VENZA Aluminum BIW Concept Study

April 2013

Contents

1.0 Introduction

- **Introduction**

The study focused on taking the steel Venza BIW and developing a CAE concept for an aluminum BIW with equivalent performance within the following boundaries:

- Project is a “feasibility study” only.
- Concept will be of riveted / bonded construction (with use of extrusions/sheet/castings)
- The use of castings in the BIW will be minimized (for cost / complexity reasons)
- Aluminum materials used in the study will be “current technology” only
- Concept will be developed in CAE (no CAD data will be created)
- No detailed manufacturing feasibility will be performed in this stage of the project
- The following load cases were defined for the project (as per the base Venza)
  - Crashworthiness
    - FMVSS 208 Frontal Crash
    - IIHS 35mph ODB Frontal Crash
    - FMVSS 301 Rear Impact
    - FMVSS 214 Side impact (MDB)
    - FMVSS 216 Roof Crush
  - NVH
    - Static torsion and bending stiffness
    - BIW normal modes (1^{st} structural)

2.0 Project Aims

- **Project Aims**
  1. Delivery of an aluminum intensive BIW FEA model
  2. Identification of materials and potential construction
  3. An evaluation of performance across all of the load cases considered
  4. Target performance to be similar to the base Venza platform
  5. Target BIW mass reduction of +30% over steel

3.0 Development Plan (NVH and Crash)

Baseline and Alignment of Venza Steel models
- Commonize BIW for materials/thickness/welds/properties/numbering
- Baseline performance for study load cases

Baseline Aluminum NVH BIW
- Venza steel gauges X1.5
- Focus on stiffness
- Castings/sheet metal/extrusions concept
- Optimization for stiffness for initial concept

Initial Concept– Aluminum
- Sheet metal geometry
- Aluminum properties

NVH
- Casting concepts
- Optimization

Iterations

Crash
- Front/ rear/ side
- Roof crush

Final Concept– Aluminum
- Extrusion Profiles
- Conceptual casting package
- Conceptual sheetmetal

4.0 Material Selection

MATERIAL SELECTION

- For the purposes of the feasibility study 4 basic aluminum materials have been selected:

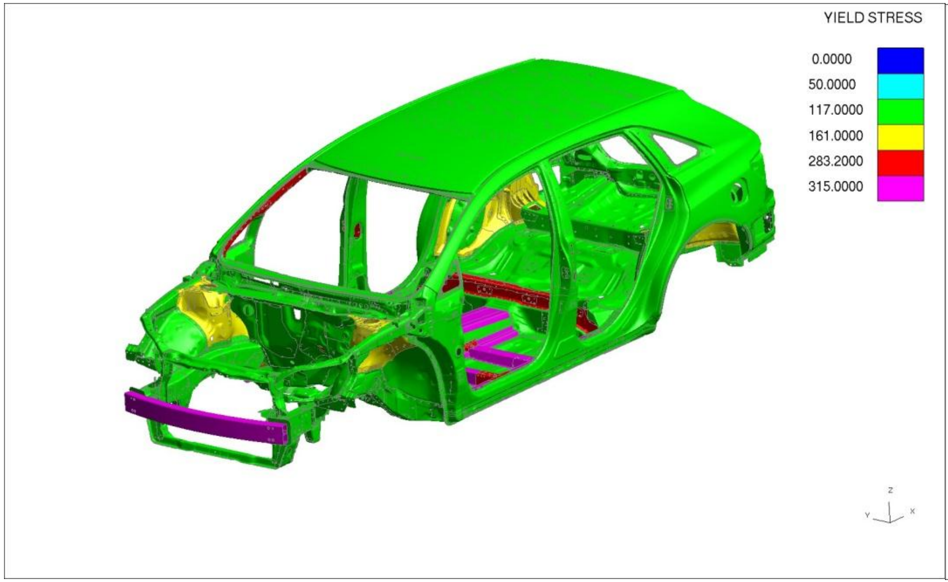
  - 6022 T6 Alloy Sheet - Used for “high” strength areas
  - 5754 O Alloy sheet - Default material for most panels
  - 6082 T6 Extrusion - Used for all extrusions
  - Generic Casting - Used for all castings

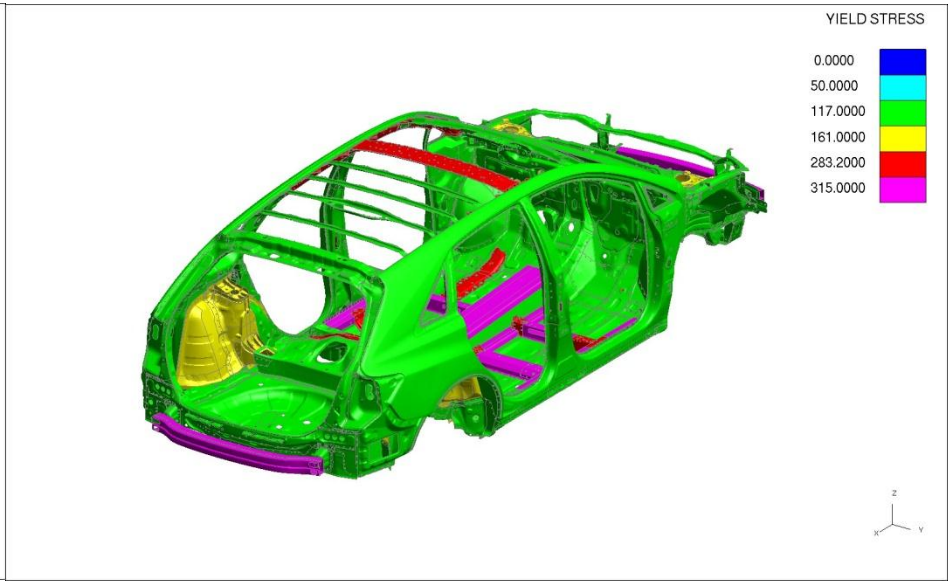
- Properties have been supplied by the Aluminum Association and a basic material model created in LS-DYNA using MAT 24 (PWL or BL stress strain curves only).
- Failure criteria is not considered at this time
- It is important to note the following:
  - This is only a structural feasibility study (formability / environmental factors not yet considered)
  - Exterior panels would use a higher grade material (6XXX T4 or similar for dentability)
  - Castings are only conceptual in the FEA model material and manufacturing process are not defined at this point
  - Aluminum door weights are projected only – not designed / developed

4.0 Material Selection

Materials (Aluminum)

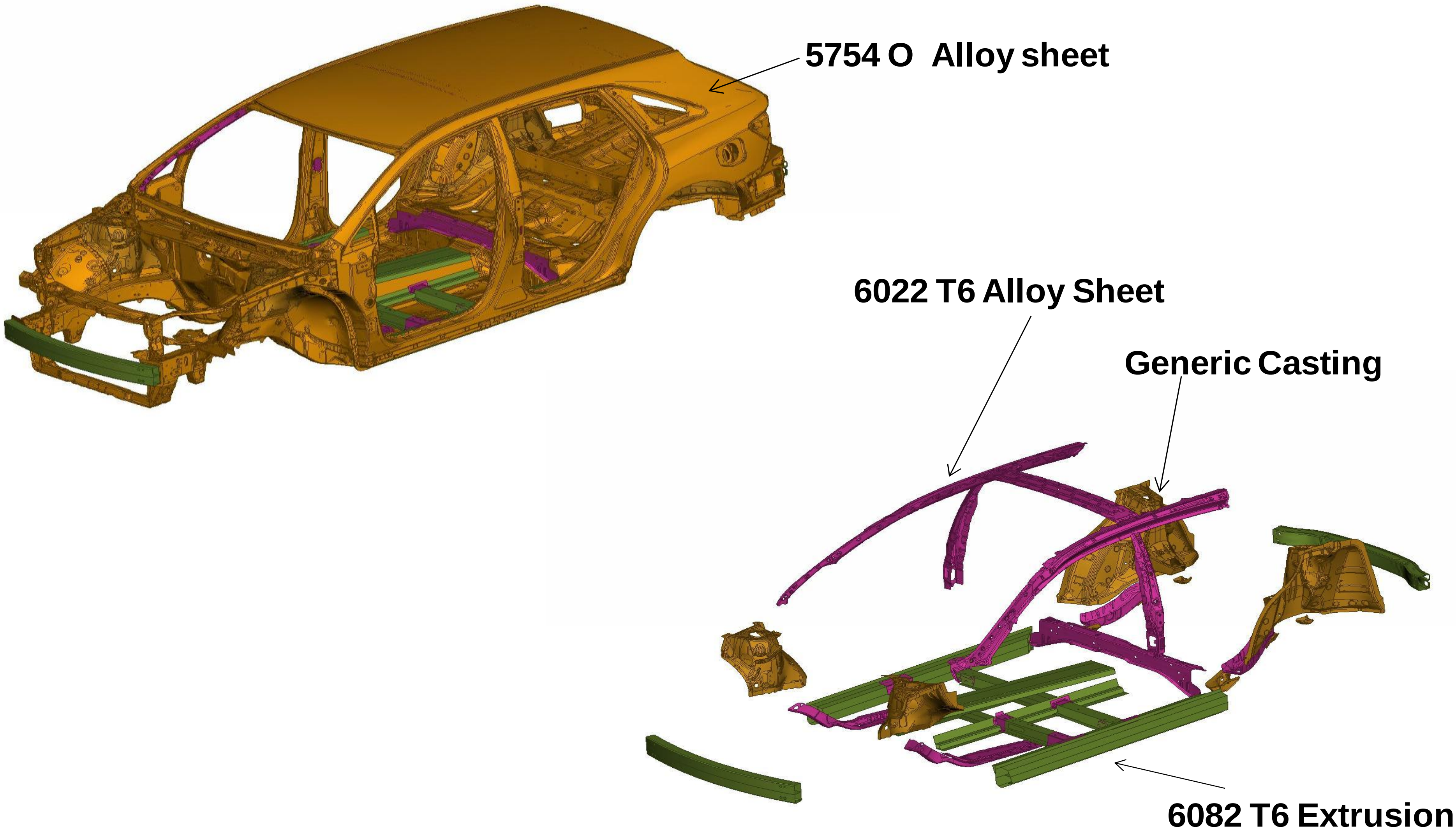
Aluminum Grade	Yield Stress
6022 T6 Alloy Sheet	290Mpa
5754 O Alloy sheet	117Mpa
6082 T6 Extrusion	315Mpa
Generic Casting	160Mpa





4.0 Material Selection

Materials by Color



5.0 Joining Technology

Self Piercing Rivets (SPR)

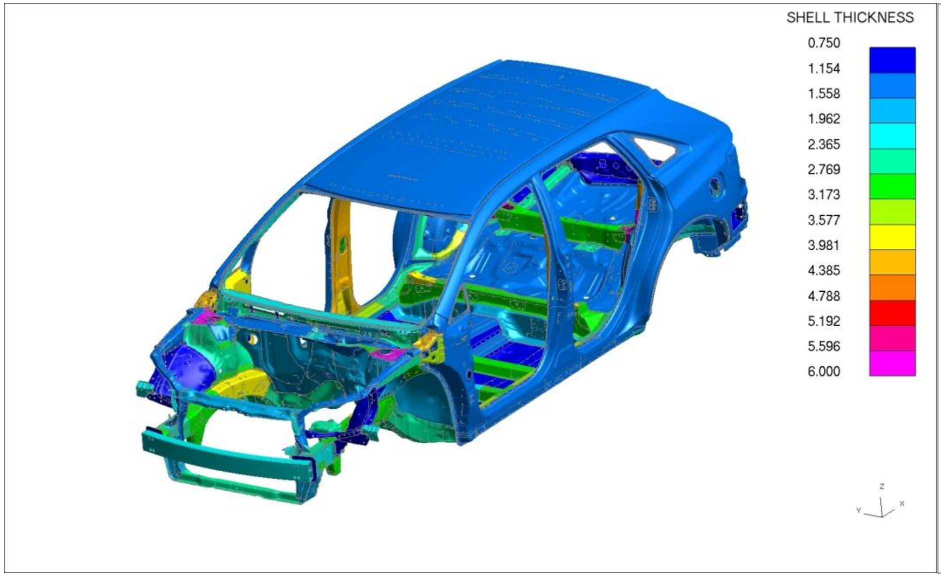
- Allow up to 4T thickness connections
- Compatible with bonding
- Mature technology (E.g. HENROB)
- For LS-DYNA/OPTISTRUCT represented as “spot welds”
- No failure will be considered in this study

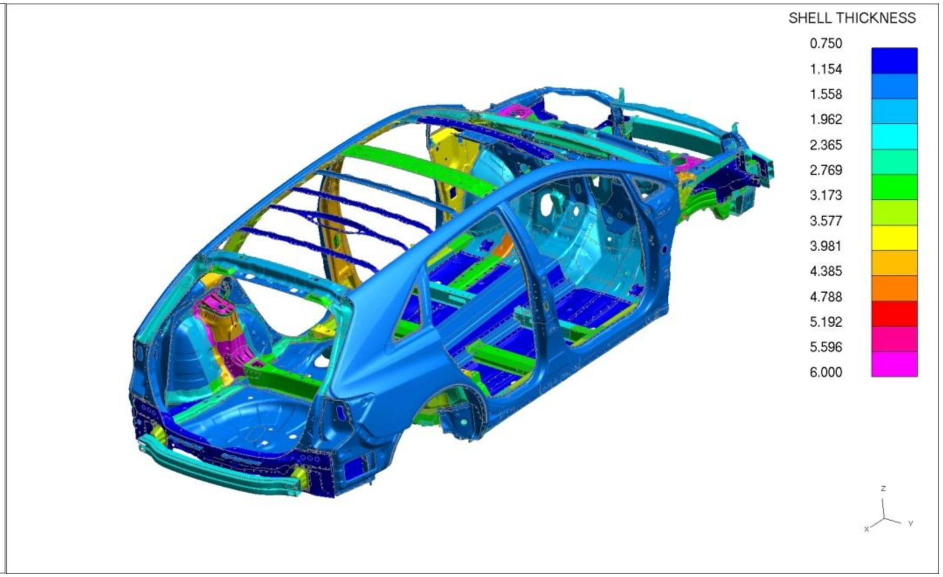
Adhesive

- The concept would use of Epoxy adhesive in addition to the Rivets for the purposes of the concept study the adhesive has not been implemented into the FEA models. The expected implications on the performance are detailed below, see recommendations.
- Global stiffness
  - Expected increase in stiffness (static) of 10-15%
  - Reduced loads in the Rivets
- Crashworthiness
  - Increased load capacity in sections during crash events
  - Reduced loading in the rivets

6.0 Aluminum BIW – Concept Description

- The concept has been developed from the steel BIW (with the aim of a similar assembly sequence)
- For the study the following bounds were selected on material thickness:
  - Extrusions (1.4mm-4mm)
  - Castings (2.5mm -10mm)
  - Stamped parts (0.9mm -3.0mm

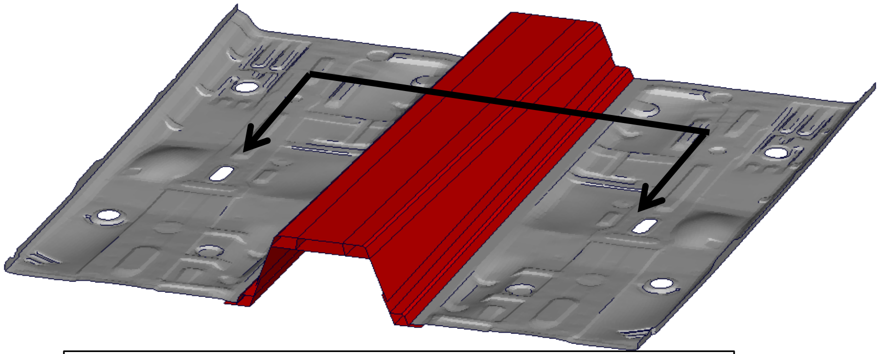


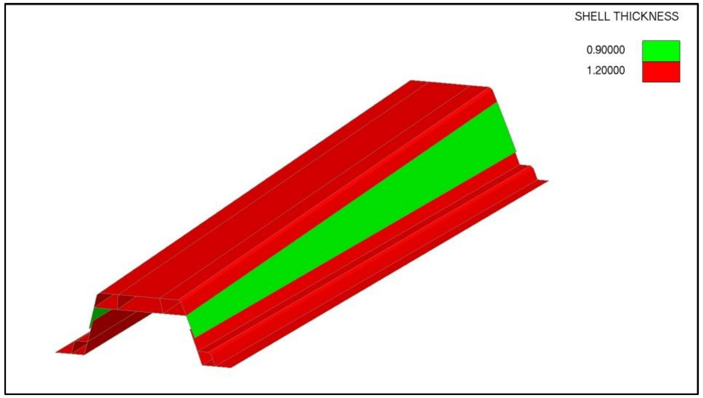


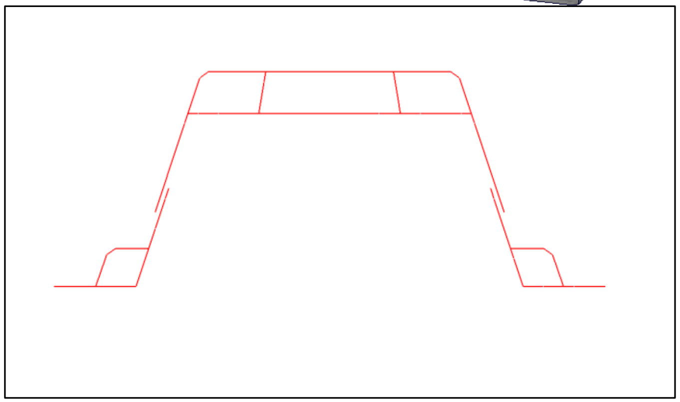
6.0 Aluminum BIW – Concept Description

Tunnel Extrusion

- The tunnel shape from the baseline floor is removed and replaced with the aluminum extrusion tunnel
- Concept requires further integration into the BIW sheet metal at the front/rear
- Extrusion profile is not optimized (potential increase in gauge may be required)





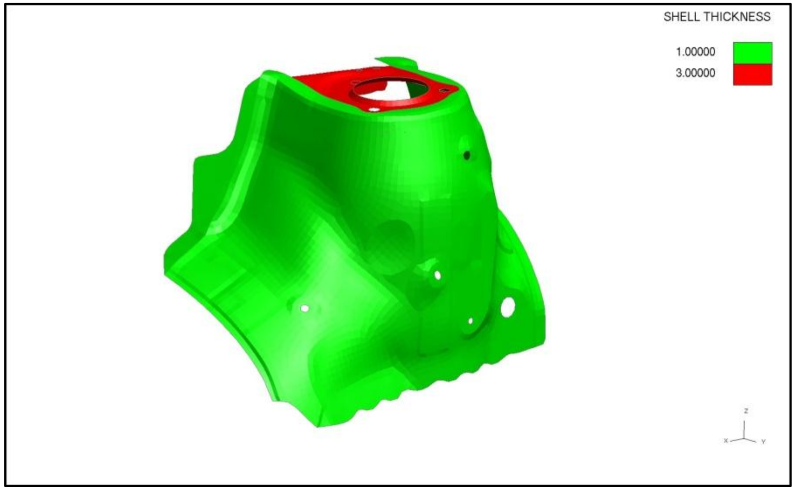


Extrusion tunnel cross section

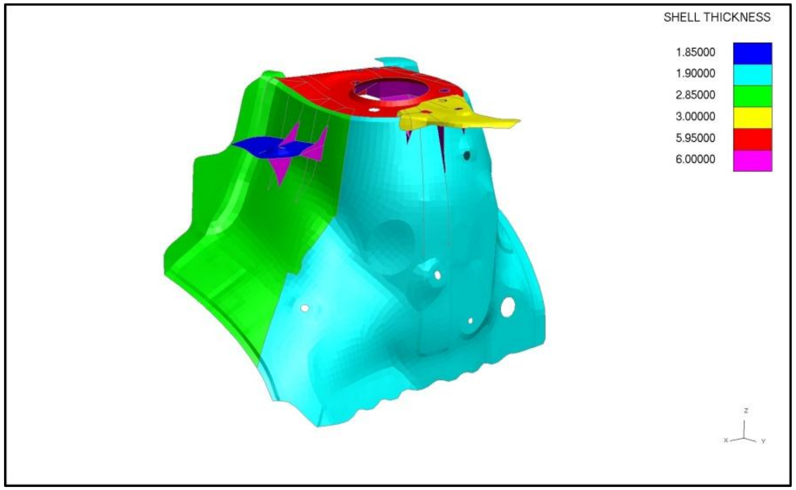
6.0 Aluminum BIW – Concept Description

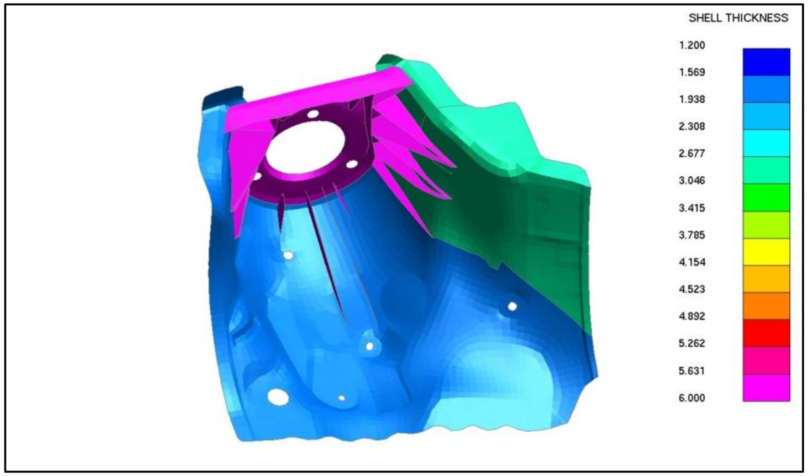
- **Shock Tower - Frontal**

Baseline (Steel)



Model 029
(Aluminum)

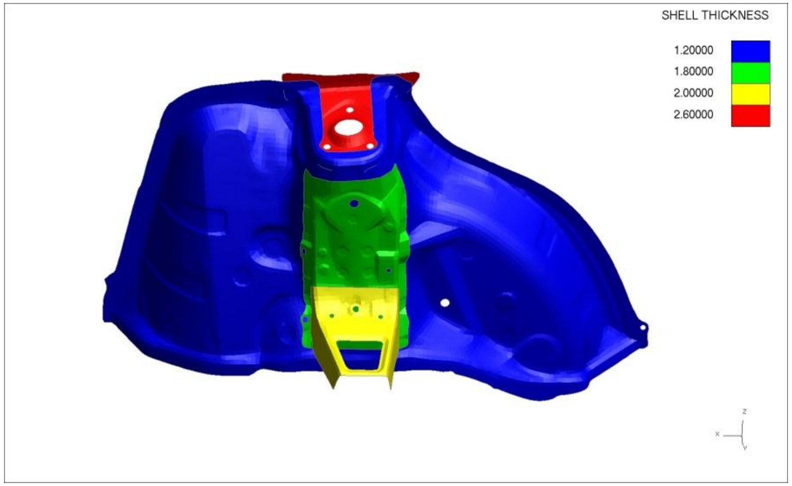


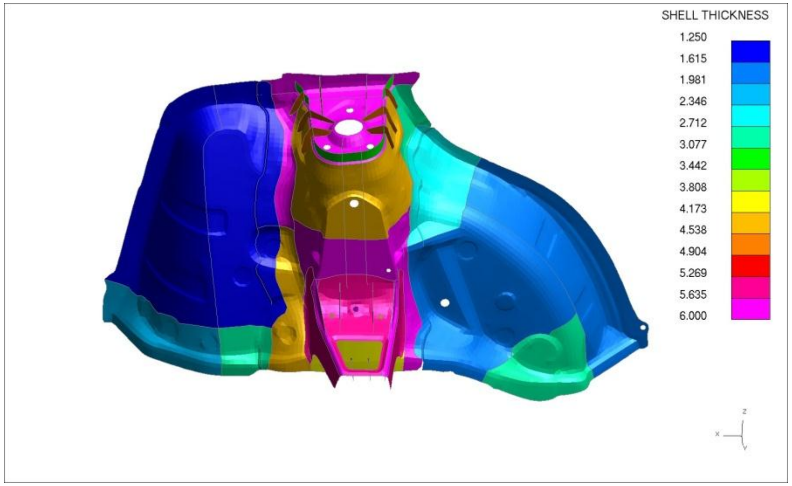


- Concept is for a 1 piece casting for the tower
- Brackets shown integral would change to bolt on

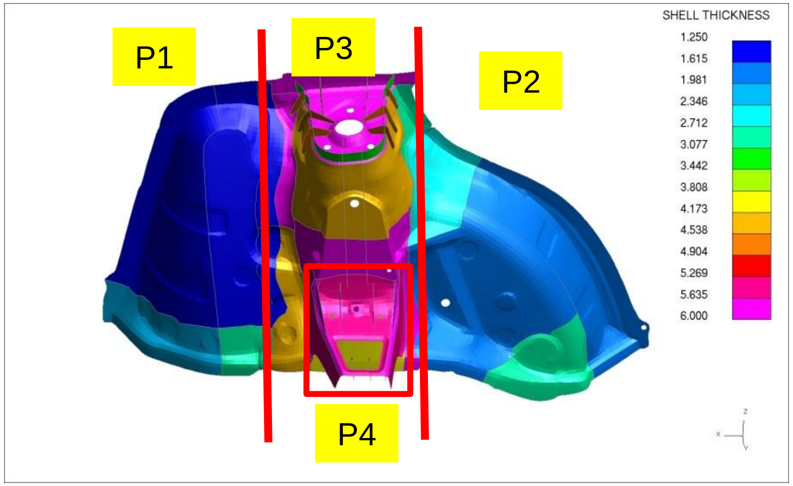
6.0 Aluminum BIW – Concept Description

- **Shock tower - rear**





- Concept is modelled as a 4 piece casting
- P1/2 have potential to go to stamping
- Complexity of P3/4 can be reduced

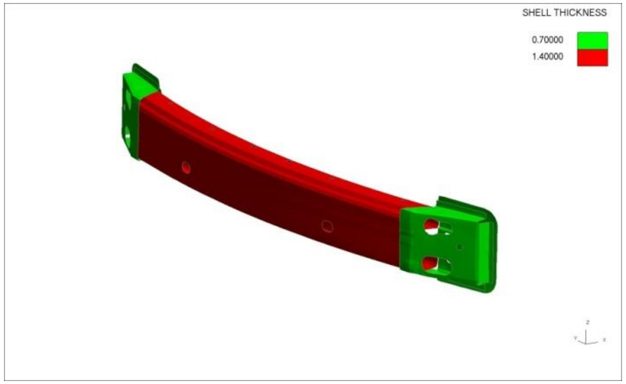


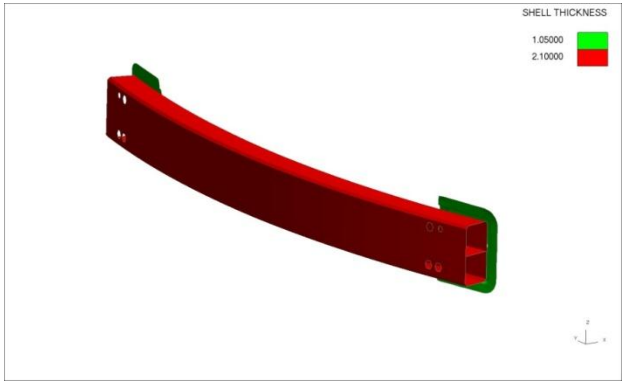
6.0 Aluminum BIW – Concept Description

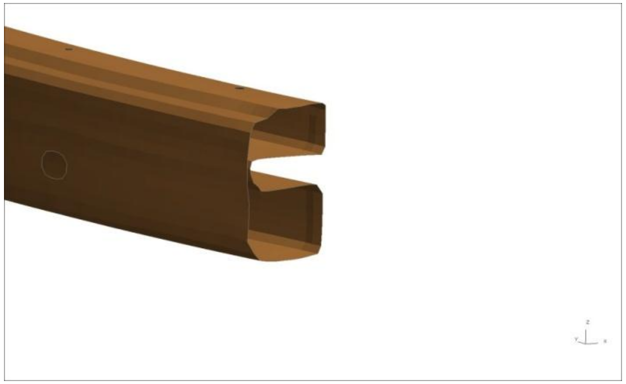
- Front Bumper

Baseline (Steel)

Model 029 (Aluminum)







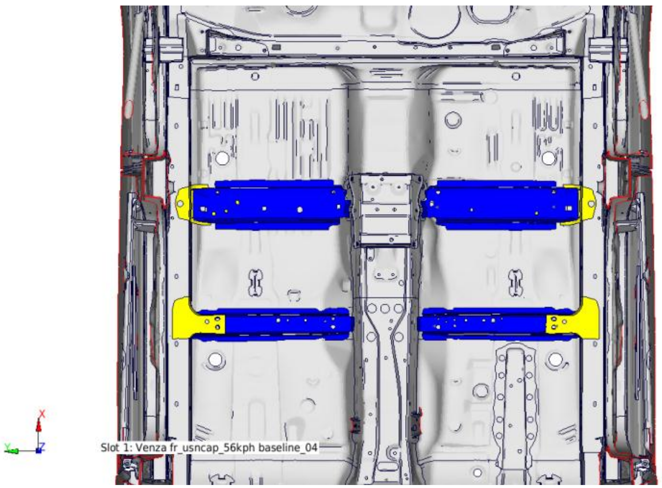
- Extruded section is not optimized (constant thickness in the concept)

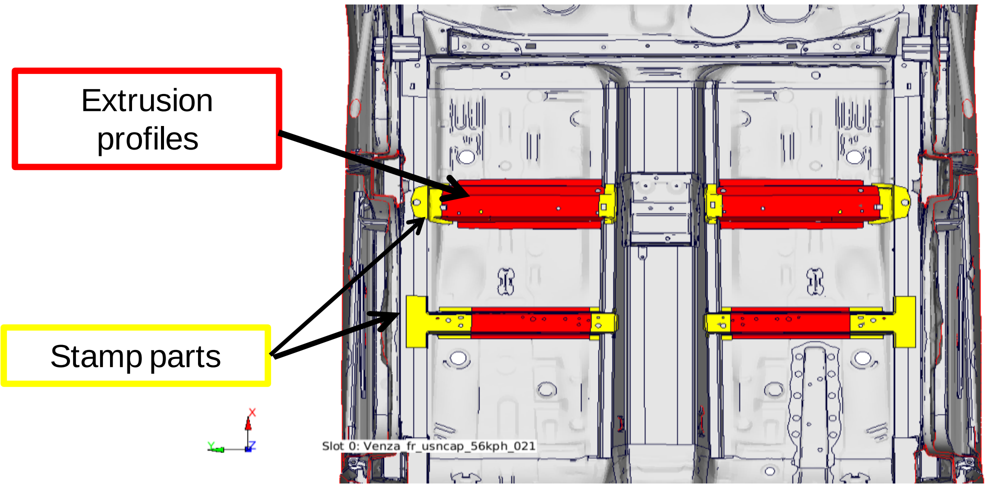
6.0 Aluminum BIW – Concept Description

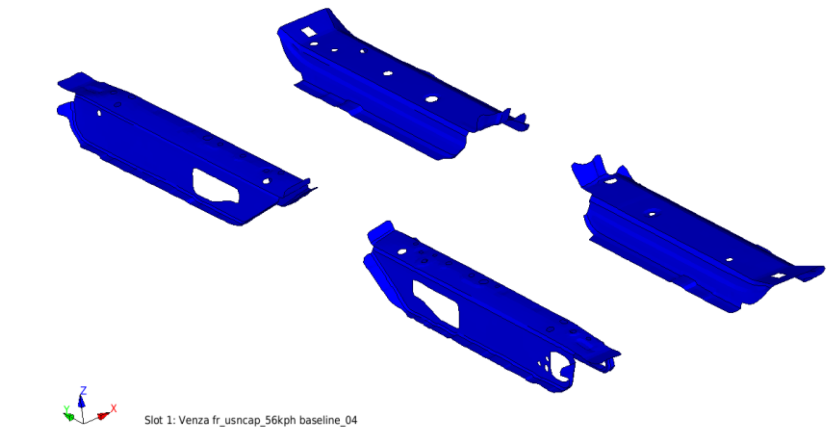
- Seat Cross Member

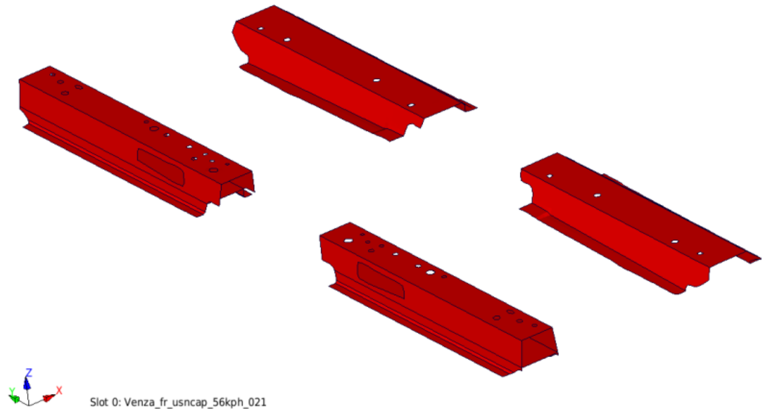
Baseline (Steel)

Model 029
(Aluminum)







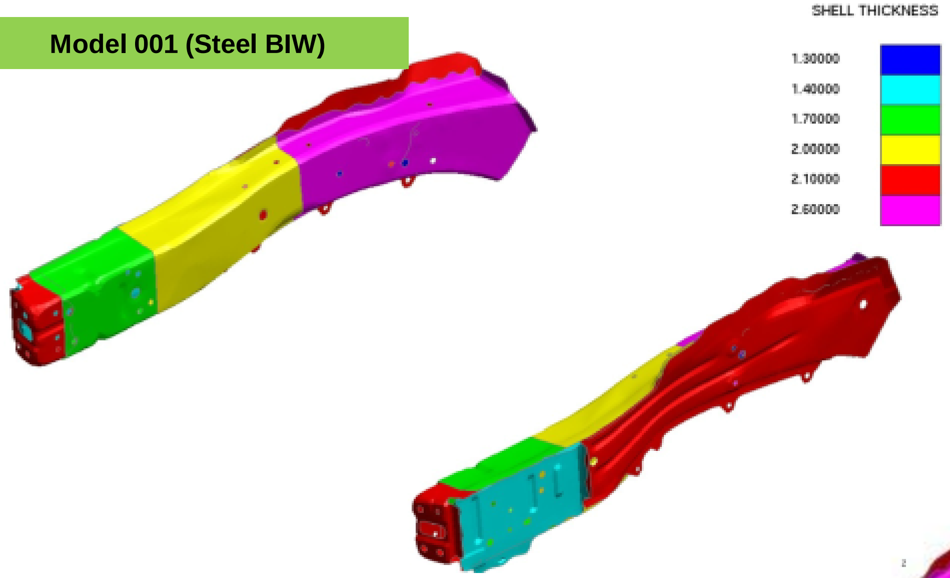


Seat Cross Member – Extrusion profiles with stamp part on the side for connections

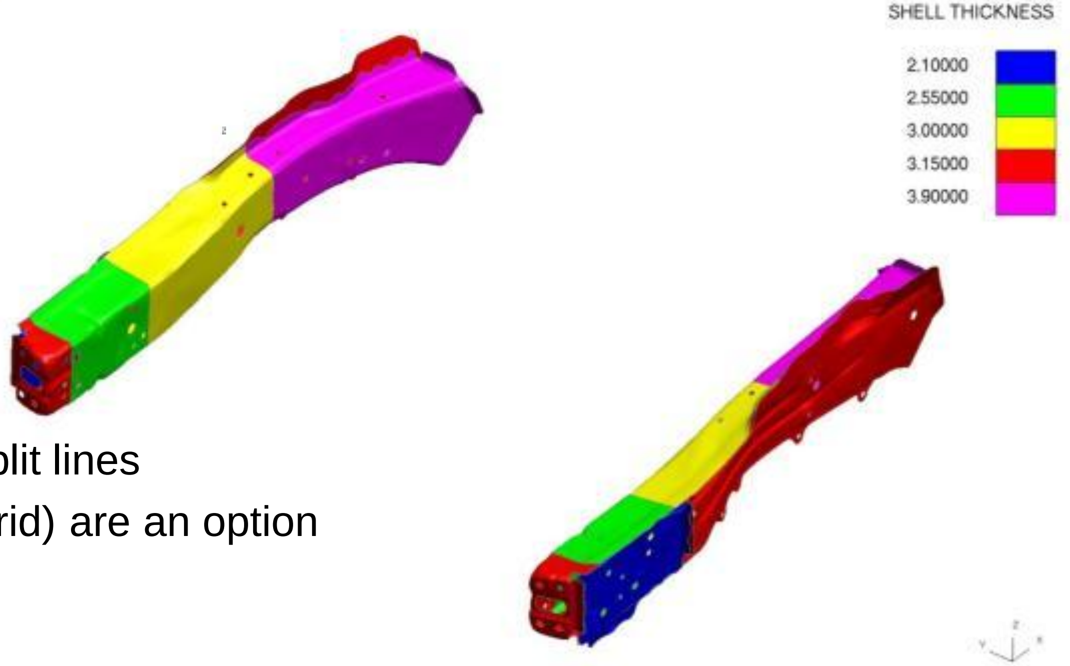
6.0 Aluminum BIW – Concept Description

- Front Rail Thickness Difference

Model 001 (Steel BIW)



Model 021 (Aluminum BIW)



- Concept follows the TWB VENZA steel split lines
- Other concepts (hydroform/extrusion/hybrid) are an option

6.0 Aluminum BIW – Concept Description

- Vehicle Mass

Area		Baseline System Mass	Optimzied Steel Model System Mass	Aluminum Model System Mass
System	Sub-system			
Closures	Door Frt	53.2	53.2	38.0*
	Door RR	42.4	42.4	31.0*
	Hood	17.8	10.1 (Aluminum)	10.1
	Tailgate	15.0	7.7 (Aluminum)	7.7
	Fenders	6.8	4.8 (Aluminum)	4.9
Mass Sub-Total		135.3	118.3	91.7
Sub-Total Savings Over Baseline		N/A	12.6%	32.2%
BIW	Underbody Asy (Floor)	40.2	32.0	20.7
	Front Structure	42.0	36.2	27.7
	Roof Asy	31.3	24.1	16.7
	Bodyside Asy	161.9	141.9	88.4
	Ladder Asy	102.6	90.2	66.0
Mass Sub-Total		378.0	324.4	219.5
Sub-Total Savings Over Baseline		N/A	14.2%	41.9%
BIW Extra	Radiater Vertical Support	0.7	0.7	0.7
	Compartment Extra	4.5	3.2	3.3
	Shock Tower Xmbr Plates	3.0	4.4	1.5
Mass Sub-Total		8.2	8.3	5.5
Sub-Total Savings Over Baseline		N/A	-1.2%	32.9%
Bumper	Front Bumper	5.1	4.7	2.8
	Rear Bumper	2.4 (Aluminum)	2.4 (Aluminum)	2.4
Mass Sub-Total		7.5	7.1	5.2
Sub-Total Savings Over Baseline		N/A	5.3%	30.7%
Mass System Total		528.9	458.1	321.9
Total Mass Saving Over Baseline		N/A	13.4%	39.1%
* Directional Mass Only				

7.0 Performance Summary NVH

- Vehicle NVH

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%

Comment:

Stiffness increased to higher than steel base stiffness.

8.0 Performance Summary Crashworthiness

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

Model Description

- Model 001 = Base Model (Steel BIW) :1_fmvss208_usncap_toyota_venza_06_050_fix_shear_failure_r7_04.key
- Model 029 = Aluminum BIW Model: 1_toyota_venza_fr_usncap_029.key

Result Summary

No.	Measurement	Variation	
		001	029
1	**G-Pulse**	1st peak=16.0g @ 9.4ms 2nd peak=45.9g @ 44.9ms	1st: 11.6g @ 11.5ms max: 49.7g @ 42.0ms
	Driver		
	Passenger		
2	**Dynamic Crush**	610.5	572.8
	Driver		
	Passenger		
3	**Dash Panel Intrusion**		
	Driver Footwell	56.7	27.8
	Driver Toepan LH	131.1	58.4
	Driver Toepan Ctr	147.2	56.2
	Driver Toepan RH	105.2	68
	Brake Pedal		
	Left IP	15.5	4
	Right IP	40.8	5.3
	Door (A-Pillar)	2.3	3.9
4	**Extra Info**		
	Time to Zero Velocity (ms)	60.5	55.7

Summary

- The crash pulse has increased over the base VENZA
- Intrusions and dynamic crush are both reduced
- Countermeasures recommended to increase efficiency of the crash pulse (increased force early in the event) and some measures to allow more dynamic crush (packaging of engine bay / more dash intrusion)

8.0 Performance Summary Crashworthiness

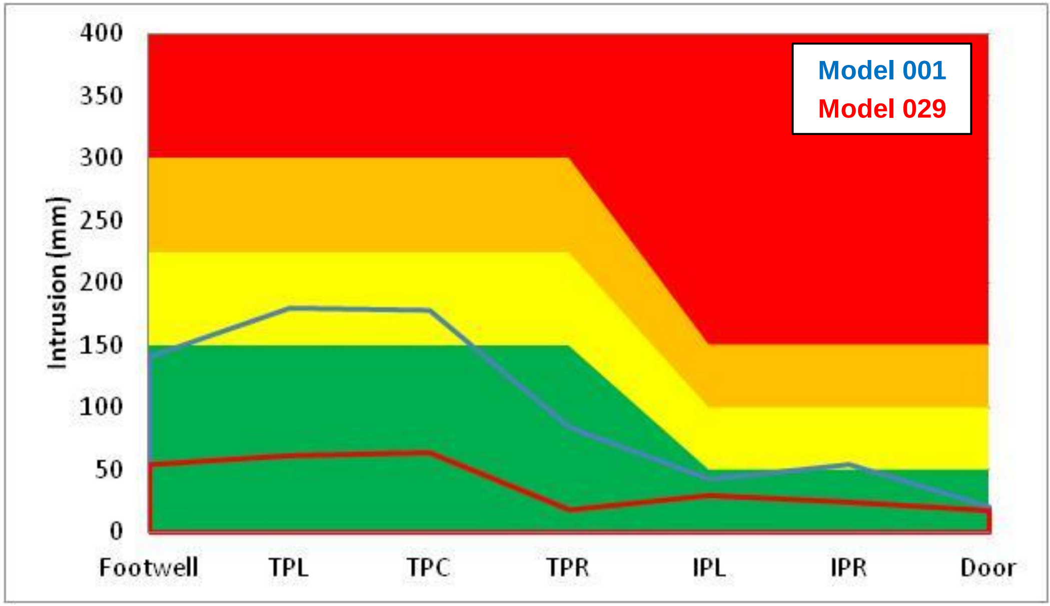
IIHS Frontal ODB Impact 35MPH

Model Description

- ❑ Model 001 = Base Model (Steel BIW) : 2_fmvss208_odb_toyota_venza_06_050_shear_failure_04.key
- ❑ Model 029 = Aluminum BIW Model: 2_toyota_venza_fr_euncap_029.key

Result Summary

No.	Measurement	Variation	
		001 (Steel BIW)	029 (Aluminum BIW)
1	**Dynamic Crush**		
	Driver	1082.9	1010.6
	Passenger		
2	**Dash Panel Intrusion**		
	Driver Footwell	141.6	54.5
	Driver Toepan LH	180.7	61.7
	Driver Toepan Ctr	179.0	64.1
	Driver Toepan RH	84.6	18.1
	Brake Pedal		
	Left IP	42.8	29.7
	Right IP	54.7	24.3
	Door (A-Pillar)	20.5	17.5
3	**Extra Info**	99.3	95.5
	Time to Zero Velocity (ms)		

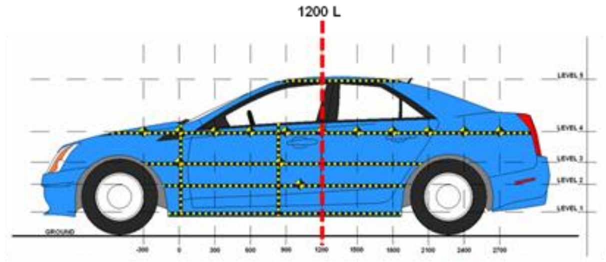


Summary

- ❑ Intrusions are all reduced compared to the base design
- ❑ Trade off against crash pulse in the FRB is possible

8.0 Performance Summary Crashworthiness

FMVSS214 Side MDB Impact



Measure Location : Longitudinal 1200 Coord.

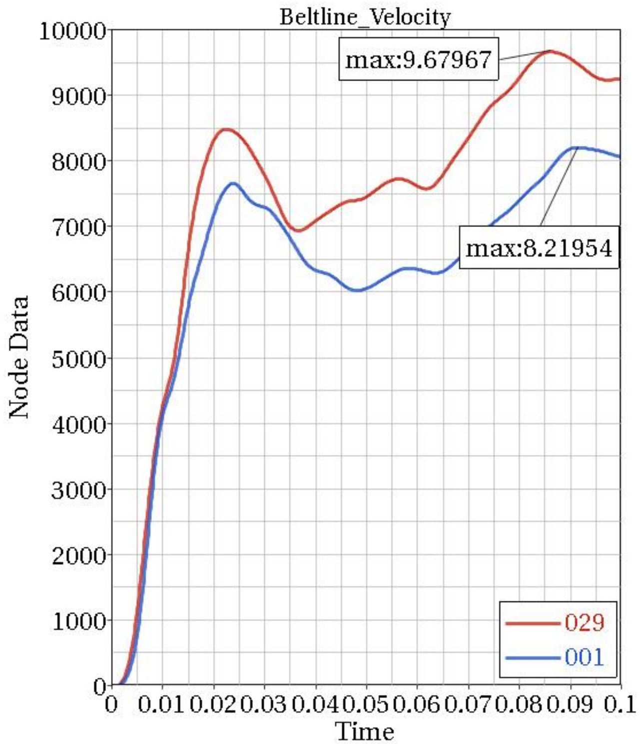
Level	Description	Height Above Ground (mm)
1	Sill Top Height	328
2	Occupant H-Point Height	630
3	Mid-Door Height	671
4	Window Sill Height	1020
5	Window Top Height	1531

Model Description

- ❑ Model 001 = Base Model (Steel BIW) : 3_fmvss214_sincap_toyota_venza_06_050_fix_shear_04.key
- ❑ Model 029 = Aluminum BIW Model: 3_toyota_venza_si_sincap_alu_029.key

Result Summary

Measured Level	001	029
Level-5	6.0	-9.6
Level-4	165.5	130.8
Level-3	245.0	187.0
Level-2	233.3	175.0
Level-1	133.7	73.3
* All measured points are taken at the vehicle exterior point		



Summary

- ❑ Predicted intrusions are similar to the baseline
- ❑ Beltline velocity has increased
- ❑ High strains in the B pillar are a concern possible countermeasures include
  - ❑ Higher grade material for the reinforcement (reduction in plastic strain)
  - ❑ Use of a Boron steel reinforcement .
  - ❑ A different reinforcement concept that results in less strain localization

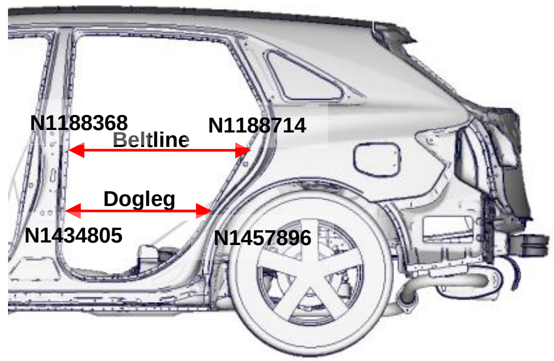
50MPH MDB REAR IMPACT

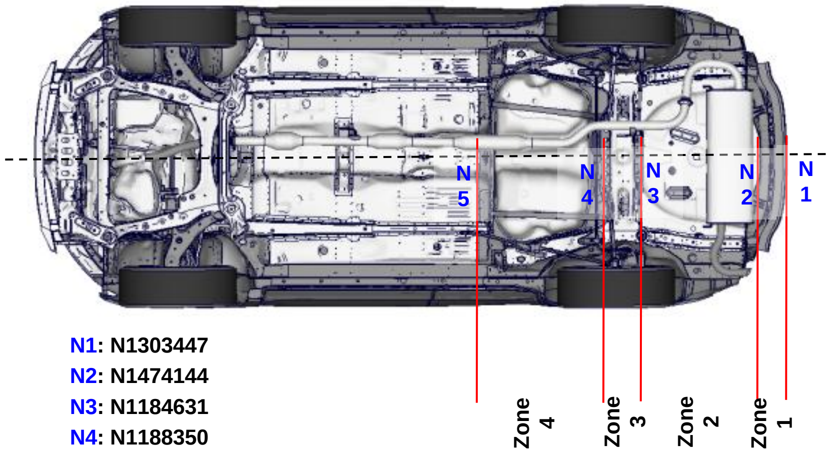
Model Description

- ❑ Model 001 = Base Model (Steel BIW) : 5_Rear_FMVSS301_toyota_venza_lh_06_050_09_shear_failure_04.key
- ❑ Model 029 = Aluminum BIW Model: toyota_venza_fmvss301_rimp_aluminum_029.key

Result Summary

No.	Measurement	Variation	
		Model 001 (Steel BIW)	029 (Aluminum BIW)
1	**Under Structure Zone Deformation (mm)**		
	Zone 1 Deformation	140.2	98.6
	Zone 2 Deformation	292.5	436.3
	Zone 3 Deformation	0.00	50.7
	Zone 4 Deformation	0.00	27.9
2	**Door Opening (mm)**		
	Beltline	1.90	10.3
	Dogleg	0.20	13.8





N1: N1303447
N2: N1474144
N3: N1184631
N4: N1188350
N5: N1735675

Summary
- ❑ Performance is degraded in the zone 2 area compared to the base VENZA
- ❑ Deformation in the area of the fuel filler and filler pipe is main area of concern
- ❑ Possible countermeasures – increased gauge/thickness in rear rail / bumper system

8.0 Performance Summary Crashworthiness

FMVSS216a Roof Crush

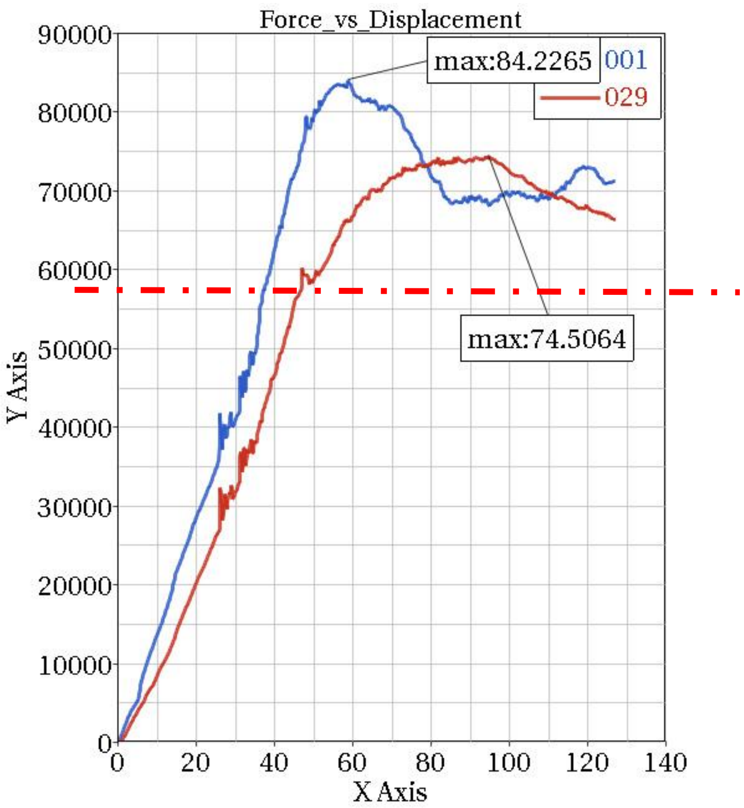
Model Description

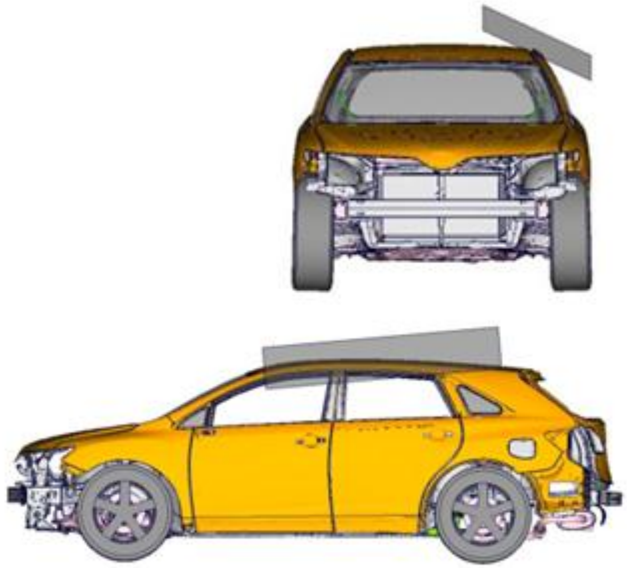
- ❑ Model 001 = Base Model (Steel BIW) : toyota_venza_roof_crush_fmvss216a_r006_050_05_shear_failure_04.key
- ❑ Model 029 = Aluminum BIW Model: toyota_venza_roof_crush_fmvss216a_029.key

Mass of CAE Model 029 = 1445.4 kg

Roof crush resistance force = 4 x UVW = 57.8 kN

Maximum Load = 74.5 kN





Summary

❑ Force requirement is met

Force Vs Displacement

9.0 Summary

- A structural feasibility study has been performed to create an aluminum BIW concept based on the steel VENZA FEA model.
- The concept is a pressed /extruded/cast aluminum structure connected using self piercing rivets and structural bonding.
- The potential mass savings in the 35 – 40% range over the base steel BIW has been shown. However, the study has not considered the following items all of which have the potential to reduce the potential mass saving:
  - Formability of the panels (this will drive changes to the geometry)
  - Material or rivet failure (a concern for the crash load cases)
  - Manufacturing (assembly considerations, access for rivet guns etc.)
  - Other load cases (that will effect the structural performance)
    - BIW durability
    - Other crash load cases (e.g. IIHS side / new FMVSS 214 etc)
    - Panel dentability
    - NVH considerations (local dynamic stiffness/acoustic etc.)
  - The effect of the Adhesive on the structural performance
  - Environmental considerations (temperature / serviceability etc.)

10.0 Recommendations and Next Steps

The recommendations and next steps for the project are detailed below for discussion:

1. **Design Feasibility Study on the Concept (to include the following)**
   - Formability of panels
   - Material selection for panels/extrusions/castings
   - Assembly feasibility
2. **Development of the Concept (Phase 2)**
   - Incorporate the learning's from the design feasibility study
   - Update material models and perform study to assess potential for failure in the base material and the rivets/bonding (material data/testing is required)
   - Investigate alternative concepts for the front rails / B pillar
   - Further optimize the body structure
   - Improve the rear crash performance
3. **Creation of Promotional Materials**
   - Information from 1 and 2 above
   - Potential demonstrator parts – including a build/test phases.

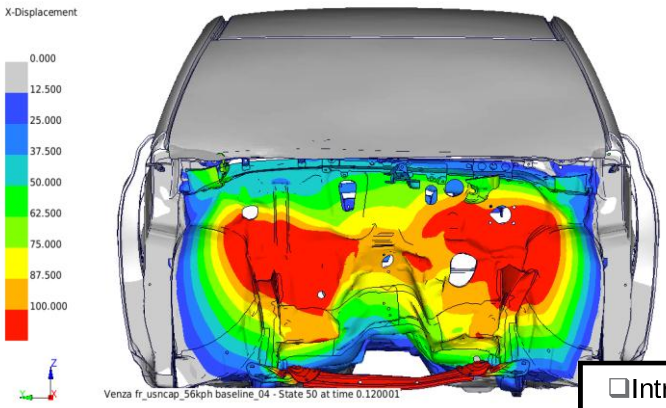
Toyota VENZA
Appendix A

Crashworthiness Details

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

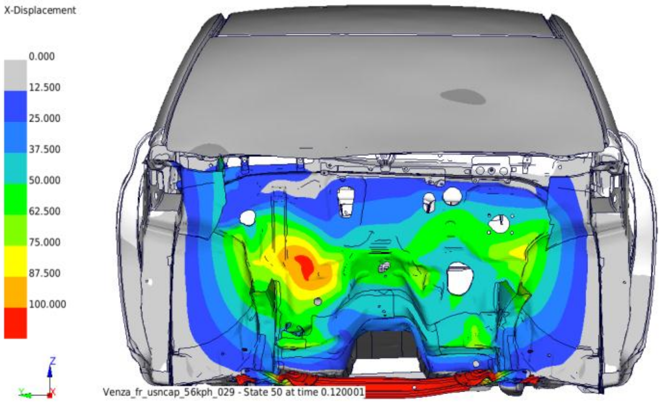
Dash Panel Intrusion Comparison

Model 001 (Steel BIW)



❑Intrusion is severe on all dash panel area.

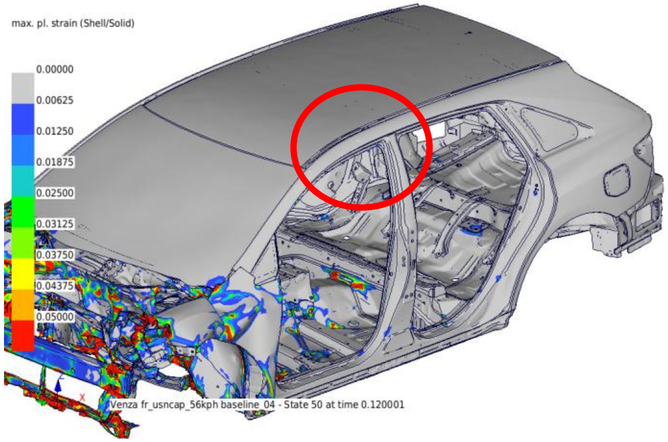
Model 029 (Aluminum BIW)



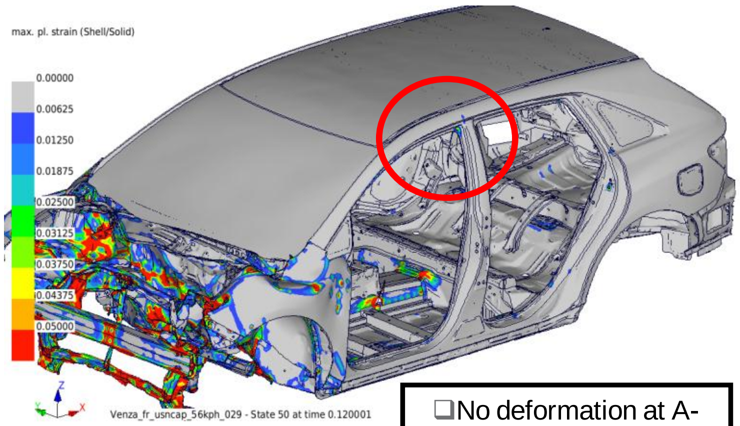
❑Dash panel intrusion is lower compared to the baseline

A-Pillar Deformation Comparison

Model 001 (Steel BIW)



Model 029 (Aluminum BIW)

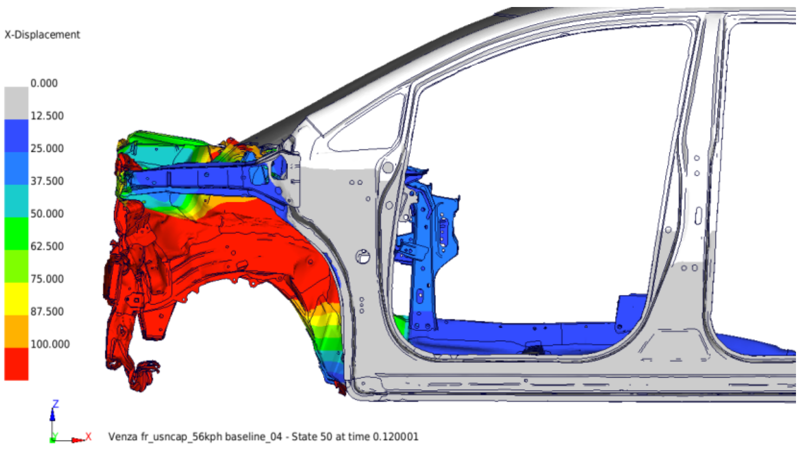


❑No deformation at A-Pillar is observed in both model.

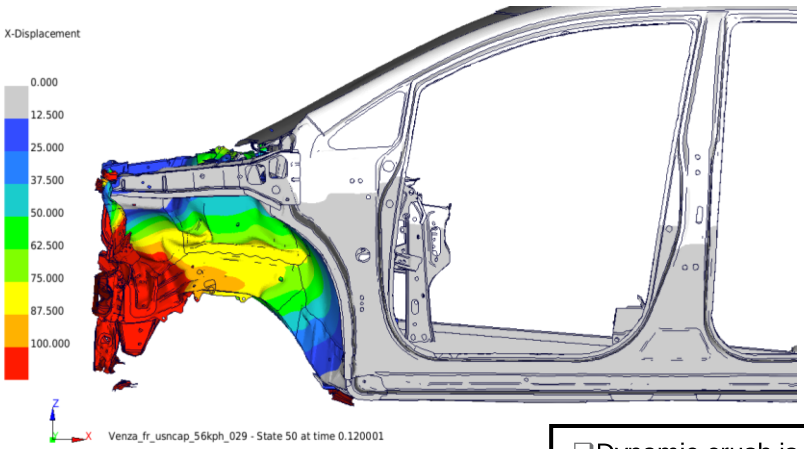
FMVSS208 - 35mph Frontal Rigid Barrier (FRB) Impact (USNCAP)

Dynamic Crush

Model 001 (Steel BIW)



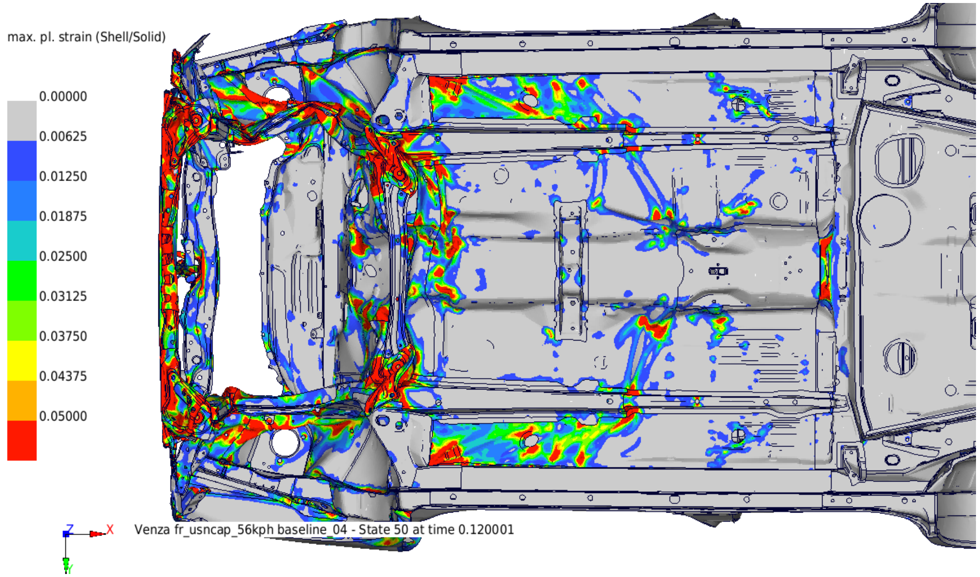
Model 029 (Aluminum BIW)



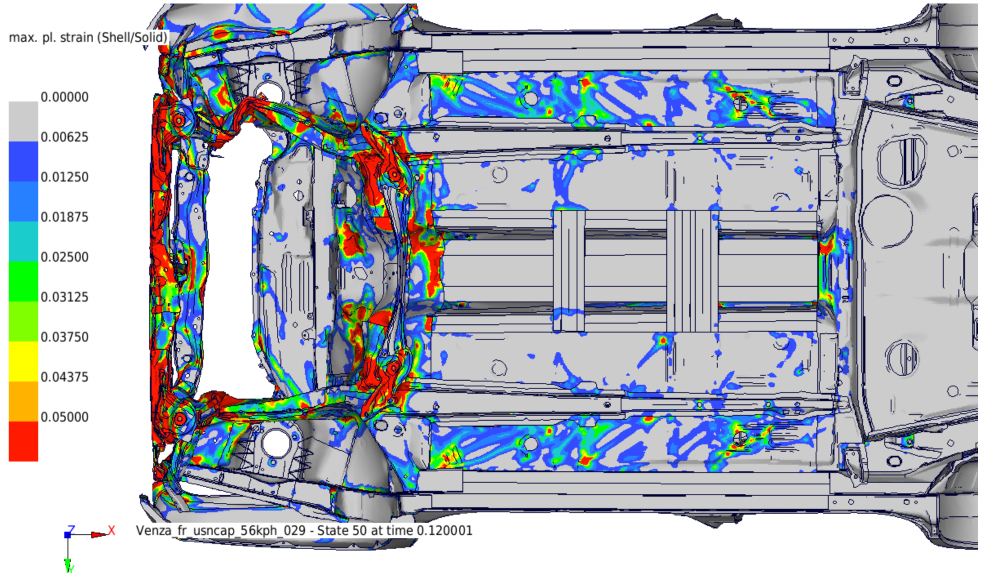
- ❑Dynamic crush is lower than the baseline

Bottom View :Plastic Strain

Model 001 (Steel BIW)



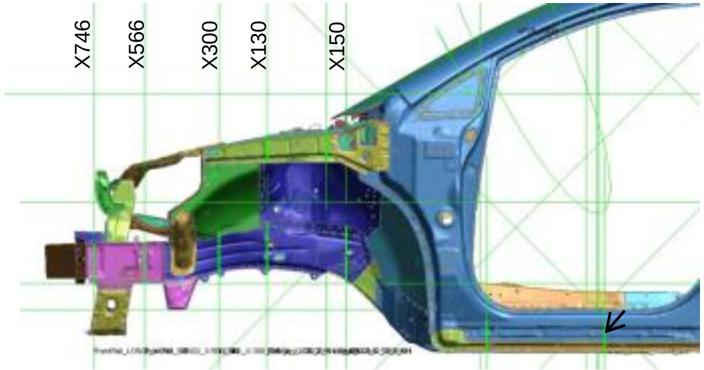
Model 029 (Aluminum BIW)

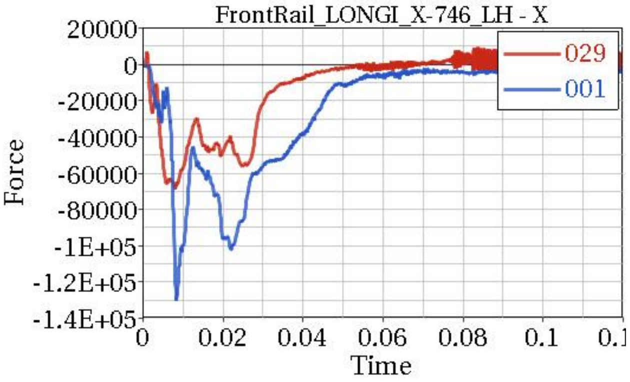


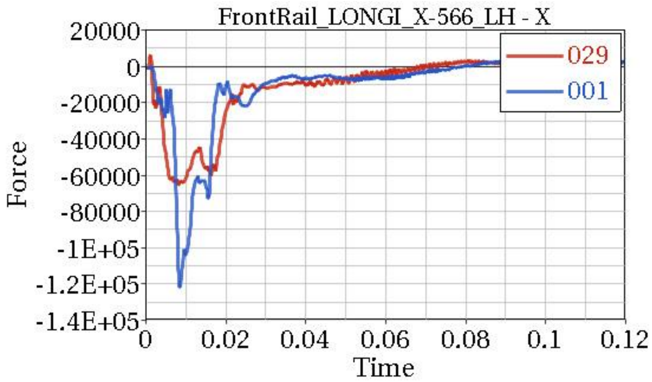
FMVSS208 - 35mph Frontal Rigid Barrier (FRB) Impact (USNCAP)

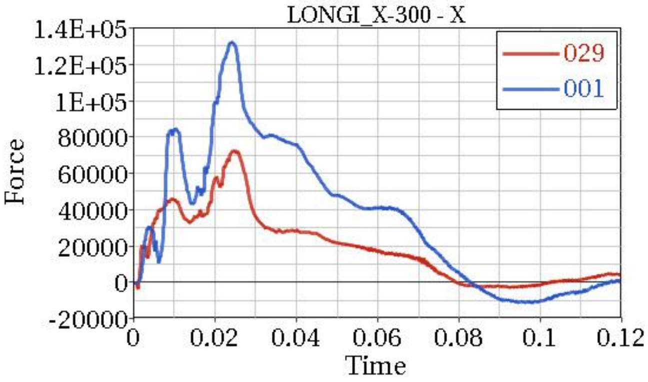
Section Force Comparison

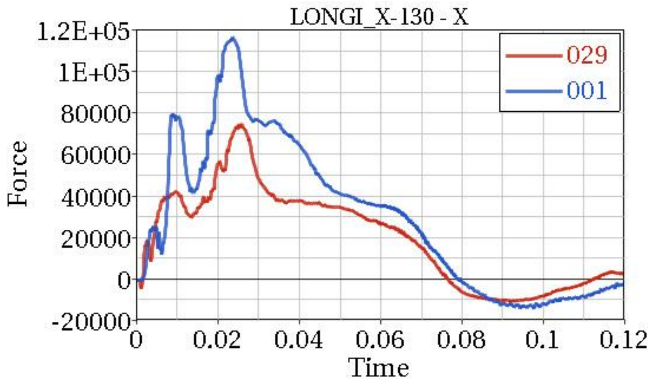
Driver Side (LH)

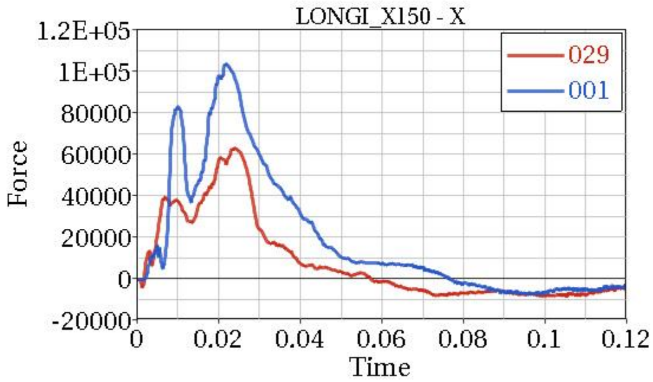








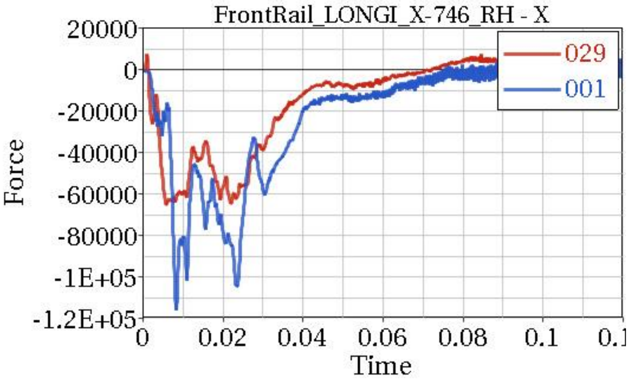


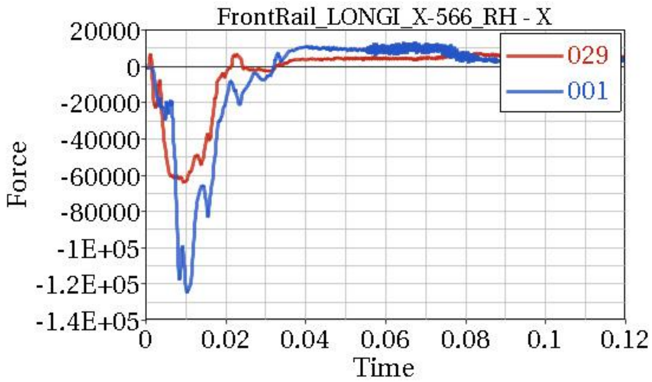


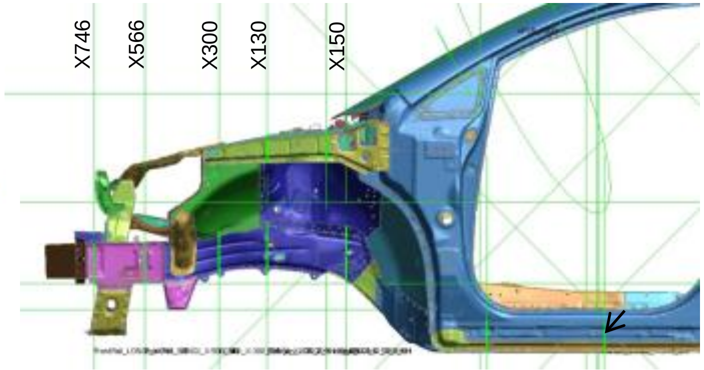
FMVSS208 - 35mph Frontal Rigid Barrier (FRB) Impact (USNCAP)

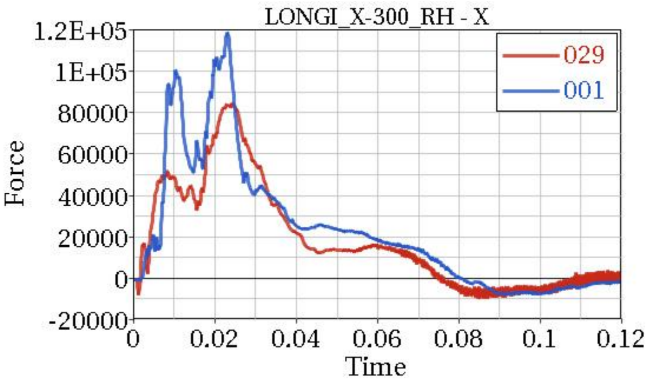
Section Force Comparison

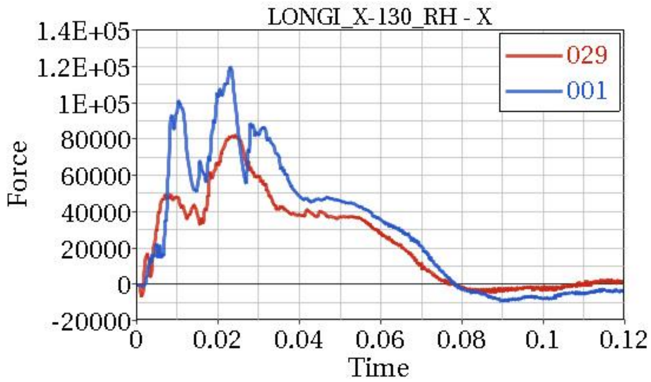
Passenger Side (RH)

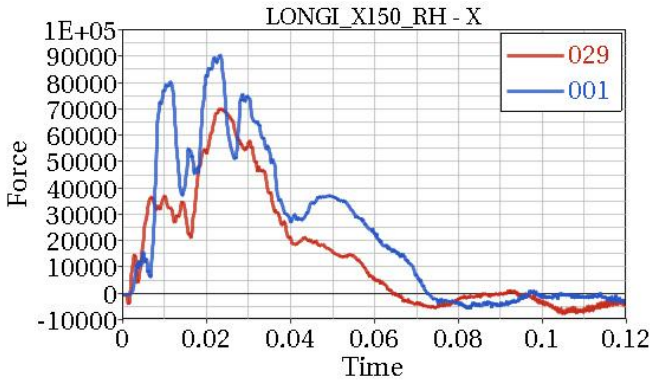






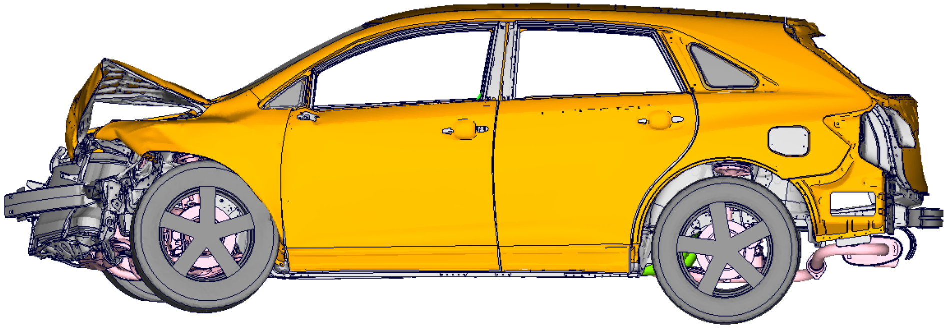


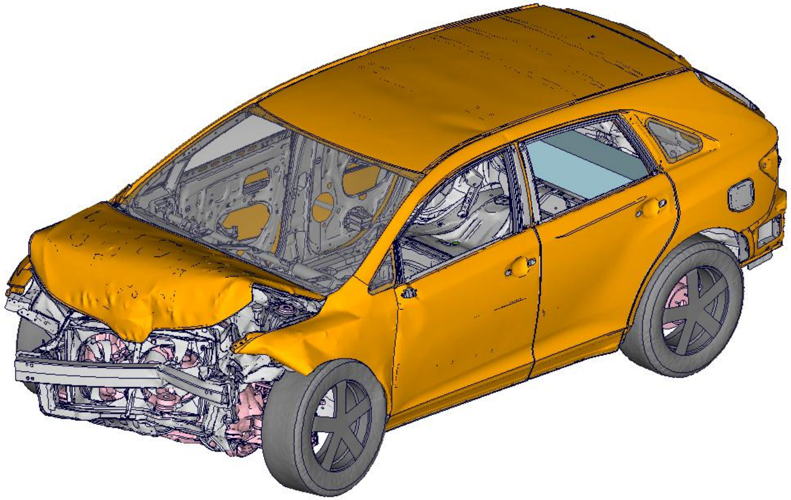


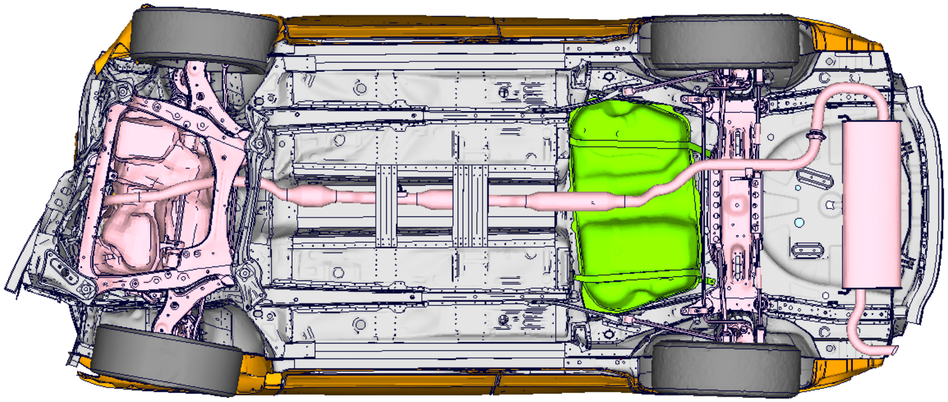


IIHS Frontal ODB Impact

Overall view



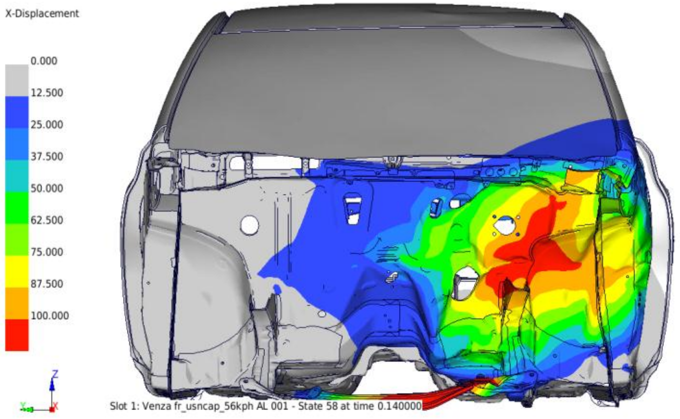




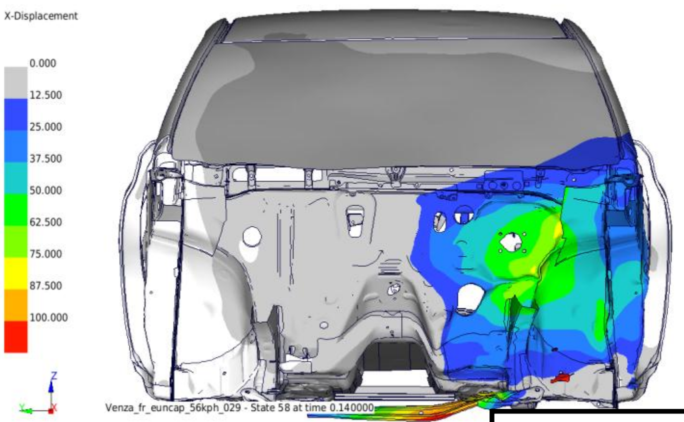
IIHS Frontal ODB Impact

Dash Panel Intrusion Comparison

Model 001 (Steel BIW)



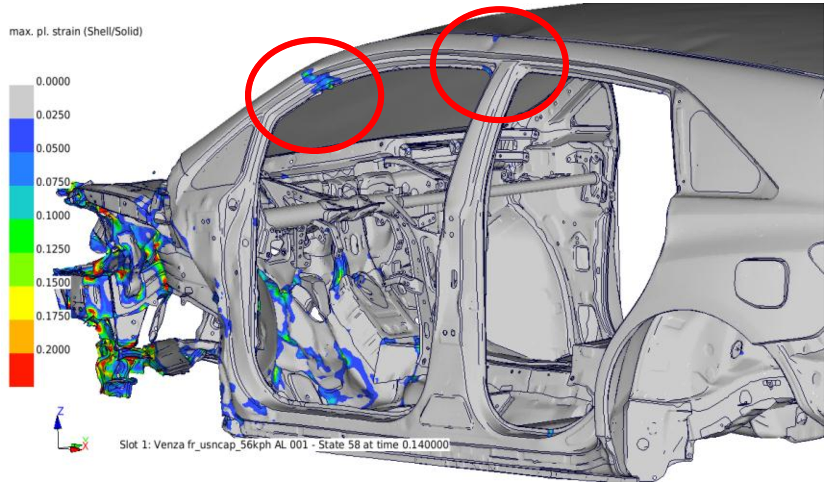
Model 029 (Aluminum BIW)



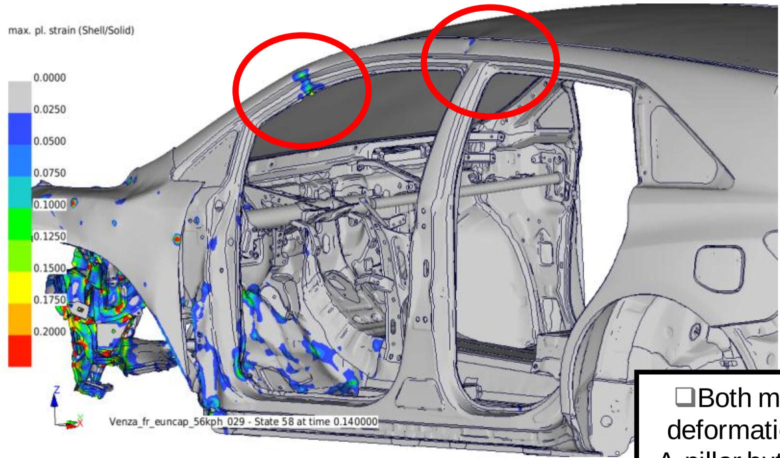
❑Dash panel intrusion lesser than baseline

A-Pillar Deformation Comparison

Model 001 (Steel BIW)



Model 029 (Aluminum BIW)

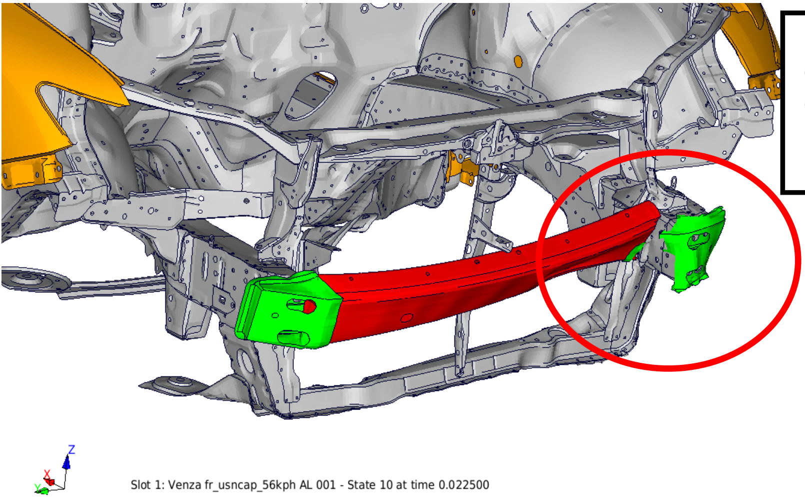


❑Both model has deformation on the A-pillar but lesser on model 029

IIHS Frontal ODB Impact

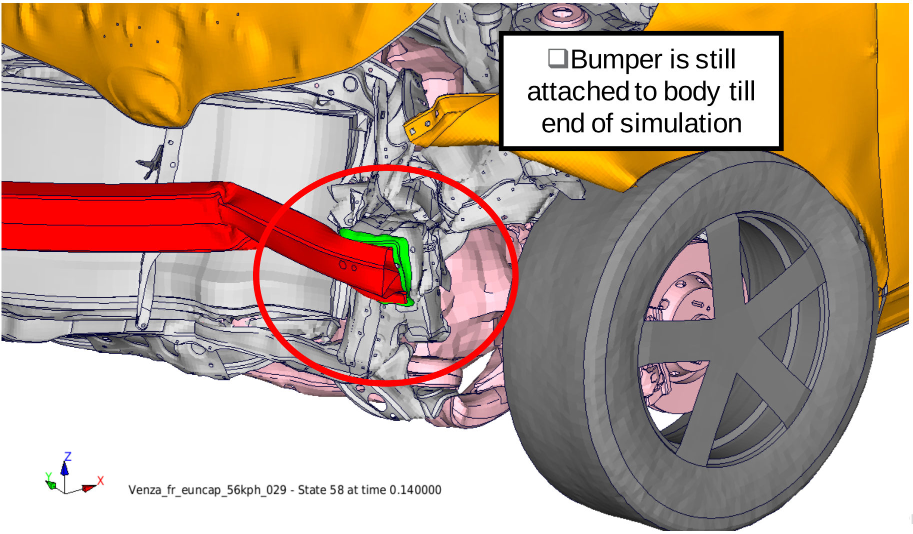
Bumper Beam

Model 001 (Steel BIW)



❑ bumper beam detached @ 22.5ms causing less energy absorption by the bumper beam

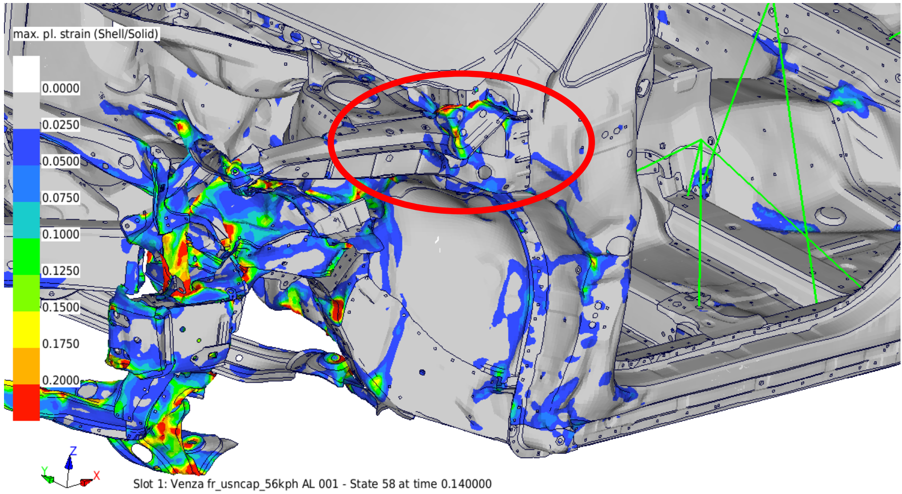
Model 029 (Aluminum BIW)



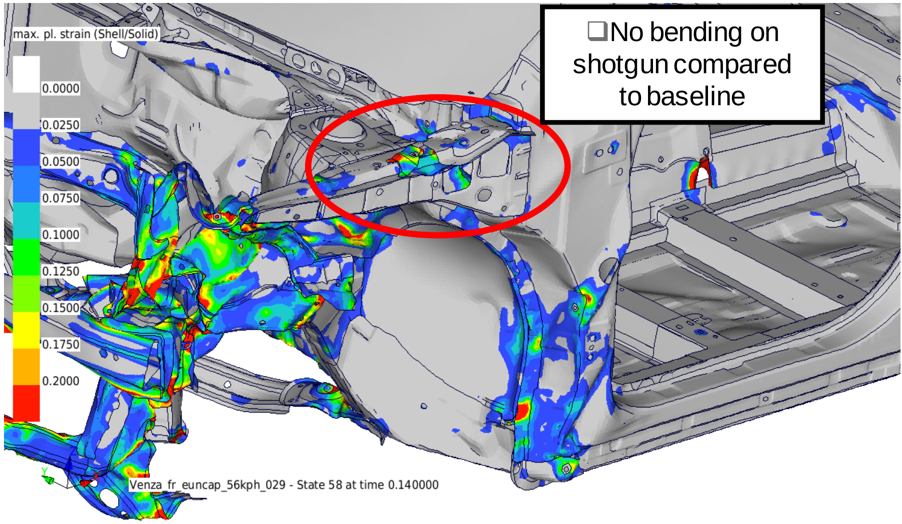
❑Bumper is still attached to body till end of simulation

Shotgun

Model 001 (Steel BIW)



Model 029 (Aluminum BIW)

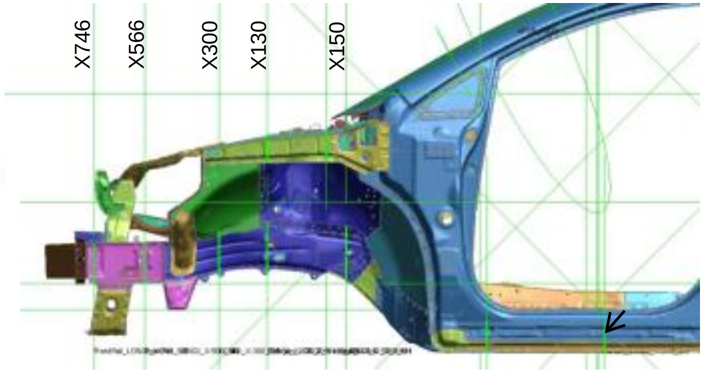


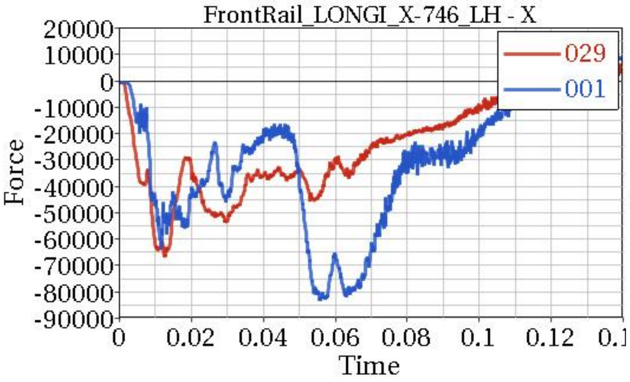
❑No bending on shotgun compared to baseline

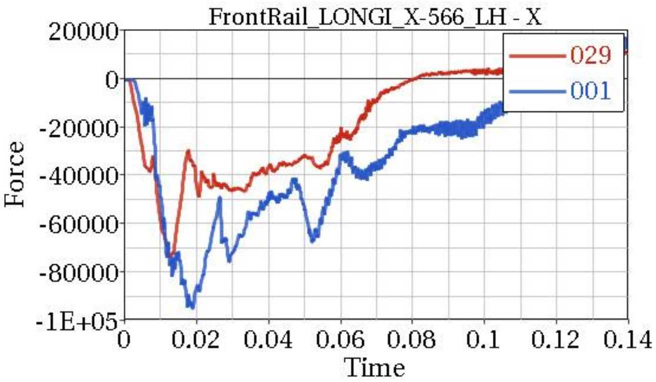
IIHS Frontal ODB

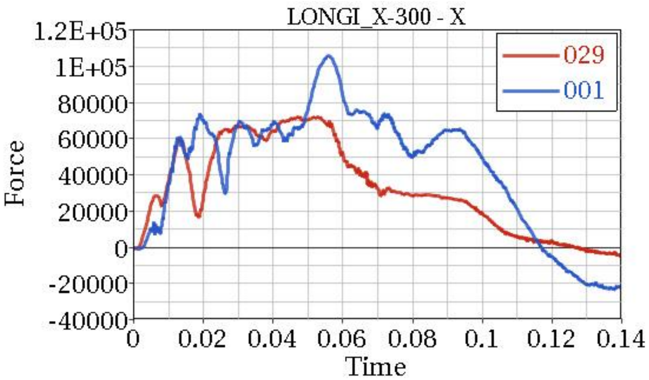
Section Force Comparison

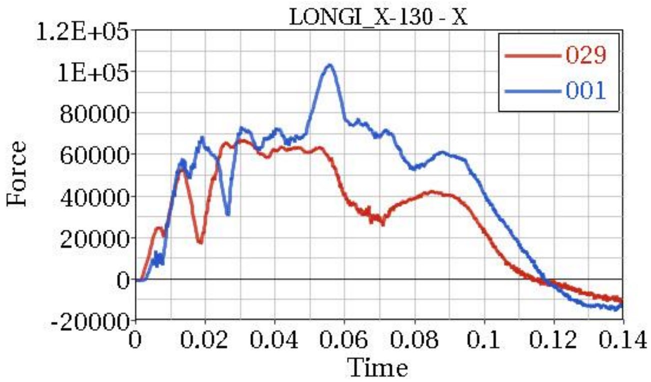
Driver Side (LH)

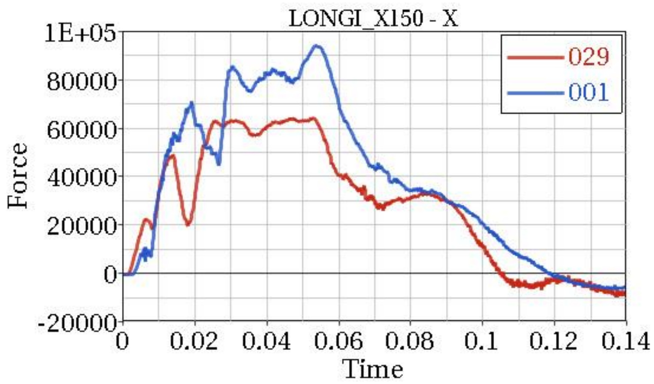








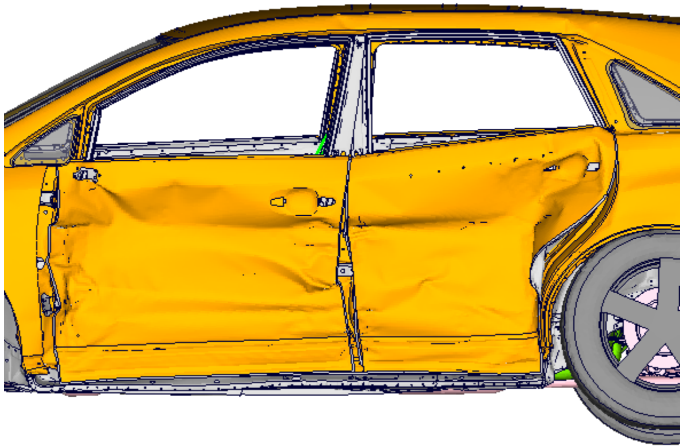




FMVSS214 Side MDB Impact

Door Deformation Comparison

Model 001 (Steel BIW)



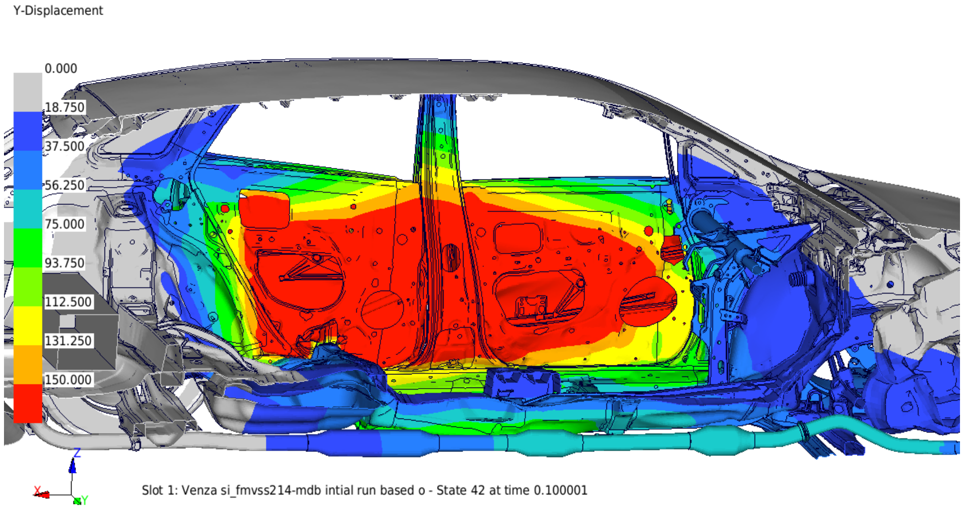
Model 029 (Aluminum BIW)

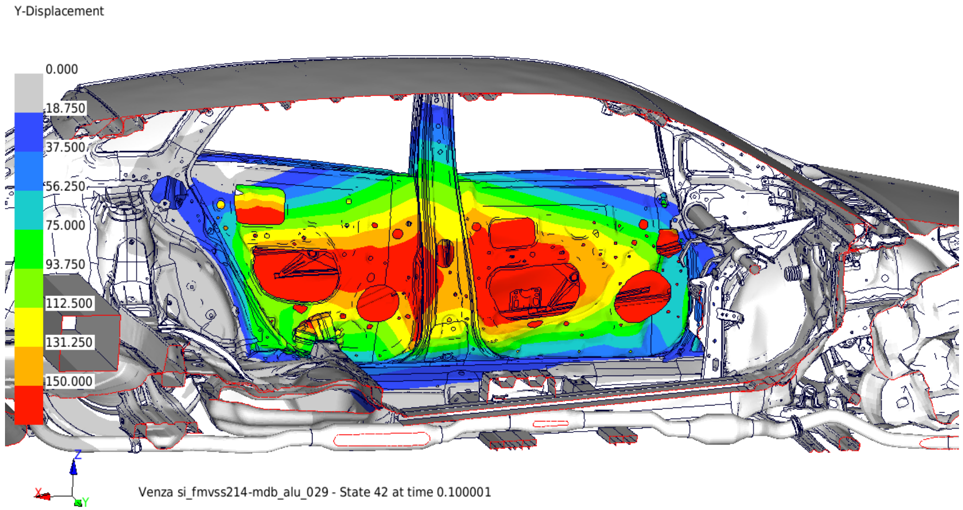
FMVSS214 Side MDB Impact

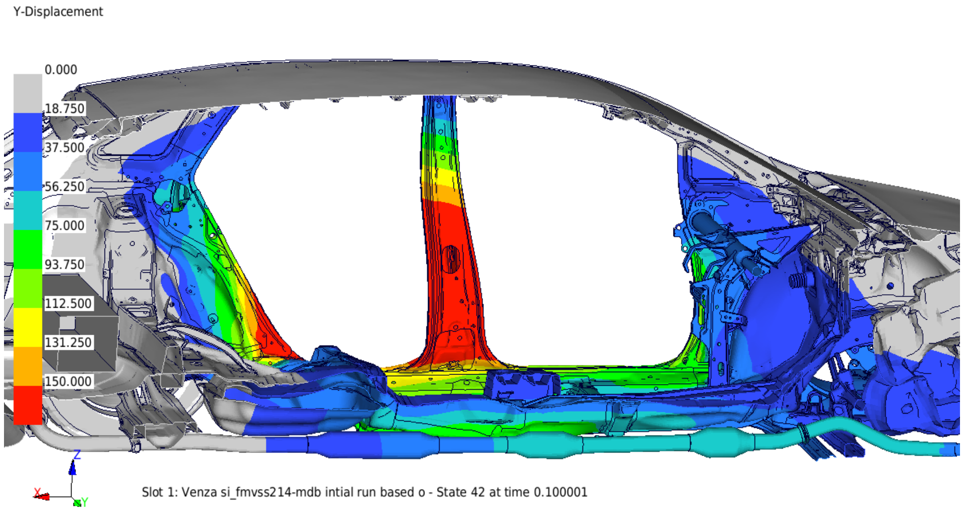
Intrusion Comparison

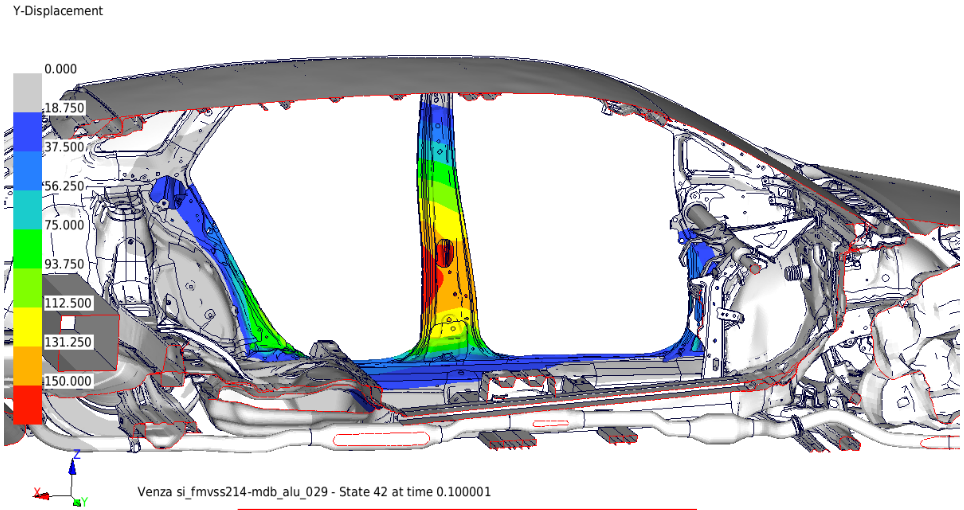
Model 001 (Steel BIW)

Model 029 (Aluminum BIW)









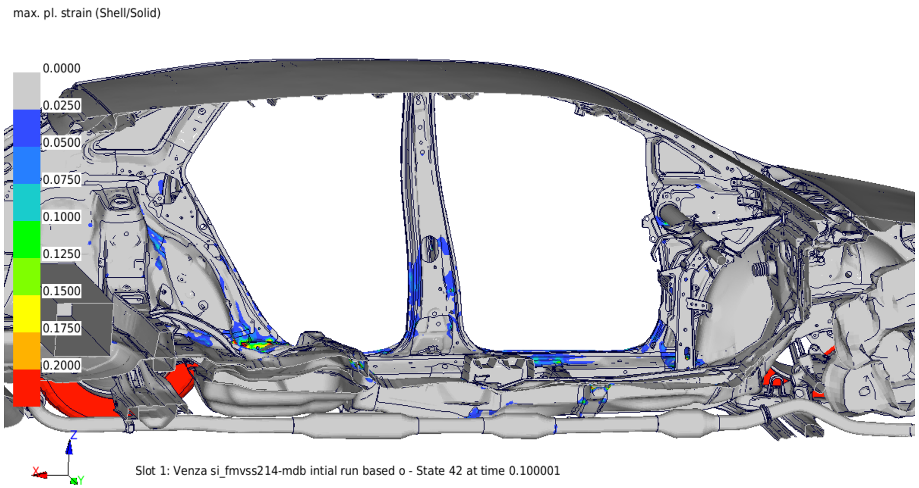
Less intrusion on model 029

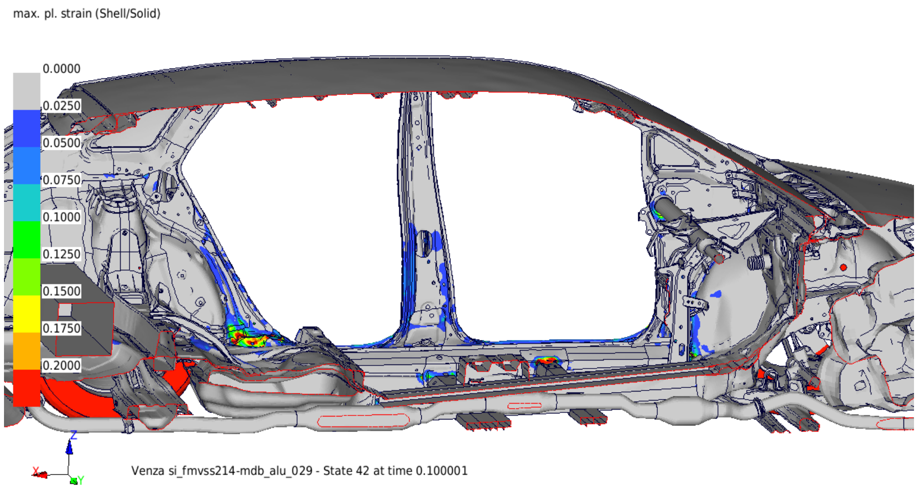
FMVSS214 Side MDB Impact

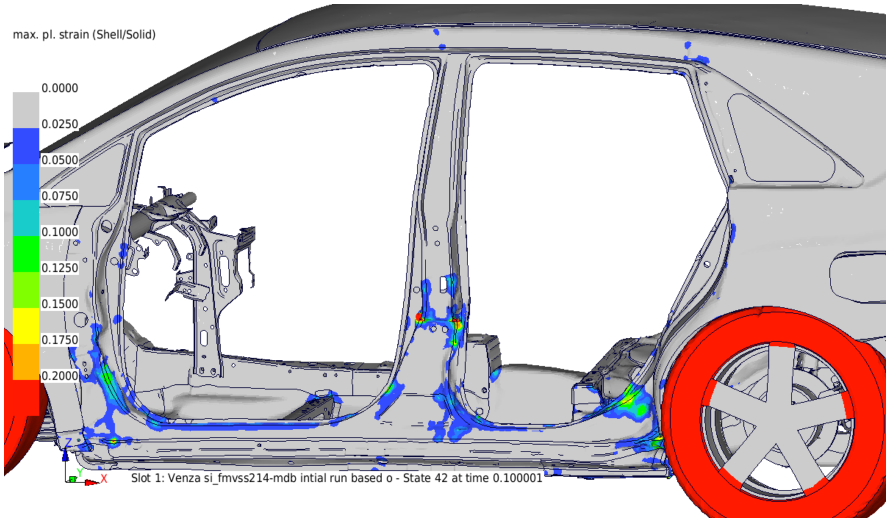
B – Pillar Deformation

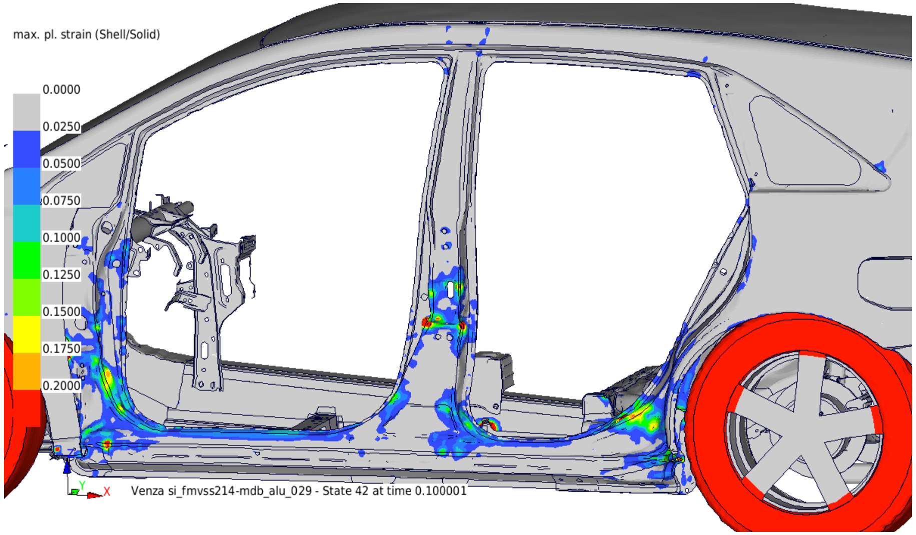
Model 001 (Steel BIW)

Model 029 (Aluminum BIW)



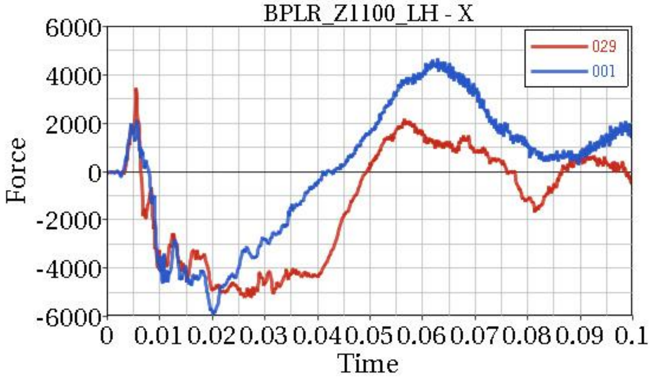


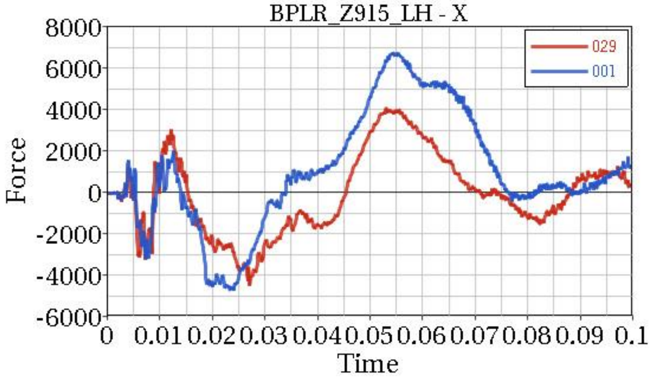


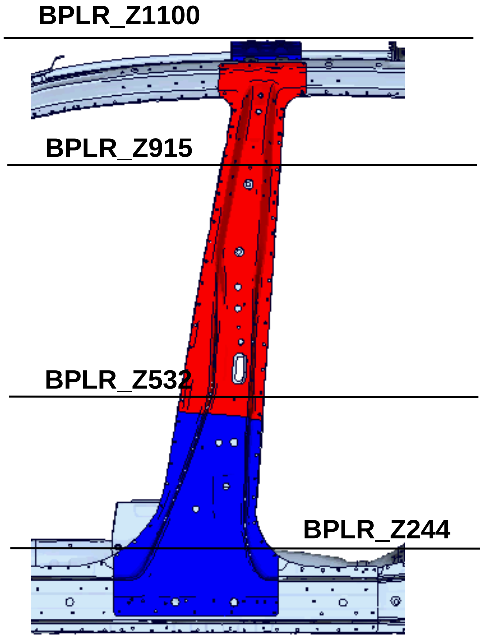


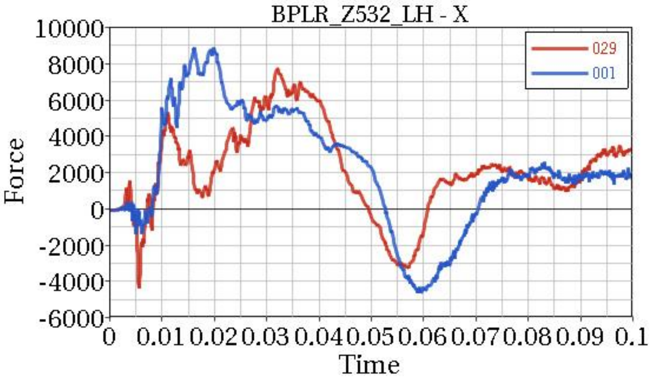
FMVSS214 Side MDB Impact

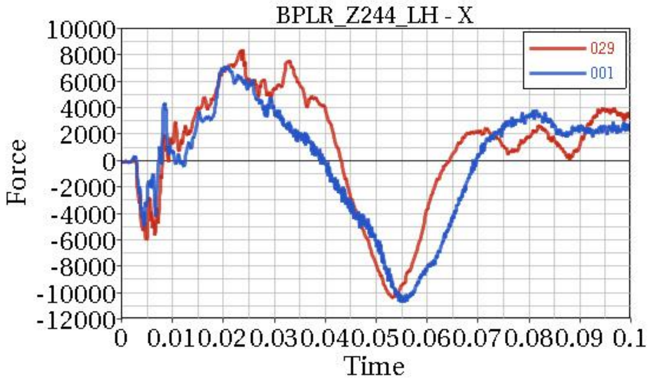
Section Force Comparison

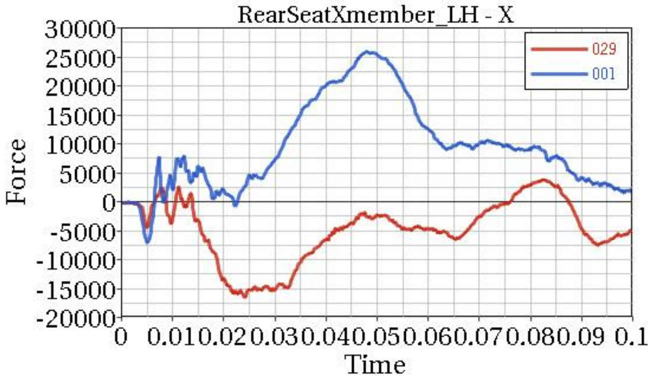


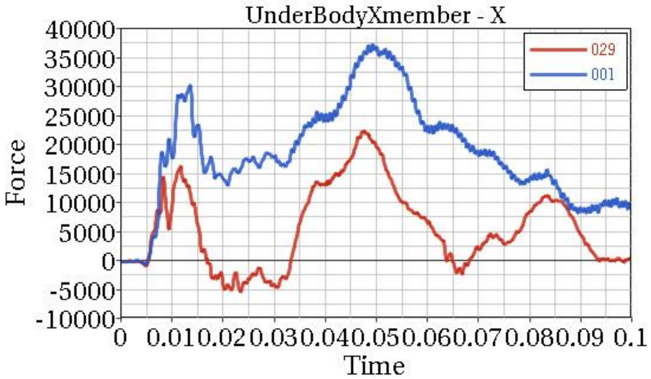


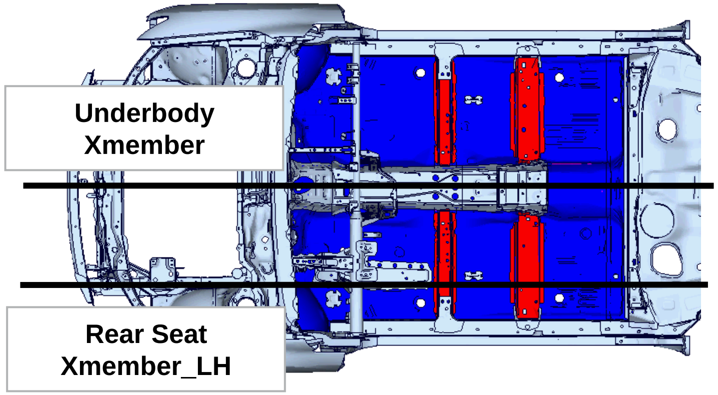








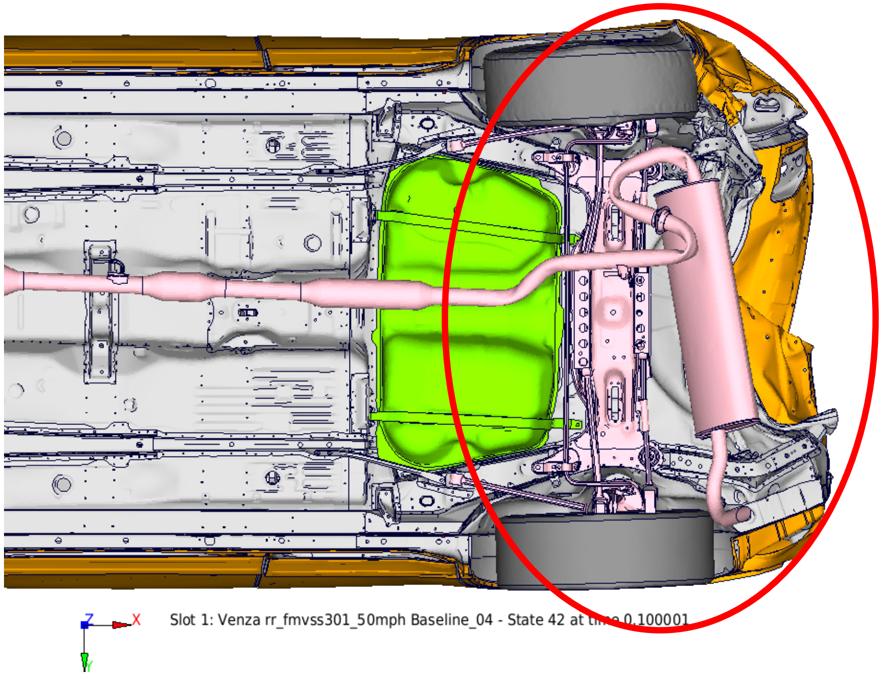




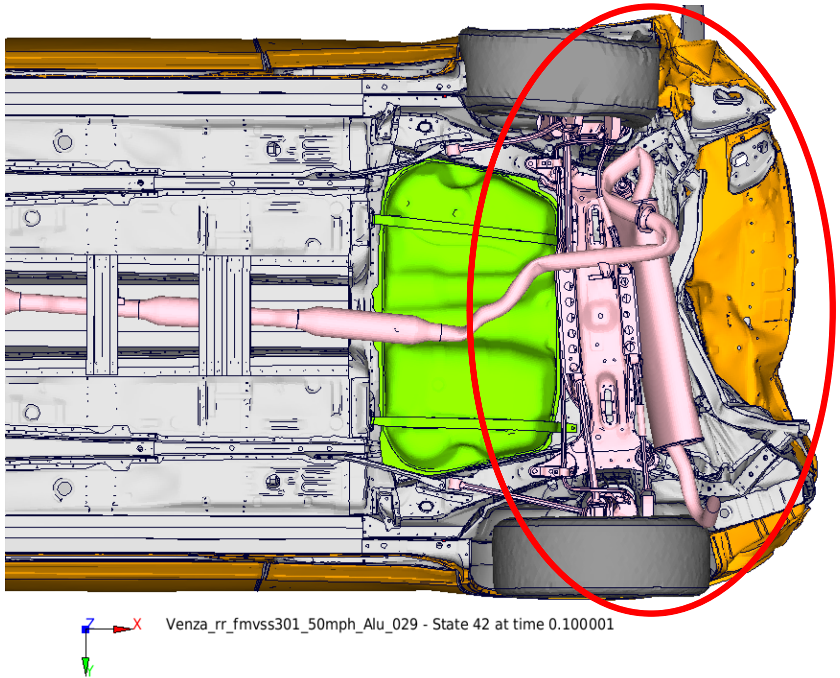
50MPH MDB REAR IMPACT

Rear Bumper Impact Bottom View at time = 0.1 second

Model 001 (Steel BIW)



Model 029 (Aluminum BIW)

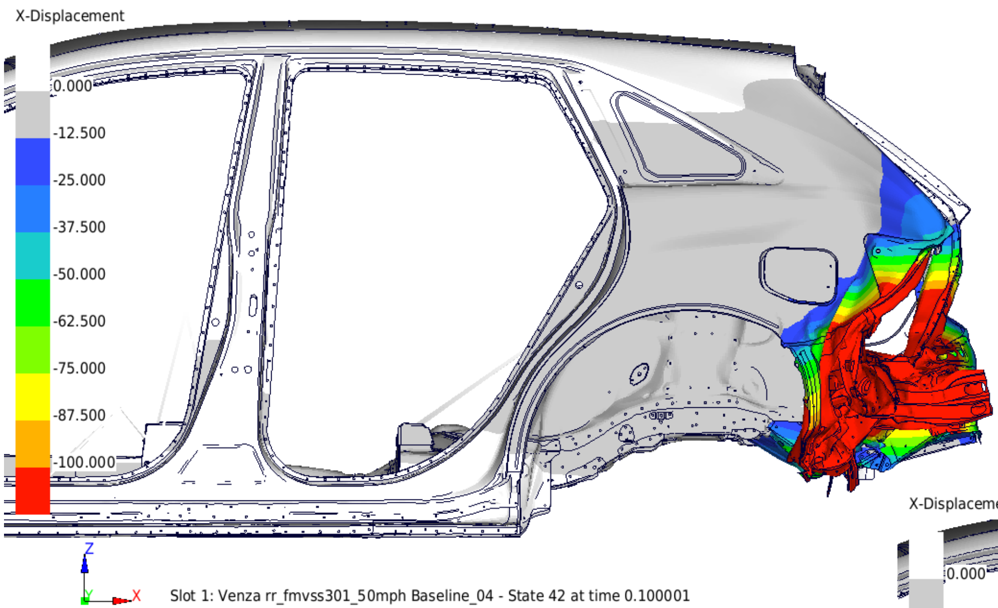


More intrusion – in zone 4

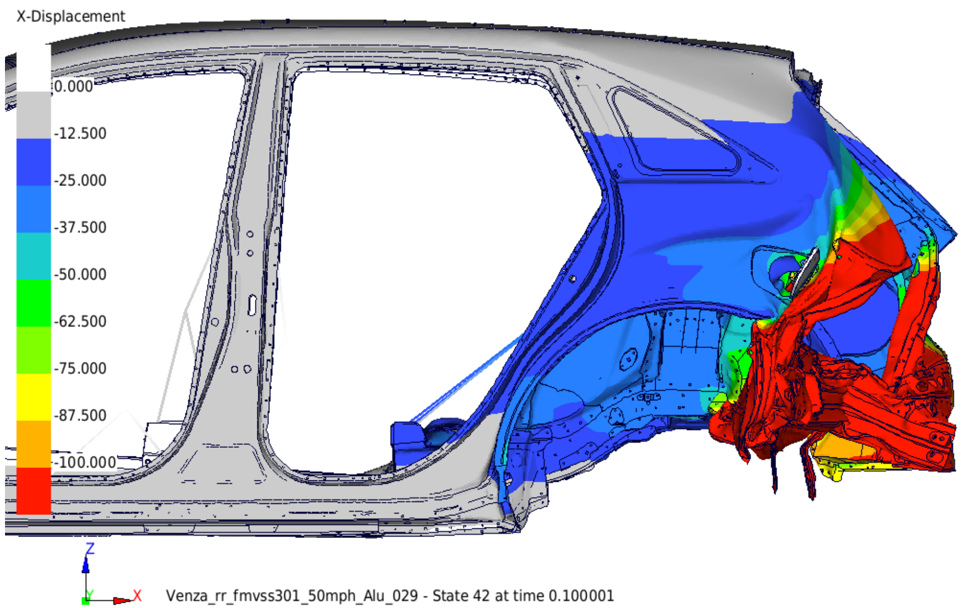
50MPH MDB REAR IMPACT

Overall view of X-Displacement at time = 0.1 second

Model 001 (Steel BIW)



Model 029 (Aluminum BIW)

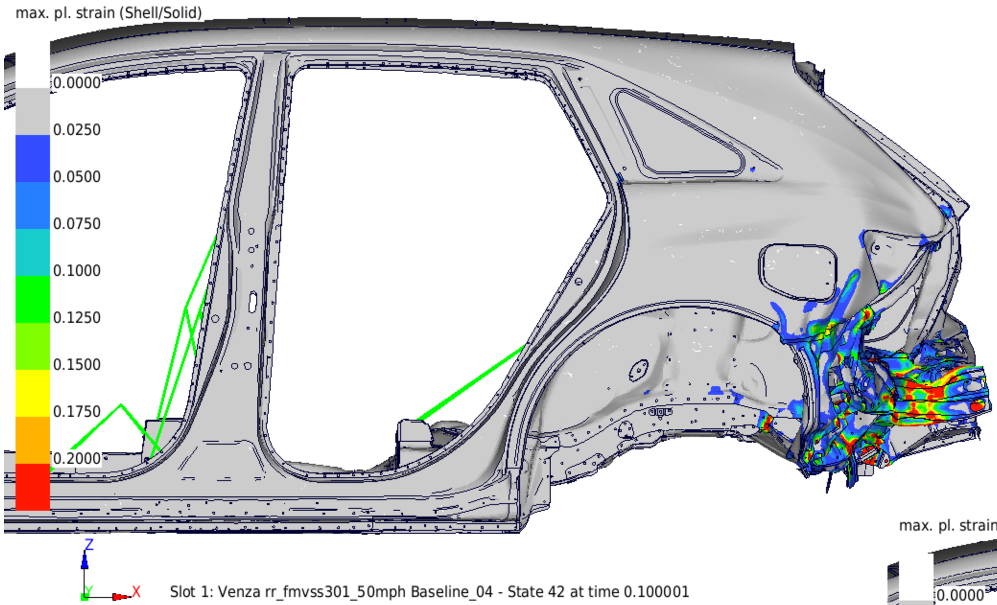


More deformation in the fuel filler area in V029

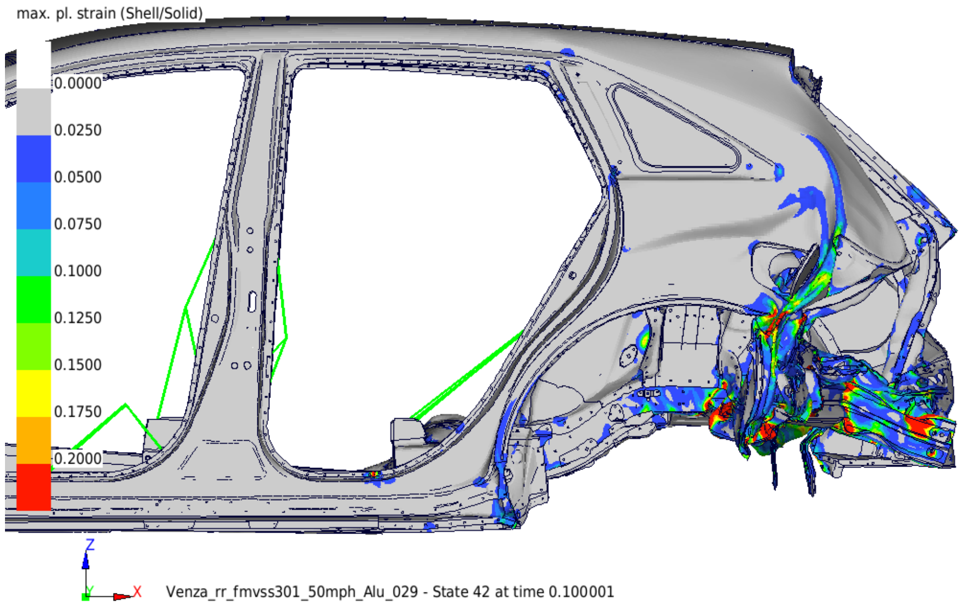
50MPH MDB REAR IMPACT

Plastic Strain Distribution at time = 0.1 second

Model 001 (Steel BIW)



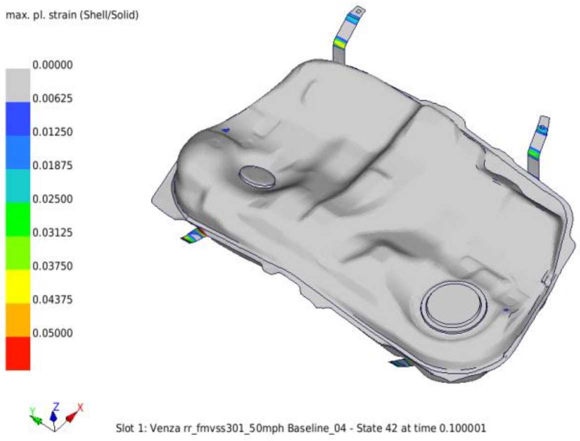
Model 029 (Aluminum BIW)



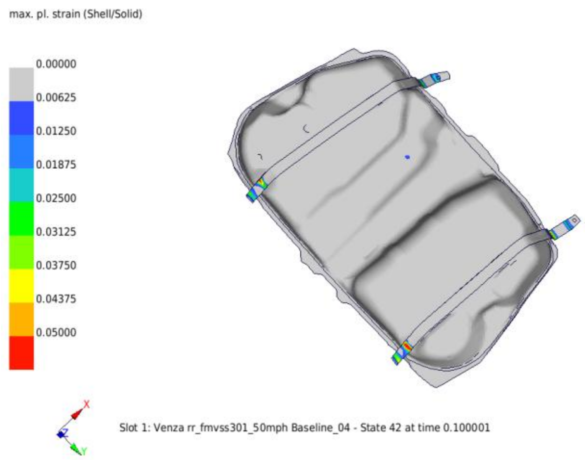
50MPH MDB REAR IMPACT

Fuel tank plastic strain at time = 0.1 second

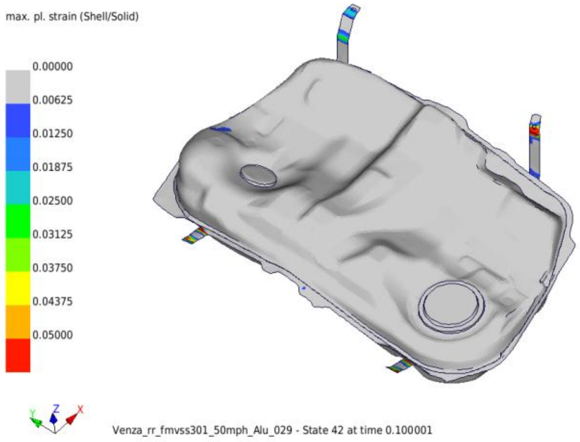
Model 001 (Steel BIW)



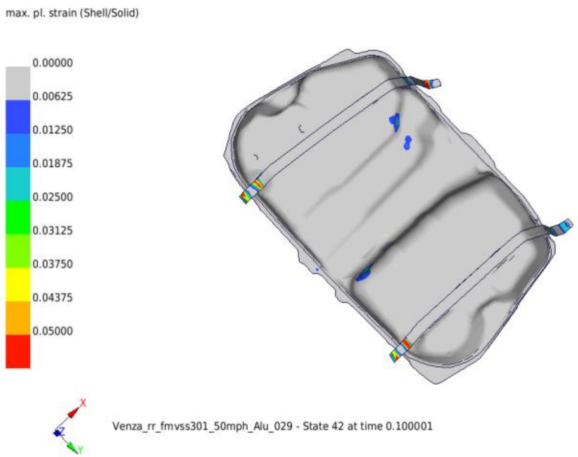
Model 001 (Steel BIW)



Model 029 (Aluminum BIW)

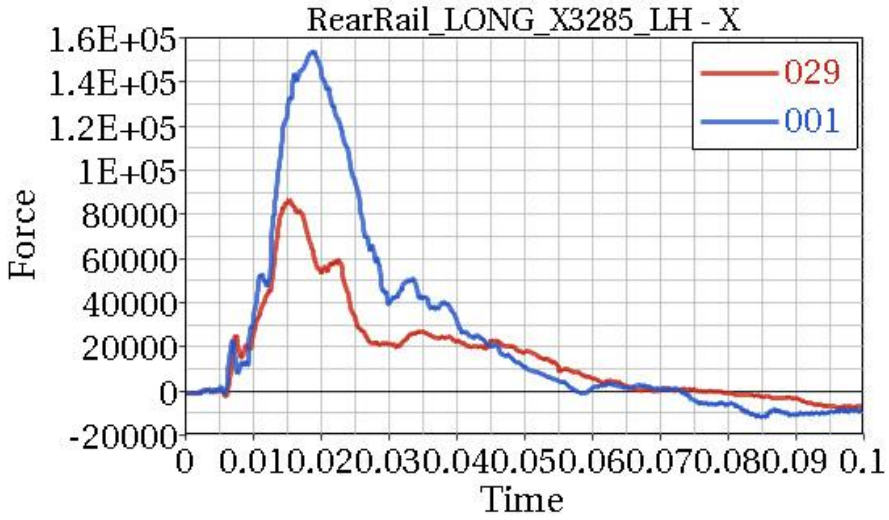


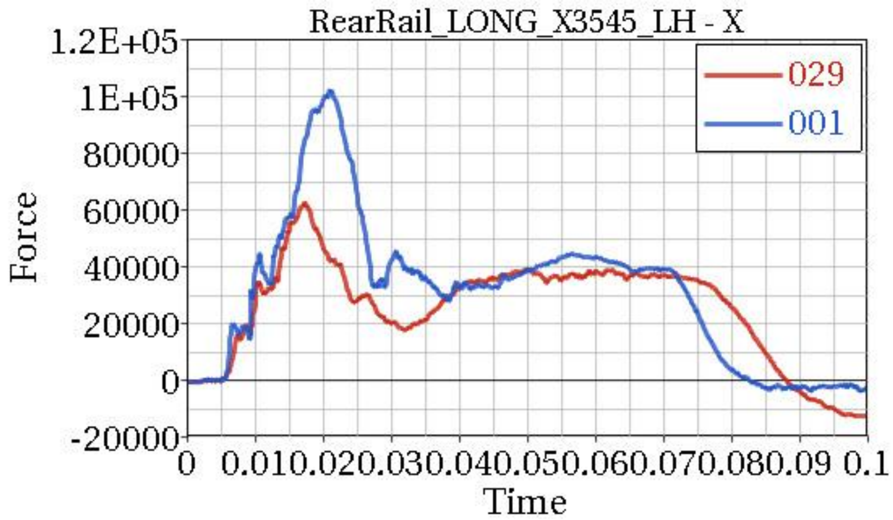
Model 029 (Aluminum BIW)

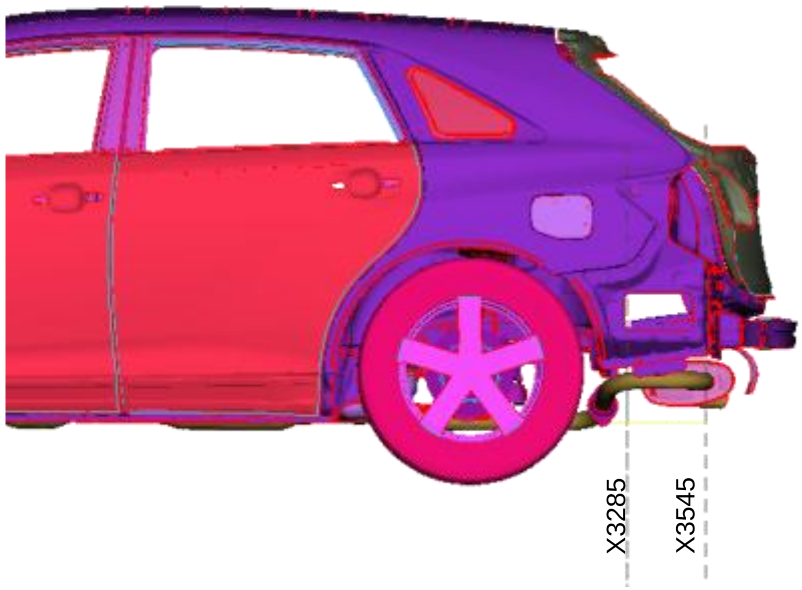


50MPH MDB REAR IMPACT

Section Forces Comparison on LHS

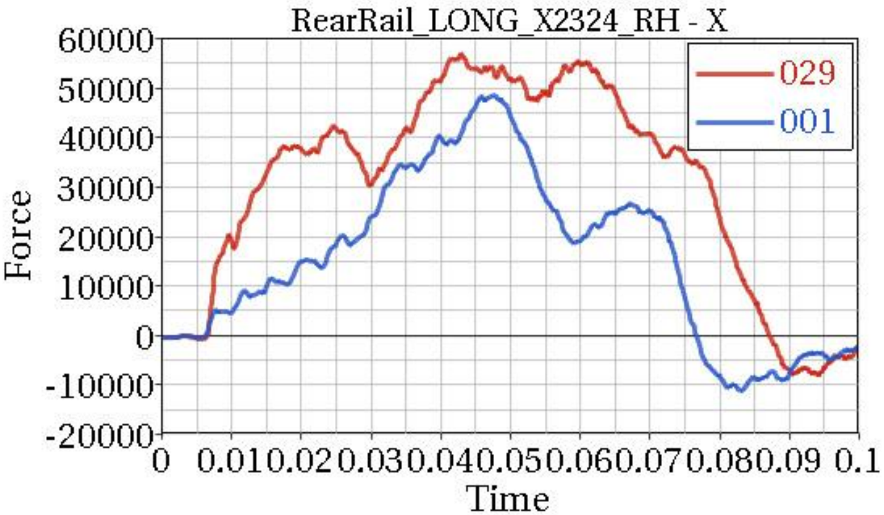


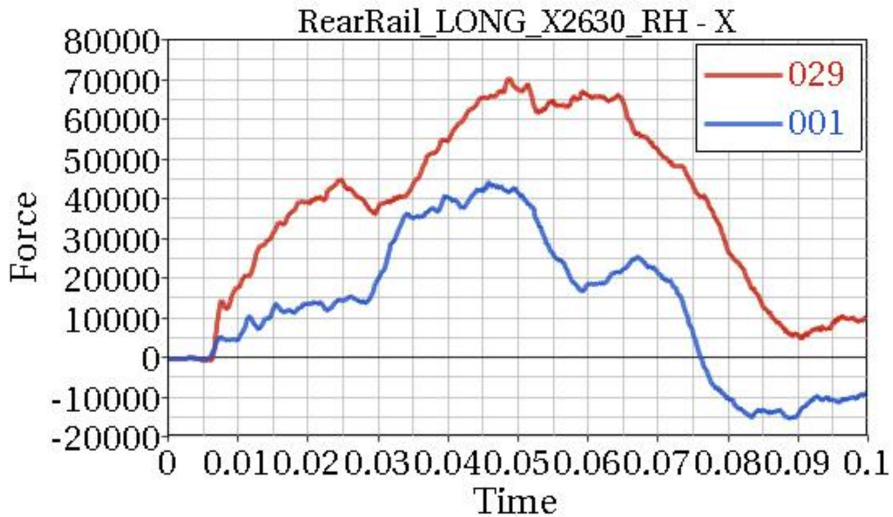


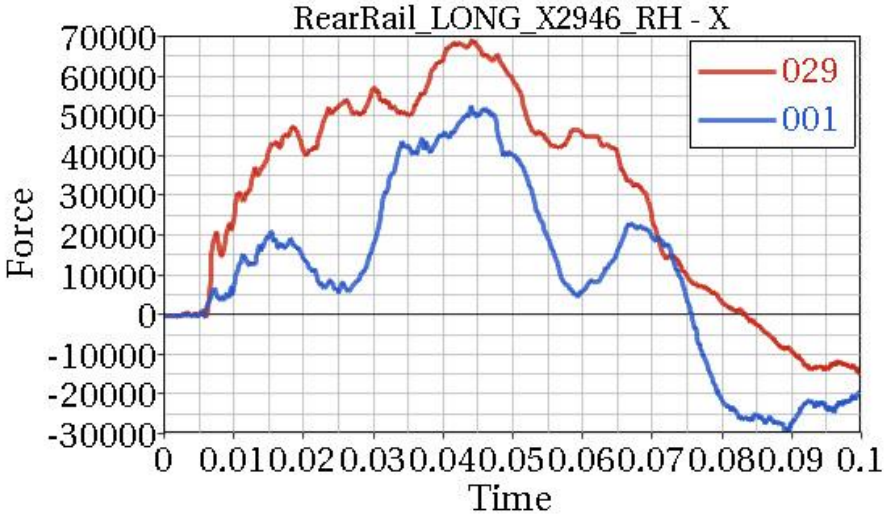


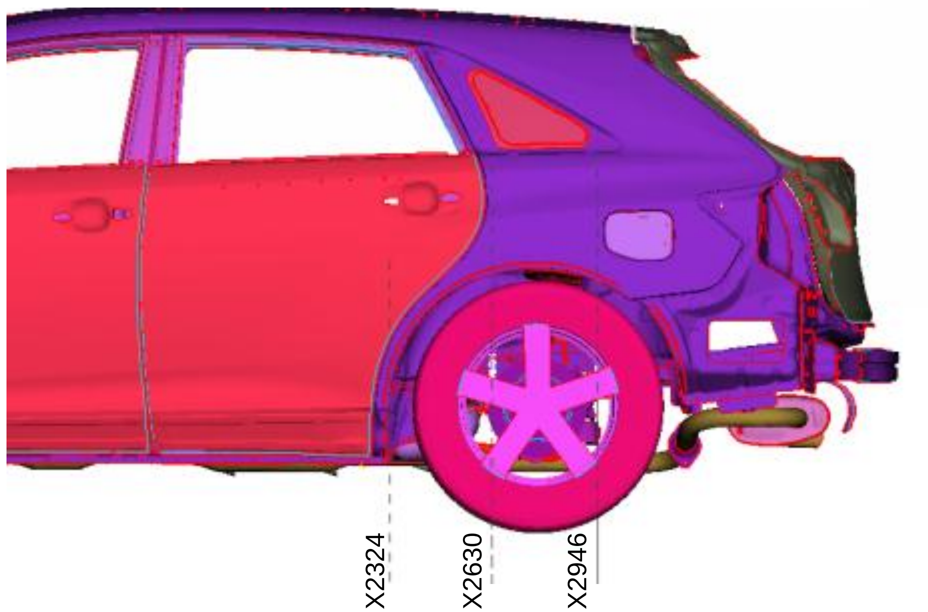
50MPH MDB REAR IMPACT

Section Forces Comparison on LHS



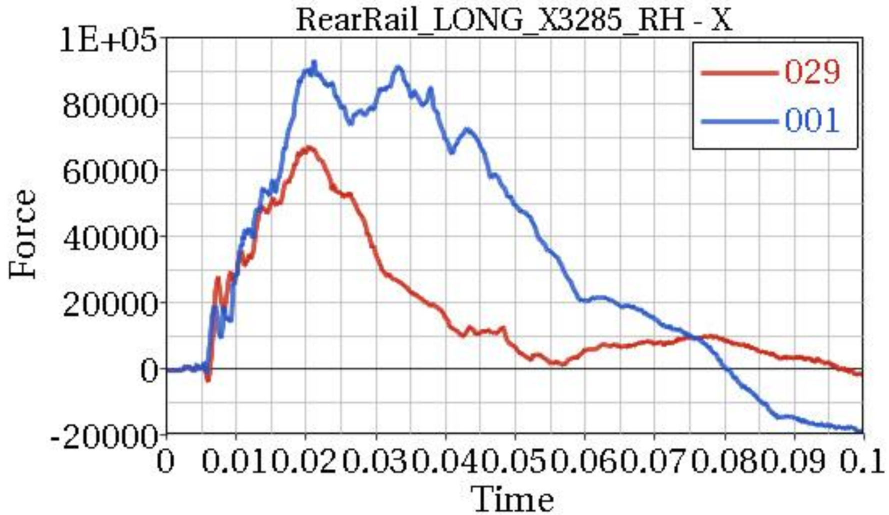


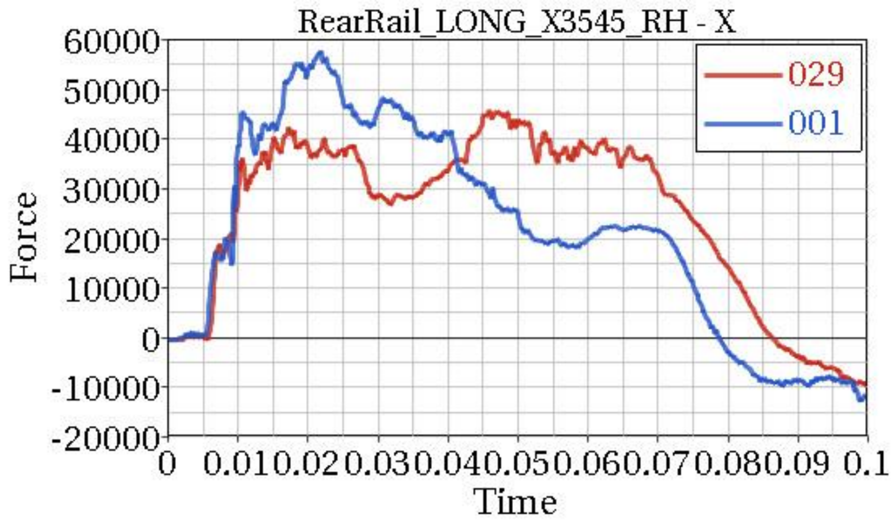


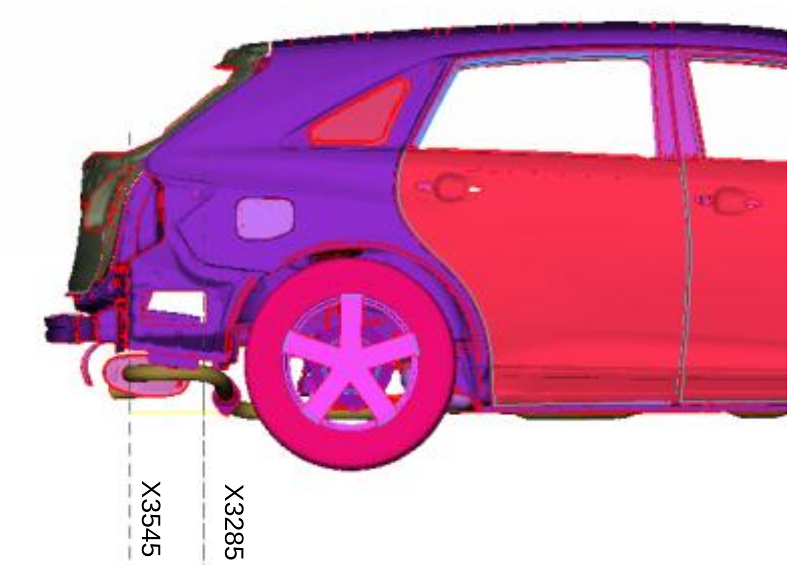


50MPH MDB REAR IMPACT

Section Forces Comparison on RHS



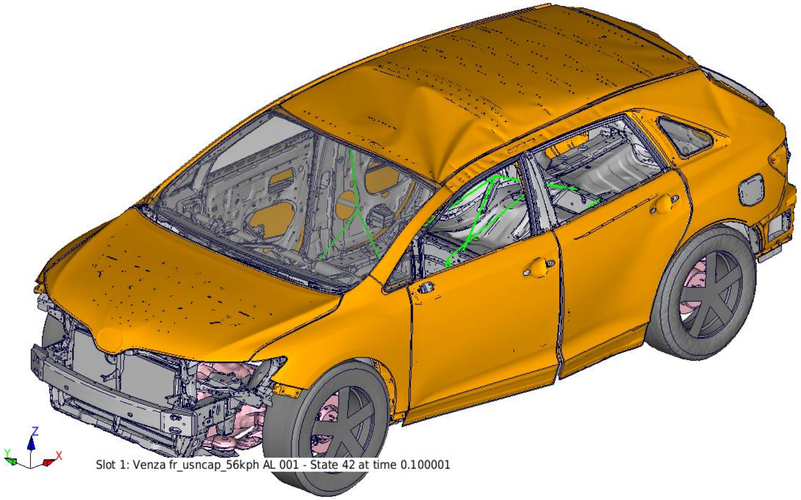


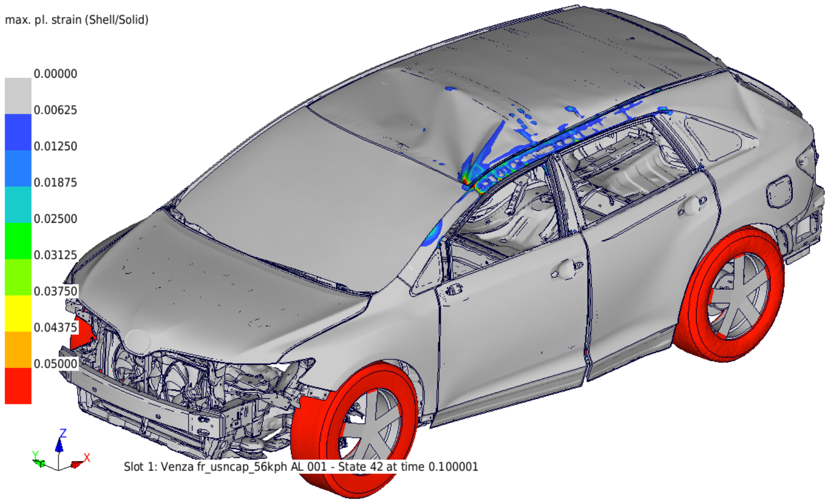


Venza Roof Crush

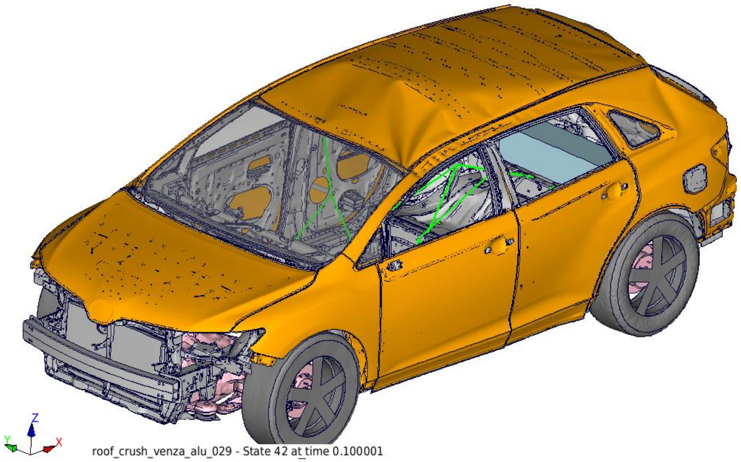
Deformation and Plastic Strain

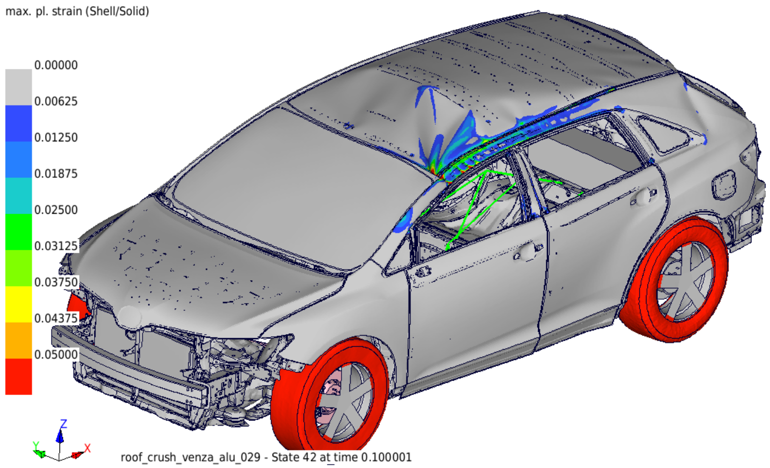
Model 001 (Steel BIW)





Model 029 (Aluminum BIW)

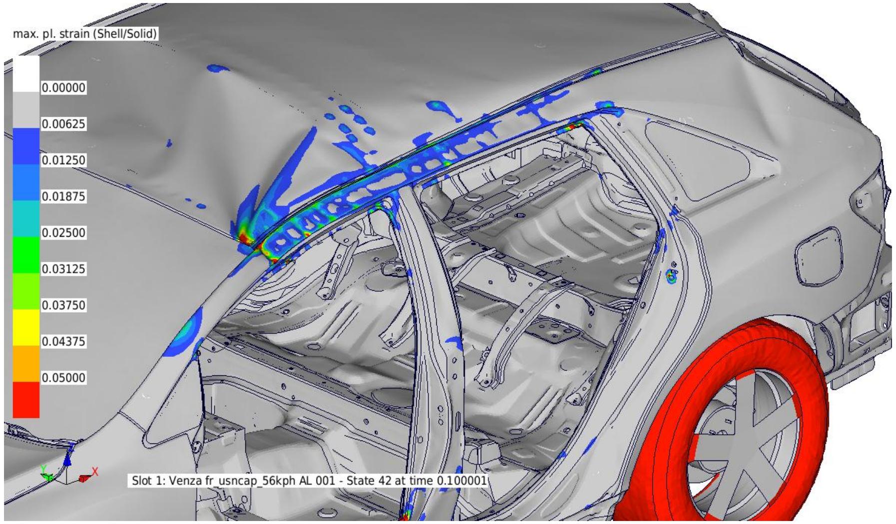


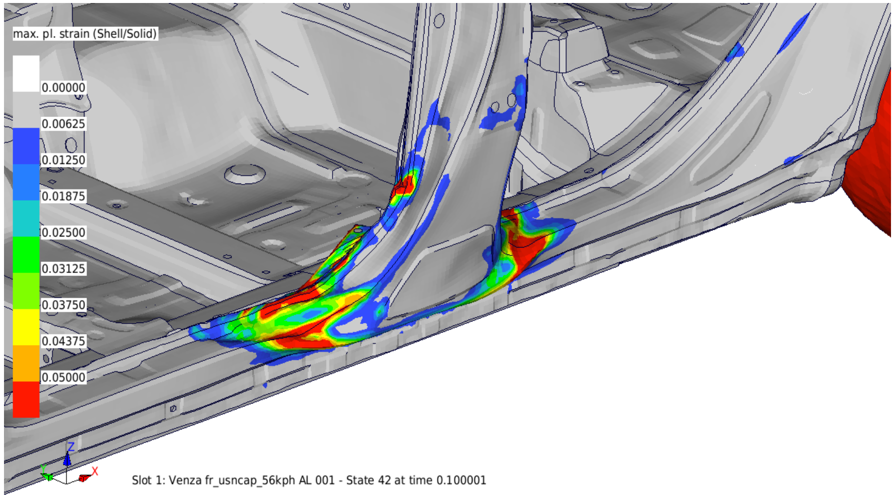


Venza Roof Crush

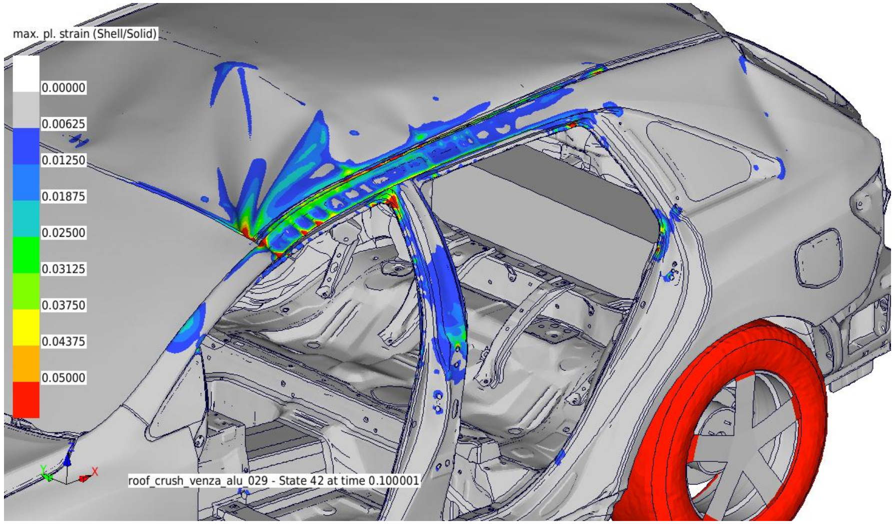
Deformation and Plastic Strain

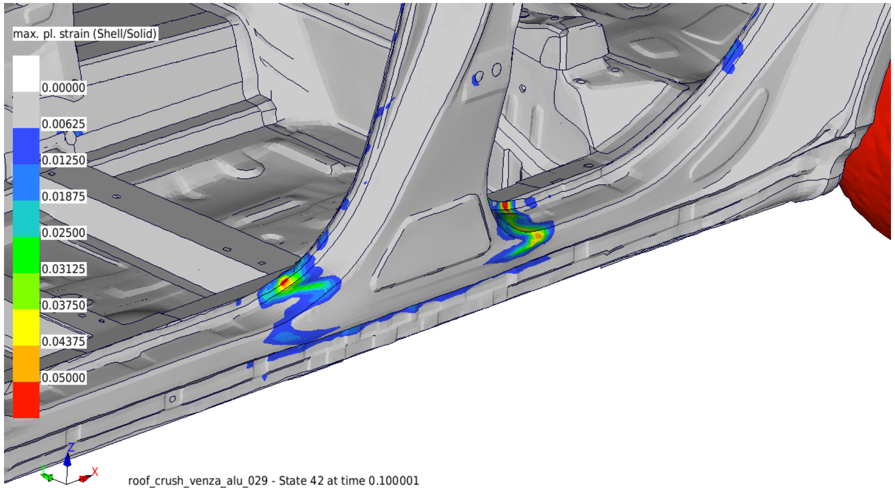
Model 001 (Steel BIW)





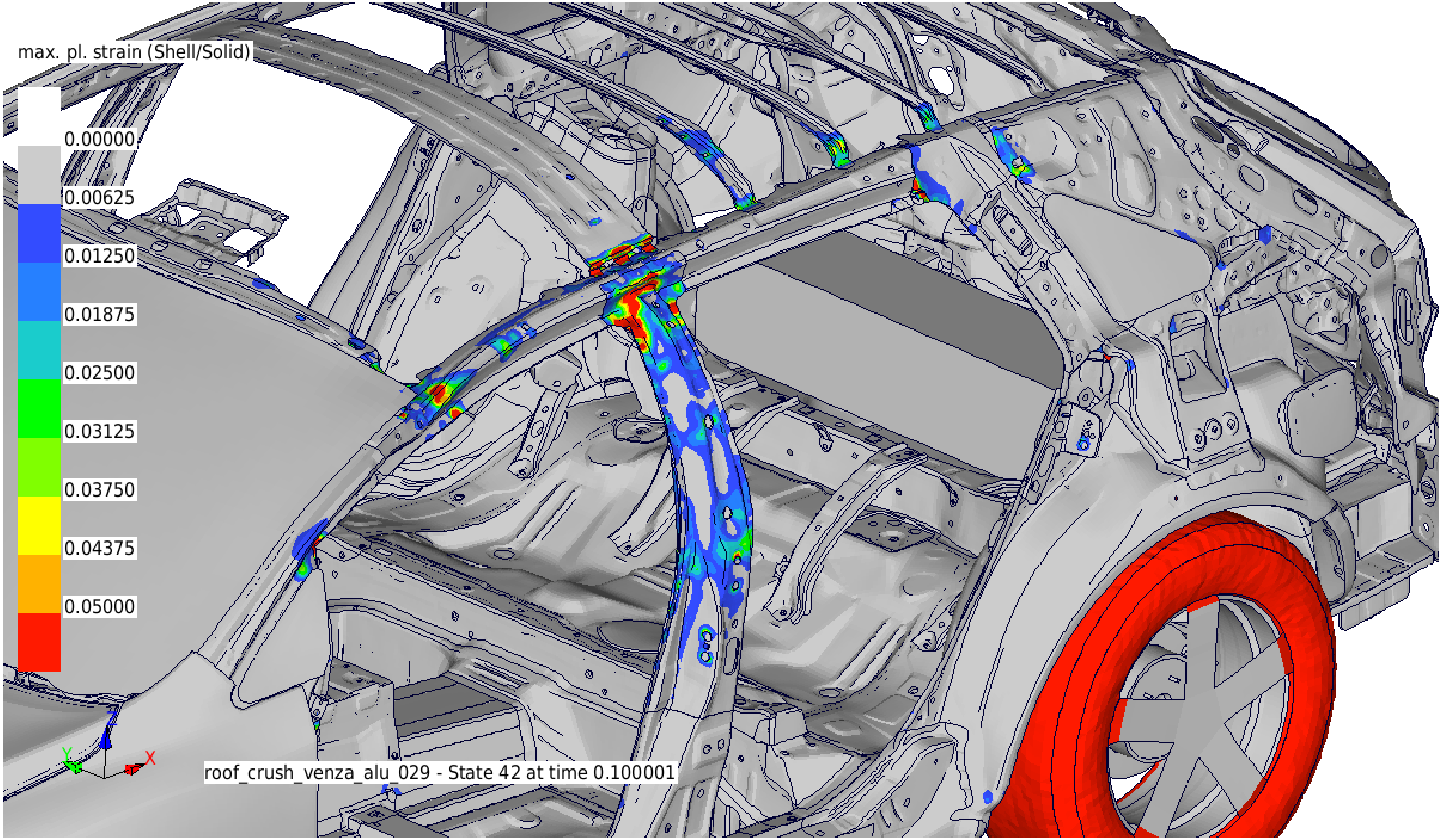
Model 029 (Aluminum BIW)





Venza Roof Crush

Plastic Strain – Alu029 – Roof Rail and B-pillar reinforcement



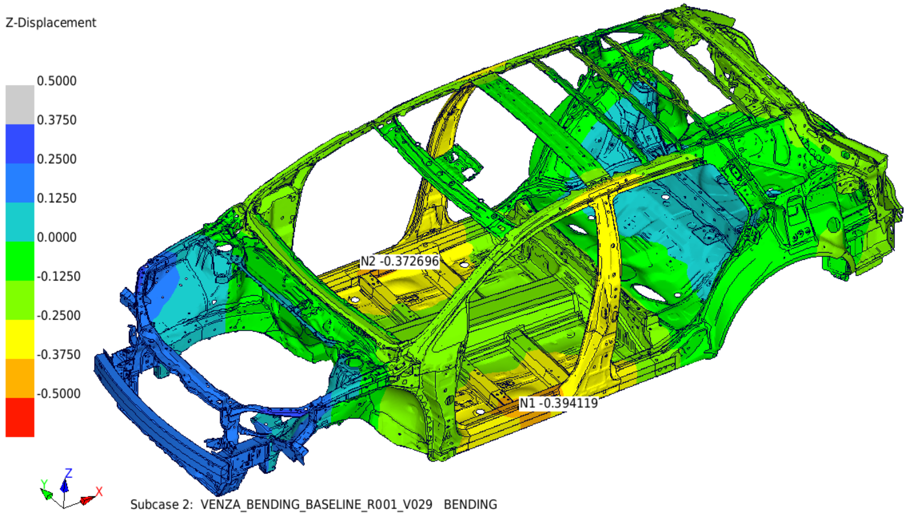
Toyota VENZA
Appendix B

NVH Details

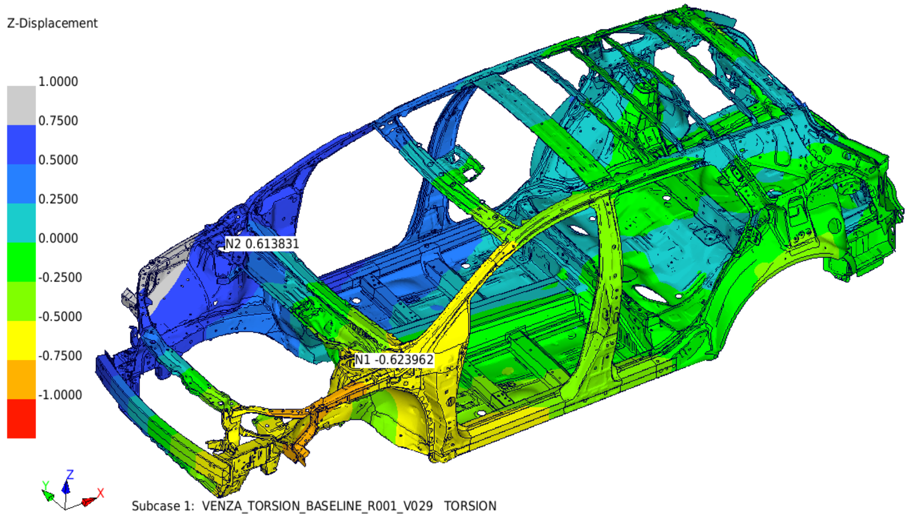
BIW Stiffness

SUMMARY - BIW STIFFNESS EVALUATION

Variant	Description	Mass (kg)	Bending Stiffness (N/mm)*	Variant vs. Basis	Torsional Stiffness (kNm/rad)	Variant vs. Basis
001 ***(baseline)***	Steel Baseline	**407.7**	**18204**	**-**	**1334**	**-**
029	Aluminum BIW from optimized steel baseline	**243.0**	**19855**	**+9.1%**	**1470**	**+10.2%**



Bending Stiffness Evaluation



Torsional Stiffness Evaluation

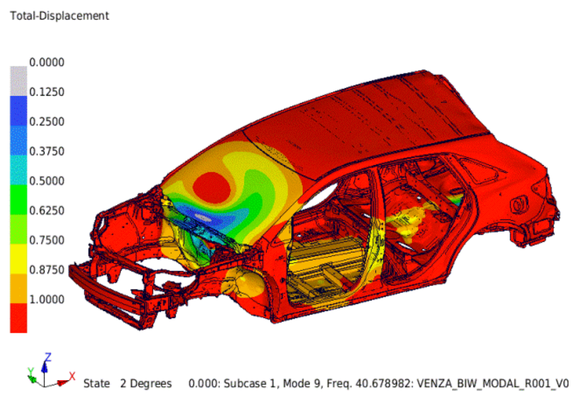
BIW Normal Modes

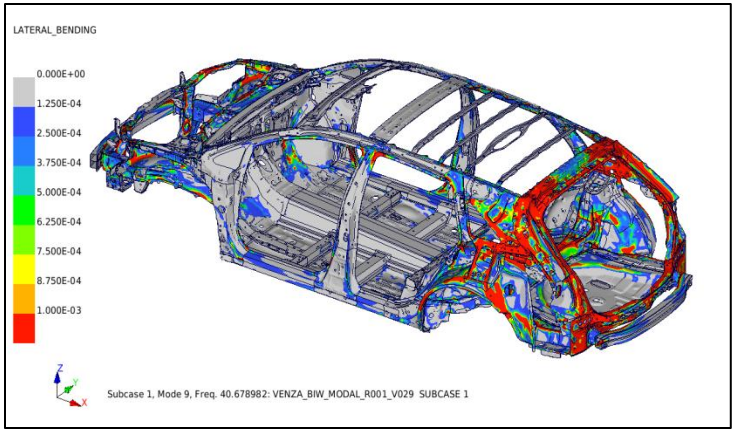
Variant: venza_biw_modal_R001_V029

R001_V029 (243.0 kg):
Rear Torsion → 40.7Hz
Lat Bending → 39.3Hz
Vertical Bending → 49.1Hz
Overall Torsion→ 64.5Hz

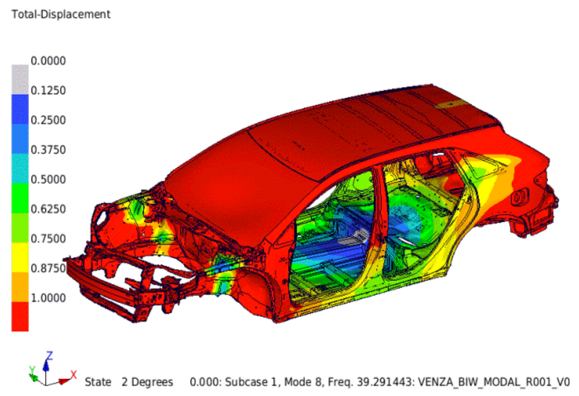
Displacement & Energy Density Plot
Displacement shown is with a Scale factor of 20

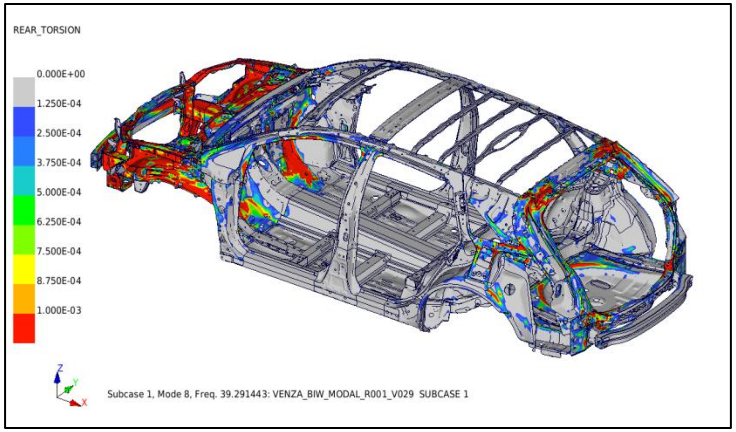
REAR TORSION





LATERAL BENDING





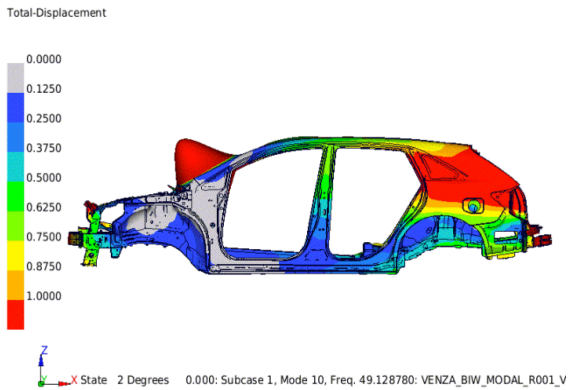
BIW Normal Modes

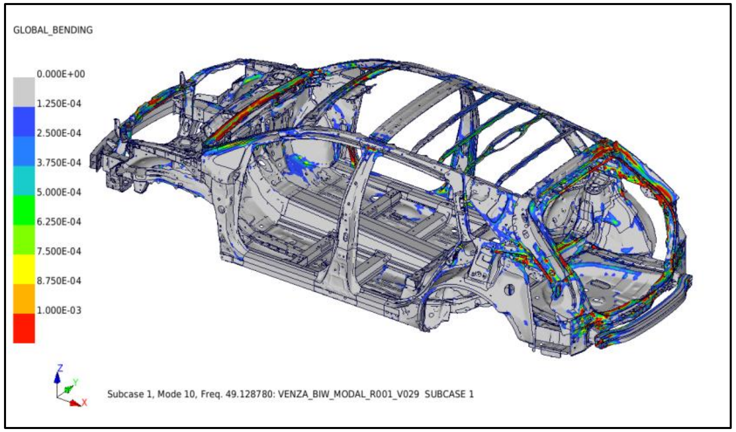
Variant: venza_biw_modal_R001_V029

R001_V029 (243.0 kg):
Rear Torsion → 40.7Hz
Lat Bending → 39.3Hz
Vertical Bending → 49.1Hz
Overall Torsion→ 64.5Hz

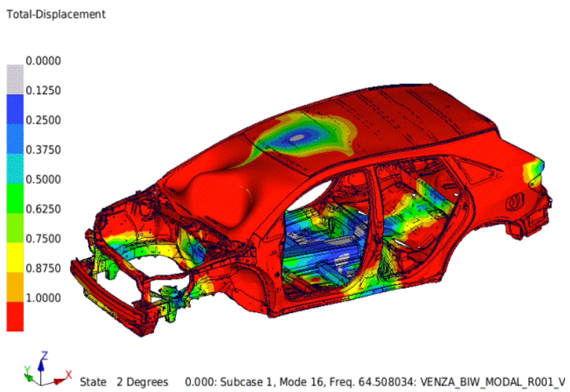
Displacement & Energy Density Plot
Displacement shown is with a Scale factor of 20

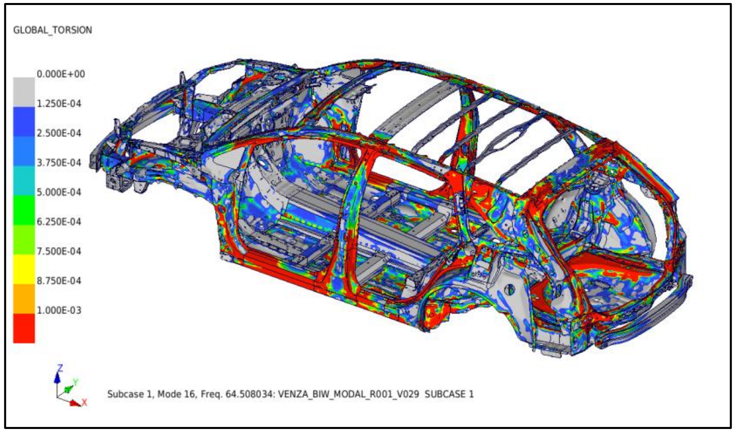
VERTICAL BENDING





OVERALL TORSION





7.0 Performance Summary NVH

- Vehicle NVH

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%

Comment:

Stiffness increased to higher than steel base stiffness.

Toyota VENZA
Appendix C

Aluminum Cost Estimates

Aluminum Cost Estimates

Description	Estimated Mass Reduction "Kg"	Estimated Cost Impact "$"	Average Cost/ Kilogram "$/Kg"
Body Structure Subsystem			
Underbody Asy	19.8	-67.56	-3.41
Front Structure Asy	14.3	-121.84	-8.49
Roof Asy	14.6	-44.81	-3.07
Bodyside Asy	72.2	-306.60	-4.25
Ladder Asy	38.1	-235.53	-6.19
Bolt on BIP Components	3.2	-3.97	-1.23
Body Closure Subsystem			
Hood Asy	7.7	-27.70	-3.62
Front Door Asy	15.0	-21.65	-1.44
Rear Door Asy	11.3	-19.31	-1.70
Rear Hatch Asy	7.2	-21.21	-2.93
Front Fenders	2.0	-16.22	-8.25
Bumpers Subsystem			
Front Bumper Asy	2.3	-8.60	-3.82
Rear Bumper Asy	0.0	0.00	0.00
Totals	207.7	-895.01	-4.31
"+" = mass decrease, "-" = mass increase			
"+" = cost decrease, "-" = cost increase			