Fleet Safety Evaluation Methodology: Application to Lightweight Vehicle Designs

Stephen Ridella
Office of Vehicle Crashworthiness Research
Mass-Size-Safety Symposium
May 13, 2013
Presentation Agenda

- Goals of the Study
- Field Crash Assessment
- Computer Simulation Approach
- Injury Assessment
- Modeling Results
- Societal Injury Risk
- Conclusions
Fleet Crash Simulation Goals

• Utilize new and existing vehicle crash models to evaluate safety of future light-weighted vehicles
  – Vehicle-to-vehicle and vehicle-to-structure crashes
    • Belted occupants only
  – Non-Regulated, non-standard crash conditions
    • Vehicle speeds from 15mph – 40 mph;
    • Represent real world crash conditions and risk of occurrence
  – Interaction between light-weighted and existing vehicles
  – Evaluate opportunities for countermeasures
    • Potentially different air-bag deployment timing for light-weighted vehicles
    • Adaptive occupant restraint systems
2009 US Traffic Fatalities

- Light Vehicles
  - V to V
  - V to Object
  - No Rollover
  - Only light passenger vehicles

- 31.86% of 2009 fatal crashes
Fatal Crashes by Initial Point of Impact

Frontal crashes represent 50.9% of fatal, non-rollover crashes, 1 or 2 vehicle crashes

Study evaluates 16.2% (50.9% of the 31.86%) of 2009 fatalities, or 5,482 2009 fatal crashes

MY1998+, planar non-rollover crashes with restrained occupants
Barrier Equivalent Speed

Speeds are broken out by vehicle type and crash configuration

Selected BES instead of NASS Delta V due to increased reporting 68% vs 59%

Simulation speeds were limited to 64 kph

NASS/CDS 1998-2009 – MAIS 3+F Injury Risk by Vehicle Class and Barrier Equivalent Speed (weighted)
Fleet Vehicle Models

4 existing full vehicle FEA models will be used to represent the fleet.

Each model was evaluated against available test data.

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Different versions validated to frontal NCAP, side NCAP, IIHS ODB, and roof crush tests</td>
<td>Validated to frontal NCAP</td>
<td>Validated to frontal NCAP test</td>
<td>Validated to frontal NCAP</td>
</tr>
<tr>
<td></td>
<td>Model includes vehicle interior components</td>
<td>Interior components available but not included</td>
<td>Interior digitized but not yet incorporated in the model</td>
<td>Expected frontal NCAP validation</td>
</tr>
</tbody>
</table>
Baseline and lightweight vehicle FEA models were developed in support of the 2017-2025 CAFE rule

Variations of Taurus model were developed to evaluate methodology

<table>
<thead>
<tr>
<th>Weight (kg)</th>
<th>Taurus</th>
<th>Venza</th>
<th>Accord</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>LW3</td>
<td>LW4</td>
</tr>
<tr>
<td>weight (kg)</td>
<td>1515</td>
<td>1138</td>
<td>1515</td>
</tr>
<tr>
<td>weight (lb)</td>
<td>3339</td>
<td><strong>2508</strong></td>
<td>3339</td>
</tr>
</tbody>
</table>
Taurus Model Variations

- Alternative models developed to evaluate methodology
  - LW3: 25% lightweight, same stiffness
  - LW4: same weight, increased stiffness

35 mph barrier results

http://www.ncac.gwu.edu/vml/models.html
Venza FEA Models

- FEV \ EDAG models
  - Venza baseline
  - Venza Low Option, 18% lightweight
- Lotus Engineering Model
  - Venza High Option, 31% lightweight

FEV Venza FEA at http://www.epa.gov/otaq/climate/solutions-vehicle.htm
Accord Model

- Electricore \ EDAG developed the lightweight Honda Accord Model

- Baseline Accord FEA model was leased for this project
  - Only LS-Dyna simulation output available to NHTSA

Fleet Simulation Overview

FEM Simulation

MADYMO Simulation

compartment crash pulse

HIC15 Chest Deflection Femur Load

Probability of AIS+ (%) vs. Chest Deflection (mm)

AIS3=
R_{head}
R_{chest}
R_{lower-ext}
**Simulation Matrix**

<table>
<thead>
<tr>
<th>Speed (mph)</th>
<th>Crash Partner</th>
<th>Crash Type Configuration</th>
<th>Occupant Sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>Fixed Object</td>
<td>Full Engagement</td>
<td>Midsize Male (Target)</td>
</tr>
<tr>
<td>20</td>
<td>Fixed Object</td>
<td>% Offset</td>
<td>Small Female (Target)</td>
</tr>
<tr>
<td>25</td>
<td>Vehicle</td>
<td>Center 10” Pole</td>
<td>Midsize Male (Partner)</td>
</tr>
<tr>
<td>30</td>
<td>Vehicle</td>
<td>Full Engagement</td>
<td>Midsize Male (Target)</td>
</tr>
<tr>
<td>35</td>
<td>Vehicle</td>
<td>% Offset</td>
<td>Small Female (Partner)</td>
</tr>
<tr>
<td>40</td>
<td>Vehicle</td>
<td>Full Engagement</td>
<td>Small Female (Target)</td>
</tr>
</tbody>
</table>

\[
AccIR(s) = \sum_{i=1}^{m=6\text{Speeds}} \sum_{j=1}^{n=5\text{Speeds}} \sum_{k=1}^{m=3\text{CrashTypes}} \sum_{l=1}^{m=4\text{OccupantTypes}} W_i(s) * \max [R_{ijkl}^{AIS3+}(s)]
\]
Finite Element Simulations

• Single-vehicle crash simulations:
  – 120 LS-DYNA runs
  – 240 MADYMO runs

• Two-vehicle crash simulations:
  – 320 LS-DYNA runs
  – 1280 MADYMO runs
MADYMO Occupant Simulations

- FEA acceleration for each Vehicle / speed / crash mode
- Toepan & Instrument Panel intrusion driven by FEA output
Injury Risk Computation

• NCAP Injury Risk functions
  – Separate risk functions for 50\textsuperscript{th} male and 5\textsuperscript{th} female
  – AIS 3+ risk Head, chest, neck, and femur

• 3 methods for combining injury risks
  – Head, Neck, Chest, & Femur
  – Head, Neck & Chest
  – Head, Neck, Chest, and intrusion penalty function
Combined Injury Risk

Each impact simulated at five speeds

- Target Full Frontal
- Target Offset Frontal
- Target Centerline Pole

**Single Vehicle (SV) Crash Configurations**

- CIR I (Combined Injury Risk Head, Neck, Chest & Knee-Thigh-Hip)
- CIR II (Head, Chest & Neck)
- CIR IIP (with A-pillar Intrusion Penalty)

**Vehicle to Vehicle (VTV) Crash Configurations**

- Target to Explorer Full
- Target to Explorer Offset
- Target to Silverado Full
- Target to Silverado Offset
- Target to Yaris Full
- Target to Yaris Offset
- Target to Taurus Full
- Target to Taurus Offset

- Target CIR I (Combined Injury Risk Head, Neck, Chest & Knee-Thigh-Hip)
- Target CIR II (Head, Chest & Neck)
- Target CIR IIP (with A-pillar Intrusion Penalty)
- Partner CIR I (Combined Injury Risk Head, Neck, Chest & Knee-Thigh-Hip)
- Partner CIR II (Head, Chest & Neck)
• Increased risk for LW vehicles at most speeds
• 5th female has higher risk
• V to V Injury risk evaluated by crash mode, partner & speed
• Risk at high speeds from femur injury risk – not representative

Alternate combined injury measures used to evaluate model sensitivity
Individual crash risks combined with the risk of crash occurring to get overall crash injury risk

Result reflects Societal Risk

Comparison between lightweight and baseline risk to identify safety considerations
Risks were computed separately for 50\textsuperscript{th} and 5\textsuperscript{th} occupants.

Baseline NASS injury risk is 1.25\% to 1.56\% for studied crashes.
## Societal Risk – Frontal Crashes

<table>
<thead>
<tr>
<th>Target Vehicle</th>
<th>Taurus Baseline</th>
<th>LW3</th>
<th>LW4</th>
<th>Accord Baseline</th>
<th>Accord LW</th>
<th>Venza Baseline</th>
<th>Venza Low Option</th>
<th>Venza High Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (lbs)</td>
<td>3339</td>
<td>2508</td>
<td>3339</td>
<td>3681</td>
<td>2964</td>
<td>3980</td>
<td>3313</td>
<td>2537</td>
</tr>
<tr>
<td>% mass reduction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Societal Risk I</td>
<td>1.25%</td>
<td>1.41%</td>
<td>1.48%</td>
<td>1.56%</td>
<td>1.73%</td>
<td>1.36%</td>
<td>1.43%</td>
<td>1.57%</td>
</tr>
<tr>
<td>Risk Increase</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Societal Risk II</td>
<td>1.01%</td>
<td>1.14%</td>
<td>1.22%</td>
<td>1.43%</td>
<td>1.57%</td>
<td>1.14%</td>
<td>1.20%</td>
<td>1.30%</td>
</tr>
<tr>
<td>Risk Increase</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Societal Risk IIP</td>
<td>1.01%</td>
<td>1.16%</td>
<td>1.23%</td>
<td>1.44%</td>
<td>1.59%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk Increase</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14%</td>
<td>21%</td>
<td>10%</td>
</tr>
</tbody>
</table>

- **Societal Risk I - Target + Partner Combined AIS3+ risk of Head, Neck, Chest & Femur**
- **Societal Risk II - Target + Partner Combined AIS3+ risk of Head, Neck, and Chest**
- **Societal Risk IIP - Target + Partner Combined AIS3+ risk of Head, Neck, and Chest with A-Pillar Intrusion Penalty**
Conclusions

• Methodology successfully evaluated vehicle designs for a range of crash configurations and speeds.
  – Results are sensitive to vehicle interior and occupant modeling.
  – Additional refinement of occupant models.

• Evaluate mass and stiffness changes independently.
  – Both factors affect safety risk.

• Highlight importance of crash safety at speeds lower than the regulatory and consumer information testing.

• Self and partner protection in two-vehicle crashes
Future Fleet Safety Research

• Incorporate steering column and A-pillar intrusion into occupant model.
• Evaluate advanced occupant restraints.
• Additional vehicle types for fleet study.
• Improve correlation between fleet model and real world crash data.
• Combine the occupant and the vehicle structure in the same simulation environment.
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