Vehicle Mass Impact on Vehicle Losses and Fuel Economy

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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
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>Weight Change</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>
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<td>4000</td>
<td>3750</td>
</tr>
<tr>
<td>-100 lbs</td>
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</tr>
<tr>
<td>-250 lbs</td>
<td>3500</td>
<td>3750</td>
<td>3500</td>
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</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)

<table>
<thead>
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<td>-500 lbs</td>
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</table>
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.

**Graphs:**

- **Ford Fusion V6 Coastdowns**
- **Ford Fusion Hybrid Coastdowns**
- **Nissan Leaf Coastdowns**
- **Ford Fusion V6 Drag Force (lbs)**
- **Ford Fusion Hybrid Drag Force (lbs)**
- **Nissan Leaf Drag Force (lbs)**
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) showed approx. 5% change in energy consumption for 10 to 13% change in mass.

• 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</th>
<th>Highway</th>
<th>Aggressive</th>
<th>City</th>
<th>Highway</th>
<th>Aggressive</th>
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</thead>
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<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>
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<td>~1.5</td>
<td>~4.0</td>
<td>~0.12</td>
<td>~0.06</td>
<td>~0.19</td>
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<td>BEV</td>
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<td>~0.1</td>
<td>~2.5</td>
<td>~0.08</td>
<td>~0.01</td>
<td>~0.10</td>
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</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