Vehicle Mass Impact on Vehicle Losses and Fuel Economy

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Idaho National Laboratory
Advanced Vehicle Testing Activity (AVTA)

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This presentation does not contain any proprietary, confidential, or otherwise restricted information
Overview

Timeline

• FY11 – Project planning, Vehicle procurement, test plan preparation
• FY12 – Vehicle coastdown testing and dynamometer fuel economy and energy consumption testing
• FY13 – Final report written, multiple presentations delivered

Barriers

• A change in vehicle mass changes the energy consumption; Is this change the same for all vehicle technologies?
• Difficult to isolate mass impact from other factors (aerodynamic change from ride height change, vehicle fuel economy repeatability, etc)
• Maintaining environmental conditions repeatability during coastdown testing

Budget

• FY12 – $ 250,000
• FY13 – $ 75,000

Partners

• Idaho National Lab - lead
• ECOtality North America – coastdown testing
• Argonne National Lab – dynamometer testing

Jointly funded by Vehicle Systems and Materials Technology Teams
Objective / Relevance

• Determine for BEV, HEV and ICE the Impact of Vehicle Mass on:
  – Vehicle drag forces
  – Vehicle fuel economy or energy consumption (MPG and Wh/mi)
• Technology dependence of Mass Impact (HEV to ICE to BEV)
  – i.e. is mass reduction more beneficial for certain technologies?
• Share results of study with DOE, Tech Teams, OEMs, etc.
Approach

• Three vehicle tested (BEV, HEV, and ICE)
  – Nissan Leaf
  – Ford Fusion Hybrid
  – Ford Fusion V6

• Multiple test weights tested for each vehicle
  – Increase and decrease from stock weight (EPA certification weight)

• On test track, coastdown testing is conducted to determine the impact of mass change on vehicle drag forces

• Road load coefficients determined from coastdown testing are used to configure the chassis dynamometer

• Chassis dynamometer testing is conducted over standardized drive cycles to determine the impact of mass change on vehicle fuel economy and energy consumption (MPG and Wh/mi)
Approach - Coastdown Testing (ECOtality)

- For each vehicle, at each test weight
  - 14 coastdowns conducted to reduce sensitivity to external variables
    - 7 in each direction to nullify any track grade variability
    - Wind, ambient temp, and humidity limits strictly adhered to
- To reduce testing variability
  - Vehicle warmed up for 30 min. prior to testing
  - Ride height is held to a small tolerance at the various vehicle test weights
  - Temperatures monitored and recorded to ensure vehicle is functioning at steady state operating conditions
    - Transmission fluid temperature
    - Tire side wall temperature (non-contact temperature sensor)
  - Consistency between coastdown and dynamometer testing
    - Same vehicle operating mode utilized
    - Same three vehicles are used for all testing

<table>
<thead>
<tr>
<th></th>
<th>Fusion ICE (V6)</th>
<th>Fusion HEV</th>
<th>Leaf BEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>+500 lbs</td>
<td>4250</td>
<td>4500</td>
<td>4250</td>
</tr>
<tr>
<td>+250 lbs</td>
<td>4000</td>
<td>4250</td>
<td>4000</td>
</tr>
<tr>
<td>EPA cert. weight</td>
<td>3750</td>
<td>4000</td>
<td>3750</td>
</tr>
<tr>
<td>-100 lbs</td>
<td>3650</td>
<td>3900</td>
<td>3650</td>
</tr>
<tr>
<td>-250 lbs</td>
<td>3500</td>
<td>3750</td>
<td>3500</td>
</tr>
</tbody>
</table>
Approach - Chassis Dynamometer Testing (Argonne)

- For each vehicle, at each test weight
  - Standardized drive cycles used for dynamometer testing
    - UDDS
    - HWFET
    - US06
- To reduce testing variability
  - Vehicle warmed up per dynamometer test procedures prior to testing
  - Same dynamometer driver for all tests
  - Temperatures monitored and recorded to ensure vehicle is functioning at same steady state operating conditions as on test track
    - Transmission fluid temperature
    - Tire side wall temperature (non-contact temperature sensor)
- Consistency between coastdown and dynamometer testing
  - Same vehicle operating mode utilized
  - Same three vehicles are used for all testing
Milestones

- Aug 2011 – Project planning and test plan complete
- Nov 2011 – Vehicles acquired and break-in miles accumulated
- Jan 2012 – Coastdown testing complete
- Feb 2012 – Analysis of coastdown data complete
- May 2012 – Chassis Dynamometer testing complete
- Nov 2012 – Results presentations to Vehicle Systems & Analysis Tech Team (VSATT) and Materials Tech Team (MTT)
- Jan 2013 – Technical paper: 2013 SAE World Congress complete
- Feb 2013 – Technical paper accepted into SAE International Journal of Alternative Powertrains
Technical Accomplishments

- A change in vehicle mass has shown a change in low speed rolling drag but less significant change in high speed drag forces.
Technical Accomplishments (continued)

• Drag forces and vehicle road load are calculated from each coastdown time and the measured mass of the vehicle

• Road load is substantially greater at higher speed (MPH)
  – Mainly due to aerodynamic drag forces

• Slight increase in road load force with respect to increase in mass
  – Most notable at lower speeds
Technical Accomplishments (cont.)

- Overall vehicle road load increases with an increase in vehicle mass.
- Low speed (MPH) vehicle drag force increases slightly greater than high speed drag force.
- The mass impact on vehicle road load appears to be independent of vehicle powertrain technology and shows a slightly non-linear trend.
Technical Accomplishments (cont.)

• Vehicle mass has significant impact on Fuel Consumption and Elec. Energy Consumption for stop & go driving
  – UDDS drive cycle
  – US06 drive cycle
• Vehicle mass has minimal impact on Fuel Consumption and Elec. Energy Consumption for constant speed driving
  – HWFET cycle
Technical Accomplishments (continued)

- Stop & Go style driving (UDDS and US06)
  - 10% to 13% change in mass
  - 2% to 6% change in energy consumption

- Conventional ICE vehicle showed the largest total change in energy consumption

- HEV and BEV significantly less total change in energy consumption due to higher powertrain efficiency
Collaboration

• Results from testing have been shared with US DOE, Tech Teams, OEMs, SAE, and others in support of improving petroleum displacement technologies

Future Work

• Possible investigation of
  • Tire rolling resistance variation
  • Cold temperature impact on road load force and vehicle fuel consumption
Technical Summary

- The light weighting benefits on fuel/energy consumption depends on the driving type.
  - In city type driving and aggressive type driving with many and/or larger accelerations, light weighting any vehicle type will reduce the energy/fuel consumption.
  - In highway type driving where a vehicle will cruise at relative steady speed light weighting vehicles does not significantly reduce the energy/fuel consumption.

- Light weighting a conventional vehicle will provided the largest improvement in fuel consumption due to the relative lower powertrain efficiency compared to a battery electric vehicle.

- This hardware and testing study maintained the powertrain constant or it did not consider benefits of mass compounding which explain the lower benefits of light weighting compared to other studies.

<table>
<thead>
<tr>
<th>Driving type</th>
<th>City [%] consumption reduction</th>
<th>Highway [%]</th>
<th>Aggressive [%]</th>
<th>City [Lge/100km] consumption reduction</th>
<th>Highway</th>
<th>Aggressive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conv. V6</td>
<td>~3.5</td>
<td>~3.0</td>
<td>~4.5</td>
<td>~0.35</td>
<td>~0.19</td>
<td>~0.40</td>
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<tr>
<td>HEV</td>
<td>~2.5</td>
<td>~1.5</td>
<td>~4.0</td>
<td>~0.12</td>
<td>~0.06</td>
<td>~0.19</td>
</tr>
<tr>
<td>BEV</td>
<td>~5.0</td>
<td>~0.1</td>
<td>~2.5</td>
<td>~0.08</td>
<td>~0.01</td>
<td>~0.10</td>
</tr>
</tbody>
</table>

Study Assumptions and limitations:
- Vehicle powertrain remained constant.
- Study does not include mass compounding.
- Results based on single car per category.
- Road load input based on track test data.
- Manufacturer recommended tire pressure maintained for all weight cases per vehicle.
Summary

• Coastdown testing is complete
• Chassis dynamometer testing is complete
• Analysis is complete
• Study findings reported to Tech Teams, OEMs and others
  – Presentation to:
    • Vehicle Systems & Analysis Tech Team
    • Materials Tech Team
  – 2013 SAE World Congress paper
  – SAE International Journal of Alternative Powertrains
Acknowledgement

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More Information

http://avt.inl.gov