



LOTUS  
ENGINEERING

The Design and Impact Performance of a  
Low Mass Body in White  
Structure

NHTSA Mass-Size-Safety Symposium

February 25, 2011

## Background – Phase 2 Body Design and Crash Analysis

- Low mass multi-material body in white (BIW) based on ICCT paper published Spring, 2010
- ARB funded BIW CAD design, crash studies and structural analysis
- 40% mass reduction target for BIW
- Low mass multi-material body in white (BIW) based on ICCT paper published in 2010
- NHTSA technical team is part of the crash model validation process
  - Shared crash models and analysis results by Lotus and NHTSA
  - Independent crash performance assessment by NHTSA
  - NHTSA feedback used to improve the crash model
  - NHTSA Toyota Venza vehicle crash test results data used to establish targets
  - NHTSA car/SUV models used to simulate car-car impacts
- EPA and DOE are technical contributors
- Lotus Phase II study results will be published approximately mid-summer, 2011

# Mass Reduction Approaches



- Efficient Design

- Optimize load paths within structures to reduce stresses on components
  - Use of computer-aided engineering (CAE) design tools to optimize vehicle for all structural attributes
- Parts integration/reduction of fasteners
- Optimize structural sections
- Parts elimination

- Materials Selection (recyclable – automotive and non-automotive)

- High-strength steel
- Aluminum
- Magnesium
- Plastics and composites (thermoplastics)

- Manufacturing and Assembly (automotive and non-automotive)

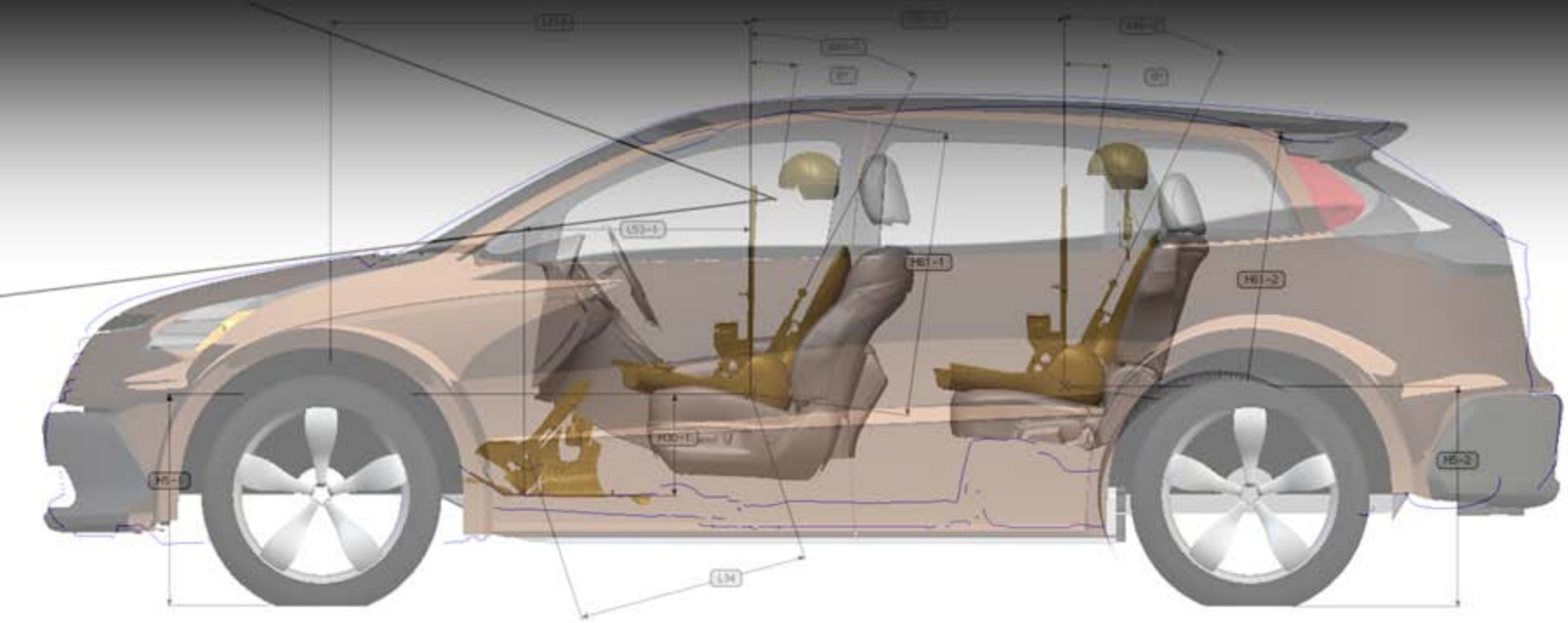
- Reduce tool count through parts integration & parts elimination
- Reduce forming energy requirements
- Reduce or eliminate fixtures
- Reduce part joining energy requirements
- Minimize scrap materials

# Low Mass Exterior Styling & Engineering Parameters

- All key interior and exterior dimensions and volumes were retained
- Target: must meet or exceed baseline crash and structural performance
- Vehicle styled to match packaging constraints
- Vehicle styled to accommodate key safety and structural dimensional targets, e.g., front crush zone
- Styling included provisions for:
  - low speed impact protection
  - increased wheelbase and track
  - more vertical “tumblehome” for roof crush
- Exterior styling used as basis for all internal structure



# Low Mass Model vs. Baseline Occupant Packaging Comparison



- All key interior and exterior dimensions and volumes were retained
- SAE Occupant Packaging and ergonomics retained
- Vision, sight line, reach, comfort and occupant package retained

# Low Mass Body in White

## **Body in White Modules:**

- Floor and underbody
- Dash panel assembly
- Front structure
- Body sides
- Roof assembly



# Body in White Modules



Front structure



Dash panel assembly



Floor and underbody



Body sides  
(LH, RH)



Roof assembly

# Body Structure Comparison

Phase 1 Low Mass Vehicle



## Materials

- Aluminum – 37%
  - Magnesium – 30%
  - Steel – 7%
  - Composite – 21%
- Mass: 221 kg.

Baseline CUV



## Materials

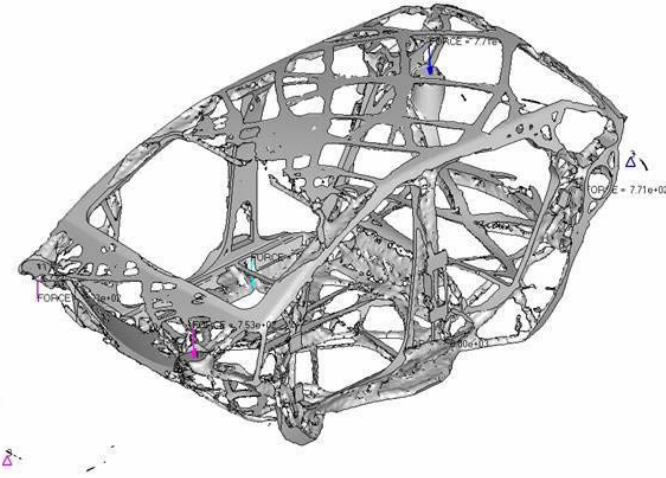
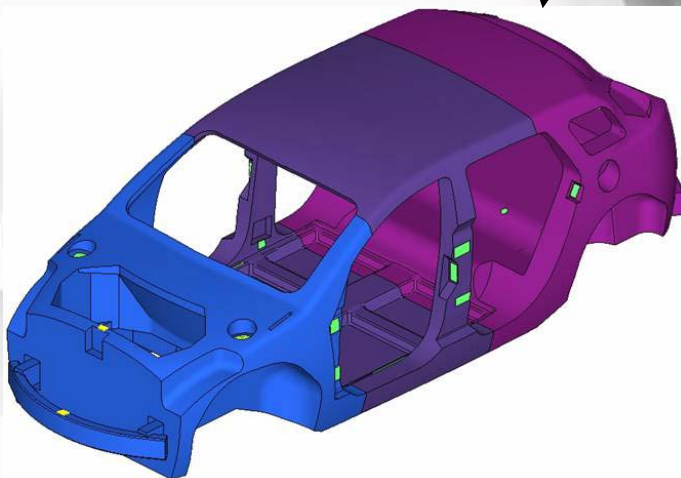
- Steel
- Mass: 382 kg



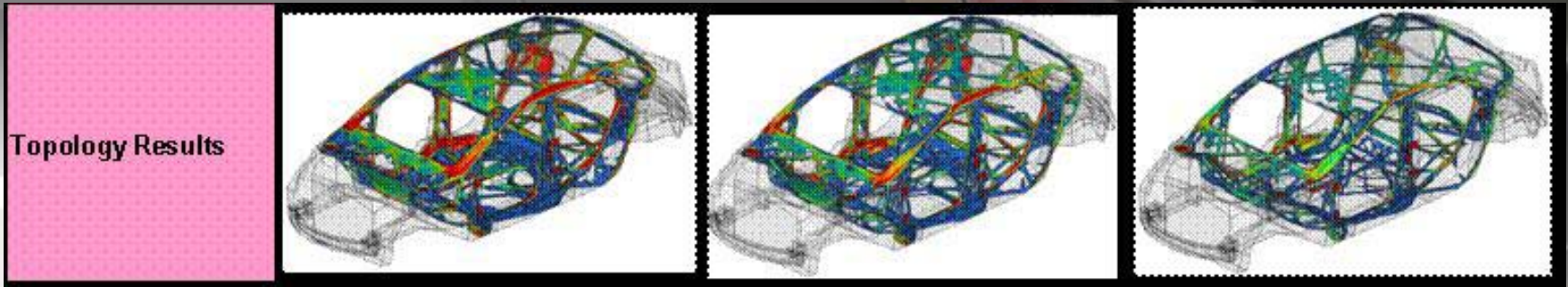
# Topology Analysis

(Relative Material Strain Energy Density Levels )

Convert CAD model to  
an optimized body structure



# CUV Topology Analysis



Magnesium

Aluminum

Steel

Topology optimization is used to identify the structural efficiencies within the package design space and to minimize mass with respect to system stiffness targets

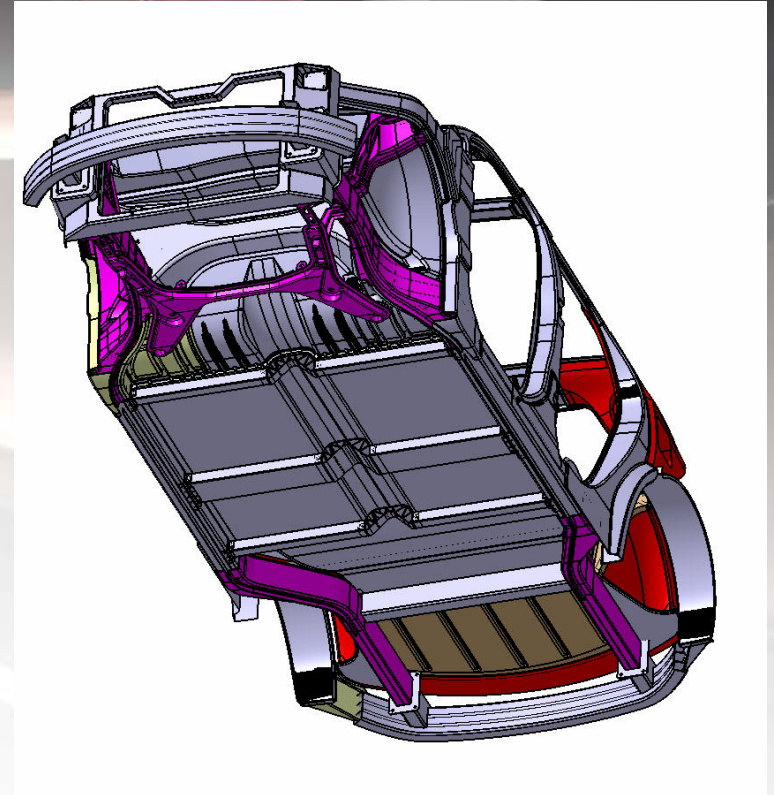
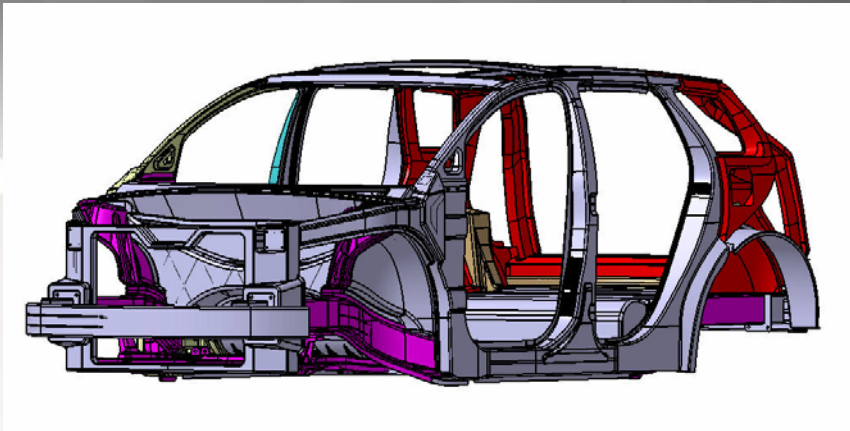
Load path determination

Shape optimization - section height and width developed

Material selection and thickness optimization based on section geometry

# Low Mass Body Status

## Body in White CAD Model



### Status

Mass: 234 kg (230 kg target)

Materials:

Aluminum – 75%

Magnesium – 12%

Steel – 8%

Composite – 5%

# Impact Modeling Loadcases

## Front Impact:

[FMVSS208 35mph Flat Barrier 0°](#)

[FMVSS208 25mph Flat Barrier 30°](#)

[FMVSS208 25mph 40% Offset Deformable Barrier](#)

IIHS 6mph Centerline Bumper

IIHS 3mph 15% Offset Bumper

## Side Impact:

[FMVSS214 33.5mph 27° Moving Deformable Barrier](#)

[FMVSS214 20mph 75° Pole Impact \(seat @ 5<sup>th</sup> %ile Female\)](#)

[FMVSS214 20mph 75° Pole Impact \(seat @ 50<sup>th</sup> %ile Male\)](#)

## Rear Impact:

[FMVSS301 50mph 70% Offset Moving Deformable Barrier](#)

IIHS 6mph Centerline Bumper

IIHS 3mph 15% Offset Bumper

## Roof Crush:

[FMVSS216 Quasi Static Crush](#)

## Other:

FMVSS210 Quasi Static Seat Belt Pull

FMVSS213 Child Restraints Systems

# Additional Frontal Impact Modeling



## Non-FMVSS 208 Front Impact Simulations:

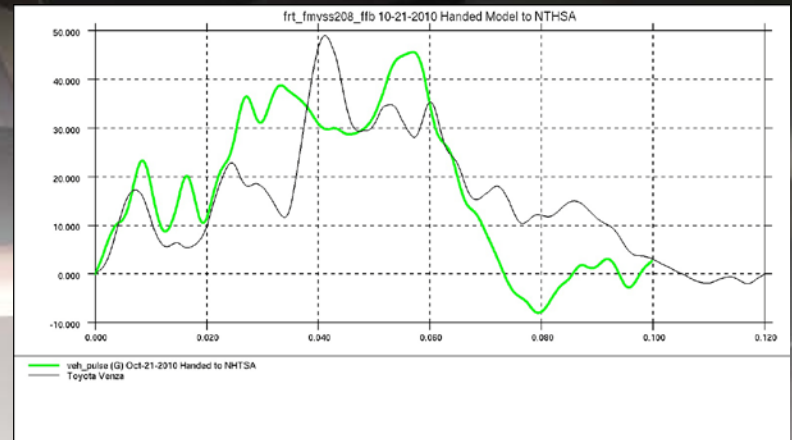
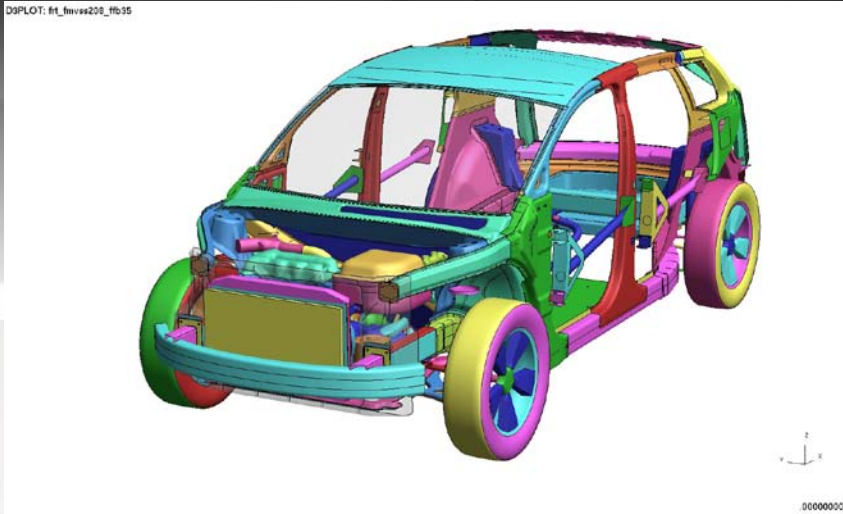
50mph Flat Barrier 0° (model integrity check only)

35mph Car to Car Impact with NCAC Ford Taurus; Taurus velocity: 27mph (similar to NHTSA analysis)

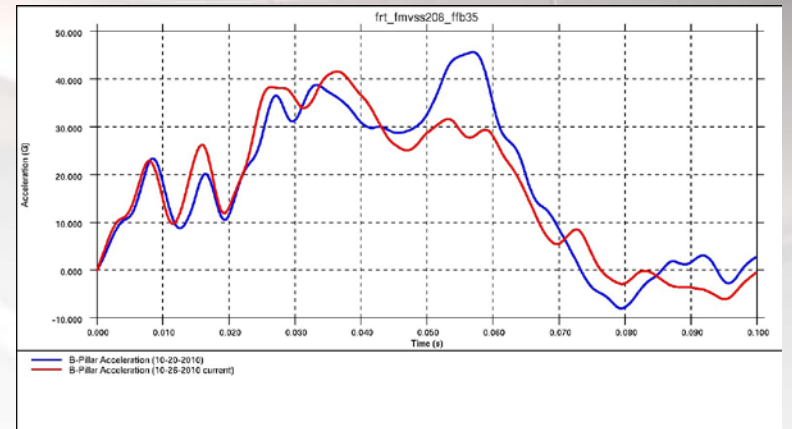
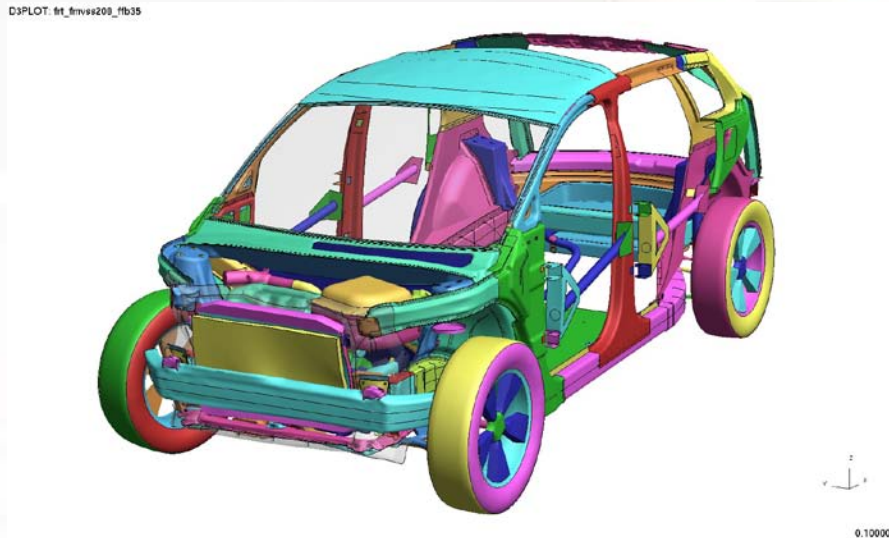
35mph Car to Car Impact with NCAC Ford Explorer; Explorer velocity: 18mph (similar to NHTSA analysis)

35mph Car to Car Impact with NCAC Ford Explorer; Explorer velocity: 40mph (model integrity check only)

# Initial Model Frontal Impact – FMVSS 208

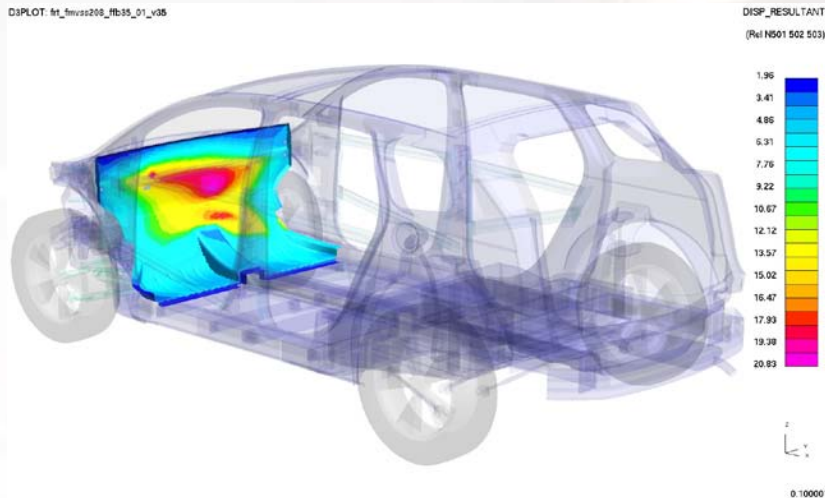
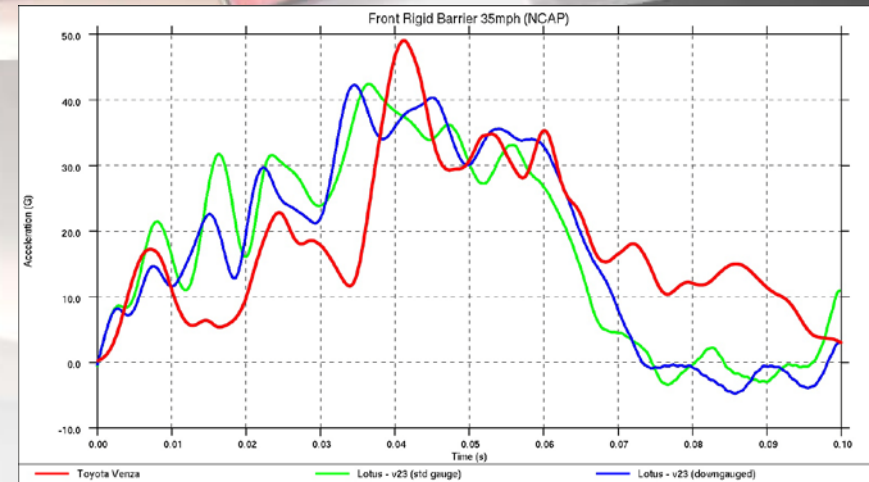
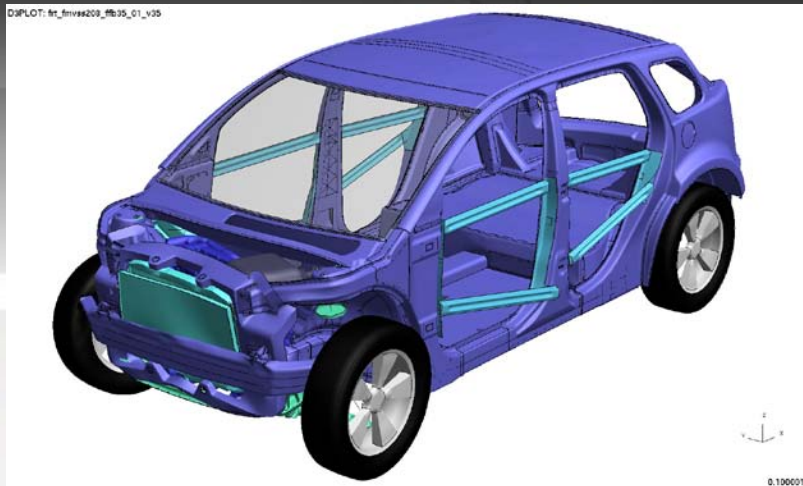


NHTSA Crash Test vs. Initial Low Mass Model (green)



Initial Low Mass Model (blue) vs. Improved Model (red)

# Version 23 Model Status - Frontal Impact – FMVSS 208

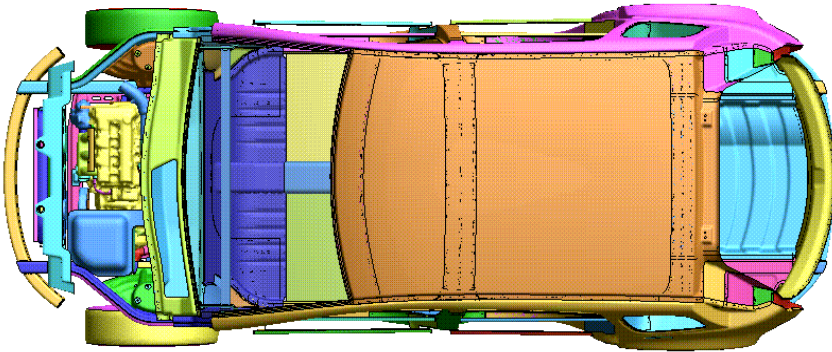


Intrusion Displacement in mm  
Maximum: 21mm (center)

NHTSA Crash Test vs. Recent Low Mass Models  
(green: std gauge; blue: reduced gauge)

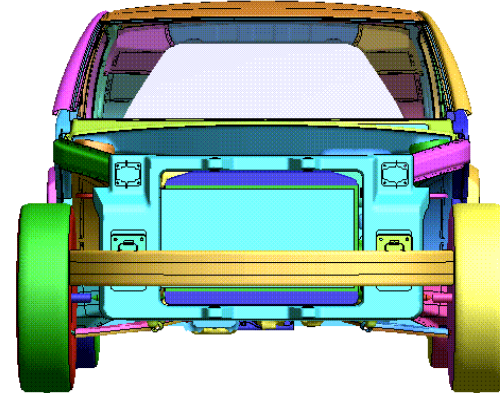
# 35mph Flat Frontal (model ver #23)

D3PLOT: frt\_fmvs208\_ffb35



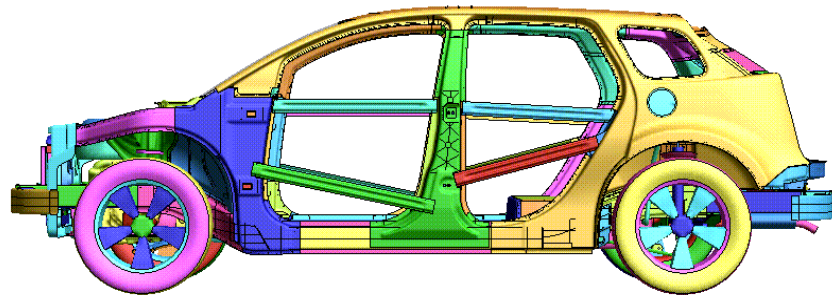
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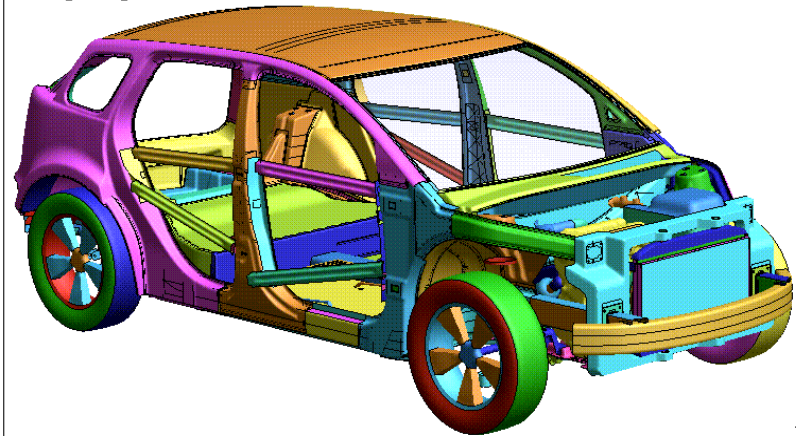
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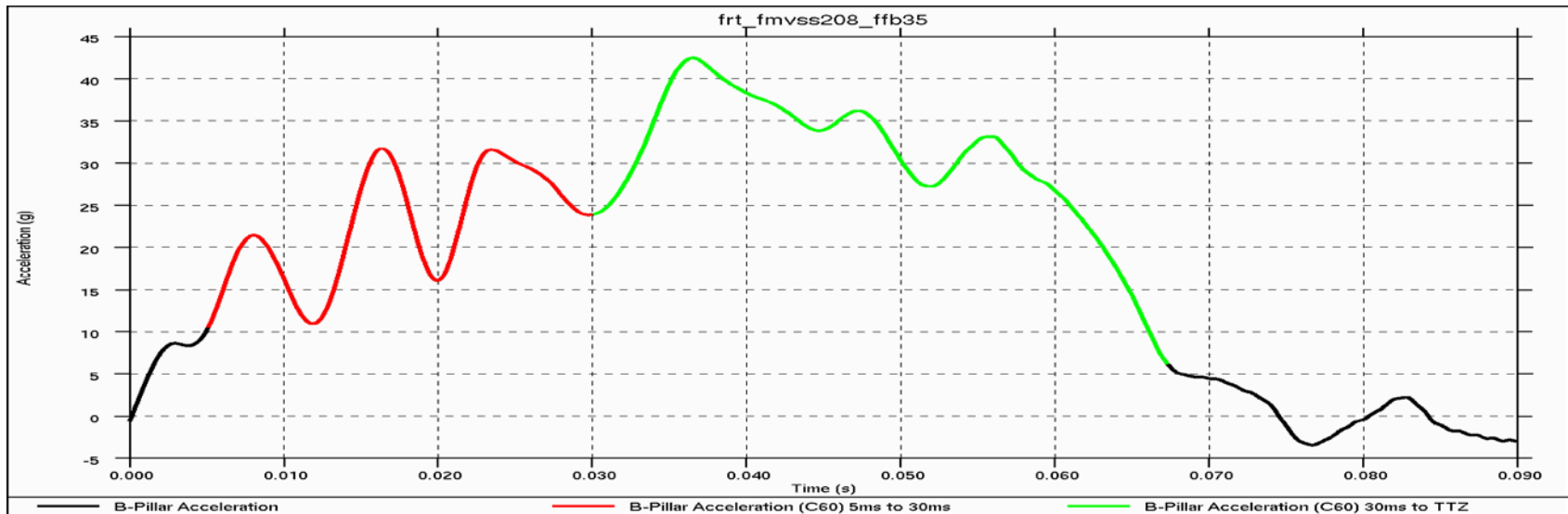
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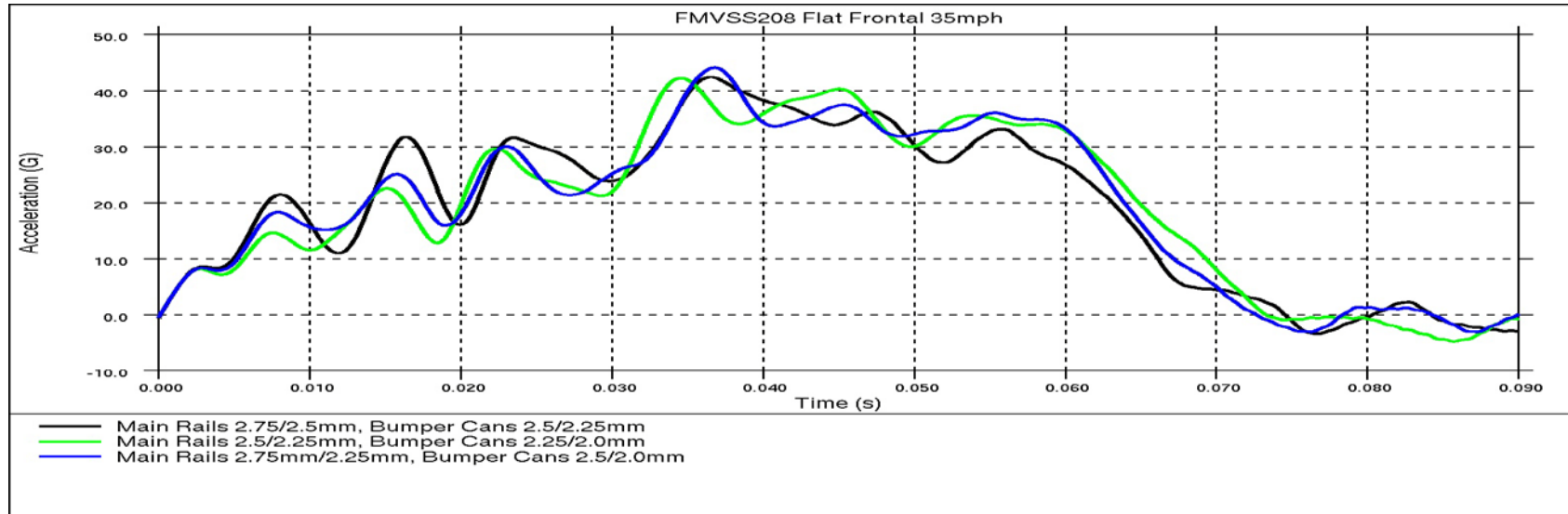
# 35mph Flat Frontal (model ver #23)



5 to 30ms Average Acceleration = 22.5g  
30ms to TTZ (60.5ms) Average Acceleration = 33.3g  
Average Accel. (whole event) = 26.7g

# Affect of Gauge Tuning – Preliminary Frontal Impact – FMVSS 208

## 35mph Flat Frontal (model ver #23 gauge change)



Ver #23 'std':

Initial peak (bumper cans) @ 8ms - 21.4G; second peak (main rail) @ 16ms - 31.8G

Ver #23 (as 'std' with main rail/bumper can vertical wall down-gauged 0.25mm):

Initial peak (bumper cans) @ 8ms - 18.3G; second peak (main rail) @ 16ms - 25.2G

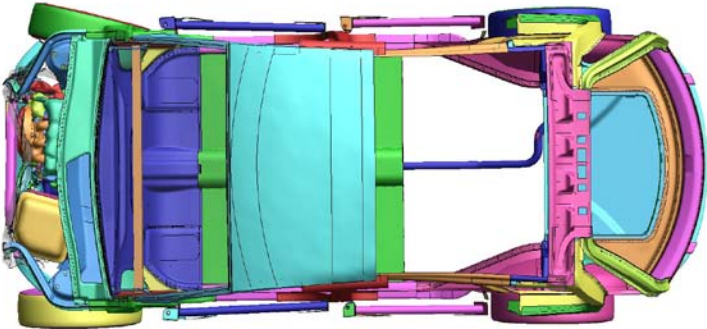
Ver #23 'std' (as 'std' with main rail/bumper can down-gauged 0.25mm):

Initial peak (bumper cans) @ 8ms - 14.7G; second peak (main rail) @ 16ms - 22.6G

# Impact Modeling – Preliminary Frontal Impact – FMVSS 208

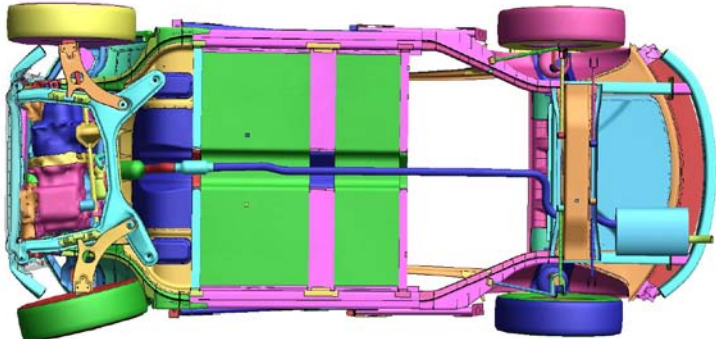
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D3PLOT: ffr\_fmvs208\_ffb35



Plan View

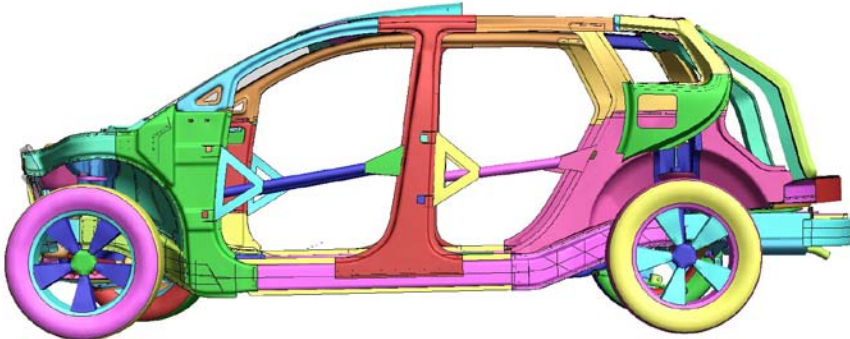
0.100001



Bottom View

0.100001

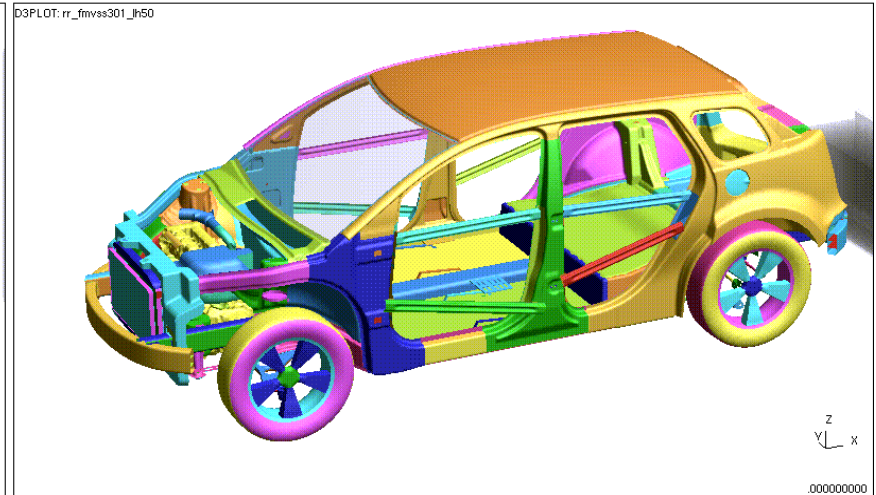
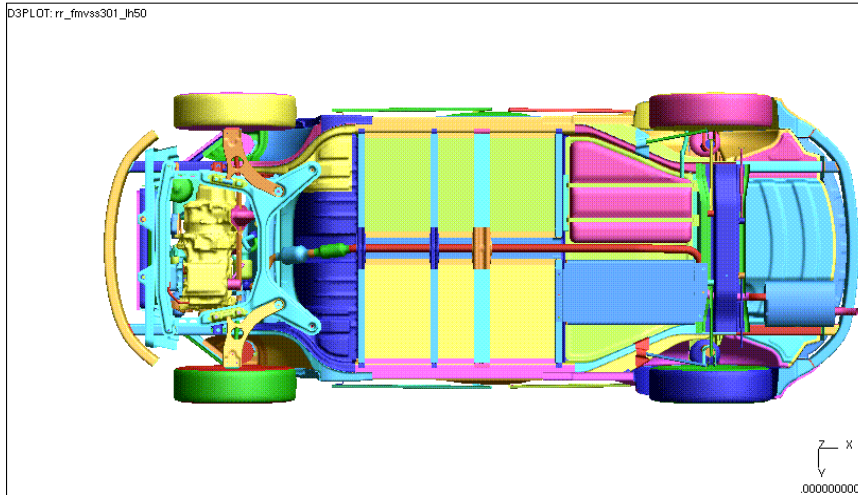
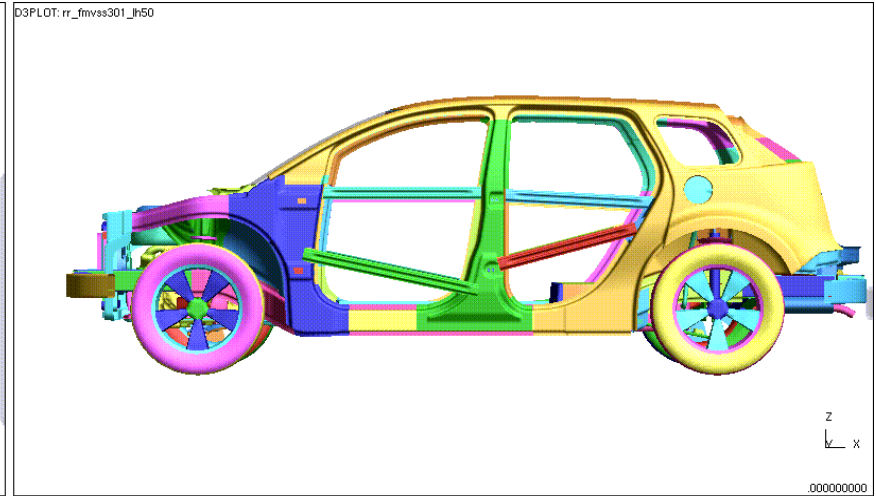
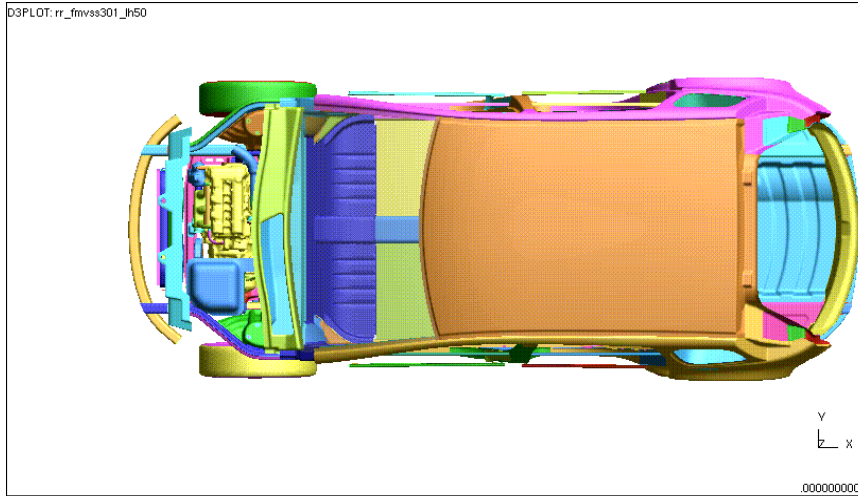
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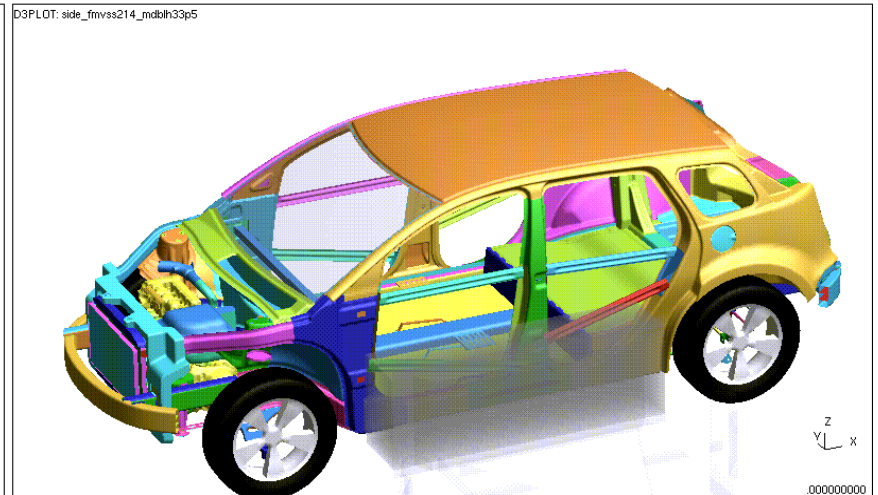
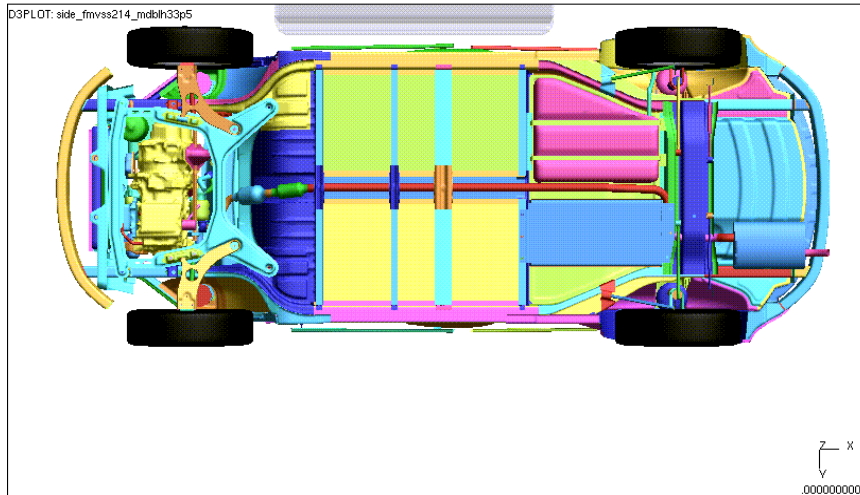
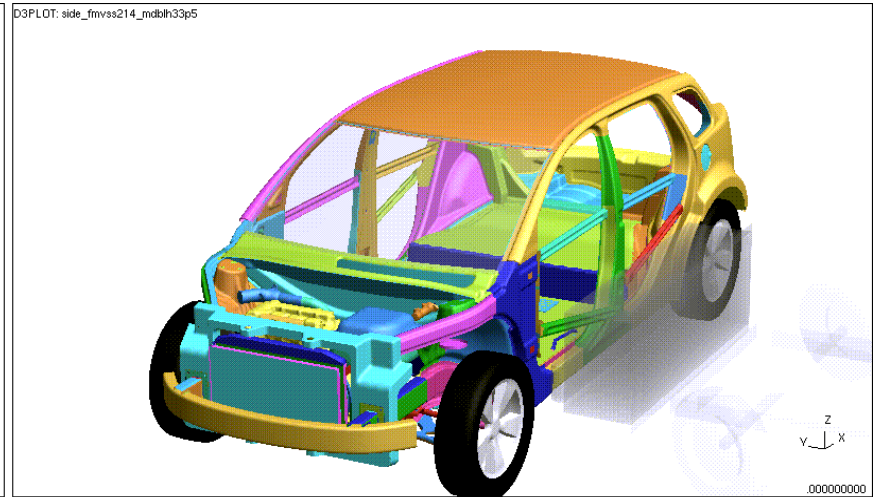
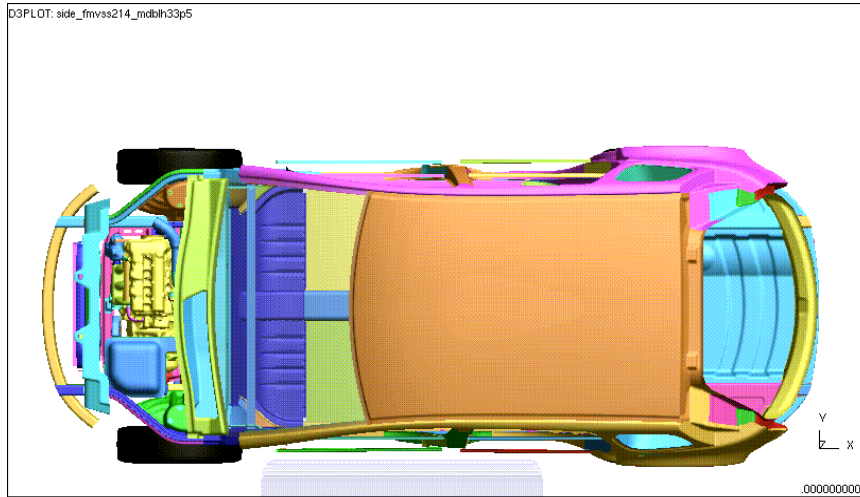
Side View

0.100001

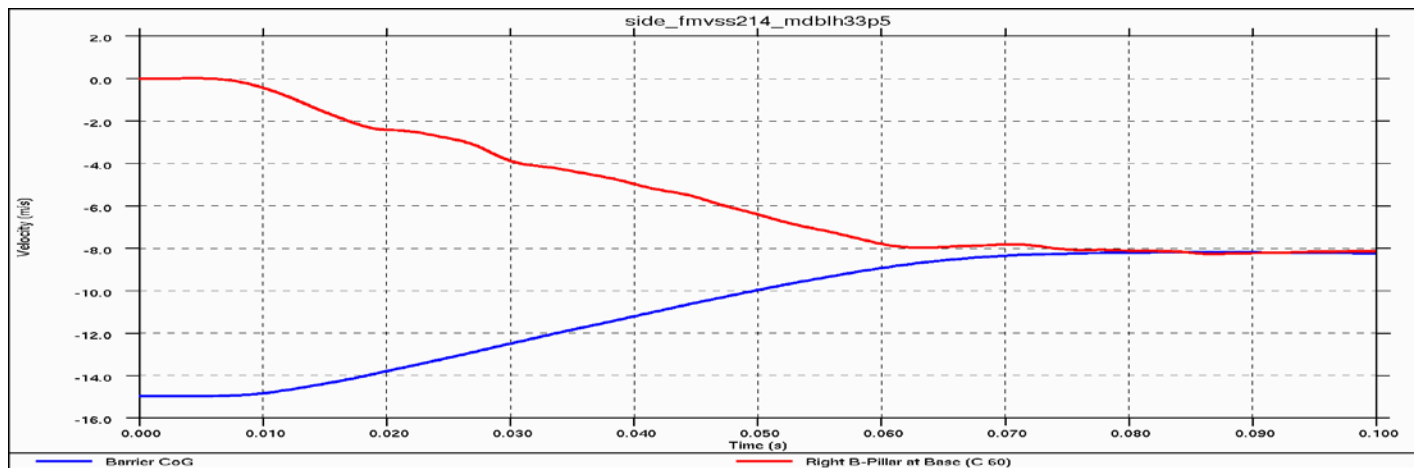
# 50mph 70% Overlap Rear Deformable Barrier (model ver #23)



# 33.5mph 27deg Crabbed Barrier (model ver #23)

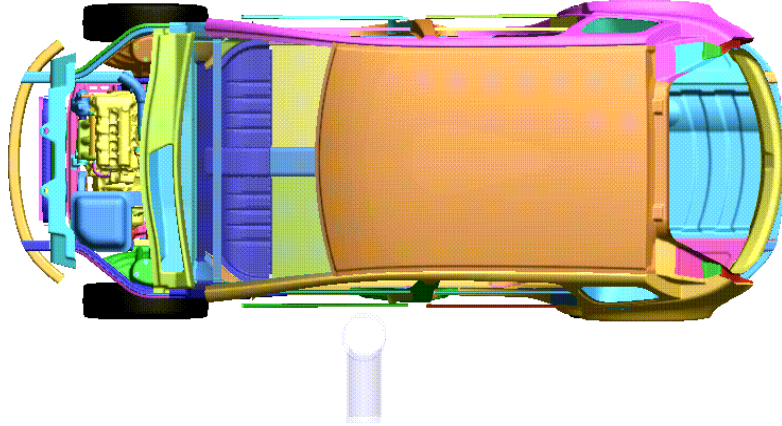


# 33.5mph 27deg Crabbed Barrier (model ver #23)



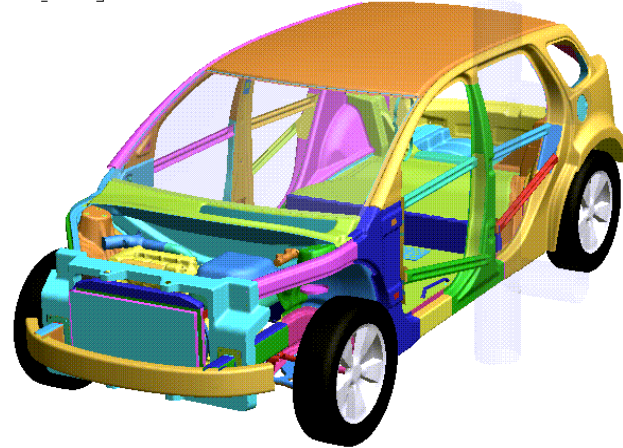
# 20mph 75deg Pole 5<sup>th</sup> %ile Female (model ver #23)

D3PLOT: side\_fmvs214\_polefrt05th



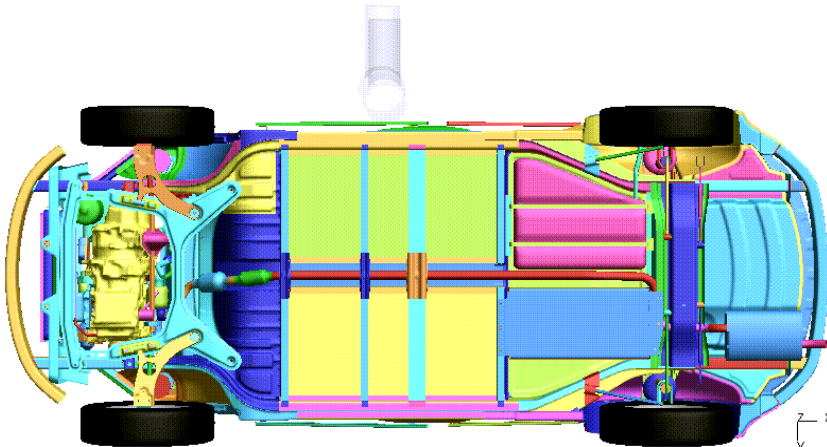
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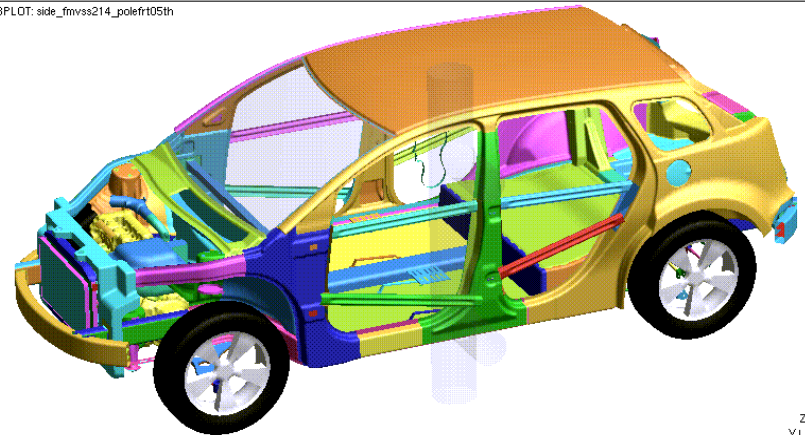
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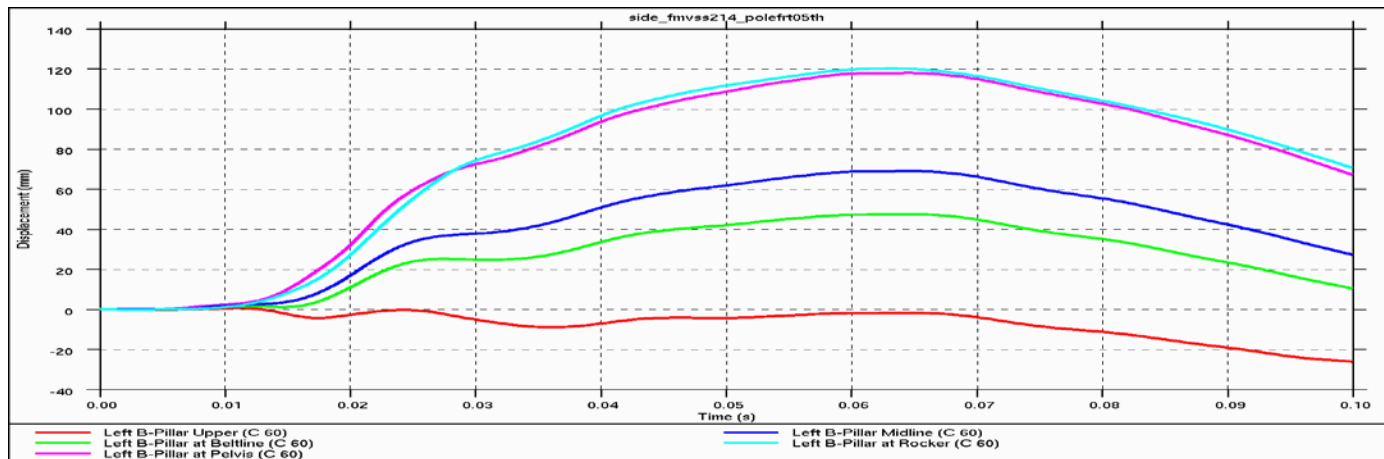
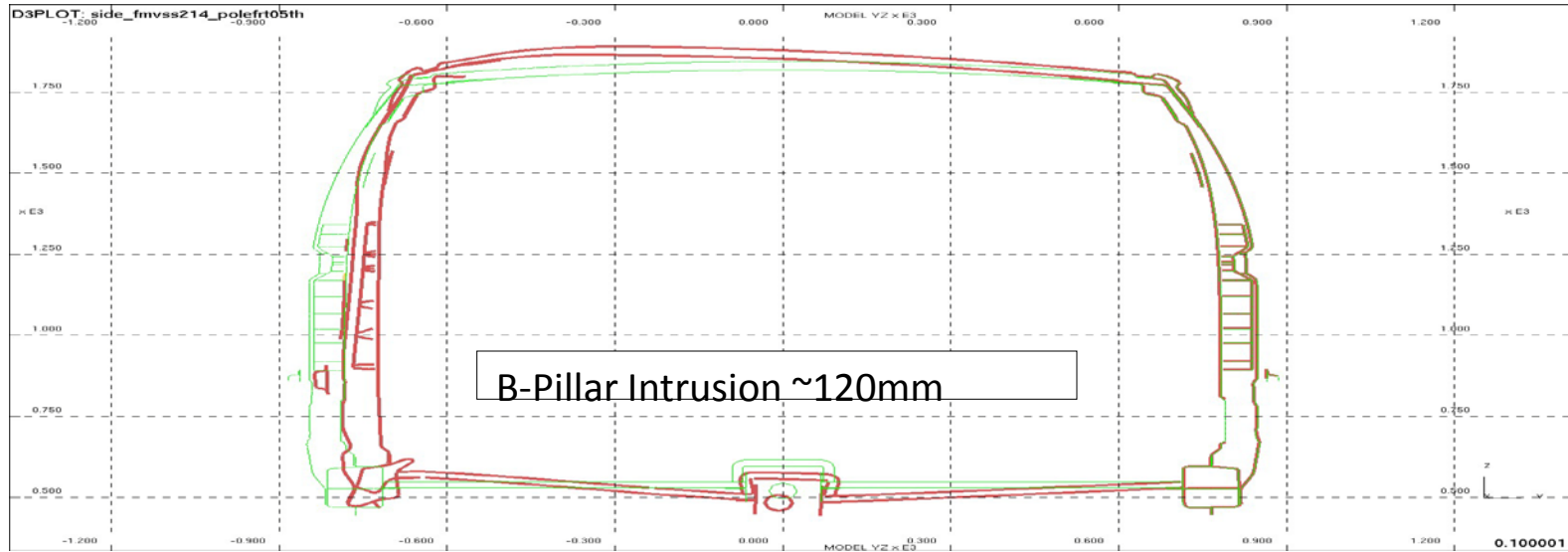
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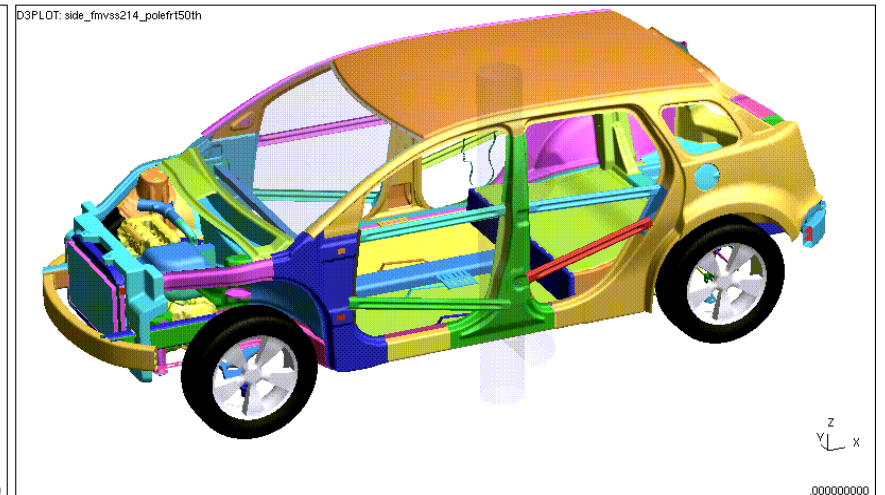
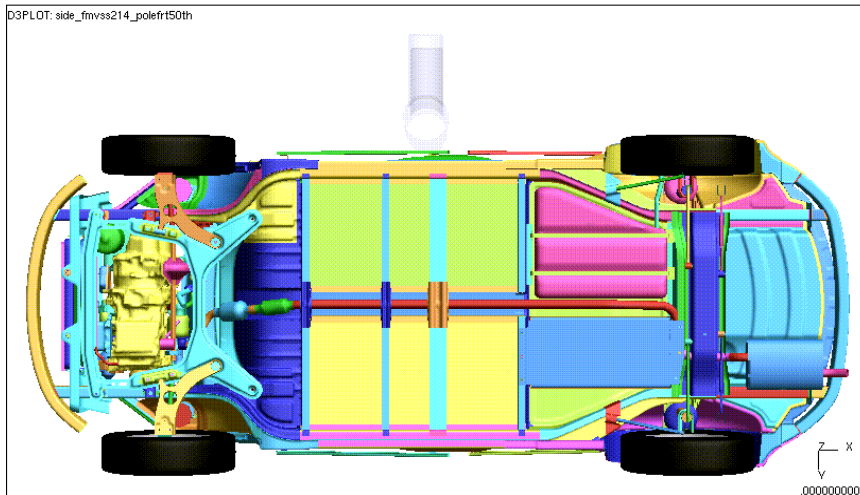
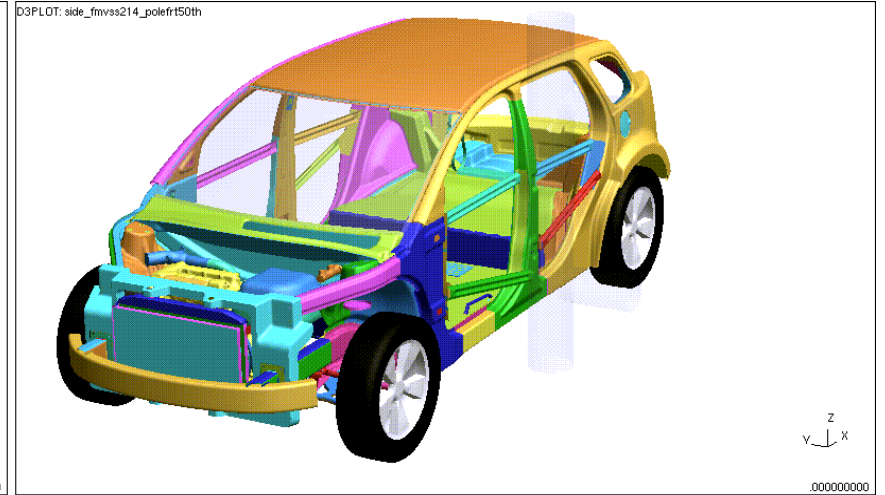
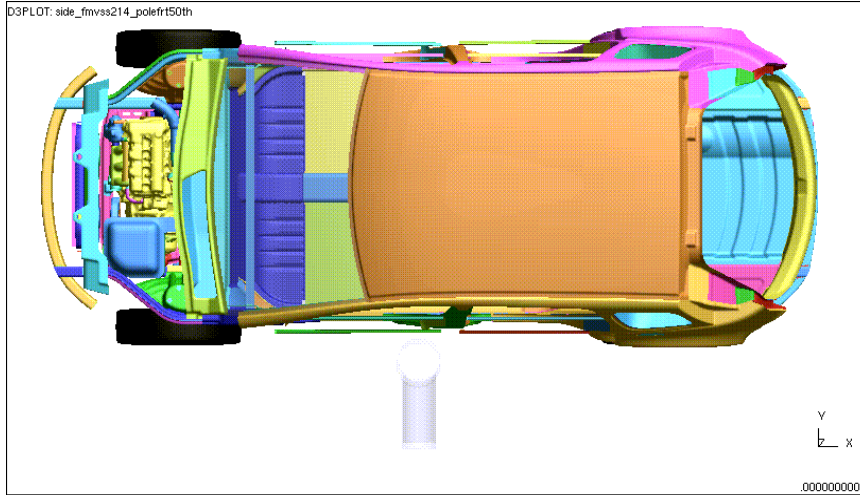
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# 20mph 75deg Pole 5<sup>th</sup> %ile Female (model ver #23)

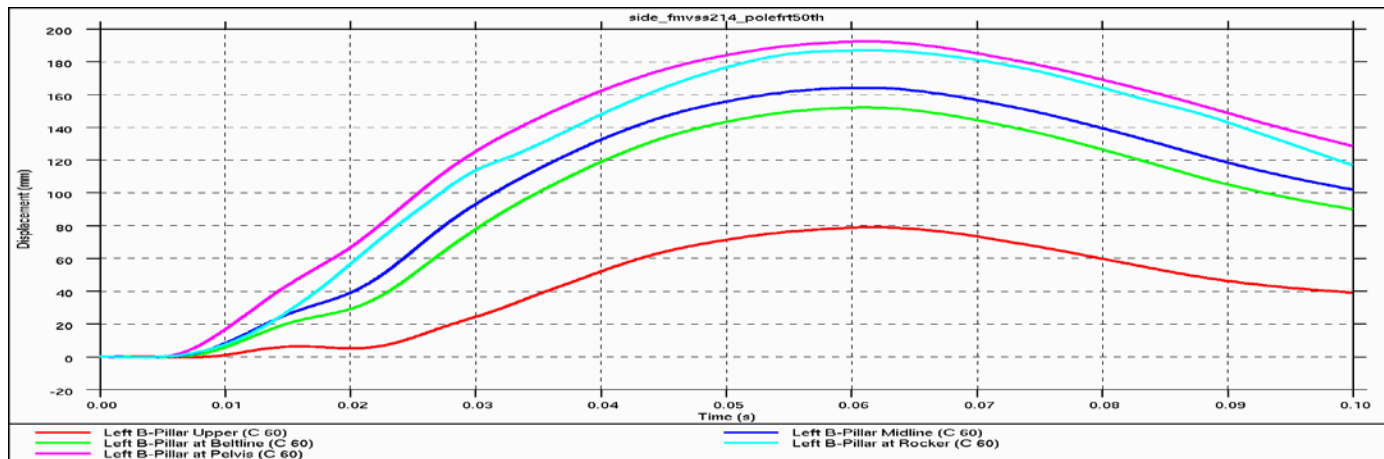
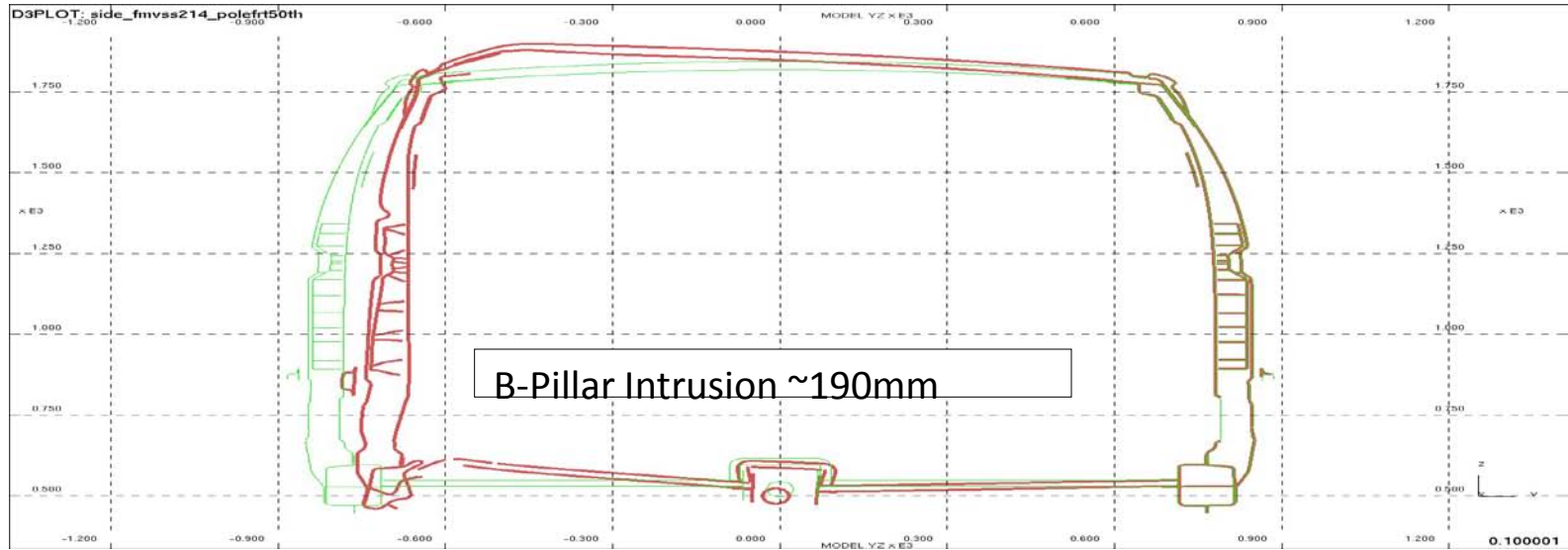




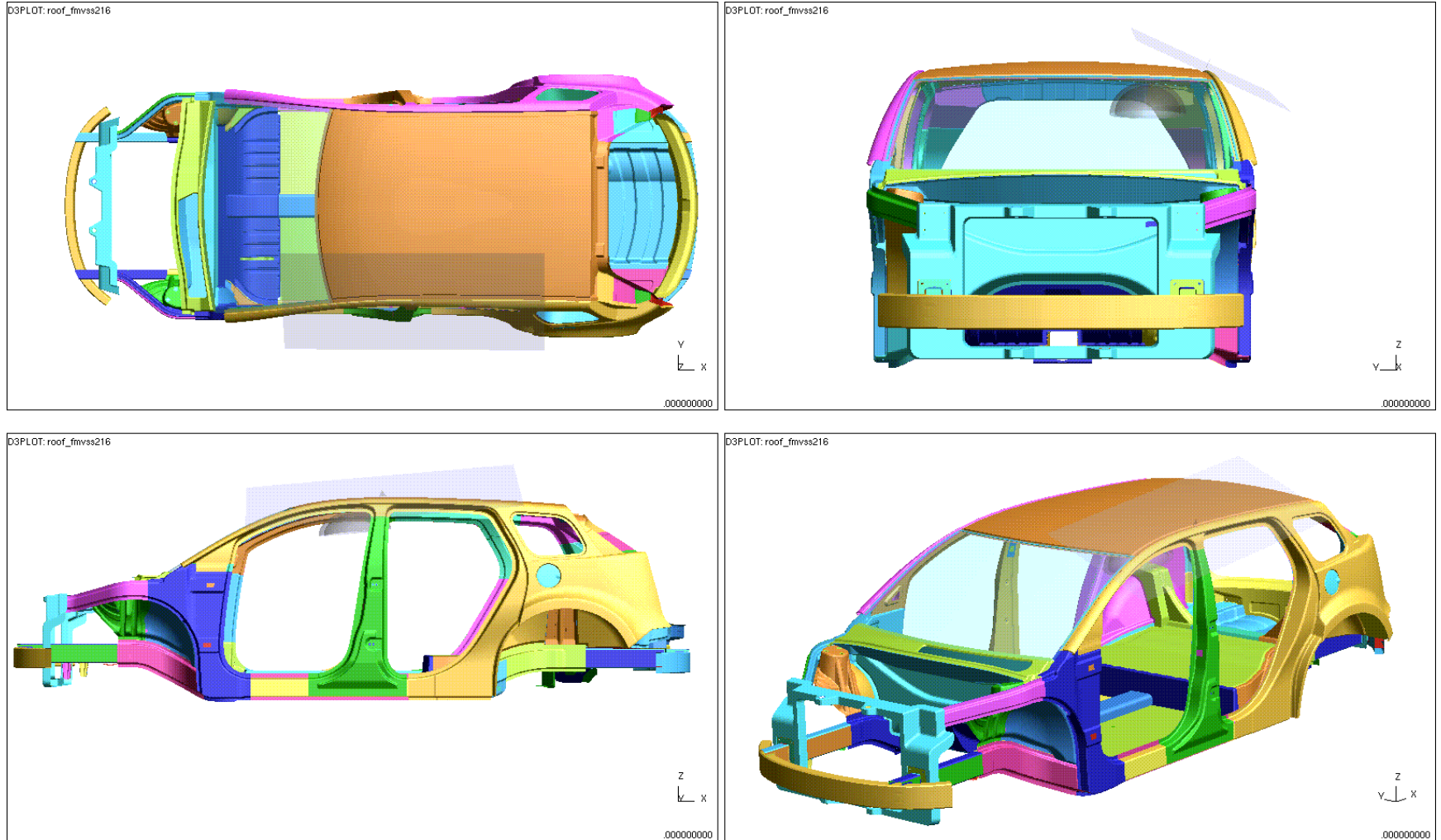
# 20mph 75deg Pole 50<sup>th</sup> %ile Male (model ver #23)



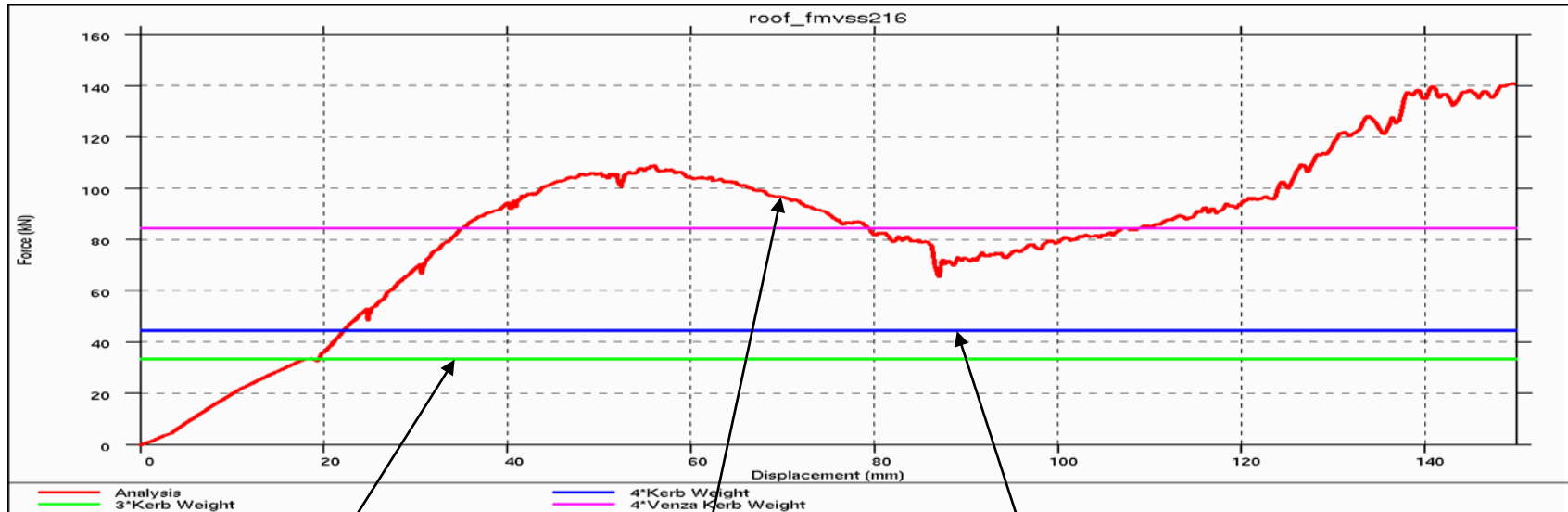
# 20mph 75deg Pole 50<sup>th</sup> %ile Male (model ver #23)



# Roof Crush (model ver #23)



# Roof Crush (model ver #23)



Low mass BIW

3x Curb Weight Target

4x Curb Weight Target

# Conclusions

- **A significantly mass reduced vehicle has the potential to meet federal impact requirements**

# Recommendations



- **Build a Phase 2 body in white and verify structural performance using non-destructive testing including:**
  - **Bending stiffness**
  - **Torsional Stiffness**
  - **Modals**
- **Build a Phase 2 complete vehicle using the low mass body in white**
  - **Demonstrate low mass vehicle**
    - **Destructive testing**



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Thank You

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