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PSAT Training

Part 04
Post-Processing Equations

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U.S. DEPARTMENT OF ENERGY

A U.S. Department of Energy laboratory
managed by UChicago Argonne, LLC

FreedomCAR & Fuel Partnership

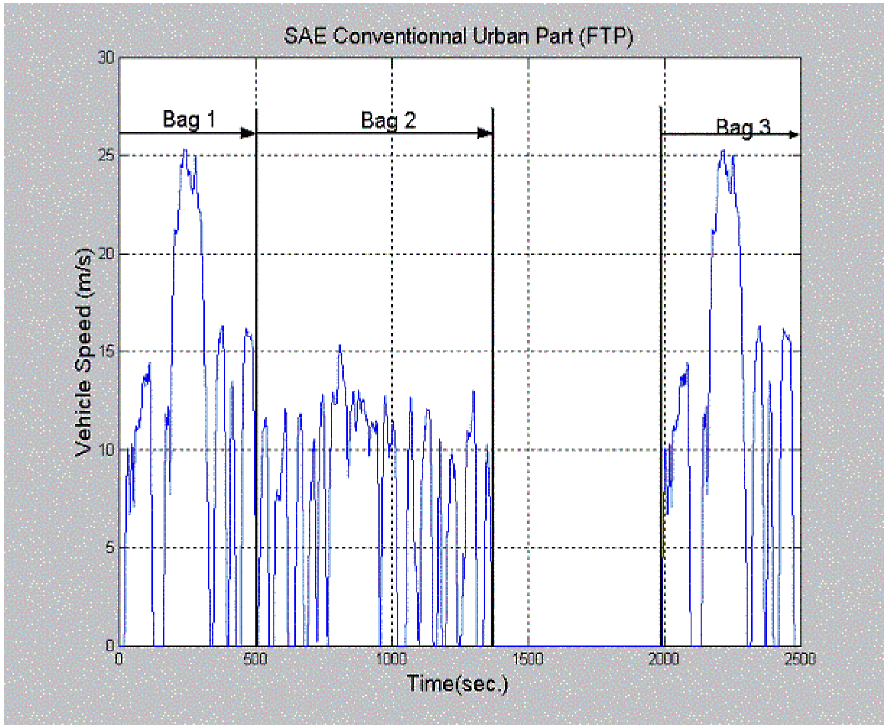
Outline

- Explanation of testing procedures
- Performance tests
- Description of main post-processing equations

1 – Test Procedures

- FTP Procedure (City)
- Highway Procedure (Highway)
- Combined Procedure (FTP + Highway)
- PHEV Preliminary Procedure
- Combined 5 Cycles Procedure

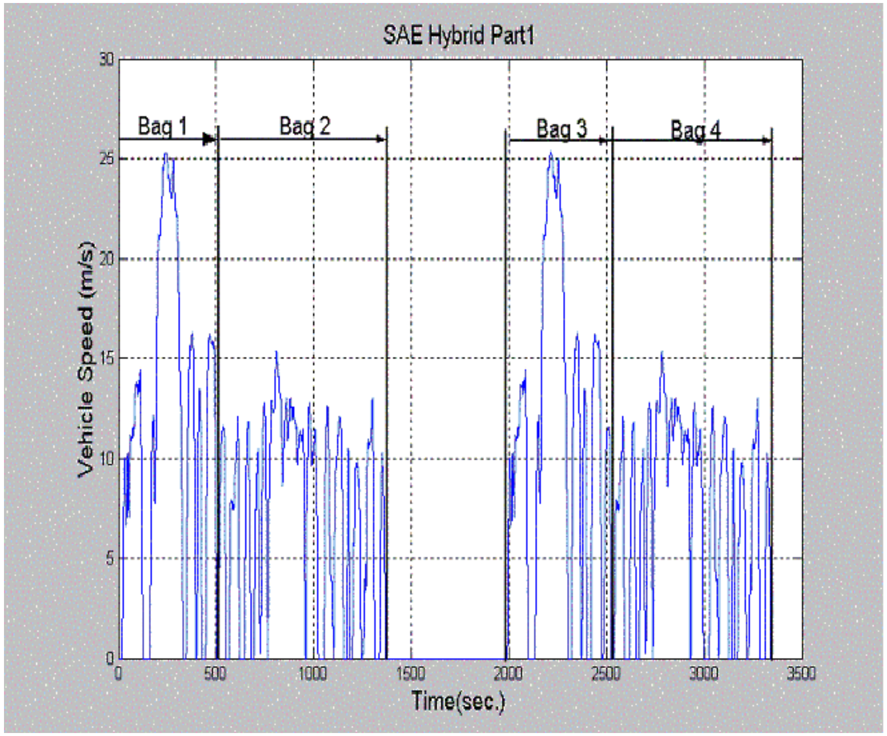
Urban Cycle – FTP75 – Option #1



For conventional, battery and fuel cell electric vehicles, one considers that Bag 2 & 4 would be the same. For this reason, we stop the test after the second 505 cycle.

$$Fuel\_economy\,(L/100km) = \left[0.43 * \frac{Fuel\_consumed\,(1) + Fuel\_consumed\,(2)}{Distance(1) + Distance(2)} + 0.57 * \frac{Fuel\_consumed\,(3) + Fuel\_consumed\,(2)}{Distance(3) + Distance(2)} \right]$$

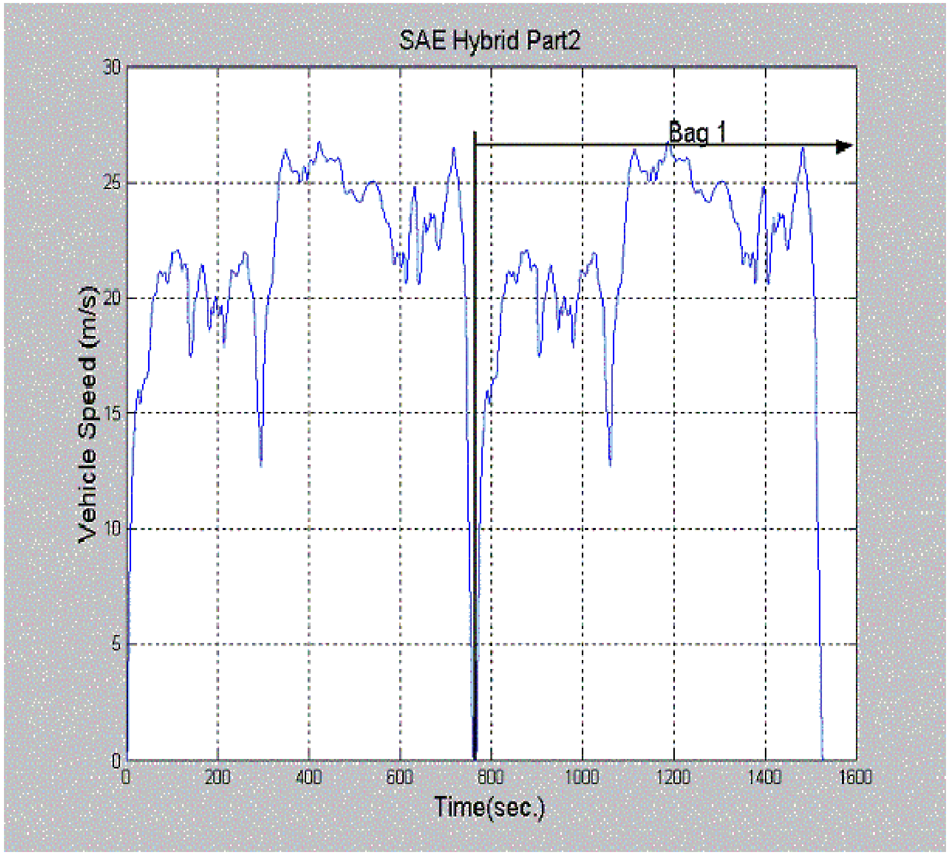
Urban Cycle – FTP75 – Option #2



For hybrid vehicles, because of SOC issues, two consecutive FUDS are performed.

$$Fuel\_economy(L/100km) = \left[0.43 * \frac{Fuel\_consumed(1) + Fuel\_consumed(2)}{Distance(1) + Distance(2)} + 0.57 * \frac{Fuel\_consumed(3) + Fuel\_consumed(4)}{Distance(3) + Distance(4)} \right]$$

Highway Cycle



For conventional, battery and fuel cell electric vehicles, one single highway cycle.
For hybrid configurations, because of SOC issues, two cycles are performed in a row.

J1711 Procedure & Stickers

- The combined fuel economy (FTP75 and Highway cycles) is calculated as follow:

$$Fuel\_economy(L/100km) = 0.55 * Fuel\_economy\_FTP75 + 0.45 * Fuel\_economy\_Highway$$

$$OR$$

$$Fuel\_economy(mpg) = \frac{1}{\frac{0.55}{Fuel\_economy\_FTP75(mpg)} + \frac{0.45}{Fuel\_economy\_highway(mpg)}}$$

- When running a J1711 procedure for hybrid vehicles, it is important to notice that the SOCinit of the highway cycle is the SOCfinal of the FTP75.

J1711 Procedure & Stickers

- In addition to the procedure, EPA applies correction factors to represent actual driving. The corrected fuel economy values are calculated as followed:

$$FTP75\_FE\_corrected(mpg) = 0.9 * Fuel\_economy\_FTP75(mpg)$$

$$Highway\_FE\_corrected(mpg) = 0.78 * Fuel\_economy\_highway(mpg)$$

- As of 2008, different ratios are applied to correct the fuel economy:

$$FTP75\_FE\_corrected(mpg) = 1 \big/ (Fuel\_economy\_FTP75(mpg) * 1609.344/3.78541178)$$

$$Highway\_FE\_corrected(mpg) = 1 \big/ (0.000308 + 1.4030/Fuel\_economy\_highway(mpg))$$

2 – Performance Tests

- Acceleration
- Gradeability

Acceleration tests

- The acceleration test consists in asking each component to provide its maximum torque (PWM=1).
- The gear ratio are defined using the maximum engine torque curve: if the maximum engine torque at gear+1 is higher than for the actual gear, we will shift.
- Even if the engine idling speed is set higher that for fuel consumption cycles, we do not pre-load the engine (clutch is still open when we start accelerating).
- The time to shift a gear is faster than for consumption cycles.

Gradeability tests

- In order to determine the maximum sustainable grade for a predefined vehicle speed, we run several simulations with different grade values until the difference between the lowest value which failed and highest which succeeded is reasonable.

3 – Main post-processing equations

- Thermal calculations
- Electrical calculations
- Powertrain Efficiencies

Thermal Component Calculations

$$Distance\ (m) = \int V_{veh}\, dt$$

$$Fuel\_economy\ (L/100\,km) = \frac{Fuel\_consumed\ (L) * 100}{Distance\ (km)}$$

$$Fuel\_consumed\ (L) = \frac{Fuel\_consumed\ (kg) * 1000}{Fuel\_density\ (g/L)}$$

$$Emission\ (g/km) = \int \frac{Emission\ (kg/s) * 1000}{Distance\ (km)} dt$$

The fuel economy gasoline equivalent is used to compare diesel and gasoline from an efficiency point of view.

Thermal Component Calculations

$$Fuel\_economy\_gas\_equiv\,(L/100\,km) = \frac{Equiv\_liters\_of\_gas * 100}{Distance\,(km)}$$

$$Equiv\_liters\_of\_gas\,(L) = \frac{Equiv\_kg\_of\_gas\,(kg) * 1000}{Fuel\_density\_gas\,(g/L)}$$

$$Equiv\_kg\_of\_gas\,(kg) = \frac{Fuel\_heating\_value}{Fuel\_heating\_value\_gas} * Fuel\_consumed\,(kg)$$

The fuel economy gasoline equivalent is used to compare diesel and gasoline from an efficiency point of view.

The default values from EEE EPA Tier II fuel are:

Gasoline density = 0.742 kg/l

Gasoline heating value = 43000000 J/kg

Thermal Component Calculations (cont'd)

$$FE\_hyb\_gas\_equiv(L/100km) = \frac{Equiv\_liters\_of\_gas + Elec\_energy\_consumed / Whperliter / \eta_{ess} / \eta_{charger} / \tilde{\eta}_{eng}}{Distance(km) / 100}$$

$$\tilde{\eta}_{eng} = \frac{Mecanical\_energy}{Thermal\_energy} = \frac{\int Teng * Weng \, dt}{Fuel\_consumed\ (kg) * Fuel\_heating\_value} ...for...engine$$

$$FE\_student\_gas\_equiv(L/100km) = \frac{Equiv\_liters\_of\_gas + Elec\_energy\_consumed / Whperliter / \eta_{ess} / \eta_{charger} / 0.3727}{Distance(km) / 100}$$

$$\tilde{\eta}_{fc} = \frac{Mecanical\_energy}{Thermal\_energy} = \frac{\int P_{fc} dt}{Fuel\_consumed(kg) * Fuel\_heating\_value} ...for...fuelcell$$

The hybrid and student competition gasoline equivalent values are used to estimate the fuel economy when the battery SOCfinal=SOCinitial.
This calculation can be considered as an alternative to SOC correction algorithms.

Electrical Component Calculations

$$Elec\_energy\_consumed(Ws) = \int Pess\,\mathrm{dt}$$

$$Electrical\_consumption(Ws/m) = \frac{Elec\_energy\_consumed(Ws)}{Distance(m)}$$

Combined Component Calculations

Student competition offboard

$$Fuel\_economy(l/m) = \frac{Equiv\_liter\_gas + \int Ess\_curr\, dt * <Voc> / \eta_{ess\_chg} / \eta_{ess\_offboard\_ch} / Wsperliter}{Distance}$$

$$with: \eta_{ess\_chg} = 0.9; \eta_{ess\_offboard\_ch} = 0.4; Wsperliter = 3.1626e7 (or 33255 Wh/gal)$$

Student competition onboard

$$Fuel\_economy(l/m) = \frac{Equiv\_liter\_gas + \int Ess\_curr\, dt * <Voc> / \eta_{ess\_onboard\_ch} / Wsperliter}{Distance}$$

$$with: \eta_{ess\_onboard\_ch} = 0.25$$

Specific Component Calculations

$$Weight\_specific\_fuel\_consumption(L/T/100km) = \frac{Fuel\_economy(L/100km)}{Mass\_vehicle/1000}$$

$$Fuel\_economy(Gal/100miles) = \frac{Fuel\_economy(L/100km) * liters\_2\_gal}{km\_2\_miles}$$

$$Weight\_specific\_fuel\_consumption(Gal/T/100miles) = \frac{Fuel\_economy(Gal/100miles)}{Mass\_vehicle/1000}$$

$$Mass\_fuel\_320\_miles(kg) = \frac{Fuel\_consumed(kg)}{Distance(miles)} * 320$$

Specific Component Calculations

$$Weight\_specific\_fuel\_consumption(L/T/100km) = \frac{Fuel\_economy(L/100km)}{Mass\_vehicle/1000}$$

$$Weight\_specific\_fuel\_consumption(Gal/T/100miles) = \frac{Fuel\_economy(Gal/100miles)}{Mass\_vehicle/1000}$$

$$Fuel\_economy(Gal/100miles) = \frac{Fuel\_economy(L/100km) * liters\_2\_gal}{km\_2\_miles}$$

$$Mass\_fuel\_320\_miles(kg) = \frac{Fuel\_consumed\,(kg)}{Distance\,(miles)} * 320$$

Powertrain Efficiencies Calculations

$$Eff\_pwt\_conv = \frac{Energy\_wh\_out - Energy\_ess\_out}{Energy\_eng\_in + Energy\_ess\_in} = \frac{\int Pwh\_in*(Pwh\_in>0)\,\mathrm{dt} - \int Pess\_out*(Pess\_in<0)\,\mathrm{dt}}{\int Peng\_in\,\mathrm{dt} + \int Pess\_out*(Pess\_in>0)\mathrm{dt}}$$

$$Eff\_pwt\_FC\_EV = \frac{Energy\_wh\_out}{Energy\_fc\_in} = \frac{\int Pwh\_in*(Pwh\_in>0)\,\mathrm{dt}}{\int Pfc\_in\,\mathrm{dt}}$$

$$Eff\_pwt\_Batt\_EV = \frac{Energy\_wh\_out - Energy\_ess\_out}{Energy\_wh\_in + Energy\_esss\_in} = \frac{\int Pwh\_in*(Pwh\_in>0)\,\mathrm{dt} - \int Pess\_out*(Pess\_in<0)\,\mathrm{dt}}{\int Pwh\_in*(Pwh\_in<0)\,\mathrm{dt} + \int Pess\_out*(Pess\_in>0)\,\mathrm{dt}}$$

$$Eff\_pwt\_par\_series\_eng = \frac{Energy\_wh\_out - Energy\_ess\_out}{Energy\_wh\_in + Energy\_eng\_in + Energy\_ess\_in}$$

$$\ldots\ldots\ldots\ldots = \frac{\int Pwh\_in*(Pwh\_in>0)\,\mathrm{dt} - \int Pess\_out*(Pess\_in<0)\,\mathrm{dt}}{\int Pwh\_in*(Pwh\_in<0)\,\mathrm{dt} + \int Peng\_in\,\mathrm{dt} + \int Pess\_out*(Pess\_in>0)\,\mathrm{dt}}$$

$$Eff\_pwt\_series\_fc = \frac{Energy\_wh\_out - Energy\_ess\_out}{Energy\_wh\_in + Energy\_fc\_in + Energy\_ess\_in}$$

$$\ldots\ldots\ldots\ldots = \frac{\int Pwh\_in*(Pwh\_in>0)\,\mathrm{dt} - \int Pess\_out*(Pess\_in<0)\,\mathrm{dt}}{\int Pwh\_in*(Pwh\_in<0)\,\mathrm{dt} + \int Pfc\_in\,\mathrm{dt} + \int Pess\_out*(Pess\_in>0)\,\mathrm{dt}}$$