Lighter and Safer Cars by Design

May 2013
DRI Compatibility Study (2008)

- Modern vehicle designs - generally good into fixed barriers
  - irrespective of vehicle type or material

- Safety discussion is really about vehicle compatibility
  - How much energy must be dissipated
  - How each vehicle decelerates

- Compatibility study - Dynamic Research Inc. (DRI)
  - SUV in moderately severe collisions
    - Cars, other SUVs, fixed obstacles
    - 3,500 collisions, using NCAP “pulses” and NASS/CDS descriptors
  - Investigate injury index (ELU)
    - SUV lighter or larger
    - Reduce ELU
## DRI Compatibility Study

Baseline: Conventional SUV with Conventional Passenger Car and LTV

<table>
<thead>
<tr>
<th>Crash Type</th>
<th>Number of Cases</th>
<th>Total ELU's</th>
<th>Net Benefit (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Baseline Case SUV</td>
<td>Reduced Weight Case SUV</td>
</tr>
<tr>
<td>Rollover</td>
<td>175</td>
<td>2.23</td>
<td>2.48</td>
</tr>
<tr>
<td>Hit Object</td>
<td>420</td>
<td>2.54</td>
<td>1.74</td>
</tr>
<tr>
<td>Hit PC</td>
<td>1750</td>
<td>1.21</td>
<td>2.47</td>
</tr>
<tr>
<td>Hit LTV</td>
<td>1155</td>
<td>25.97</td>
<td>34.02</td>
</tr>
<tr>
<td>Subtotal</td>
<td>3500</td>
<td>31.95</td>
<td>40.71</td>
</tr>
<tr>
<td>In PC</td>
<td>1750</td>
<td>28.00</td>
<td>9.70</td>
</tr>
<tr>
<td>In LTV</td>
<td>1155</td>
<td>25.99</td>
<td>11.28</td>
</tr>
<tr>
<td>Subtotal</td>
<td>2905</td>
<td>53.99</td>
<td>20.98</td>
</tr>
<tr>
<td>Overall</td>
<td>3500 SUV + 2905 OV</td>
<td>85.94</td>
<td>61.69</td>
</tr>
</tbody>
</table>
## DRI Compatibility Study

20% Reduced Weight SUV (Single Vehicle) into Conventional Fleet

<table>
<thead>
<tr>
<th>Crash Type</th>
<th>Number of Cases</th>
<th>Baseline Case SUV</th>
<th>Reduced Weight Case SUV</th>
<th>Increased Length Case SUV</th>
<th>Net Benefit (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Reduced Weight Case SUV</td>
<td>Increased Length Case SUV</td>
<td>Reduced Weight Case SUV</td>
</tr>
<tr>
<td>Rollover</td>
<td>175</td>
<td>2.23</td>
<td>2.48</td>
<td>0.53</td>
<td>-11.2</td>
</tr>
<tr>
<td>Hit Object</td>
<td>420</td>
<td>2.54</td>
<td>1.74</td>
<td>0.81</td>
<td>31.5</td>
</tr>
<tr>
<td>Hit PC</td>
<td>1750</td>
<td>1.21</td>
<td>2.47</td>
<td>1.19</td>
<td>-104.1</td>
</tr>
<tr>
<td>Hit LTV</td>
<td>1155</td>
<td>25.97</td>
<td>34.02</td>
<td>26.27</td>
<td>-31.0</td>
</tr>
<tr>
<td>Subtotal</td>
<td>3500</td>
<td>31.95</td>
<td>40.71</td>
<td>28.80</td>
<td>-27.4</td>
</tr>
</tbody>
</table>

### Overall Total

<table>
<thead>
<tr>
<th>Crash Type</th>
<th>Number of Cases</th>
<th>Baseline Case SUV</th>
<th>Reduced Weight Case SUV</th>
<th>Increased Length Case SUV</th>
<th>Net Benefit (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Reduced Weight Case SUV</td>
<td>Increased Length Case SUV</td>
<td>Reduced Weight Case SUV</td>
</tr>
<tr>
<td>In PC</td>
<td>1750</td>
<td>28.00</td>
<td>9.70</td>
<td>16.79</td>
<td>65.4</td>
</tr>
<tr>
<td>In LTV</td>
<td>1155</td>
<td>25.99</td>
<td>11.28</td>
<td>19.59</td>
<td>56.6</td>
</tr>
<tr>
<td>Subtotal</td>
<td>2905</td>
<td>53.99</td>
<td>20.98</td>
<td>36.38</td>
<td>61.1</td>
</tr>
</tbody>
</table>

| Overall Total | 3500 SUV + 2905 OV | 85.94 | 61.69 | 65.18 | 28.2 | 24.2 |
DRI Compatibility Study

Increased Length (4.5") SUV (Single Vehicle) into Conventional Fleet

<table>
<thead>
<tr>
<th>Crash Type</th>
<th>Number of Cases</th>
<th>Baseline Case SUV</th>
<th>Reduced Weight Case SUV</th>
<th>Increased Length Case SUV</th>
<th>Net Benefit (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Reduced Weight</td>
</tr>
<tr>
<td>SUV Driver</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Case SUV</td>
</tr>
<tr>
<td>Rollover</td>
<td>175</td>
<td>2.23</td>
<td>2.48</td>
<td>0.53</td>
<td>-11.2</td>
</tr>
<tr>
<td>Hit Object</td>
<td>420</td>
<td>2.54</td>
<td>1.74</td>
<td>0.81</td>
<td>31.5</td>
</tr>
<tr>
<td>Hit PC</td>
<td>1750</td>
<td>1.21</td>
<td>2.47</td>
<td>1.19</td>
<td>-104.1</td>
</tr>
<tr>
<td>Hit LTV</td>
<td>1155</td>
<td>25.97</td>
<td>34.02</td>
<td>26.27</td>
<td>-31.0</td>
</tr>
<tr>
<td>Subtotal</td>
<td>3500</td>
<td>31.95</td>
<td>40.71</td>
<td>28.80</td>
<td>-27.4</td>
</tr>
<tr>
<td>OV Driver</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In PC</td>
<td>1750</td>
<td>28.00</td>
<td>9.70</td>
<td>16.79</td>
<td>65.4</td>
</tr>
<tr>
<td>In LTV</td>
<td>1155</td>
<td>25.99</td>
<td>11.28</td>
<td>19.59</td>
<td>56.6</td>
</tr>
<tr>
<td>Subtotal</td>
<td>2905</td>
<td>53.99</td>
<td>20.98</td>
<td>36.38</td>
<td>61.1</td>
</tr>
<tr>
<td>Overall Total</td>
<td>3500 SUV +</td>
<td>85.94</td>
<td>61.69</td>
<td>65.18</td>
<td>28.2</td>
</tr>
<tr>
<td></td>
<td>2905 OV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Lighter and Safer Cars by Design

DRI Compatibility Study Findings:

- Reduced mass or Length
  Reduced fleet ELU’s

- Mass (-20%)
  Fleet ELU’s reduced 28%
  Reduced struck vehicle ECU’s 61%
  Some increase in Lt. vehicle ELU’s

- Length (Design) (+4 inch)
  Fleet ELU’s reduced 24%
  Reduced longer vehicle driver ECU’s by 10%
  Reduced struck vehicle ECU’s 33%

Note: Observations are directional not absolute
STIFFNESS RELEVANCE AND STRENGTH RELEVANCE IN CRASH OF CAR BODY COMPONENTS

Official report 83440 by ika
May 2010
Light-weighting Potential of High-Strength Steel and Aluminum

• University of Aachen ika (Germany)
  • Mid-size European Sedan

• Objective
  – Maximum auto body weight saving potential
    • Steel
    • Aluminum

Source: ika - University of Aachen and the European Aluminium Association (EAA)
Analytical Analysis

• Objective
  – Maximum auto body weight saving potential

• Methodology
  – Model body - classify components (strength or stiffness limited)
    • NVH
    • Collision performance (index: intrusion)
  – Optimize body components – material, grade, gauge
    • High-strength steel grades (including ultra high-strength steel)
    • Aluminum alloys
26 Components for Quantitative Evaluation

1. Sidewall
2. Roof Crossmember
3. Roofrail
4. IP Crossmember
5. Cowl
6. Strut Tower Front
7. Longitudinal Upper
8. Longitudinal Front
9. Crash Management System
10. Firewall
11. A-Pillar
12. Roof
13. Rearwall
14. Strut Tower Rear
15. Floor
16. Longitudinal Rear
17. C-Pillar
18. B-Pillar
19. Crossmember Rear
20. Crossmember Floor
21. Sill
22. Tunnel
23. Door Panels (outer + inner)
24. Door Frame
25. Door Crash Management
26. Door Hinge Reinforcement

Source: ika - University of Aachen and the European Aluminium Association (EAA)
Stiffness Load Cases

Static Torsional Stiffness

Evaluation:
Torsional stiffness calculated from deflection of evaluation point on front longitudinal

Static Bending Stiffness

Evaluation:
Bending stiffness calculated from maximum deflection of bending lines (generally sill)

Source: ika - University of Aachen and the European Aluminium Association (EAA)
Strength Load Cases

Evaluated Using European and U.S. Crash Standards

- **Euro NCAP Front Crash**
  - Velocity 64 km/h
  - EEVC deformable barrier
  - 40% offset

- **Euro NCAP Side Crash**
  - Velocity 50 km/h
  - EEVC moving deformable barrier

- **FMVSS 301 Rear Crash**
  - Velocity 48 km/h
  - Rigid moving barrier
  - 0% offset

- **Euro NCAP Front Crash**
  - Velocity 64 km/h
  - EEVC deformable barrier
  - 40% offset

*Source: ika - University of Aachen and the European Aluminium Association (EAA)*
Light-weighting Potential by Material

Source: ika - University of Aachen and the European Aluminium Association (EAA)
Key Findings

• NVH and Safety performance objectives **appear achievable** with reduced mass designs

• Strength not the limiting factor for a majority of body components (Mass)

• **Weight reduction potential**
  – High-strength steel (YS to 1,200 MPa) = ~11%
  – Aluminum (YS to 400 MPa) = ~40%
Objectives:

- Mass Reduction – 20%
- Retain: Size, Functionality, Safety (5 Star), NVH, Performance
- Use proven body structure
- Cost increase < 10%
- Materials and process available and practical 2017

Source: EDAG
Body is Key to Vehicle Mass Reduction

Mid-size SUV (MMV)
Mass Reduction by System

System Mass (Kg)

Body
Interior
Engine
Wht/Tires
Susp.
Trans
Brake
Fram/Mtg
Driveline
Electrical
Exhaust
Fuel syst.
Steering
HAC
Infot.

Mass Reduction

Source: EDAG/EPA
Findings:

- Reduced mass mid-size cross-over SUV appears capable of meeting all design objectives size, functionality, safety, NVH, performance.
- 18% (313 Kg) vehicle mass reduction – (MMV)
  - advanced steel – BIW reduction 14%
  - total body mass reduction 14%
  - aluminum – closures, chassis, suspension, brakes
- Estimated cost impact: - $148 (reduction)

Source: EDAG
Objectives:

- Maximum Mass Reduction – Aluminum Intensive Body
- Retain: Size, Functionality, Safety (5 Star), NVH, Performance
- Use proven body structure
- Cost increase: TBD
- Materials and process available and practical 2017

Source: EDAG
AIV Body Design Process
(NVH and Crash)

Baseline and Alignment of Steel models

Baseline Aluminum NVH BIW

Initial Concept – Aluminum

NVH

Iteration

Collision

Final Concept – Aluminum

© Copyright 2010 EDAG GmbH & Co. KGaA. All rights reserved.
# Mid-size SUV

**Aluminum BIW Concept Study**

<table>
<thead>
<tr>
<th>Study Description</th>
<th>Overall Torsion Mode (Hz)</th>
<th>Overall Lateral Bending Mode (Hz)</th>
<th>Rear End Match Boxing Mode (Hz)</th>
<th>Overall Vertical Bending Rear End Breathing Mode (Hz)</th>
<th>Torsion Stiffness (KN.m/rad)</th>
<th>Bending Stiffness (KN/m)</th>
<th>Test Weight BIW (Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Model</td>
<td>54.6</td>
<td>34.3</td>
<td>32.4</td>
<td>41.0</td>
<td>1334.0</td>
<td>18204.5</td>
<td>407.7</td>
</tr>
<tr>
<td>Aluminum BIW</td>
<td>64.5</td>
<td>39.3</td>
<td>40.7</td>
<td>49.1</td>
<td>1469.6</td>
<td>19855.0</td>
<td>243.0</td>
</tr>
<tr>
<td>Percentage Change (%)</td>
<td>+18.1%</td>
<td>+14.6%</td>
<td>+25.6%</td>
<td>+19.8%</td>
<td>+10.2%</td>
<td>+9.1%</td>
<td>-40.4%</td>
</tr>
</tbody>
</table>

© Copyright 2010 EDAG GmbH & Co. KGaA. All rights reserved.
Mid-size SUV
Aluminum BIW Concept Study

Deformation Mode Comparison: Front Area @80 msec.
Dash Panel Intrusion Comparison

- Model 001 (Steel BIW)
- Model 029 (Aluminum BIW)

A-Pillar Deformation Comparison

- Model 001 (Steel BIW)
- Model 029 (Aluminum BIW)

- Intrusion is severe on all dash panel area.
- Dash panel intrusion is lower compared to the baseline.
- No deformation at A-Pillar is observed in both model.
Dynamic Crush

Model 001 (Steel BIW)

Model 029 (Aluminum BIW)

FMVSS208 - 35mph Frontal Rigid Barrier (FRB) Impact (USNCAP)

Dynamic crush is lower than the baseline

Bottom View: Plastic Strain

Model 001 (Steel BIW)

Model 029 (Aluminum BIW)
Mid-size SUV
Aluminum BIW Concept Study

FMVSS208 – 35 mph Frontal Rigid Barrier Impact

© Copyright 2010 EDAG GmbH & Co.
KGaA. All rights reserved.
Mid-size SUV
Aluminum BIW Concept Study

Findings:

• Aluminum intensive mid-size cross-over SUV appears capable of meeting all design objectives
  • size, functionality, safety, NVH, performance

• 28% (476 Kg) total vehicle mass reduction
  • aluminum – BIW, closures, chassis, suspension, brakes
  • Body mass reduction 39%

• Estimated cost impact: + $534 ($1.12/Kg)
  • Net of secondary mass reductions

Source: EDAG
Mid-size SUV

Aluminum BIW Concept Study

Compatibility Simulation

• 56km/h Car to Car with 40% Overlap
Dash Panel Intrusion Comparison

Model 001 (Steel BIW)

Model 029 (Aluminum BIW)

A-Pillar Deformation Comparison

Model 001 (Steel BIW)

Model 029 (Aluminum BIW)

8.0 Car to Car Simulation
Aluminum Mid-size SUV
Car-to-Car Collision Simulation

Velocity & Acceleration

aluminum Delta V Is 4m/s larger
Aluminum Mid-size SUV
Car-to-Car Collision Simulation

• Max Section Forces
  – Front Rail

<table>
<thead>
<tr>
<th>No</th>
<th>Base (kN)</th>
<th>Alloy (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>90.7</td>
<td>67.0</td>
</tr>
<tr>
<td>2</td>
<td>99.4</td>
<td>64.2</td>
</tr>
<tr>
<td>3</td>
<td>94.4</td>
<td>80.2</td>
</tr>
<tr>
<td>4</td>
<td>95.9</td>
<td>76.3</td>
</tr>
<tr>
<td>5</td>
<td>93.9</td>
<td>58.9</td>
</tr>
<tr>
<td>6</td>
<td>77.2</td>
<td>75.1</td>
</tr>
<tr>
<td>7</td>
<td>95.4</td>
<td>95.4</td>
</tr>
<tr>
<td>8</td>
<td>68.0</td>
<td>64.7</td>
</tr>
<tr>
<td>9</td>
<td>47.4</td>
<td>45.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No</th>
<th>Base (kN)</th>
<th>Alloy (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>19.3</td>
<td>19.1</td>
</tr>
<tr>
<td>2</td>
<td>27.2</td>
<td>32.4</td>
</tr>
<tr>
<td>3</td>
<td>26.5</td>
<td>41.2</td>
</tr>
<tr>
<td>4</td>
<td>29.1</td>
<td>42.1</td>
</tr>
<tr>
<td>5</td>
<td>32.3</td>
<td>40.9</td>
</tr>
<tr>
<td>6</td>
<td>23.7</td>
<td>29.8</td>
</tr>
<tr>
<td>7</td>
<td>48.1</td>
<td>55.7</td>
</tr>
<tr>
<td>8</td>
<td>43.6</td>
<td>43.3</td>
</tr>
<tr>
<td>9</td>
<td>37.4</td>
<td>36.9</td>
</tr>
</tbody>
</table>
Key Findings

- Safety Implications
  - Intrusions
    - AIV floor pan intrusions reduced
  - Global Velocity / Acceleration
    - AIV concept more severe deceleration
    - Potentially higher occupant loading (with the same restraints system)

- Conclusions
  - AIV Structure design changes to accommodate
    - Increased structure stiffness
    - Higher energy absorption capacity
Conclusions:

- Vehicle design, not mass, Key to Collision Performance

- Reduced mass body structures with equal or superior collision performance appear feasible

- Potential Body mass reduction
  - AHSS (10-12 % reduction)
  - MMV Optimization (12-16 % reduction)
    - Steel, AHSS, Al, Mg
  - Aluminum (AIV) (24-28 % reduction)
    - Aluminum, AHSS

- Mix of BIW solutions likely
  - AHSS – price critical market segment: Downsizing
  - MMV (body) – size-cost optimization: MODERATE downsizing
  - AIV (body) – size critical market segment: LIMITED downsizing