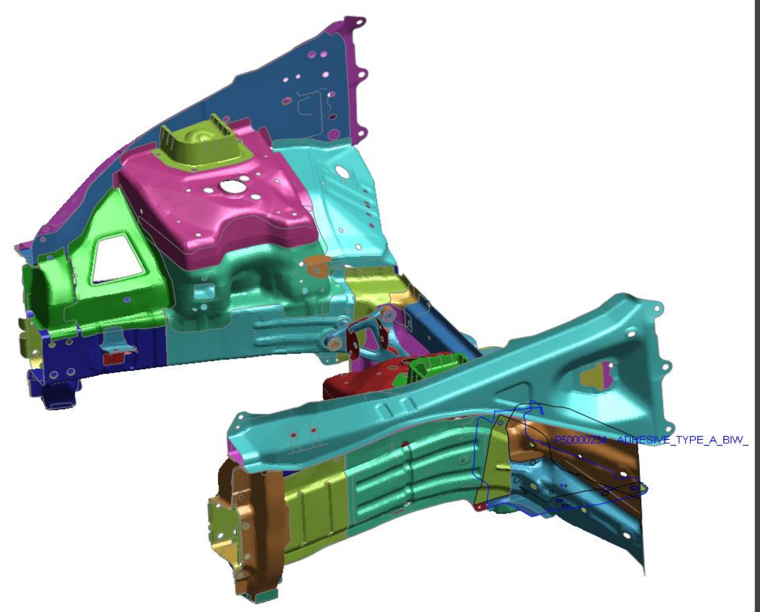
# Giga Casting Steel Alternatives



John Catterall – Auto/Steel Partnership

Madhu Jampala - Detroit Engineered Products

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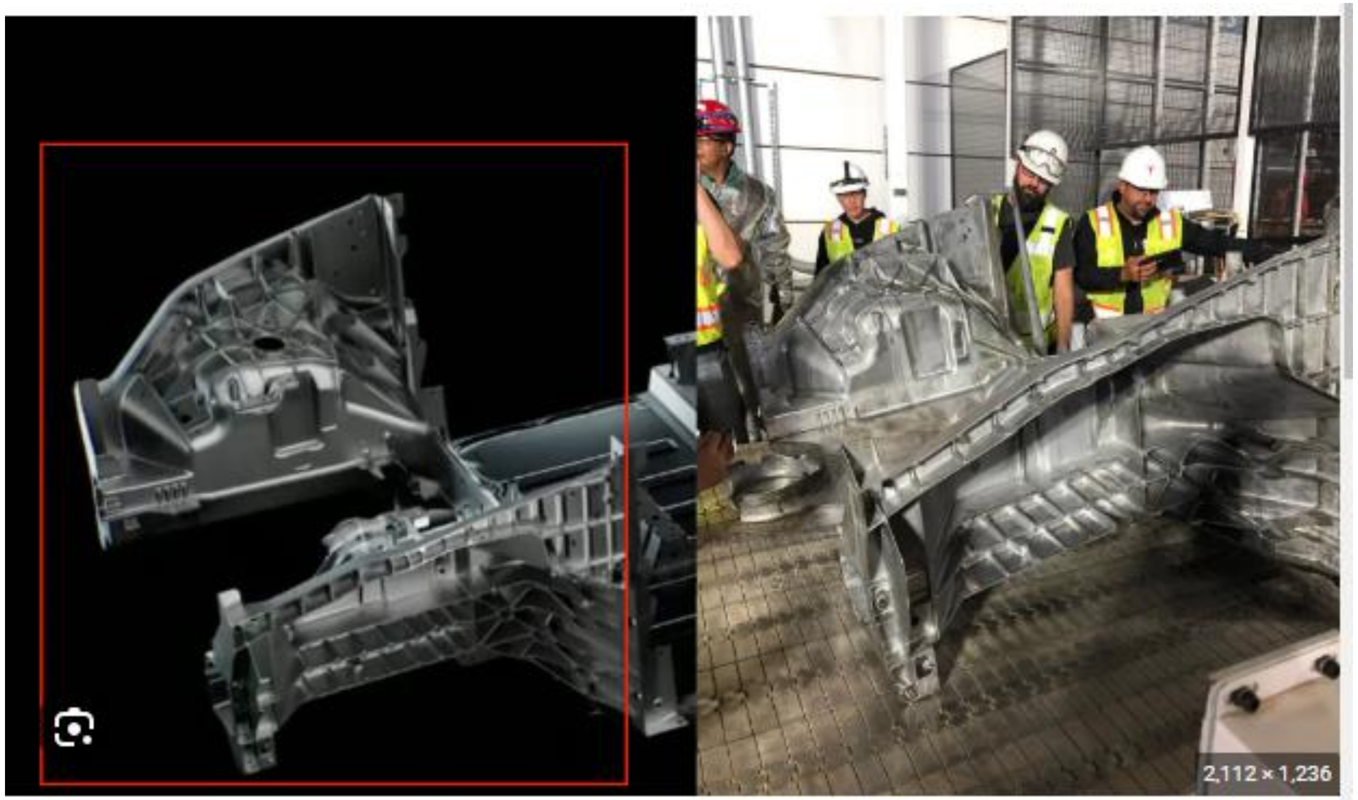
TOYOTA

# Project Details

Study focused on assessment and replacement of a generic front giga casting; evaluating performance, mass, cost and sustainability. To control project scope, the front-end only was assessed and re-designed. However, full vehicle models were analyzed.



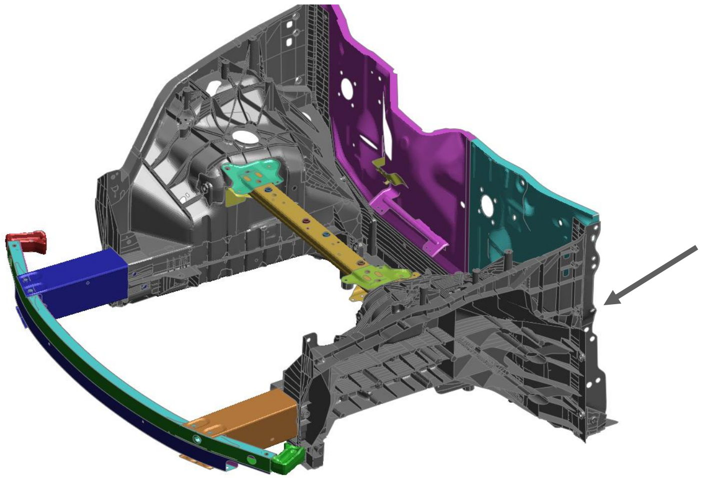
# Project Approach

GDIS

- Two baseline designs were studied –
  - Steel Baseline: To Validate CAE reverse engineered models
  - AL Baseline: giga casting reverse engineered and replaced front end using the steel baseline.
  - Evaluated CAE performance of both the models and these metrics were used to establish performance targets.
- Two alternative steel designs were developed and fully analyzed, a splayed rail and a clamshell two-piece front rail design. The alternate steel designs beyond the front rails are very similar.
- **Both alternate designs met or exceeded the performance of the baselines to which they were compared.**
- Part consolidation efforts for the new designs were performed.
- Manufacturing feasibility of the new designs were assessed.
- A cost and sustainability study was performed at the end of the project.

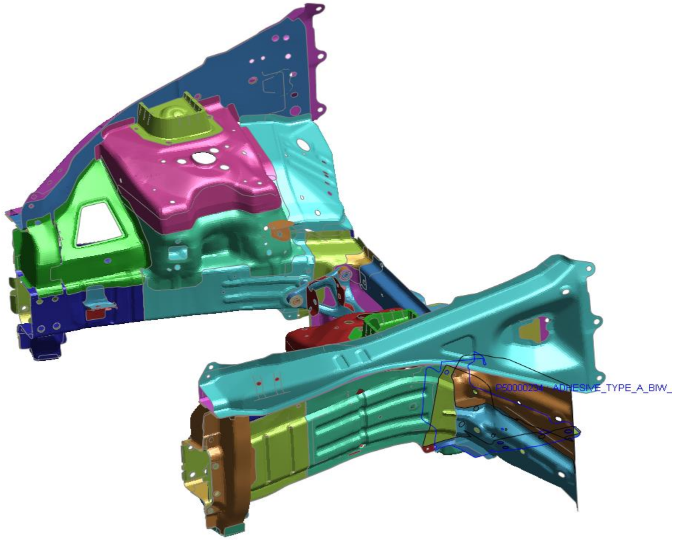
# Designs Assessed

GDIS



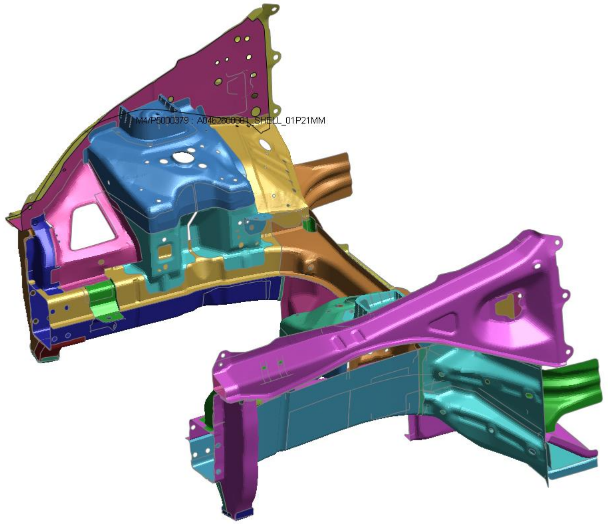
74.7 kg Giga Casting

(grey portion only)



70.5 kg Steel Splayed Rails

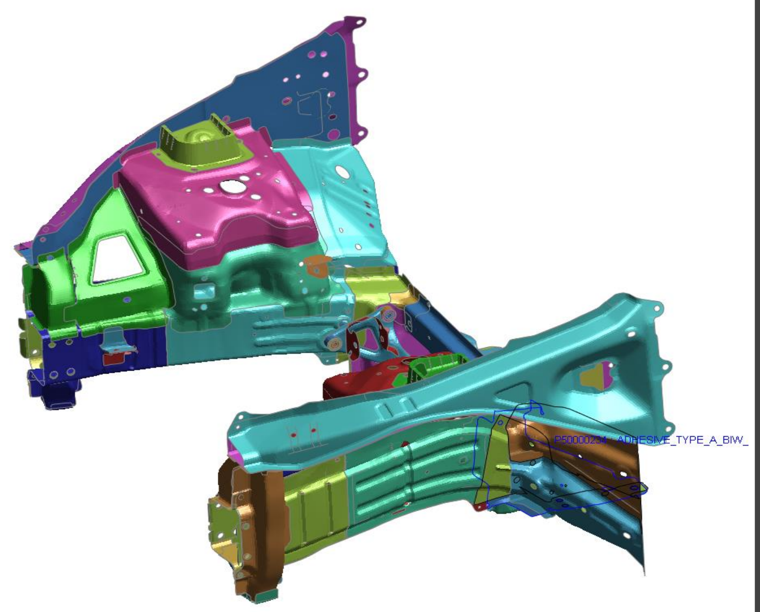
- equivalent to casting



70 kg Steel Clamshell Rails

- equivalent to casting

# Giga Casting Steel Alternatives



**Hand – Off To;**

**Madhu Jampala - Detroit Engineered Products**

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# Scope and Approach:

**Scope:**

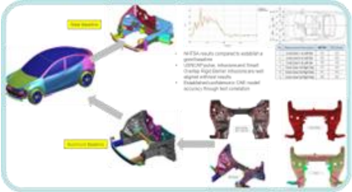
- Develop a **steel alternative** to giga-cast front-end with focus on concept development and 3G optimization (Geometry, Gauge, Grade)
- Key Load cases Considered:
  - Crash Performance: US NCAP (35 mph rigid wall), Small Overlap
  - Stiffness: BIW Modes, Global (Bending & Torsion), Shock Tower Local

**Approach:**

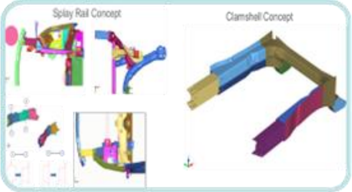
1. Baseline Development
   - Reverse-engineered steel BIW (full vehicle) and giga-cast front-end
   - Built full vehicle high-fidelity FE models
2. Correlation & Validation
   - Benchmarked against NHTSA public data
   - Ensured model accuracy and reliability
3. Target Setting
   - Defined performance targets from validated baseline
4. Design & Optimization
   - Applied 3G optimization
   - Developed 2 steel design concepts
5. Evaluation
   - Assessed performance, cost, and sustainability trade-offs

**Objective:** Achieve giga-cast equivalent performance with a scalable steel solution

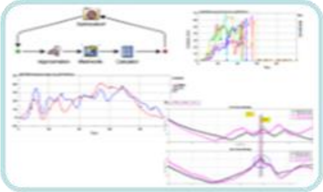
**Baseline & CAE Targets**



**Concepts**



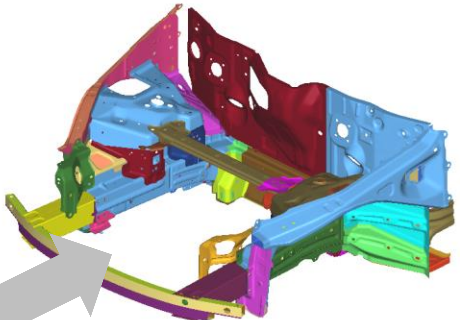

**Optimization**



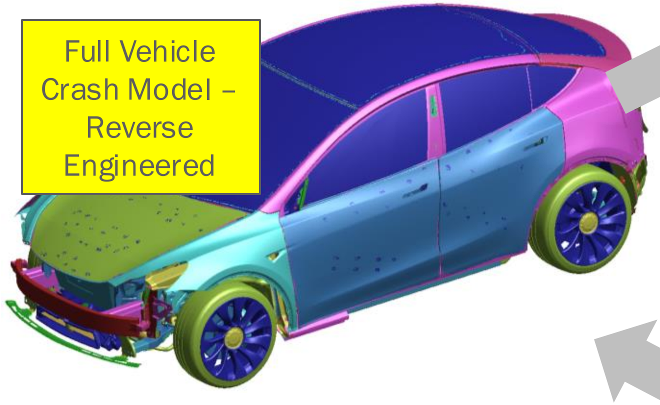
**Sustainability and Cost**

# Baseline FE Models

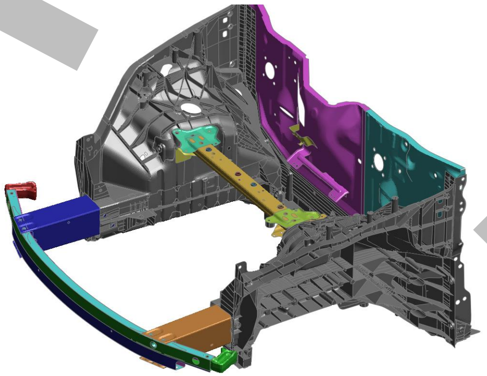
Steel Baseline

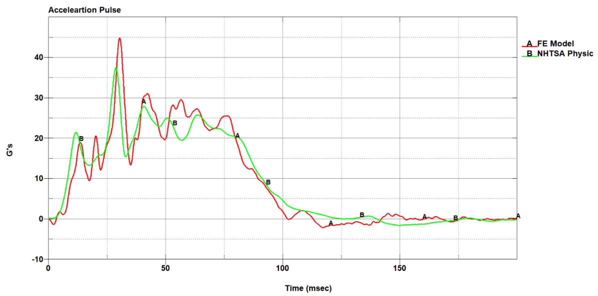


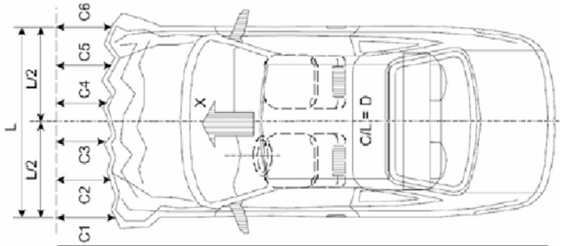
Full Vehicle Crash Model – Reverse Engineered



Aluminum Baseline



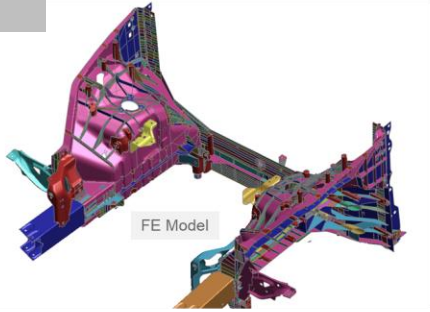


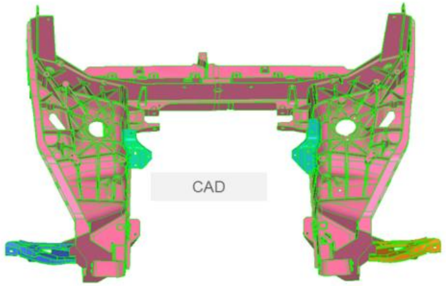




| No | Measurement Description | NHTSA | FEA (Steel) |
|---|---|---|---|
| C1 | Crush Zone 1 at Left Side | 345 | 333 |
| C2 | Crush Zone 2 at Left Side | 420 | 428 |
| C3 | Crush Zone 3 at Left Side | 425 | 448 |
| C4 | Crush Zone 4 at Right Side | 415 | 440 |
| C5 | Crush Zone 5 at Right Side | 421 | 454 |
| C6 | Crush Zone 6 at Right Side | 380 | 350 |

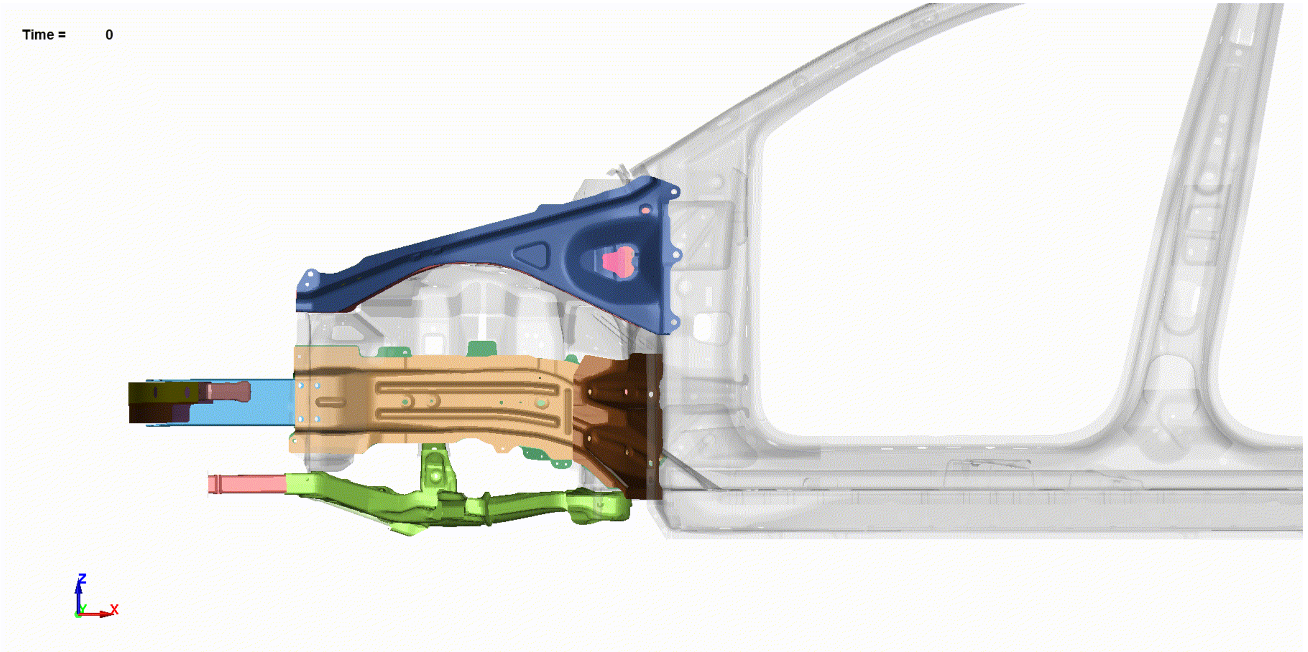
- NHTSA results compared to establish a good baseline
- USNCAP pulse, intrusions and Small Overlap Rigid Barrier intrusions are well aligned with test results
- Established confidence in CAE model accuracy through test correlation

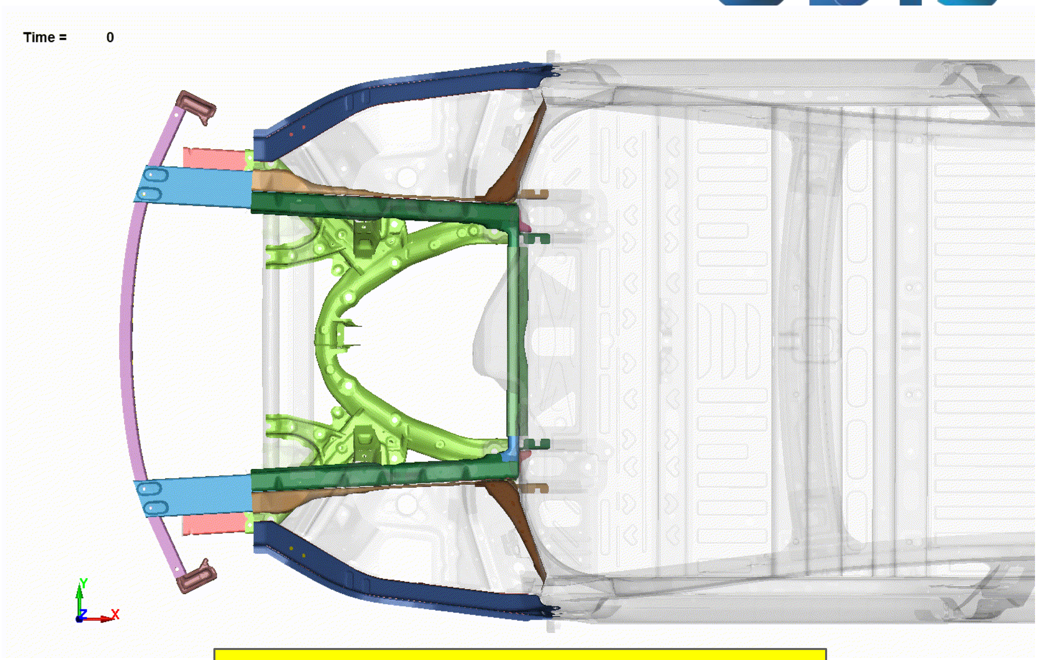


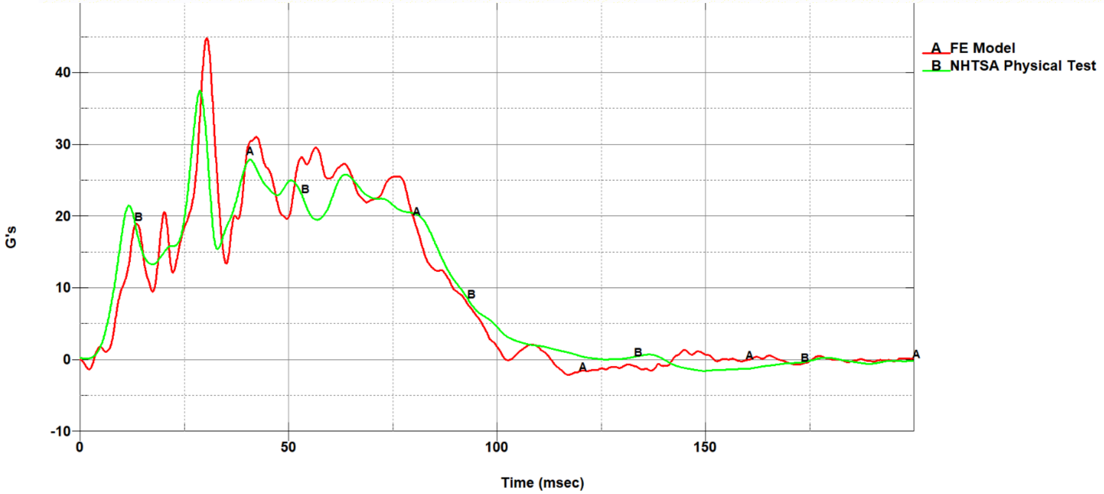


# Steel Baseline - USNCAP

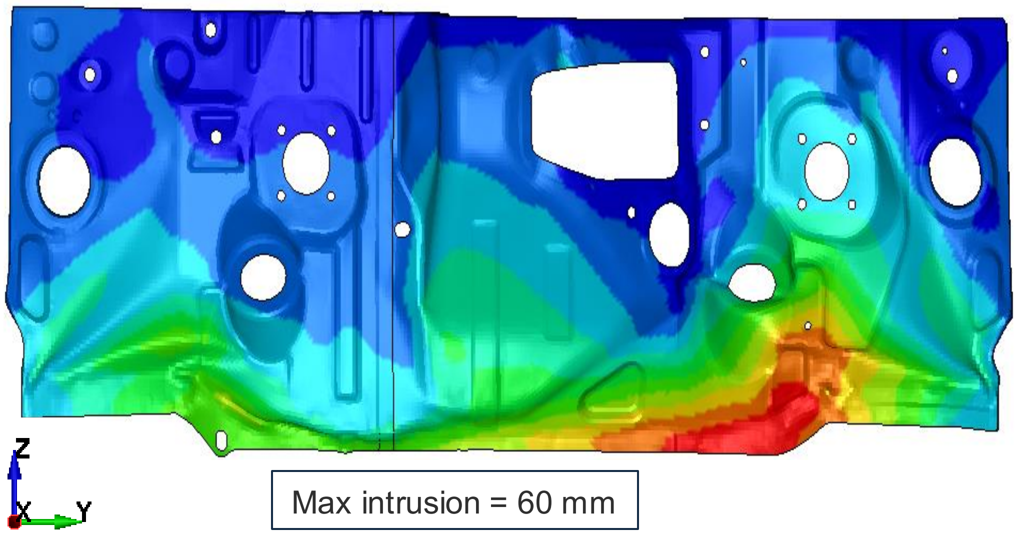


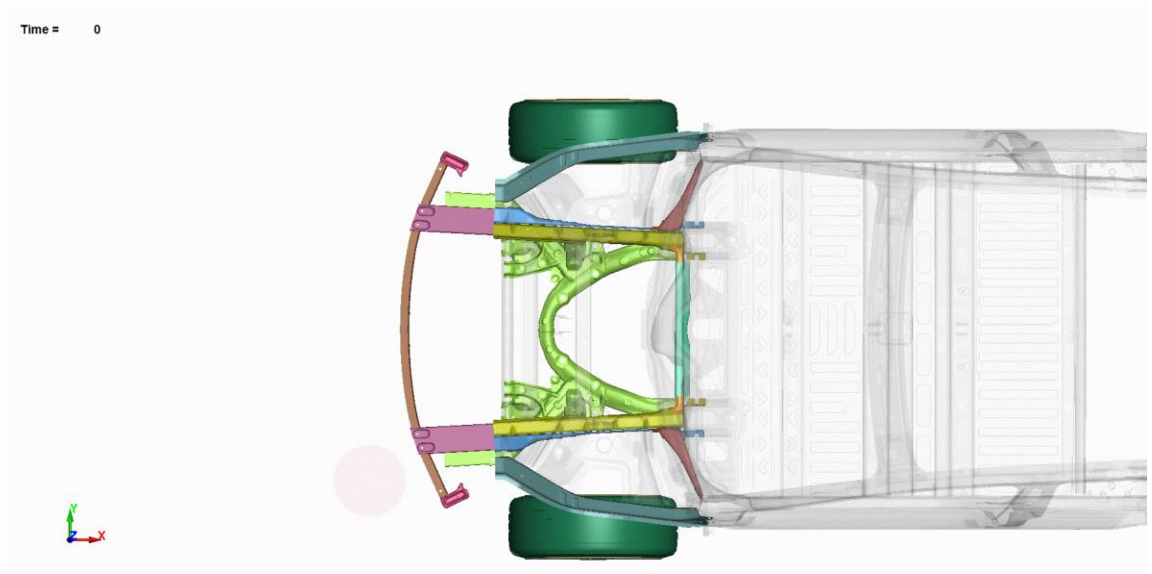

CAE model shows a good correlation with test results

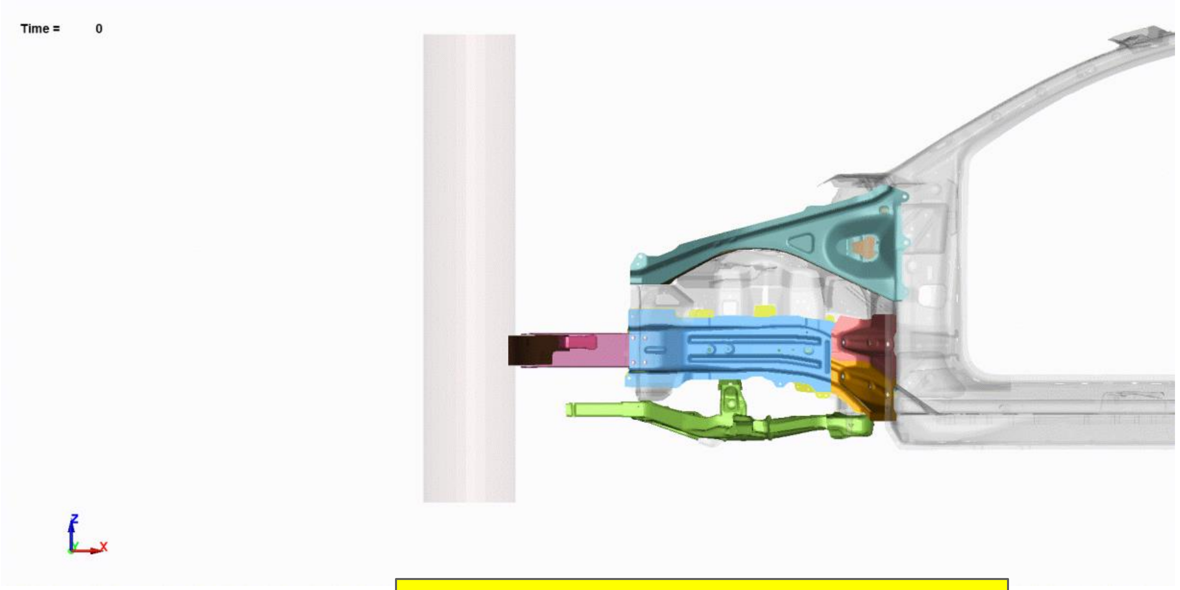
Dash Intrusions

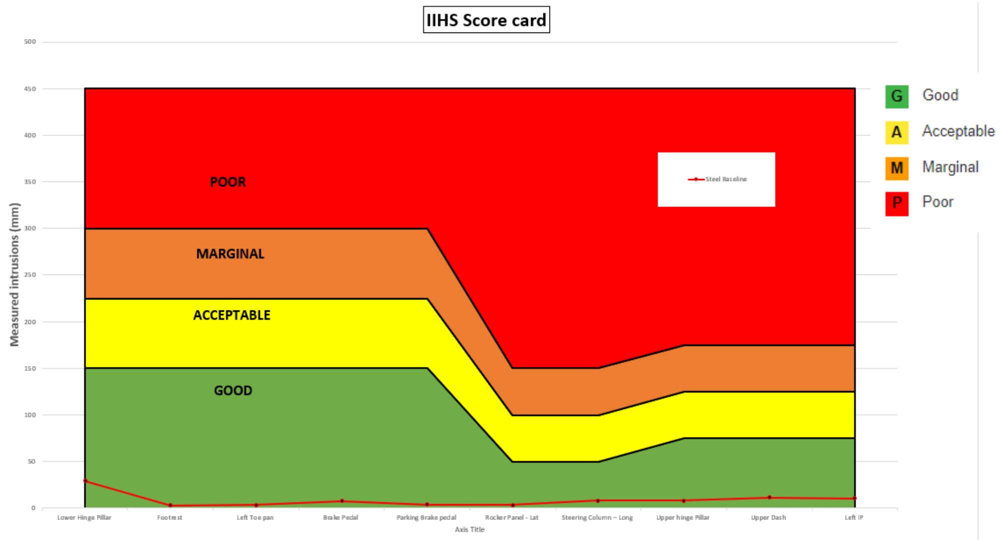


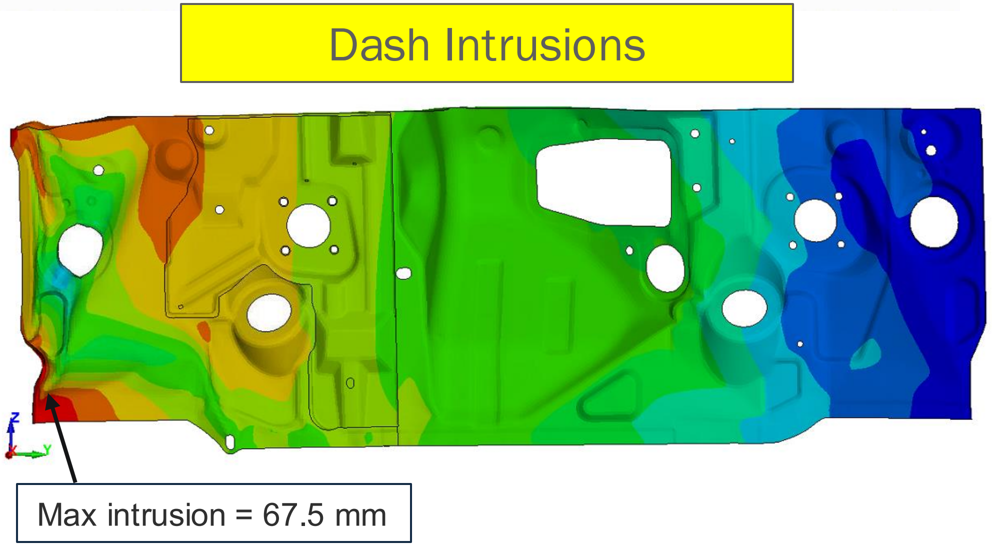

Max intrusion = 60 mm

# Steel Baseline – Small Overlap Rigid Barrier



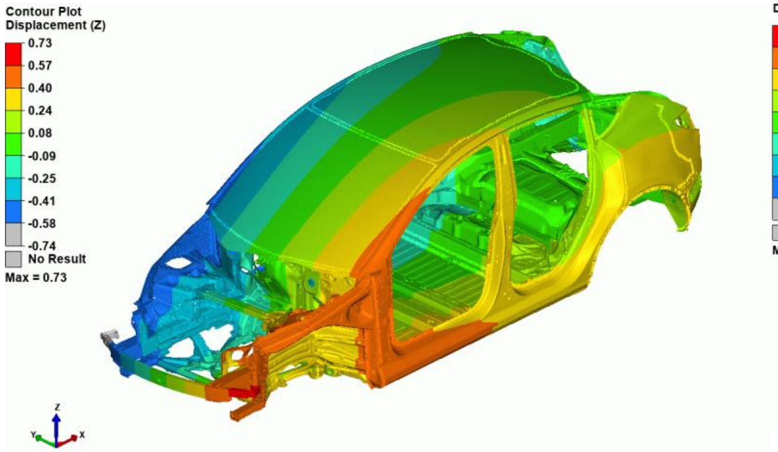



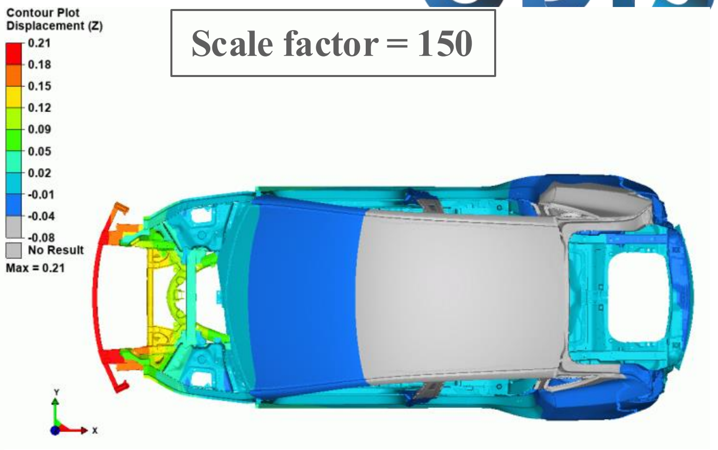



# Steel Base – BIW Stiffness and Shock tower

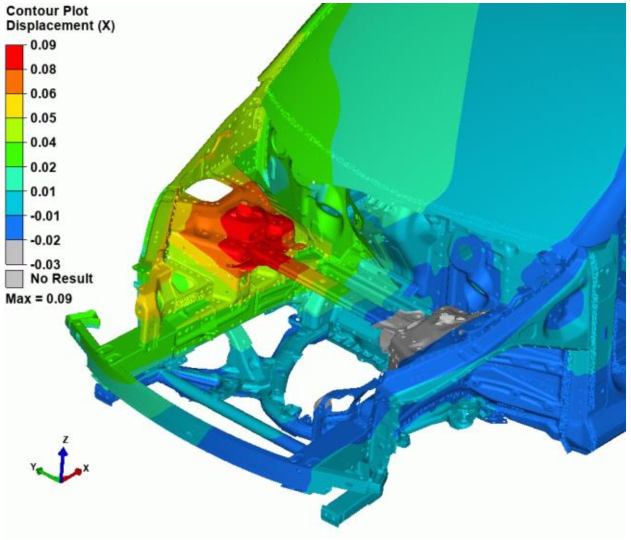

Bending stiffness = 14.8 kN/mm



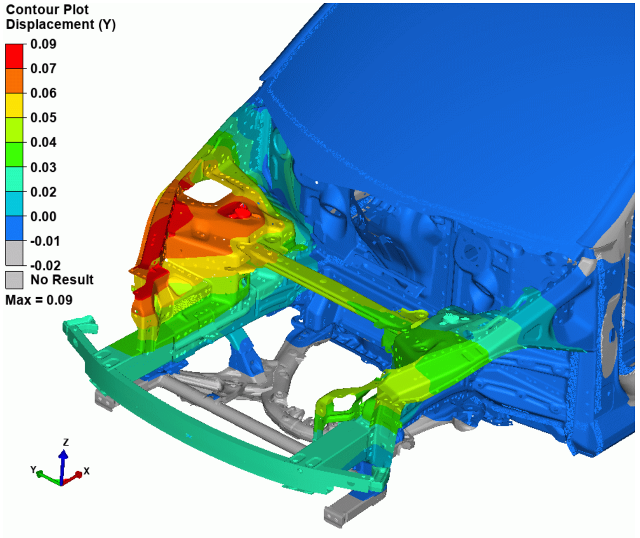

Torsional stiffness = 17 kN-m/deg.



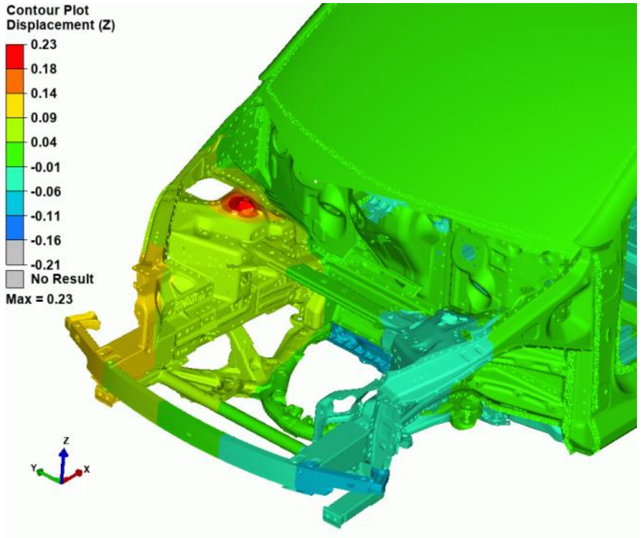

Lateral stiffness = 6.2 kN/mm




Shock tower stiffness -X = 12.5 kN/mm

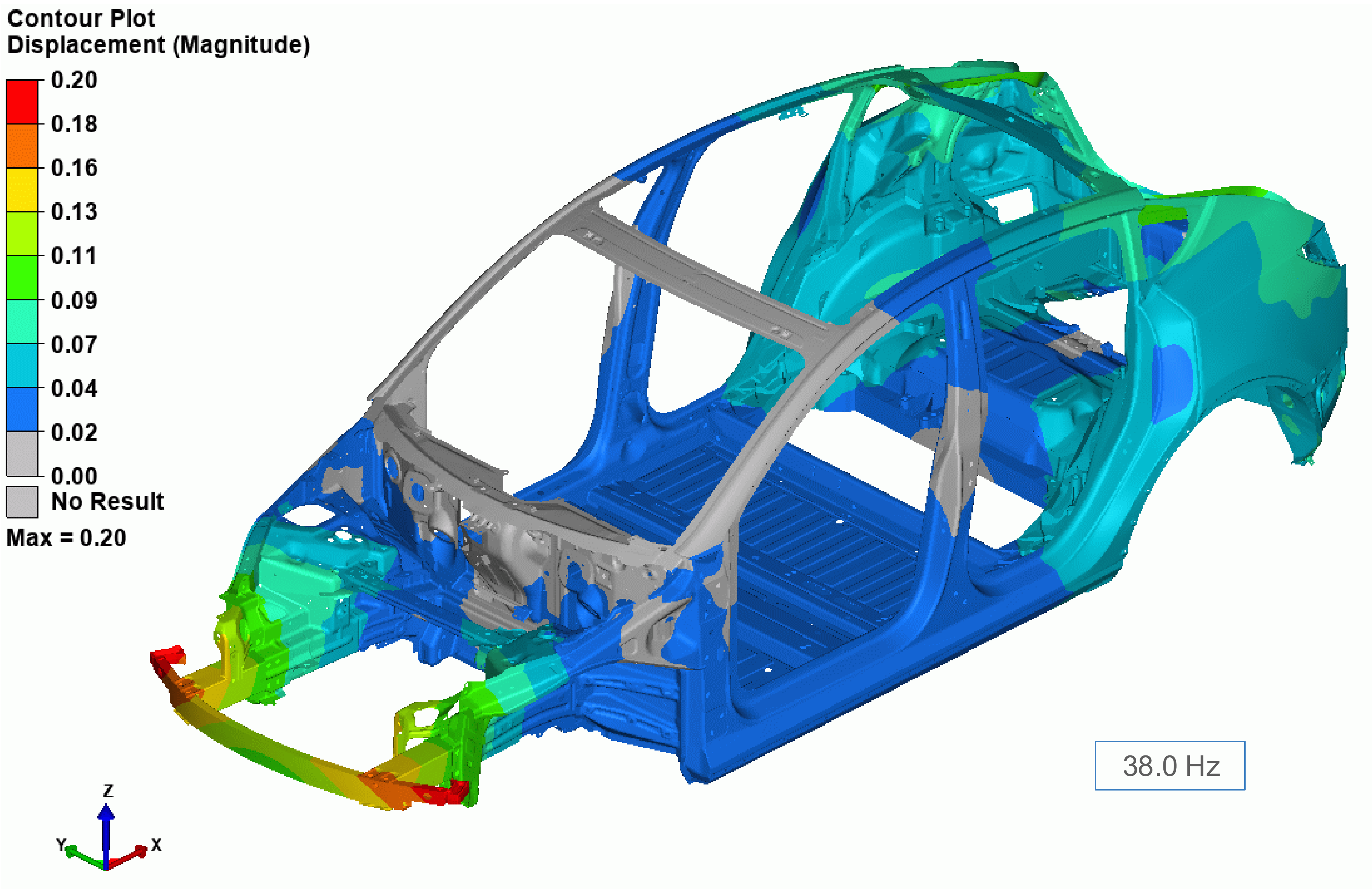



Shock tower stiffness -Y = 14.2 kN/mm

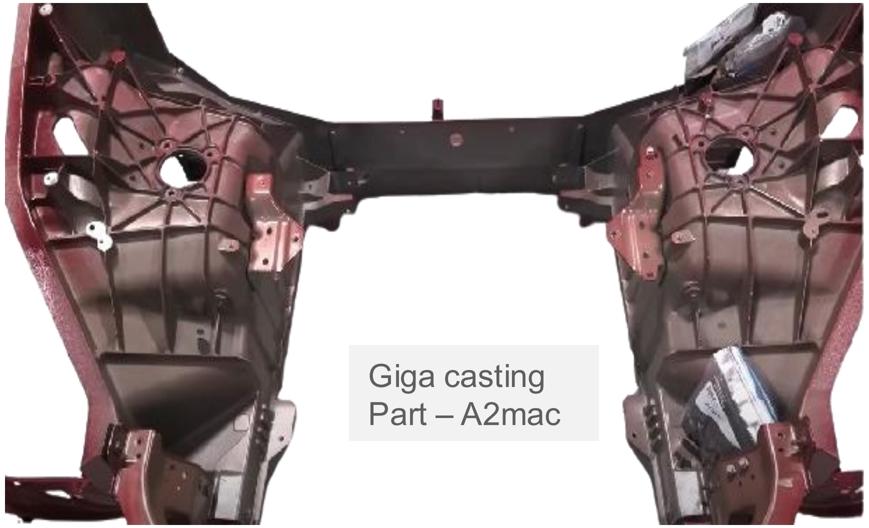


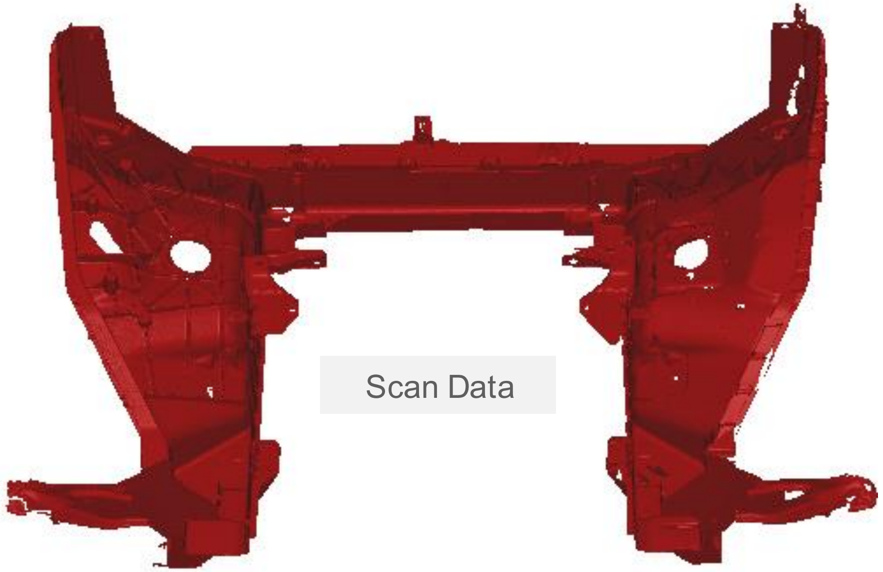

Shock tower stiffness -Z = 5.8 kN/mm

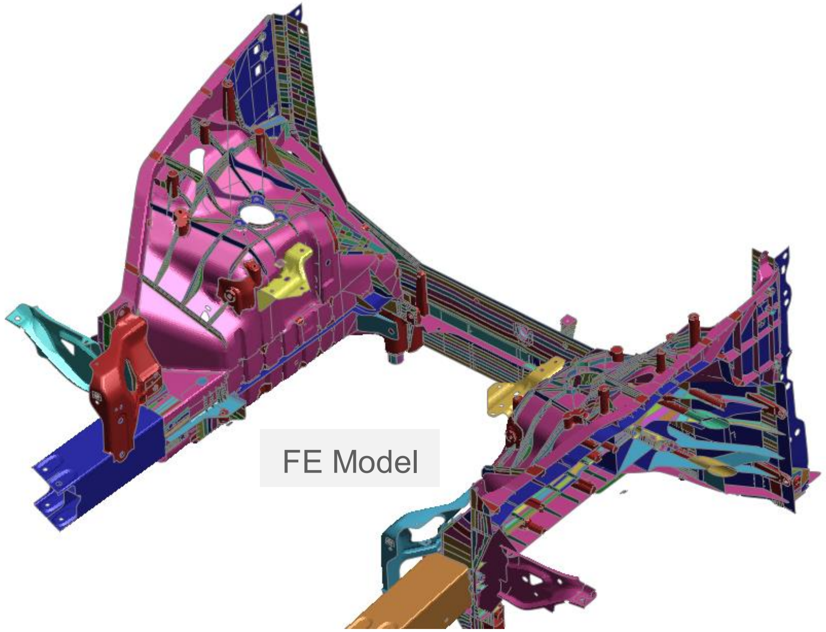
# Steel Base – BIW normal modes (torsional Mode)

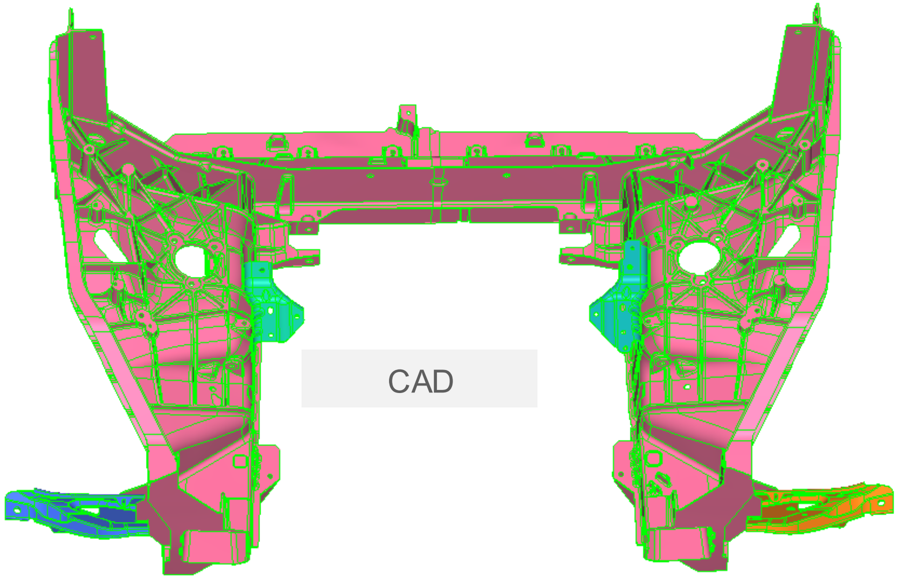


# Aluminum Baseline - Giga casting

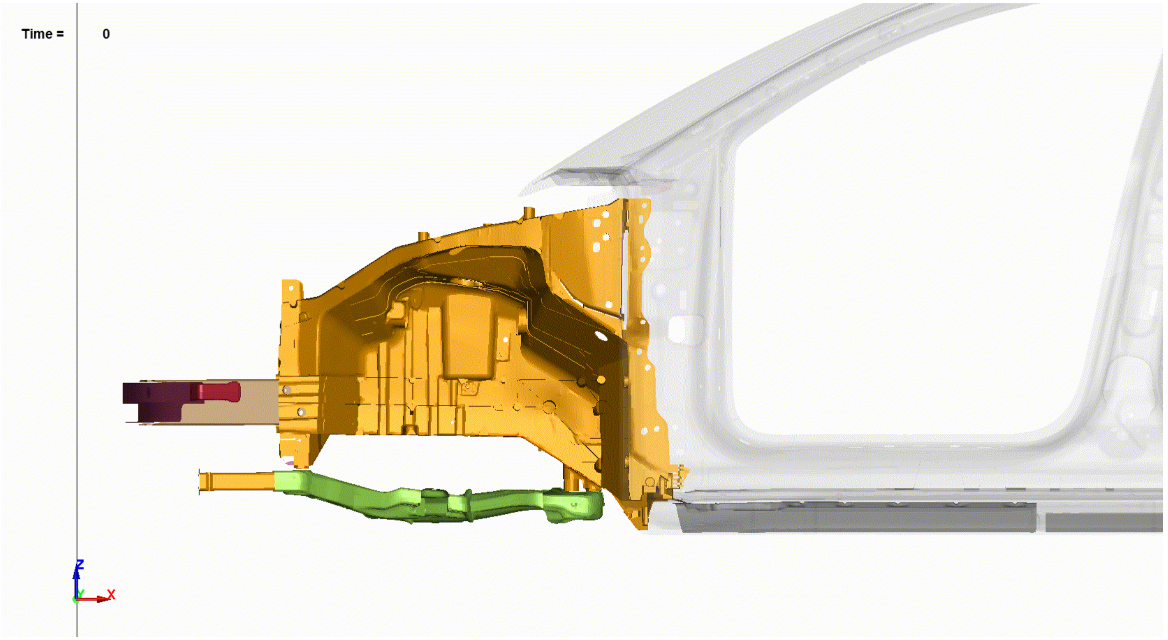


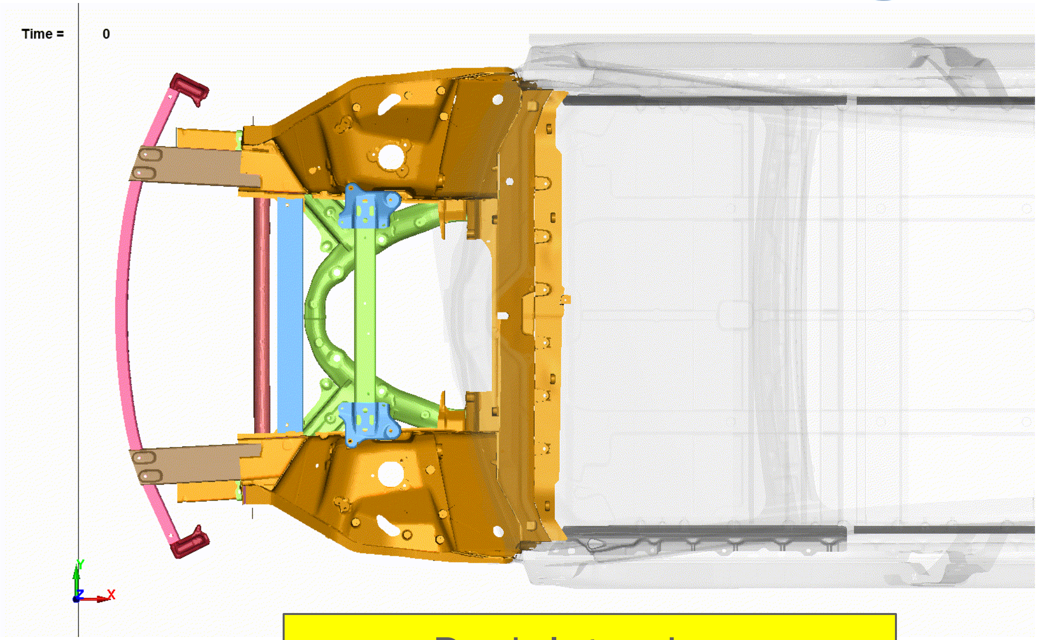



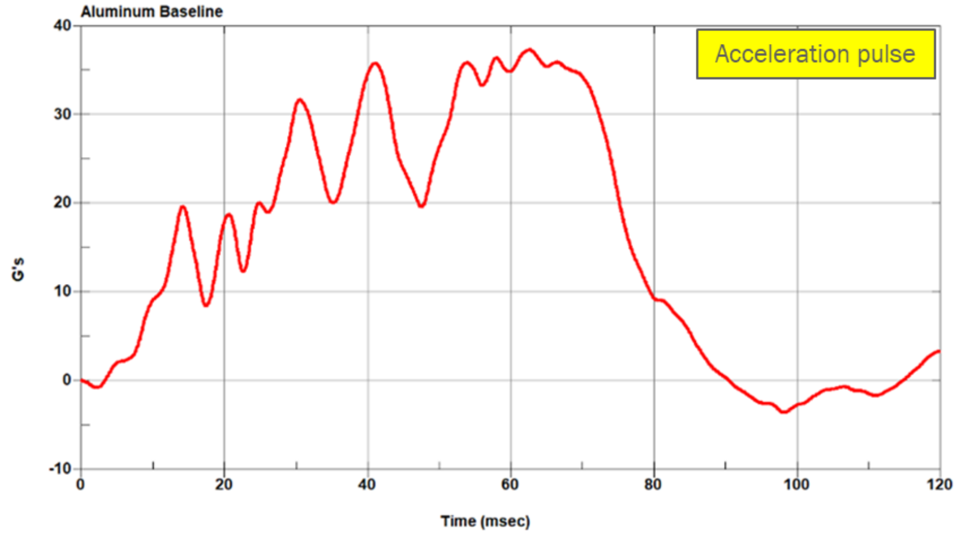



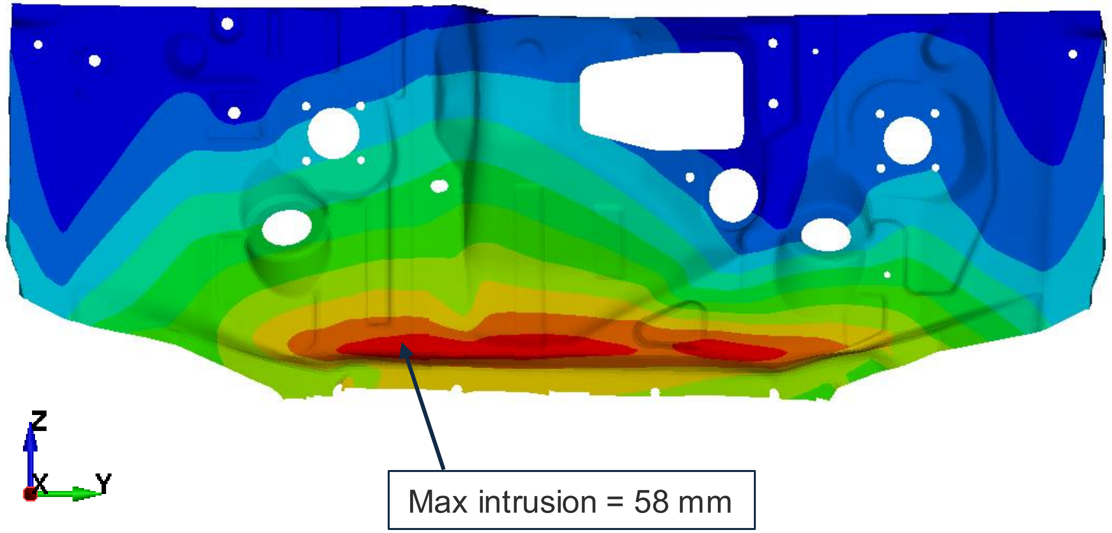
# AL Baseline - USNCAP



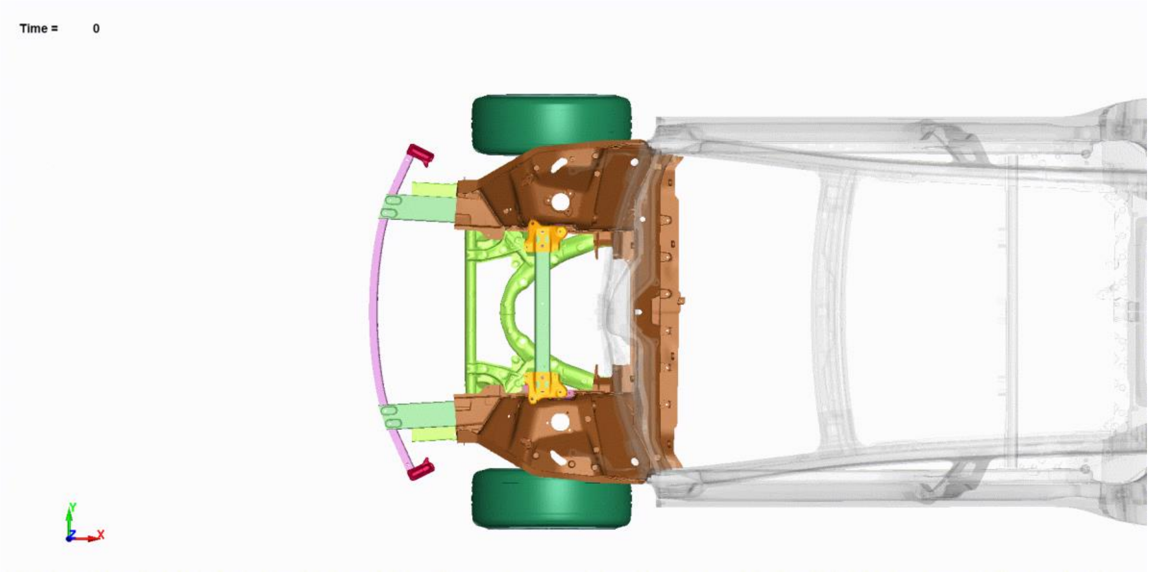



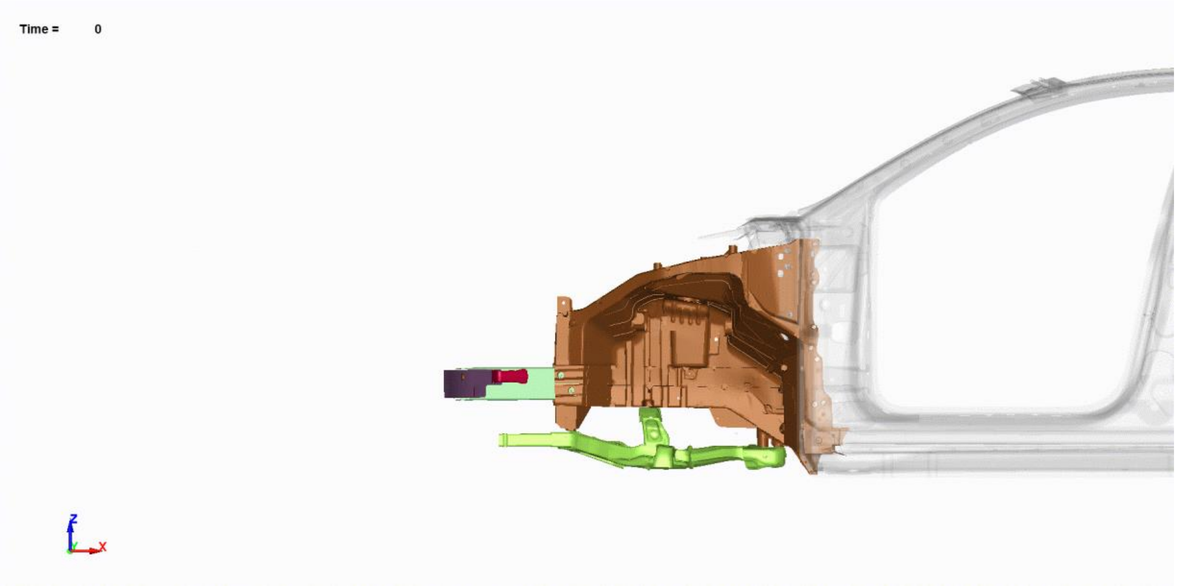



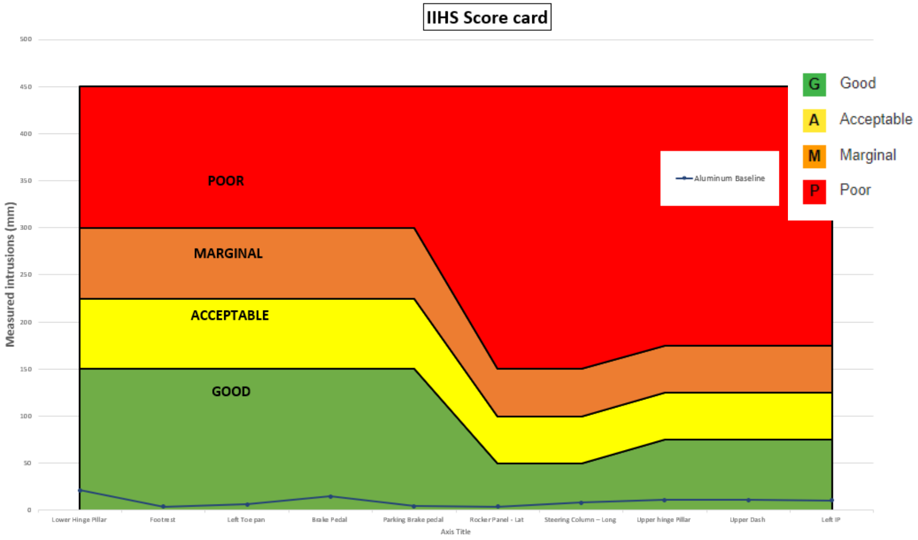

Dash Intrusions

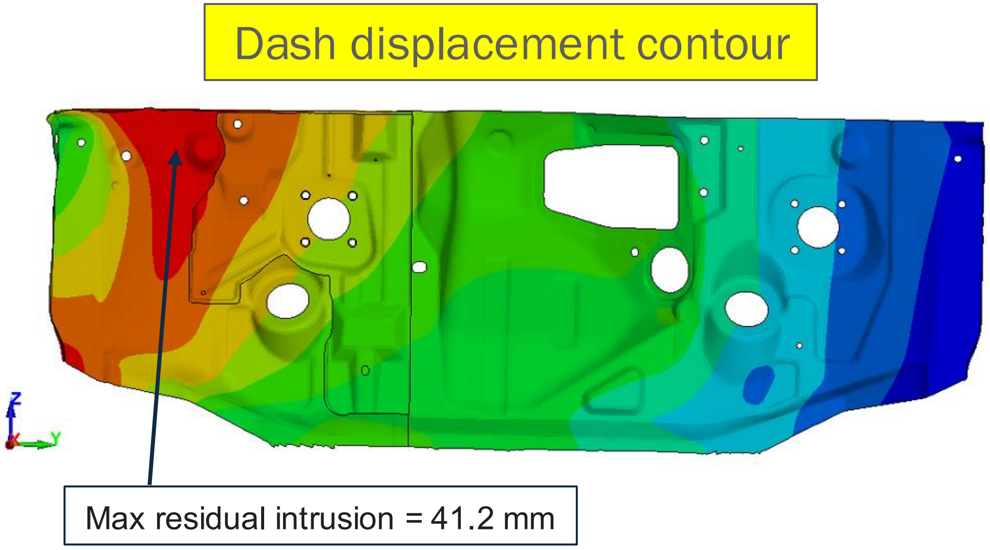


# AL Baseline - Small Offset Rigid Barrier

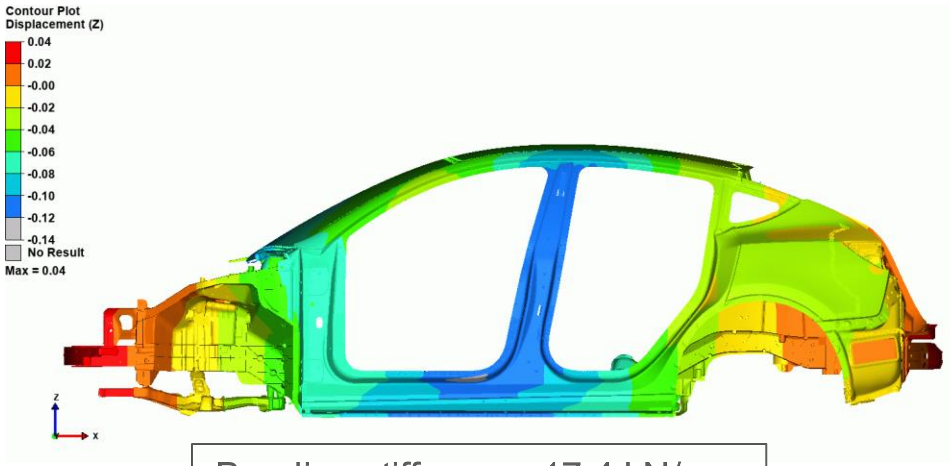


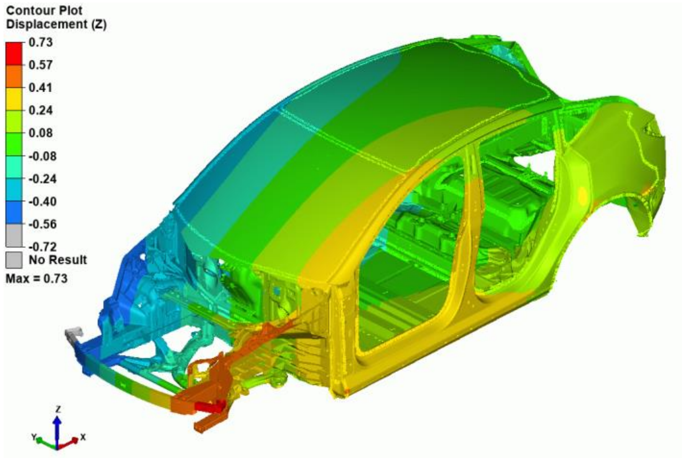



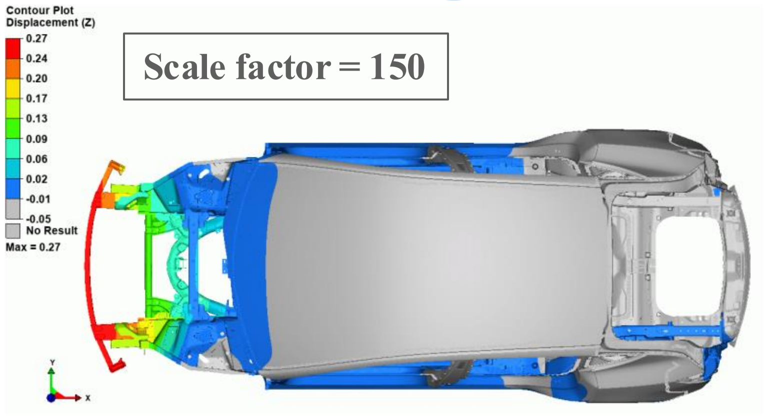
# AL Base – BIW Stiffness and Shock tower



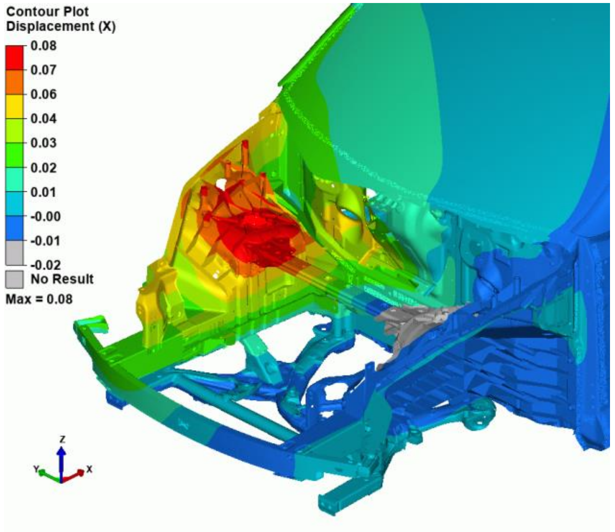

Bending stiffness = 17.4 kN/mm



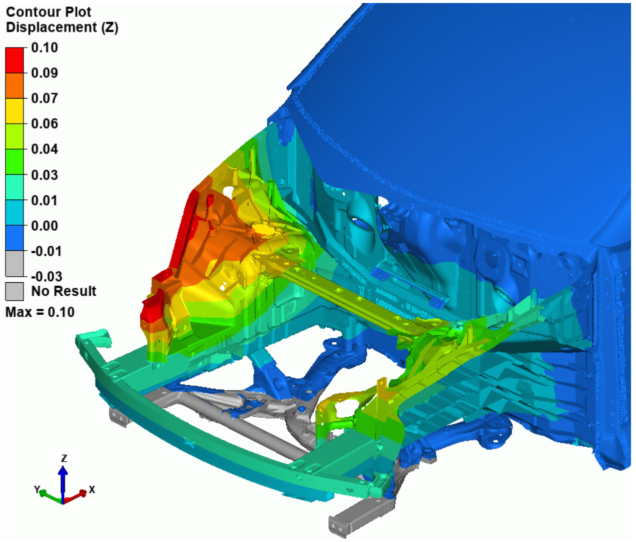

Torsional stiffness = 22.8 kN-m/deg.



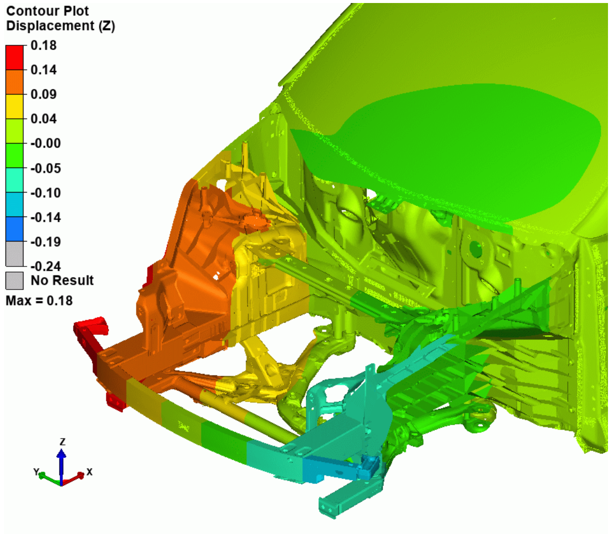

Lateral stiffness = 5 kN/mm




Shock tower stiffness -X = 14.2 kN/mm



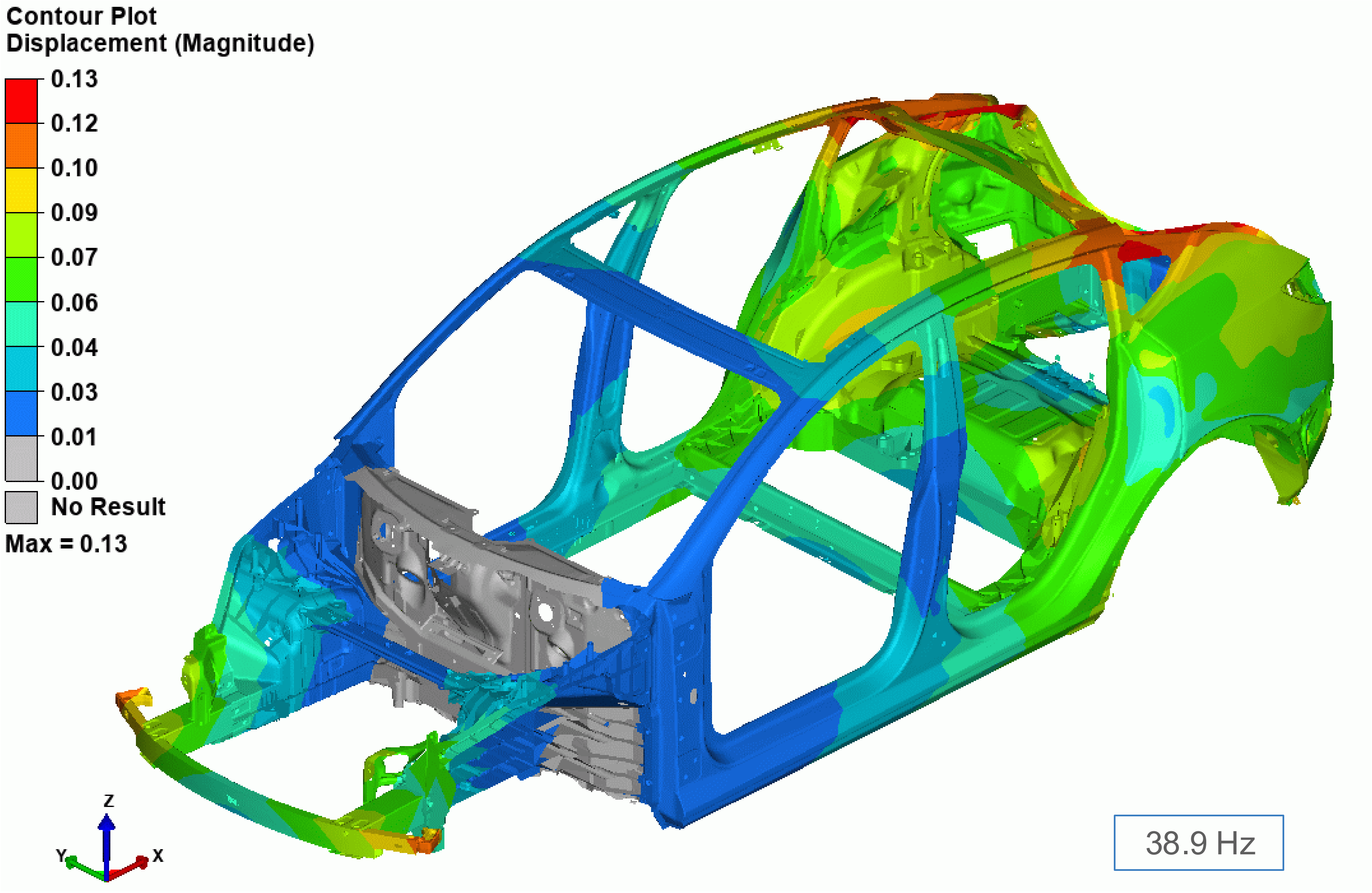

Shock tower stiffness -Y = 14.2 kN/mm




Shock tower stiffness -Z = 9.1 kN/mm

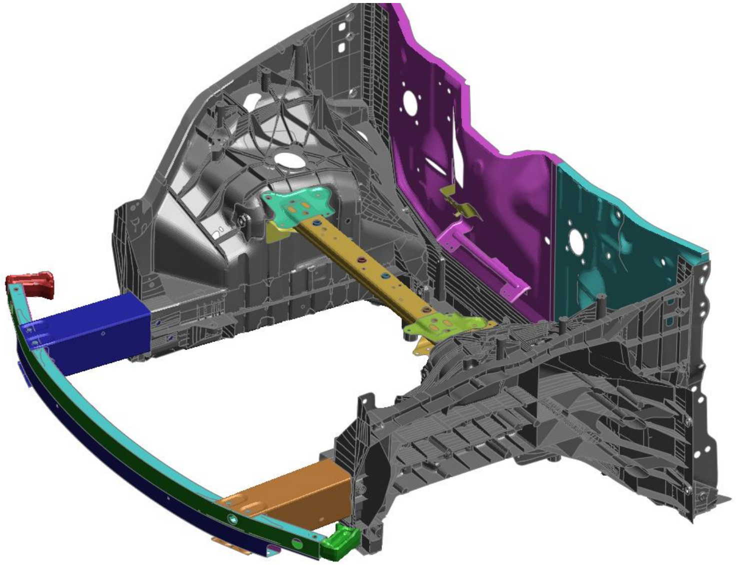
# AL Base – BIW normal modes (Torsional Mode)

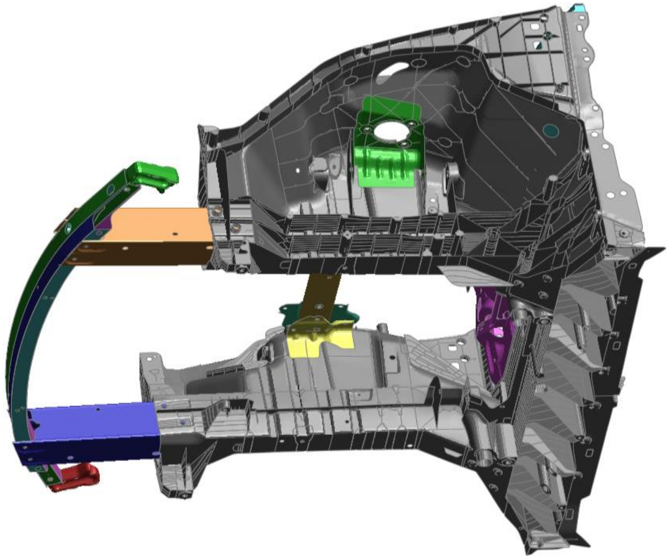
GDIS

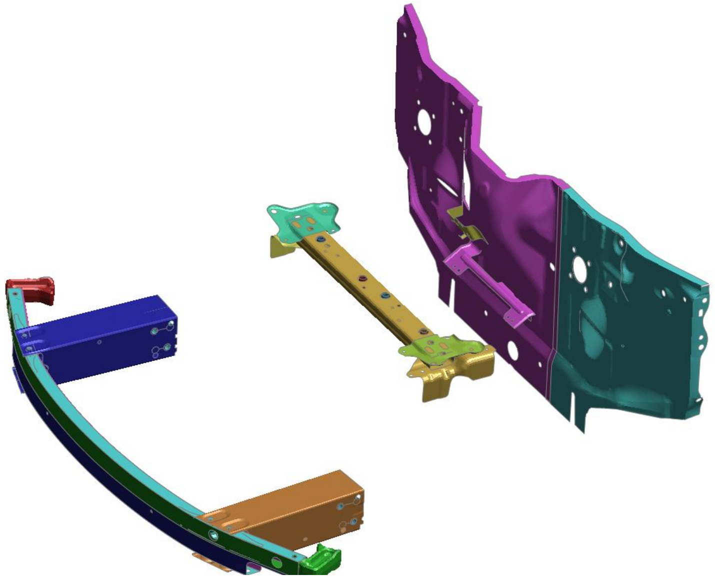


# Design Space for Optimization – Mass Summary

- Design Space: Giga Casting and Surrounding parts (Front Bumper and Crush can Assembly, Shock tower Cross member, Dash and Reinforcements)
- Giga casting integrates – EDM Mounts and other shock tower castings







**Summary:**

- **No of Parts:**
  - **Giga Casting – 3** *(Giga Casting + Shock Reinforcement)*
  - **Shock Tower Cross Member – 5**
  - **Dash Assembly - 5**
  - **Front Bumper – 5** (Including 2 foam)
- **Mass Summary:**
  - Giga Casting = 62.2 Kg (CAE model based, *actual 74.7Kg*)
  - Shock Tower Cross Member = 1.75 Kg
  - Front Bumper + Crush Can = 9.2 Kg
  - Dash Assembly = 2.75 Kg

Design Space:
1. Mass = 76 kg
2. Part Count = 18 parts

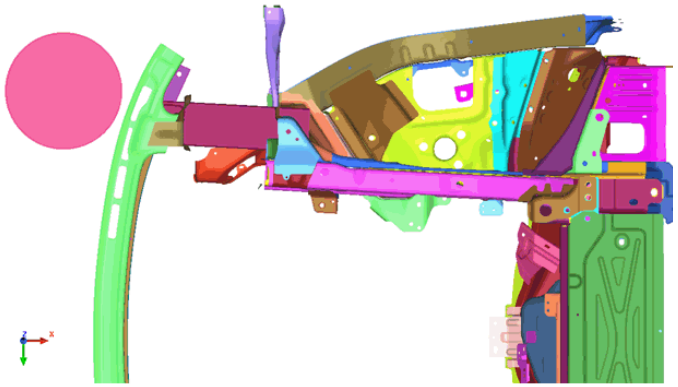
# Project Details – CAE Performance Targets

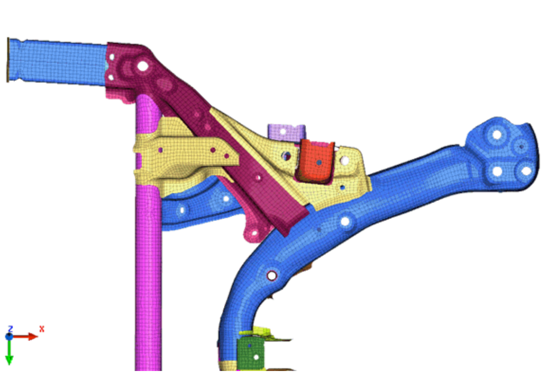
GDIS

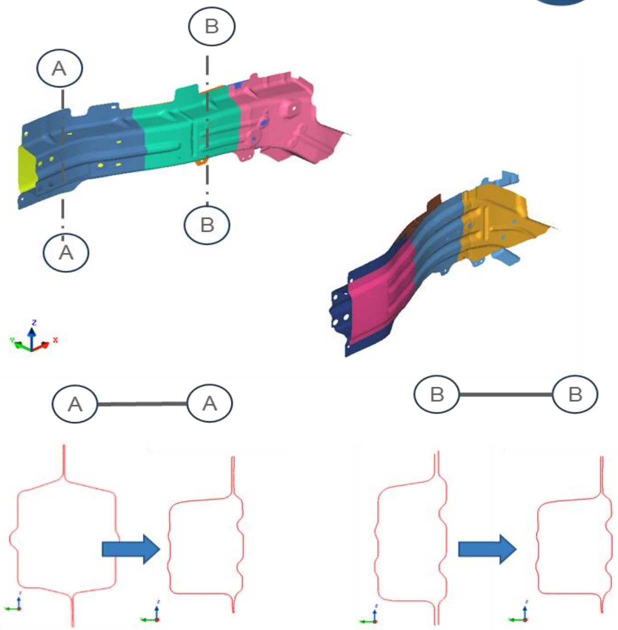
- Targets set to fall at least between the two baselines

| Load case | Measuring Points (Units) | CAE Targets | Steel | Aluminum |
|---|---|---|---|---|
| Mass | Front End CAE Model (kg) | | 93.75 | 76 |
| No Parts | Front End Design Space | | | 18 |
| BIW Frequency | BIW Torsional Mode (Hz) | | 38 | 40.2 |
| BIW - Stiffness | BIW Torsional (KN-m/deg) | | 17.0 | 22.8 |
| BIW - Stiffness | BIW Bending (KN/mm) | | 14.8 | 17.4 |
| BIW - Stiffness | BIW Lateral (KN/mm) | | 6.3 | 5.0 |
| Shock Stiffness | X- Direction (KN/mm) | | 12.5 | 14.2 |
| | Y- Direction (KN/mm) | | 14.2 | 14.2 |
| | Z- Direction (KN/mm) | | 5.8 | 9.1 |
| US NCAP | Time To Zero Velocity (msec) | > 67 msec | 69.3 | 67.6 |
| | Dynamic Crush (mm) | > 670 mm | 669 | 678 |
| | Sill Drop(mm) | < 24 mm | 7.16 | 24 |
| | Peak Pulse 0 -20 msec G's | > | 18.9 | 19.5 |
| | Peak Pulse 20 -60 msec G's | < | 44.9 | 36.3 |
| SORB | Lower Hinge Pillar (mm) | <= 135.0 | 29.3 | 21.3 |
| | Footrest (mm) | <= 135.0 | 3.1 | 3.9 |
| | Left Toe pan (mm) | <= 135.0 | 3.5 | 6.3 |
| | Brake Pedal (mm) | <= 135.0 | 7.7 | 14.6 |
| | Parking Brake Pedal (mm) | <= 135.0 | 3.8 | 4.4 |
| | Rocker Panel - Lat (mm) | <= 45.0 | 3.5 | 4.0 |
| | steering Column – Long (mm) | <= 45.0 | 8.1 | 8.2 |
| | Upper hinge Pillar (mm) | <= 67.0 | 8.3 | 10.9 |
| | Upper Dash (mm) | <= 67.0 | 11.5 | 11.1 |
| | Left IP (mm) | <= 67.0 | 10.5 | 10.6 |

# Front End concepts

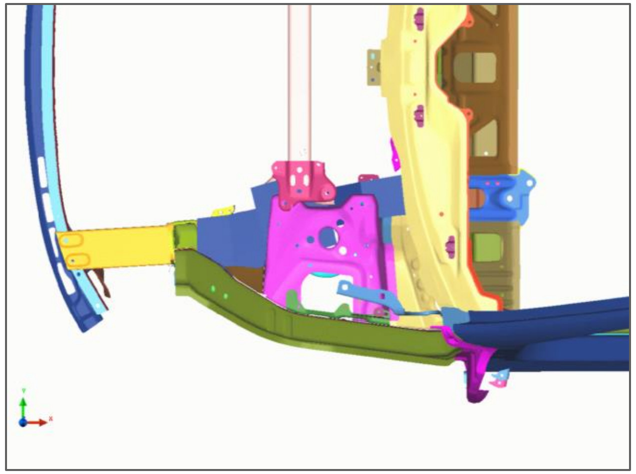


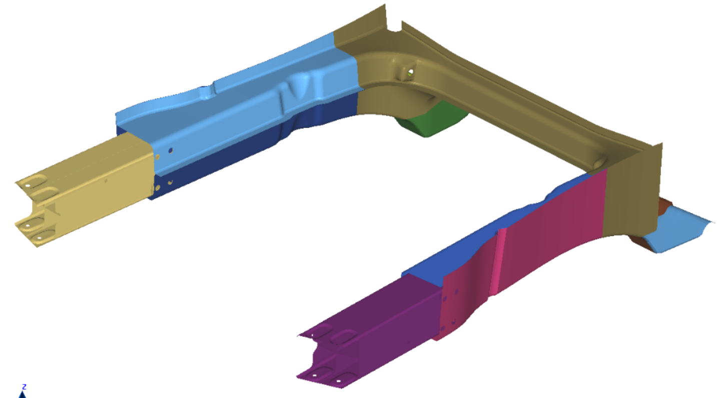





3G Design Variables (Geometry, Gauge and Grade)

- Front Rails splay (straight to Splay)
- Cradle splay
- Rail Height and width, Shotgun width and height
- Laser weld blanks
- Material grades
- Gauges (front end parts as per the design space)
- Clamshell Front Rails

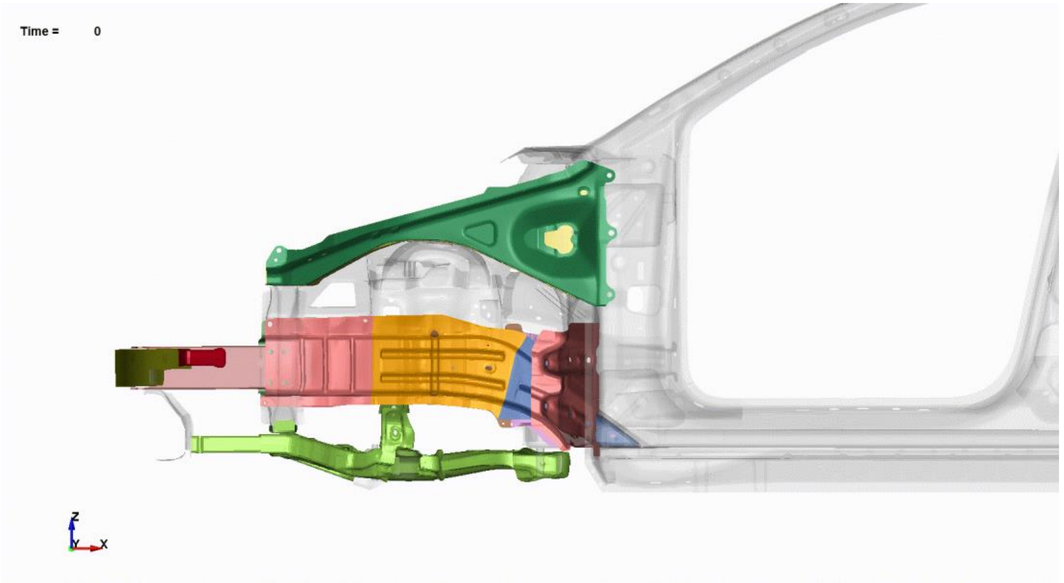


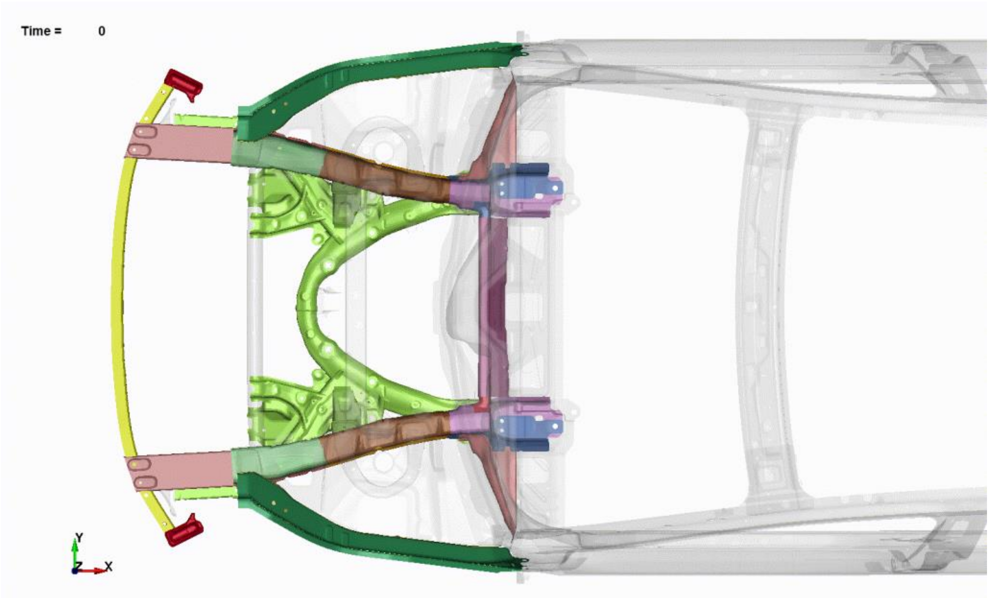


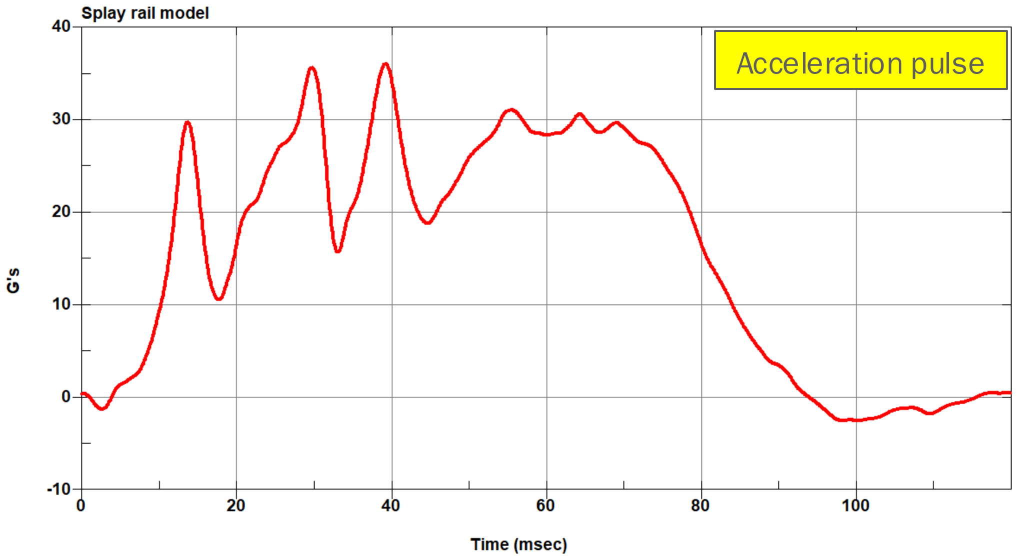
**Clamshell Front Rails**

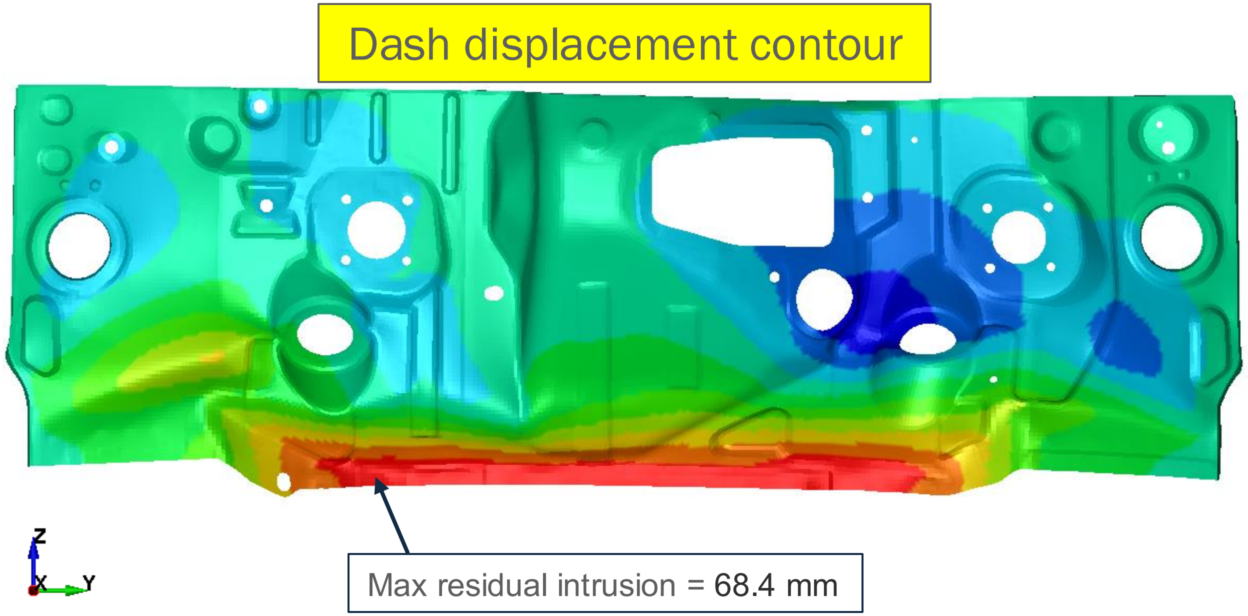
Finalized 2 Front End concepts – Splay Rail Design and Clamshell Design

# Splay Rail - USNCAP

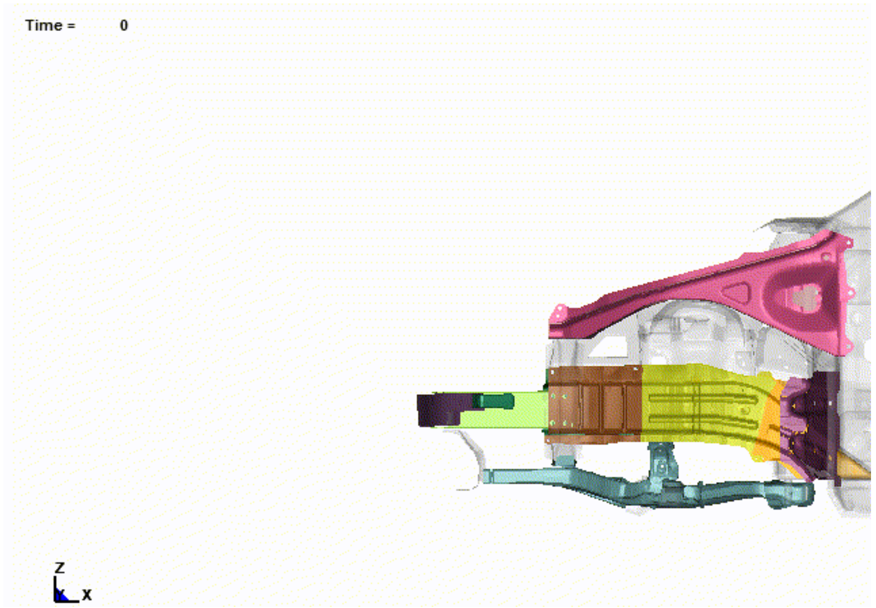


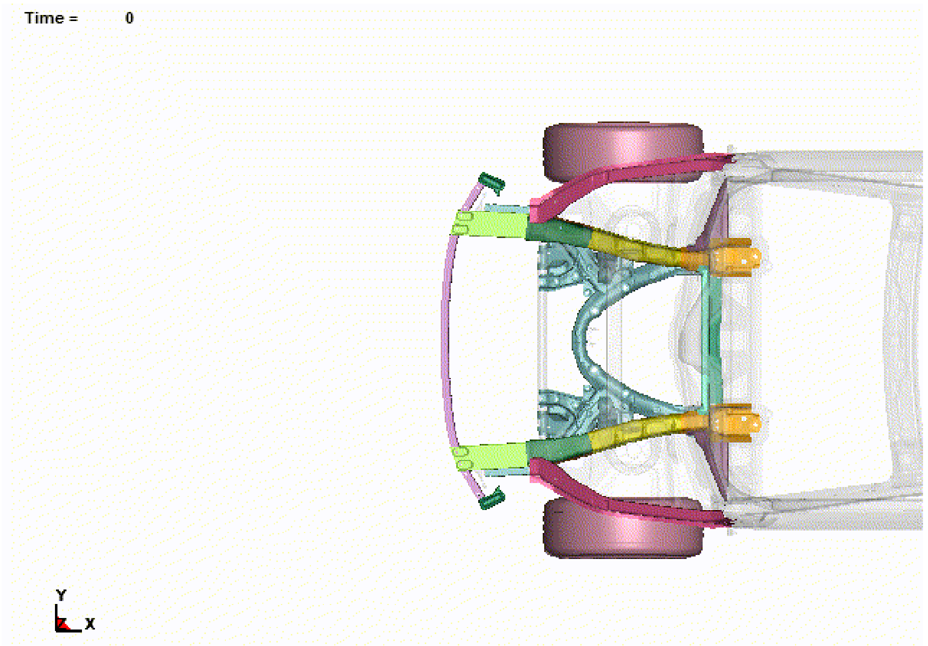



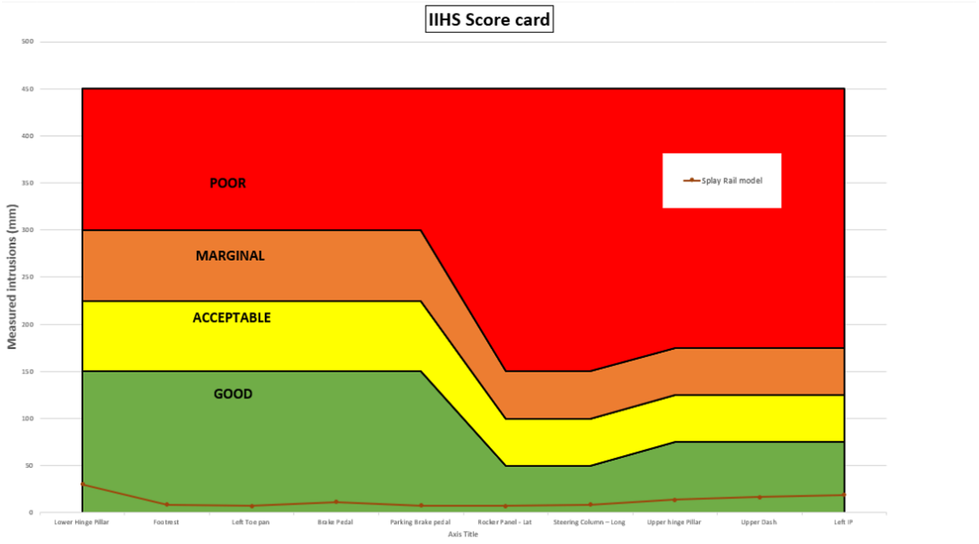



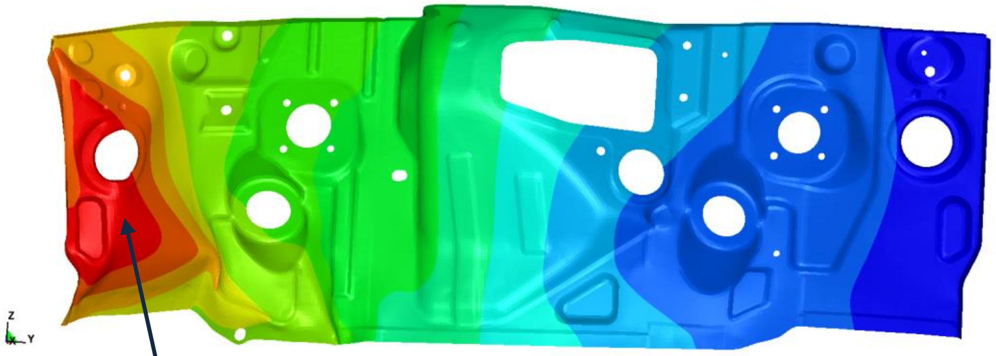
# Splay Rail - Small Offset Rigid Barrier



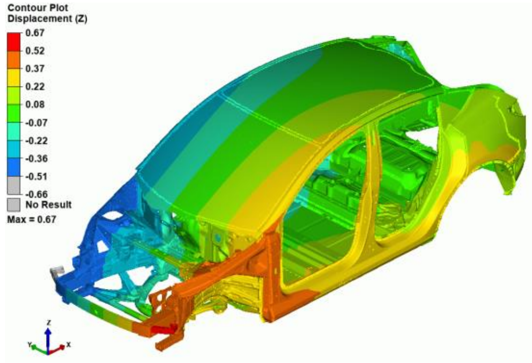

Dash displacement contour



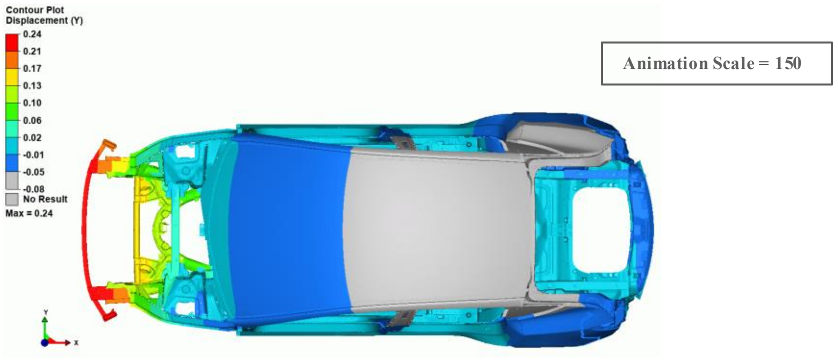
Max residual intrusion = 64 mm

# Splay Rail - Stiffness

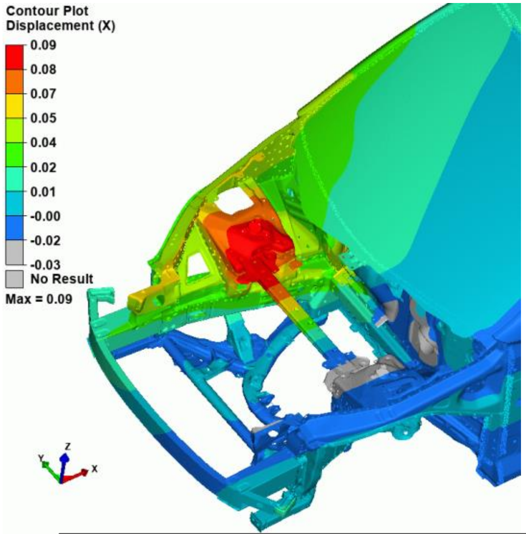

Bending stiffness = 14.3 kN/mm



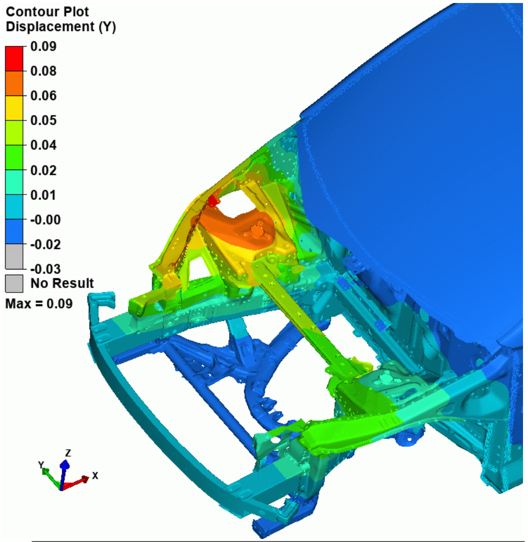

Torsional stiffness = 20.2 kN-m/deg.



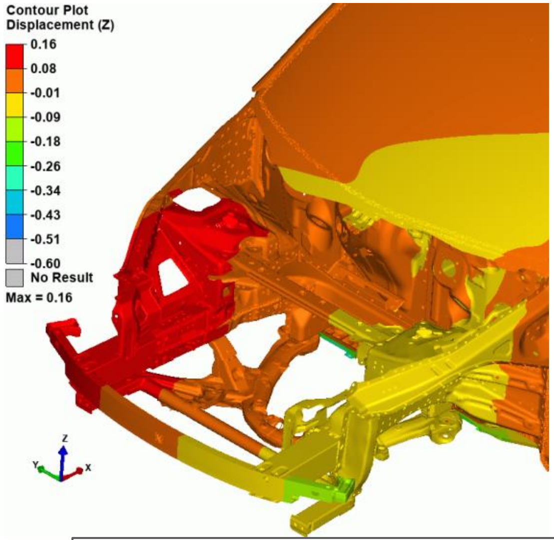

Lateral stiffness = 5.5 kN/mm




Shock tower stiffness X = 12.5 kN/mm

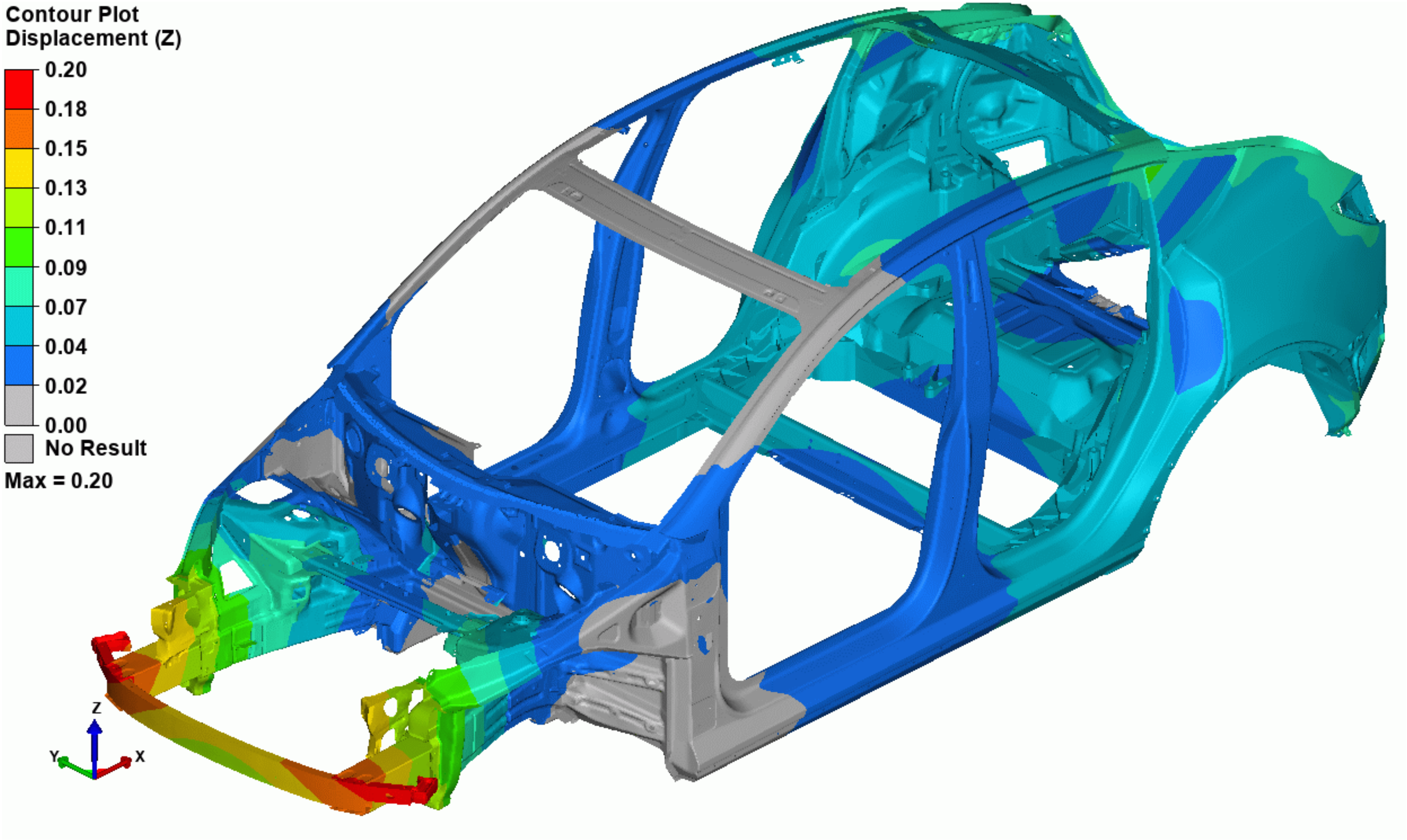



Shock tower stiffness Y = 14.2 kN/mm




Shock tower stiffness Z = 8.3 kN/mm

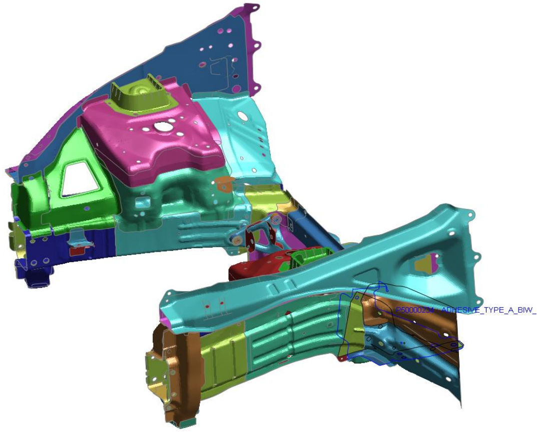
# Splay Rail – BIW Frequency

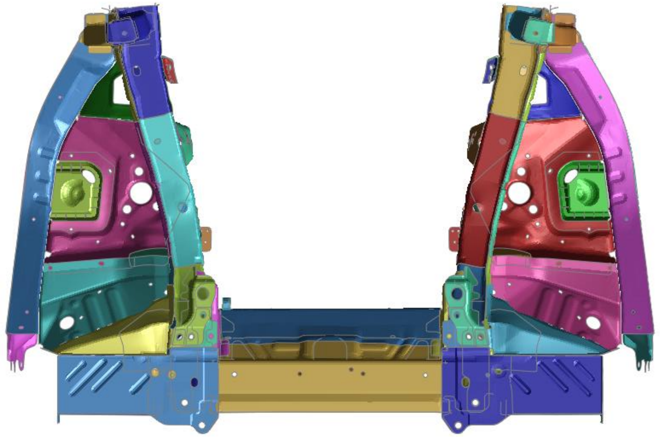


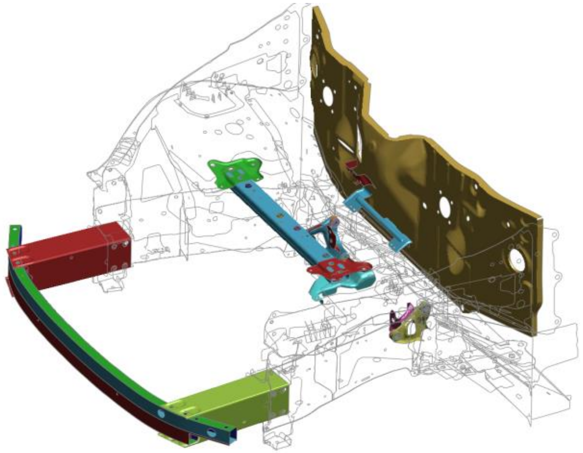

Scale factor = 150

# Splayed Rail Design

- Giga Casting Equivalent Design space consists of Front Bumper Assembly, Shock to Shock Brace, Front Load path, EDM attachments, Front Dash Assembly along with Lower 1 Bar

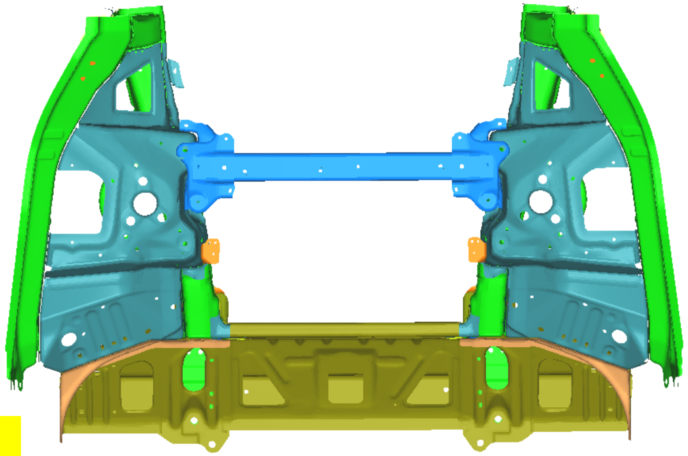


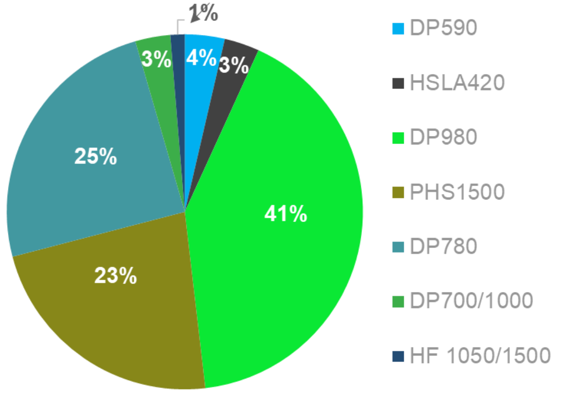




**Summary:**

- **No of Parts:**
  - **Steel Front End = 65**
  - **EDM Mounts = 4**
  - **Shock Tower Cross Member – 5**
  - **Dash Assembly - 3**
  - **Front Bumper – 3** (Including 2 foam)
- **Mass Summary:**
  - Steel Front End = 68.4 Kg (CAE model based)
  - EDM Mounts – 1.9 Kg
  - Shock Tower Cross Member = 1.5 Kg
  - Front Bumper + Crush Can = 7.6 Kg
  - Dash Assembly = 2.6 Kg

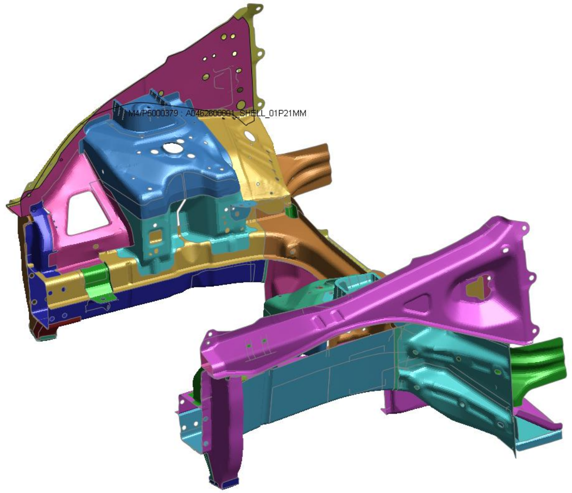


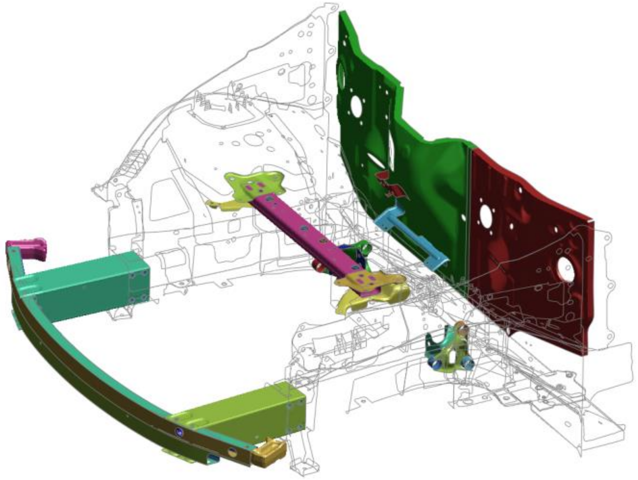



- Steel Front End – Mass = 82 Kg
- No of Parts → 80
- AHSS Steel Dominant

# Clamshell Rail Design

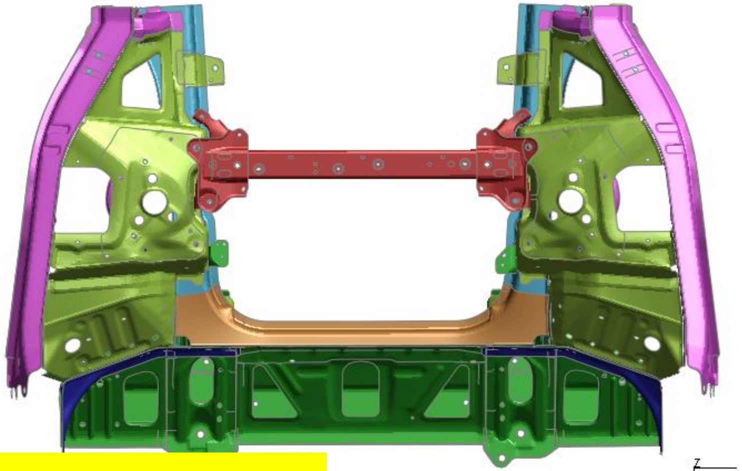
GDIS

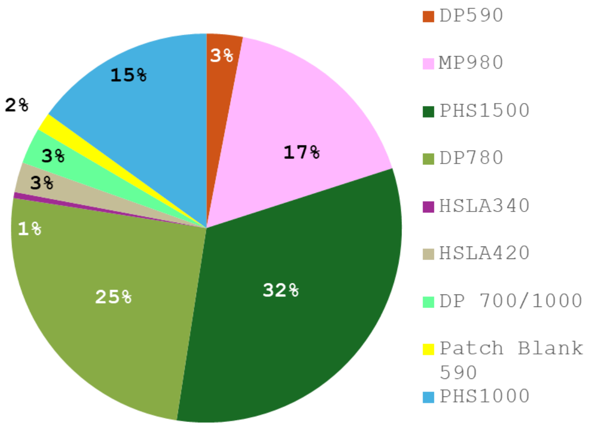




**Summary:**

- **No of Parts:**
  - **Steel Front End = 55**
  - **EDM Mounts = 4**
  - **Shock Tower Cross Member – 5**
  - **Dash Assembly - 4**
  - **Front Bumper – 5** (Including 2 foam)
- **Mass Summary:**
  - Steel Front End = 68 kg (CAE model based)
  - EDM Mounts – 1.9 Kg
  - Shock Tower Cross Member = 1.2 Kg
  - Front Bumper + Crush Can = 9.8 Kg
  - Dash Assembly = 2.6 Kg






- Steel Front End – Mass = 83.5 Kg
- No of Parts → 63
- AHSS Steel Dominant

**** PERFORMS SIMILAR TO SPLAY RAIL DESIGN*

# CAE Performance Summary

GDIS

| Loadcase | Measuring Points (Units) | CAE Targets | Steel | Aluminum | Splay Rail | ClamShell |
|---|---|---|---|---|---|---|
| Mass | kg | | 93.75 | 76 | 82 | 83.5 |
| No Parts | Front End Design Space | | | 18 | 80 | 63 |
| BIW Frequency | BIW Torsional Mode (Hz) | | 38 | 40.2 | 38.8 | 38.9 |
| BIW - Stiffness | BIW Torsional (KN-m/deg) | | 17.0 | 22.8 | 20.2 | 19.07 |
| BIW - Stiffness | BIW Bending (KN/mm) | | 14.8 | 17.4 | 14.3 | 14.3 |
| BIW - Stiffness | BIW Lateral (KN/mm) | | 6.3 | 5.0 | 5.5 | 5,2 |
| Shock Stiffness | X- Direction (KN/mm) | | 12.5 | 14.2 | 12.5 | 12.5 |
| | Y- Direction (KN/mm) | | 14.2 | 14.2 | 14.2 | 14.3 |
| | Z- Direction (KN/mm) | | 5.8 | 9.1 | 8.3 | 7.1 |
| US NCAP | Time To Zero Velocity (msec) | > 67 msec | 69.3 | 67.6 | 72.2 | 69.4 |
| | Dynamic Crush (mm) | > 670 mm | 669 | 678 | 672 | 648 |
| | Sill Drop(mm) | < 24 mm | 7.16 | 24 | 18.5 | 3.62 |
| | Peak Pulse 0 -20 msec G's | > | 18.9 | 19.5 | 29.8 | 25.8 |
| | Peak Pulse 20 -60 msec G's | < | 44.9 | 36.3 | 36.1 | 38.5 |
| SORB | Lower Hinge Pillar (mm) | <= 135.0 | 29.3 | 21.3 | 30.5 | 32.4 |
| | Footrest (mm) | <= 135.0 | 3.1 | 3.9 | 8.54 | 5.94 |
| | Left Toe pan (mm) | <= 135.0 | 3.5 | 6.3 | 7.47 | 10.4 |
| | Brake Pedal (mm) | <= 135.0 | 7.7 | 14.6 | 11.7 | 7.63 |
| | Parking Brake Pedal (mm) | <= 135.0 | 3.8 | 4.4 | 7.71 | 8.71 |
| | Rocker Panel - Lat (mm) | <= 45.0 | 3.5 | 4.0 | 7.31 | 5.44 |
| | steering Column – Long (mm) | <= 45.0 | 8.1 | 8.2 | 8.65 | 11 |
| | Upper hinge Pillar (mm) | <= 67.0 | 8.3 | 10.9 | 13.9 | 16.3 |
| | Upper Dash (mm) | <= 67.0 | 11.5 | 11.1 | 16.6 | 10.8 |
| | Left IP (mm) | <= 67.0 | 10.5 | 10.6 | 19 | 11.5 |

- All CAE performance targets achieved by both concepts
- Clamshell architecture reduces part count and complexity
- Manufacturability validated through comprehensive simulation
- Cost and sustainability assessments completed and summarized

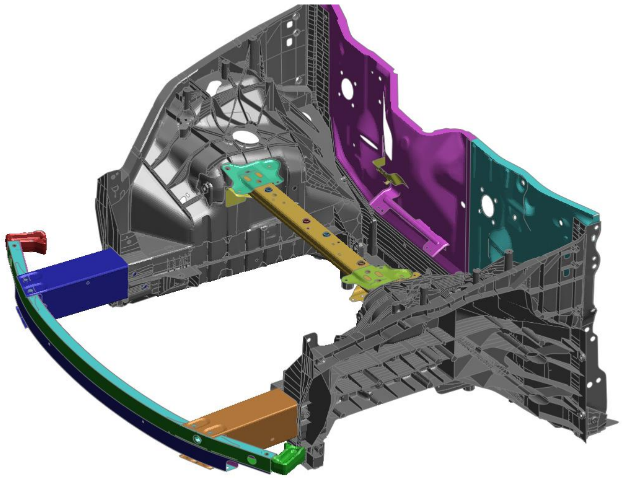
# Cost and sustainability

**Hand – Off To;**

**John Catterall – Auto/Steel Partnership**

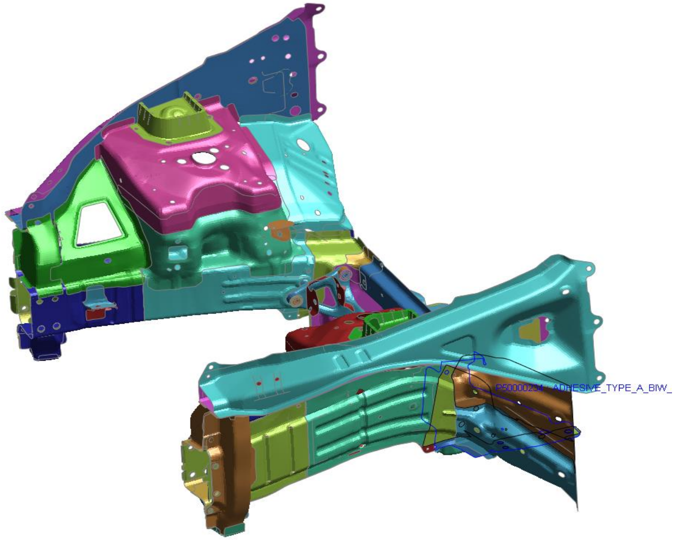
GREAT DESIGNS IN STEEL™

# Mass Comparison



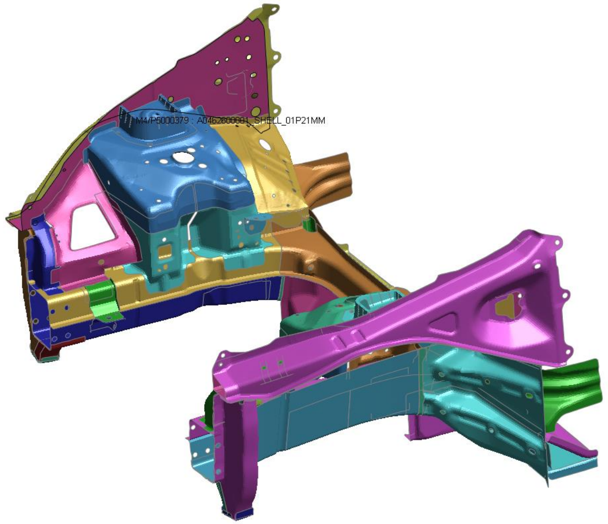
74.7 kg Giga Casting

(grey portion only)



70.5 kg Steel Splayed Rails

- equivalent to casting



70 kg Steel Clamshell Rails

- equivalent to casting

# Project Results - Costing

Using the WorldAutoSteel cost model, an engineering cost comparison was performed comparing the two steel alternative designs with the aluminum giga casting baseline.

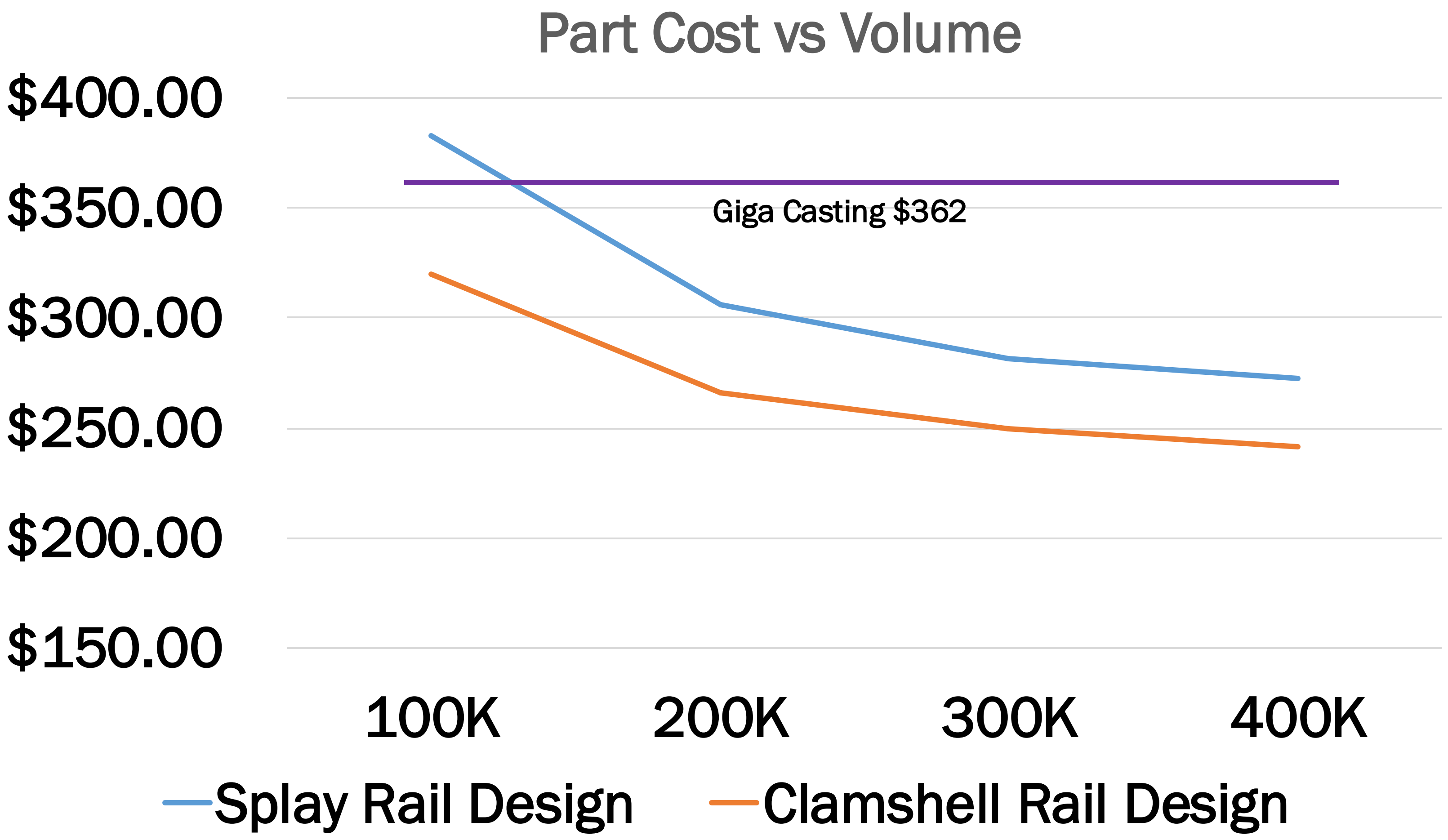
The WorldAutoSteel cost model assumes a greenfield site with no logistics costs but does calculate tooling and equipment investment. The investment costs are amortized over the life of an expected program to generate an assembly piece cost. Cost of capital use is proportioned over the program life.

For this study, a five-year program life was assumed and various volume scenarios calculated.

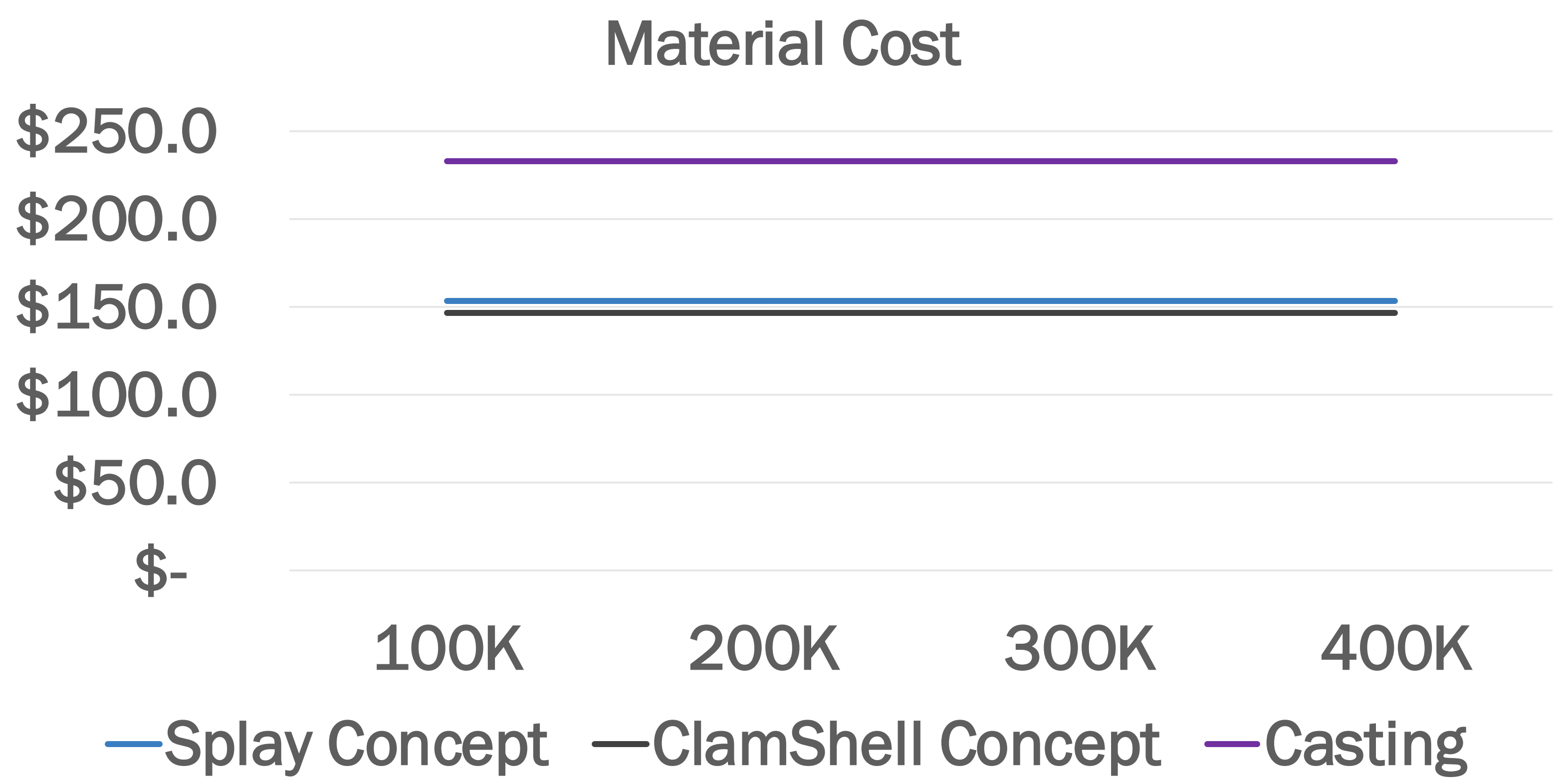
This approach is very good for A to B engineering cost comparisons but does not relate to commercial pricing in any way.

Capital investments and expected volumes may be key factors when considering which of the engineering solutions contained in this study to pursue. If a company/companies already has the capital in place to stamp and assemble steel, this may be the most lucrative approach.

# Project Results – Costing

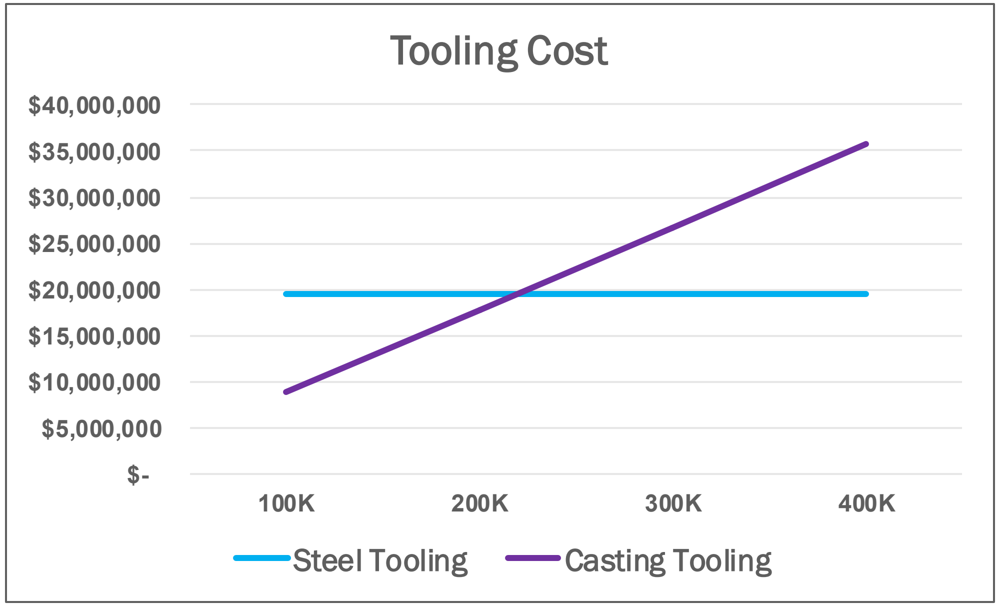


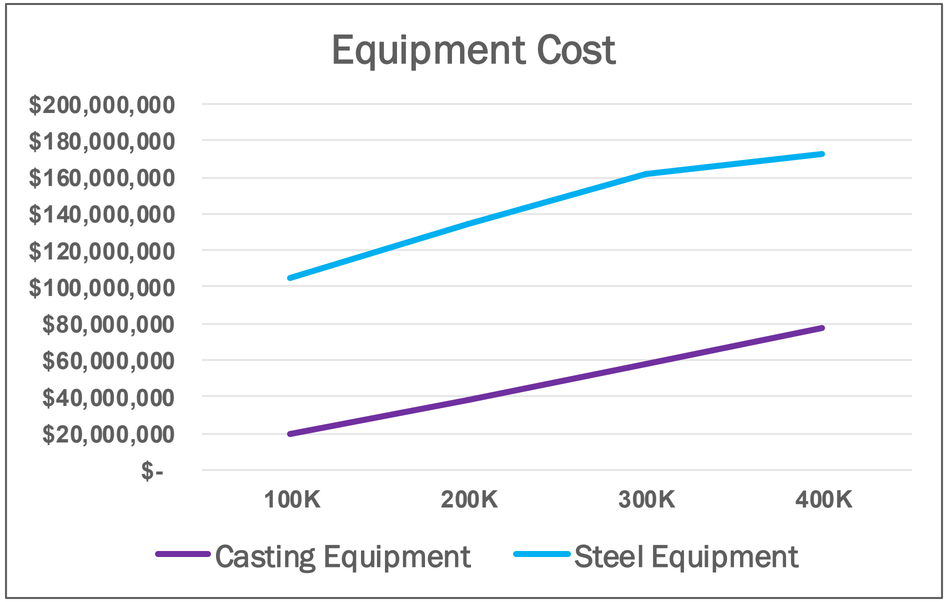
# Project Results – Costing



# Project Results – Costing - Investment

| Investment Cost | 100K | 200K | 300K | 400K |
|---|---|---|---|---|
| Steel Tooling | $ 19,480,000 | $ 19,480,000 | $ 19,480,000 | $ 19,480,000 |
| Casting Tooling | $ 8,910,000 | $ 17,820,000 | $ 26,730,000 | $ 35,640,000 |
| Casting Equipment | $ 19,250,000 | $ 38,500,000 | $ 57,750,000 | $ 77,000,000 |
| Steel Equipment | $ 105,345,000 | $ 134,370,000 | $ 161,805,000 | $ 172,125,000 |



# Project Results – Sustainability

**Methodology:** The kilograms of $CO_2$ calculated for both the aluminum castings and steel used in this comparison had the $CO_2$ from scrap production backed out of the calculation. This was done by assigning it (casting risers, stamping scrap, etc.) as material from secondary production and not included in the calculation for the final component.

University of California at Santa Barbara (**UCSB) model calculations:**

"Contender Vehicle 1" is the vehicle with the giga-casting, while "Contender Vehicle 2" is the vehicle with the steel design.

The "Baseline Vehicle" is the vehicle without a front-end module which was used to calculate the production $CO_2$ emissions of the two contender vehicles. It is not a complete vehicle, so the use phase calculations are meaningless.

# Project Results - Sustainability

Steel Has A Lower Carbon Footprint

For the materials production:

| Material | Production Emissions ($kg\ CO_2$) |
|---|---|
| Aluminum Giga casting | 1,255 |
| Steel alternate (assumes 10% EAF steel content) | 143 |
| *Difference in manufacturing phase production emissions* | *1,112* |

For finishing the raw material into final form:

| Material | Finishing Emissions ($kg\ CO_2$) |
|---|---|
| Aluminum Giga casting | 84 |
| Steel alternate | 49 |

Total Manufacturing:

| Material | Manufacturing Emissions ($kg\ CO_2$) |
|---|---|
| Aluminum Giga casting | 1,339 |
| Steel alternate | 192 |
| *Difference (penalty for using aluminum giga casting)* | *1,147* |

**Methodology:** The kilograms of $CO_2$ calculated for both the aluminum castings and steel used in this comparison had the $CO_2$ from engineered scrap backed out of the calculation. This was done by assigning it (casting risers, stamping scrap, etc.) as material from secondary production and not included in the calculation for the final component.

For reference, production of the **steel vehicle produces 5,809 kg CO2**.
The difference in the weight results in a **26kg less CO2 production for the steel vehicle** in the use phase if this was an electric vehicle. This is the result of **429 MJ less electricity** used in the use phase due to the reduced vehicle weight.

Reference: UCSB Automotive Energy GHG Model, Version 5.1

# Project Conclusions

Two credible baselines were established to set performance targets.

Two alternative steel designs were developed that met the set performance targets, with casting replace parts being approximately 4kg lighter (5%).

Significant part consolidation for the alternate steel designs was achieved to control cost and mass.

The new steel designs were determined to be manufacturing feasible.

The new steel designs show a cost benefit at 100K and above annual volumes.

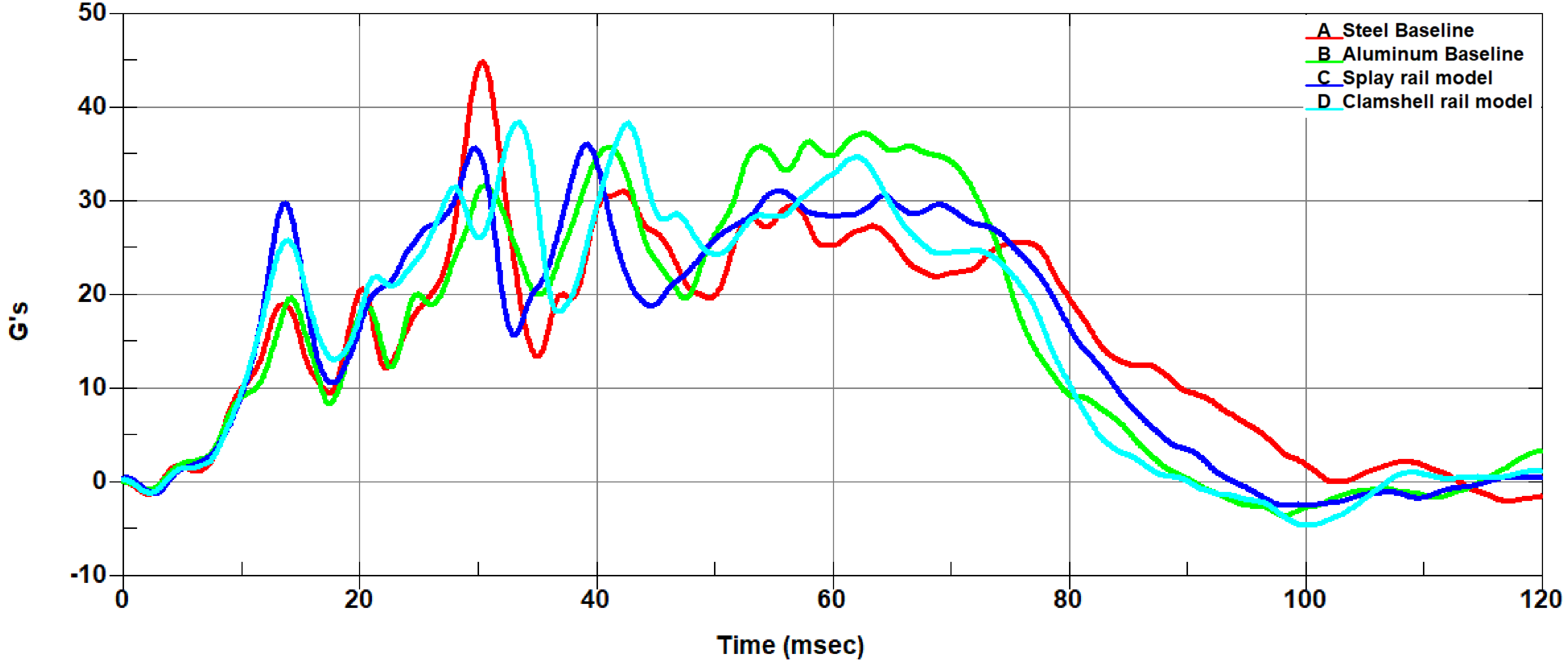
At annual volumes just above 200K the tooling costs for the aluminum casting surpass those for steel.

The steel alternate designs show a significant benefit versus the aluminum casting when evaluated for $CO_2$ emissions.

# BACK UP

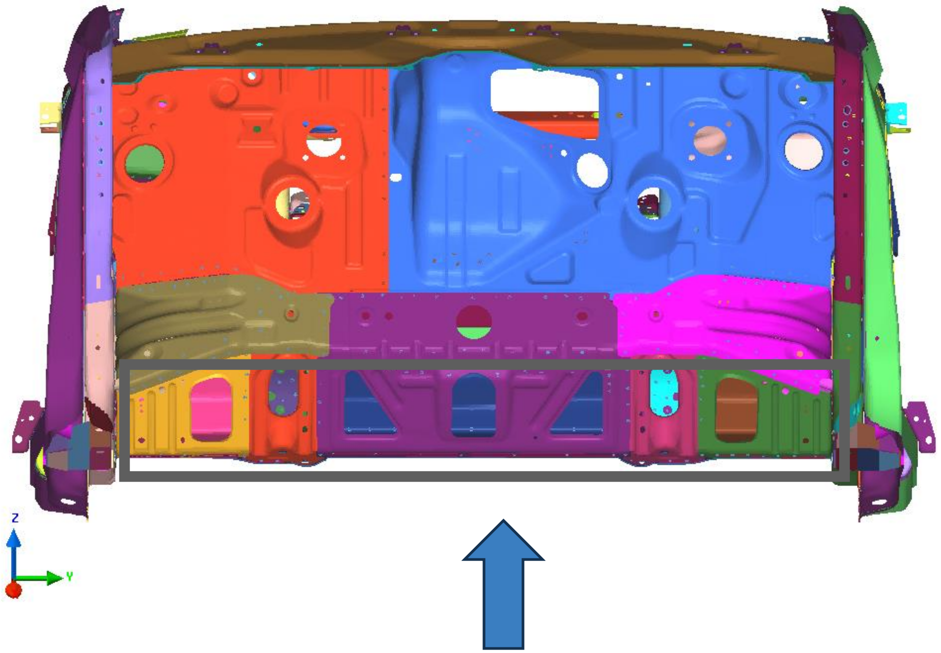
# Project Results – Crash, USNCAP – Pulse Overlay

Acceleration Pulses



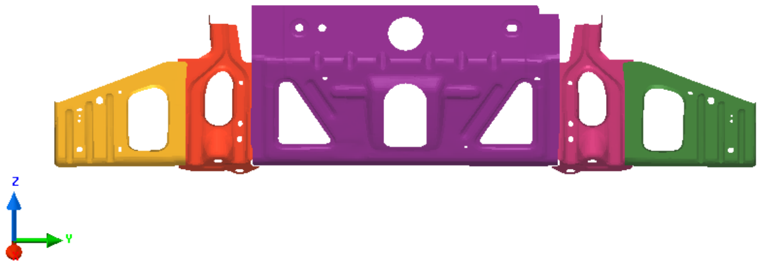
# Project Results – Part Consolidation Examples

Lower Dash

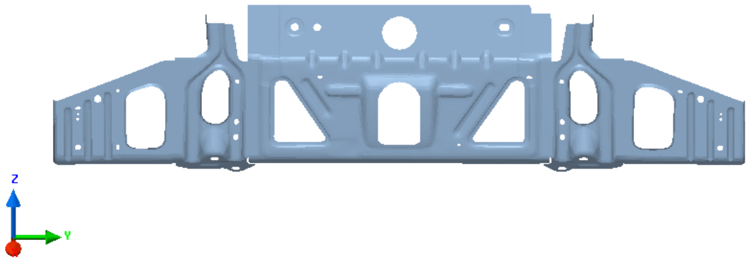


Back view

Before



After

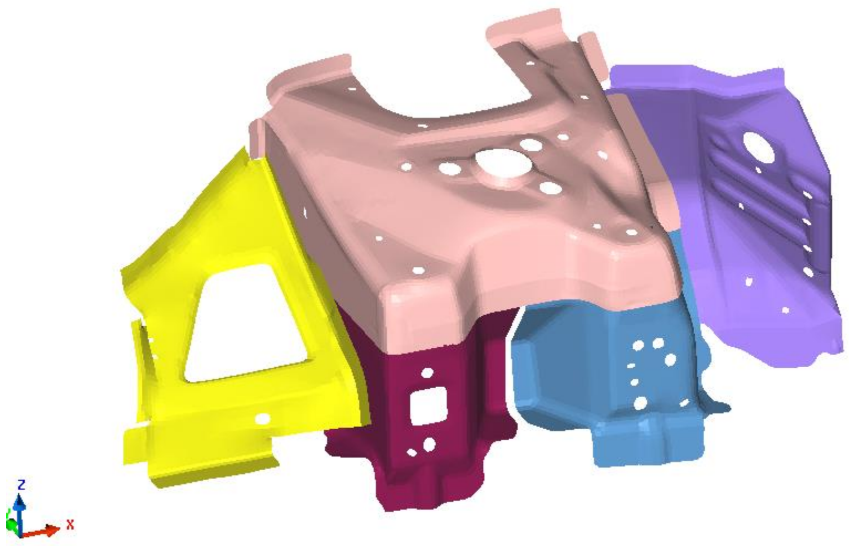


- Parts count reduced from 5 into 1

# Project Results – Part Consolidation Examples

Shock Tower

Before

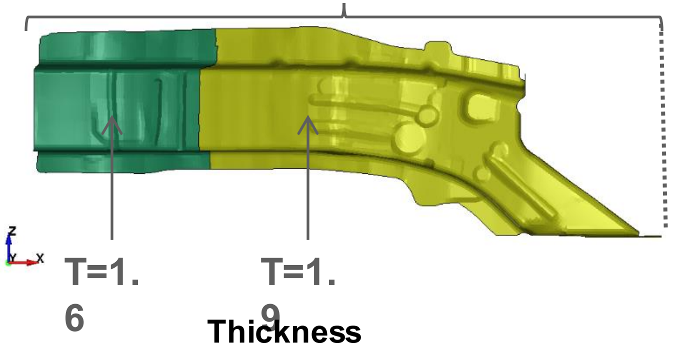


After

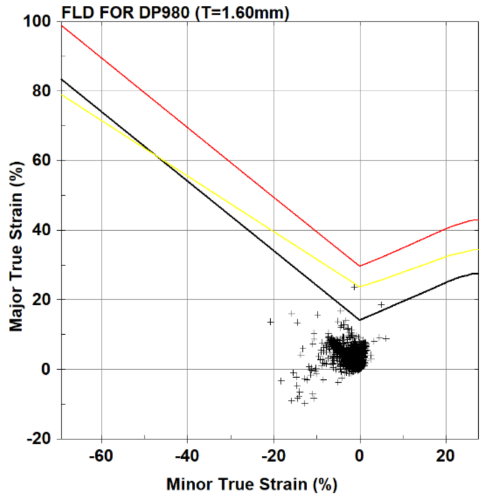
- Parts count reduced from 5 into 2 per side

# Project Results – Manufacturing Feasibility Examples – Front Rail Inner

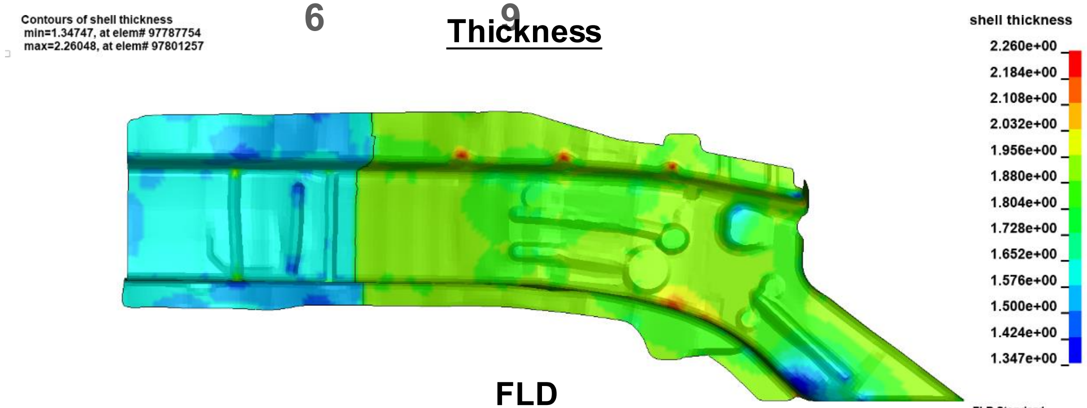
DP_980




**Material : DP980**
Yield Stress = 0.66GPa
Tensile Strength= 1.22GPa




<u>**Thickness**</u>

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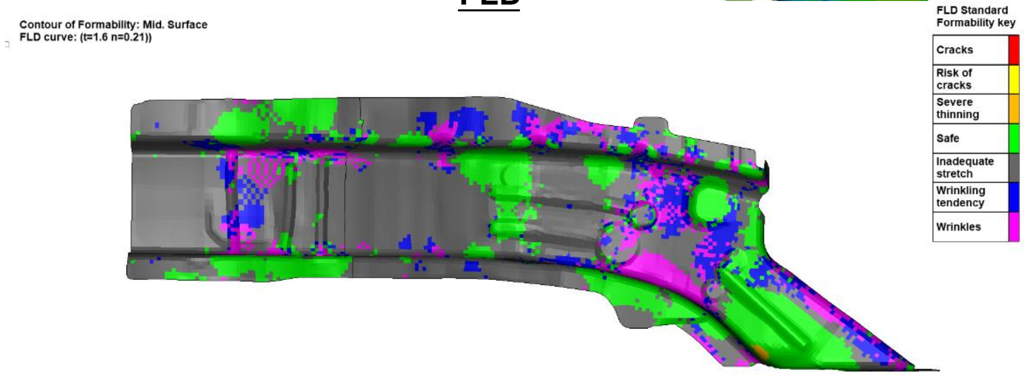
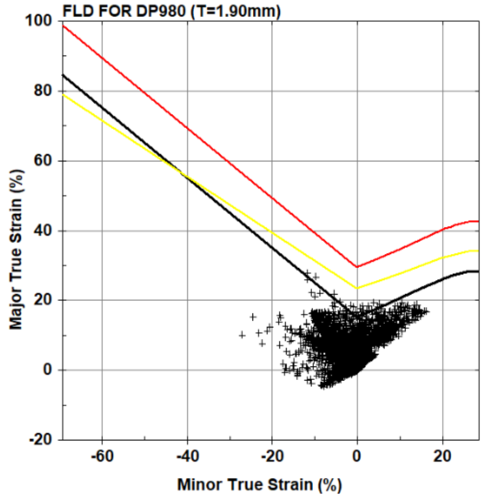
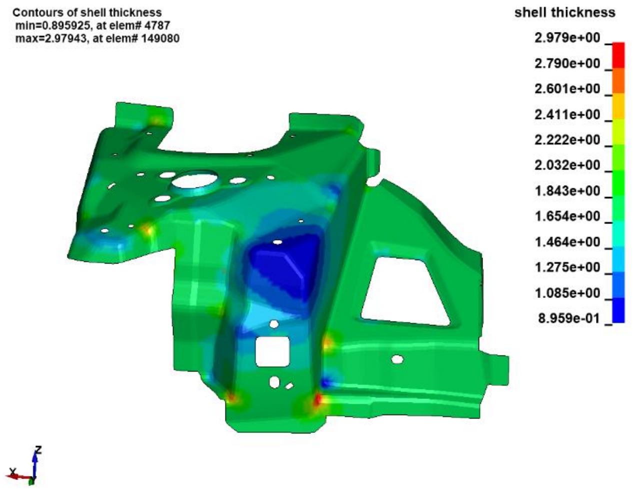


# Project Results – Manufacturing Feasibility Examples – Shock Tower

Material : DP780
Thickness : 1.70mm
Yield Stress = 0.597GPa
Tensile Strength= 1.01GPa

**Thickness**

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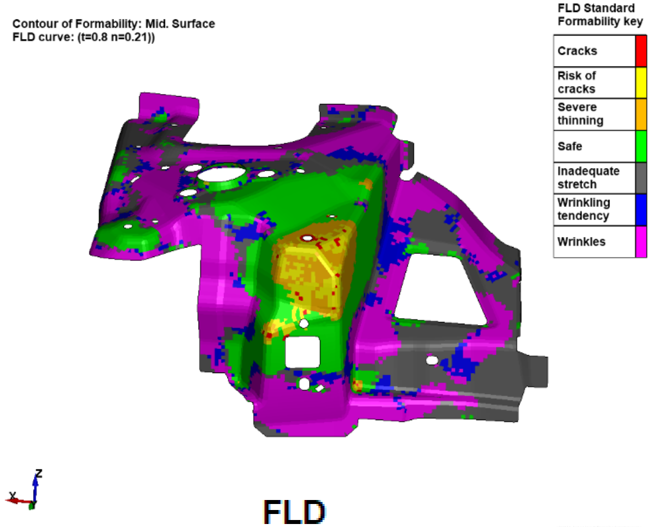
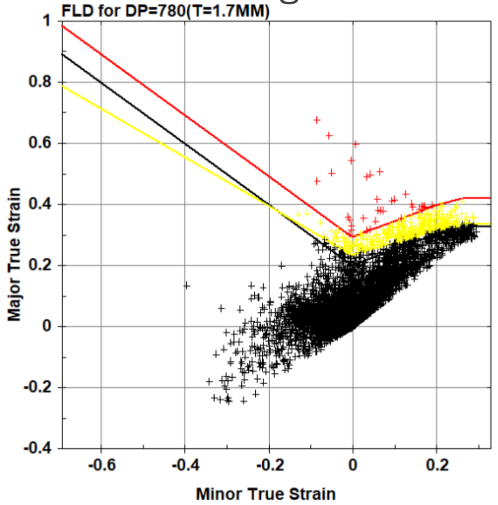
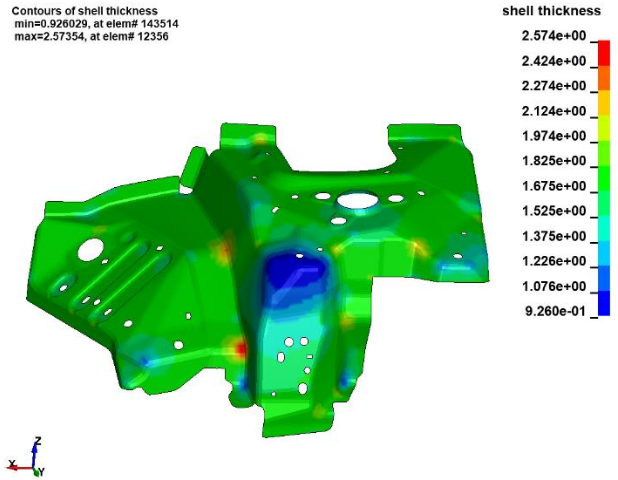



**Thickness**

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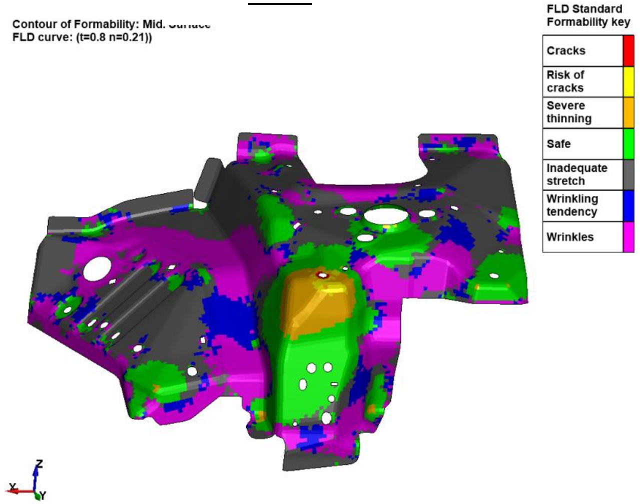
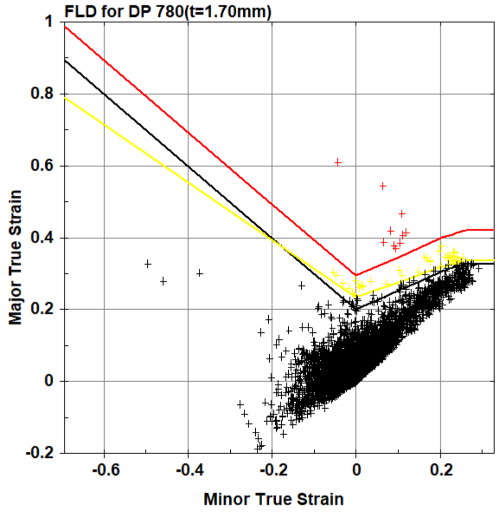


# Project Results - Sustainability

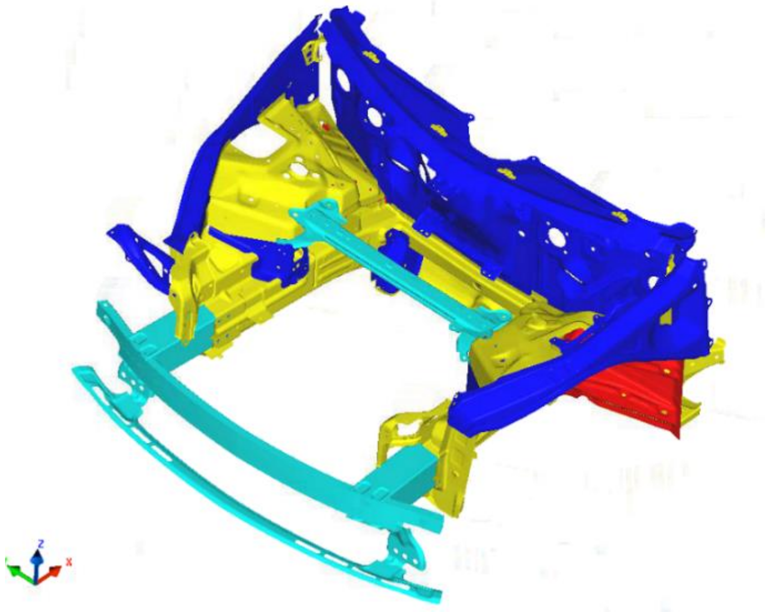
Using the University of California at Santa Barbara (UCSB) Automotive Energy GHG Model, Version 5.1  a sustainability comparison was performed comparing the two steel alternative designs with the aluminum giga casting baseline.

The main goal of the UCSB Model is to quantify the energy and GHG impacts of automotive material substitution under a broad range of conditions and in a completely transparent fashion. Users can review all calculations, and parameters are changeable at the user's discretion. The functional unit of all studied product systems is defined as transportation services of passenger vehicles of equivalent size, utility, equipment, and powertrain configuration over their total vehicle life. The model uses attributional life cycle assessment (ALCA) methodology, even though consequential system expansion is used to account for the GHG and energy implications of scrap inputs to and outputs from the vehicle life cycle.

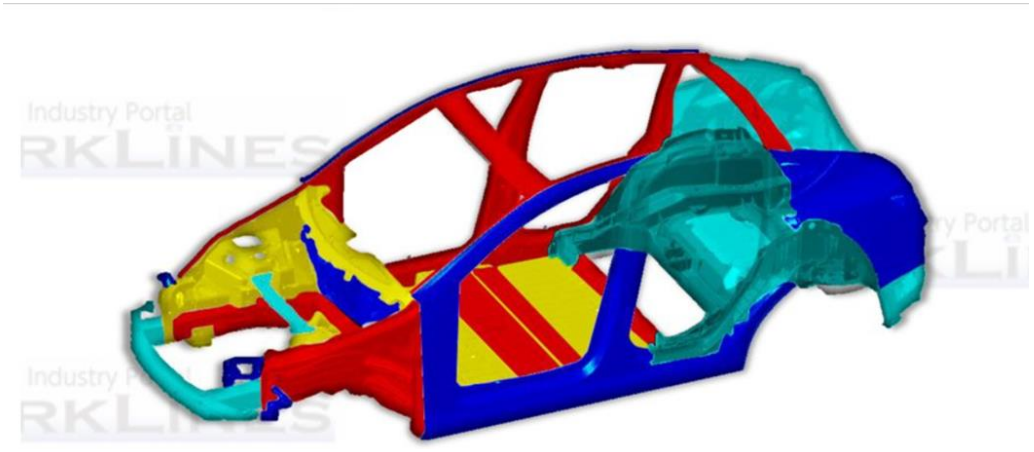
# Model Y- Geometrical Overview- 2020

GDIS

**Material Mapping 2020 Model Y CAE-Model**

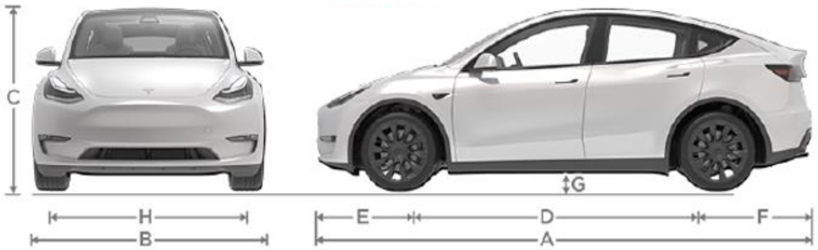


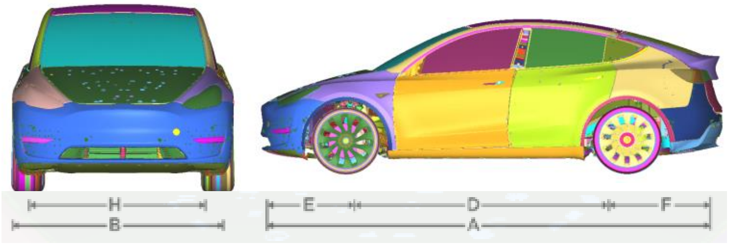
**2020 Model Y - benchmarked**




| Aluminum | Mild Steel | High Strength Steel | Ultra High Strength Steel |
|---|---|---|---|
| Yield Strength = 120 Mpa | Yield Strength < 500 Mpa | Yield Strength 500 < 1000 Mpa | Yield Strength > 1000 Mpa |

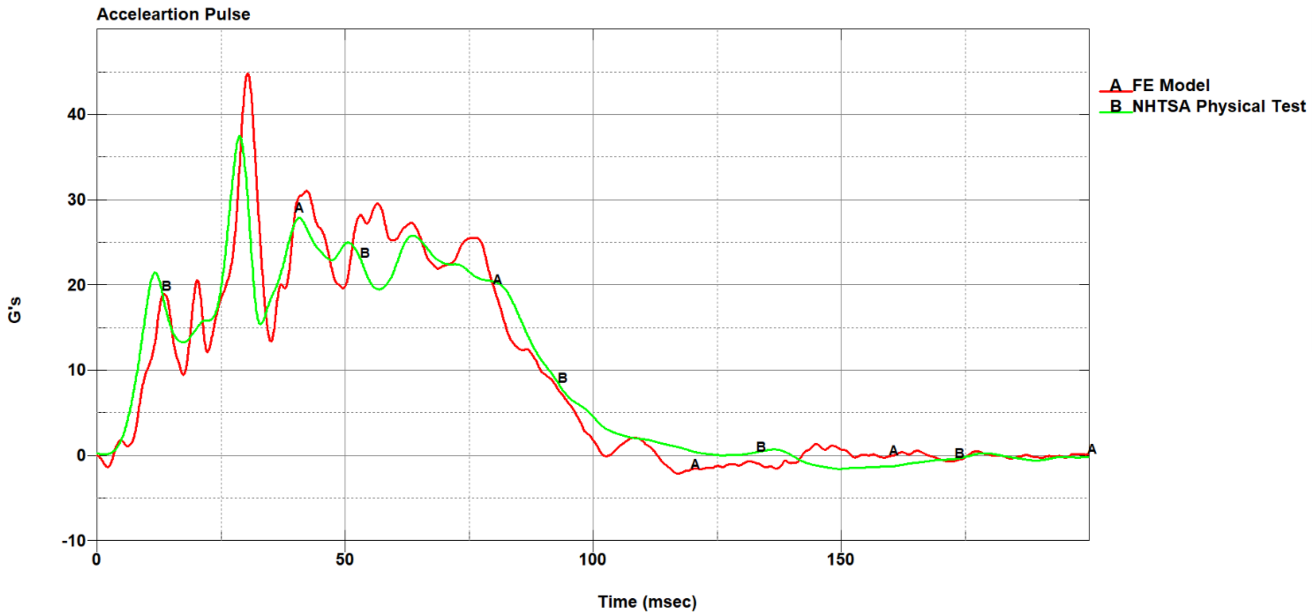
# Model Y- Geometrical Overview

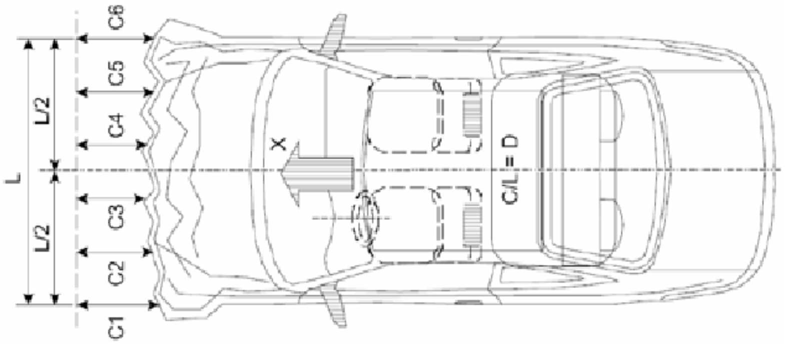



| | | 2020 model Y Vehicle | 2020 Model Y CAE model |
|---|---|---|---|
| Physical Dimensions (mm) | Length (A) | 4751 | 4751 |
| | Width(B) | 1921 | 1920 |
| | Height (C) | 1624 | 1624 |
| | Wheelbase (D) | 2890 | 2890 |
| | Front Overhang (E) | 847 | 847 |
| | Rear Overhang (F) | 986 | 986 |
| | Ground clearance (G) | 167 | 167 |
| Mass (kg) | Overall Mass | -- | |
| | BIW Assembly | -- | 366.6 |
| | Front Bumper | -- | 9 |
| | Front Cradle | -- | 20.78 |

# USNCAP Correlation



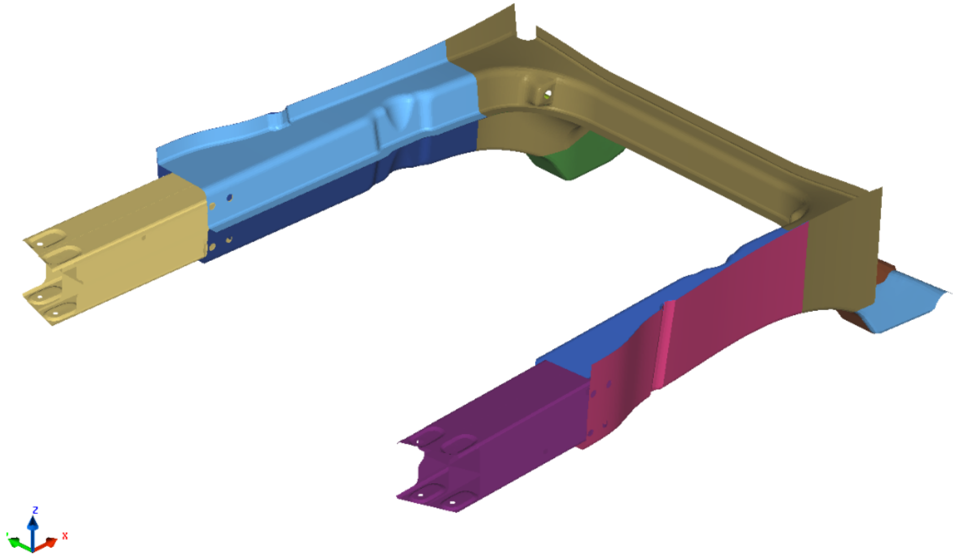



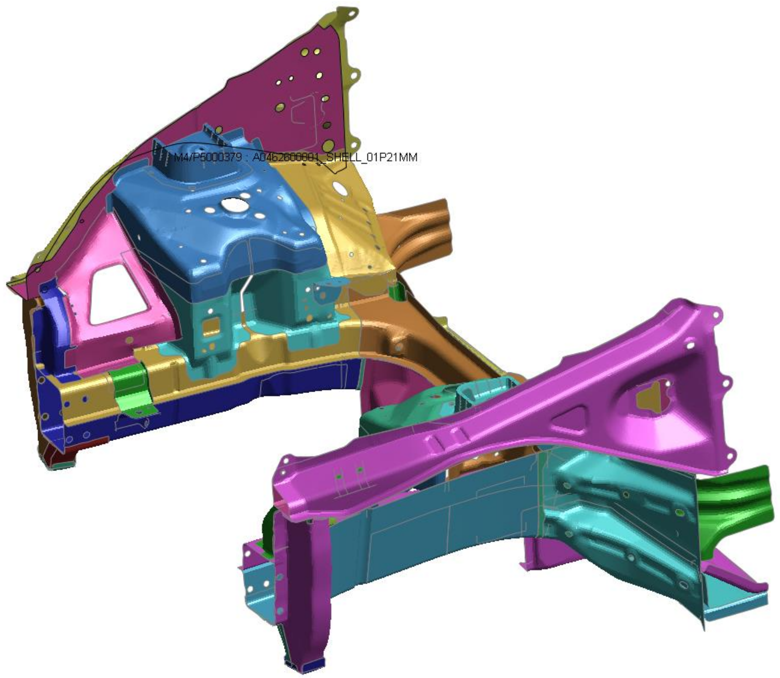

**Physical Test Results from NHTSA**

| No | Measurement Description | NHTSA | FEA (Steel) |
|---|---|---|---|
| C1 | Crush Zone 1 at Left Side | 345 | 333 |
| C2 | Crush Zone 2 at Left Side | 420 | 428 |
| C3 | Crush Zone 3 at Left Side | 425 | 448 |
| C4 | Crush Zone 4 at Right Side | 415 | 440 |
| C5 | Crush Zone 5 at Right Side | 421 | 454 |
| C6 | Crush Zone 6 at Right Side | 380 | 350 |

- The Acceleration pulse is from Binary-outs which are downloaded from NHTSA website and it is overlayed with the Fe-Model pulse taken at same position as the Crash test on Rear sill x pulse
- Intrusions ae with in +/- 5% of the test
- Established confidence in CAE model accuracy through test correlation

# Front End concept 2

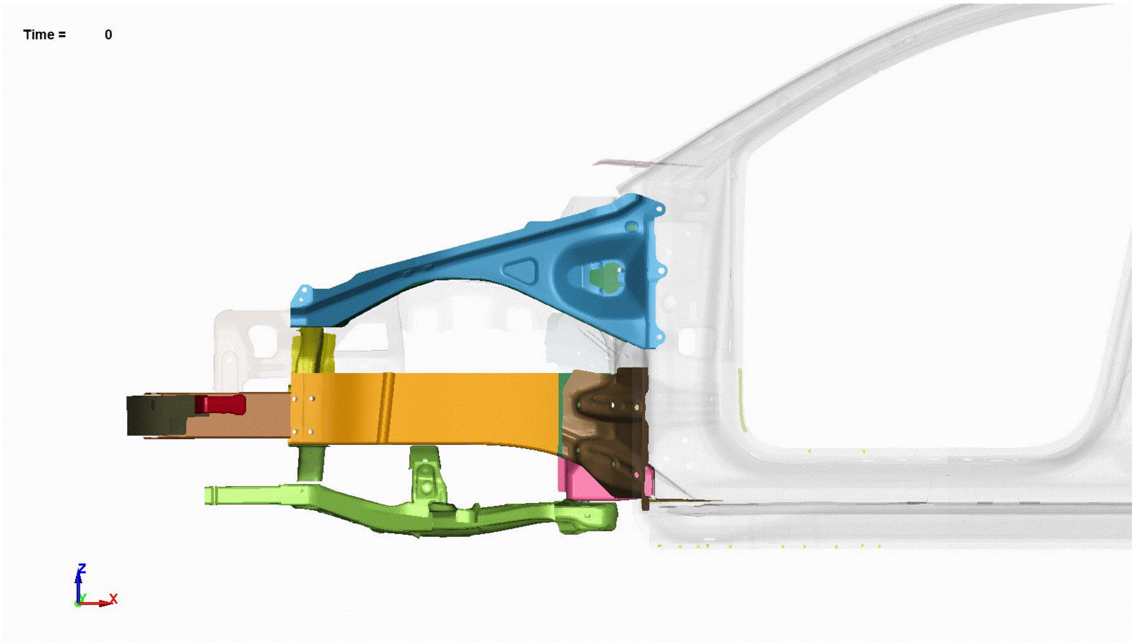


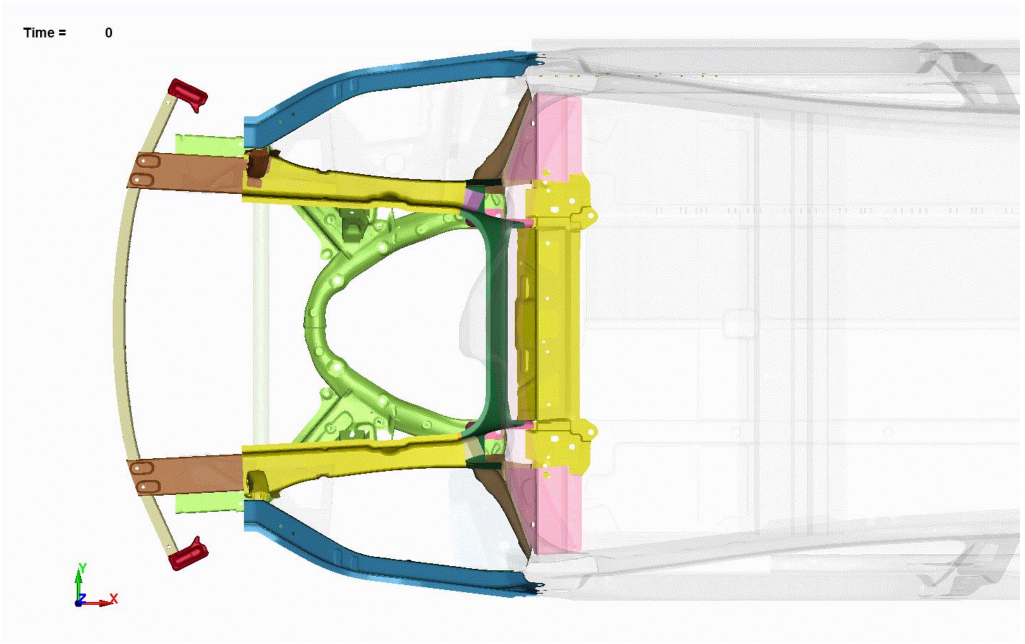


Clamshell Design Concept:

1. Front rails and crush from the concept 1 design replaced with clamshell concept
2. Redesigned shock tower and other surrounding components
3. Optimized the design concept by considering the gauges of the front end components
4. Clamshell design advantages:
    1. Significant part count reduction
    2. Performance very similar to splay rail – not showing today in the interest of time

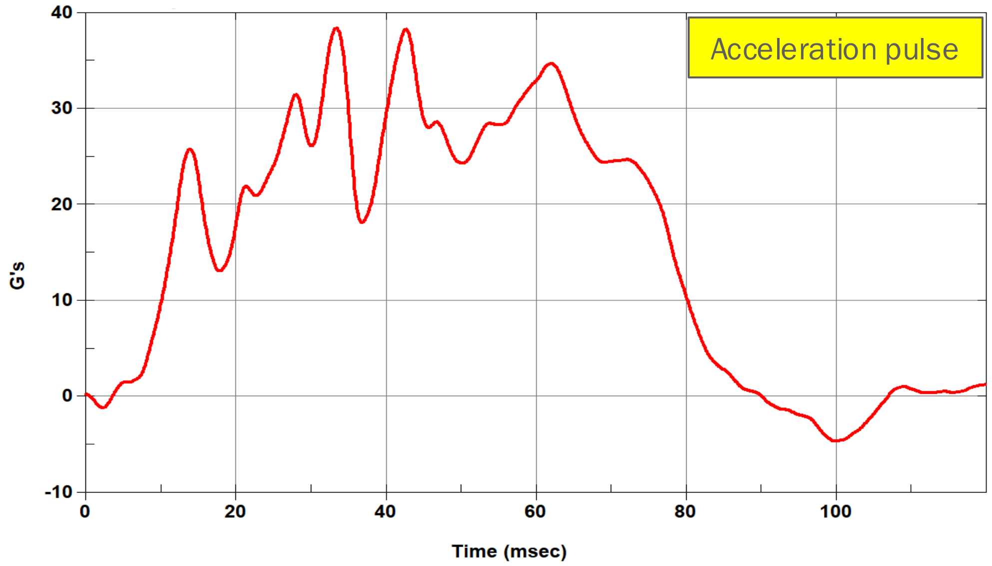
# Clam shell Model- USNCAP

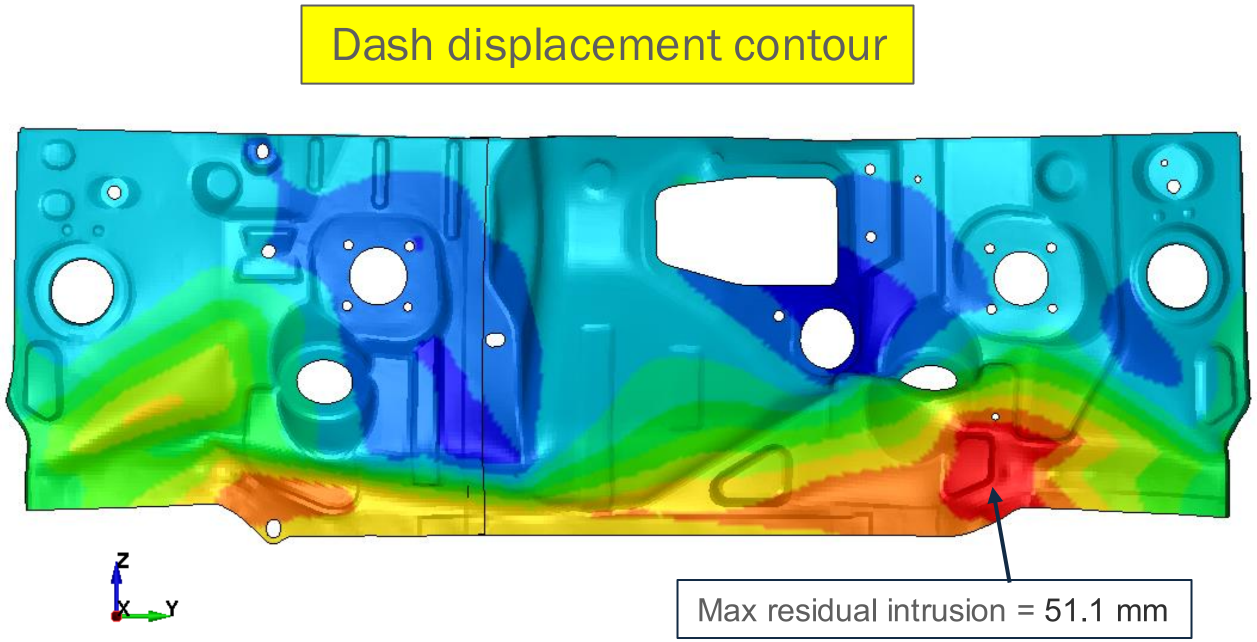



| Load cases | Measuring Points | CAE Targets | Clamshell Rail |
|---|---|---|---|
| US NCAP | Time To Zero Velocity (msec) | 65.0 | 69.4 |
| | Dynamic Crush mm | 737.0 | 648 |
| | Sill Drop(mm) | 10.0 | 3.62 |
| | Peak Pulse 0 -20 msec G's | - | 25.8 |
| | Peak Pulse 20 -60 msec G's | - | 38.5 |

# Clam shell Model- USNCAP

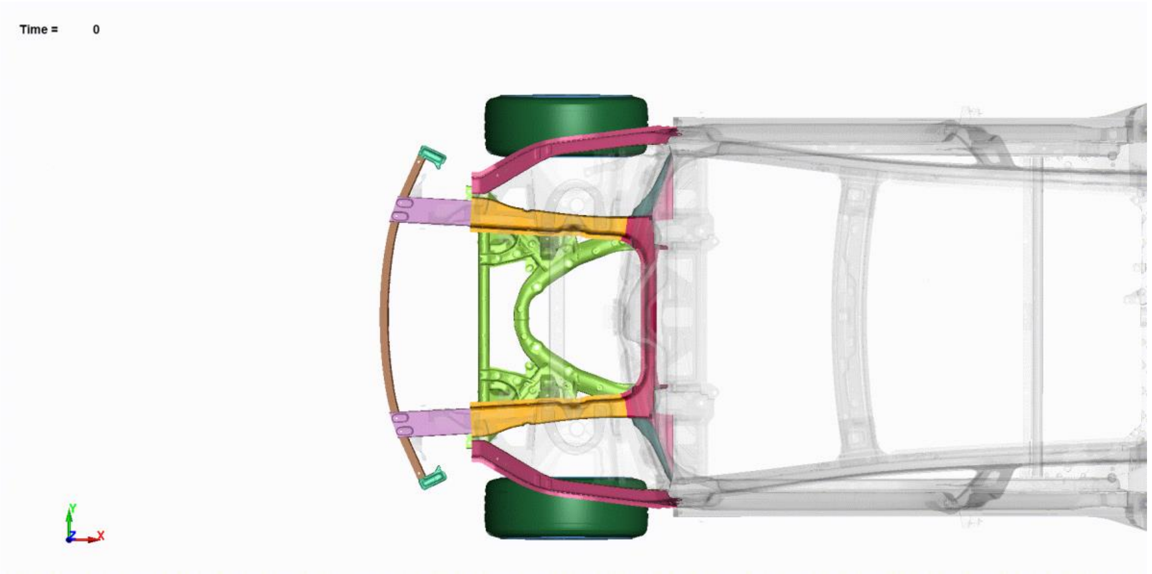


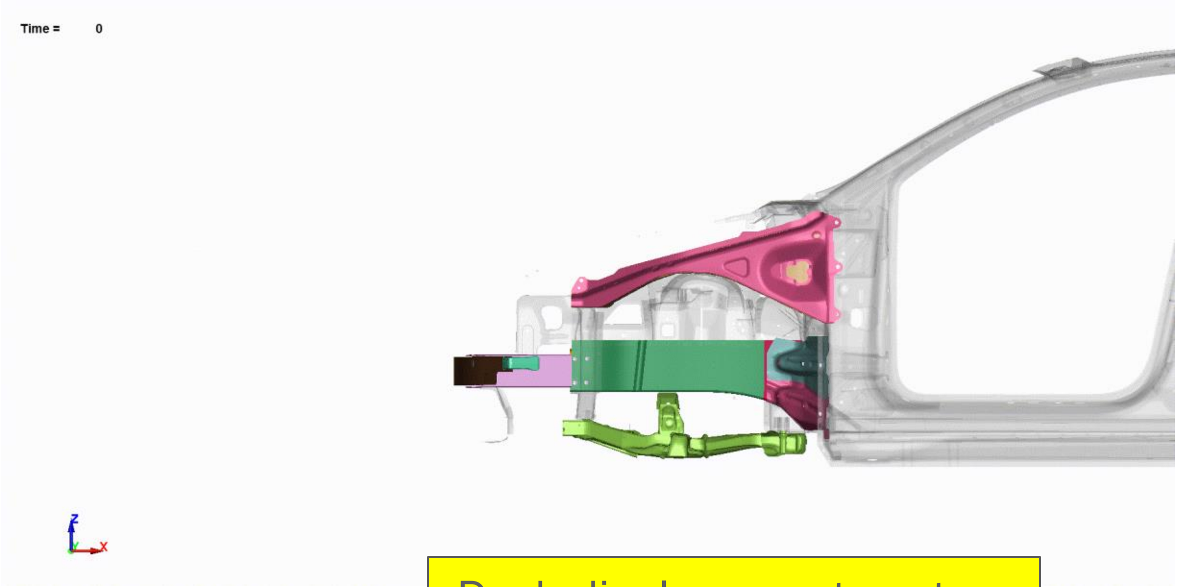



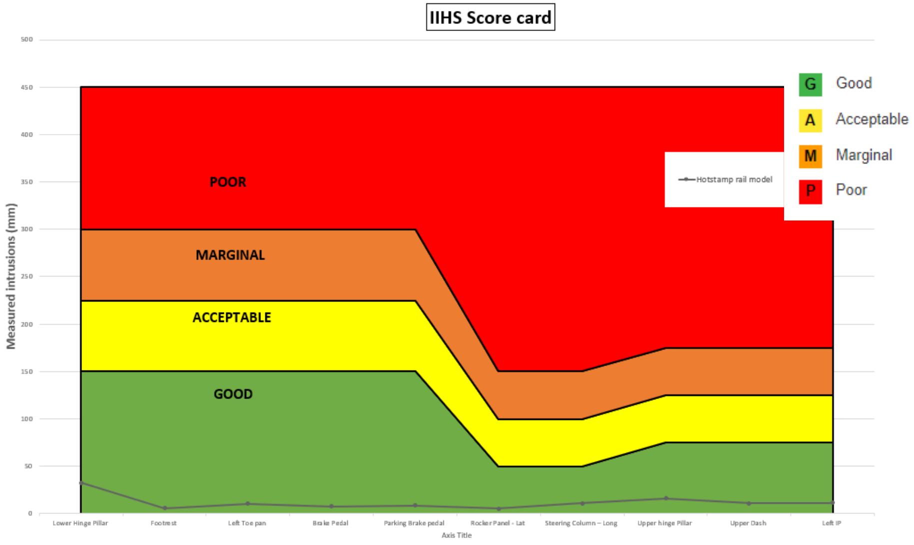

**Physical Test Results from NHTSA**

- The Acceleration pulse is from Binary-outs which are downloaded from NHTSA website and it is overlayed with the Fe-Model pulse taken at same position as the Crash test on Rear sill x pulse
- Intrusions ae with in +/- 5% of the test
- Established confidence in CAE model accuracy through test correlation

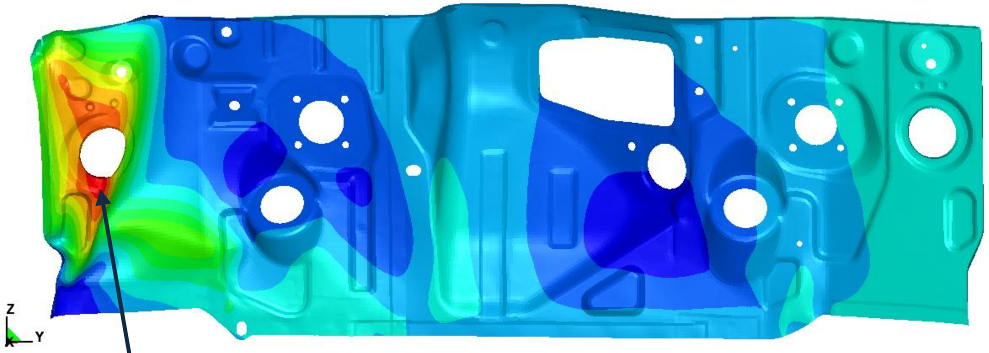
# Clam shell Model- Small Offset Rigid Barrier




Dash displacement contour

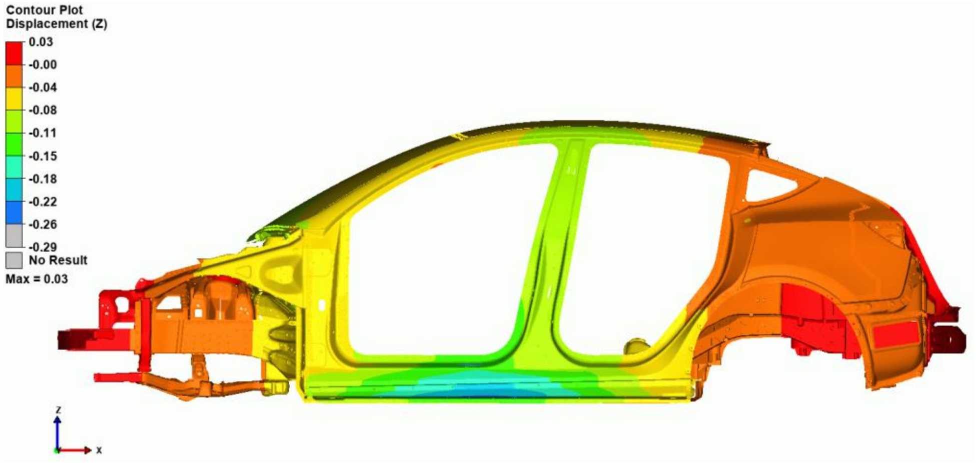


Max residual intrusion = 62.7 mm

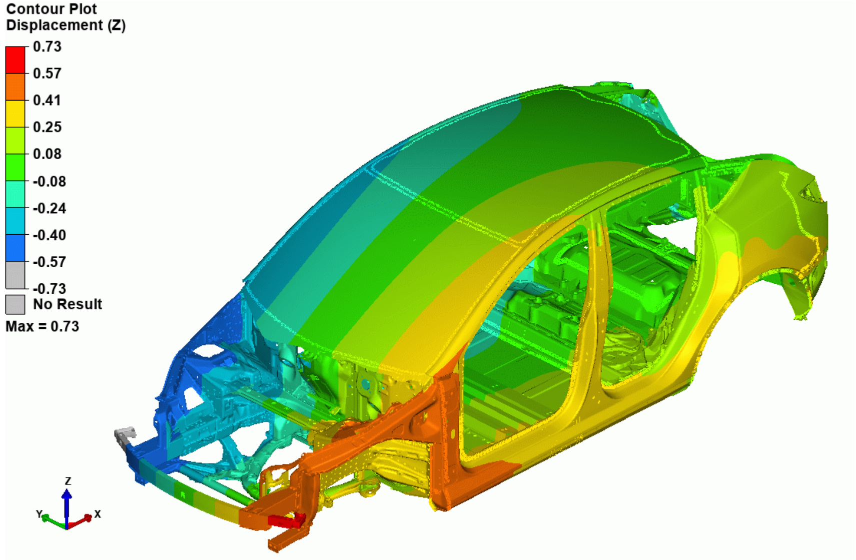
# Project Results –Global Stiffness

Clam shell model

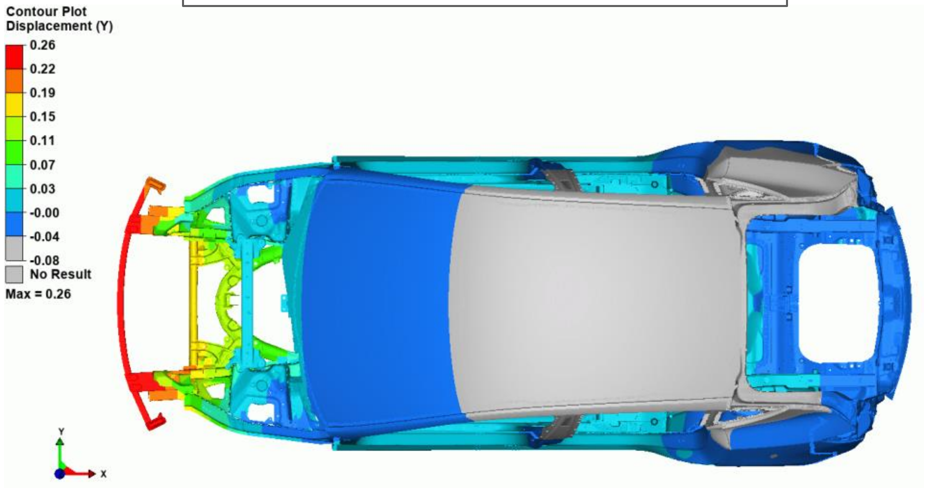
Global Bending stiffness = 14.3 kN/mm




Global Torsional stiffness = 19.1 kN-m/deg.




Lateral stiffness = 5.2 kN/mm

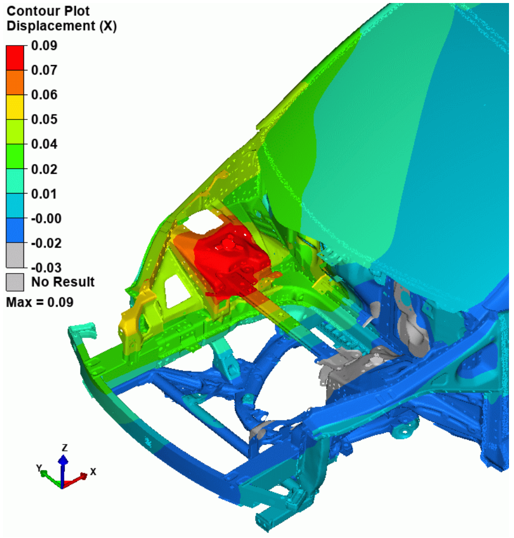



Scale factor = 150

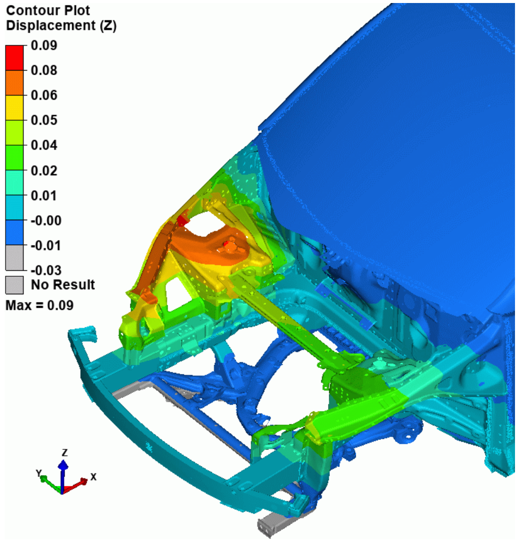
# Local attachment Stiffness –Shock Tower

GDIS

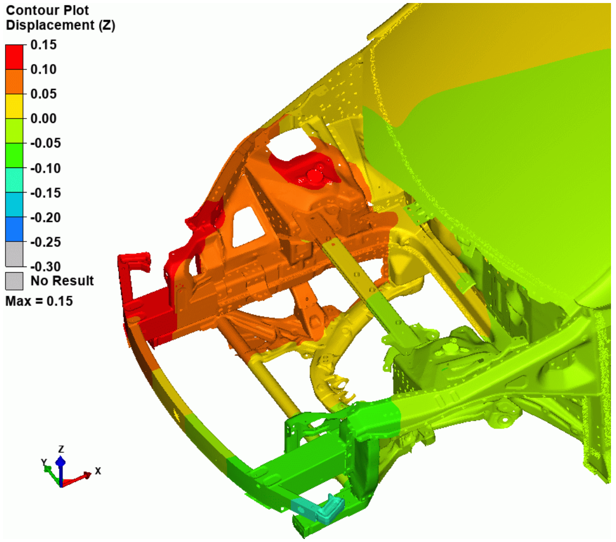
Clam shell model




Shock tower stiffness -X = 12.5 kN/mm




Shock tower stiffness -Y = 14.3 kN/mm

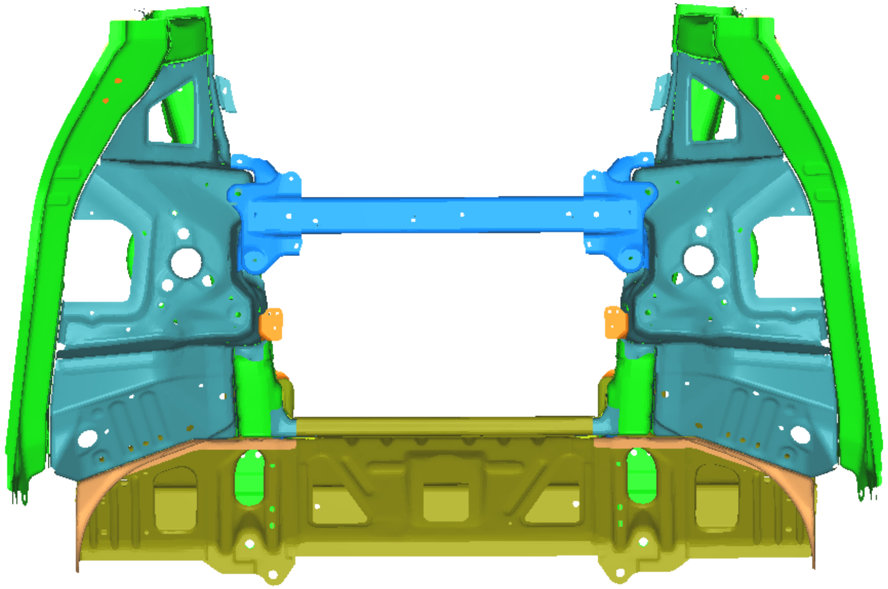


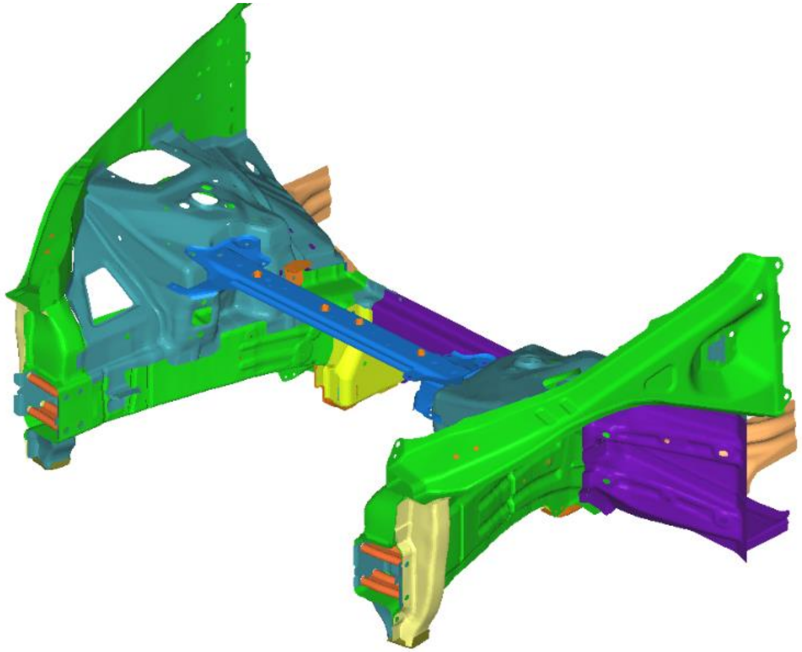

Shock tower stiffness -Z = 7.1 kN/mm

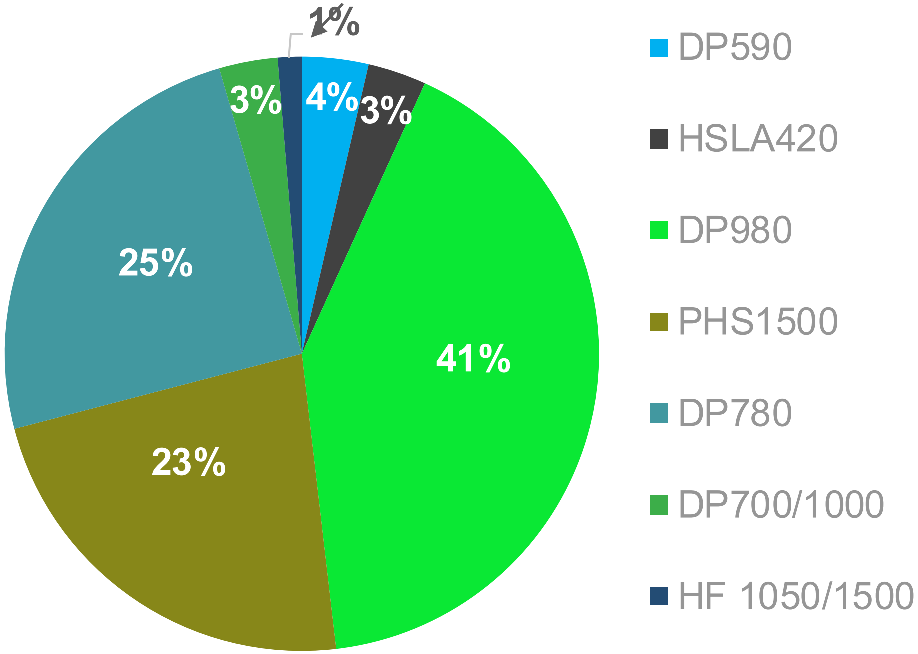
| Load cases | Units | Clam shell model |
| --- | --- | --- |
| Mass (CAE Design space) * | Kg | 83.5 |
| Global Torsion mode | Hz | 38.9 |
| Global Lateral mode | Hz | 41.1 |
| Global V.Bending mode | Hz | 52.9 |
| BIW - Torsional Stiffness | BIW (KN-m/deg) | 19.1 |
| BIW - Bending Stiffness | BIW (KN/mm) | 14.3 |
| BIW - Lateral Stiffness | BIW (KN/mm) | 5.2 |
| Front shock tower stiffness(X,Y,Z) | KN/mm | 12.5(X)<br>14.3(Y)<br>7.1(Z) |

Scale factor = 150

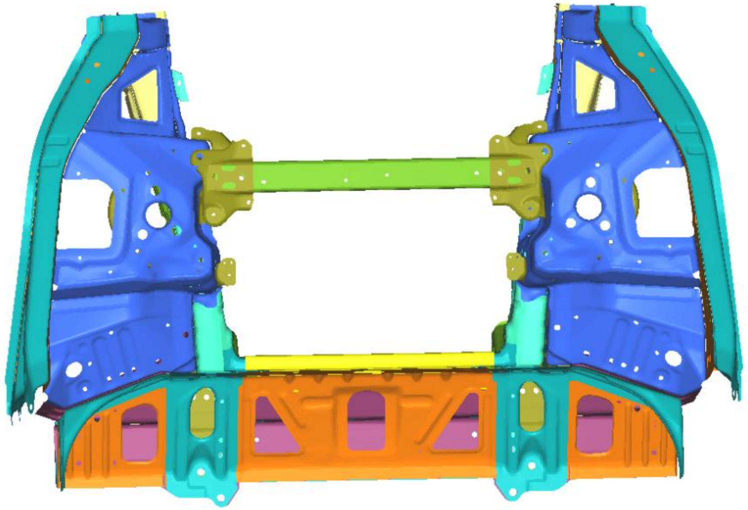
# Project Details – Splayed Rail Steel Grades

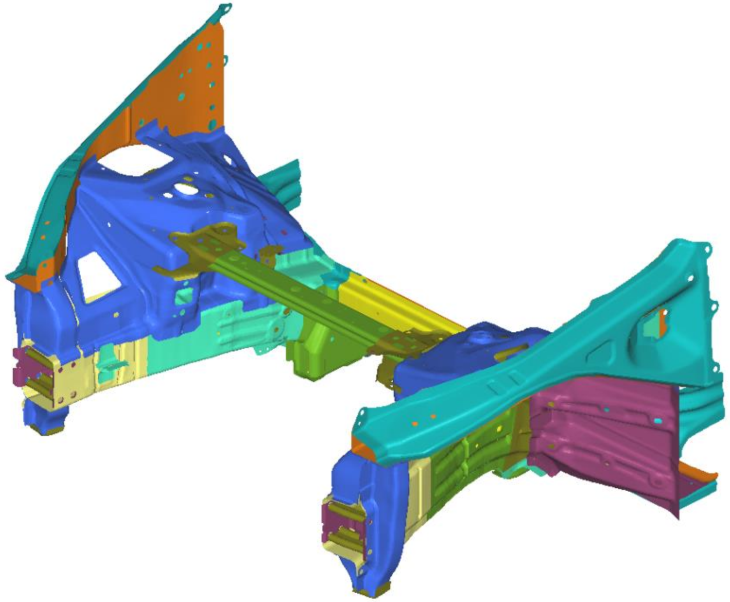


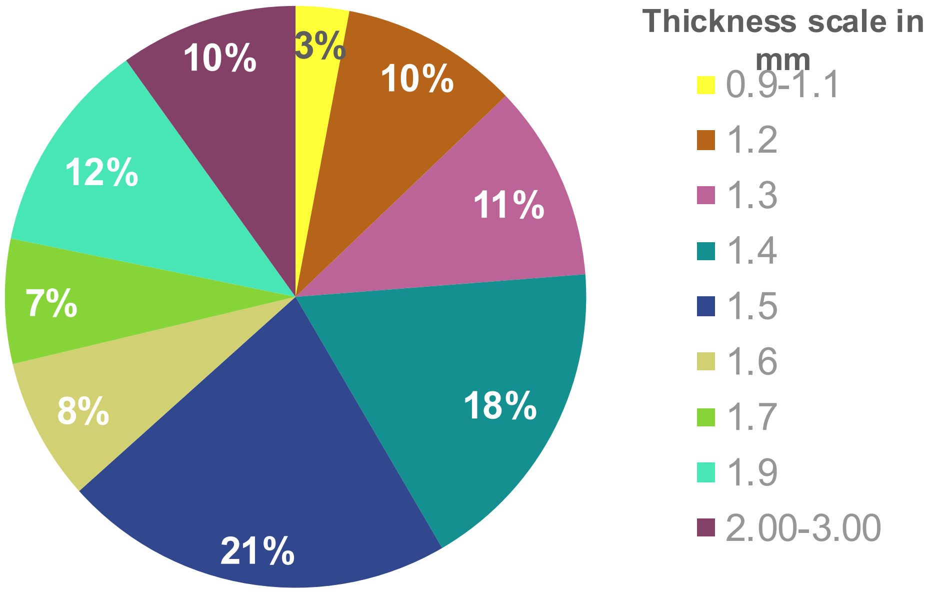




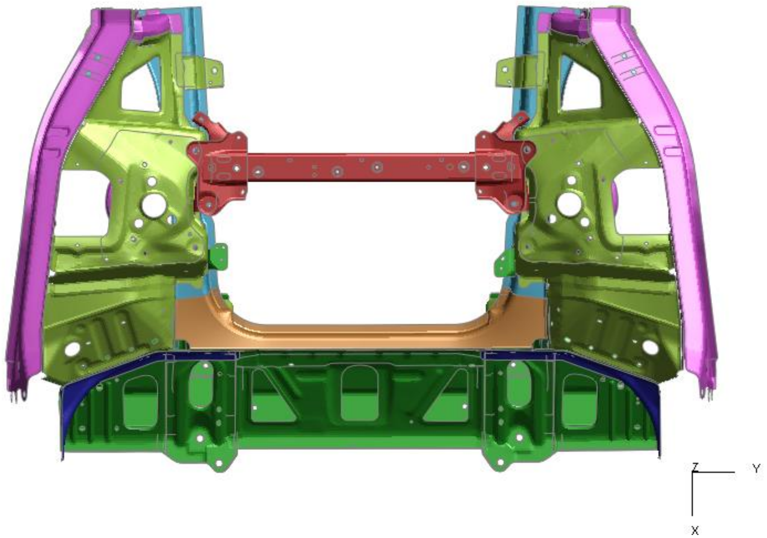
# Project Details – Splayed Rail Steel Gauges

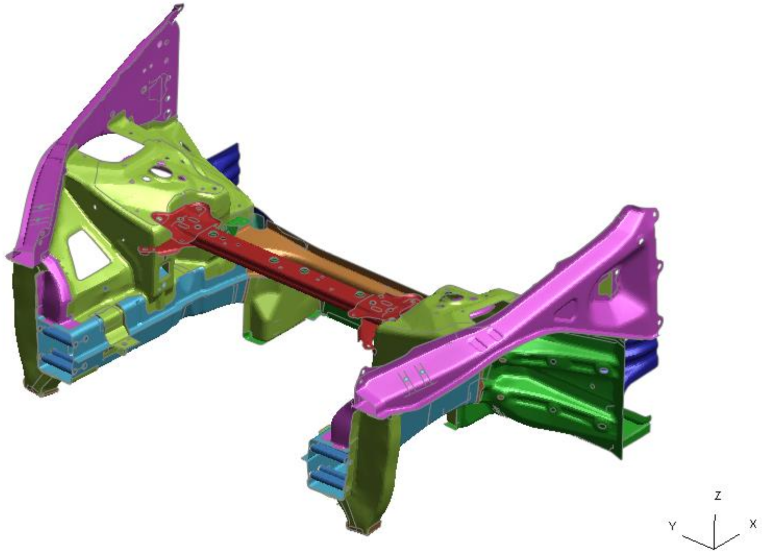


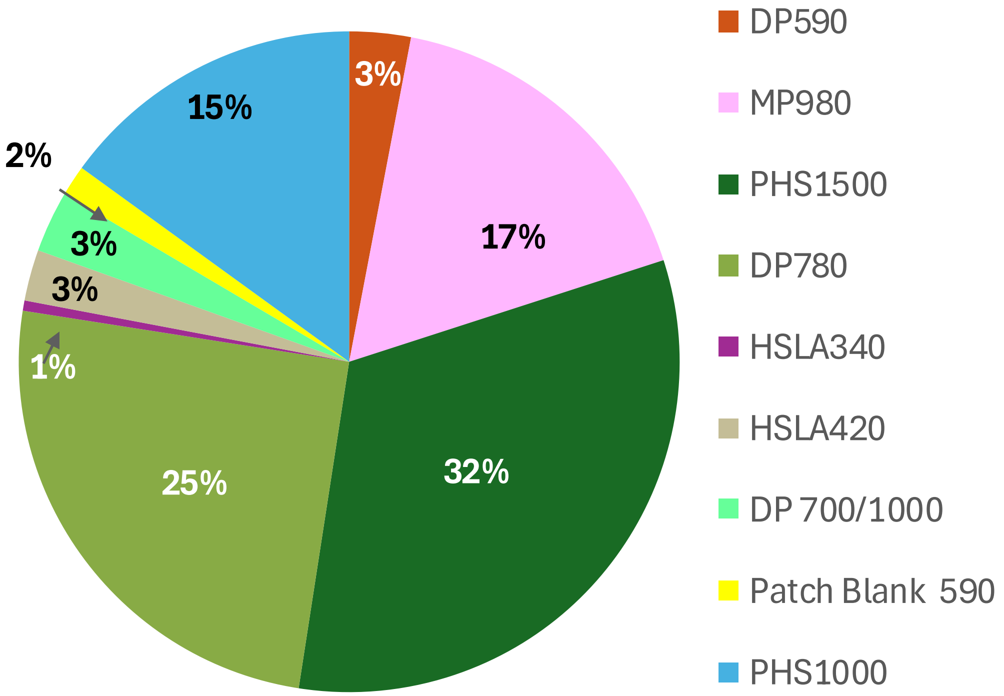




# Project Details – Clamshell Rail Steel Grades



# Project Details – Clamshell Rail Steel Gauges