ALUMINUM
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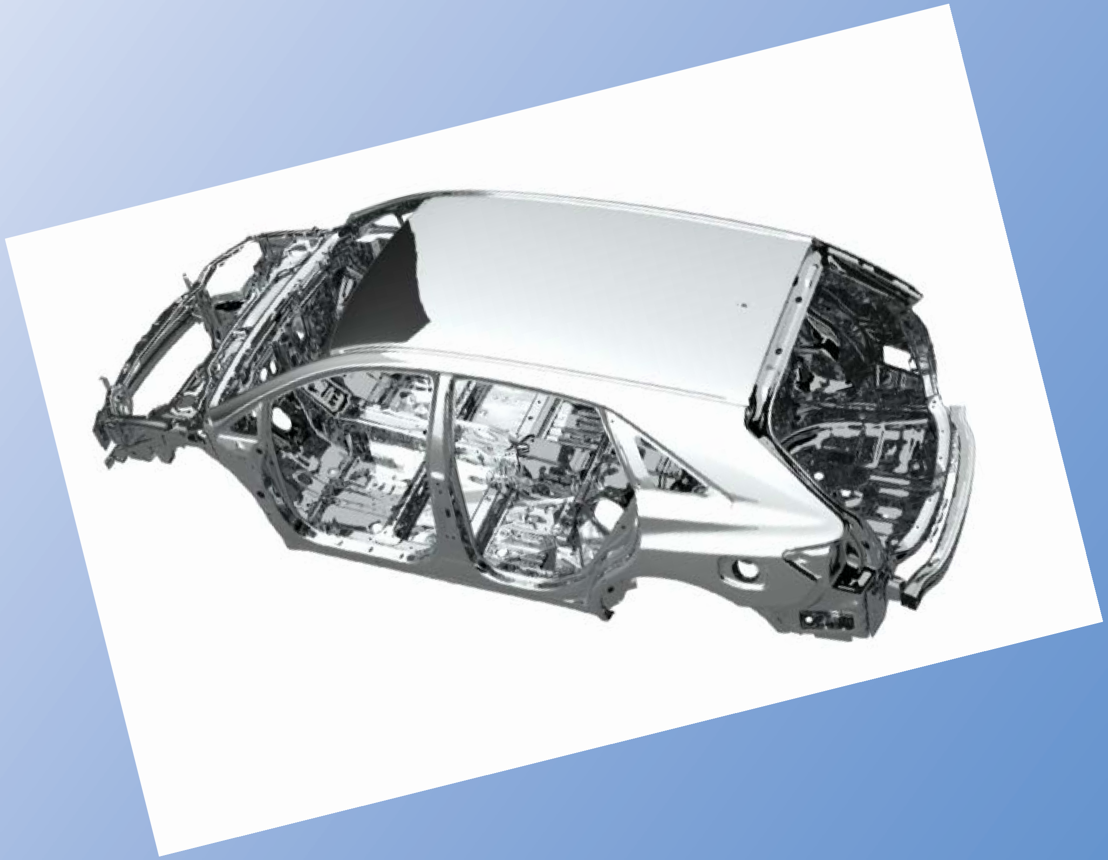
Lighter and Safer Cars by Design



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

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DRI Compatibility Study

Baseline: Conventional SUV with

Conventional Passenger Car and LTV

	Crash Type	Number of Cases	Total ELU's: Baseline Case SUV	Total ELU's: Reduced Weight Case SUV	Total ELU's: Increased Length Case SUV
SUV Driver	Rollover	175	2.23	2.48	0.53
SUV Driver	Hit Object	420	2.54	1.74	0.81
SUV Driver	Hit PC	1750	1.21	2.47	1.19
SUV Driver	Hit LTV	1155	25.97	34.02	26.27
	Subtotal	3500	31.95	40.71	28.80
OV Driver	In PC	1750	28.00	9.70	16.79
OV Driver	In LTV	1155	25.99	11.28	19.59
	Subtotal	2905	53.99	20.98	36.38
	Overall Total	3500 SUV + 2905 OV	85.94	61.69	65.18

Net Benefit (%): Reduced Weight Case SUV	Net Benefit (%): Increased Length Case SUV
-11.2	76.2
31.5	68.1
-104.1	1.7
-31.0	-1.2
-27.4	9.9
65.4	40.0
56.6	24.6
61.1	32.6
28.2	24.2

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DRI Compatibility Study

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

	Crash Type	Number of Cases	Total ELU's			Net Benefit (%)	
			Baseline Case SUV	Reduced Weight Case SUV	Increased Length Case SUV	Reduced Weight Case SUV	Increased Length Case SUV
SUV Driver	Rollover	175	2.23	2.48	0.53	-11.2	76.2
SUV Driver	Hit Object	420	2.54	1.74	0.81	31.5	68.1
SUV Driver	Hit PC	1750	1.21	2.47	1.19	-104.1	1.7
SUV Driver	Hit LTV	1155	25.97	34.02	26.27	-31.0	-1.2
	Subtotal	3500	31.95	40.71	28.80	-27.4	9.9
OV Driver	In PC	1750	28.00	9.70	16.79	65.4	40.0
OV Driver	In LTV	1155	25.99	11.28	19.59	56.6	24.6
	Subtotal	2905	53.99	20.98	36.38	61.1	32.6
	Overall Total	3500 SUV + 2905 OV	85.94	61.69	65.18	28.2	24.2

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DRI Compatibility Study

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

	Crash Type	Number of Cases	Total ELU's			Net Benefit (%)	
			Baseline Case SUV	Reduced Weight Case SUV	Increased Length Case SUV	Reduced Weight Case SUV	Increased Length Case SUV
SUV Driver	Rollover	175	2.23	2.48	0.53	-11.2	76.2
	Hit Object	420	2.54	1.74	0.81	31.5	68.1
	Hit PC	1750	1.21	2.47	1.19	-104.1	1.7
	Hit LTV	1155	25.97	34.02	26.27	-31.0	-1.2
	Subtotal	3500	31.95	40.71	28.80	-27.4	9.9
OV Driver	In PC	1750	28.00	9.70	16.79	65.4	40.0
	In LTV	1155	25.99	11.28	19.59	56.6	24.6
	Subtotal	2905	53.99	20.98	36.38	61.1	32.6
	Overall Total	3500 SUV + 2905 OV	85.94	61.69	65.18	28.2	24.2

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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

Source: *EDAG*

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

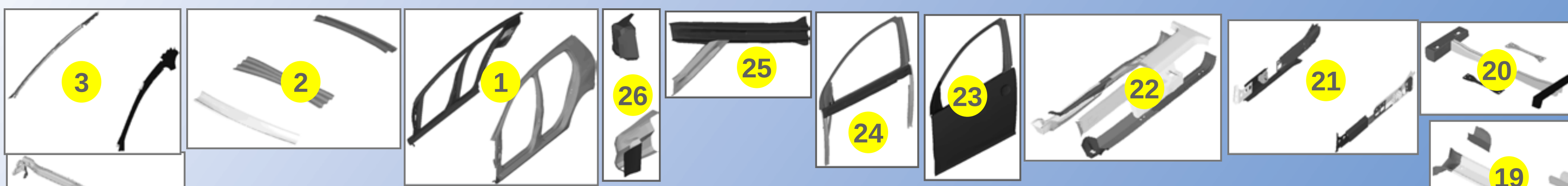
- University of Aachen ika (Germany)
  - Mid-size European Sedan
- Objective
  - – Maximum auto body weight saving potential
    - Steel
    - Aluminum

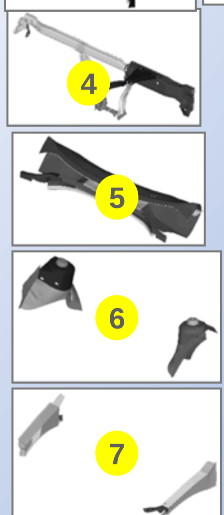
Source: **ika - University of Aachen and the European Aluminium Association (EAA)**

Analytical Analysis

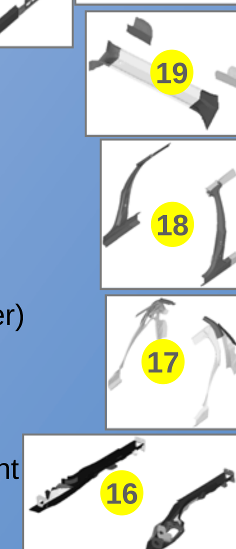
- Objective
  - Maximum auto body weight saving potential
- Methodology
  - Model body - classify components (strength or stiffness limited)
    - NVH
    - Collision performance (index: intrusion)
  - Optimize body components – material, grade, gauge
    - High-strength steel grades (including ultra high-strength steel)
    - Aluminum alloys

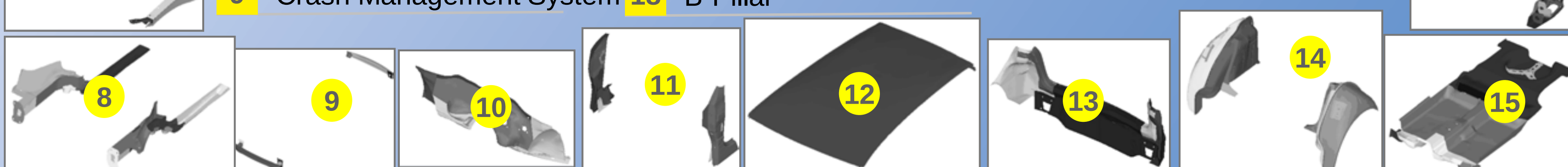
26 Components for Quantitative Evaluation





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

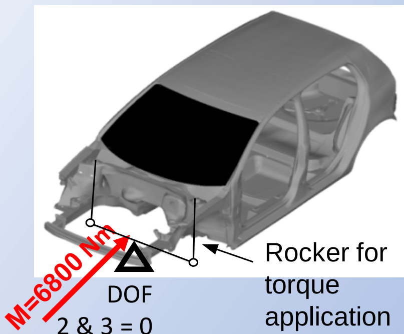




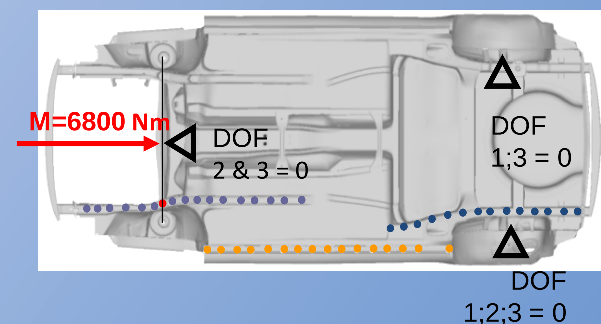
Source: **ika - University of Aachen and the European Aluminium Association (EAA)**

Stiffness Load Cases

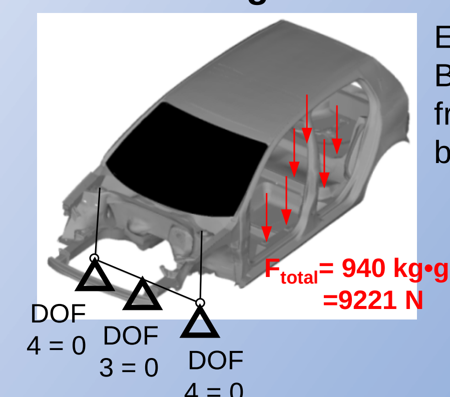
Static Torsional Stiffness



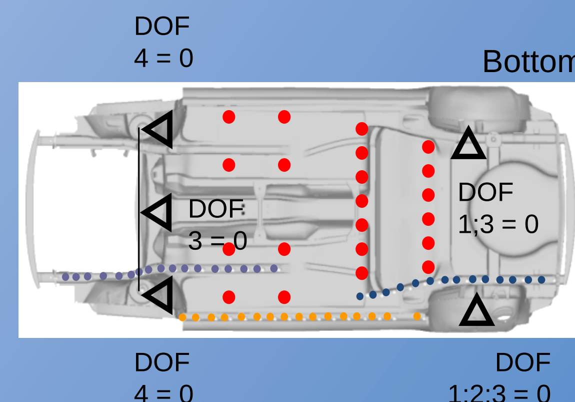
Evaluation:
Torsional stiffness calculated from deflection of evaluation point on front longitudinal



Static Bending Stiffness



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

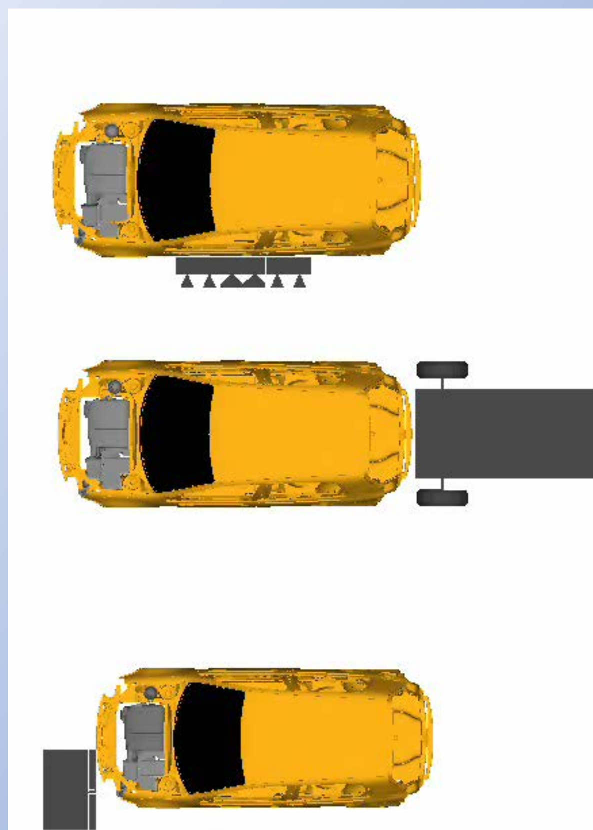


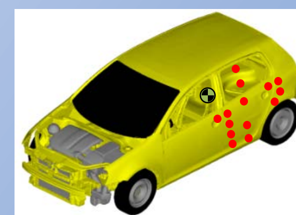
Red dots = Load/force application
Black dots = Deflection measured
Orange dots = Deflection measured
Blue dots = Deflection measured

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

Strength Load Cases

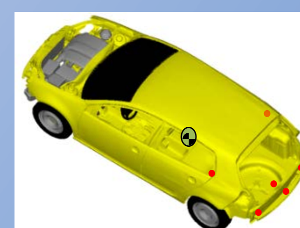
Evaluated Using European and U.S. Crash Standards





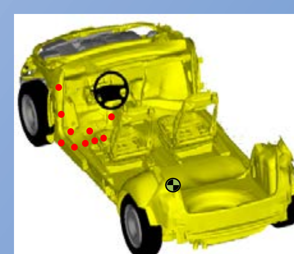
Euro NCAP Side Crash

- Velocity 50 km/h
- EEVC moving deformable barrier



FMVSS 301 Rear Crash

- Velocity 48 km/h
- Rigid moving barrier
- 0% offset



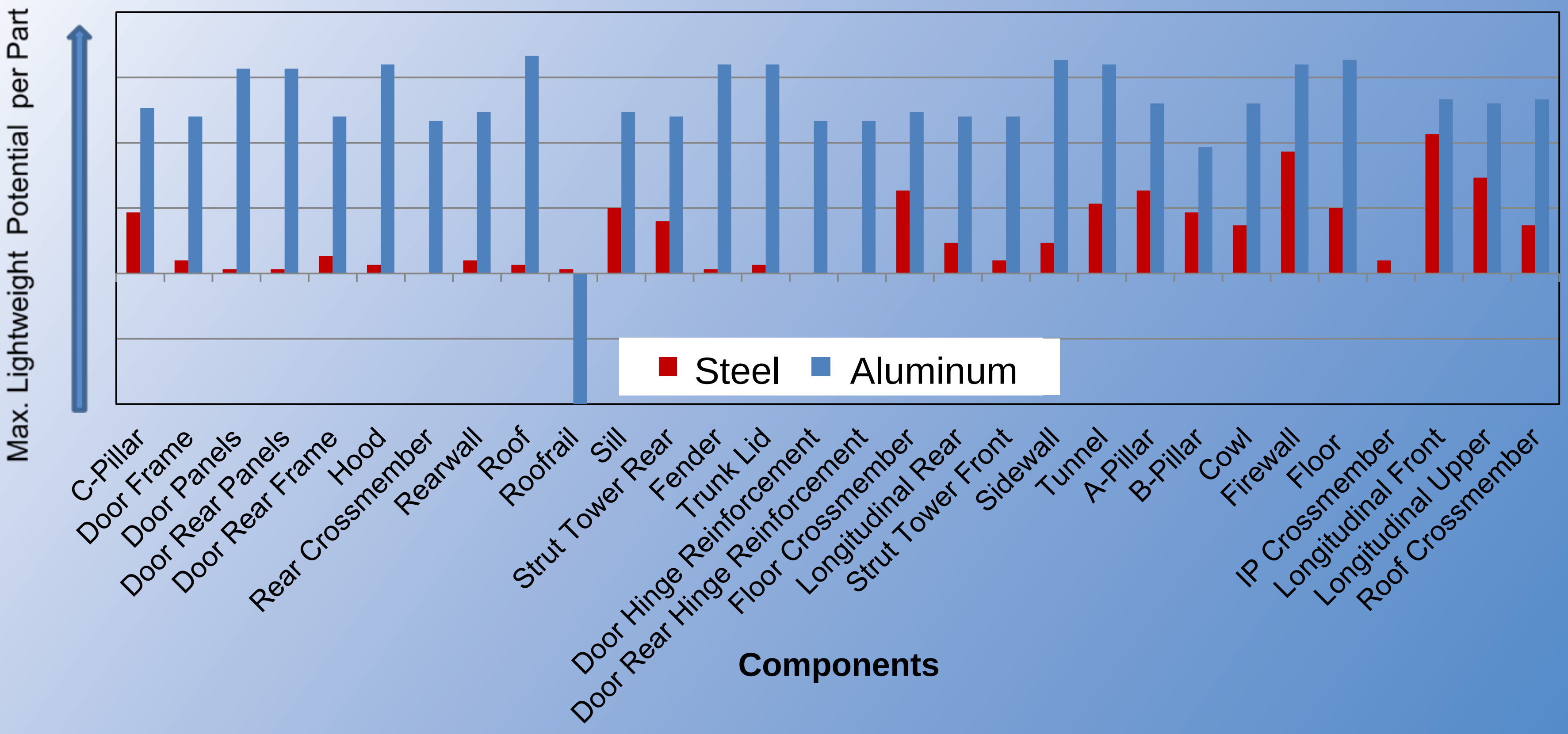
Euro NCAP Front Crash

- Velocity 64 km/h
- EEVC deformable barrier
- 40% offset

● Intrusion Evaluation Point ◉ Acceleration Evaluation Point

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%**

http://www.eaa.net/en/applications/automotive/studies/

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

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“Light-Duty Vehicle Mass Reduction and Cost Analysis – Midsize Crossover Utility Vehicle”

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*

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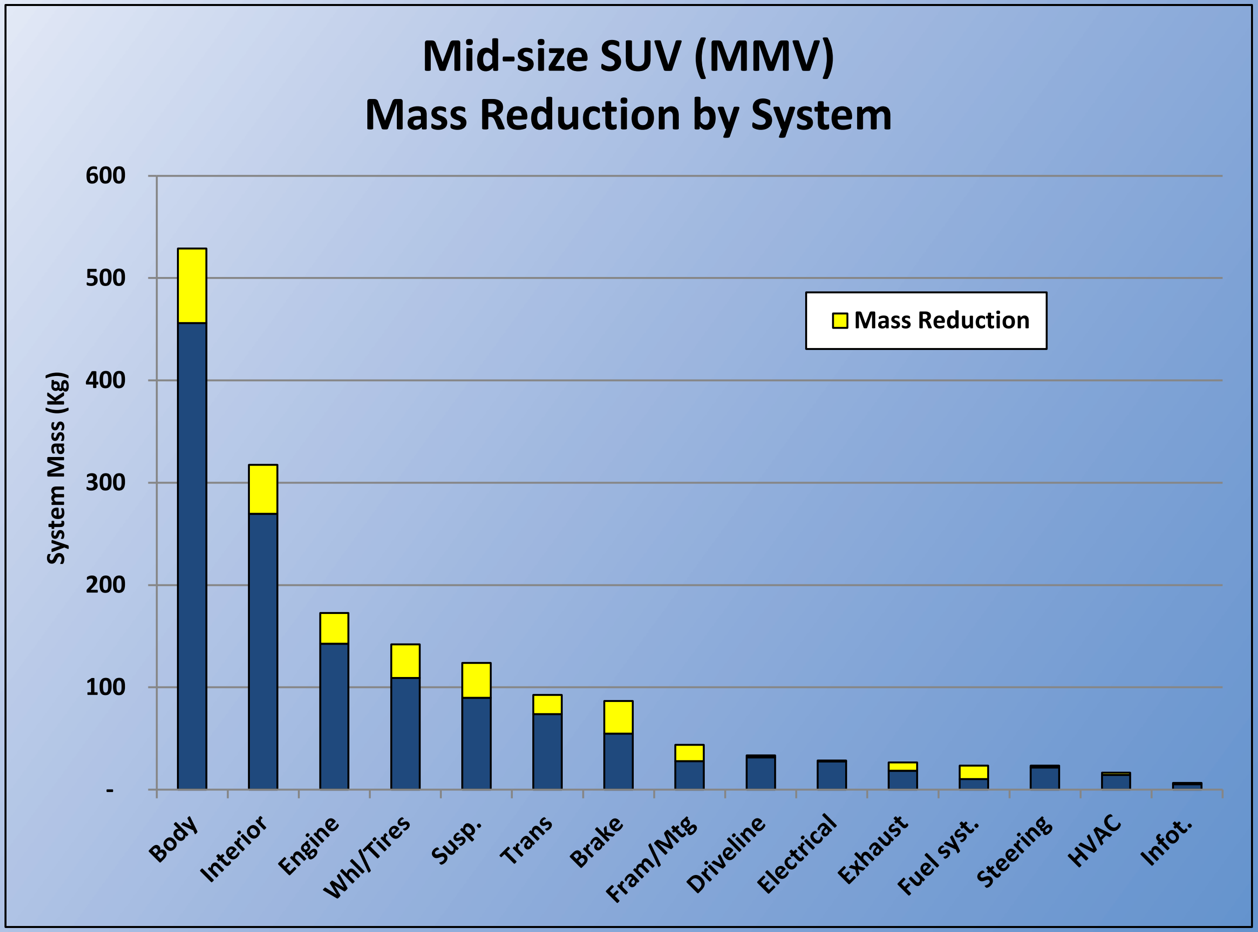
Body is Key to Vehicle Mass Reduction



Source: EDAG/EPA **http://www.epa.gov/otaq/climate/documents/420r12026.pdf**

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"Light-Duty Vehicle Mass Reduction and Cost Analysis - Midsize Crossover Utility Vehicle"

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*

ALUMINUM IN TRANSPORTATION
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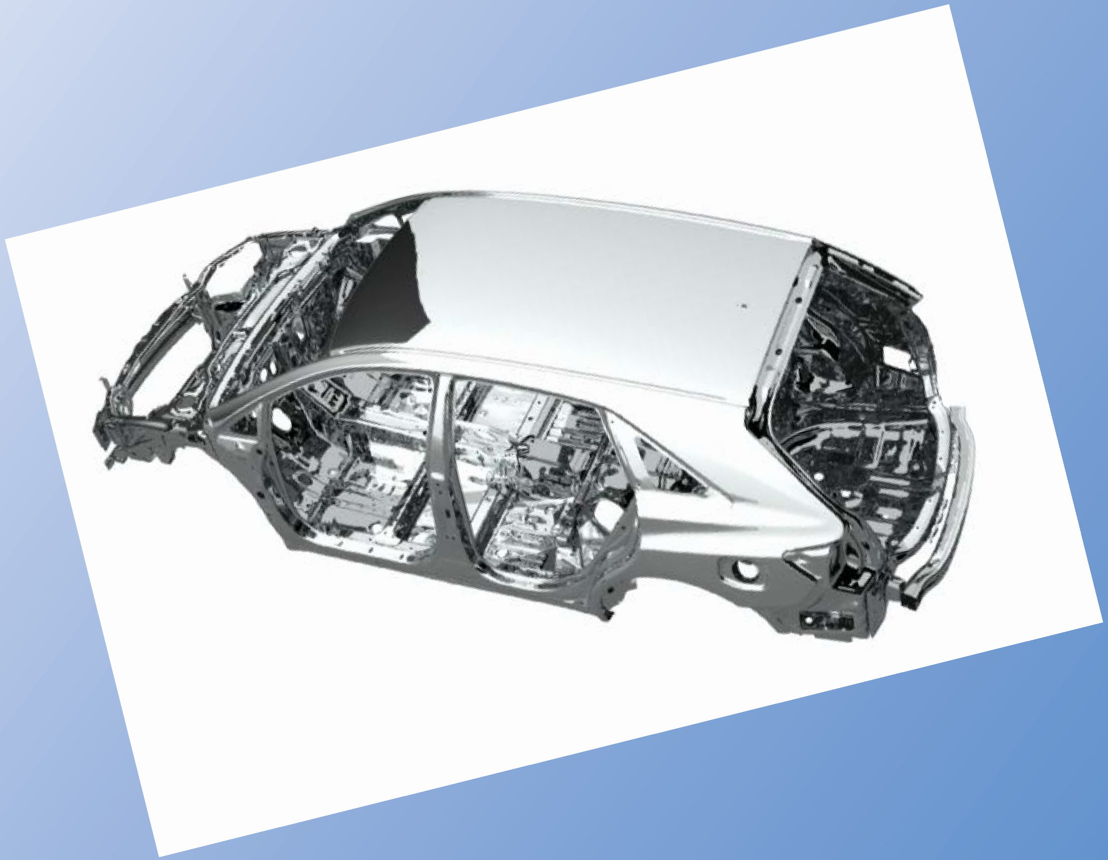
Mid-size SUV
<u>Aluminum</u> BIW Concept Study



January 2013

Mid-size SUV
Aluminum BIW Concept Study

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

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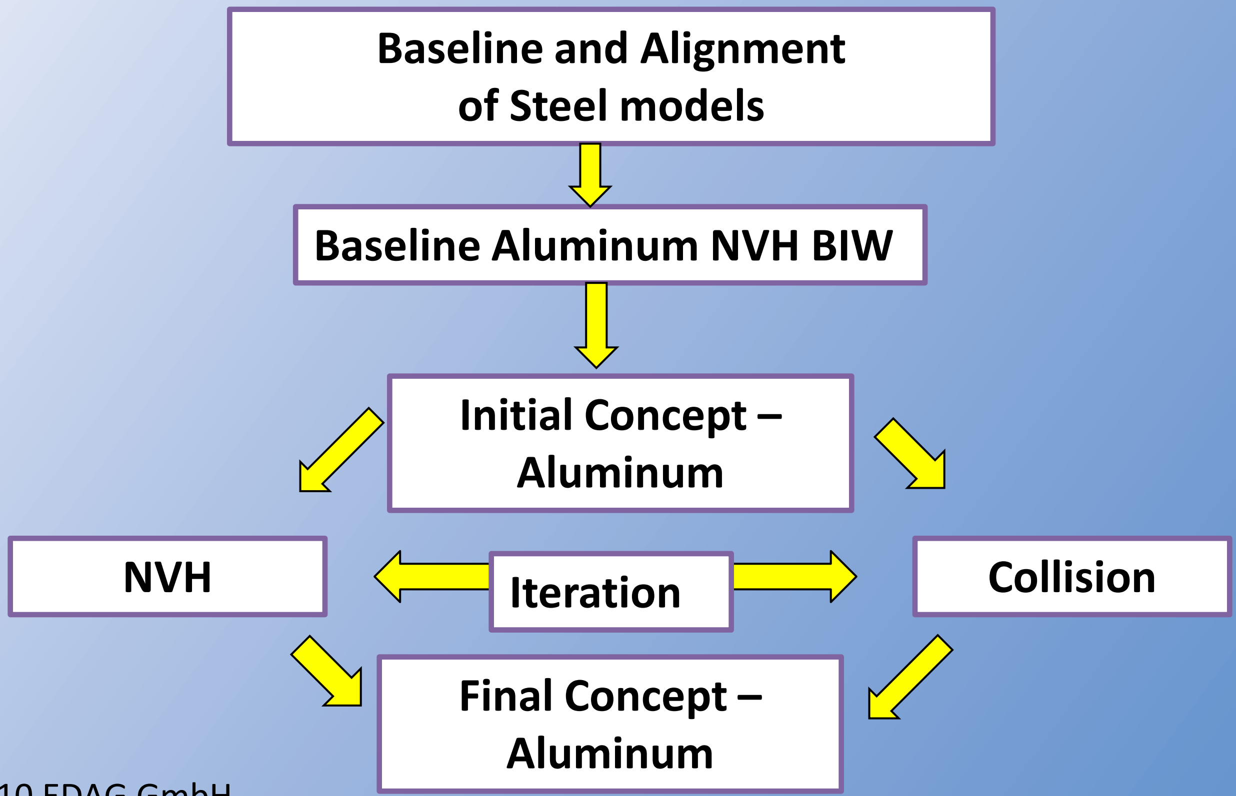
AIV Body Design Process
(NVH and Crash)



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Mid-size SUV
Aluminum BIW Concept Study

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

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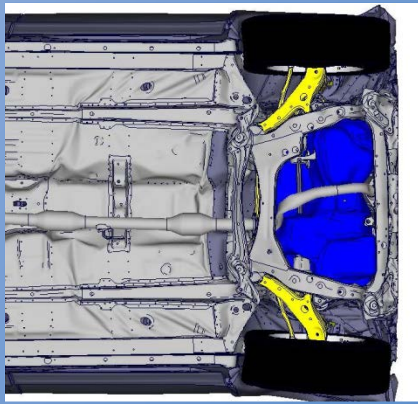
Mid-size SUV
Aluminum BIW Concept Study



Deformation Mode Comparison: Front Area @80 msec.

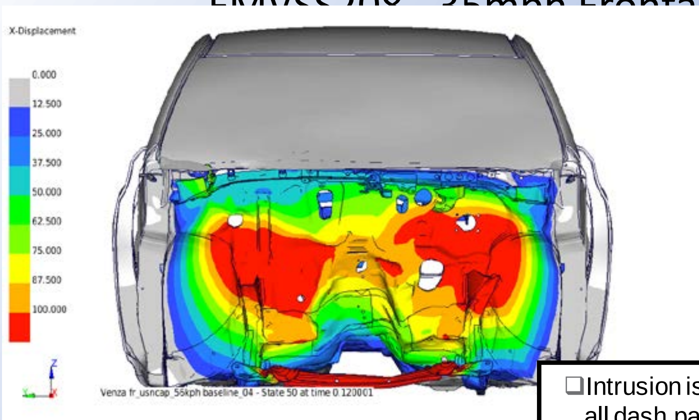
Mid-size SUV

Aluminum BIW Concept Study

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

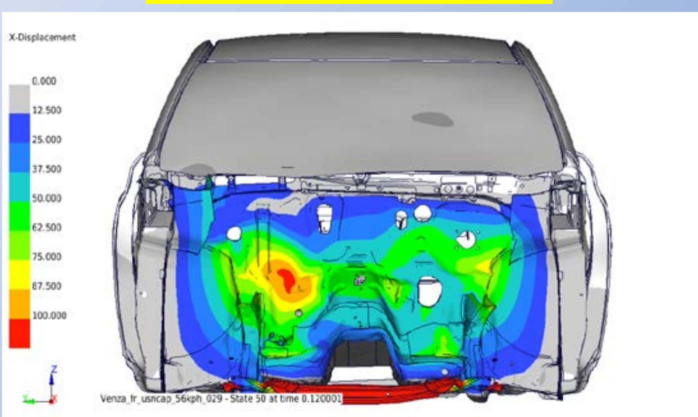
Dash Panel Intrusion Comparison

Model 001 (Steel BIW)



❑Intrusion is severe on all dash panel area.

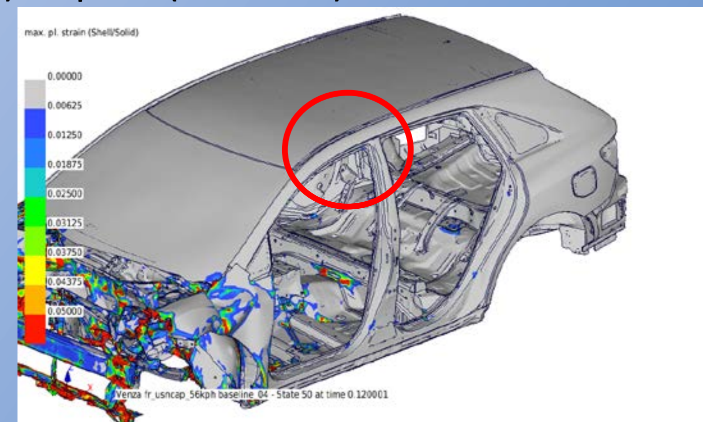
Model 029 (Aluminum BIW)



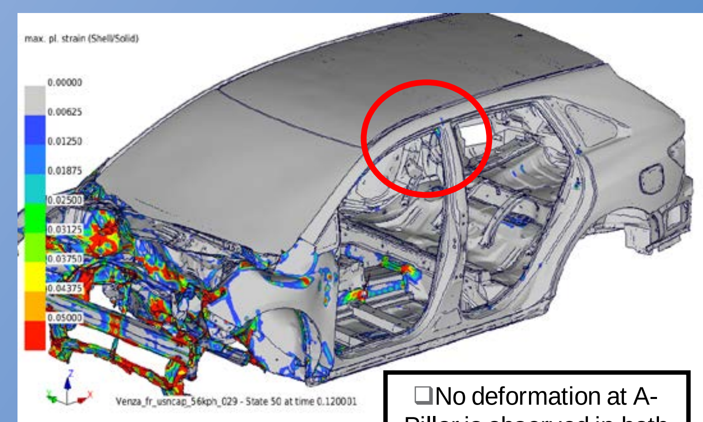
❑Dash panel intrusion is lower compared to the baseline

A-Pillar Deformation Comparison

Model 001 (Steel BIW)



Model 029 (Aluminum BIW)



❑No deformation at A-Pillar is observed in both model.

Mid-size SUV

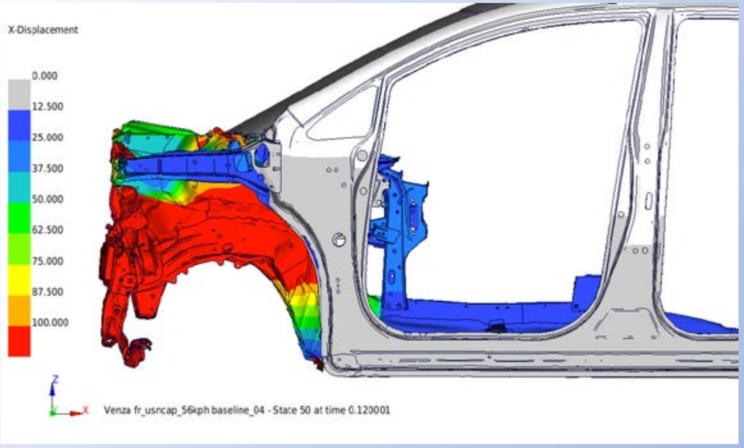
Aluminum BIW Concept Study

Dynamic Crush

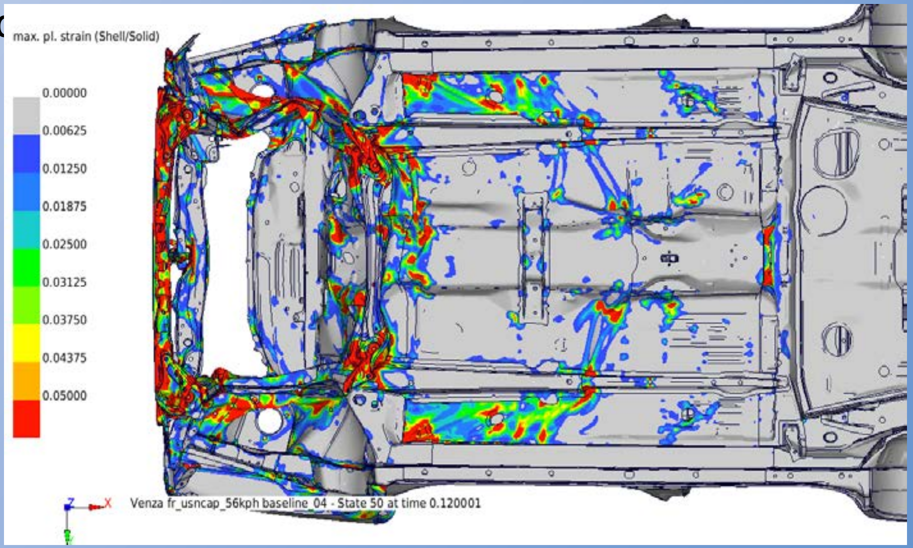
Bottom View :Plastic Strain

Model 001 (Steel BIW)

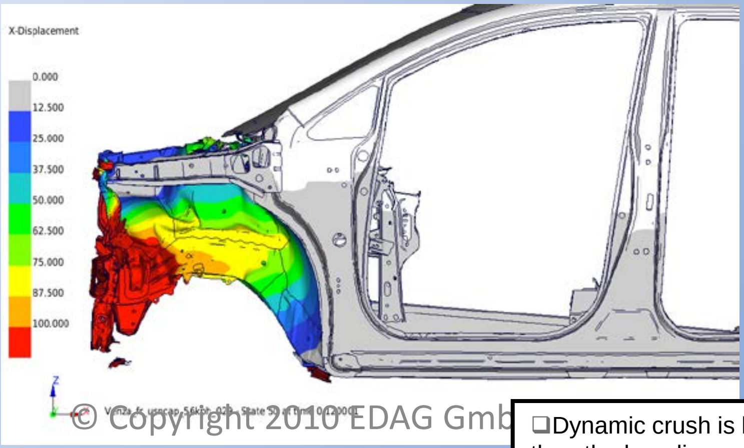
FMVSS208 - 35mph Frontal Rigid



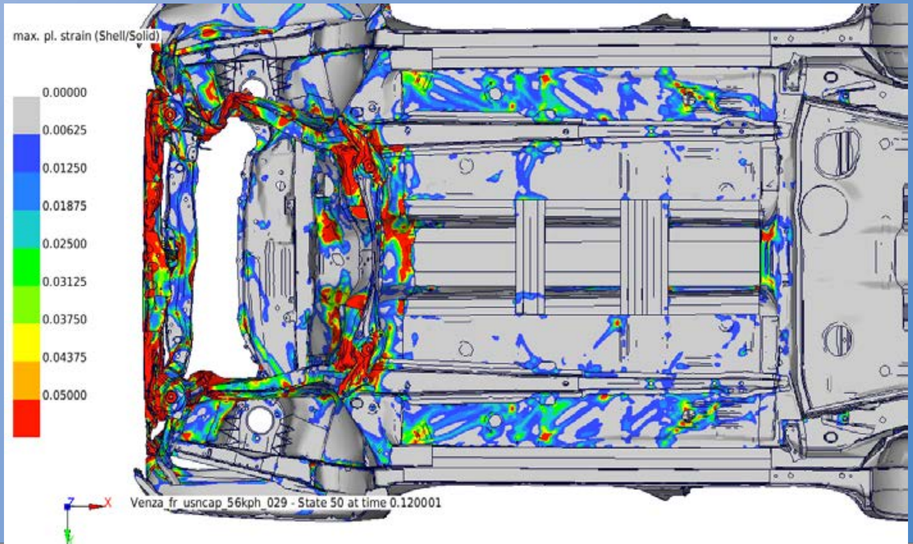
Model 001 (Steel BIW)



Model 029 (Aluminum BIW)



Model 029 (Aluminum BIW)



- Dynamic crush is lower than the baseline

Mid-size SUV
Aluminum BIW Concept Study

ALUMINUM IN TRANSPORTATION
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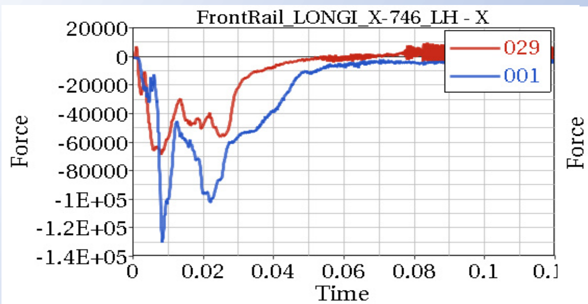
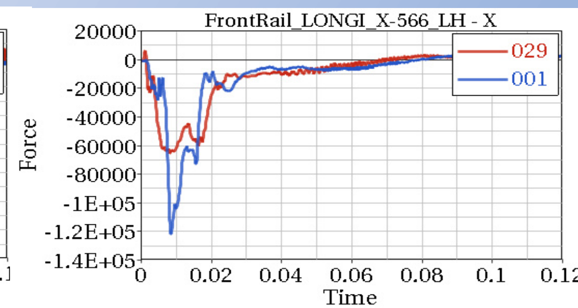
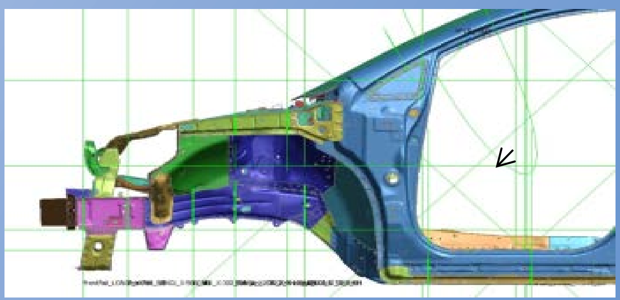
FMVSS208 – 35 mph Frontal Rigid Barrier Impact

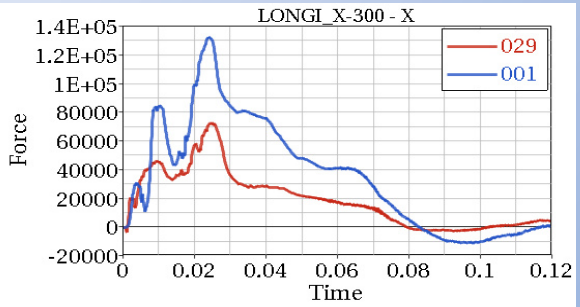
Driver Side (LH)

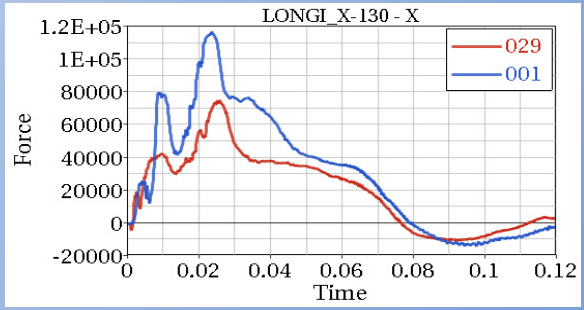
X746 X566 X300 X130 X150

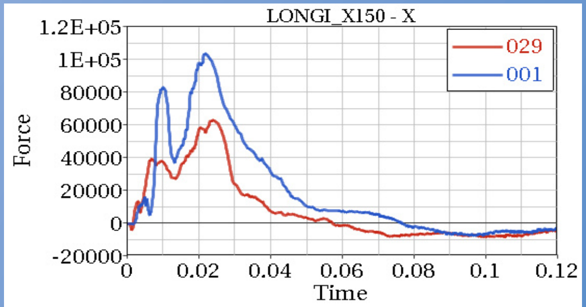












Mid-size SUV
Aluminum BIW Concept Study

Findings:

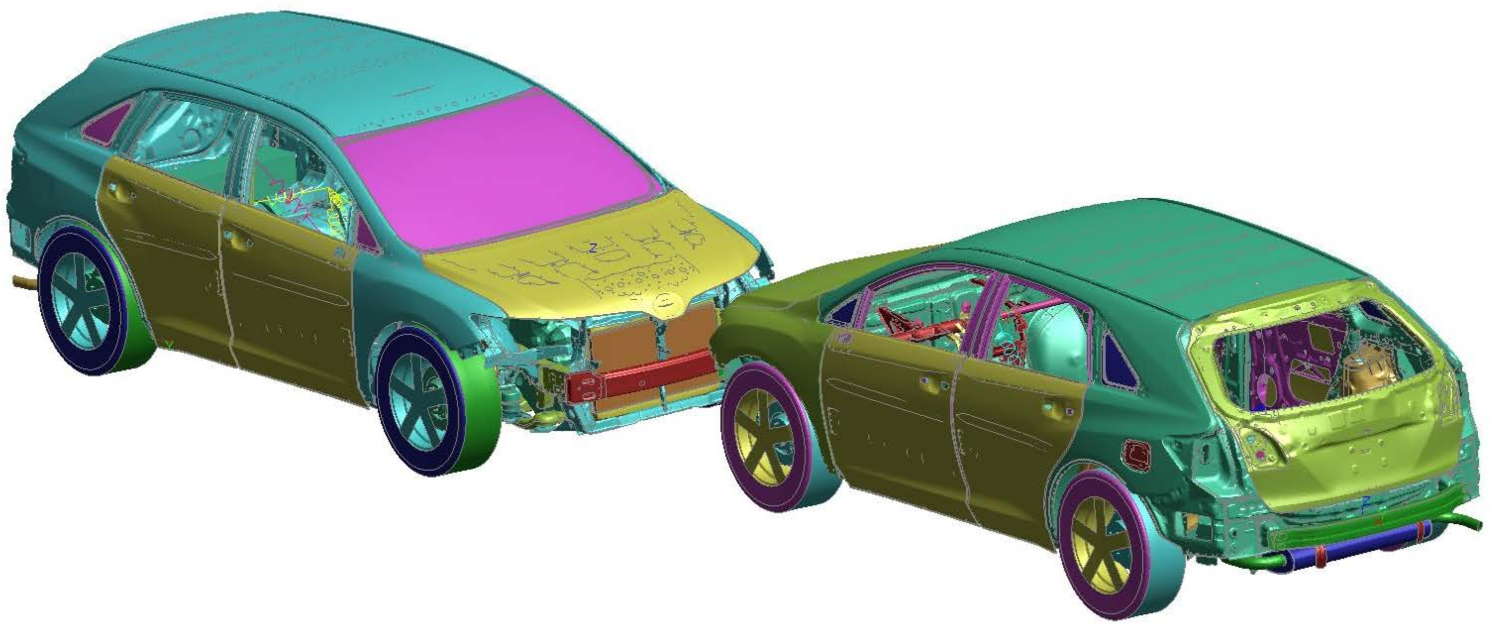
- Aluminum intensive mid-size cross-over SUV appears capable of meeting all design objectives
  - size, functionality, safety, NVH, performance
- 28% (476 Kg) total vehicle mass reduction
  - aluminum – BIW, closures, chassis, suspension, brakes
  - Body mass reduction 39%
- Estimated cost impact: + $534 ($1.12/Kg)
  - Net of secondary mass reductions

***Source**: EDAG*

Mid-size SUV

Aluminum BIW Concept Study

Compatibility Simulation



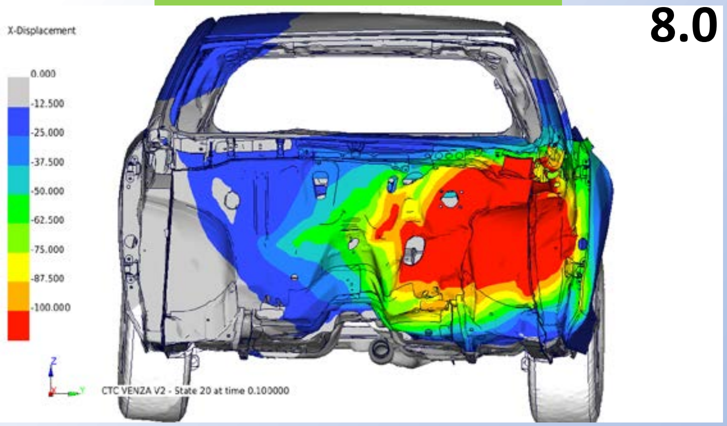
• 56km/h Car to Car with 40% Overlap

8.0 Car to Car Simulation

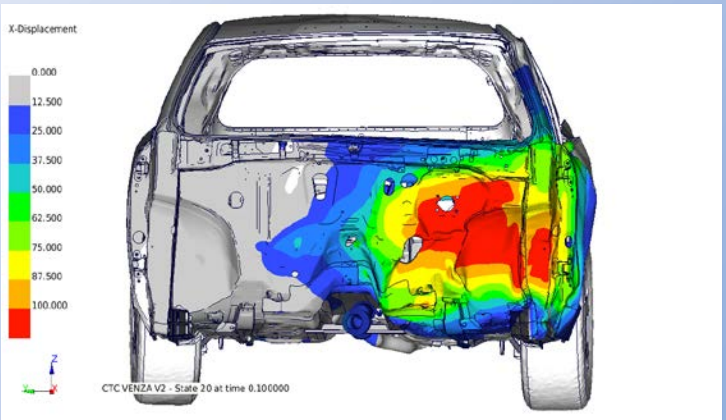
THE ALUMINUM ASSOCIATION, INC.

Dash Panel Intrusion Comparison

Model 001 (Steel BIW)

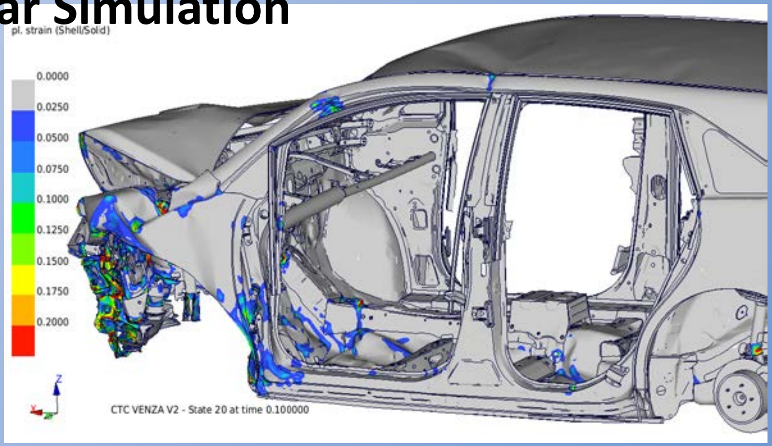


Model 029 (Aluminum BIW)

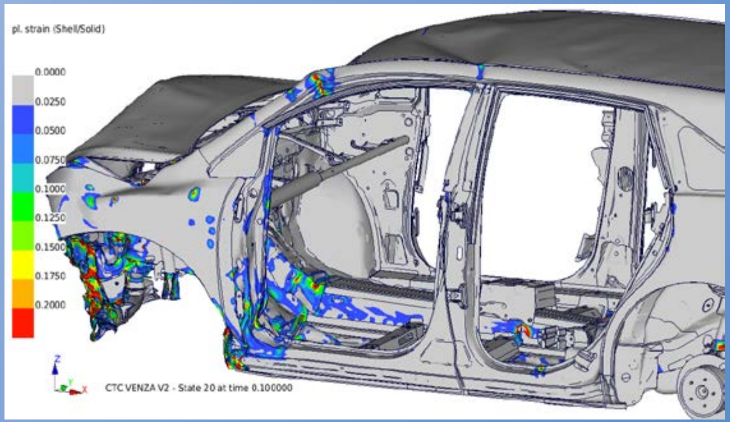


A-Pillar Deformation Comparison

Model 001 (Steel BIW)

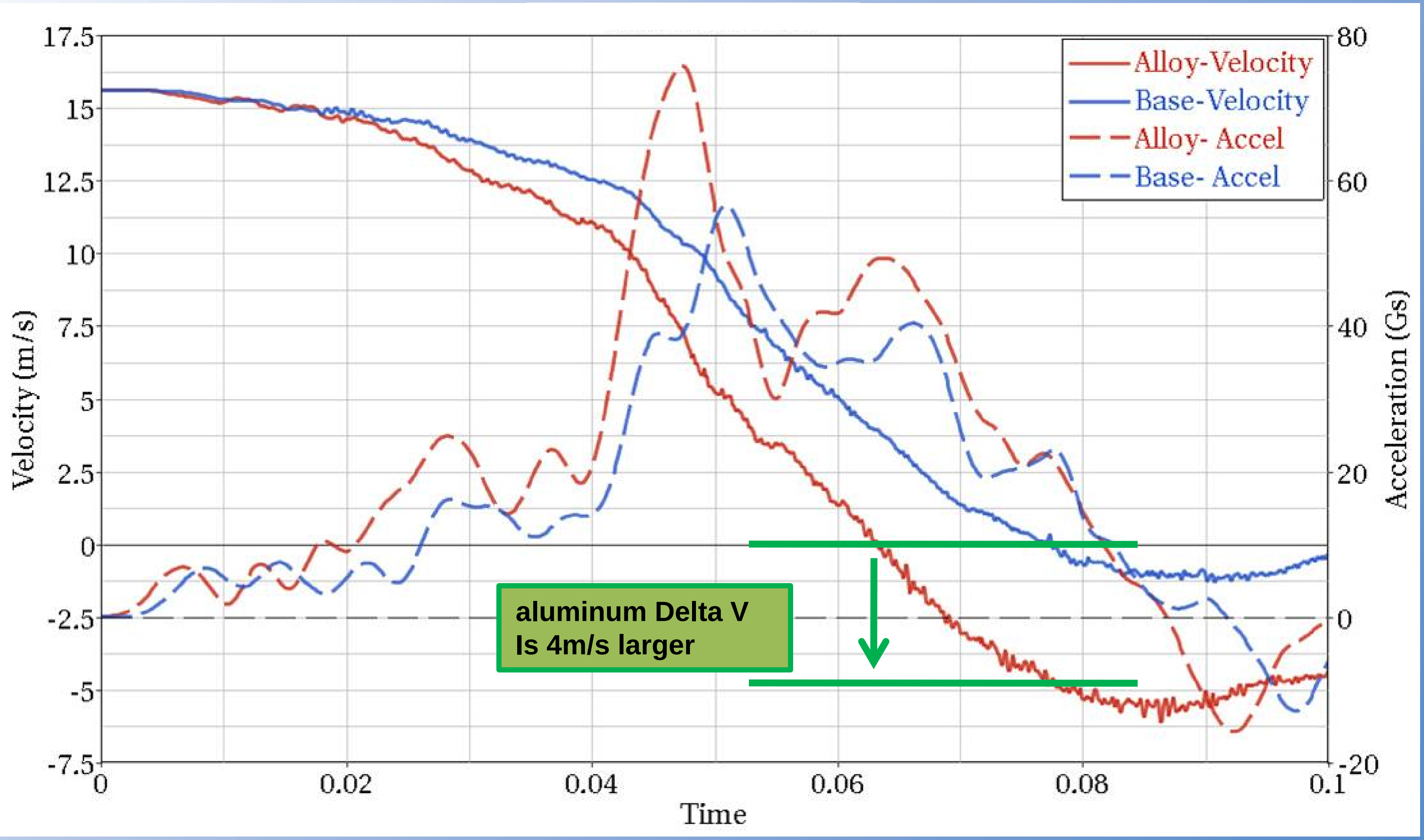


Model 029 (Aluminum BIW)



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

Velocity & Acceleration



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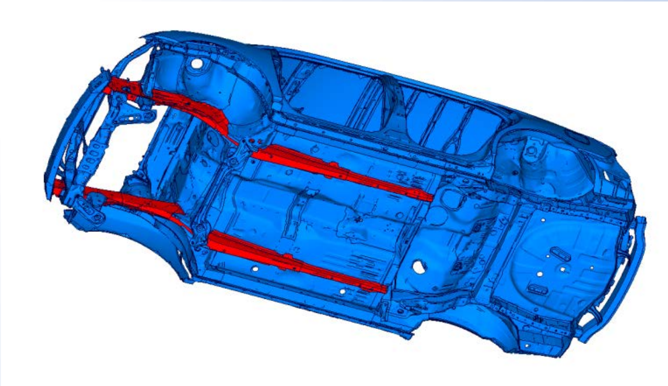
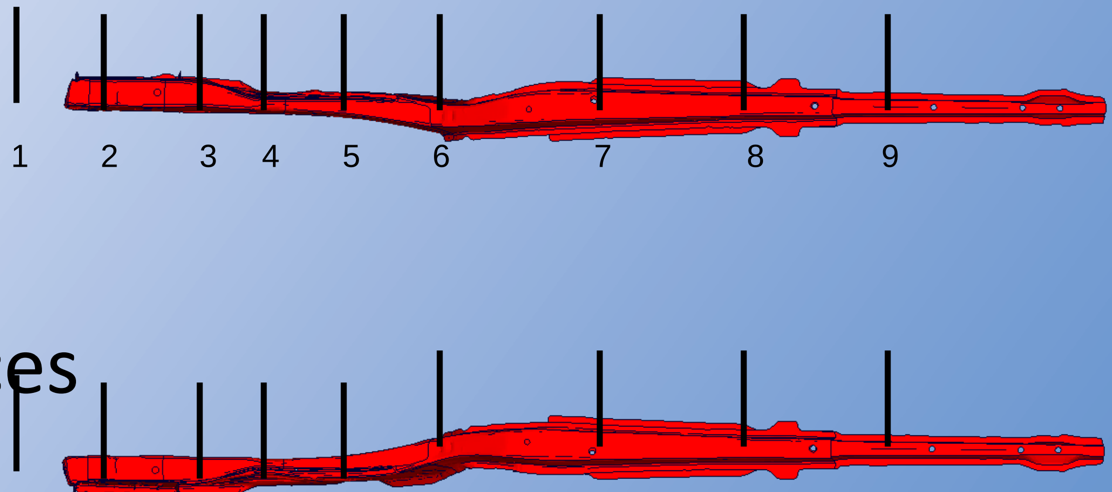
Aluminum Mid-size SUV Car-to-Car Collision Simulation



- Max Section Forces
  - Front Rail



LHS

No	Base (kN)	Alloy (kN)
1	90.7	67.0
2	99.4	64.2
3	94.4	80.2
4	95.9	76.3
5	93.9	58.9
6	77.2	75.1
7	95.4	95.4
8	68.0	64.7
9	47.4	45.7

RHS

No	Base (kN)	Alloy (kN)
1	19.3	19.1
2	27.2	32.4
3	26.5	41.2
4	29.1	42.1
5	32.3	40.9
6	23.7	29.8
7	48.1	55.7
8	43.6	43.3
9	37.4	36.9

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

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

Lighter and Safer Cars by Design

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 Steel, AHSS, Al, Mg	(12-16 % reduction)
Aluminum (AIV) Aluminum, AHSS	(24-28 % reduction)

- 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

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