Operational Characteristics of the First Mass-Produced HEV - The Toyota Prius

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MY 1998 Toyota Prius

- First Production HEV
- Sold in Japan ($16,900 US dollars)
- Sales started December 1997
- Production 1000/month
- Production doubled in June 1998

Argonne Testing:

- Two vehicles delivered in June 1998
- 1st mileage accumulation, then instrumentation effort
- Argonne testing began March 1999

Other Prius Testing

U.S. Environmental Protection Agency

- Tested fuel economy and emissions.
- Tracked battery Ah
- Results: 48.5 mpg city, 49.8 hwy
- [*see EPA420-R-98-006, Aug. 1998*]

National Renewable Energy Laboratory

- Inspected and test electric machines and battery pack
- Domestic Automakers
- Proprietary disassembly and testing

Focus of Argonne Testing

- Comprehensive instrumentation of vehicle
- Data to reveal operational behavior
- Understand powertrain control and energy management strategies
- Argonne will work with NREL and SwRI to develop and validate a vehicle simulation model of Prius

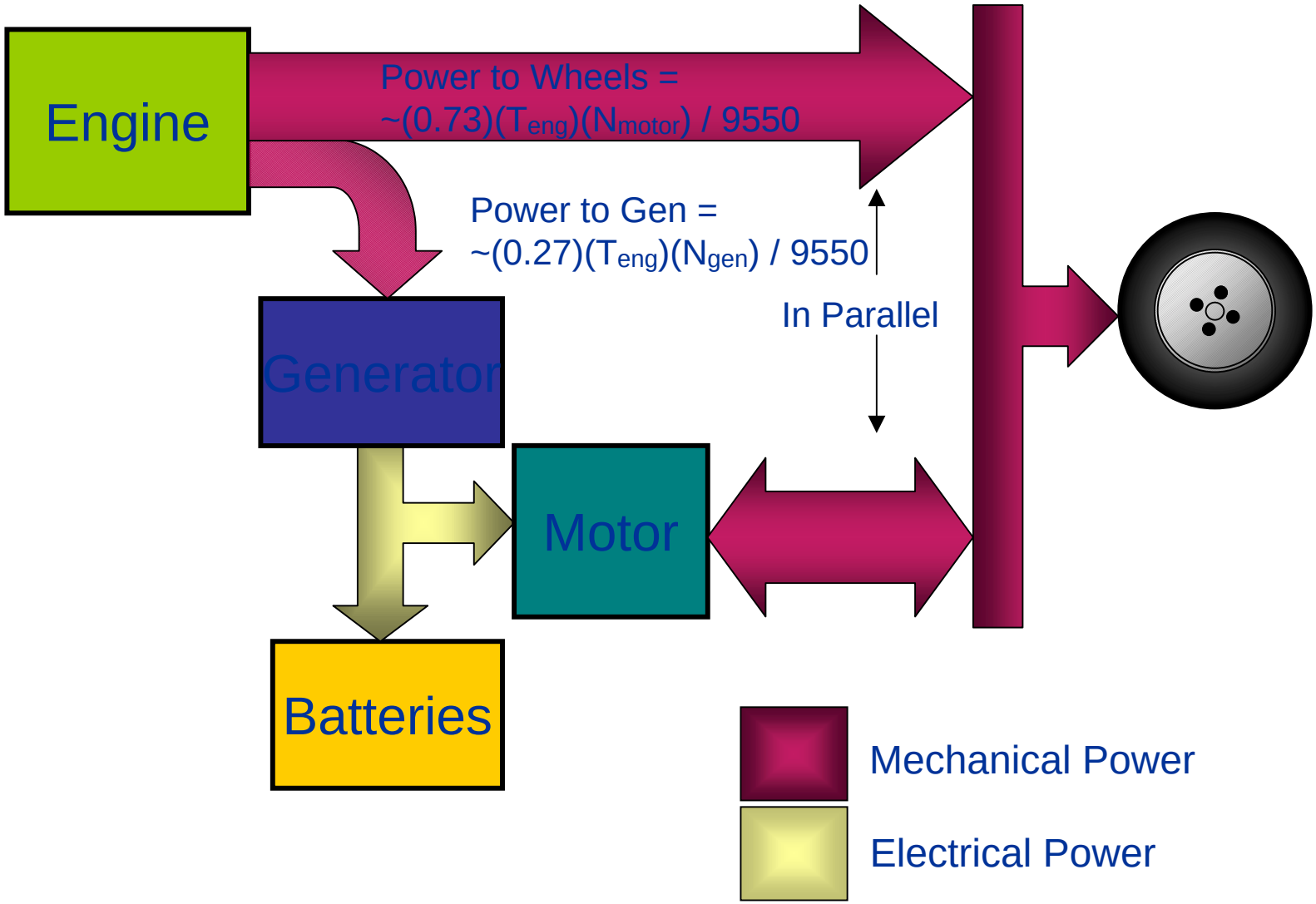
Prius Instrumentation

- Dedicated Ah battery monitor installed
- Acquired signals:

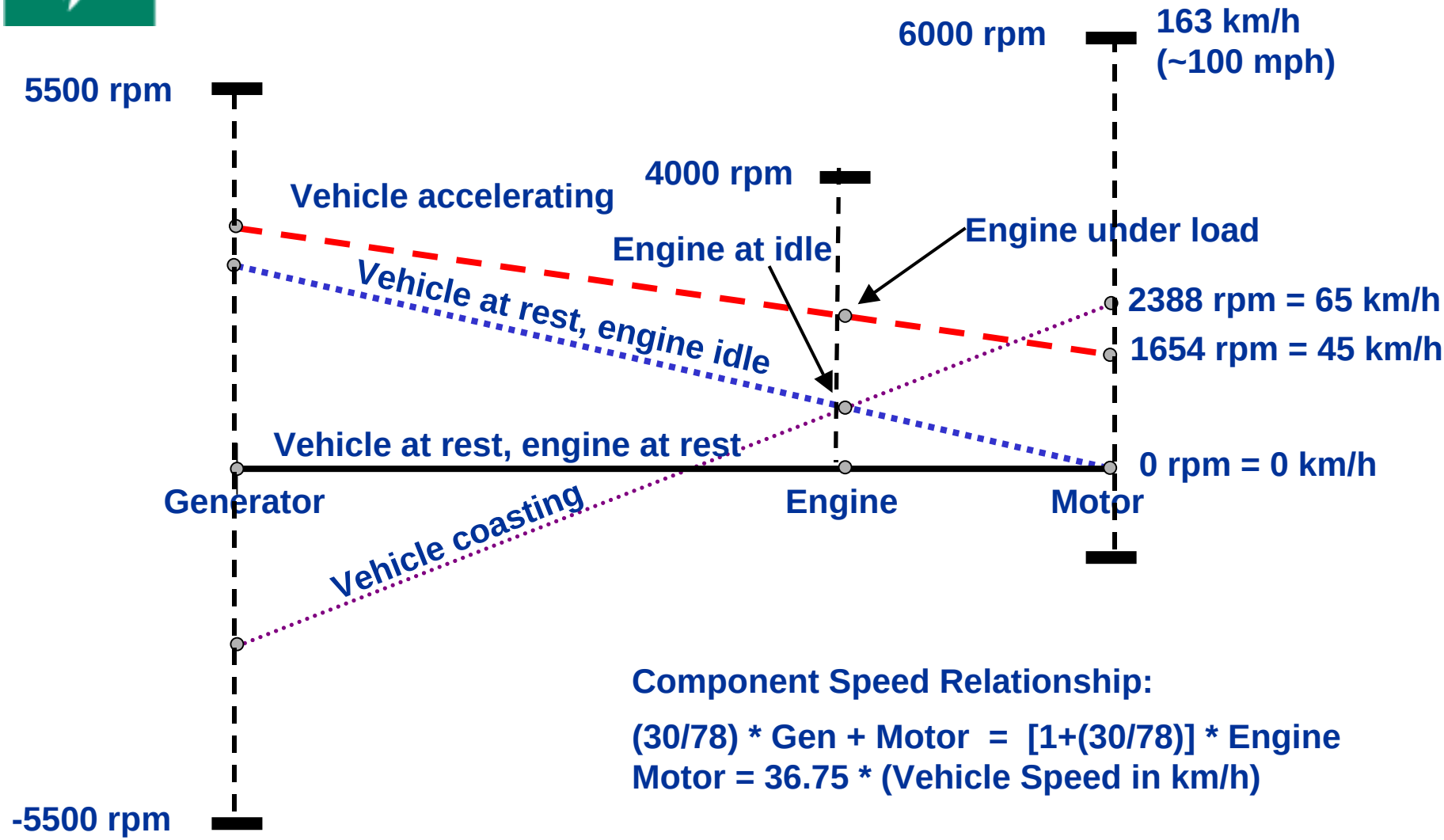
Measured Signals
- Vehicle (wheel) speed
- Battery voltage
- Battery current
- Accelerator pedal position
- Brake request
- Front and rear brake pressure
- Engine speed
- Engine throttle position
- Engine mass airflow
- Exhaust gas temperature
- Coolant temperature

Calculated Signals
- Generator speed
- Motor speed

Prius Power Flow



Component Speed Relationship

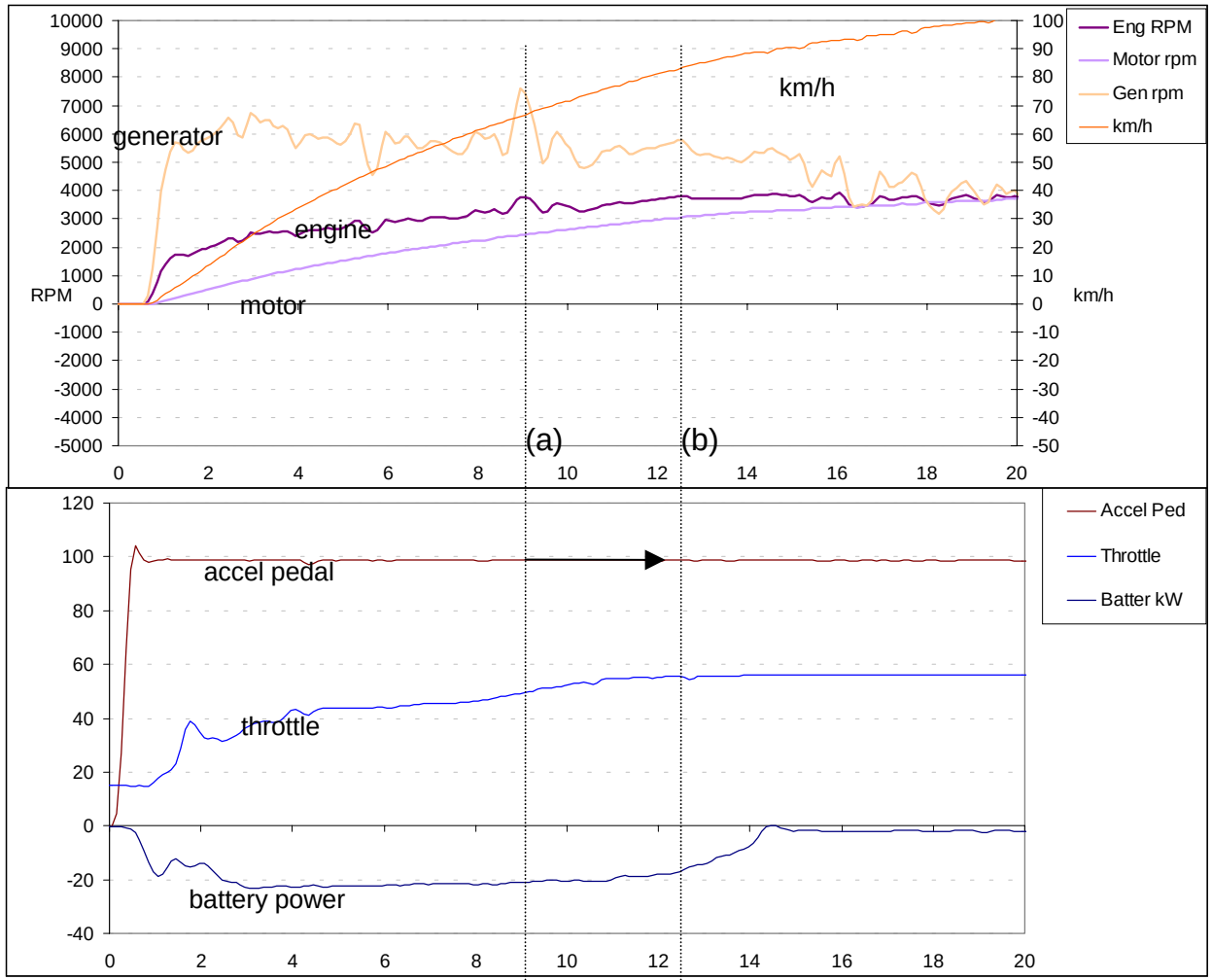


Component Speed Relationship:

(30/78) * Gen + Motor = [1+(30/78)] * Engine
Motor = 36.75 * (Vehicle Speed in km/h)

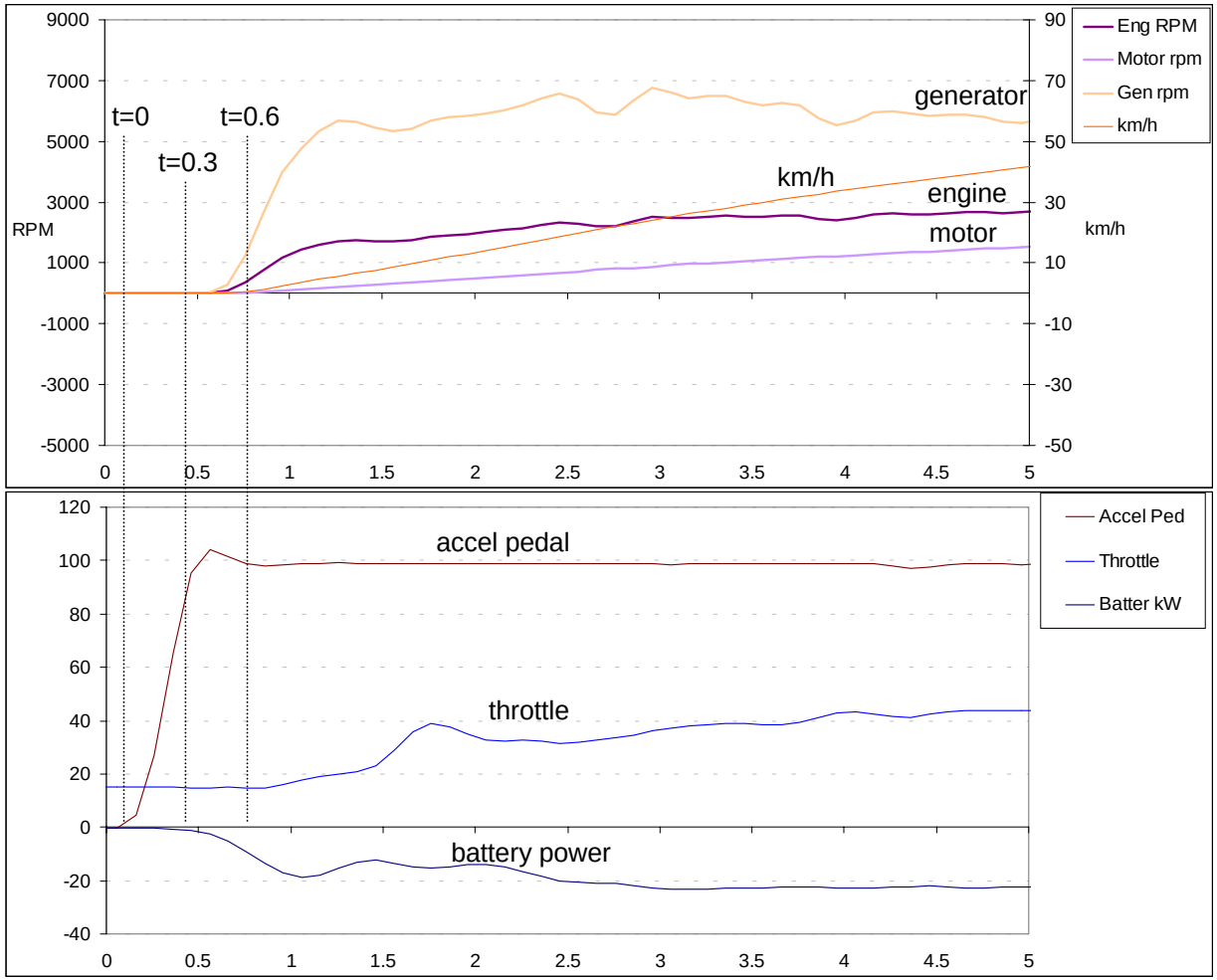
Prius Powertrain Control: Full Acceleration

- Zero to 100 km/h in ~17-18 seconds
- As motor speed increases, engine speed will build while generator is at its speed limit.
  - The generator can come off its speed limit and engine is brought to full power.
  - When engine is at full power, net battery power is zeroed and vehicle continues to accelerate only under engine derived power



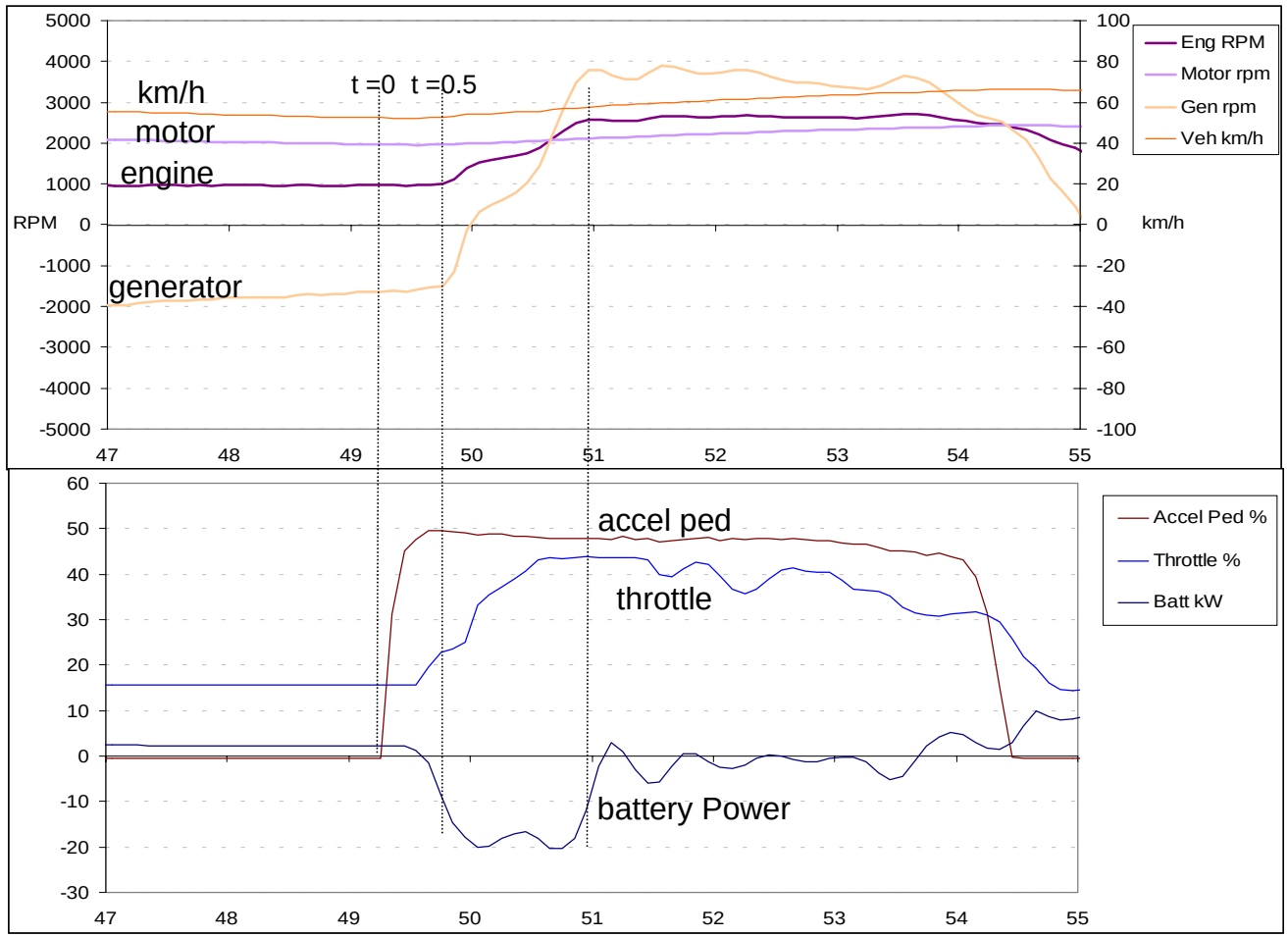
Prius Powertrain Control: Powertrain Response Latency

- Delay between driver command and vehicle response is ~0.6 seconds
- Delay between driver command and powertrain response is ~0.3 seconds
- Powertrain takes another 0.3 seconds to move the vehicle



Prius Powertrain Control: Coast then Accelerate

- Generator must reverse speed to bring engine off idle
- Battery power trace shows motor assist while engine is brought to desired power level

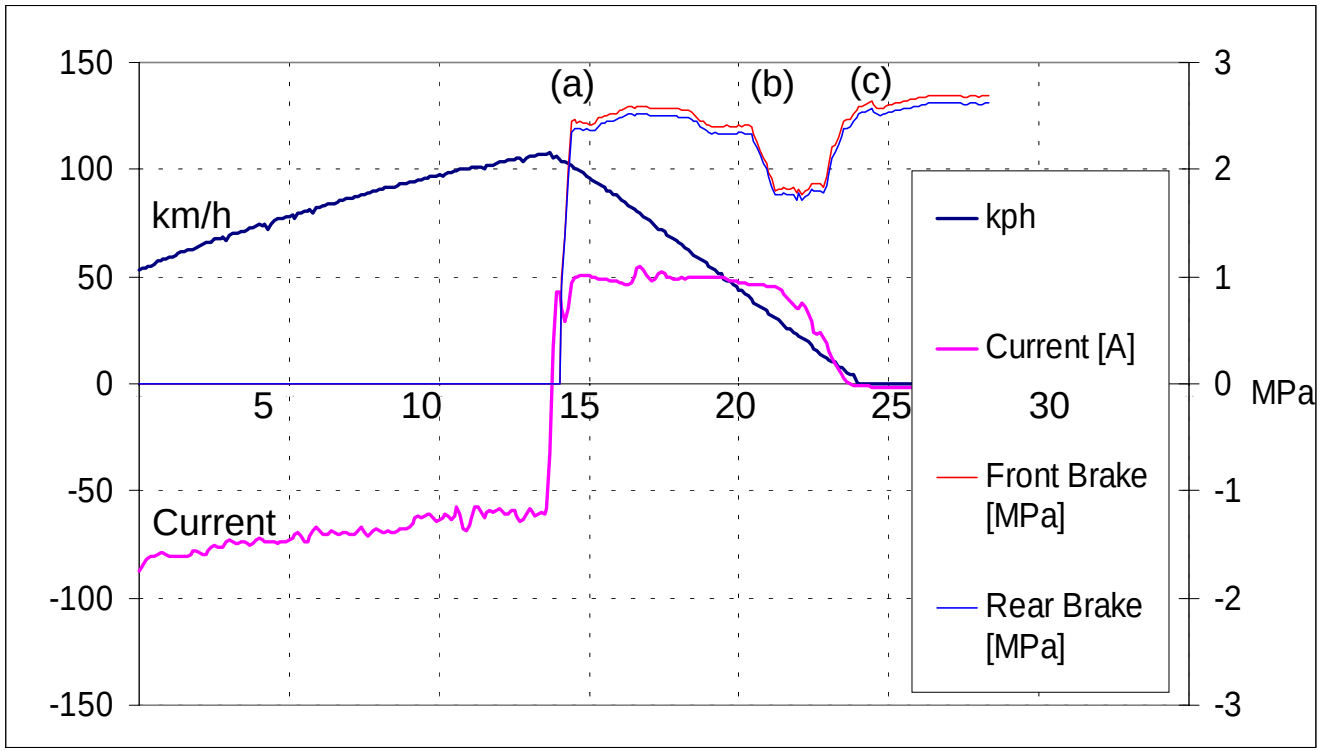


Prius Powertrain Control: Active Braking System

a) At beginning of brake event, regen is max-ed and hydraulic braking takes the remainder of the braking force

b) When available brake power is low enough, hydraulic brakes are diminished to maximize regen energy

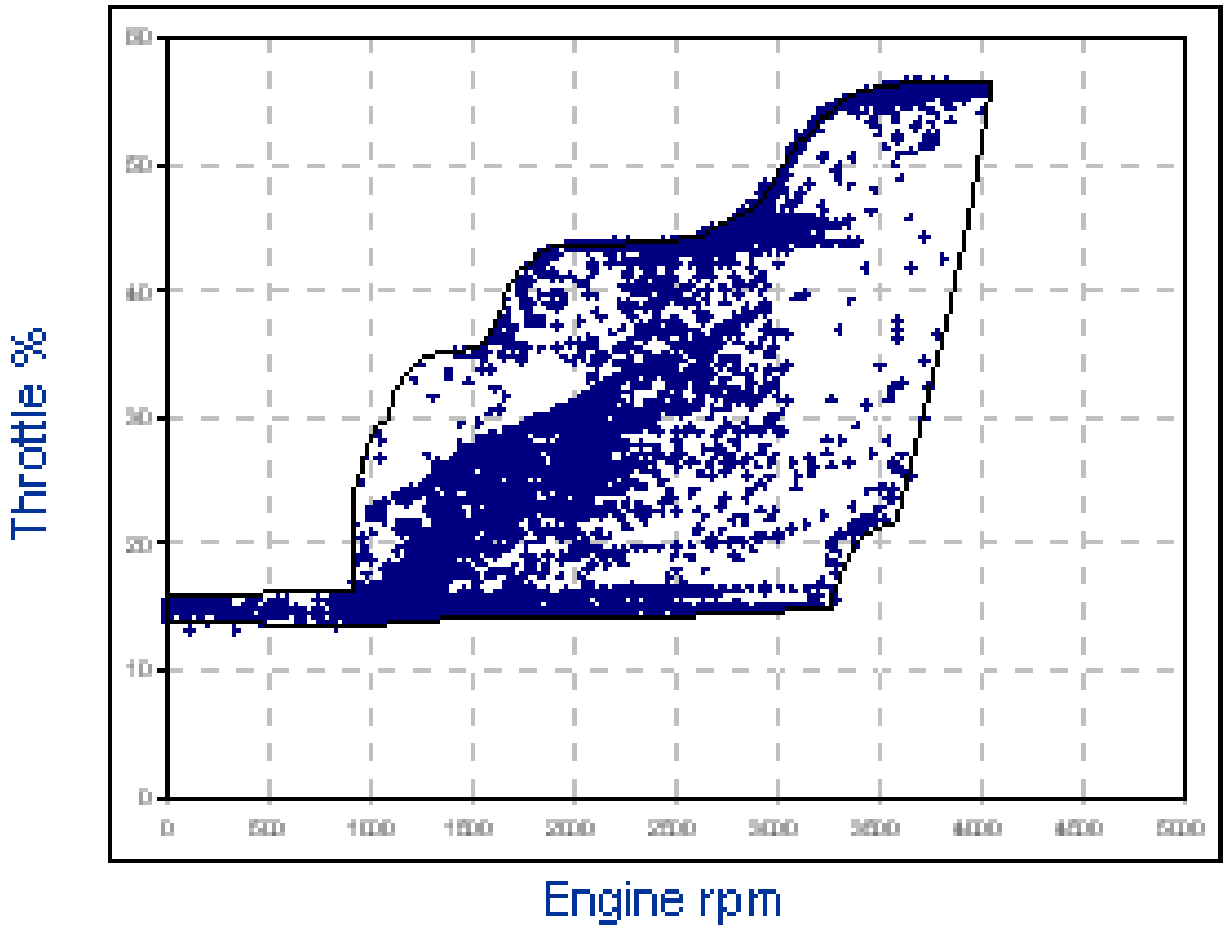
c) When vehicle comes to stop, full hydraulic brakes are activated



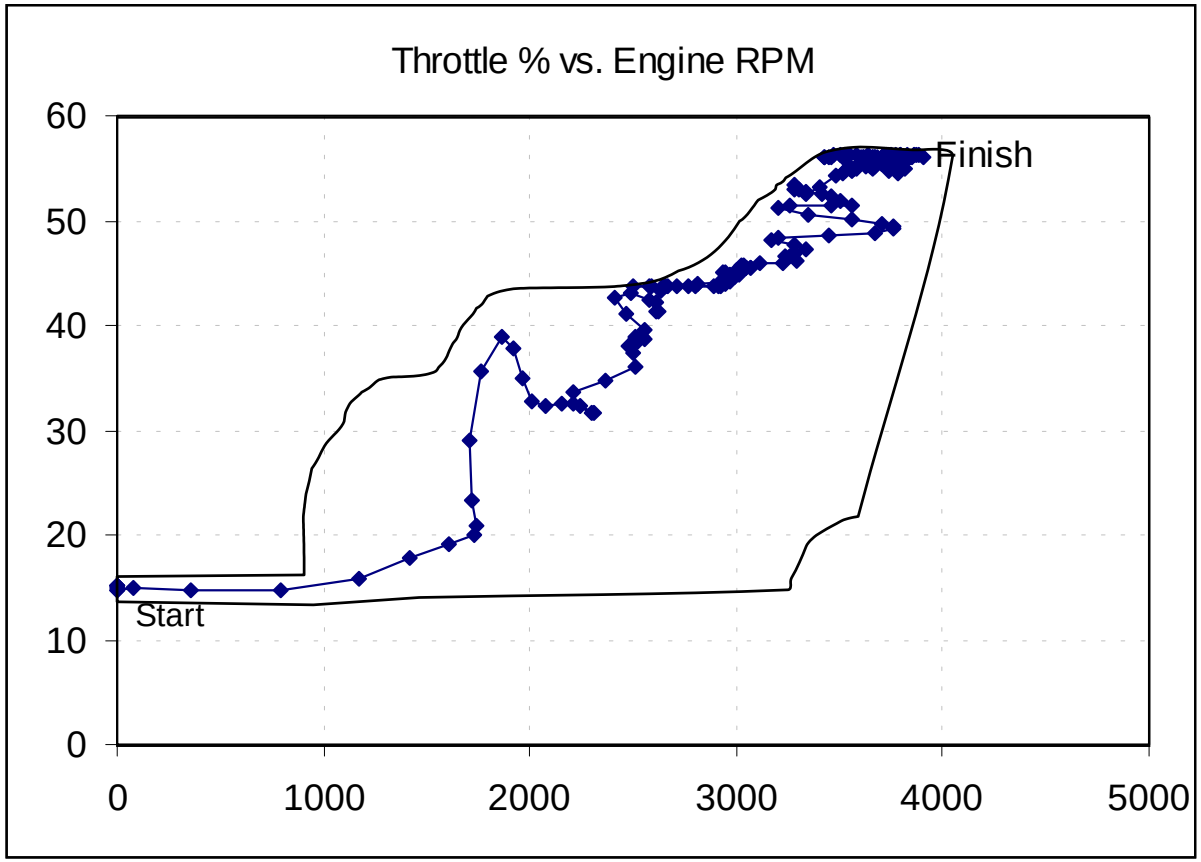
Prius Driveability

- Acceleration performance
  - 0-60 mph range from 14 -20 sec depending on vehicle, SOC, and prior driving
- Braking
  - Some drivers feel it can be too responsive and nonlinear
- Powertrain control delay
  - Vehicle response depends on generator speed, engine speed, and vehicle speed
  - During dynamometer testing, vehicle response to driver input is not always consistent from test to test

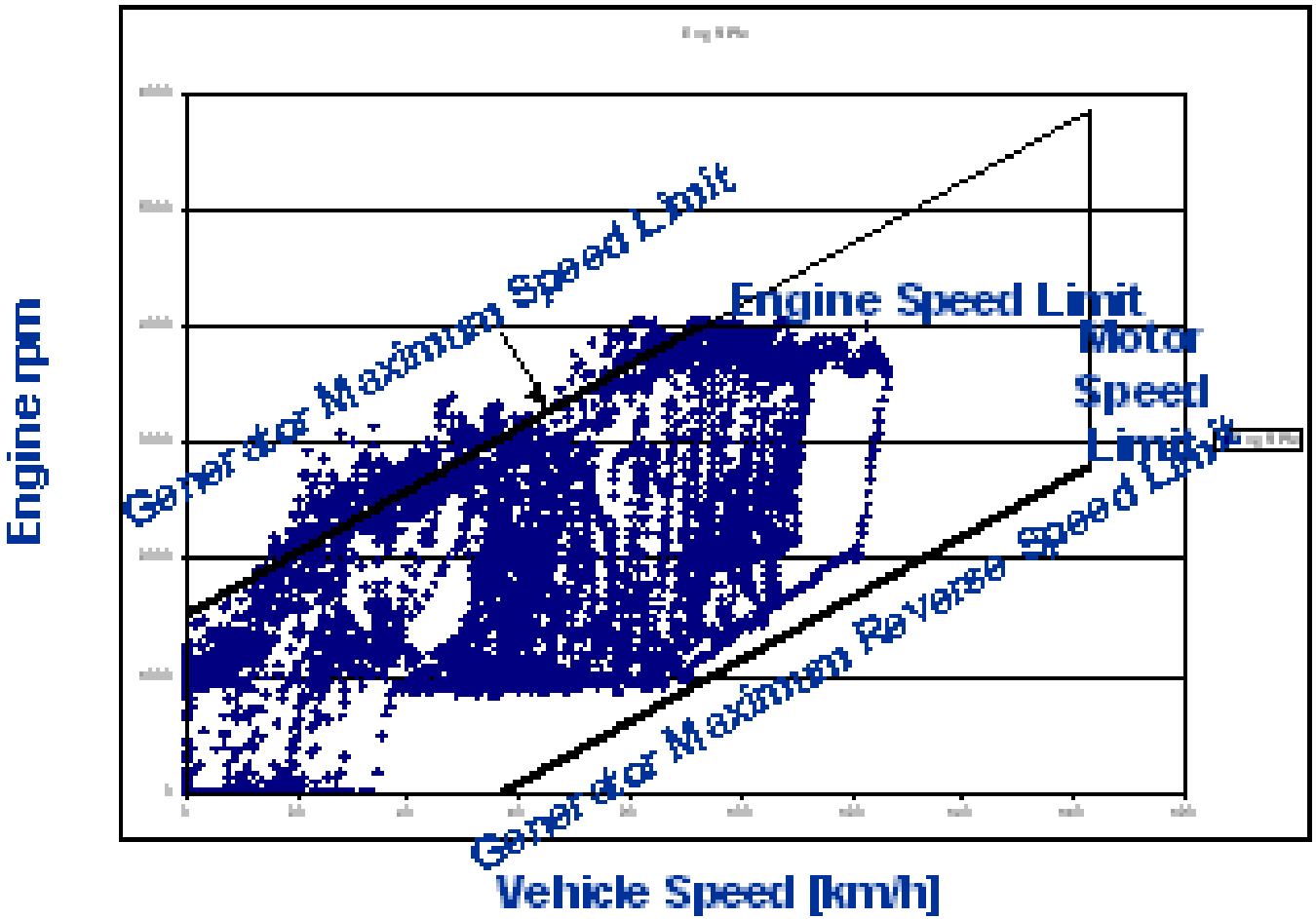
Observed Envelope of Engine Operation



Engine Operation Under Full Acceleration

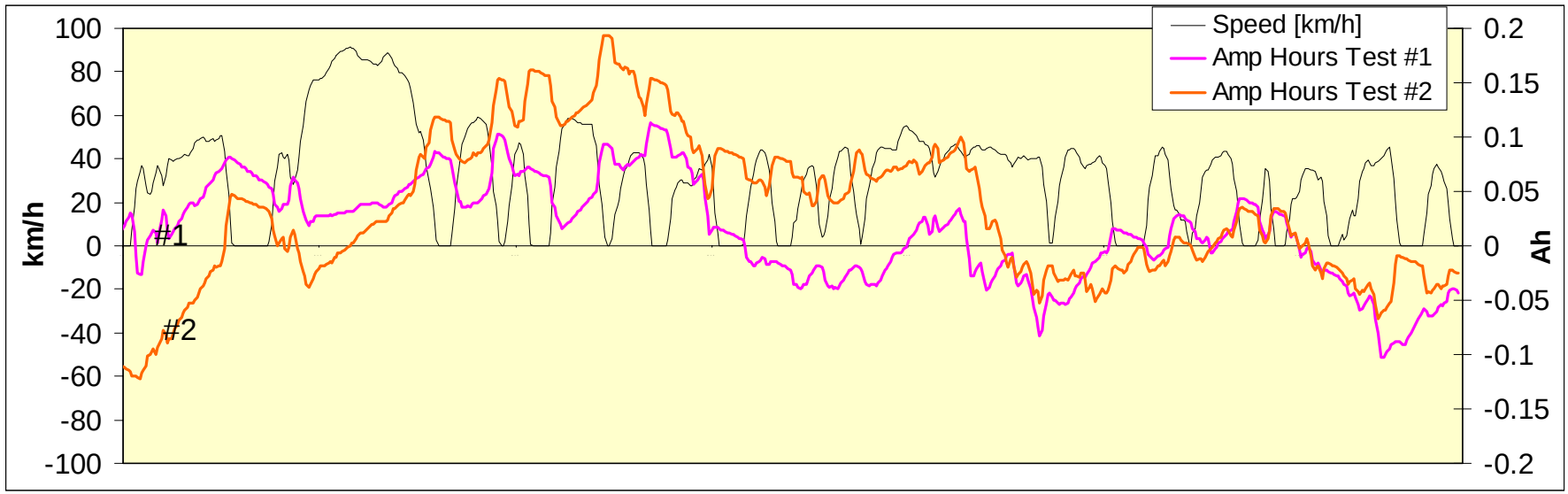


Component Speeds Limit Engine Speed



Energy Management

- Ah window is very narrow
- Varied initial SOC yields similar end result
- Aggressive driving will invoke “turtle light” (no motor assist); charge recovery is very rapid



Future Argonne Prius Testing

Testing is ongoing, current data are preliminary

- Place torque sensor between engine and transaxle assembly for in-vehicle engine torque measurements
- Perform chassis dynamometer tests of certification and other cycles
- Perform chassis dynamometer load and speed sweeps
- Remove and map engine
- Incorporate engine in other bench-test HEV powertrains