Impact of Drive Cycle Aggressiveness and Speed on HEVs Fuel Consumption Sensitivity

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Phillip Sharer,
Romain Leydier,
Aymeric Rousseau,
Argonne National Laboratory
Argonne Study Demonstrated HEV’s Have Higher Fuel Consumption Sensitivity to Aggressive Driving

- Many anecdotal reports from HEV owners that in-use fuel economy does not match the US EPA estimates
  - Chassis dynamometer testing
  - 6 vehicles (2 HEVs and 4 conventional)
  - UDDS, HWFET, US06, ATDS
  - Cycle multiplier factor
  - HEV’s higher sensitivity
Cycle Multiplier Factor

![Graph showing vehicle speed (km/h) vs. time (seconds) for different scaling factors. The graph includes lines for Scaling Factor 0.8, Scaling Factor 1.0, and Scaling Factor 1.2. The x-axis represents time in seconds, ranging from 0 to 1400. The y-axis represents vehicle speed in km/h, ranging from 0 to 120.]
Initial Argonne Studied Demonstrated that Prius was More Sensitive
Simulation Study Conducted to Determine the Factors Affecting Sensitivity

- Chose Vehicles
  - Toyota Prius (2004)
- Chose Cycles:
  - UDDS (Urban Dynamometer Driving Schedule - City)
  - HWFET (Highway Fuel Economy Test - Highway)
- Used Argonne’s Powertrain Systems Analysis Toolkit
- Correlated Models with Test Results
- Updated Definition of Sensitivity
Things which Could Make a Big Difference which We Didn’t Look at

- Air Conditioning
- Thermal Behavior
  - Cold Start
  - Elevated Operating Temperatures
- Component Wear and Maintenance
  - Tire Type, Air Pressure
  - Oil Changes
  - Tune ups
- Weather Conditions
- Road Way Conditions
PSAT Drivetrain Models Correlated with Test Results

**Ford Focus**

<table>
<thead>
<tr>
<th>Drive Cycle</th>
<th>APRF Test (L/100 km)</th>
<th>PSAT (L/100km)</th>
<th>Percent Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>UDDS</td>
<td>8.8</td>
<td>8.9</td>
<td>1.1%</td>
</tr>
<tr>
<td>HWFET</td>
<td>6.2</td>
<td>6.2</td>
<td>~0%</td>
</tr>
</tbody>
</table>

**Toyota Prius**

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<tr>
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<th>APRF Test (L/100 km)</th>
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<tbody>
<tr>
<td>UDDS</td>
<td>3.3</td>
<td>3.2</td>
<td>-3.0%</td>
</tr>
<tr>
<td>HWFET</td>
<td>3.5</td>
<td>3.5</td>
<td>~0%</td>
</tr>
<tr>
<td>US06</td>
<td>5.6</td>
<td>5.1</td>
<td>-9.8%</td>
</tr>
<tr>
<td>Japan1015</td>
<td>3.1</td>
<td>3.0</td>
<td>-3.2%</td>
</tr>
<tr>
<td>NEDC</td>
<td>3.4</td>
<td>3.4</td>
<td>~0%</td>
</tr>
</tbody>
</table>
Fuel Economy Trends are Verified

Ford Focus

Test vs Simulation for Ford Focus

Simulation
Test

Fuel Consumption (L/100 km)
Cycle Scaling Factor

Toyota Prius

Test vs Simulation for Toyota Prius

Simulation
Test

Fuel Consumption (L/100 km)
Cycle Scaling Factor
Correlation is Limited by Uncertainty of Tests and Models

Pedal position leads to unexpected engine ON/OFF
Why Update the Definition?

\[
\frac{\Delta E_{\text{Fuel}}}{\Delta \gamma} = \frac{\Delta E_{\text{Load}}}{\Delta \gamma}
\]

Initial Definition

Updated Definition

- Cycle multiplier - systematic way to transform the cycle to vary vehicle Load
- Many other ways to transform the cycle
- \( \frac{\Delta E_{\text{Load}}}{\Delta \gamma} \) mixes in the sensitivity of the cycle to cycle Multiplier
- Drivetrain’s mass sensitivity is a special case (SAE 06 paper)
So, Why is the Prius More Sensitive to Aggressive Driving?

**UDDS**

- \( \Gamma_{Fuel Load} = -1.56 \)
- \( \Gamma_{Fuel Load} = 2.14 \)

**HWFET**

- \( \Gamma_{Fuel Load} = 2.76 \)
- \( \Gamma_{Fuel Load} = 2.69 \)
Powertrain Factors Influencing Sensitivity

- Engine Efficiency
  - High efficiency -> low sensitivity

- Engine Efficiency Rate of Change
  - Increased efficiency with increased load -> low sensitivity
  - Decreased efficiency with decreased load -> low sensitivity

- Regenerative Braking
  - Any regenerative braking -> lowers sensitivity
  - Saturated regenerative braking -> lowers sensitivity
High Engine Efficiency Makes the Prius Less Sensitive to Aggressive Driving than the Focus

Ford Focus

Toyota Prius
Slow Rate of Change of the Engine Efficiency Makes the Prius More Sensitive to Aggressive Driving than the Focus
Regenerative Braking Makes the Prius Less Sensitive to Aggressive Driving than the Focus
Focus Engine Becomes More Efficient During Aggressive Driving Offsetting the Increase in Demand

- Prius Engine Efficiency > Focus Engine Efficiency
  - = Prius Less Sensitive
- Prius Change in Engine Efficiency < Focus Change in Engine Efficiency
  - = Prius More Sensitive
- Prius Regenerative Braking
  - = Prius Less Sensitive
The Change in Engine Efficiency is the Dominant Effect

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<tbody>
<tr>
<td></td>
<td>Focus</td>
<td>Prius</td>
<td>Focus</td>
<td>Prius</td>
</tr>
<tr>
<td>Engine Peak Efficiency</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Engine Efficiency Variation</td>
<td>---</td>
<td>0</td>
<td>--</td>
<td>-</td>
</tr>
<tr>
<td>Regenerative Energy</td>
<td>NA</td>
<td>-</td>
<td>NA</td>
<td>0</td>
</tr>
</tbody>
</table>

+ indicates increase in sensitivity
- indicates decrease in sensitivity
0 no effect on sensitivity
NA not applicable
Prius More Sensitive on the UDDS than Focus But Similar on HWFET

- For the conventional Focus, an increase in engine efficiency when the drive cycle became more aggressive leads to a decrease in sensitivity.
- For the HWFET driving cycle, both conventional and HEV vehicles behave similarly as a result of the high vehicle speed and the low regenerative braking and vehicle stop events.
- Main factors thermal effects, air conditioning, accessory load.

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