VENZA Aluminum BIW Concept Study

April 2013
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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 (1st 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
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)

<table>
<thead>
<tr>
<th>Aluminum Grade</th>
<th>Yield Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>6022 T6 Alloy Sheet</td>
<td>290 Mpa</td>
</tr>
<tr>
<td>5754 O Alloy sheet</td>
<td>117 Mpa</td>
</tr>
<tr>
<td>6082 T6 Extrusion</td>
<td>315 Mpa</td>
</tr>
<tr>
<td>Generic Casting</td>
<td>160 Mpa</td>
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</tbody>
</table>

![Diagram of a car structure with stress color coding](image)

![Diagram of another car structure with stress color coding](image)
4.0 Material Selection

Materials by Color

- 5754 O Alloy sheet
- 6022 T6 Alloy Sheet
- Generic Casting
- 6082 T6 Extrusion
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)
6.0 Aluminum BIW – Concept Description

- **Shock Tower - Frontal**
  
  Baseline (Steel)

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

Model 029
(Aluminum)
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

  • Extruded section is not optimized (constant thickness in the concept)
6.0 Aluminum BIW – Concept Description

- Seat Cross Member

Baseline (Steel)

Model 029 (Aluminum)

Extrusion profiles

Stamp parts

Seat Cross Member – Extrusion profiles with stamp part on the side for connections
6.0 Aluminum BIW – Concept Description

- Front Rail Thickness Difference

  - Concept follows the TWB VENZA steel split lines
  - Other concepts (hydroform/extrusion/hybrid) are an option
### 6.0 Aluminum BIW – Concept Description

*Vehicle Mass*

<table>
<thead>
<tr>
<th>Area</th>
<th>System</th>
<th>Sub-system</th>
<th>Baseline System Mass</th>
<th>Optimized Steel Model System Mass</th>
<th>Aluminum Model System Mass</th>
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<tbody>
<tr>
<td><strong>Closures</strong></td>
<td>6.0 Aluminum BIW – Concept Description</td>
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<td>Door Frt</td>
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<td><strong>Sub-Total Savings Over Baseline</strong></td>
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<td>Underbody Asy (Floor)</td>
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<td>Ladder Asy</td>
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<td><strong>Sub-Total Savings Over Baseline</strong></td>
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<td><strong>BIW Extra</strong></td>
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<td><strong>Sub-Total Savings Over Baseline</strong></td>
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<td>Front Bumper</td>
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<td><strong>Mass Sub-Total</strong></td>
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<td><strong>Sub-Total Savings Over Baseline</strong></td>
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<td><strong>Total Mass Saving Over Baseline</strong></td>
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*Directional Mass Only*
## 7.0 Performance Summary NVH

- Vehicle NVH

<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>
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<tbody>
<tr>
<td>Baseline Model</td>
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<td>34.3</td>
<td>32.4</td>
<td>41.0</td>
<td>1334.0</td>
<td>18204.5</td>
<td>407.7</td>
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<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>
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<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>

**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

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

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

<table>
<thead>
<tr>
<th>No.</th>
<th>Measurement</th>
<th>Variation</th>
<th>001 (Steel BIW)</th>
<th>029 (Aluminum BIW)</th>
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<tbody>
<tr>
<td>1</td>
<td>Dynamic Crush</td>
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<td>1082.9</td>
<td>1010.6</td>
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<tr>
<td></td>
<td>Driver</td>
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<td>2</td>
<td>Dash Panel Intrusion</td>
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<td>141.6</td>
<td>54.5</td>
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<td>Driver Footwell</td>
<td></td>
<td>180.7</td>
<td>61.7</td>
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<td></td>
<td>Driver Toepan LH</td>
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<td>179.0</td>
<td>64.1</td>
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<td>Driver Toepan Ctr</td>
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<td>Driver Toepan RH</td>
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<td>42.8</td>
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<td>Brake Pedal</td>
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<td>54.7</td>
<td>24.3</td>
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<td>Left IP</td>
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<td>20.5</td>
<td>17.5</td>
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<td>3</td>
<td>Extra Info</td>
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<td>99.3</td>
<td>95.5</td>
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<tr>
<td></td>
<td>Time to Zero Velocity (ms)</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 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**

#### Model Description
- Model 001 = Base Model (Steel BIW): 3_fmvss214_sincap_toyota_henza_06_050_fix shear_04.key
- Model 029 = Aluminum BIW Model: 3_toyota_henza_si_sincap_alu_029.key

#### Result Summary

<table>
<thead>
<tr>
<th>Measured Level</th>
<th>Model 001</th>
<th>Model 029</th>
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<tbody>
<tr>
<td>Level-5</td>
<td>6.0</td>
<td>-9.6</td>
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<tr>
<td>Level-4</td>
<td>165.5</td>
<td>130.8</td>
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<tr>
<td>Level-3</td>
<td>245.0</td>
<td>187.0</td>
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<td>Level-2</td>
<td>233.3</td>
<td>175.0</td>
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<tr>
<td>Level-1</td>
<td>133.7</td>
<td>73.3</td>
</tr>
</tbody>
</table>

* 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

![Measured Level Chart](image_url)

![Beltline Velocity Chart](image_url)
8.0 Performance Summary Crashworthiness

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

<table>
<thead>
<tr>
<th>No.</th>
<th>Measurement</th>
<th>Variation</th>
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<tbody>
<tr>
<td></td>
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<td>Model 001 (Steel BIW)</td>
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<td>Under Structure Zone Deformation (mm)</td>
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<td>Zone 1 Deformation</td>
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<td>Zone 2 Deformation</td>
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<td>Zone 3 Deformation</td>
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<td>Zone 4 Deformation</td>
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<td>2</td>
<td>Door Opening (mm)</td>
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<td>Beltline</td>
<td>1.90</td>
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<td>Dogleg</td>
<td>0.20</td>
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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
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
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 001 (Steel BIW)

Model 029 (Aluminum BIW)

Model 029 (Aluminum BIW)

☐ Dynamic crush is lower than the baseline
FMVSS208 - 35mph Frontal Rigid Barrier (FRB) Impact (USNCAP)

Section Force Comparison

**Driver Side (LH)**

- FrontRail_LONGI_X-746_LH - X
  - Force vs Time graph with data points at 029 and 001.

- FrontRail_LONGI_X-566_LH - X
  - Force vs Time graph with data points at 029 and 001.

- LONGI_X-300 - X
  - Force vs Time graph with data points at 029 and 001.

- LONGI_X-130 - X
  - Force vs Time graph with data points at 029 and 001.

- LONGI_X150 - X
  - Force vs Time graph with data points at 029 and 001.
FMVSS208 - 35mph Frontal Rigid Barrier (FRB) Impact (USNCAP)

Section Force Comparison

**Passenger Side (RH)**

![Force Comparison Graphs](image-url)
IIHS Frontal ODB Impact

**Dash Panel Intrusion Comparison**
- Model 001 (Steel BIW)
- Model 029 (Aluminum BIW)

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

**A-Piller Deformation Comparison**
- Model 001 (Steel BIW)
- Model 029 (Aluminum BIW)

- Dash panel intrusion lesser than baseline

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**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)**: No bending on shotgun compared to baseline.
- **Model 029 (Aluminum BIW)**: No bending on shotgun compared to baseline.
IIHS Frontal ODB

Section Force Comparison

Driver Side (LH)

Graphs showing force comparison over time for different sections:
- FrontRail_LONGI_X-746_LH - X
- FrontRail_LONGI_X-566_LH - X
- LONGI X-300 - X
- LONGI X-130 - X
- LONGI X-150 - X

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Door Deformation Comparison

Model 001 (Steel BIW)

Model 029 (Aluminum BIW)
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

BPLR_Z1100 LH - X

BPLR_Z915 LH - X

BPLR_Z532 LH - X

BPLR_Z244 LH - X

Rear Seat Xmember_LH - X

UnderBody Xmember - X

Underbody Xmember

Rear Seat Xmember_LH
50MPH MDB REAR IMPACT

Rear Bumper Impact Bottom View at time = 0.1 second

Model 001 (Steel BIW)

More intrusion – in zone 4

Model 029 (Aluminum BIW)
50MPH MDB REAR IMPACT

Overall view of X-Displacement at time = 0.1 second

Model 001 (Steel BIW)

More deformation in the fuel filler area in V029

Model 029 (Aluminum BIW)
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 029 (Aluminum BIW)
50MPH MDB REAR IMPACT

Section Forces Comparison on LHS

RearRail_LONG_X3285_LH - X

RearRail_LONG_X3545_LH - X
Section Forces Comparison on LHS

RearRail_LONG_X2324_RH - X

RearRail_LONG_X2630_RH - X

RearRail_LONG_X2946_RH - X

Time

Force

0 0.010.020.030.040.050.060.070.080.09 0.1

0 0.010.020.030.040.050.060.070.080.09 0.1

0 0.010.020.030.040.050.060.070.080.09 0.1
Section Forces Comparison on RHS

RearRail_LONG_X3285_RH - X

-20000 0 20000 40000 60000 80000 1E+05
0 0.010 0.020 0.030 0.040 0.050 0.060 0.070 0.080 0.090 0.1
Time

Force

RearRail_LONG_X3545_RH - X

-10000 0 10000 20000 30000 40000 50000 60000
0 0.010 0.020 0.030 0.040 0.050 0.060 0.070 0.080 0.090 0.1
Time

Force

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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

max. pl. strain (Shell/Solid)

roof_crush_venza_alu_029 - State 42 at time 0.100001
Toyota VENZA
Appendix B
NVH Details
# BIW Stiffness

## SUMMARY - BIW STIFFNESS EVALUATION

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

### Bending Stiffness Evaluation

### Torsional Stiffness Evaluation
BIW Normal Modes

Variant: venza_biw_modal_R001_V029

**Displacement & Energy Density Plot**

*Displacement shown is with a Scale factor of 20*

<table>
<thead>
<tr>
<th>Mode</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rear Torsion</td>
<td>40.7</td>
</tr>
<tr>
<td>Lateral Bending</td>
<td>39.3</td>
</tr>
<tr>
<td>Vertical Bending</td>
<td>49.1</td>
</tr>
<tr>
<td>Overall Torsion</td>
<td>64.5</td>
</tr>
</tbody>
</table>

**R001_V029 (243.0 kg):**

- Rear Torsion: 40.7 Hz
- Lat Bending: 39.3 Hz
- Vertical Bending: 49.1 Hz
- Overall Torsion: 64.5 Hz
BIW Normal Modes

Variant: venza_biw_modal_R001_V029

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

R001_V029 (243.0 kg):
- Rear Torsion → 40.7Hz
- Lat Bending → 39.3Hz
- Vertical Bending → 49.1Hz
- Overall Torsion → 64.5Hz
### 7.0 Performance Summary NVH

**Vehicle NVH**

<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>

**Comment:**

Stiffness increased to higher than steel base stiffness.
Toyota VENZA
Appendix C
Aluminum Cost Estimates
## Aluminum Cost Estimates

<table>
<thead>
<tr>
<th>Description</th>
<th>Estimated Mass Reduction &quot;Kg&quot;</th>
<th>Estimated Cost Impact &quot;$&quot;</th>
<th>Average Cost/Kilogram &quot;$/Kg&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Body Structure Subsystem</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underbody Asy</td>
<td>19.8</td>
<td>-67.56</td>
<td>-3.41</td>
</tr>
<tr>
<td>Front Structure Asy</td>
<td>14.3</td>
<td>-121.84</td>
<td>-8.49</td>
</tr>
<tr>
<td>Roof Asy</td>
<td>14.6</td>
<td>-44.81</td>
<td>-3.07</td>
</tr>
<tr>
<td>Bodyside Asy</td>
<td>72.2</td>
<td>-306.60</td>
<td>-4.25</td>
</tr>
<tr>
<td>Ladder Asy</td>
<td>38.1</td>
<td>-235.53</td>
<td>-6.19</td>
</tr>
<tr>
<td>Bolt on BIP Components</td>
<td>3.2</td>
<td>-3.97</td>
<td>-1.23</td>
</tr>
<tr>
<td><strong>Body Closure Subsystem</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hood Asy</td>
<td>7.7</td>
<td>-27.70</td>
<td>-3.62</td>
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<tr>
<td>Front Door Asy</td>
<td>15.0</td>
<td>-21.65</td>
<td>-1.44</td>
</tr>
<tr>
<td>Rear Door Asy</td>
<td>11.3</td>
<td>-19.31</td>
<td>-1.70</td>
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<tr>
<td>Rear Hatch Asy</td>
<td>7.2</td>
<td>-21.21</td>
<td>-2.93</td>
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<tr>
<td>Front Fenders</td>
<td>2.0</td>
<td>-16.22</td>
<td>-8.25</td>
</tr>
<tr>
<td><strong>Bumpers Subsystem</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Front Bumper Asy</td>
<td>2.3</td>
<td>-8.60</td>
<td>-3.82</td>
</tr>
<tr>
<td>Rear Bumper Asy</td>
<td>0.0</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td>207.7</td>
<td>-895.01</td>
<td>-4.31</td>
</tr>
</tbody>
</table>

"+" = mass decrease, "-" = mass increase
"+" = cost decrease, "-" = cost increase