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An Analysis of Impact Performance and Cost Considerations for a Low Mass Multi-Material Body Structure

NHTSA Mass/Size/Safety Workshop

May 13, 2013

Agenda

1. Background
2. Factors Driving Future Automobile Design
3. Fuel Economy Factors
4. Engineering Parameters:
   Materials, Manufacturing and Joining
5. Design Methodology
6. Lightweight BIW Design and Crash /Structure Performance
7. Cost Analyses
8. Summary Remarks

Background – Phase 1 And Phase 2 Studies

- The Energy Foundation (California based) contracted Lotus to write a Mass Reduction Opportunities (paper) study in 2009 and selected a Toyota Venza (CUV) as the baseline vehicle
- Lotus developed two scenarios: 1. a 2017 MY 20% mass reduced vehicle (Low Development) and 2. a 2020 MY 40% mass reduced vehicle (High Development) – a powertrain study was not part of the Lotus contract
- EPA developed a parallel hybrid powertrain for the Low Development vehicle
- ICCT (International Council on Clean Transportation) published peer reviewed Mass Reduction Opportunities study in Spring, 2010 which is called the Lotus Phase 1 study
- California Air Resources Board (ARB) contracted Lotus to design a lightweight 2020 MY BIW (Body in White) and closures and perform crash studies and structural analyses to verify performance potential in Qtr. 3 2010
- Lotus selected for the Phase 2 study because it, uniquely, is an OEM manufacturing lightweight cars that is also an engineering consultancy
- ARB set a 40% mass reduction target for the Phase 2 BIW and set dimensional/volumetric constraints identical to baseline Toyota Venza
- Phase 2 non-BIW masses are based on the 40% mass reduced systems developed in the Phase 1 2010 ICCT paper
- NHTSA technical team was part of the Phase 2 crash model validation process
  - Lotus and NHTSA shared crash models and analysis results
  - Independent crash performance assessment by NHTSA
  - NHTSA feedback used to improve the crash model
  - NHTSA Toyota Venza production vehicle crash test results data used to establish targets
  - NHTSA car/SUV models used to simulate car-car impacts
- EPA and DOE were technical contributors
- Lotus Phase II peer reviewed study published by ARB 4th Qtr. 2012
- Lotus studies used as reference for DOT/EPA/NHTSA pending future safety/emission/FE regulations

Phase 1 Mass and Cost Results

The charts below are from the 2010 Lotus mass reduction study published by ICCT (link: http://www.theicct.org/pubs/Mass_reduction_final_2010.pdf) that developed design approaches that reduced cost and mass in non-body systems to partially offset the added cost for the low mass BIW.

Mass and Cost Summary	Baseline CUV	Low Mass	Low Mass
		Mass	Cost Factor
Body	382.50	221.06	1.35
Closures/Fenders	143.02	83.98	0.76
Bumpers	17.95	15.95	1.03
Thermal	9.25	9.25	1.00
Electrical	23.60	15.01	0.96
Interior	250.60	153.00	0.96
Lighting	9.90	9.90	1.00
Suspension/Chassis	378.90	217.00	0.95
Glazing	43.71	43.71	1.00
Misc.	30.10	22.90	0.99
Totals:	1289.53	793.76	
Base CUV Powertrain Mass	410.16	Mass	Wtd. Cost
Base CUV Total Mass	1699.69	61.6%	103.0%

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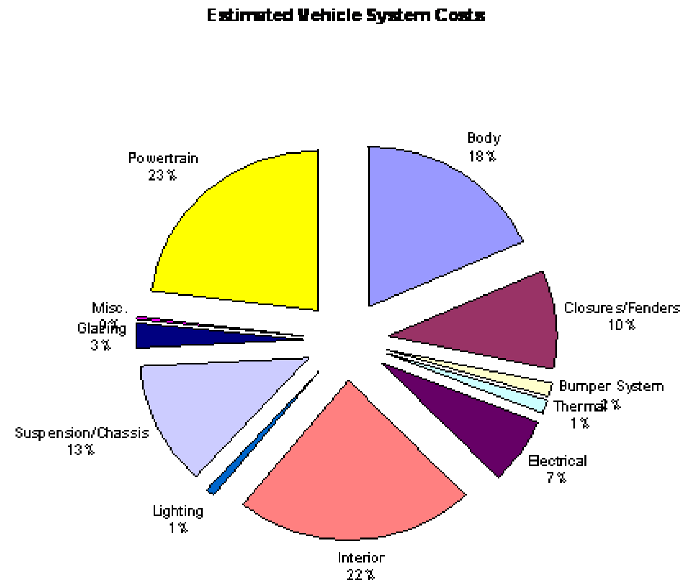

The above Phase 1 masses were utilized for the Phase 2 Impact Analyses

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Fundamental Factors Driving Future Automotive Design

5/16/2013

Fuel Economy and CO_2 Emissions

- 54.5 mpg for cars and light-duty trucks by Model Year 2025
- Nearly doubles the fuel efficiency of those vehicles compared to new vehicles currently on our roads
- Fleet average equivalent of 54.5 mpg translates to an EPA "window sticker" average of about 40 mpg
- Projected consumer savings of more than $1.7 trillion at the gas pump
- Estimated reduction in U.S. oil consumption of 12 billion barrels
- Emissions reduced by 6 billion metric tons over the life of the program

CO_2 = Fuel Combusted *0.99*(44/12)

CO_2 = CO_2 emissions in lbs.

Fuel = weight of fuel in lbs.

0.99 = oxidation factor (1% un-oxidized)

44 = molecular weight of CO_2

12 = molecular weight of Carbon

1 gallon of gasoline creates approx. 20 lbs CO_2

1 gallon of diesel fuel creates approx. 22 lbs CO_2

http://www.whitehouse.gov/the-press-office/2012/08/28/obama-administration-finalizes-historic-545-mpg-fuel-efficiency-standard

http://www.insideline.com/car-news/historic-545-mpg-still-goal-in-final-2025-cafe-rules.html

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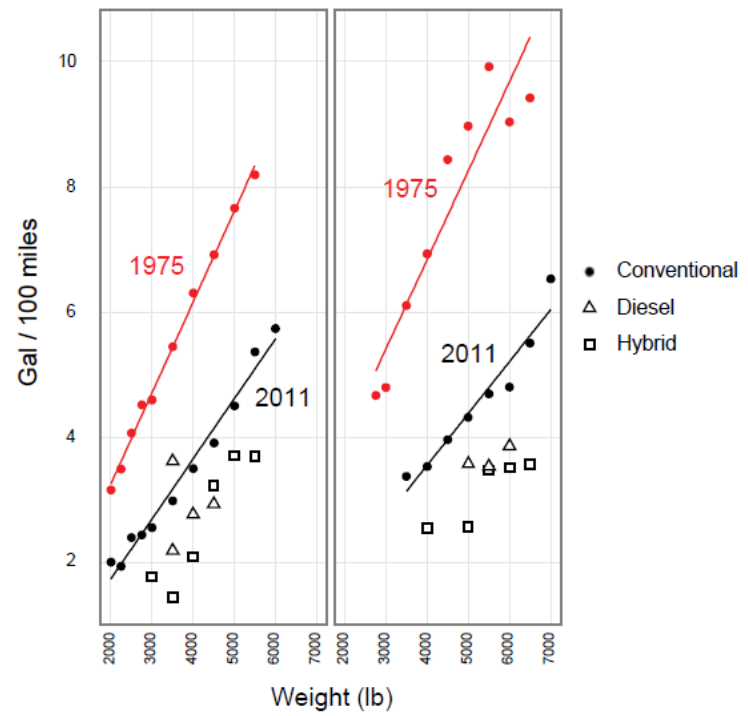
Fuel Economy Factors

Mass Reduction Effects

- Every 10% reduction in vehicle mass improves fuel economy by about 7%
- Reducing vehicle mass by 30% results in about a 21% MPG increase
- Reduced fuel consumption reduces CO_2 emissions
- Mass de-compounding impact
- Positive effect on vehicle performance
- Effect of reduced mass on vehicle evasive capability

Laboratory 55/45 Fuel Consumption vs. Vehicle Weight, MY 1975 and MY 2011



http://www.epa.gov/otaq/cert/mpg/fetrends/2012/420r12001.pdf

Other Non-Mass Related Factors Impacting Fuel Economy

- Aerodynamics
- Vehicle frontal area
- Tire/Wheel size/weight/friction
- Engine efficiency
- Transmission efficiency
- Gearing




Nissan Versa	Hyundai Accent	Chevy Cruze Eco	Toyota Scion Iq
2345 lbs.	2396 lbs.	3,018 lbs.	2127 lbs.
27 MPG	33 MPG	33 MPG (manual)	37 MPG (VVT)
MPG Delta:	+22%	+22%	+37%
Weight Delta	+2.2%	+28.7%	-9.3%

$$HP_{road}=((1/2)\,\rho\, Cd\, A_f\, v^2 + TC*W)*v$$

where:

AR = air resistance [lbs.]

ρ = air density [lbs/ft^3]

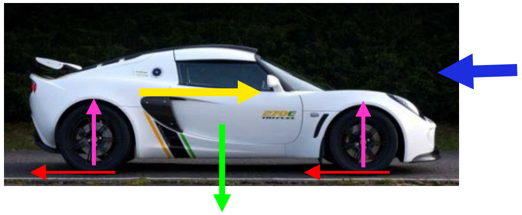
A = the car frontal area [ft^2]

v = car speed [ft/s]

TC = tire friction coefficient [dimensionless]

W = vehicle weight [lbs.]

Cd = the coefficient of aerodynamic resistance [dimensionless]



Tire Rolling Resistance

Vehicle Weight

Aerodynamic force

Driving Force

Reaction Force

Weight source: http://www.iseecars.com/cars/lightest-cars

Fuel economy source: http://www.fueleconomy.gov/feg/noframes/31647.shtml

Light Weight Effect on Performance

- Reduced Fuel Consumption
- Improved braking with reduced width tires
- Improved handling with reduced section tires
- Equivalent acceleration times with less horsepower
- Lower center of gravity

Exige S V6	Porsche 911 Turbo
345 HP 3.5L S V6	500 HP 3.8L T B6
2,380 lbs	3,461 lbs
6.90 lbs/HP	6.92 lbs/HP
3.8s 0-60	3.5s 0-60
170 MPH	194 MPH
$75,000	$137,500

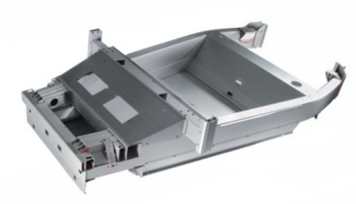
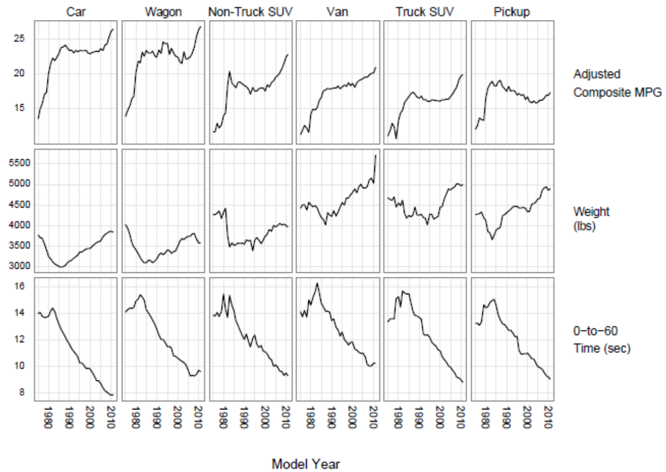


Figure 10

Fuel Economy and Performance by Vehicle Type



http://www.epa.gov/otaq/cert/mpg/fetrends/2012/420r12001.pdf

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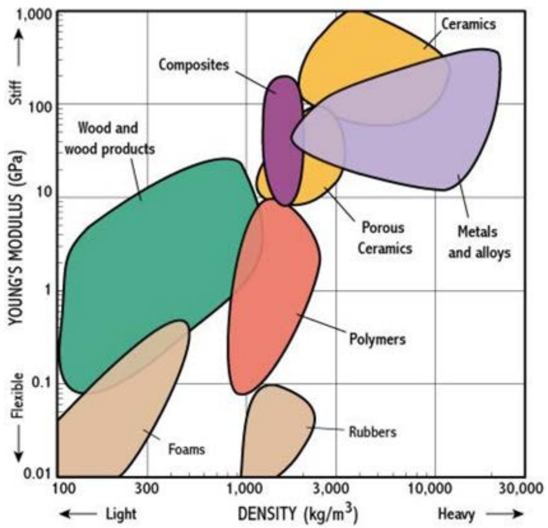
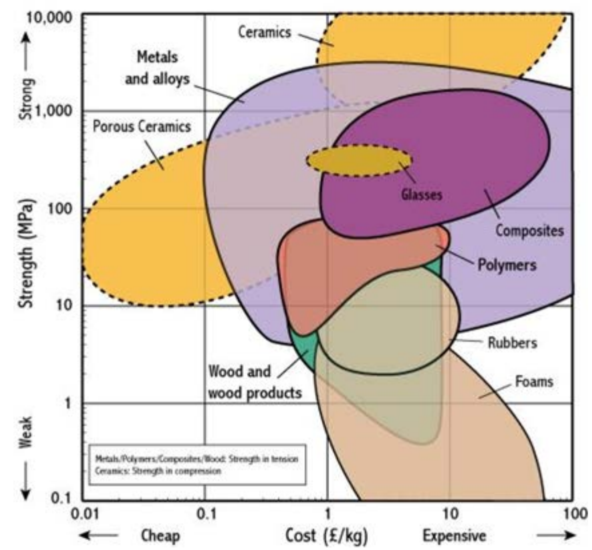
Engineering Parameters:

Materials, Manufacturing and Joining

Materials Selection

- Use a holistic design approach to select materials which best support the total vehicle mass, cost, performance and infrastructure constraints
- Choose materials based on performance, cost and mass for each specific area
- Incorporate recycled materials into design
- Utilize proven software
- Consider all materials
  - Steel
  - Aluminum
  - Magnesium
  - Plastics
  - Carbon fiber
  - Titanium
  - Ductile cast iron
  - Other





Use of Lightweight Materials Doesn't Guarantee a Low Mass Vehicle

- The Lamborghini Aventador body incorporates a carbon fiber center section with aluminum front and rear substructures

- The Ford Mustang Shelby GT500 curb weight is >200 lbs. lighter using a steel body

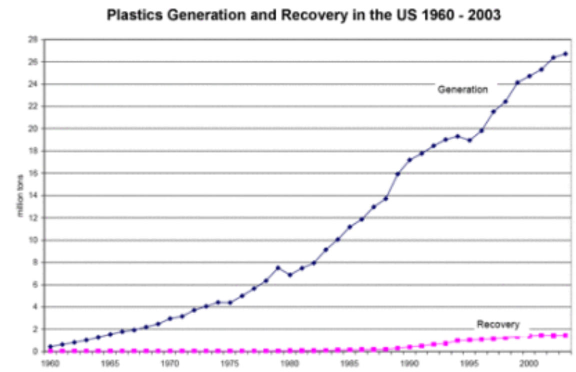
	2013 Aventador	2013 Shelby GT500	Delta
MSRP	$394,000	$54,000	$340,000
Curb Weight - lbs.	4,085	3,852	**233**
Length - inches	188.2	189.4	-1.2
Width - inches	79.9	73.9	6.0
Height - inches	44.7	55.9	-11.2
Adj'd Veh. Volume[1] - ft3	292	317	-25
Specific Density - lb./ft3	14.0	12.2	**1.8**
Engine HP	691	662	29
Lbs/HP	5.9	5.8	0.1
0-60 MPH - seconds	3.0	3.5	-0.5
Lateral g's	0.95	1.00	-0.05
Braking 70 - 0 MPH - feet	146	155	-9
Top speed - MPH	217	189	28

1 L x W x H; Shape Factors: 0.75 - Aventador; 0.70 – Shelby GT500

Vehicle data source: manufactuers web sites

Recycled Materials Offer an Opportunity for Reducing Costs

Each year, an estimated 500 billion to 1 trillion plastic bags are consumed worldwide.
That's over one million plastic bags used per minute.
planetgreen.discovery.com/home-garden/plastic-bag-facts.html



Americans use and dispose of **100 billion** plastic shopping bags each year and at least 12 million barrels of oil are used per year in the manufacture of those plastic grocery bags.
The Wall Street Journal

Less than 5 percent of plastic grocery bags are recycled in the U.S.
Environmental Protection Agency.

Plastic bags can take up to 1,000 years to break down

http://www.worldwatch.org/node/5565

The amount of petroleum used to make a plastic bag would drive a car about 115 metres.
It would take only 14 plastic bags to drive one mile!
www.sprep.org/factsheets/pdfs/plasticbags.pdf

In 2007 in the U.S., about **31 million tons**, or 12.1 percent of total municipal waste, was plastic.
www.thegreenguide.com/home-garden/energy-saving/greenwashing/2

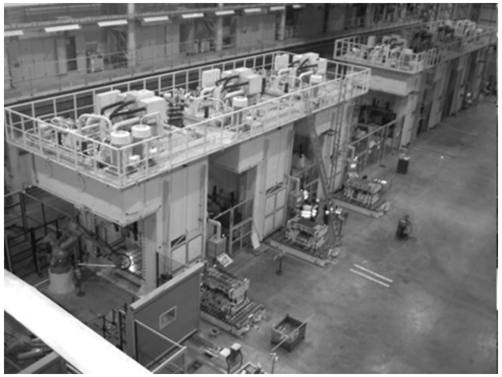
31 million tons of plastic waste were generated in 2010, representing 12.4 percent of total MSW.
http://www.epa.gov/osw/conserve/materials/plastics.htm#recycle

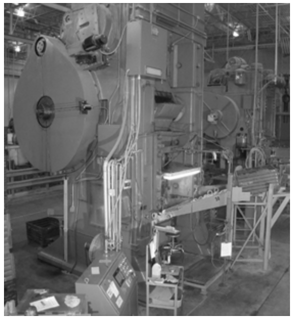
Only 8 percent of the total plastic waste generated in 2010 was recovered for recycling.

http://www.epa.gov/osw/conserve/materials/plastics.htm#recycle

Manufacturing Process Selection

- Manufacturing process chosen based on cycle time, running costs, utilization factor, and investment
- All processes considered
  - Stamping
  - Casting
    - Low pressure
      - Die cast
      - Investment cast
      - Ablation cast
    - High pressure
      - Thixomolding
  - Extrusion
    - Impact
      - Cold forming
  - High pressure forming
  - Molding
  - Ultra high speed forming
    - EMP
  - Other



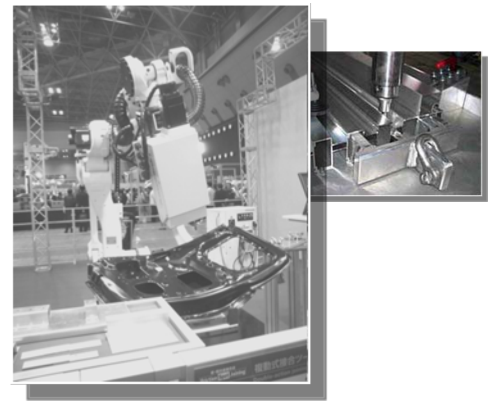


- Tooling investment is a key consideration
  - Castings provide high level of integration which reduces the part & tool count
  - Extrusion tools are typically < $20,000 vs. six figure stamping dies
  - Single sided tools offer longer term potential
- Processes chosen to meet cycle time requirements and part cost contribution targets while minimizing material scrap rates
  - Extrusions and castings reduce tool costs and lower scrap rate vs. stampings

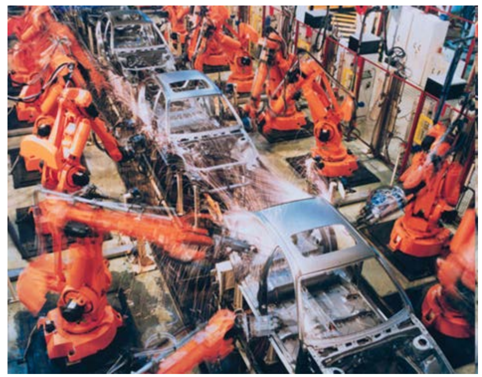
Joining Process Selection

- Processes chosen based on strength, fatigue/durability, cost and mass for each specific attachment

- Process selected to contribute to overall system performance, cost & mass targets
  - 100% continuous joint contributes to an increase in body stiffness
  - Increase in body stiffness allows reduction in material thickness which contributes to mass savings
  - Minimize parent material property degradation (HAZ)
  - Minimizing flange width contributes to mass and cost reduction
    - RSW flange is approximately 30% - 40% wider than a friction spot joint flange



- All processes considered
  - RSW
  - Clinching
  - Mechanical fastening
  - Laser welding
  - Continuous resistance welding
  - Friction stir welding
  - Friction spot joining
  - Bonding (structural adhesives)
  - Other



- Galvanic & Corrosion protection are key considerations
  - Material coatings chosen to meet long term durability requirements
  - Coatings selected to be compatible with joined materials and joining processes
  - Cost is a major consideration

- Processes chosen to meet cycle time requirements

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Body Design Methodology

5/16/2013

Non-Ferrous Body in White Financial Considerations

The average cost of non-ferrous materials for a multi-material body in white is typically 3 to 4 times higher than a ferrous BIW

The material cost for a BIW that is half the weight of a steel body will be 1.5 to 2.0 times higher than the material costs for ferrous materials

Utilizing 100% stampings and welding the BIW will create tooling and assembly costs roughly equivalent to an all steel BIW

Designing a primarily non-ferrous BIW using traditional ferrous forming and joining processes will result in a substantially more expensive body structure

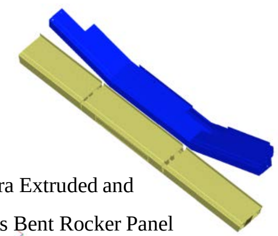
A different design approach is required to offset the added cost of a non-ferrous body structure

Design Methodology Overview

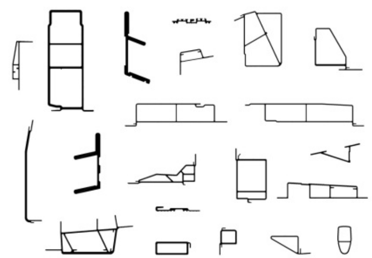
- Use a total vehicle, holistic approach to mass reduction
- Utilize a multi-material approach to selectively use the best material for each specific area
- Incorporate a high level of component integration using castings
- Design for low cost tooling, e.g., extrusions
- Minimize scrap material by process selection
- Maximize structural attributes through continuous joining techniques, e.g., structural adhesives
- Utilize electronics/electrical systems to replace mechanical hardware

Steel rear structure

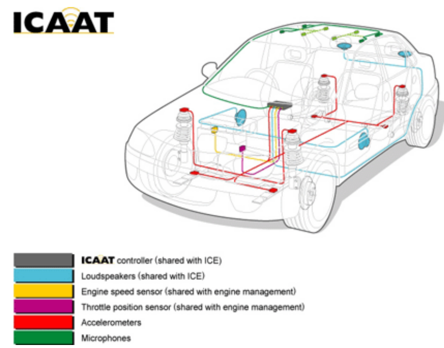
Evora Riv-Bonded Chassis



Evora Extruded and
Press Bent Rocker Panel



Evora Extrusion Geometries

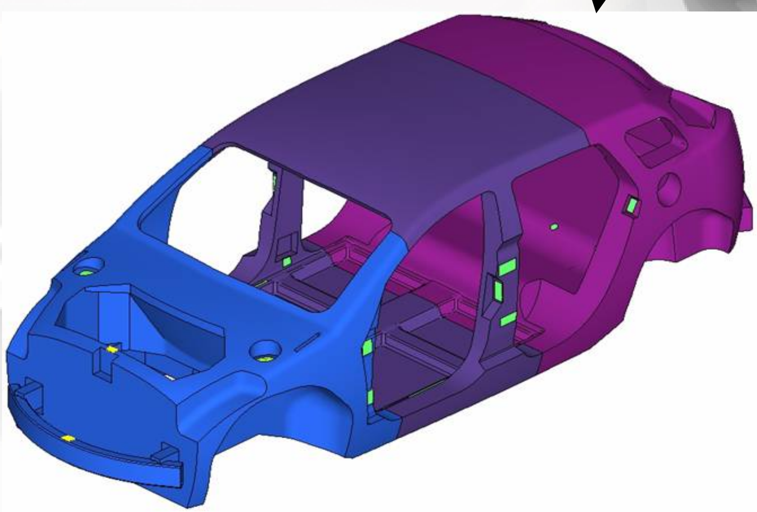


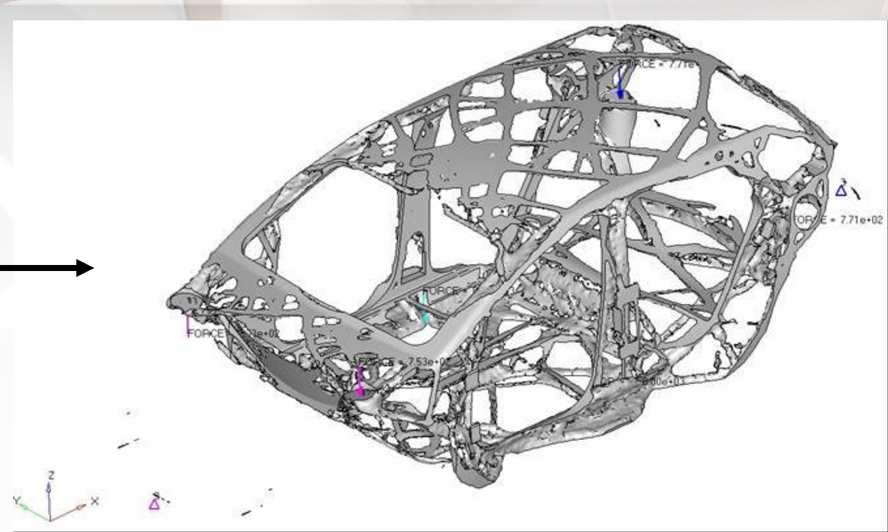
In-Car Active Acoustic Tailoring

BIW Design - Topology Analysis

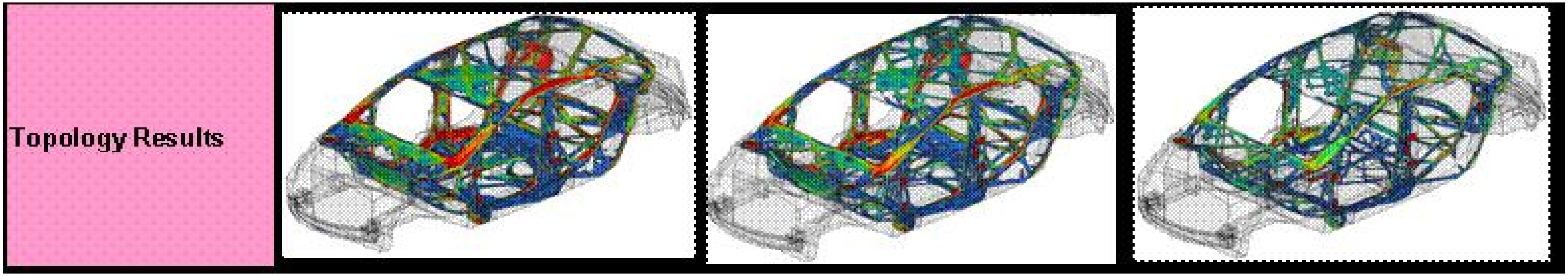
(Relative Material Strain Energy Density Levels)

Convert CAD model to
an optimized body structure





CUV Topology Analysis



Magnesium Aluminum Steel

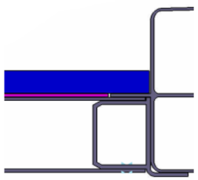
Topology optimization is used to identify the structural efficiencies within the package design space and to minimize mass with respect to system stiffness targets

Load path determination

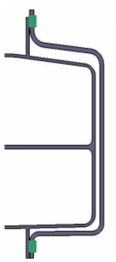
Shape optimization - section height and width developed

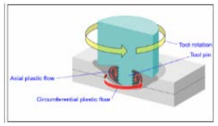
Material selection and thickness optimization based on section geometry

Lotus Phase 2 Multi-Material Body Structure – Exploded View

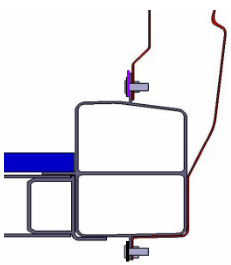


Section 1



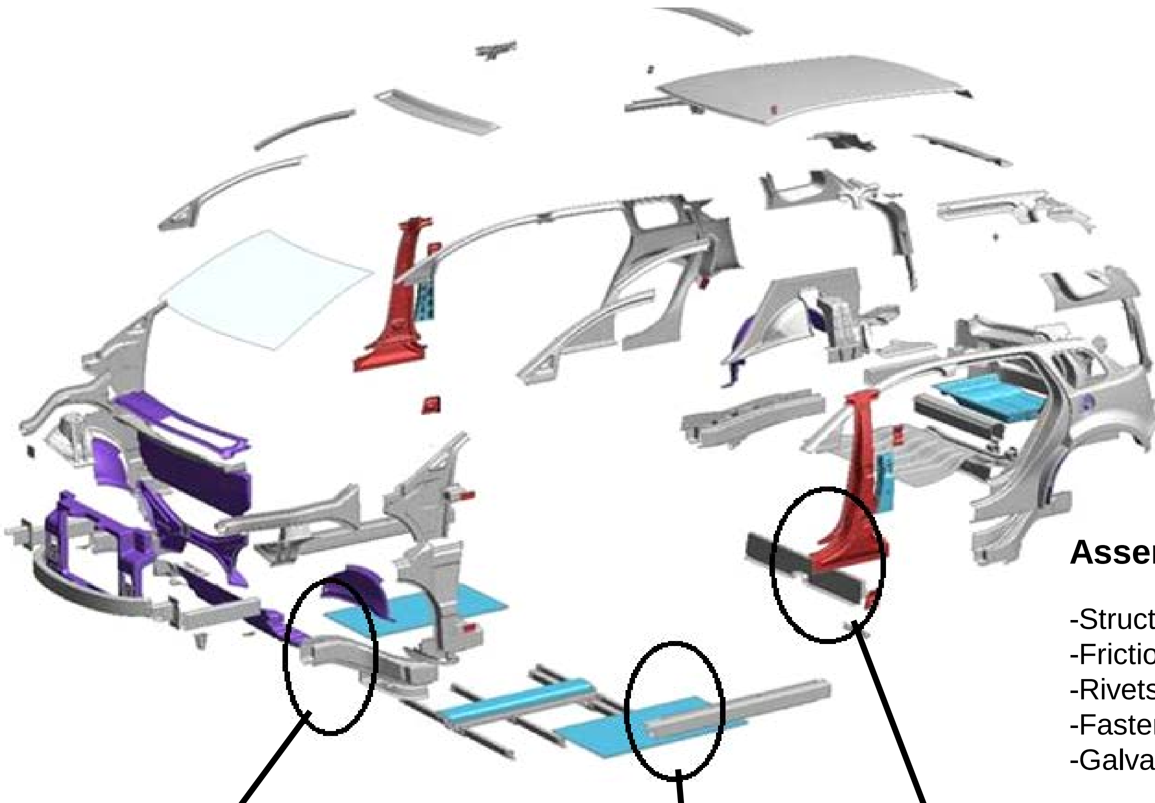


Section 2



Section 3

100% bonded using structural adhesive



Section 1 – Rivet: SPR (shown), Rivtek®

Section 2 – Friction Spot Joint

Section 3 – Mechanical Fastener (nylon washer shown)

Color Chart:

Aluminum: Silver

Magnesium: Purple

Steel: Red

Composite: Blue

Assembly Methodology

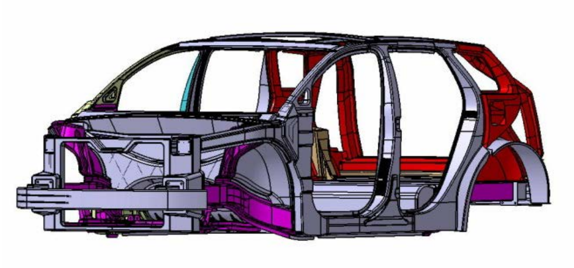
- Structural adhesive bonding (Henkel)
- Friction spot joining (Kawasaki)
- Rivets (Rivtec®)
- Fasteners
- Galvanic protection (Henkel)

GM Multi-Material Chassis – 2014 Chevrolet Corvette

- The C7′s all-new aluminum frame is 57 percent stiffer and 99 pounds (45 kg) lighter than the steel frame of the previous-generation C6.
- The frame rails on the C7 are composed of five customized aluminum segments. These include aluminum extrusions at each end, a center main rail section, and hollow-cast nodes at the suspension interface points.
- Carbon-nano composite, an advanced blend of traditional composite material and carbon fiber, used on the underbody panels — allowing them to be light without losing strength of stiffness
- $52 million dedicated to the body shop that will manufacture the new aluminum frame.

http://gmauthority.com/blog/2013/01/deep-dive-the-chassis-of-the-2014-corvette-stingray

Low Mass Body In White Mass Summary



Low Mass BIW FEA Model

Toyota Venza BIW

Mass Status

	Low Mass BIW	Toyota Venza BIW
Mass:	241 kg (-37%)	383 kg
Materials:		
	Aluminum: 75%	Steel: 100%
	Magnesium: 12%	HSS: 49%
	Steel: 8%	
	Composite: 5%	
Parts:	<170 (-35%)	>260

Why Structural Adhesive Bonding?

- 100% of flange run length is structurally bonded
  - Improves body stiffness
  - Allows reduction in material gauge to save weight
  - Reduces number of welds required, i.e., joint span is increased

Lotus Exige S

- Projected cost savings vs. RSWs

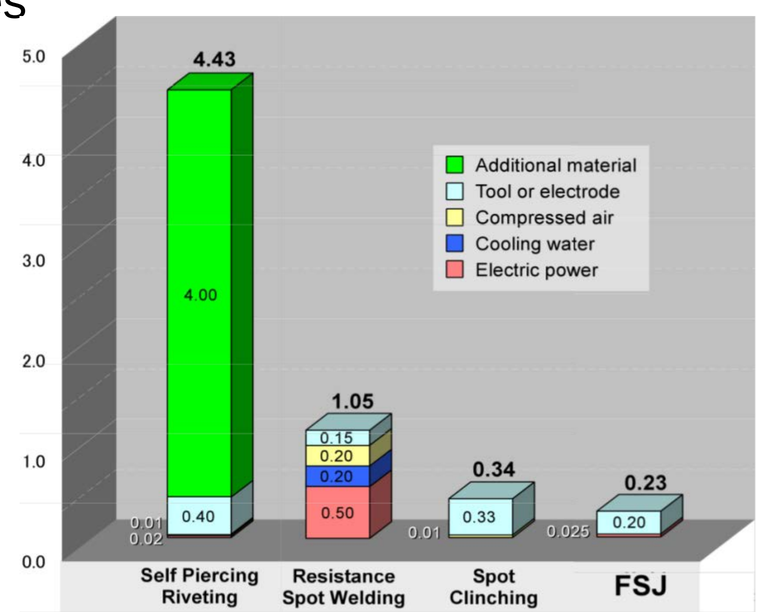
- Proven over 18 years of Lotus production
  - Chassis routinely subjected to high stresses
  - Lotus vehicles frequently used for track days
  - Owners regularly push the car to near dynamic limits

Lotus Evora

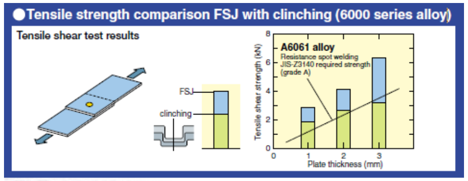
- Lotus Exige S (Supercharged V6) uses Elise chassis
  - Same lb./HP as Porsche 911 Turbo
  - 20 year old design met structural requirements

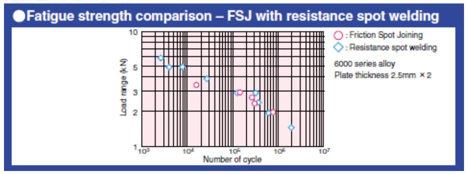
Why Friction Spot Joining (FSJ)?

- Substantially reduced cost vs. other joining technologies
  - 1/5 the cost of a RSW
    - 5000 RSWs on typical SUV cost approximately $250
  - Order of magnitude less cost than self piercing rivets
  - Does not increase vehicle mass vs. rivets



- Joint Strength
  - Rated comparable to RSWs for strength in lab testing





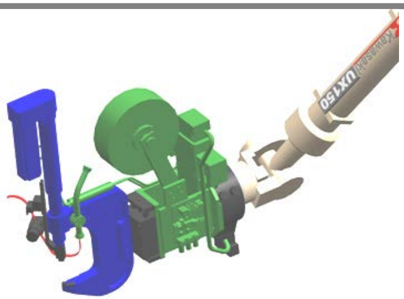
- No parent material degradation at joint
  - Material stays in plastic region during joining process
  - RSWs create molten state and degrade material strength

- Reduced flange width reduces material mass/cost
  - Typical RSW flange is 30% - 40% wider than FSJ flange (26mm – 28mm vs. 20mm)

Typical Rivet Types

Self-Pierce Rivet.

Requires double sided access.

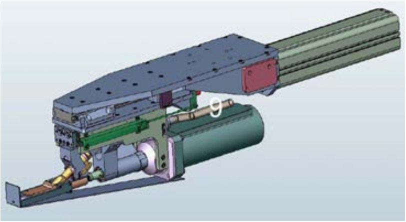


Typical Gun and Robot Configuration

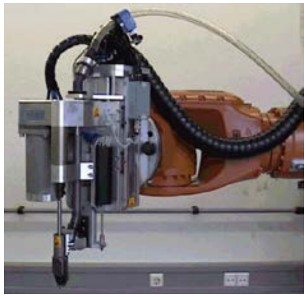
Typical Gun shape and size

Flow Drill Screw.

Requires single sided access.



Typical Gun shape and size

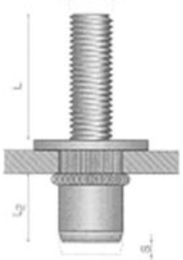


Typical Gun and Robot Configuration

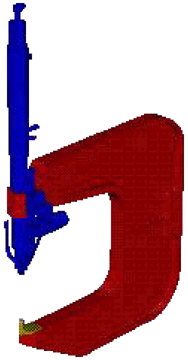
Self-Pierce Stud.

Requires double sided access.

Blind Rivet Stud.



Requires single sided access.

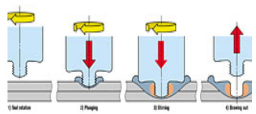


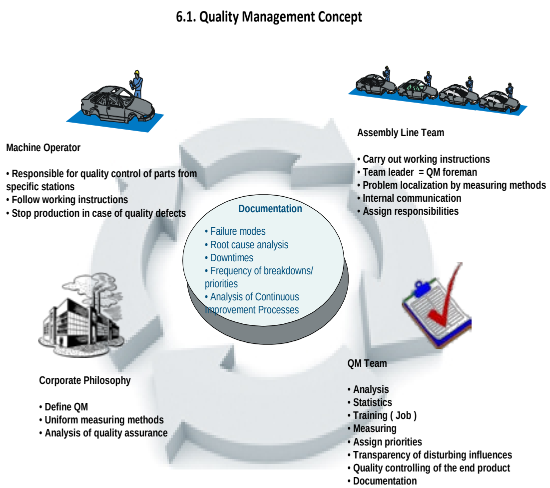
Typical Gun shape and size

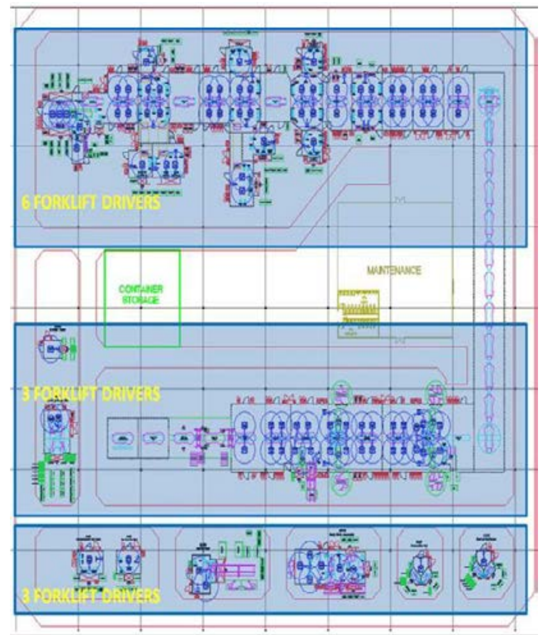
Multi-Material Low Mass Body In White Assembly Considerations

Assembly Methodology

-Structural adhesive bonding (Henkel)
-Friction spot joining (Kawasaki)
-Rivets (Rivtec®)
-Fasteners
-Galvanic protection (Henkel)







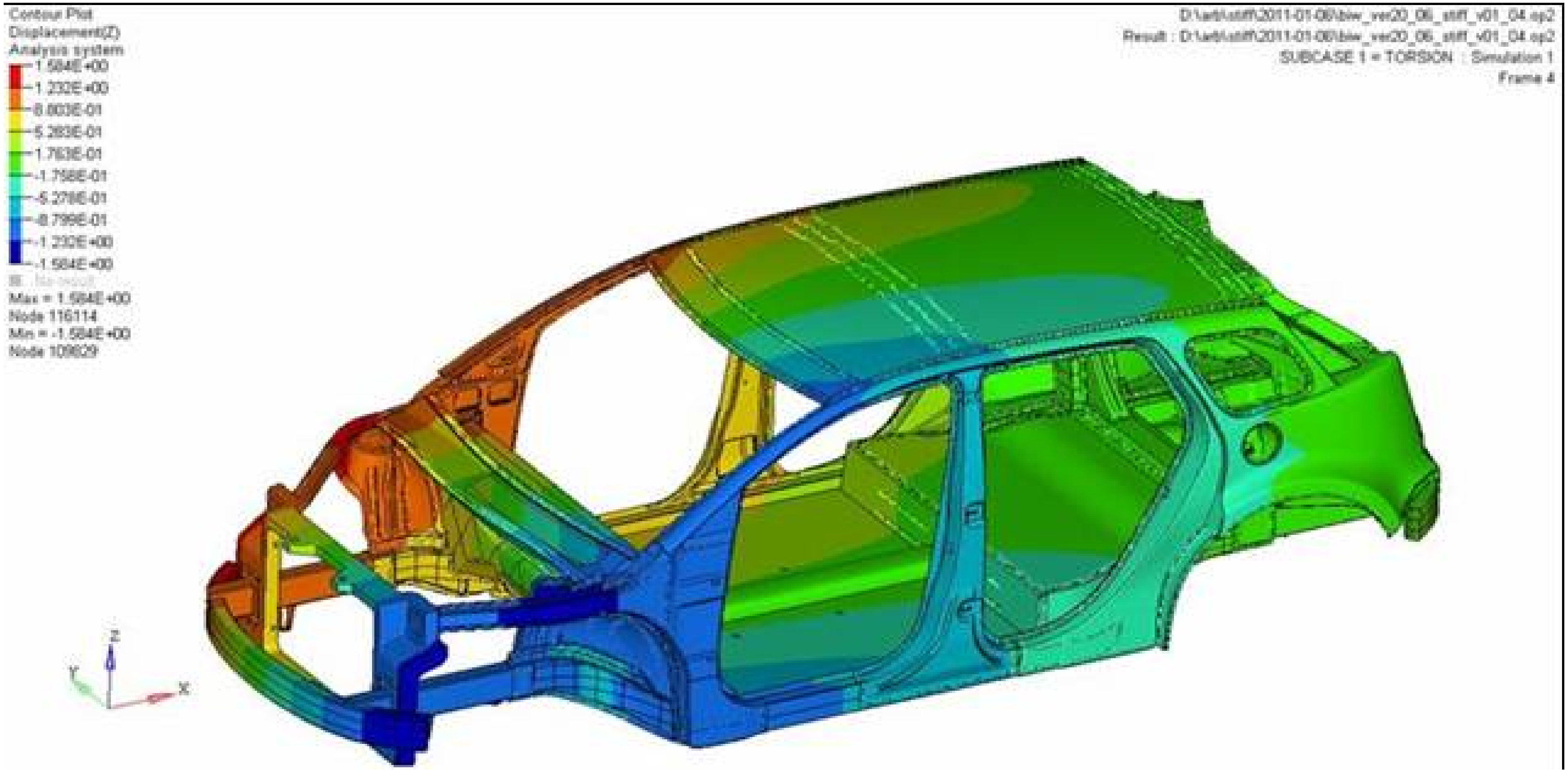
BIW Plant
<$53,000,000

Quality Driven Assembly Process

ENGINEERING

Lightweight BIW Structure/Crash Performance

Phase 2 BIW Torsional Stiffness Model



Torsional Stiffness Target: 27,000 Nm/deg (BMW X5)

Phase 2 BIW Torsional Stiffness (V26): 32,900 Nm/deg

Phase 2 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 @ 5th %ile Female)
- FMVSS214 20mph 75° Pole Impact (seat @ 50th %ile Male)

Rear Impact:

- FMVSS301 50mph 70% Offset Moving Deformable Barrier
- IIHS 6mph Centerline Bumper
- IIHS 3mph 15% Offset Bumper

Roof Crush:

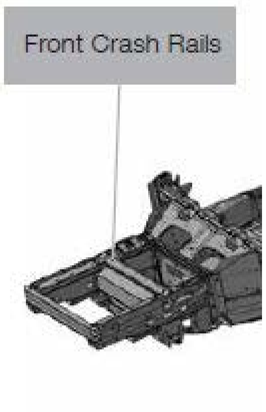
- FMVSS216 Quasi Static Crush

Other:

- FMVSS210 Quasi Static Seat Belt Pull
- FMVSS213 Child Restraints Systems

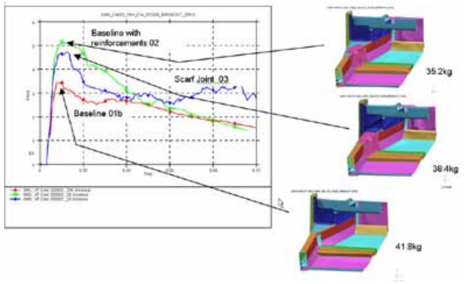
Light Weight Material Crash Performance – Evora Front Impact

- In the Evora front impact, crash energy is absorbed by crushing the aluminum longitudinal members.
- Bolt-on extruded aluminum crash structure/front subframe absorbs the energy
- The integrity of the passenger cell was shown to be extremely good with footwell deformation typically less than 10mm and minimal deformation of the door apertures such that both doors could be easily opened after the test



Ideal energy absorbing crush behavior

Lotus Evora Front Rail



Crash Test Joint Development Modeling

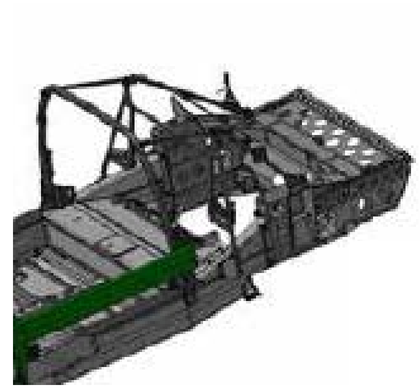
Federal legislative 35mph rigid barrier impact simulation and test

Light Weight Material Crash Performance – Evora Side Impact

- A high strength tubular steel seat belt anchorage frame, connected to the sill section, forms the B-pillar, and loops over the top of the occupants

- The door structure, which consists of a 7000 series high strength aluminum door beam, connects the tubular B-pillar to the door hinge on the extruded aluminum A-pillar.

- This structure together with the compliant design of the door trim and the wrap around form of the seat contribute to give the Evora excellent protection from a side impact.



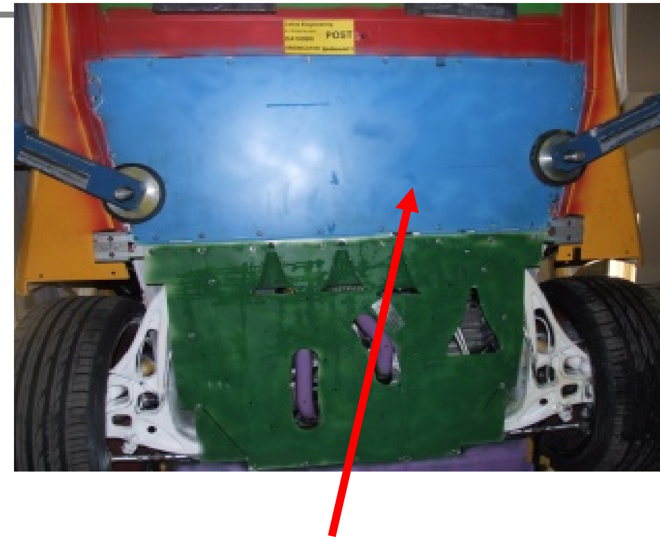
Federal 50mph Rear Impact – Evora Fuel Tank Integrity

Engine did not contact bulkhead

Door shut gaps maintained

Doors opened easily post test

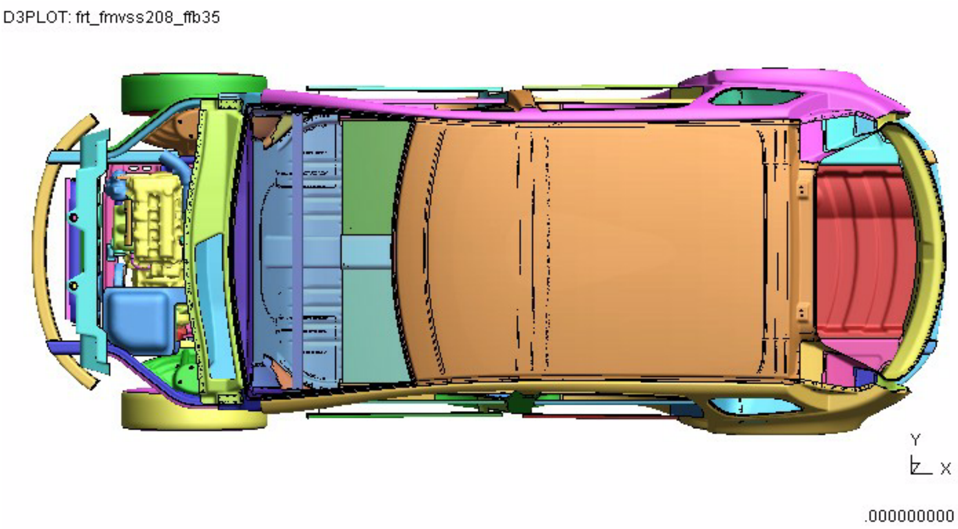
Sub-frame to bonded structure joint intact

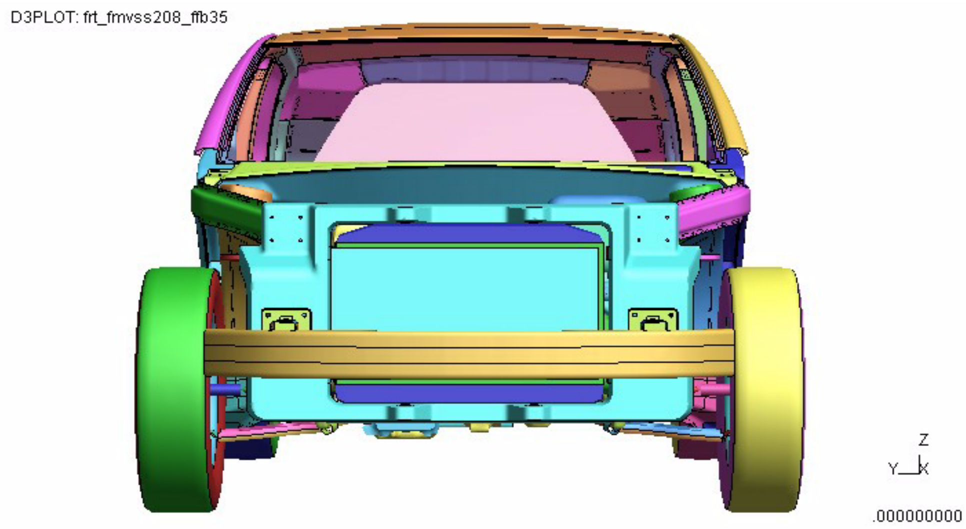


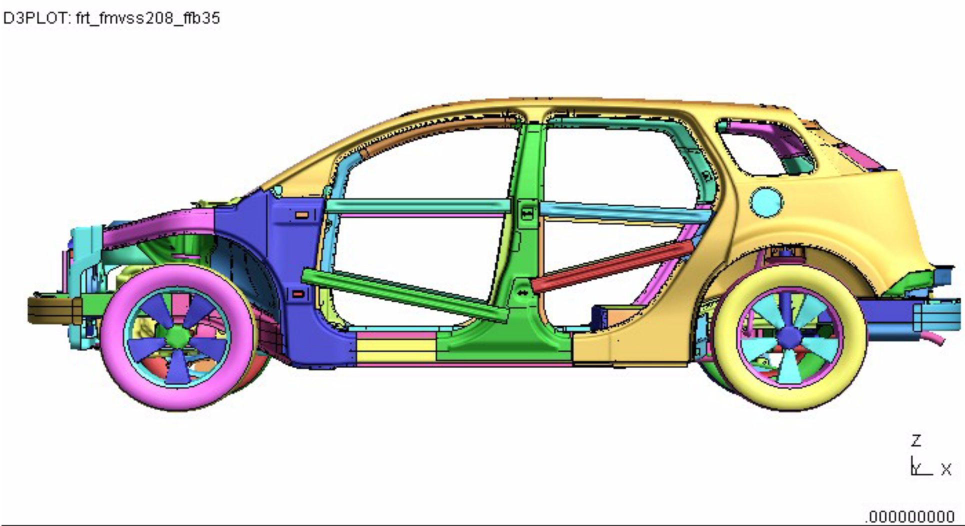
No deformation of tank bay area.

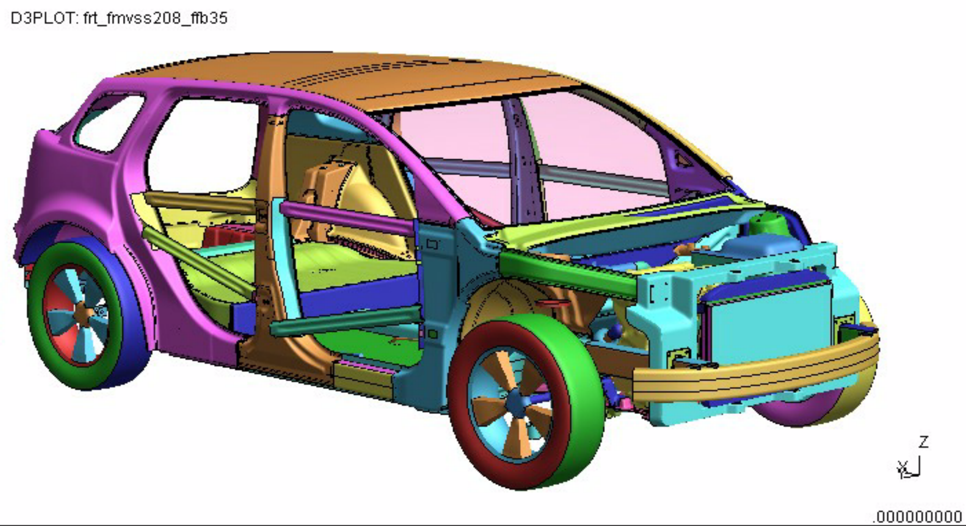
Post test rear bulkhead deformation

FMVSS 208 35mph Flat Frontal Barrier (Model V26)





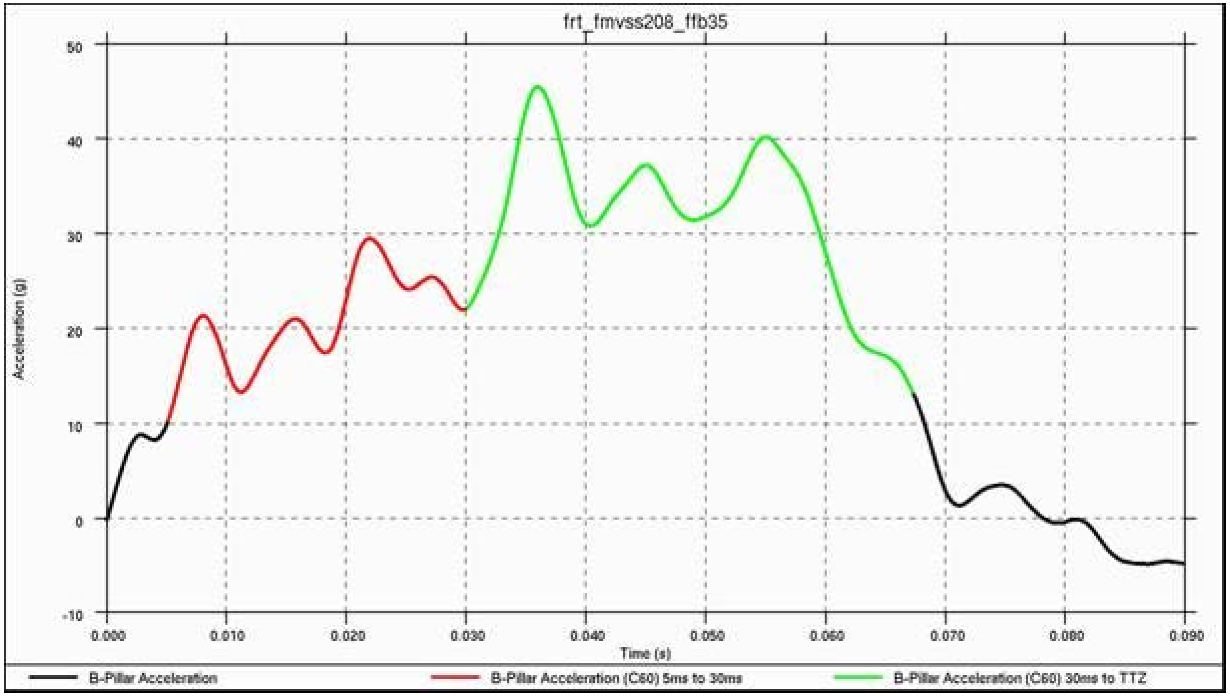




FMVSS 208 35mph Flat Frontal Barrier (Model V26) Results

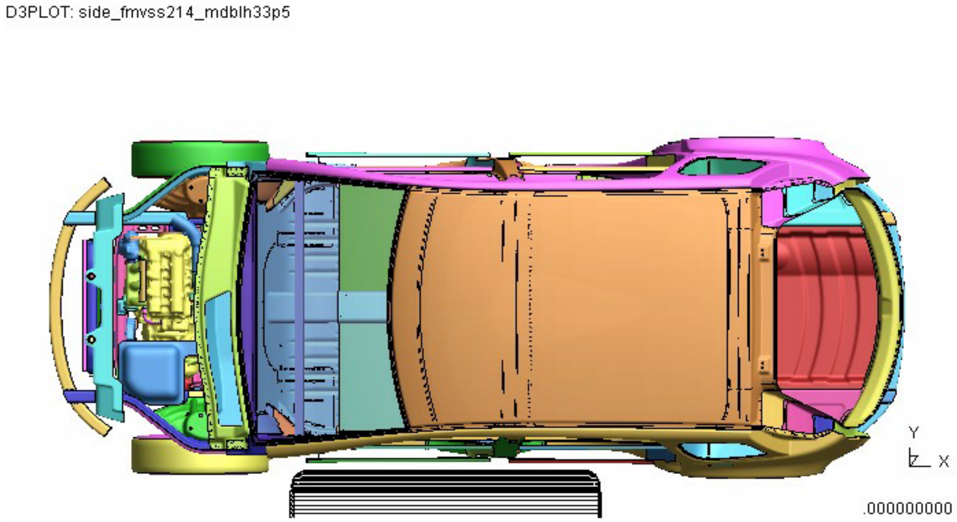
Front Impact:

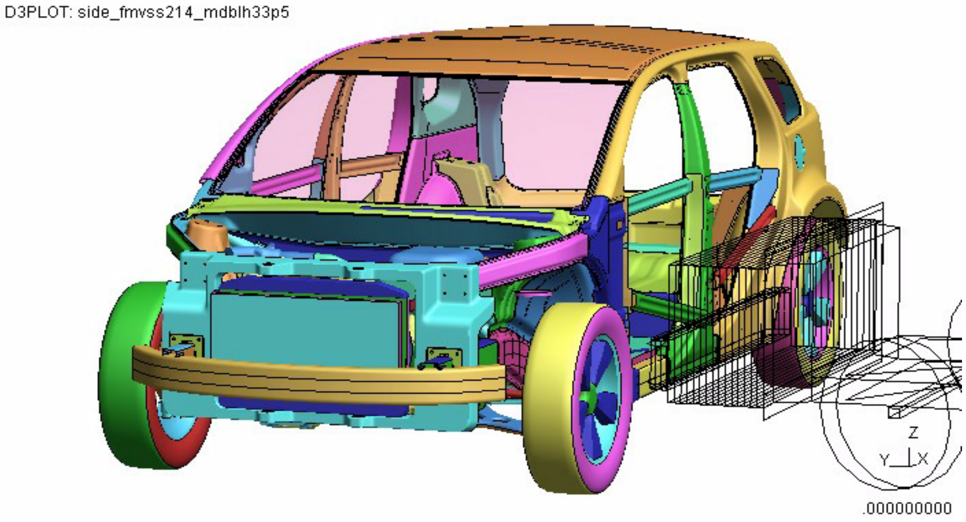
FMVSS208 35mph Flat Barrier 0°

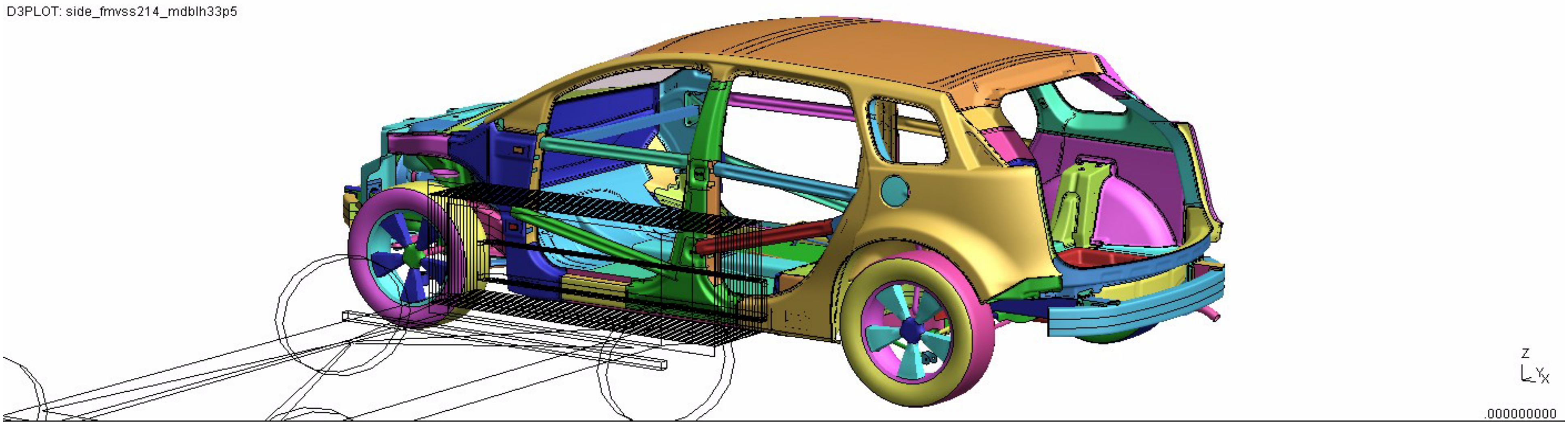


5 to 30ms Average Acceleration = 20.9g
30ms to TTZ (59.5ms) Average Acceleration = 34.7g
Average Accel. (total event) = 26.7g

FMVSS 214 33.5mph 27deg Moving Deformable Barrier (Model V26)

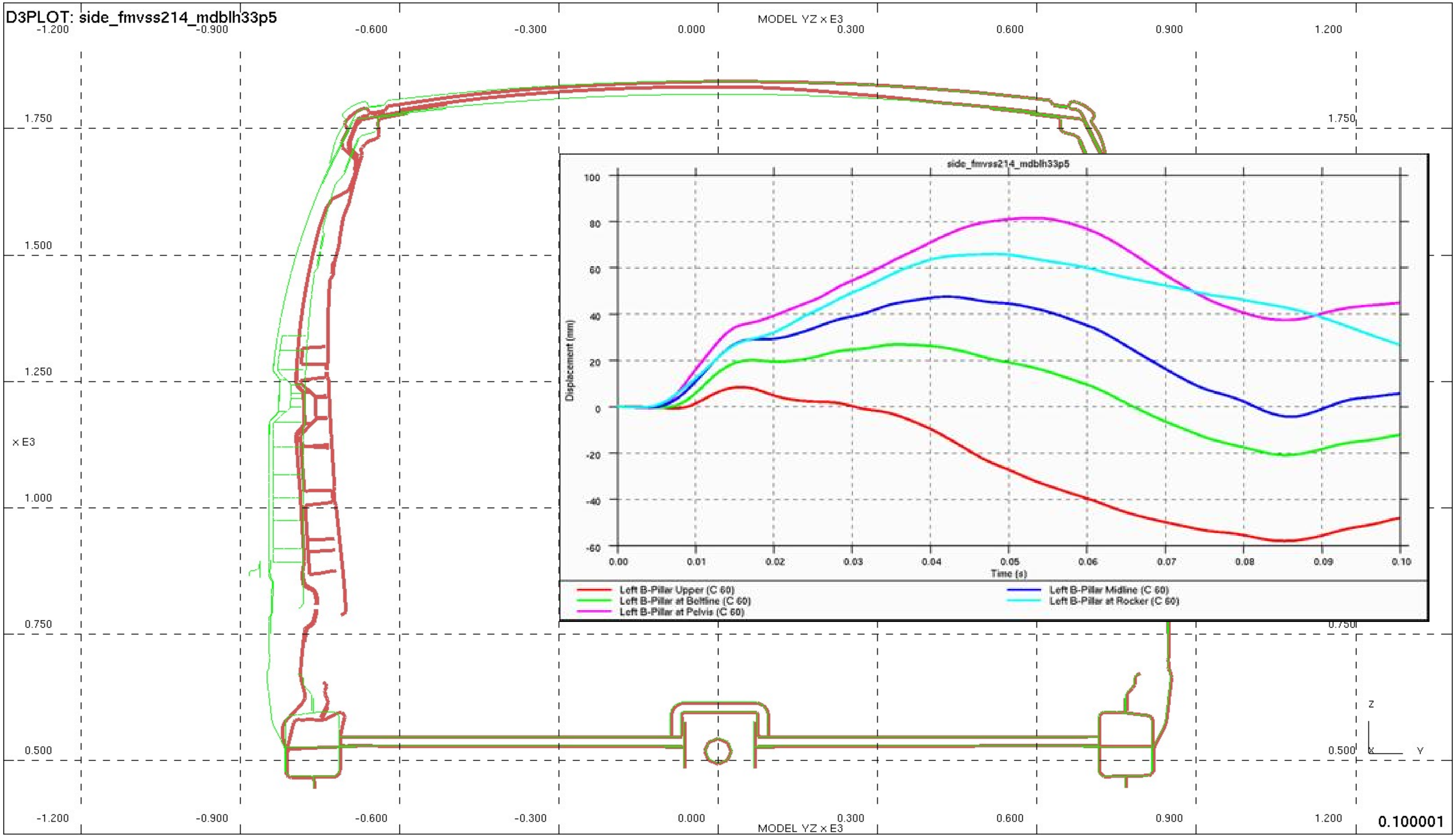




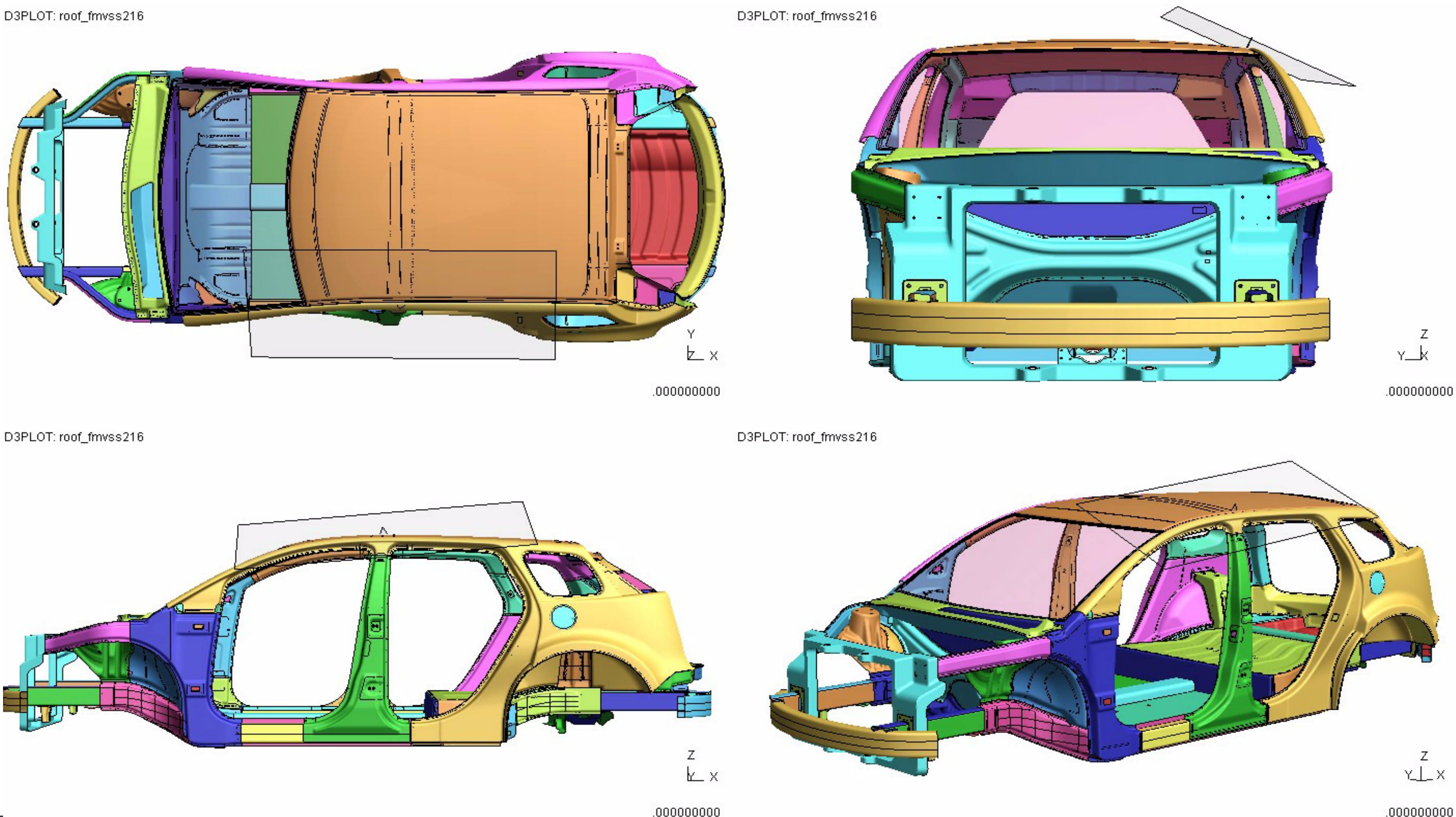


FMVSS 214 33.5mph 27deg Moving Deformable Barrier (Model V26)

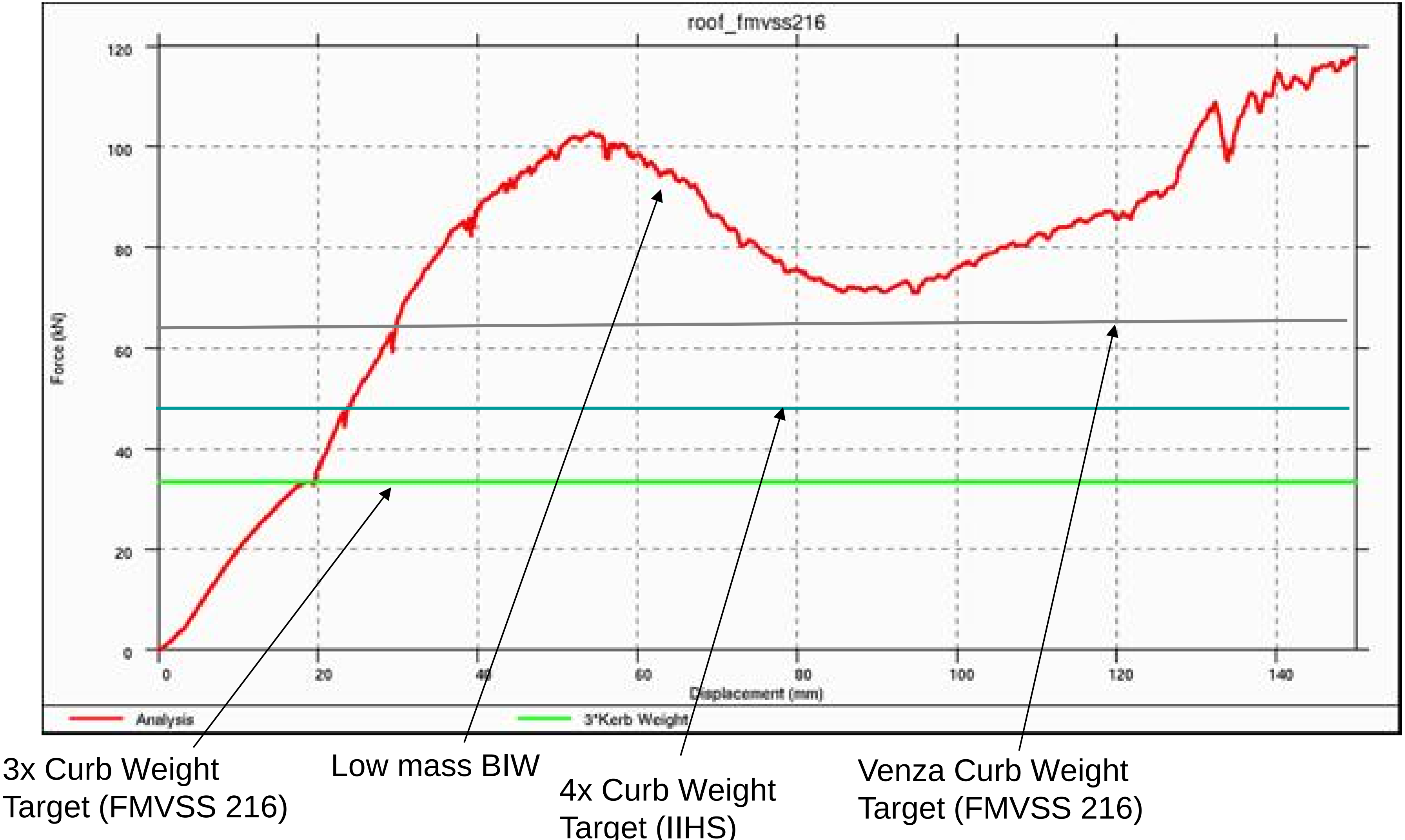
B Pillar Intrusion Levels



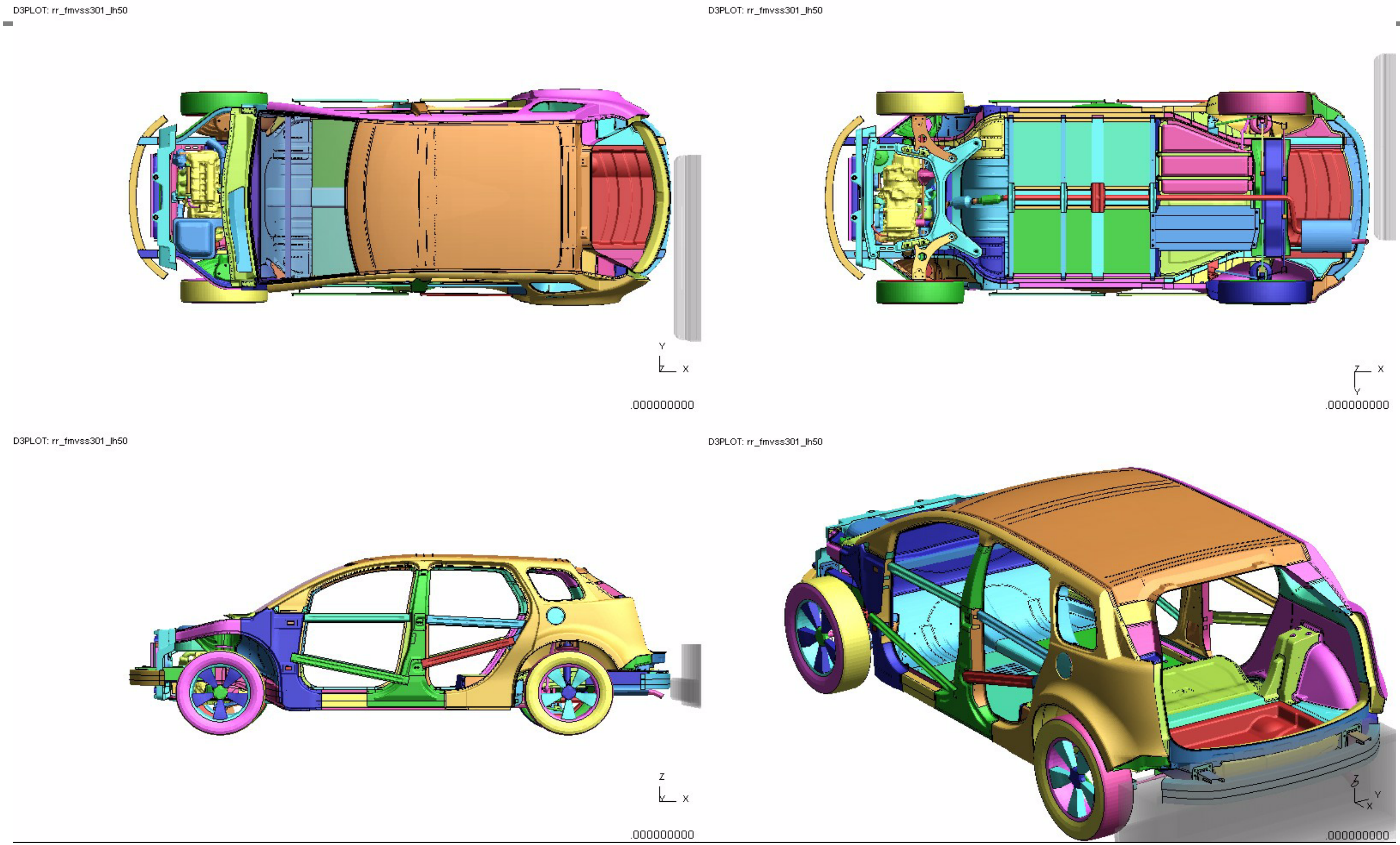
FMVSS 216 Quasi Static Roof Crush (Model V26)



FMVSS 216 Quasi Static Roof Crush (Model V26) Results

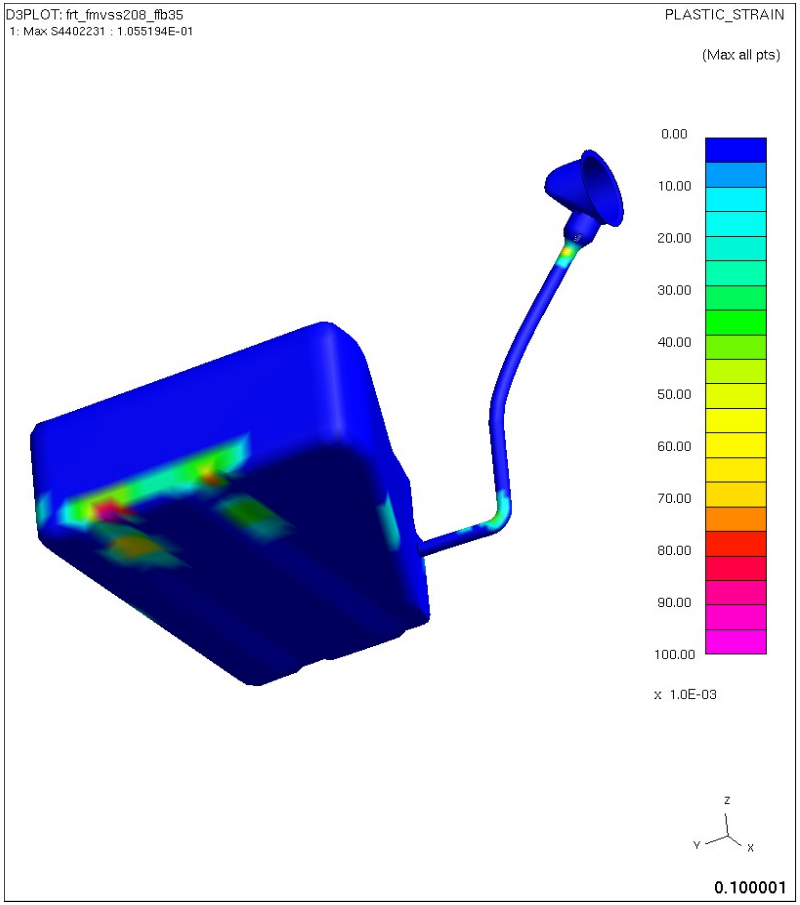


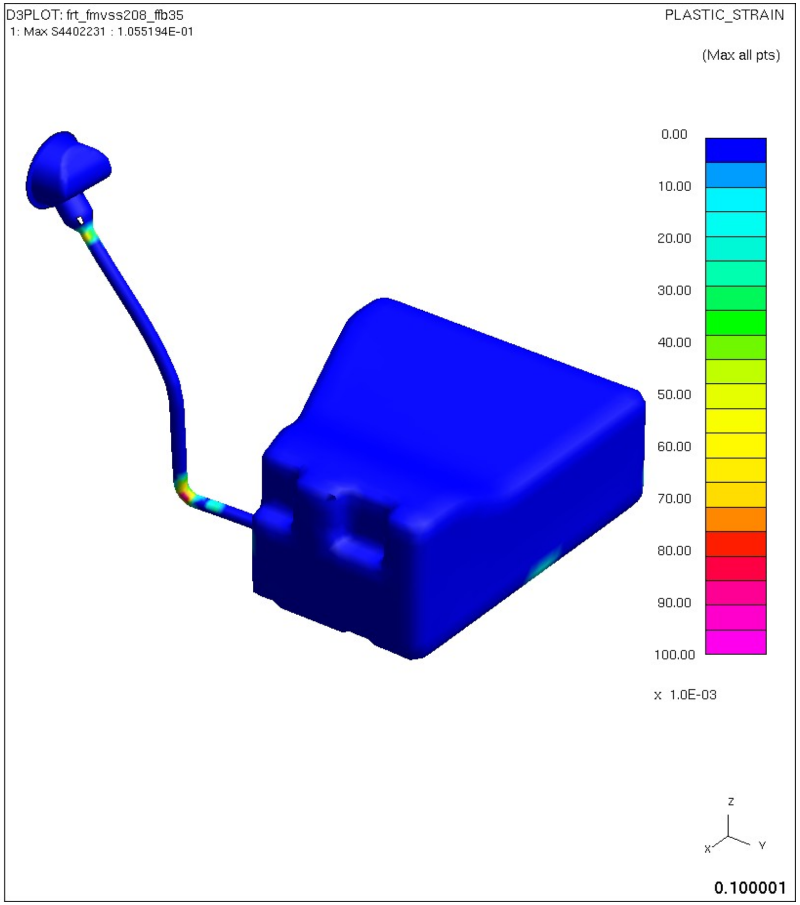
FMVSS 301 50mph 70% Overlap Moving Deformable Barrier (Model V26)



FMVSS 301 50mph 70% Overlap Moving Deformable Barrier (Model V26)

Fuel Tank Strain





The fuel tank plastic strains showed a maximum of around 10%, indicating that there should be no failure of the tank due to contact with any of the surrounding components.

Low Mass Vehicle Impact/Structural Summary

- Low mass BIW has the potential to meet world class stiffness targets

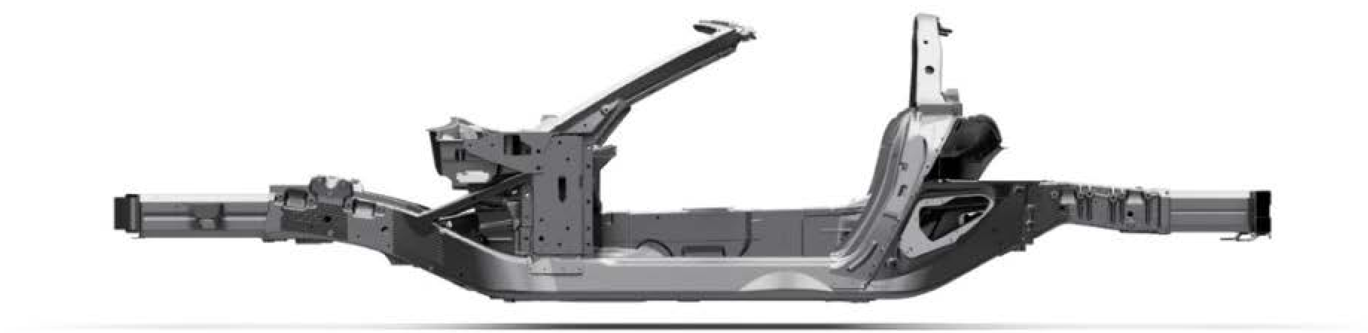
- Modeled impact performance indicates the lightweight body has the potential to meet crash requirements for FMVSS 208, 214, 216 and 301

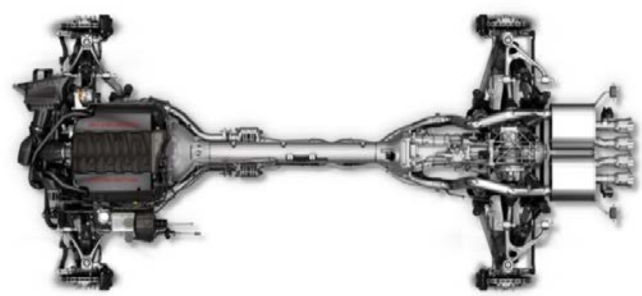
ENGINEERING

Noise, Vibration & Harshness (NVH) Management

GM Multi-Material Chassis – 2014 Chevrolet Corvette

- Unwanted noise is reduced and ride & handling is improved thanks to the structure's greater torsional rigidity.





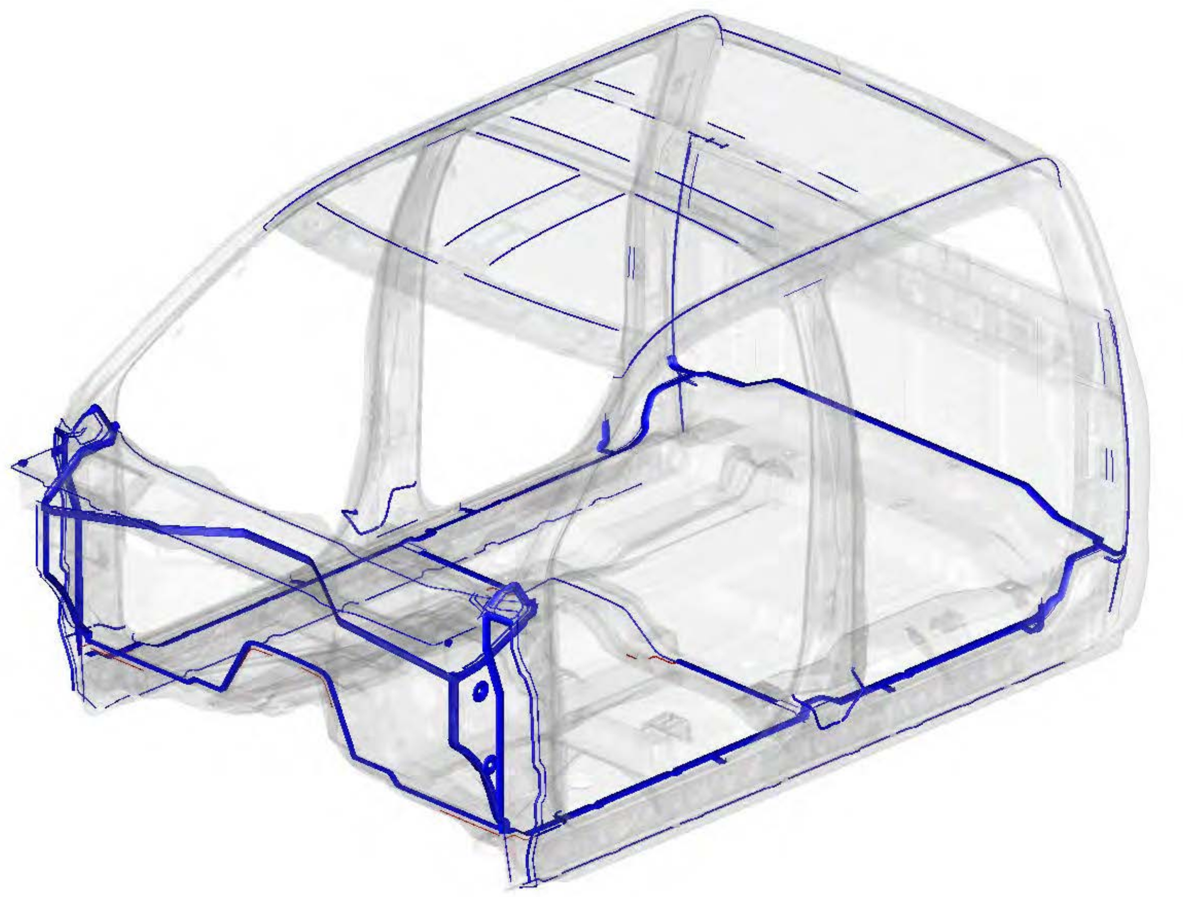
http://gmauthority.com/blog/2013/01/deep-dive-the-chassis-of-the-2014-corvette-stingray

GM Steel Cab – 2014 Chevrolet Silverado

Optimized body joints to enable robust sealing

103% increase in structural adhesive

44% reduction in airborne noise paths.



GM Steel BIW – Hyundai i40 (Sonata)

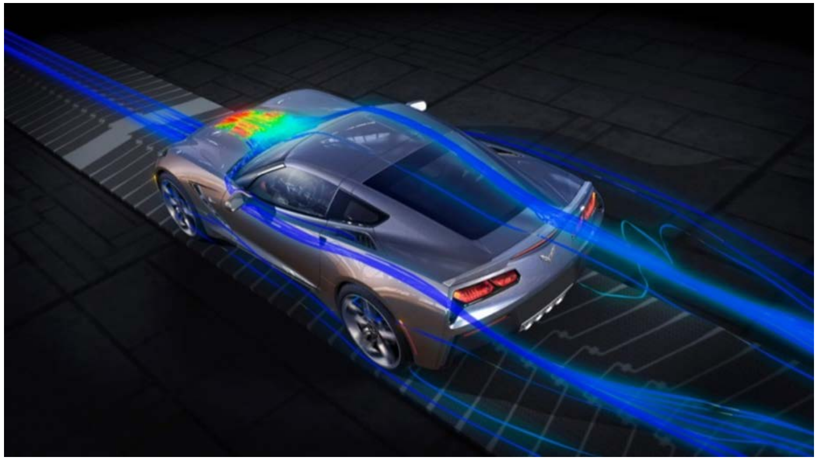
Underbody design is an important design consideration for reducing Cd

Improved airflow management has a positive affect on NVH

NVH Management Summary

Increased body/chassis stiffness, improved sealing by the use of structural adhesives and improved airflow management contribute to a reduction in NVH

Fundamental NVH management principles are applicable to both ferrous and non-ferrous structures



ENGINEERING

Cost Analysis

5/16/2013

Low Mass Body In White Mass and Cost Summary

Cost Status

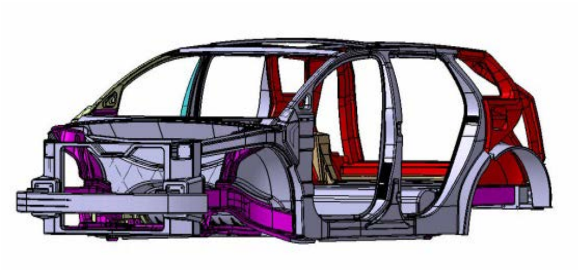
Piece Cost: +60% (+$723/unit)
Part tooling: -60% (-$233/unit)
Assembly: -37% (-$251/unit)

BIW Cost with New Plant Amortized over 3 years (60,000/yr): $3,469 (+118% vs. baseline)

Assembled BIW : $3, 098 (108% vs. baseline @ 60,000/yr)

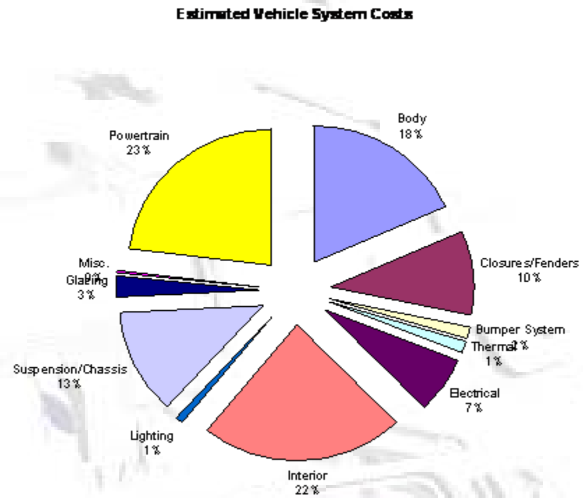
Initial Cost Factor: 118%
(Assembled BIW + BIW Plant)

Cost Factor: 108% (> 3 years)
(Assembled BIW)



Low Mass BIW

BIW Cost Offset Sensitivity Analysis



37% mass reduced BIW (Phase 2 study)

+118%/108% BIW cost factors (w/without BIW plant cost)

40% mass reduced non-BIW systems (Phase 1 study)

Cost parity for all non-body systems less powertrain

	Cost Factor	Cost Weighting Factor	Weighted Cost Factor
Complete body	118.00%	18.00%	21.24%
Non-body	100.00%	82.00%	82.00%
Totals		**100.00%**	**103.24%**
Cost Differential			**3.24%**

Includes BIW Assembly Plant Cost Amortization (3 years)

	Cost Factor	Cost Weighting Factor	Weighted Cost Factor
Complete body	108.00%	18.00%	19.44%
Non-body	100.00%	82.00%	82.00%
Totals		**100.00%**	**101.44%**
Cost Differential			**1.44%**

BIW Assembly Plant Cost Fully Amortized

Effect of Vehicle Weight Reduction on MSRP – C Class Vehicles

- The Hyundai Elantra, the 2012 North American Car of the Year, uses materials similar to those used in domestic competitors, e.g., steel body/closures

- The Hyundai Elantra is 15% lighter and 10% less expensive, on average, than comparable C class vehicles from Chrysler, Ford and GM (cars have automatic transmissions, four wheel disc brakes, alloy wheels, cloth interiors)

Vehicle	MSRP - USD	Weight - lbs.	Wt. Delta - lbs.	Int. Vol. - Ft^3 - EPA	Trunk - Ft^3 - EPA	MSRP Delta vs. Elantra
Hyundai Elantra GLS Auto	$18,760	2701	Base	96	15	Base
Chevrolet Cruze 2LT Auto[1]	$21,325	3102	401	95	15	$2,565
Dodge Dart SXT Automatic	$21,025	3242	541	97	13	2,265
Ford Focus SE Auto[2]	$19,490	2935	234	91	13	730
Averages (Chrysler, GM, Ford)	$20,613	3093	392	94	14	$1,853

Vehicle content adjusted to be comparable for all vehicles
Basic Warranty: Hyundai: 60 months/60,000 miles; others: 36 months, 36,000 miles
Powertrain Warranty: Hyundai: 120 months, 100k miles; Chevrolet, Dodge: 60 months, 100k miles; Ford: 60 months, 60K miles




ENGINEERING

1 Base price adjusted down by $1,000 to offset leather interior and heated seats
2 Base price adjusted up by $895 to add alloy wheels and four wheel disc brakes (SE Sport package)
All data from OEM websites

Cost per Pound Analysis – C Class Vehicles

- A lighter weight car using the same material classes as a heavier car with a similar material classes will have a higher “apparent” cost/lb. than a heavier car
- Applying the average $/lb. value for Chrysler, Ford and GM competitors to the Hyundai Elantra results in an additional 4% price advantage for the lighter Elantra which results in a 14% cost advantage

Vehicle	MSRP - USD	Weight - lbs.	$/lb.	New Elantra MSRP	Additional Margin @ Comp. $/lb.	MSRP Delta vs. Elantra @ Avg. Comp. $/lb.
Hyundai Elantra GLS Auto	$18,760	2701	$6.95	$18,007	$753	Base
Chevrolet Cruze 2LT Auto[1]	$21,325	3102	$6.87			$3,318
Dodge Dart SXT Automatic	$21,025	3242	$6.49			$3,018
Ford Focus SE Auto[2]	$19,490	2935	$6.64			$1,483
Average (Chrysler, GM, Ford)	$20,613	3093	$6.67			$2,606

Vehicle content adjusted to be comparable for all vehicles

1 Base price adjusted down by $1,000 to offset leather interior and heated seats
2 Base price adjusted up by $895 to add alloy wheels and four wheel disc brakes (SE Sport package)
All data from OEM websites

30% Lighter Future Dodge Dart Aero Manual Cost Analysis

- A 30% weight reduction on the Dodge Dart Aero Manual results in a 956 lb. savings
- A 30% weight reduction results in a 43% increase in allowable cost/lb. for the same MSRP
- Reducing the total vehicle weight by 30% allows an additional $2.59/lb. (approx. $1.73/lb. @ man. cost[1]) to be budgeted to offset the cost of lighter weight materials with no MSRP cost increase

	2013 Dodge Dart Aero Manual	30% Lighter Dart Aero Manual	Smart for 2 - Passion
Curb Weight - lbs.	3,186	2,230	1,808
MSRP	$19,295	$19,295	$14,890
$/lb.	$6.06	$8.65	$8.24
Relative $/lb	100%	143%	136%
Engine Size - L	1.4	0.7	1.0
Engine HP	160	112	70
Specific Output - HP/L	114	150	70
Lbs/HP	19.9	19.9	25.8
Tire Loading - lbs/mm of section width	3.89	2.59	2.74
Fuel Tank Capacity - gallons	15.8	13.1	8.7
Highway MPG	**41**	**50**	**38**
Highway Range - miles	648	648	331
EPA Combined MPG[2]	**32**	**39**	**33**

Vehicle data source: http://www.dodge.com/hostc/bmo/CUD201319/models.do

1 General RPE (Retail Price Equivalent) of 1.5 per peer reviewed study (Rogozhin et al, 2009)

2 Using relationship: 30% mass reduction = 21% fuel economy increase including powertrain adjustment

Summary Remarks

- There is potential for a light weight, multi-material body structure to meet or exceed the stiffness of an all steel body structure

- There is potential for a substantially mass reduced body structure to meet federal crash test requirements

- It is possible to manufacture a high volume, light weight vehicle at an MSRP competitive with significantly heavier competitors

- By using an holistic, total vehicle approach to mass reduction there is potential to utilize more expensive, lighter weight materials in volume production automobile and truck body structures while maintaining competitive vehicle pricing

Potential Next Steps

- Build and test the Phase 2 BIW
  - Expensive to tool
  - Limited testing for a single body structure
  - Creates an empirical database for industry usage

- Build and test the Phase 2 front structure
  - Reduced costs vs. total BIW
  - Can be done relatively quickly
    - Standalone structure
    - Attach to existing body structure
  - Creates an empirical database for industry usage

- Build and test the Phase 2 roof structure
  - Reduced costs vs. total BIW
  - Can be done relatively quickly
    - Standalone structure
    - Attach to existing body structure
  - Creates an empirical database for industry usage

Thank You

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