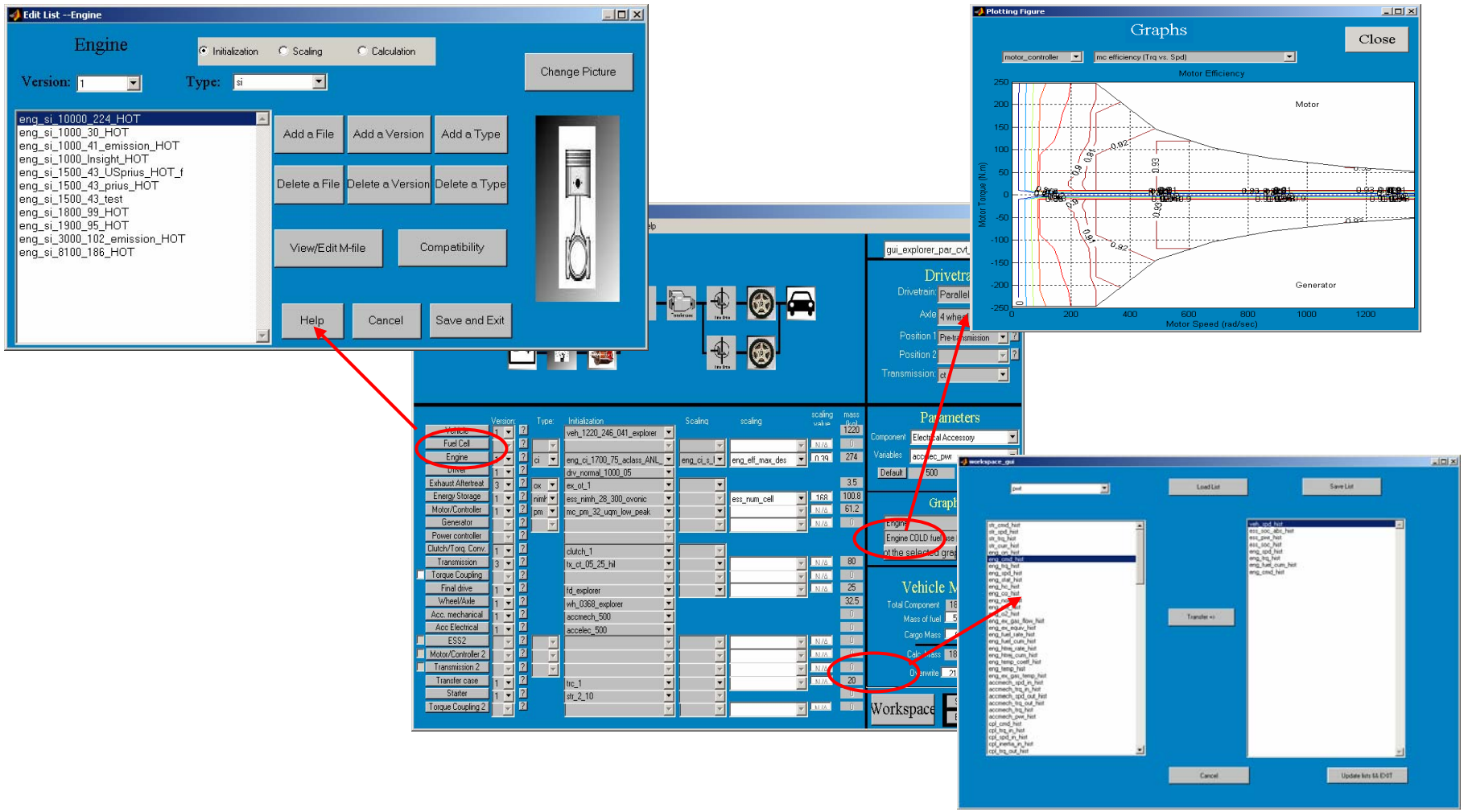


Figure 4: Power split hybrid

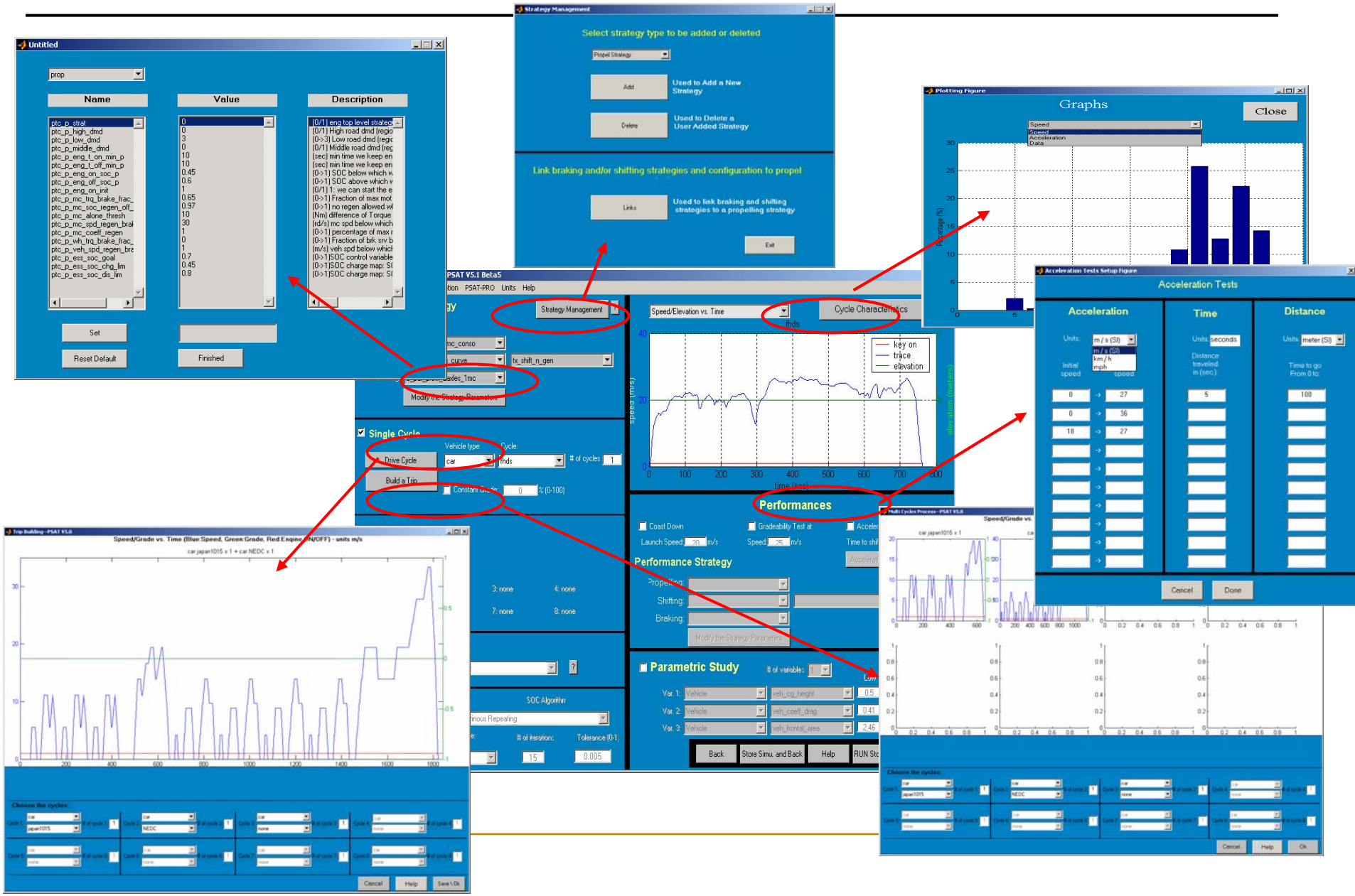
PSAT GUI


Vehicle Configuration
Simulation Setup
Post-processing
Cycle
Engine
Motor
Combined
Statistics
Perfo
Warnings

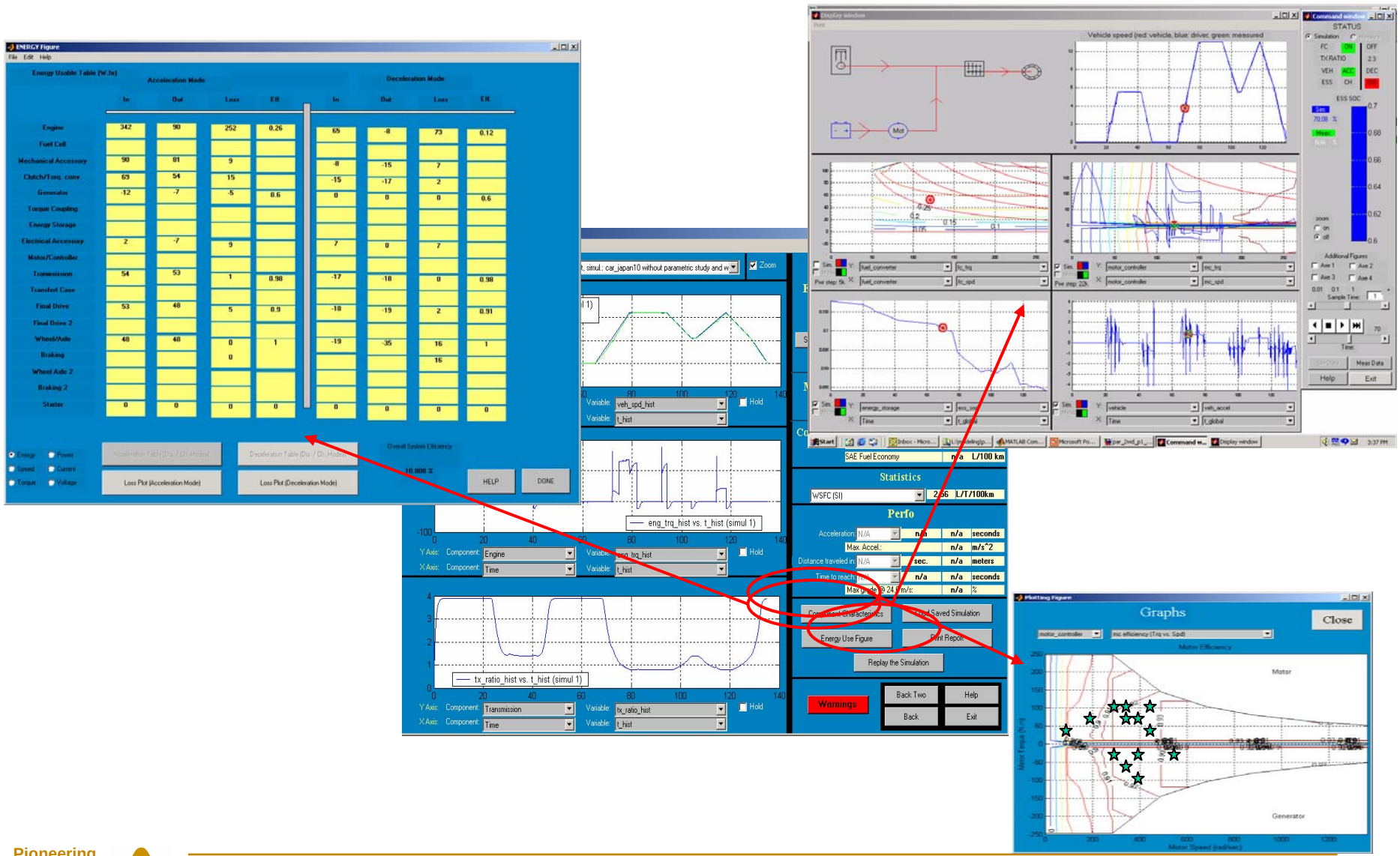
Initialization Windows



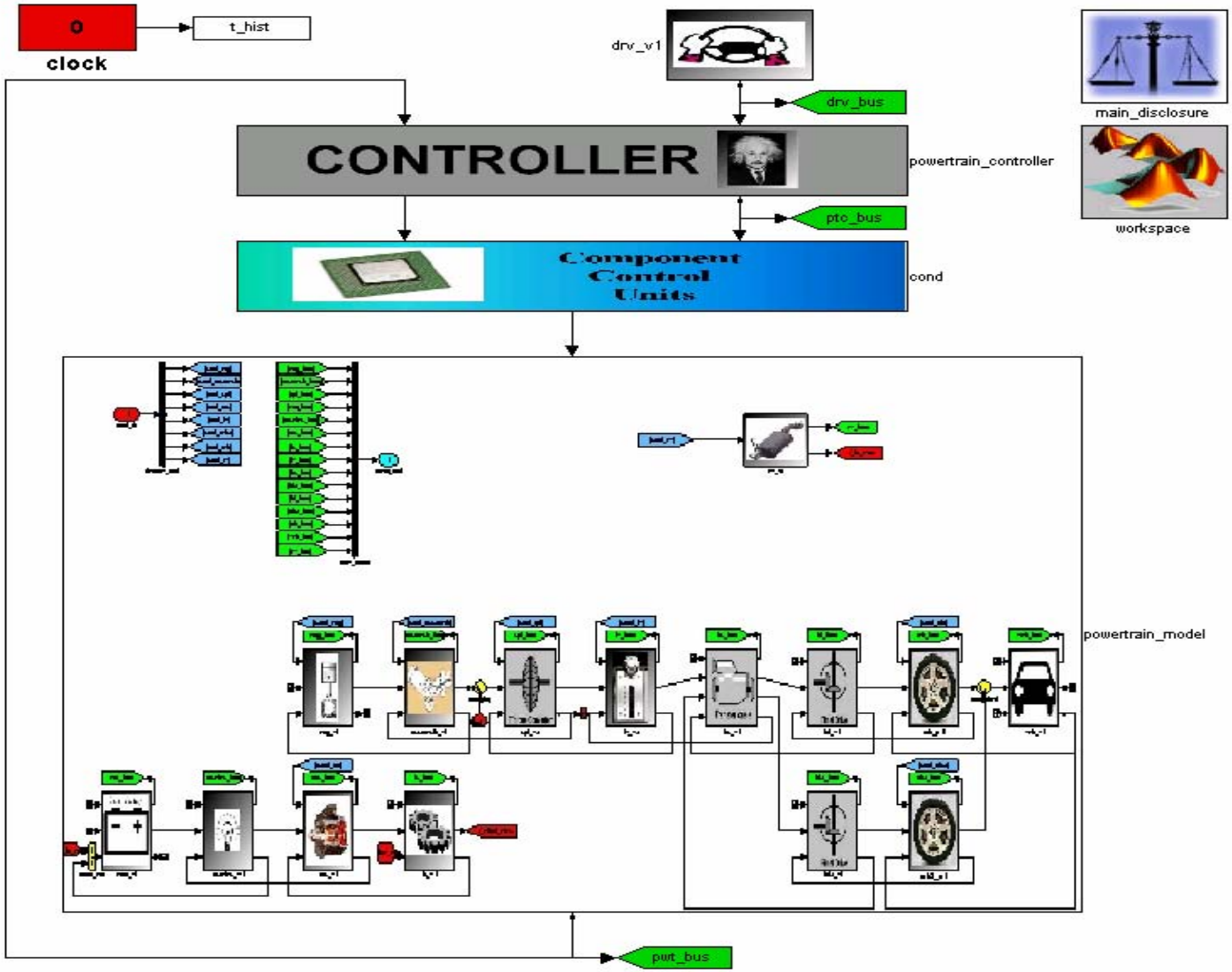
Cycle Choice Windows



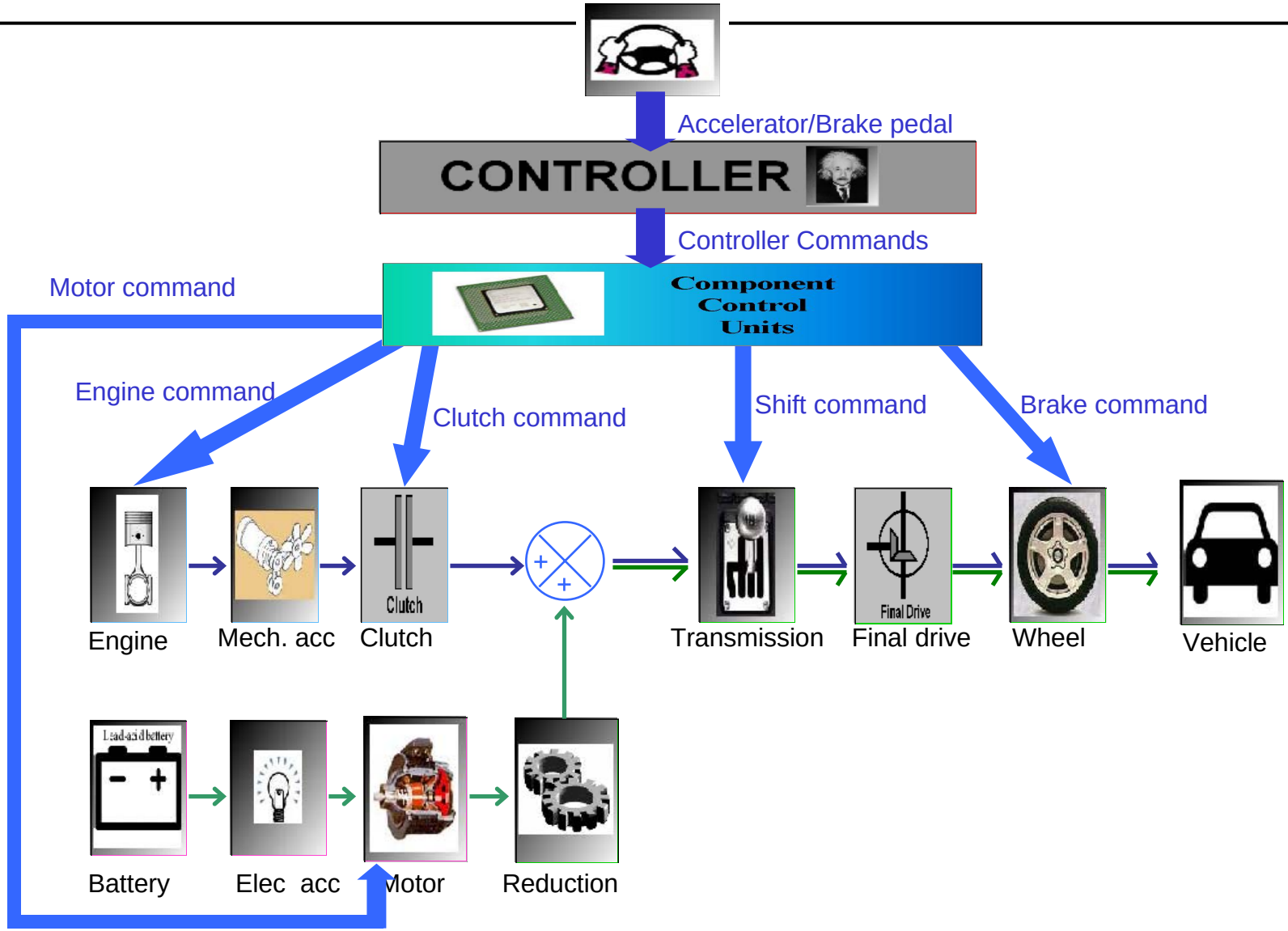
Post-Processing Windows



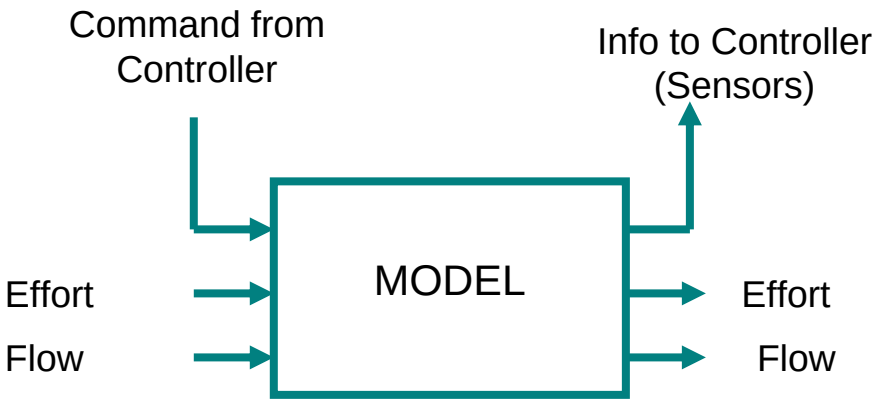
Example of PSAT Simulink Model



PSAT Structure Flows Intuitively



PSAT Component Model Format Is Generic

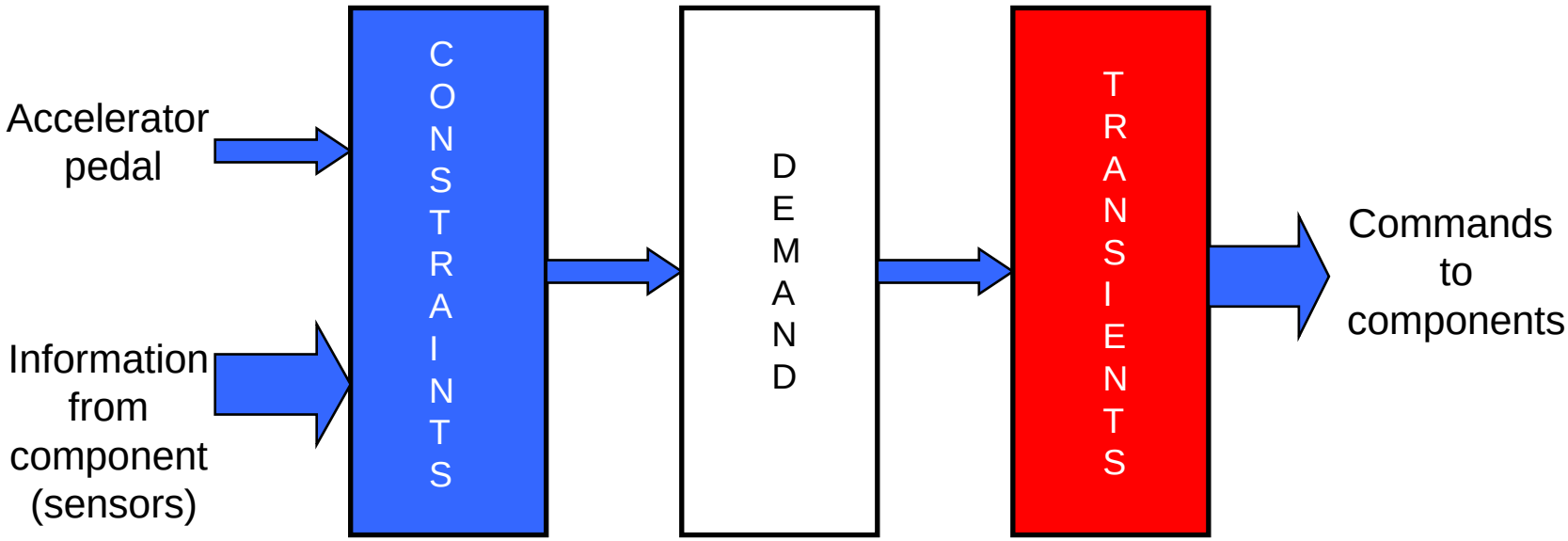


	Effort	Flow
Engine	Torque	Speed
Motor	Voltage	Current

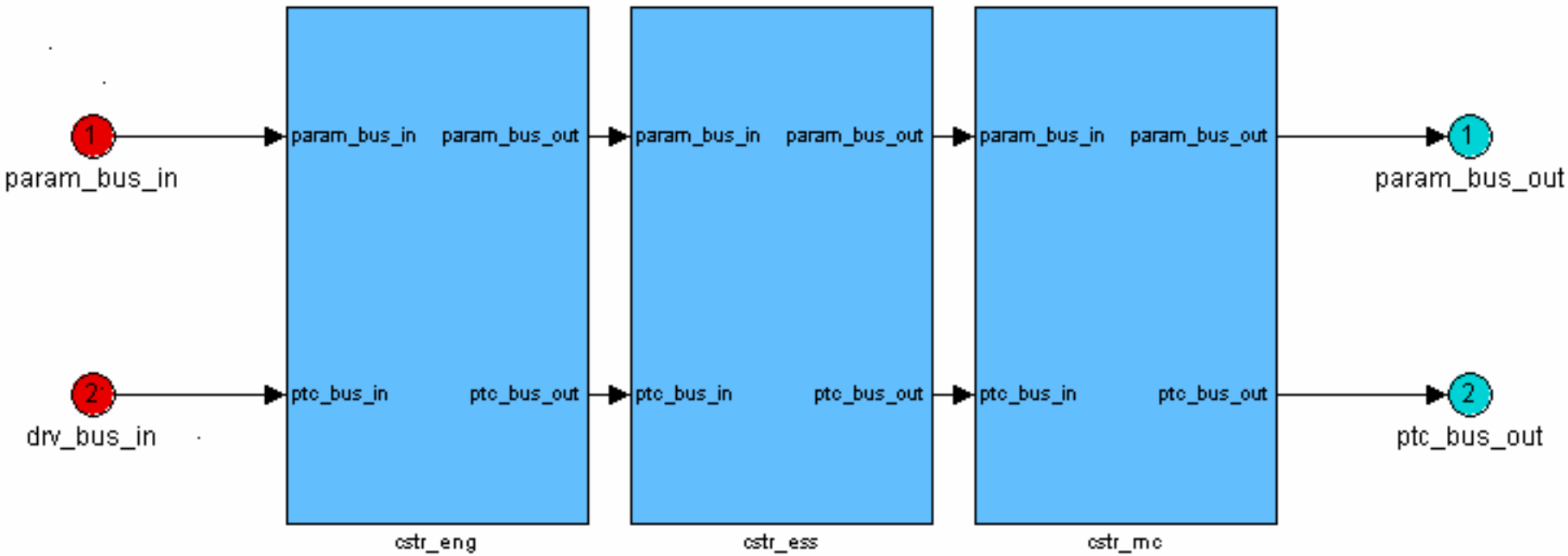
All the component models have the same number of inputs (3) and outputs (3)

Generic Power Controller Organization

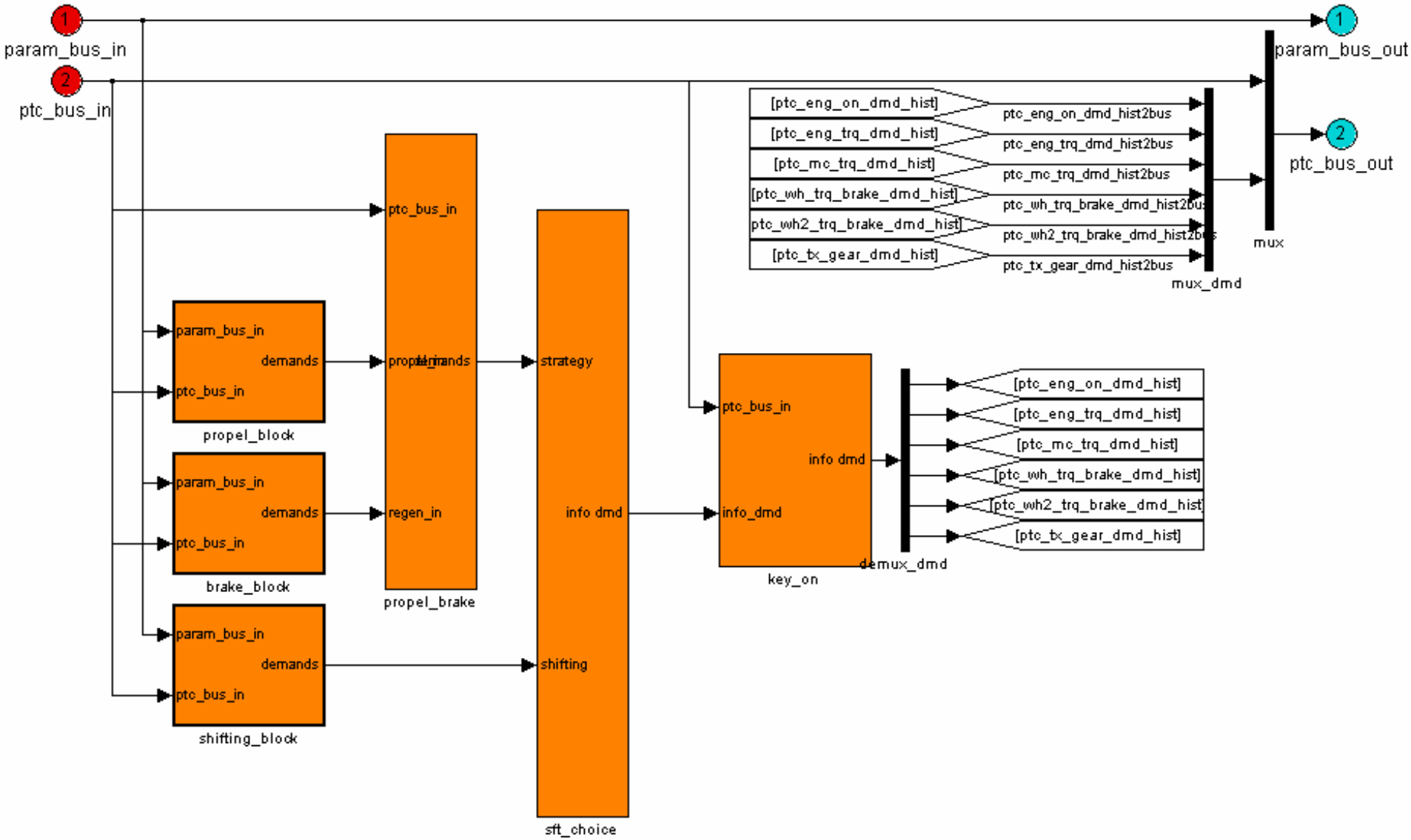
A generic organization common to all powertrains



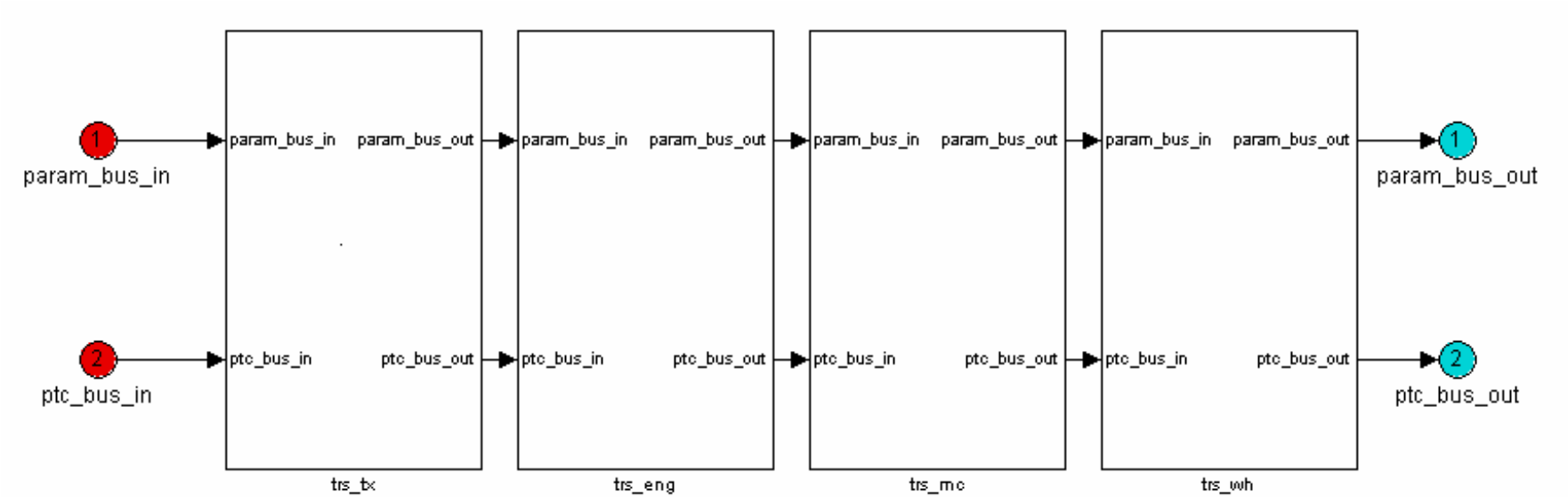
Constraint Block in Simulink



Demand Block in Simulink

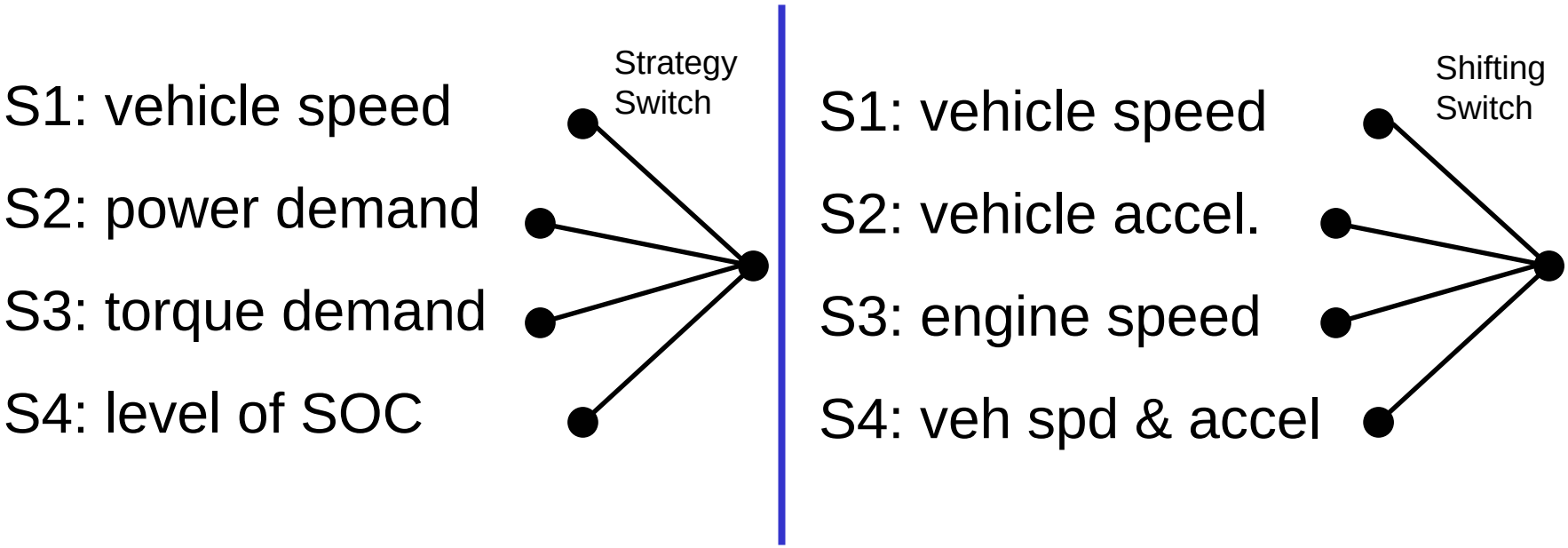


Transient Block in Simulink



Control and Shifting Selections Are Easy

Within the same drivetrain model, we can switch between different control strategies and different shifting algorithms.



We ONLY compare separate strategies and shifting
We can EASILY implement new ones

PSAT Is Flexible and Reusable

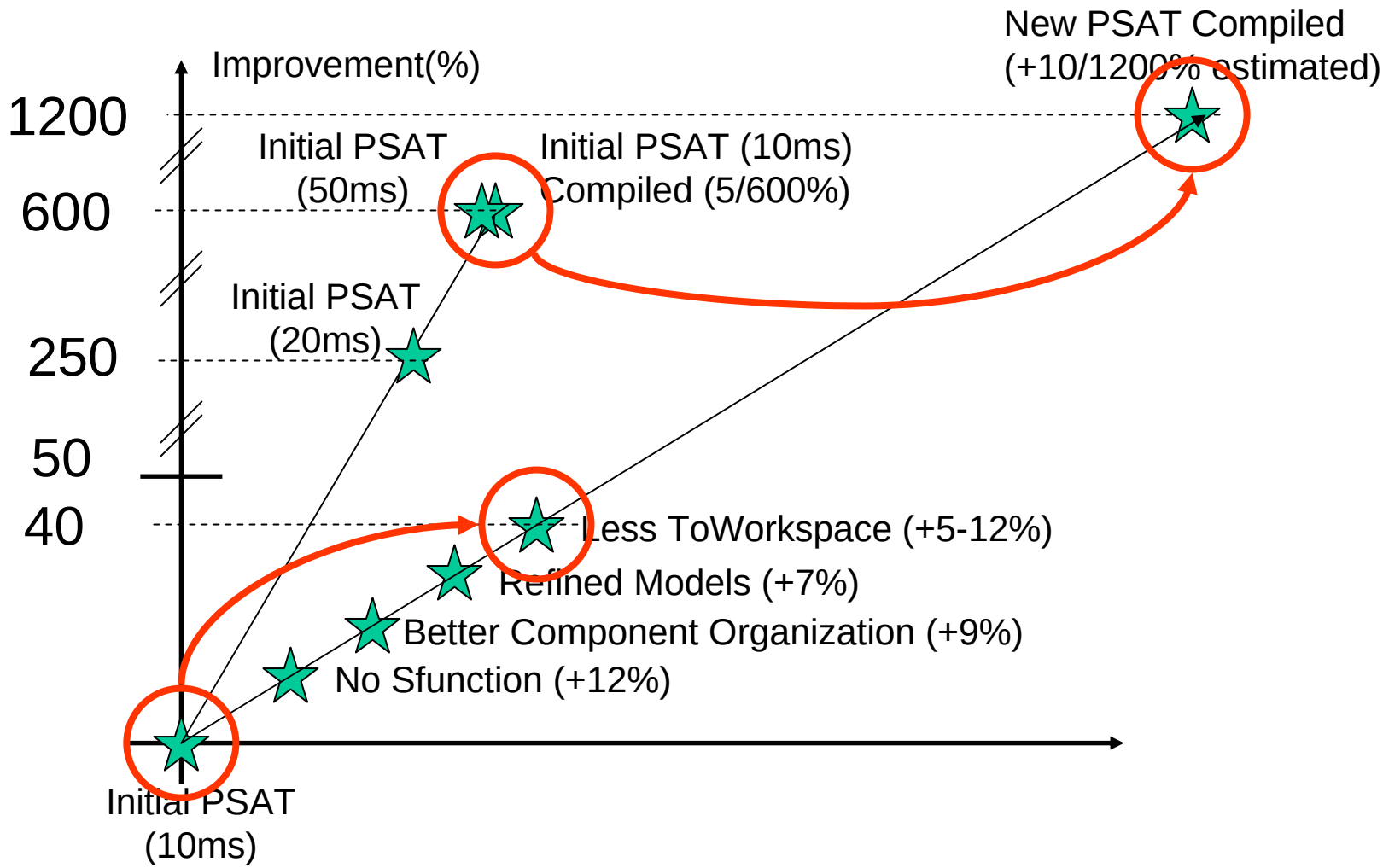
- **Drivetrains constructed from user choices**
- **Numerous configurations can be explored(>150: conventional, parallel, series, power split...)**
- **Several strategies can be compared within the same model using switches**
- **Can add new component data, models and control**
- **Model format is generic (3 inputs/3 outputs)**
- **Multiple uses of same model possible**
- **Software is highly parameterized**

PSAT Is User-Friendly

- **Easy integration of initialization files, component models or control strategies through its Graphical User Interface**
- **Easy comparison of different levels of model sophistication and control strategies**
- **Post simulation analysis is enhanced through use of a voltage bus for more realistic transient behavior**

PSAT has been designed to take transients into account and handle different levels of modeling detail ... allowing the user to match the level of sophistication with the application.

PSAT Speed Increased Up to 12X with Same Accuracy



Outline

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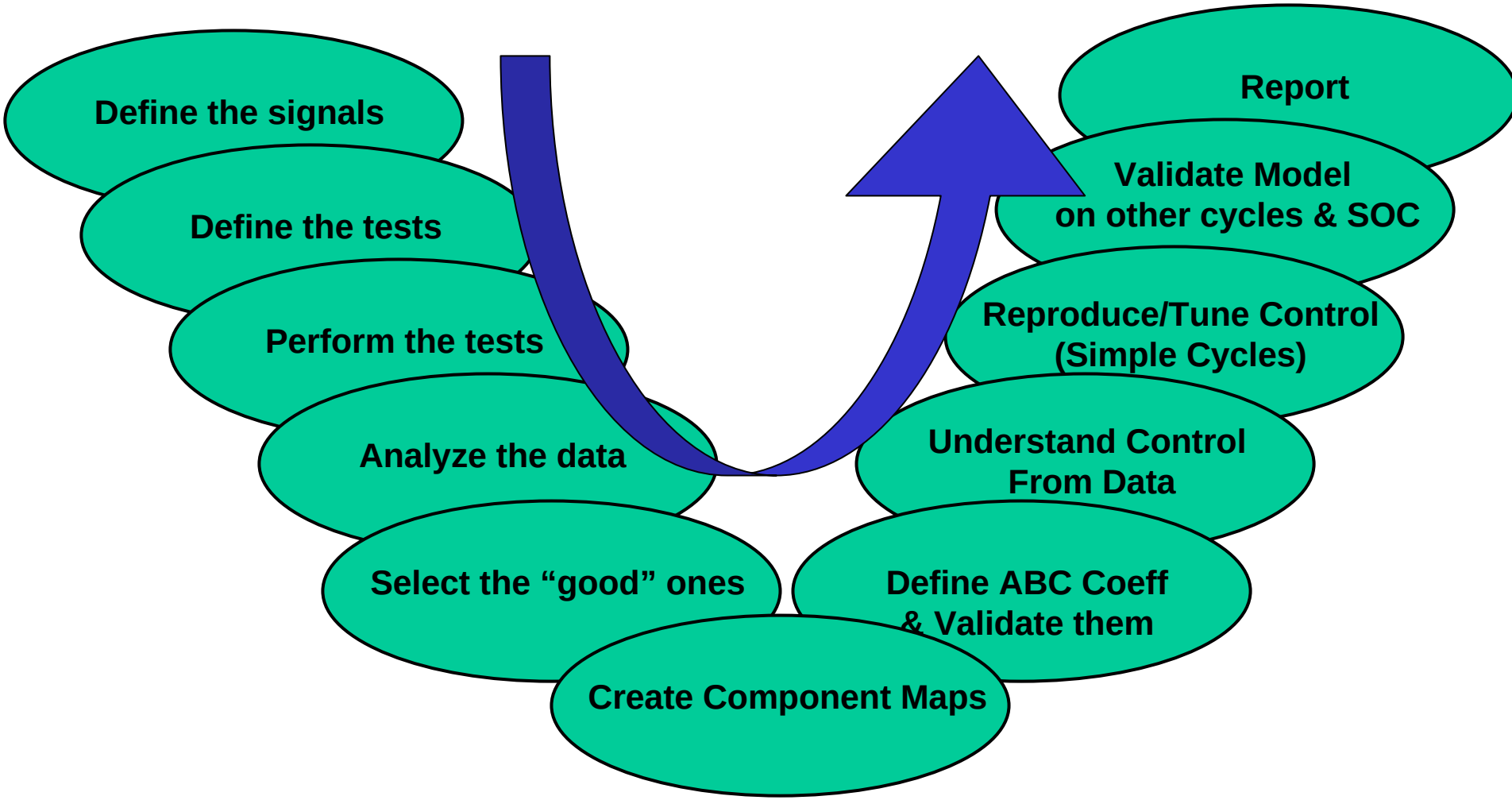
- PSAT Overview
- **Validation**
- Example of Work Done at ANL
- Perspectives

Accurate Validation Provides Confidence in Studies Results

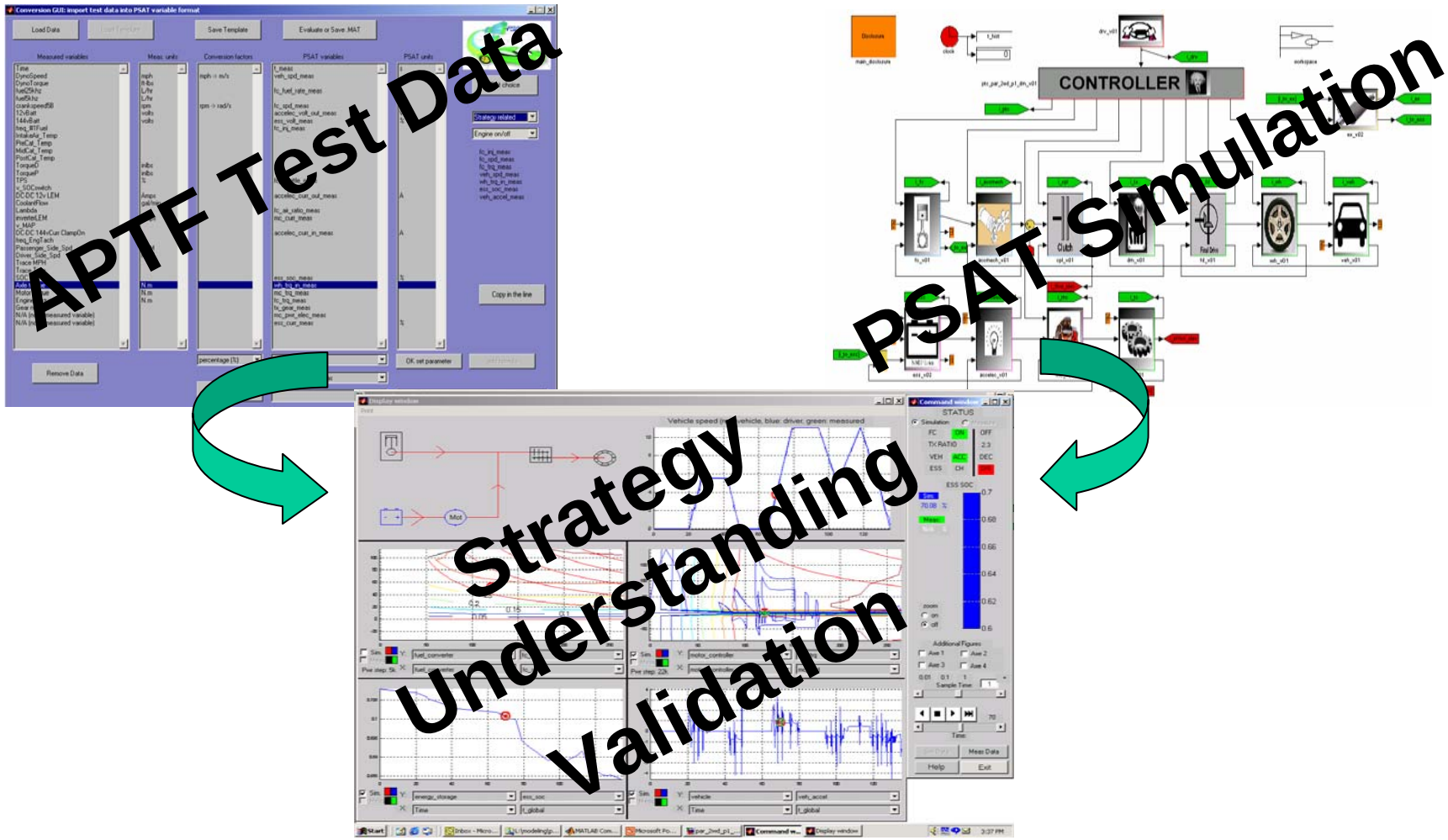
- **Ford Taurus 97 3.0L V6 has been validated within limits of test capabilities (1% FE, 10% Emissions)**
- **Japan Prius* & Honda Insight* Fuel Economy & SOC validated within 5% for several driving cycles**
- **Ford P2000* Validated within 5% for Fuel Economy & SOC**

*Japan Prius, Honda Insight & Ford P2000 validations have been realized with APTF Data

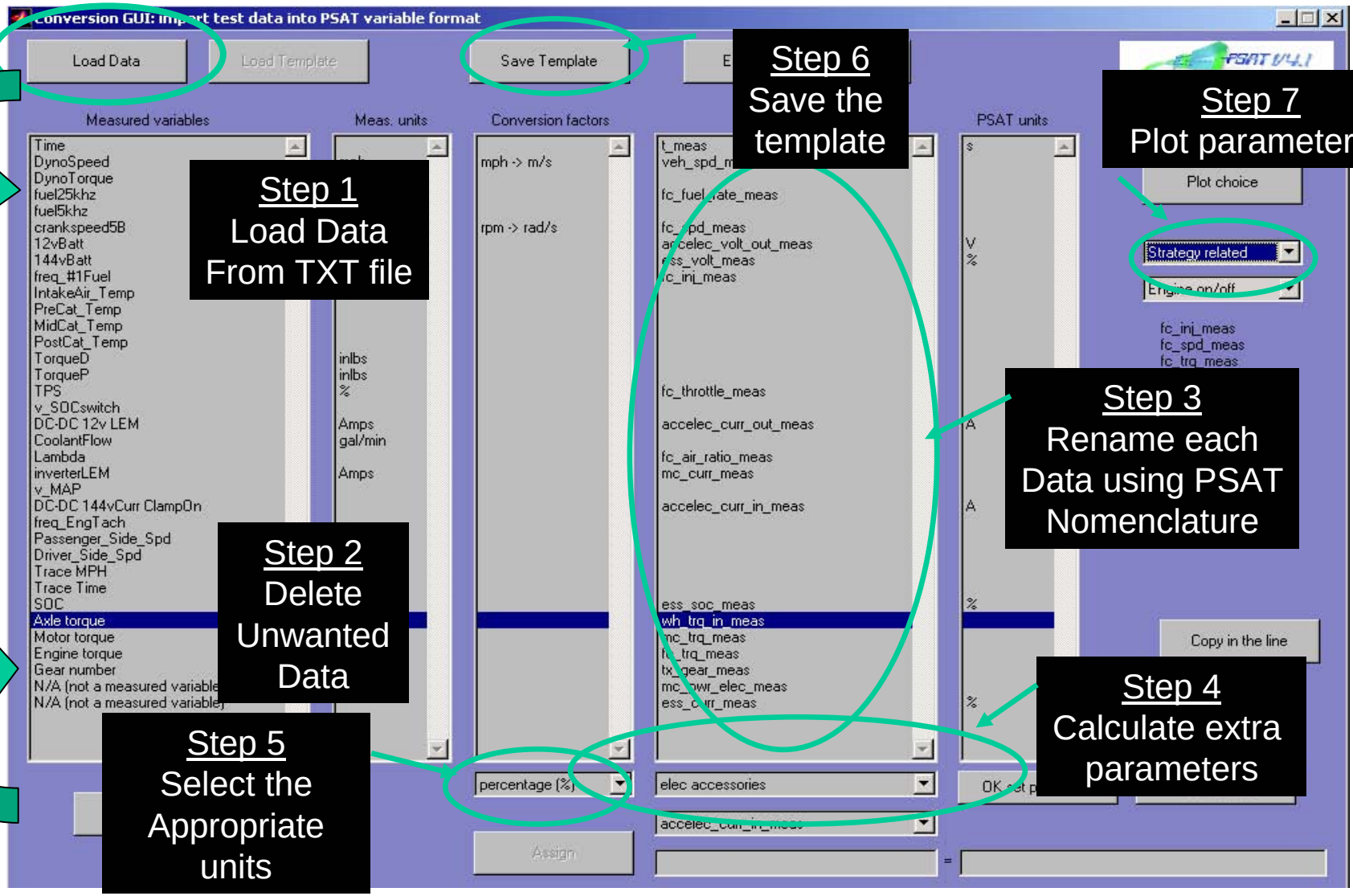
Validation Steps



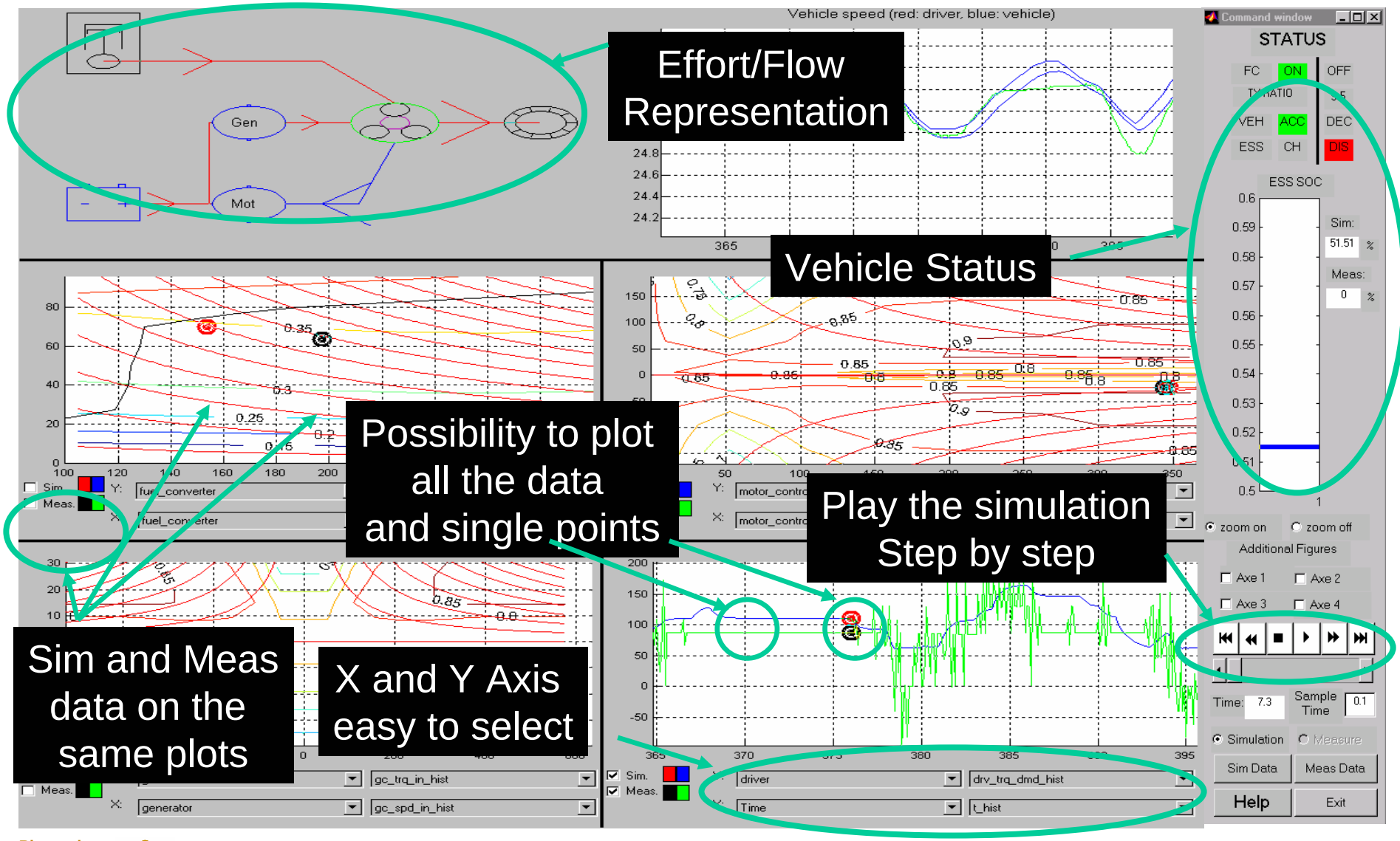
New Tools Allow Users to Speed Up Validation



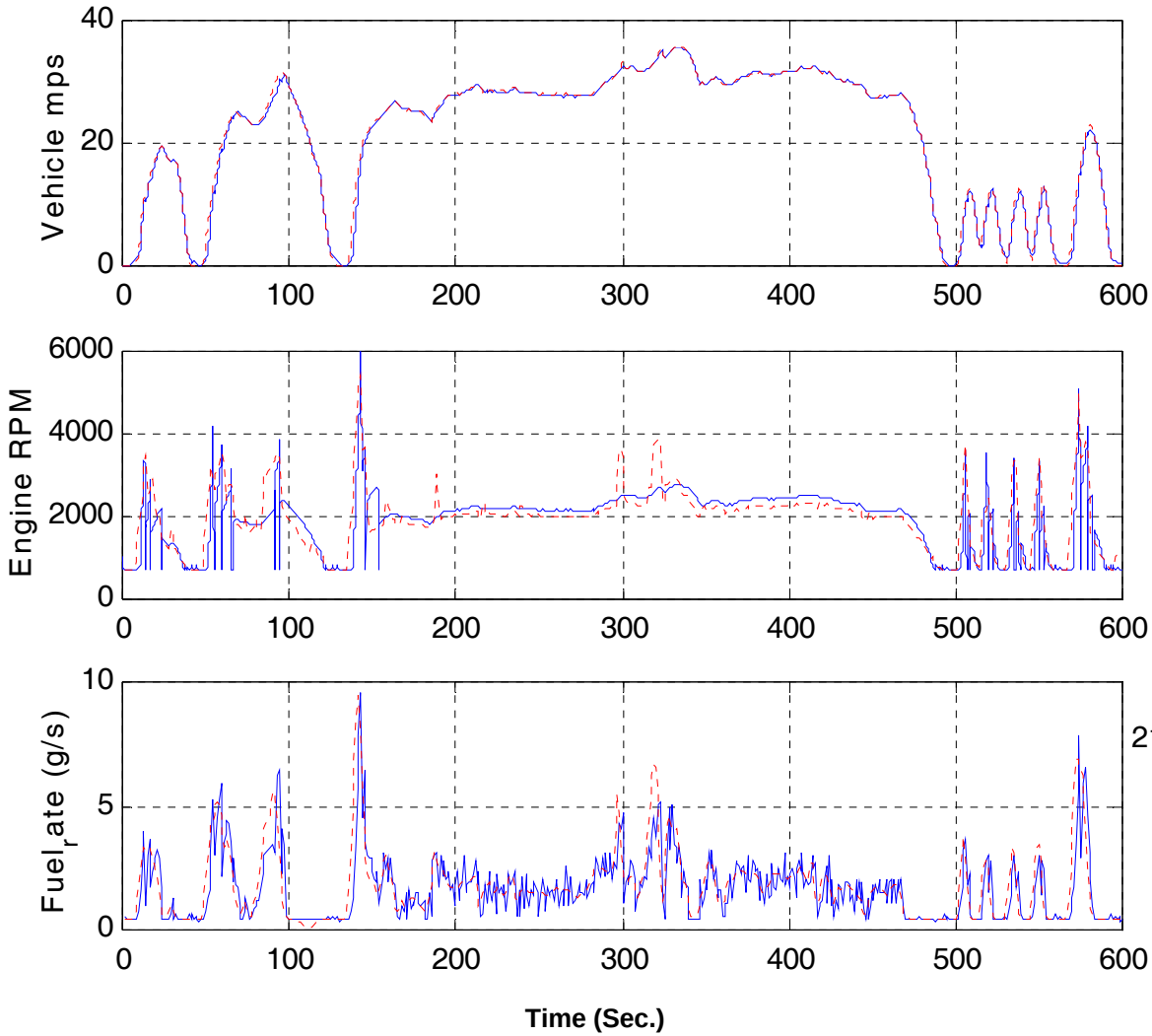
Integration of Test Data Is Immediate!



Innovative Window to Replay Tests and Simulation



Conventional Validation - Taurus

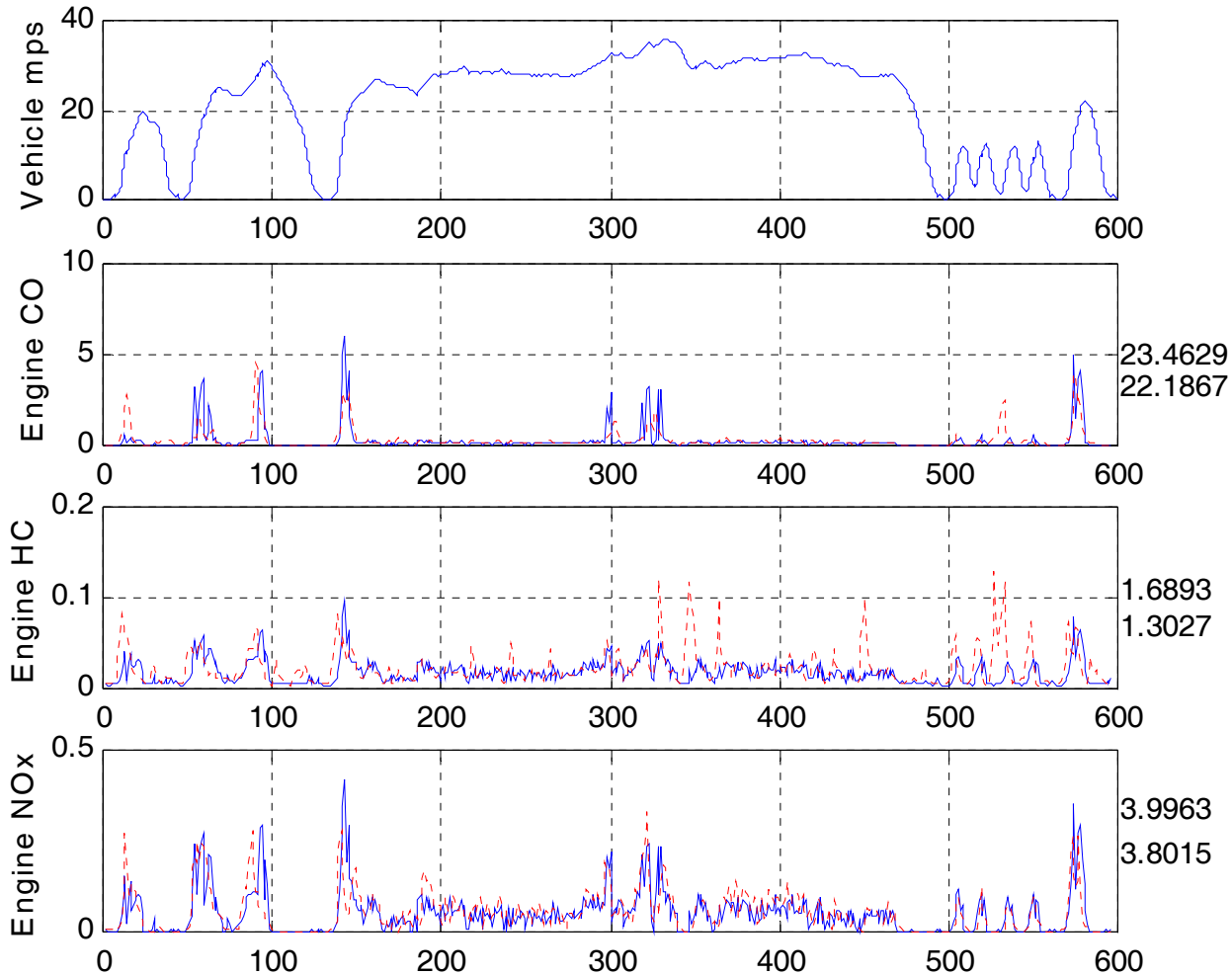


US06 Cycle

Test/Simulated Consumptions: 22.9 / 22.6 mpg

Blue = modeling
Red = testing

Conventional Validation - Taurus

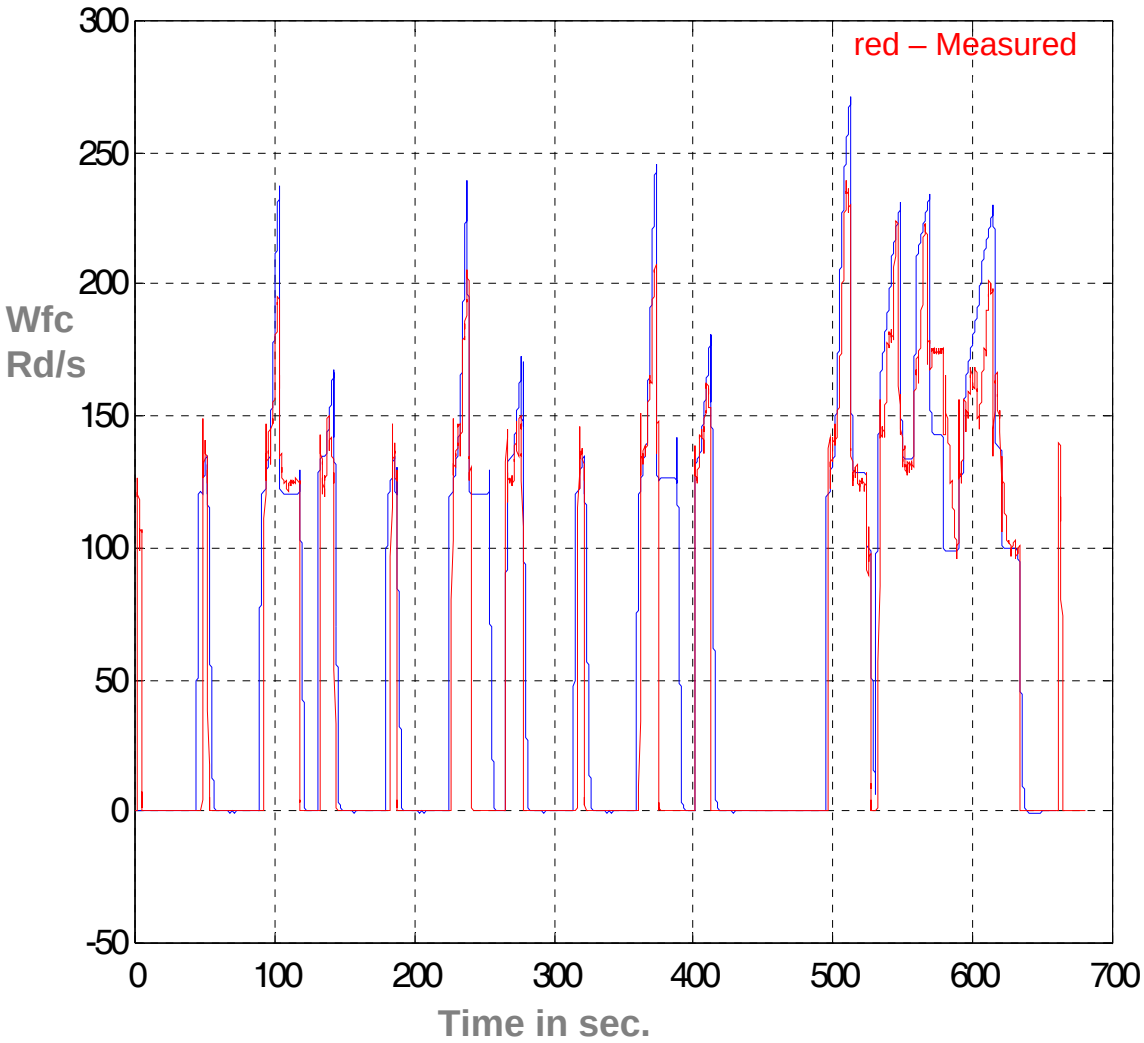


US06 Cycle

Pre-catalyst emissions

Blue= modeling
Red=testing

HEV Validation - Japan Prius

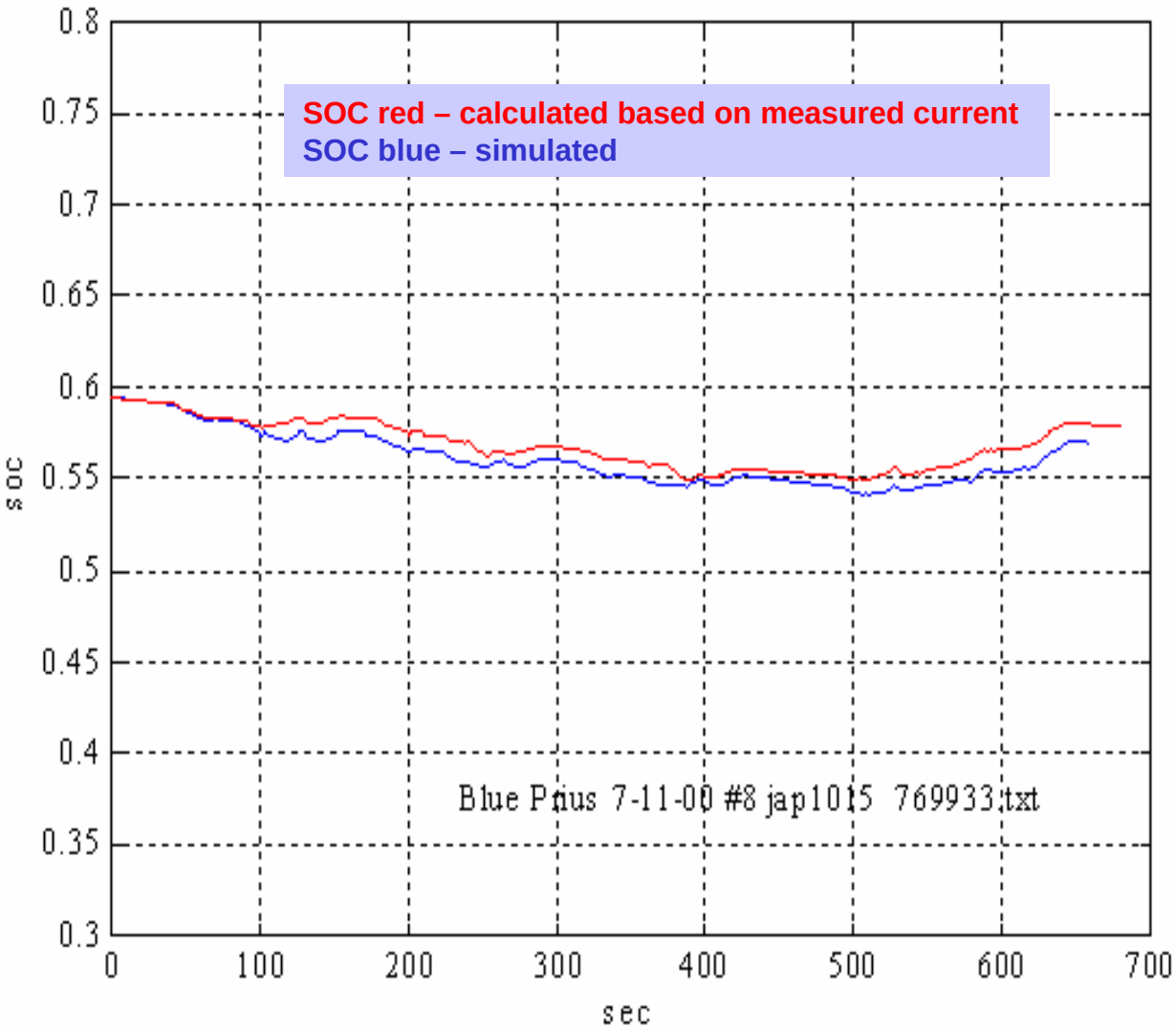


Japan 10-15 Cycle

Test/Simulated Consumptions: 47.6 / 45.6 mpg

SOC difference between test and Simulation 0.01

HEV Validation - Japan Prius



Japan 10-15 Cycle

Test/Simulated Consumptions: 47.6 / 45.6 mpg

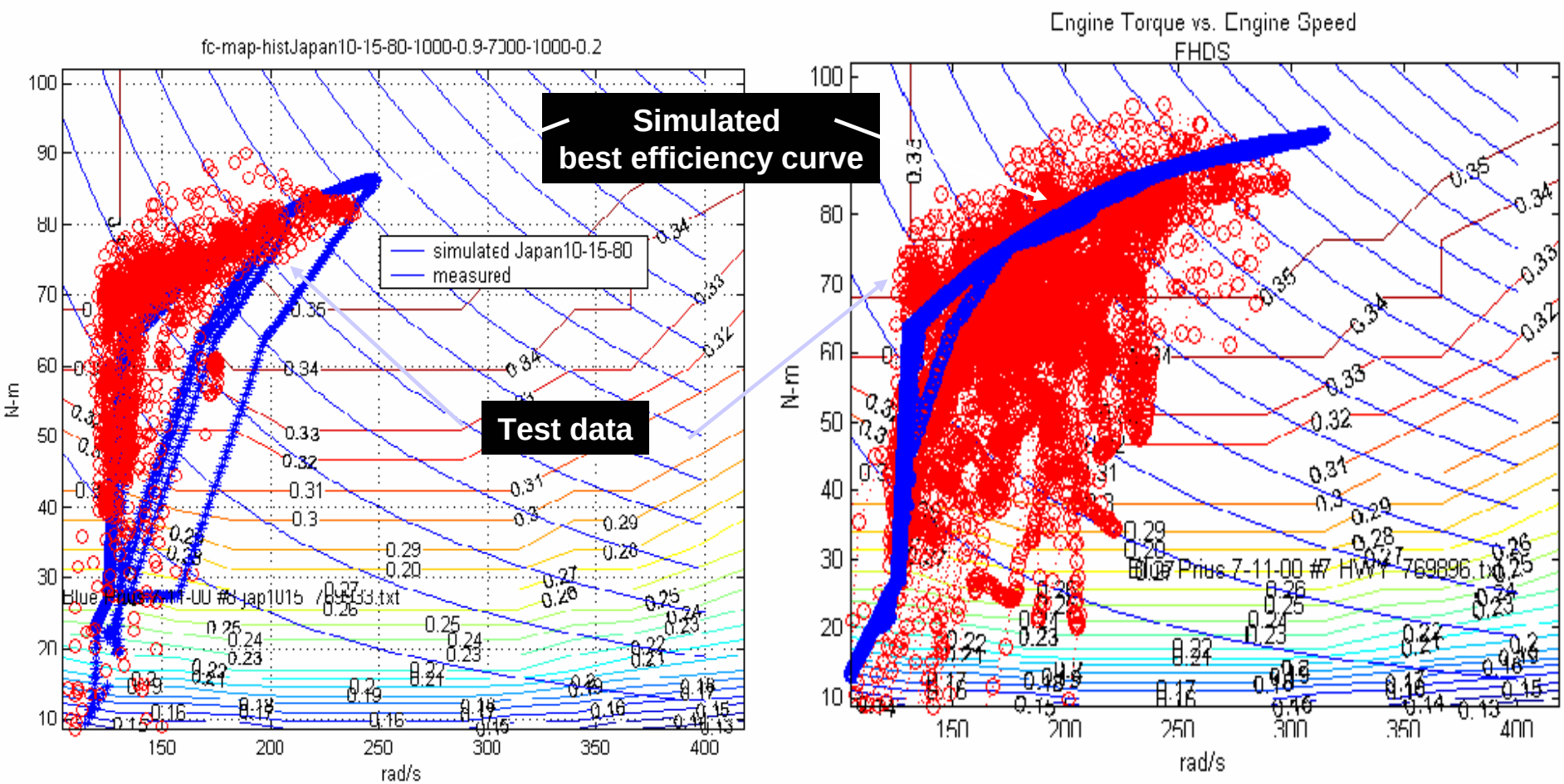
SOC difference between test and simulation 0.01

HEV Validation - Japan Prius

Engine torque vs. Engine Speed

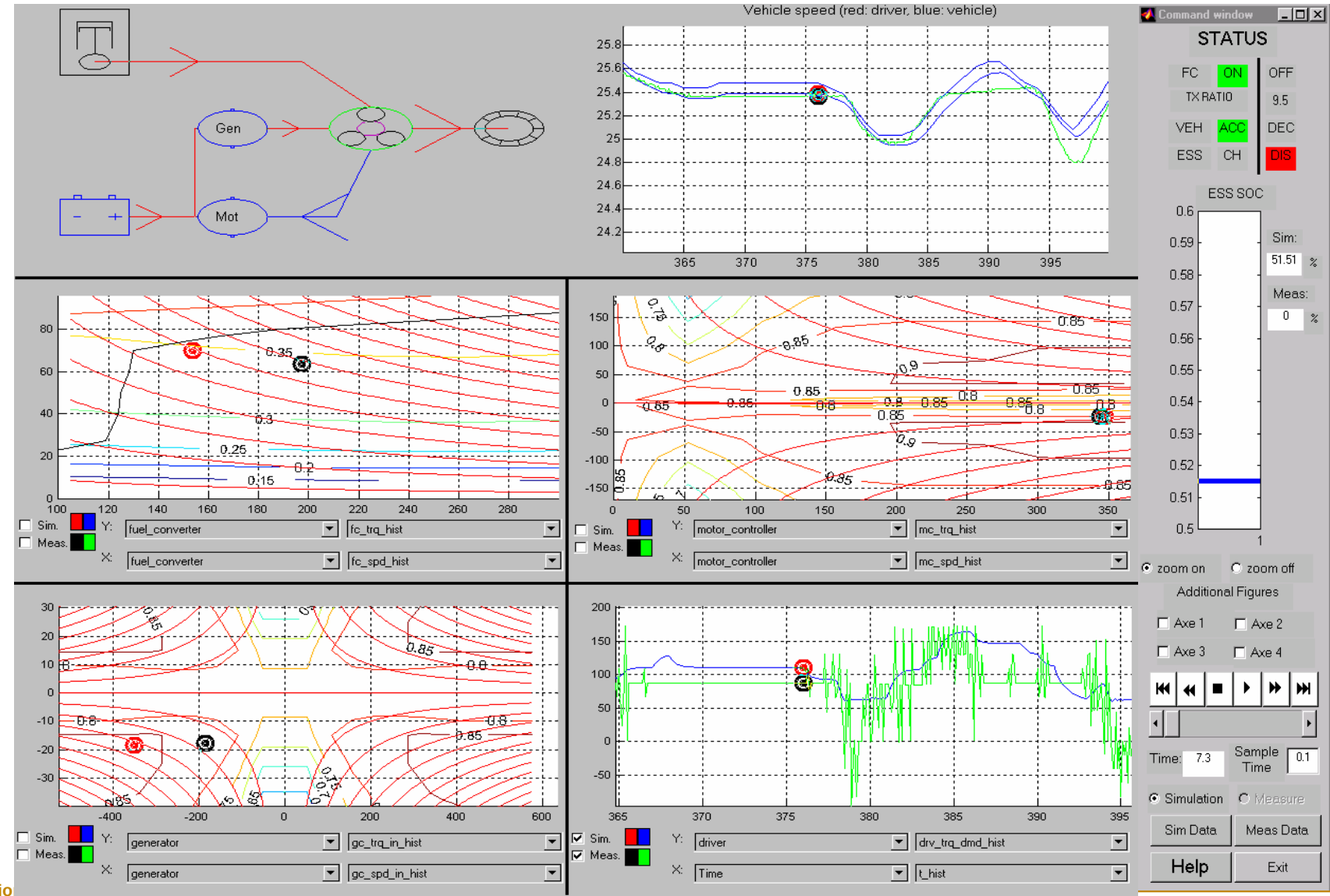
Japan 10-15

FHDS

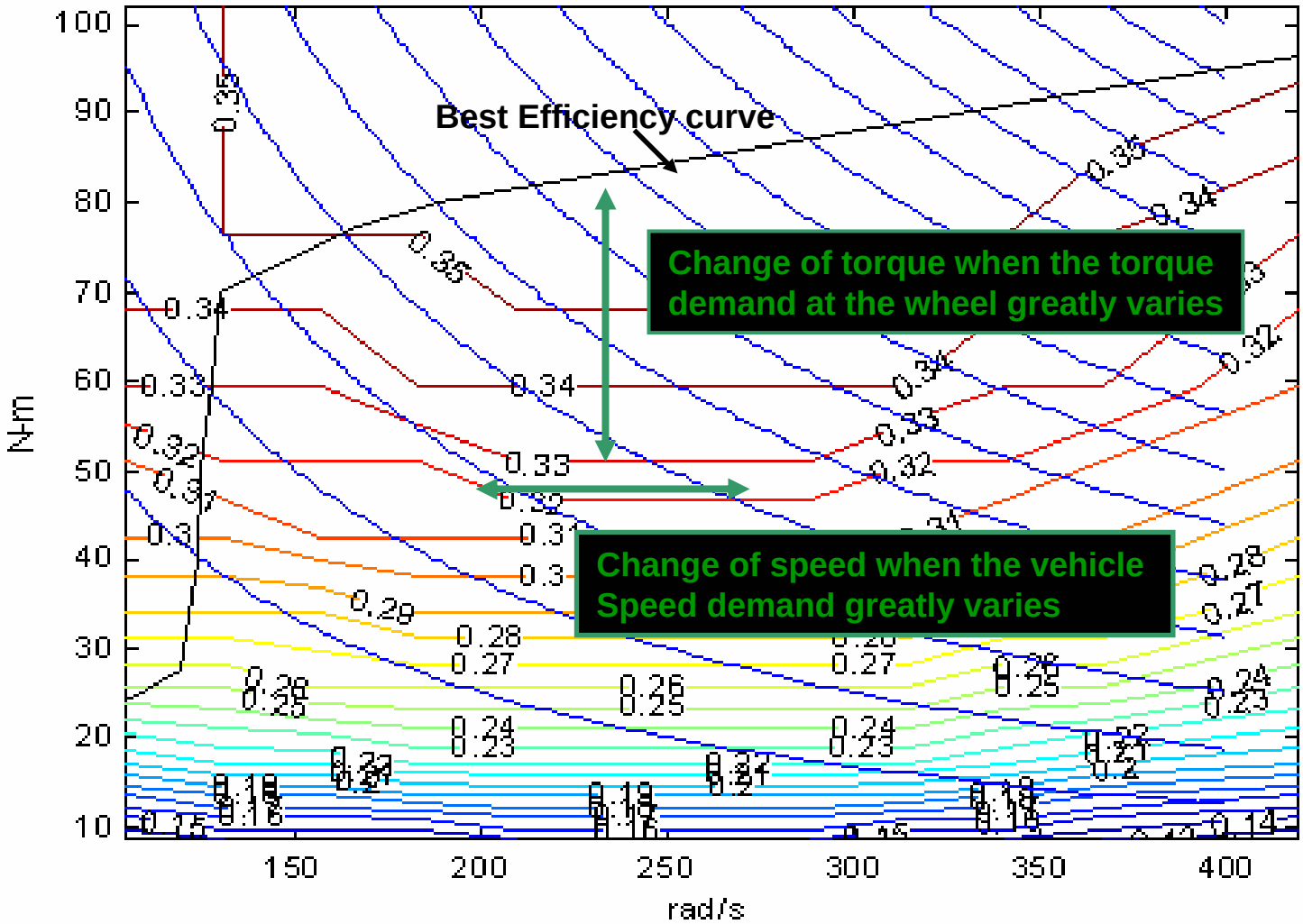


Science and Technology

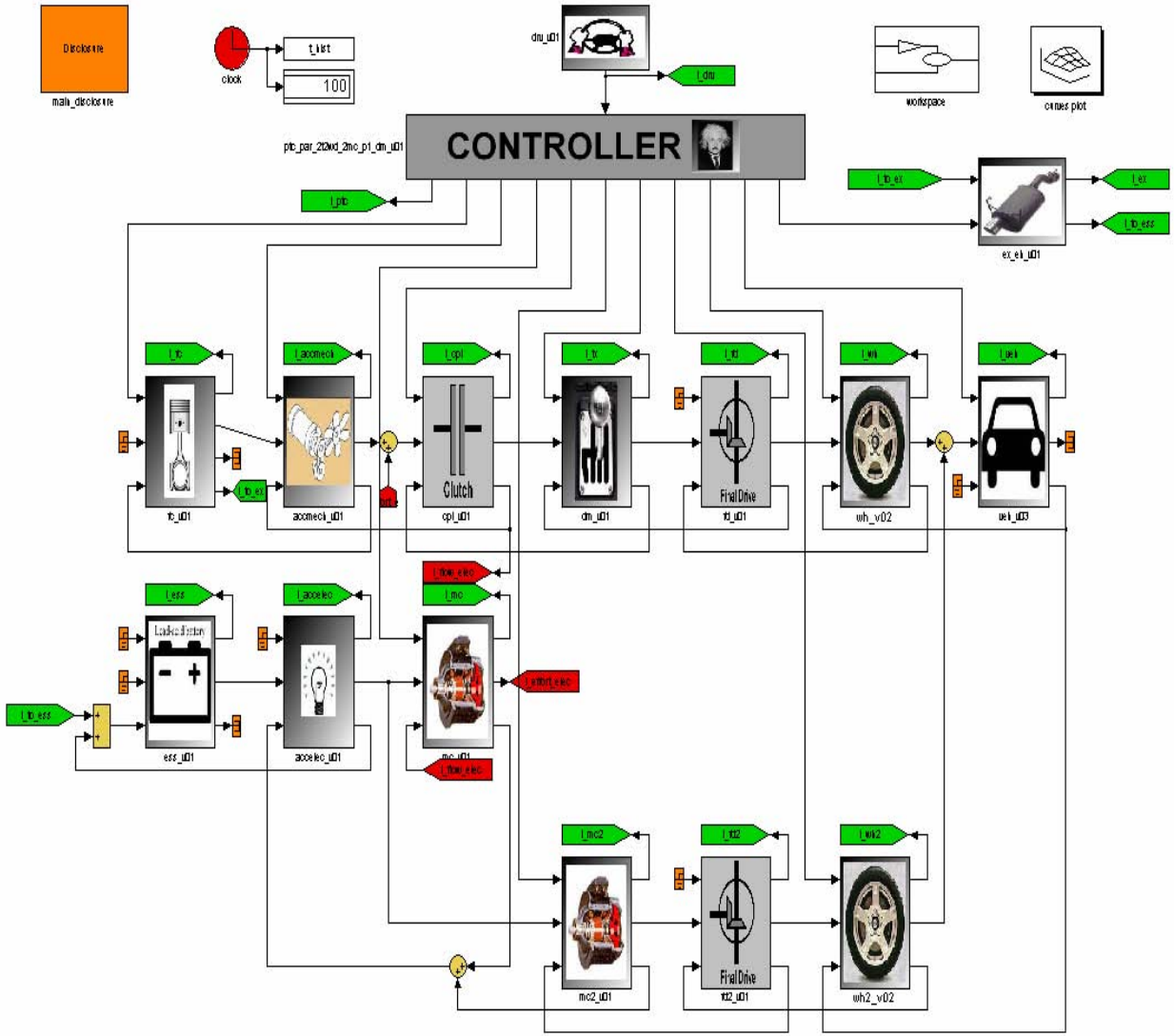
Specific Tools Are Necessary to Understand and Develop Advanced Controls



The Japan Prius Does Not Always Follows the Best Efficiency Curve



HEV Precept Correlation



Combined

Test/Simulated Consumptions: 79.6 / 76 mpg

Small SOC difference in Simulation

HEVs Validated Within 5% FE & SOC

Japan Prius

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

Honda Insight

Cycle	Cons test mpg	Cons simul mpg	Diff in %	SOC init	SOCf test	SOCf simul	Diff in %
Japan 10-15	57.9	58.8	1.5	0.596	0.610	0.611	0.4
NEDC	60.6	60.2	0.6	0.600	0.602	0.583	3.6
FHDS	74.2	75.3	1.4	0.590	0.588	0.589	0.2
FUDS	58.3	57.8	0.8	0.728	0.706	0.720	2.0

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  - Fuel Cell Modeling
  - Transient Engine Emission Models
  - Trade-off between FE & Emission
  - Potential Gains for Class 2B Vehicle
- Perspectives

Transient Fuel Cell Modeling Needed for FreedomCAR

- **Develop engineering models of FC systems and components using the GCtool architecture.**
- **GCtool is design-oriented ... models are too slow (complex) for transient driving cycles**
- **Details may not be available for building mechanistic models**
- **Flexible to arrange component configuration**
- **Some existing models can be adapted**

Engineering Model

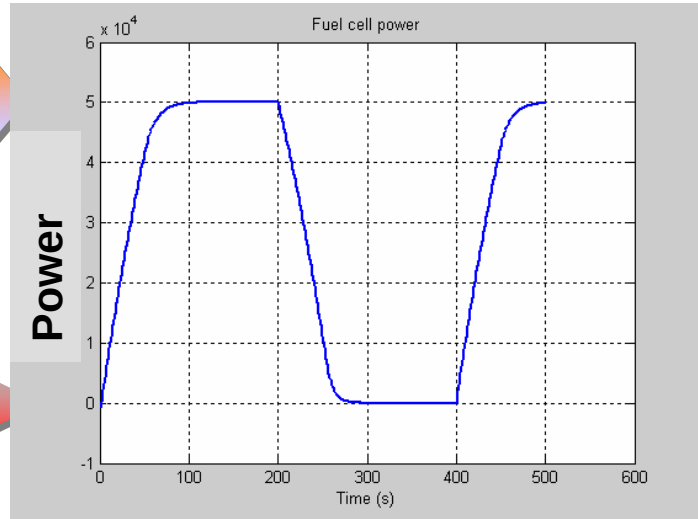
- **Solve conservation equations for energy, mass, species and momentum to develop performance maps.**
  - ATR: Composition (P, T, GHSV, A/F, W/F)
  - WGS: CO Conversion (P, T, GHSV, COin, H2O/CO)
  - PROX: CO/H2 Conv. (P, T, GHSV, COin, O2/CO)
  - PEFC: V(P, T, I, CO, AB)
- **Performance maps are design-specific**
- **Models are transient, can be multinodal and may directly interact with other components**

GCTool-ENG Along with PSAT Allows Realistic Modeling

GCtool Fuel Cell Configuration

Transient FC Model in MATLAB

PSAT Transient Vehicle Model



Succession Of Accel./Deccel.
In PSAT - Direct H2 Fuel Cell

Transient Fuel Cell Evaluation within Transient Vehicle Model

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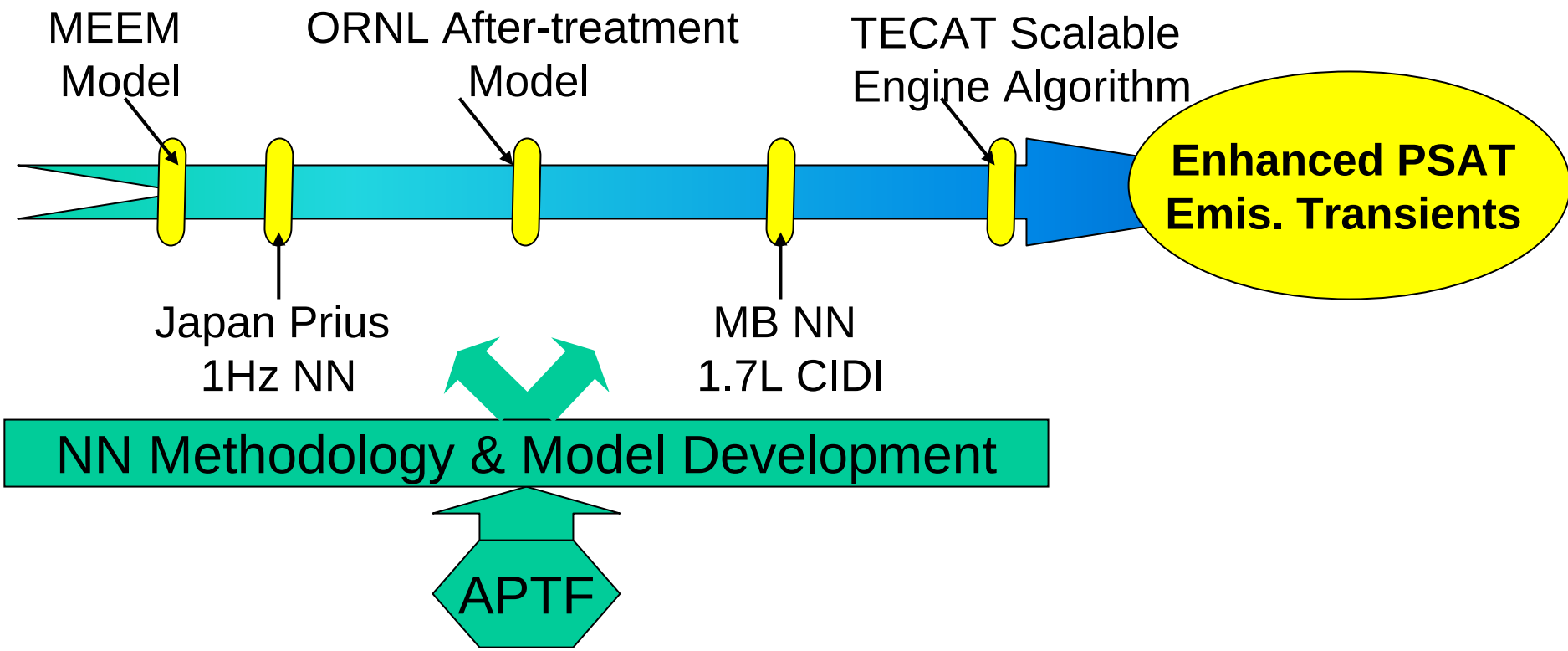
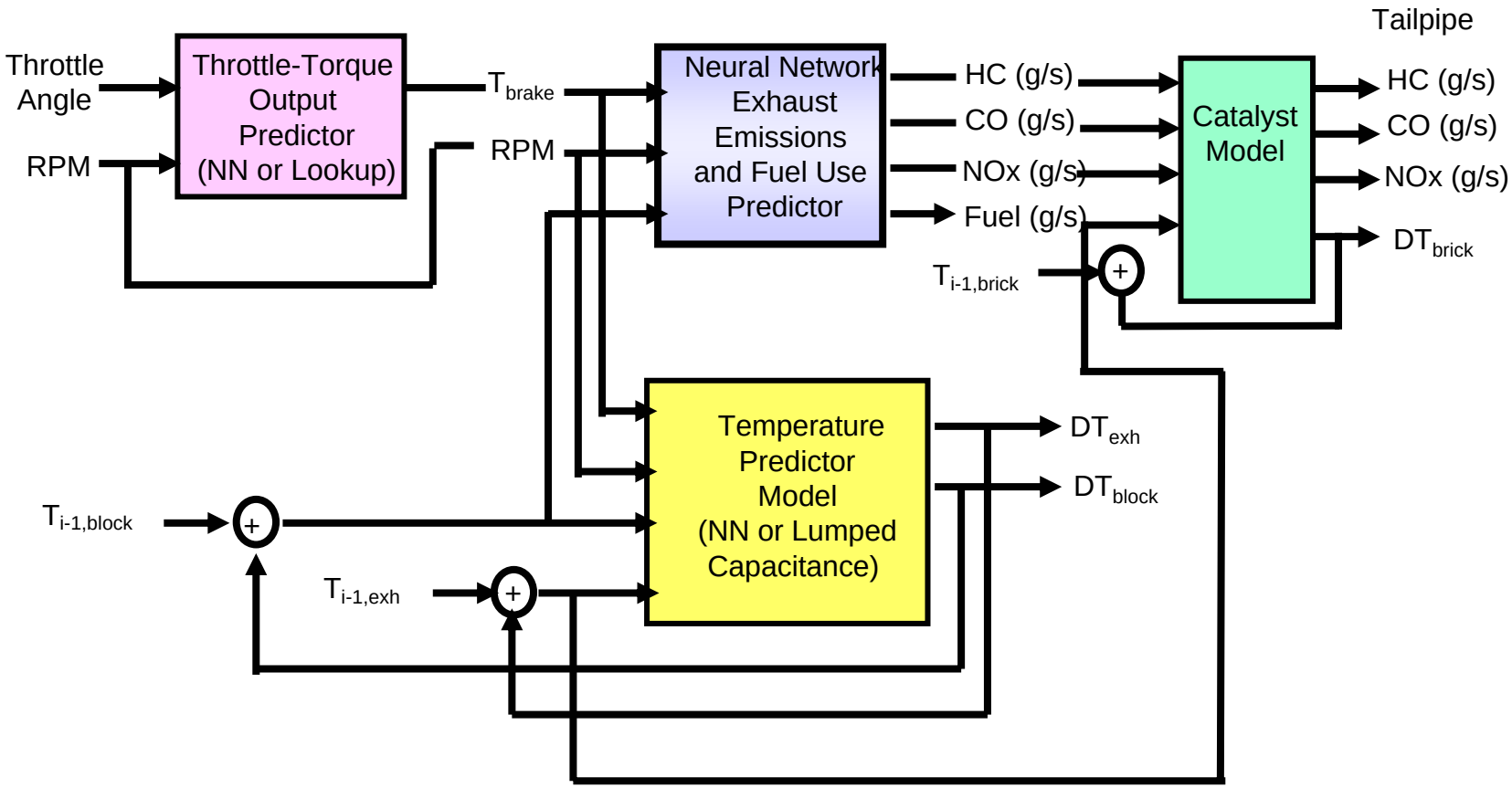
Improved Transient Emission Modeling Needed

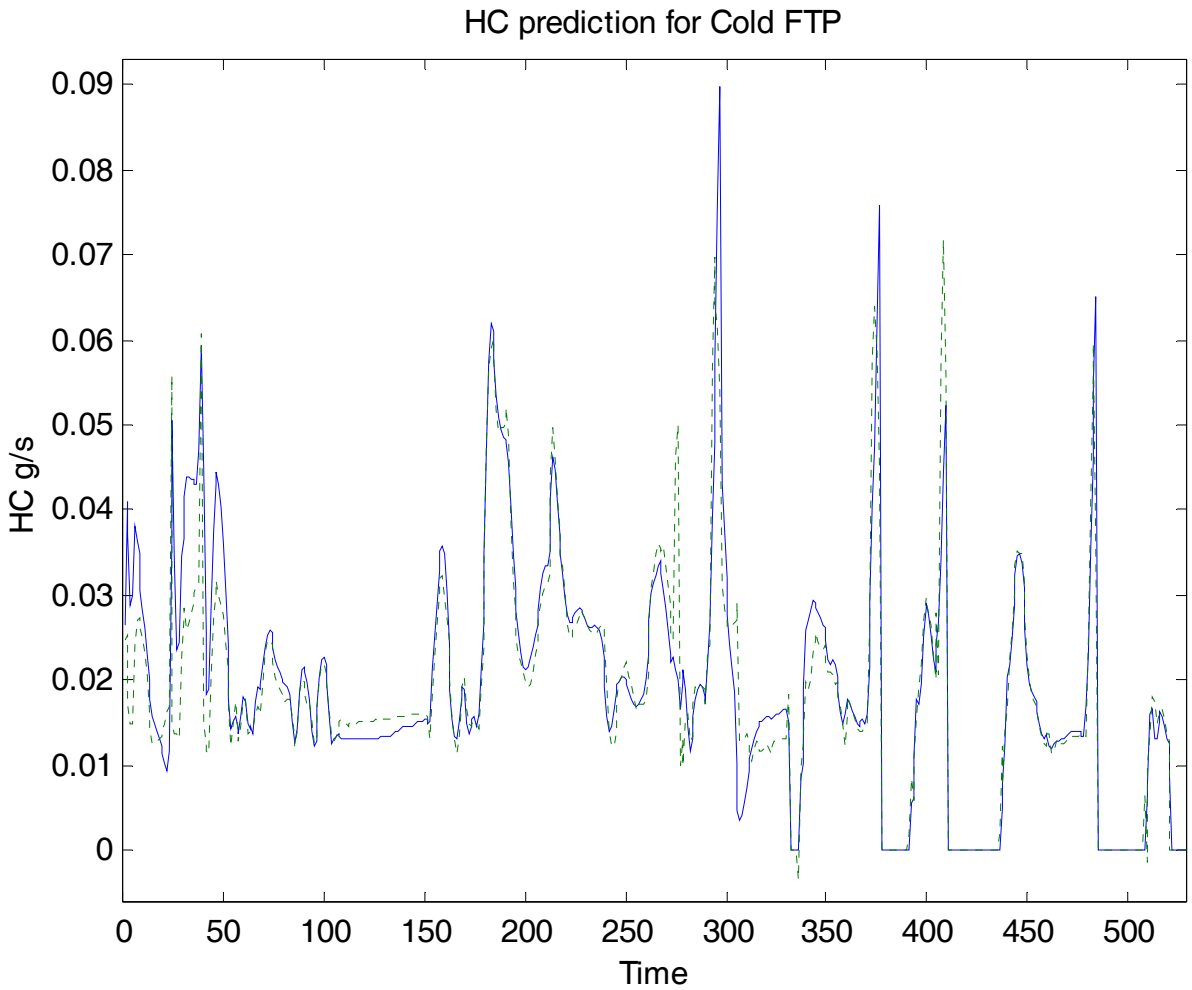


Overview of the Japan Prius Engine NN Model



T_{block} = Engine Block Temperature, T_{exh}= Engine Exhaust Temperature, T_{brick} = Catalyst Brick Temperature,
t = Torque i-1 = last time step

HC Plot for Cold FTP



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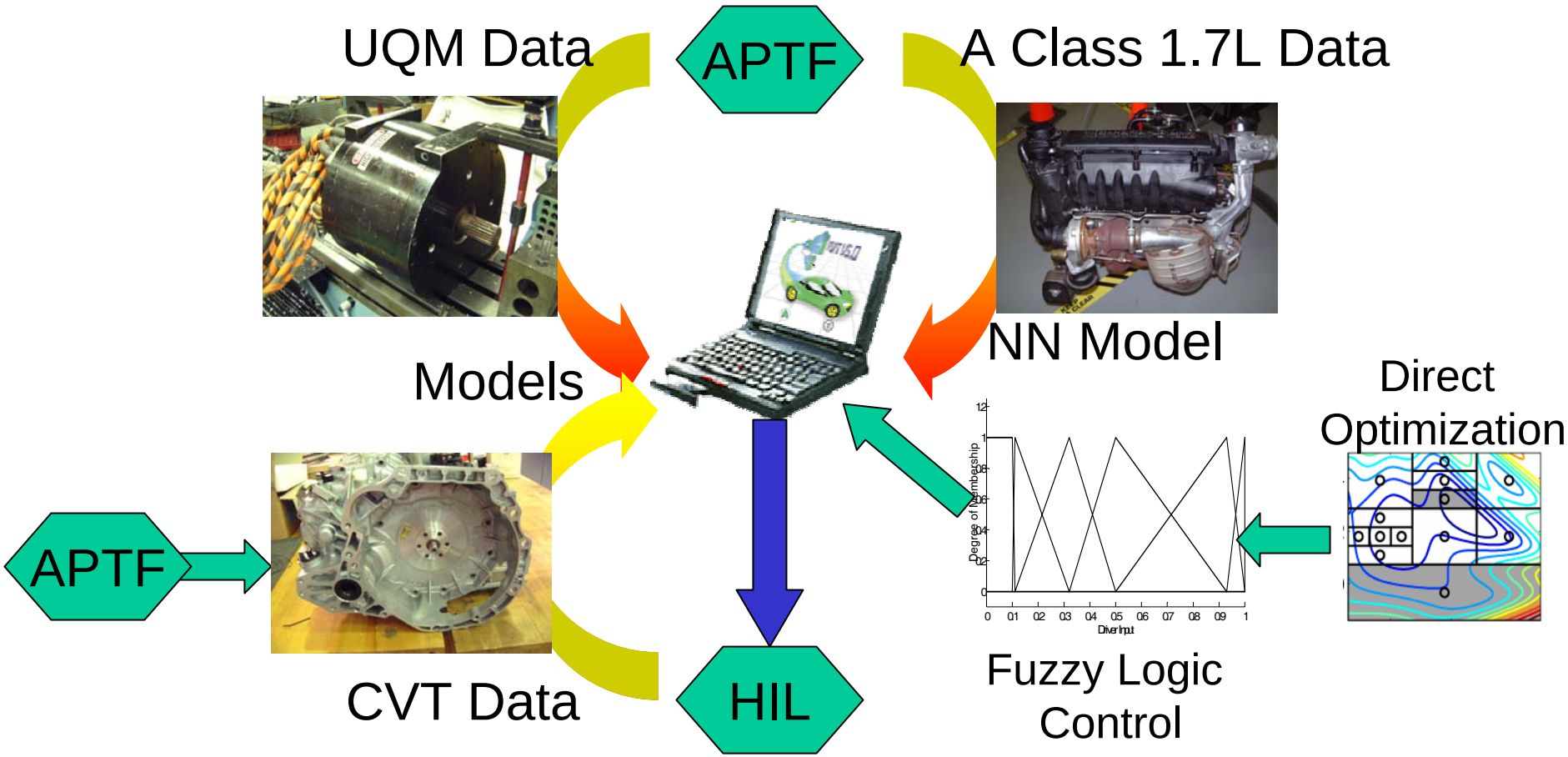
Trade-off Between Fuel Economy & Emission



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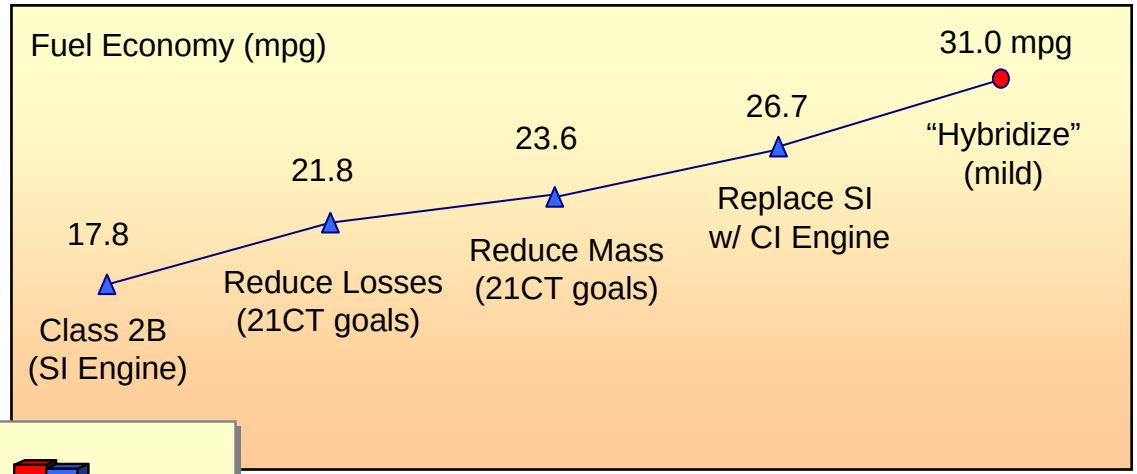
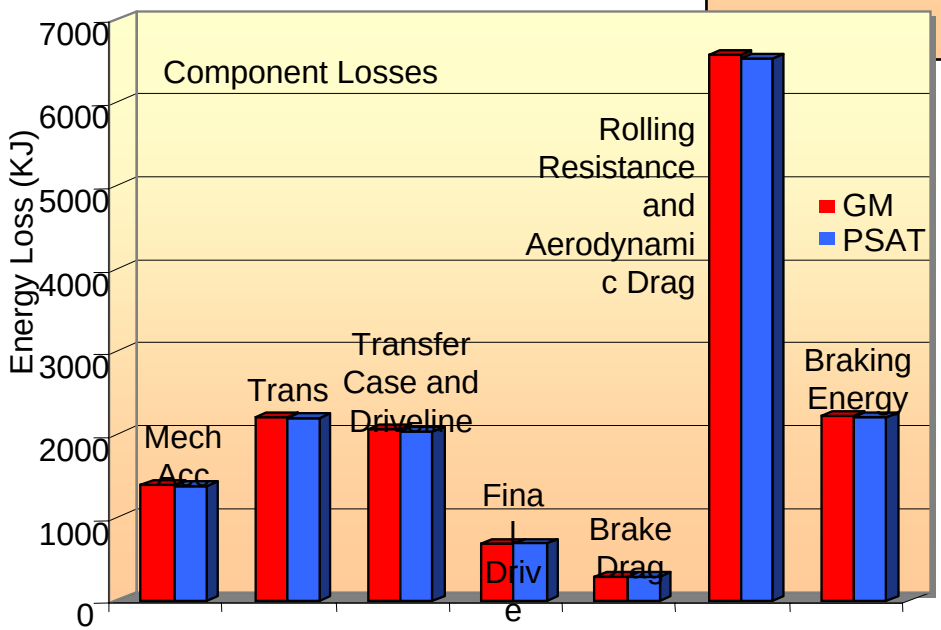
Potential Gains for Class 2B Vehicle



Combined EPA Cycle
(55 FUDS/45 FHDS)



Comparison Between
GM Data And PSAT
Silverado Pickup

Outline

- ANL Philosophy
- PSAT Overview
- Validation
- Example of Work Done at ANL
- **Perspectives**

Summary/Perspectives

- **PSAT is a state-of-the-art powertrain modeling tools allowing users to simulate unrivaled number of predefined configuration (>130)**
- **PSAT has been developed for external users and development emphasized on easy integration of initialization files, component models, and control strategy integration**
- **PSAT simulates transients and allows realistic control**