Innovation, the NRC 2015 CAFE Report, and the Mid-Term Review

August 20, 2015
Commend the NRC Committee for an Excellent Report, Overall

- Excellent technical discussion and information
  - Technical sections on spark-ignition engine efficiency, advanced combustion systems, supervisory control strategies in hybrid electric vehicles, high-energy batteries, and transmission architectures are particularly illuminating.

- Nice summary of how the use of full-vehicle simulation modeling in combination with lumped parameter modeling has improved the regulatory agencies' estimation of fuel economy impacts, and how tear-down studies have improved cost estimates.

- The relationships between footprint, mass, and safety are clearly surveyed, along with the safety benefits of advanced materials, vehicle design, and crash-avoidance technology.

- Wholeheartedly concur with the committee's recommendation to gather data on real-world fuel economy to assess the gap between real-world fuel economy and certification values.

- Overview of EPA and NHTSA modeling and analyses is a valuable reference.

- Suggestion to use actual weight instead of weight classes is sound.
NRC Lightweighting Costs an Anomaly

- Complete anomaly in an otherwise excellent report
- Started with EDAG study for larger weight reduction – when they were done, “low” costs were x4 and “high” costs x6
Just one example of the problems: Honda Lightweighting “countermeasures”

Scenario 3 – 10 Percent Mass Reduction

The EDAG study resulted in a cost of $0.96/kg ($0.44/lb) for a 22 percent reduction in mass primarily using high-strength steel and aluminum closure panels. Necessary “countermeasures” (from Honda) to accommodate the mass reduction technologies and their additional mass requirements are identified below:

- Subframe safety, 0 kg / 0 lb
- Dashboard crashworthiness, 55.11 lb (25 kg)
- Side impact safety, 22.04 lb (10 kg)
- Rear crash safety, 33.07 lb (15 kg)
- Ride comfort; NVH; handling, 39.68 lb (18 kg)
- Other (miscellaneous), 15.43 lb (7 kg)
- Business conditions (platform parts), 88.18 lb (40 kg)
- Add-back for decompounding, 92.59 lb (42 kg)

Total, 346.13 lb (157 kg)

(346.13 lbs. reinstated by Honda to the EDAG study’s initial 689 lbs.)

Not a “clean sheet design”, but “countermeasures” for EDAG’s design. Examples:
- Added stiffeners and changed specific parts to higher strength, instead of re-optimizing design of all parts
- Increased rear frame strength instead of relocating fuel pipe
- Required commonality between 2011 Civic and Accord parts, not future redesigns
Pre-5-mph bumper standards
5-mph bumper “Countermeasure”
Thus the committee is not able to judge what the net effect would be of addressing Honda’s concerns through clean sheet design.” (Page 6-16)
NRC Lightweighting Costs should be Ignored

- Being charitable, anyone using Honda’s exact countermeasures for vehicles in 2025 doesn’t understand how vehicles are being designed
  - There are two full redesign cycles before 2025. All desired characteristics will be carefully incorporated into full model redesigns – using continuously improving models – instead of using “countermeasures”

- "Implementation of mass reduction techniques can provide several benefits that might be attractive to an OEM." (page 6-10)
All conventional technology forecasts are conservative – not unique to NRC report

Donald Rumsfeld hit the nail on the head, although in a different context:

"there are known knowns; there are things that we know that we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns, the ones we don't know we don't know."
Application to recent studies

- Any credible report assesses the “knowns”
  - 2011 NAS CAFE report was explicit that it only assessed current technology.

- Agencies try to include the “known unknowns”
  - e. g. substantial effort to assess “Learning”

- But the “unknown unknowns” – innovation – are rarely even acknowledged
  - Despite long history of constant technology innovation
The Real Technology Breakthrough

Computers

- Computer design, computer simulations, and on-vehicle computer controls are revolutionizing vehicles and powertrains
- The high losses in the internal combustion engine are an opportunity for improvement
- Transmissions are improving rapidly
- Reducing size and cost of hybrid system
- Especially important for lightweight materials
  - Optimize hundreds of parts – size and material
  - Capture secondary weight – and cost – reductions
2002 NAS CAFE Report Examples

Thorough study with best efforts at technology projections – used by NHTSA for its LDT CAFE rulemakings through 2008

- **Current production turbos have doubled the projected fuel economy increase** – 12-15% versus projected 5-7%
  - Advanced turbos are in development that will double it again
  - Innovations: Improved materials; GDI/turbo synergies, cooled EGR

- **Current 6-speed transmissions cost less than 4-speed**
  - Projected 150-$300 cost increase
  - Innovation: Entirely new design that allows more speeds without any increase in gears and clutches

- **Dual-Clutch Automated Manual completely unanticipated**
  - In wide use by a variety of manufacturers
Innovation not anticipated in 2017-25 rule

- Manufacturers solving longstanding problems with **CVTs**
  - Car share jumped from 15% in 2012 to 26% in 2014
- **48-v hybrids**, with significant benefits at lower cost
  - Audi will put into production next year
- **Engines that exceed forecasted 2025 efficiency**:
  - Mazda’s production SkyActiv engine, 13:1 compression ratio
  - Toyota’s announced expansion of Atkinson cycle engines to conventional vehicles
  - Dedicated-EGR engines, with similar efficiency to current diesel engines – Peugeot announced production plans in 2018
  - 2-step connecting rod – variable compression ratio – FEV & AVL
- High-volume vehicles that already achieve or exceed average projected weight reduction for 2025
  - 2015 Ford F150, 2016 Chevy Cruise
The Committee’s finding in comparing 2014 MY vehicles to the 2008 MY baseline suggests that technologies are more effective than estimated by NHTSA (p. 8-33):

“that the actual fuel consumption reductions based on EPA certification test data meet, and in some cases exceed, the aggregation of NHTSA technology effectiveness estimates.”
How Can Studies Accommodate Innovation?

- They can’t – it’s unknown
- But this is why it is a mistake to analyze only the “known” reasons why technologies might not develop as anticipated
  - Innovation almost always overwhelms this

  “Low” NRC estimates are actually a reasonable midrange
  “High” estimates should not be used
Comments on Mid-Term Review

- EPA/NHTSA/CARB are doing some amazing new work that will improve accuracy and add credibility to the technology projections.

- It’s going to be easier and cheaper to meet the standards than we think.
  - Many paths to compliance.

- Ironically, this is what keeps manufacturers up at night – there are many ways to comply and not much time to figure out the best solutions:
  - What if my competitors figure out a way to meet the standards that costs $1,000 per vehicle less?
Other Consumer Benefits from Technology

- Turbocharging, GDI, FFV, hybrid – low rpm torque
  - F150 buyers aren't spending an extra $595 for the V6 turbo over the V8 in order to improve fuel economy - they want the low-rpm torque.
  - Hybrids provide instant torque response from the electric motor
- 7+ speed transmissions – better acceleration and less noise
- Lightweighting – better acceleration, braking, and handling
  - Ford isn't touting the improved efficiency from the aluminum body on the 2015 F150 as much as the improved acceleration, handling, and braking and the increased payload and towing capacity.
- High-strength steel and aluminum – better crash properties
- Aluminum – does not rust
Background
Turbo Dedicated EGR Engine

- Highly dilute, low temperature combustion
- \( \sim 1\% \text{ H}_2 \) by volume in the intake
- Advanced ignition systems required
- 40-42% brake thermal efficiency (similar to diesel)
- PSA 2018 introduction
Hybrid Cost Reduction

- **Higher-power Li-ion batteries coming**
  - smaller, lighter, lower cost

- **FEV Teardown Cost Studies**
  - 2014 update: Cost of the motor/generator/clutch subsystem dropped 14% in 3 years

- **P2 Hybrid – Integration of motor/transmission**

- **Micro-Hybrids**
  - **Valeo** *(The Battery Show 9/16/2014)* and Ricardo *(2015 SAE Government/Industry meeting)* are working on 48v micro-hybrid systems and claim they are much more cost effective than full hybrids
EPA: 7% weight reduction in 2025
2015 Ford F150 almost doubles this – 10 years early

Vanguard of a truly radical transformation in how vehicles are designed and built

In the largest selling vehicle in the US

Weight reduction:
318 kg, 14%
Engine downsize:
3.5L to 2.7L

First use of aluminum body in high volume production vehicle

95% of body—Aluminum
77% of frame—HSS

Source: http://www.ford.com/trucks/f150/2015/
GM’s 2016 Chevy Cruze will also double the 2025 assessment – with only 3% aluminum!

**Lightweight Architecture in Steel**
All new global compact architecture – First entry 2015 Chevrolet Cruze

- **Weight reduction:** 15%
- **Torsional stiffness:** +23% (better handling)

**Weight reduction strategies:**
- **High amount of Advanced HSS and Press Hardened Steels**
- **Improved Designs: Thin metal strategy**
- C-shape front rail (from U-shape)
- **Loadpath strategy**

<table>
<thead>
<tr>
<th>Material</th>
<th>Previous</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild steel</td>
<td>42%</td>
<td>25%</td>
</tr>
<tr>
<td>High strength steel</td>
<td>41%</td>
<td>35%</td>
</tr>
<tr>
<td>Advanced HSS &amp; dual-phase steel</td>
<td>14%</td>
<td>19%</td>
</tr>
<tr>
<td>Press hardened steel</td>
<td>3%</td>
<td>18%</td>
</tr>
<tr>
<td>Aluminum</td>
<td></td>
<td>3%</td>
</tr>
</tbody>
</table>

THE ALL NEW COMPACT ARCHITECTURE, K.P.Eckhardt & M.Küpper, Opel – Aachen Body Engineering Days, 9-24-2014
## Examples of lightweight vehicles in production

<table>
<thead>
<tr>
<th>Vehicle make</th>
<th>Model year</th>
<th>Weight reduction (kg)*</th>
<th>Weight reduction (%)*</th>
<th>Designed market</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ford F150</td>
<td>2015</td>
<td>318</td>
<td>14%</td>
<td>US</td>
</tr>
<tr>
<td>Acura MDX</td>
<td>2014</td>
<td>111</td>
<td>5%</td>
<td>US</td>
</tr>
<tr>
<td>GM Cadillac CTS</td>
<td>2014</td>
<td>111</td>
<td>6%</td>
<td>US</td>
</tr>
<tr>
<td>Peugeot 308 SW Blue Hdi</td>
<td>2014</td>
<td>140</td>
<td>9%</td>
<td>EU</td>
</tr>
<tr>
<td>VW Golf TDI</td>
<td>2015</td>
<td>49</td>
<td>4%</td>
<td>EU</td>
</tr>
<tr>
<td>Audi Q7</td>
<td>2014</td>
<td>363</td>
<td>15%</td>
<td>US, EU</td>
</tr>
<tr>
<td>BMW i3 EV</td>
<td>2014</td>
<td>249</td>
<td>17%</td>
<td>US, EU</td>
</tr>
<tr>
<td>Land Rover Range Rover</td>
<td>2014</td>
<td>350</td>
<td>14%</td>
<td>US, EU</td>
</tr>
<tr>
<td>Porsche Cayenne</td>
<td>2012</td>
<td>181</td>
<td>8%</td>
<td>US, EU</td>
</tr>
<tr>
<td>Audi A8</td>
<td>2014</td>
<td>145</td>
<td>7%</td>
<td>US, EU</td>
</tr>
<tr>
<td>Audi A3</td>
<td>2014</td>
<td>80</td>
<td>6%</td>
<td>US, EU</td>
</tr>
<tr>
<td>Nissan Leaf</td>
<td>2012</td>
<td>80</td>
<td>5%</td>
<td>US, EU</td>
</tr>
<tr>
<td>Lamborghini Huracan</td>
<td>2015</td>
<td>78</td>
<td>5%</td>
<td>US, EU</td>
</tr>
<tr>
<td>Audi TT 3rd gen 2.0 TDI</td>
<td>2015</td>
<td>50</td>
<td>4%</td>
<td>US, EU</td>
</tr>
</tbody>
</table>

* The weight of new models are compared to its predecessors, except for BMW i3 EV, which is compared to the conventional steel structure.

CAFE/CO₂ standards: 7% weight reduction in 2025
Lightweighting Process Improvements

- To reinforce the GM strategies, two statements from Peter Reyes, the chief engineer of the revamped F-150 pickup truck:
  - 15 years ago, it took nine months for Ford Motor Co to make two possible designs for a vehicle frame. Now, he can create 100 different examples in that time."
  - “Ford used CAE tools to digitally experiment with more lightweight materials and test those components against "a blizzard of stiffness and strength requirements,"
- These CAE tools are where the real competition is occurring, which means manufacturers will be able to optimize the material, shape, and thickness of every part on every vehicle before 2025. Average weight reductions of 20 to 25% should be easily obtained by 2030.

### Innovation Examples – vs. 2002 NRC Report

<table>
<thead>
<tr>
<th>Technology</th>
<th>Source</th>
<th>Benefit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbo-charging and downsizing (no cyl. reduction)</td>
<td>2001 NRC Report</td>
<td>5-7%</td>
<td>$250-$400</td>
</tr>
<tr>
<td></td>
<td>Draft RIA – 18 bar</td>
<td>12-15%</td>
<td>$342</td>
</tr>
<tr>
<td></td>
<td>Draft RIA – 24 bar</td>
<td>16-20%</td>
<td>$550</td>
</tr>
<tr>
<td></td>
<td>Draft RIA – w/ boosted EGR</td>
<td>20-25%</td>
<td>$967</td>
</tr>
<tr>
<td>4- to 6-speed automatic</td>
<td>2001 NRC Report</td>
<td>3-4%</td>
<td>$150-$300</td>
</tr>
<tr>
<td></td>
<td>Draft RIA</td>
<td>3-4%</td>
<td>($15)</td>
</tr>
<tr>
<td>Automatic to DCT</td>
<td>Draft RIA</td>
<td>4-6%</td>
<td>($154-$223)</td>
</tr>
</tbody>
</table>

- Cost is direct manufacturing cost
- NRC Report is Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards, 2002
- Draft RIA is for NHTSA/EPA proposed standards for 2017-25 light-duty vehicles

Add list of technologies not discussed in 2002
# Accelerating Technology Introduction in the U.S. driven by Fuel Economy Regulation

<table>
<thead>
<tr>
<th>Year</th>
<th>GDI</th>
<th>Turbo</th>
<th>VVT</th>
<th>Stop/Start</th>
<th>Hybrid</th>
<th>6 speed</th>
<th>7+ speed</th>
<th>CVT</th>
</tr>
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<tbody>
<tr>
<td>2004</td>
<td>-</td>
<td>4%</td>
<td>44%</td>
<td>-</td>
<td>0.9%</td>
<td>5%</td>
<td>0.4%</td>
<td>2%</td>
</tr>
<tr>
<td>2005</td>
<td>-</td>
<td>2%</td>
<td>49%</td>
<td>-</td>
<td>1.9%</td>
<td>6%</td>
<td>0.4%</td>
<td>3%</td>
</tr>
<tr>
<td>2006</td>
<td>-</td>
<td>3%</td>
<td>58%</td>
<td>-</td>
<td>1.5%</td>
<td>12%</td>
<td>2%</td>
<td>3%</td>
</tr>
<tr>
<td>2007</td>
<td>-</td>
<td>4%</td>
<td>63%</td>
<td>-</td>
<td>3.2%</td>
<td>16%</td>
<td>2%</td>
<td>10%</td>
</tr>
<tr>
<td>2008</td>
<td>3%</td>
<td>4%</td>
<td>63%</td>
<td>-</td>
<td>3.3%</td>
<td>19%</td>
<td>3%</td>
<td>11%</td>
</tr>
<tr>
<td>2009</td>
<td>4%</td>
<td>4%</td>
<td>79%</td>
<td>-</td>
<td>2.9%</td>
<td>19%</td>
<td>3%</td>
<td>11%</td>
</tr>
<tr>
<td>2010</td>
<td>9%</td>
<td>4%</td>
<td>92%</td>
<td>-</td>
<td>5.5%</td>
<td>33%</td>
<td>3%</td>
<td>14%</td>
</tr>
<tr>
<td>2011</td>
<td>18%</td>
<td>8%</td>
<td>95%</td>
<td>-</td>
<td>3.4%</td>
<td>54%</td>
<td>5%</td>
<td>12%</td>
</tr>
<tr>
<td>2012</td>
<td>28%</td>
<td>10%</td>
<td>98%</td>
<td>0.9%</td>
<td>4.6%</td>
<td>58%</td>
<td>6%</td>
<td>15%</td>
</tr>
<tr>
<td>2013</td>
<td>37%</td>
<td>15%</td>
<td>98%</td>
<td>3.0%</td>
<td>5.3%</td>
<td>60%</td>
<td>8%</td>
<td>18%</td>
</tr>
<tr>
<td>2014</td>
<td>42%</td>
<td>19%</td>
<td>98%</td>
<td>6.2%</td>
<td>6.0%</td>
<td>59%</td>
<td>9%</td>
<td>26%</td>
</tr>
</tbody>
</table>

Source: 2014 EPA Fuel Economy Trends Report – **Cars only**

GDI: Gasoline Direct Injection
CVT: Continuously Variable Transmission – includes hybrid sales
VVT: Variable Valve Timing
Example of Technology Upgrade: High-Selling Passenger Cars 2010 to 2014
Fuel Prices have Little Impact on Standard Stringency
Manufacturers are more Loss/Risk Averse than Consumers

- Mislocating the accelerator pedal by < 1 inch cost Toyota billions of dollars
- What if consumers don’t accept technology?
  - Has been consumer dissatisfaction with some early idle stop systems and DCT and CVT transmissions (although some manufacturers did them well)
- What if my technology package to comply with standards costs $3,000 – and my competitor did it for $1,500?
- Manufacturers want to test all options before committing
For more information...

- ICCT Passenger Vehicles website:
  [http://www.theicct.org/passenger-vehicles](http://www.theicct.org/passenger-vehicles)
- Global Passenger Vehicle Standards Update:
- US CAFE Standards:
- EU LDV CO2 Regulation:
- Review and Comparative Analysis of Fiscal Policies to promote fuel economy:
- CO2 Standards:
  [http://www.theicct.org/issues/co2-standards](http://www.theicct.org/issues/co2-standards)