Multi-Material Lightweight Vehicles: Mach-II Design

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Project ID #
LM088

Acknowledgement

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Overview

Timeline

- Start Date: 2012-Feb
- End Date: 2015-Sep

Budget

Total Project Funding	$20,288,755
• DOE:	$10,000,000
• Vehma/Ford	$10,288,755
Budget Period 1 & 2 Funding	$15,897,536
Expenditure of Funds to date	
• DOE	$ 5,961,593
• Vehma	$ 3,372,609
• Ford	$ 2,773,175

Partners

- Vehma International
- Ford Motor Company

Barriers

Mach I – 22% vehicle reduction was obtained compared to the 37-40% reduction target. Further mass reduction was constrained by requirements of 2012 FMVSS regulations, donor vehicle architecture, and project scope and funding. Material availability for prototype build resulted in thickness/material substitutions from what was released for Mach I prototype build.

Mach II – Mature material information for impact and fatigue CAE analysis was limited for composite materials researched for development. While many components have be designed at a 50% weight reduction, the full vehicle curb weight target of 50% weight savings is proving elusive. While keeping the size and cargo space, much of the customer comfort , convenience and quietness attributes must be compromised to achieve the weight savings.

Project Objectives / Relevance

Project Objectives

1. Design and build Mach-I prototype vehicles, maintaining donor vehicle architectural space in an effort to mass reduction potential relative to a 2002 baseline vehicle. Mach I design shall a) utilized "commercially available" or "demonstrated" materials and manufacturing processes, b) include an OEM Partner to validate and test the vehicle, c) demonstrate integration of the light weight material vehicle system into an existing OEM body shop, avoiding niche assembly/coating processes. The Mach-I concept will be prototyped using an existing production donor vehicle with new MMLV components integrated to create full vehicles and subassemblies for testing. The prototype vehicles will be tested by the OEM to validate the design, material, and process used to manufacture the light weight Mach-I vehicle design is viable for OEM production. (FMVSS, NVH, Durability, and Corrosion)

   Mach-I Result: 23.5% Vehicle-level Mass Reduction was reported at 2013 AMR

2. Design a Mach-II concept vehicle, without architectural constraints, that will obtain a mass reduction of 50%, as compared to the 2002 Taurus baseline vehicle. Mach-II design will incorporate materials and manufacturing process that "show potential" but are not yet proven commercially viable for high volume production. Examples include magnesium wrought body components for both class A surfaces and inner panels and carbon fiber materials in structural and sheet components. The use of these materials pose a large challenge in joining and corrosion. The Mach-II design concept will identify the joint and material combinations that will need further research to mitigate corrosion and joint challenges.

   Mach-II Result: 2014 AMR Report

The Mach-I vehicle architecture is defined by the donor vehicle to facilitate full-vehicle integration required for vehicle testing and validation by the OEM. The Mach-I design includes a manufacturing component, which include modular assembly methods which illustrate the feasibility to build the Mach-I vehicle in an existing body shop.* The Mach-II design will be a "new design architecture" without architecture and integration constraint imposed by the donor vehicle and existing body shop BOP.

Relevance

- Reducing weight is an key enabler to reducing fuel consumption.
- Lightweight vehicle architecture design
  - Multi-material body in white (BIW) and closure architectures do not exist in today's market for high volume competitive cost multi-material components*.
  - High volume/low cost joining of dissimilar materials (Self Piercing Rivet, SPR) for BIW & Closures does not exist in today's market*.
  - High volume/low costs polycarbonate and chemically toughened glass does not exist in today's market*.

* Technology Gap

MMLV Program

Vehicle Lightweighting Project

- Baseline Vehicle:
  - 2013 Fusion
- Mach I Vehicle,
  - Existing commercially available materials & production processes
  - Establish a benchmark, without cost considerations
- Mach II Vehicle:
  - Advanced materials & processes
  - Identify technology gaps

Timeline

	Activity	Status	Completion
✓	Mach I Design & CAE	completed	Q1 2013
•	Mach I Prototype Build	in-process	Q3 2014
•	Mach I Validation Test	post prototype build	Q1 2015
✓	Mach II Design & CAE	in-process	Q2 2014

Mach II – Weight STATUS
as of 4 March 2014

U.S. DEPARTMENT OF ENERGY

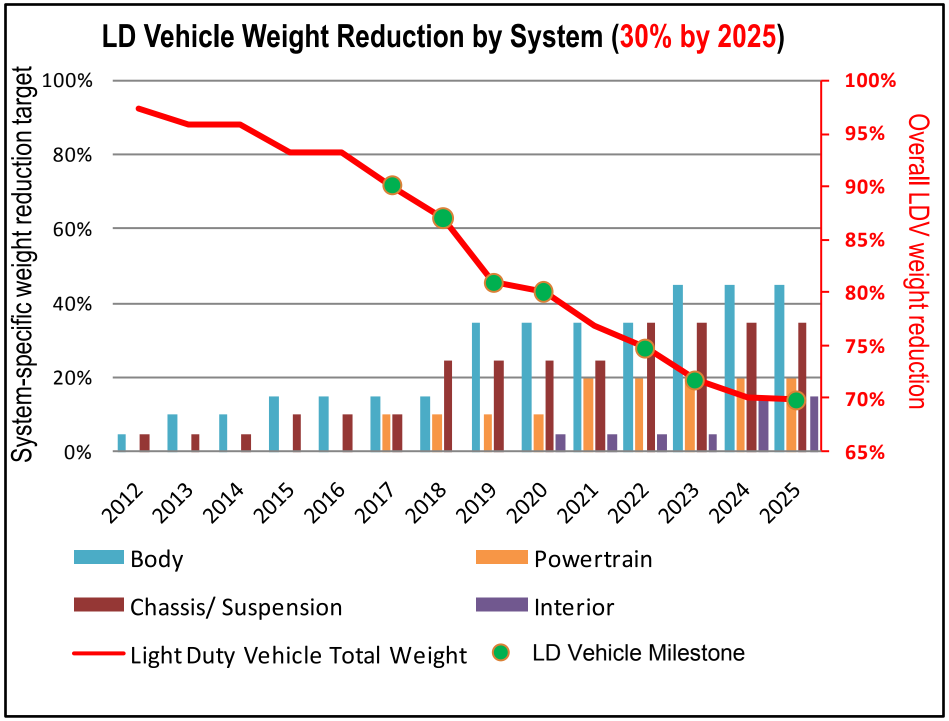
VEHMA

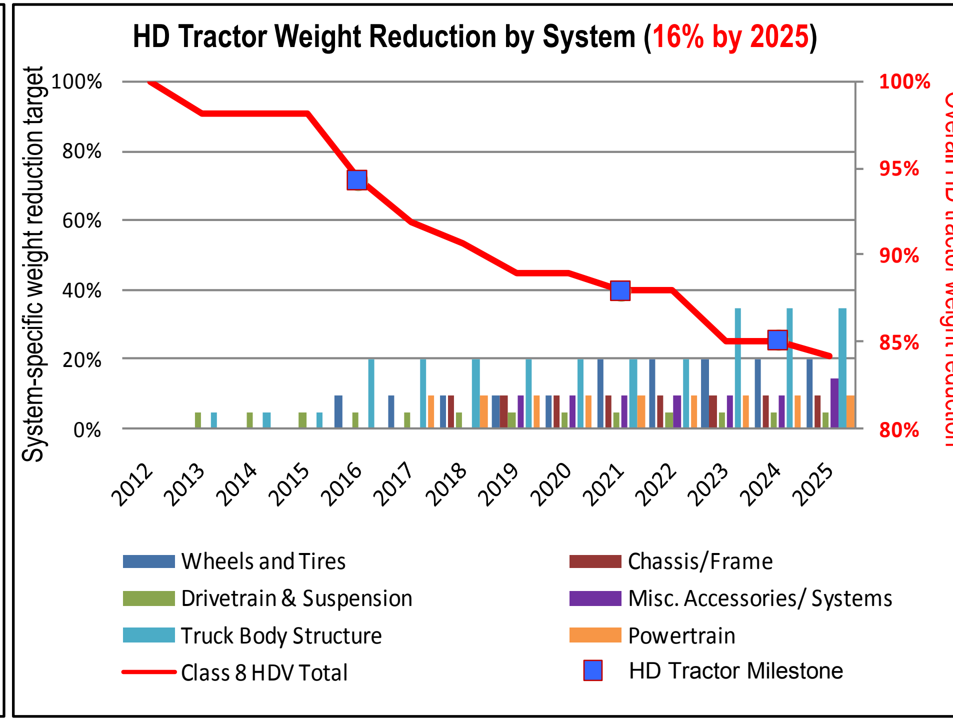
Ford

MMLV	Multi Material Lightweight Vehicle					
PMT Description	**2002 Taurus**	**2013 Fusion**	**MMLV Mach I DESIGN FINAL**	**MMLV Mach I Prototype Planned**	**MMLV Mach II Design Targets (PRELIM)**	**MMLV Mach II Design Status (4 Mar '14)**
Body Exterior and Closures (kg)	**574**	**594**	**456**	**489**	**237**	**355**
Body-in-White	n.a.	326	250	251		183
Closures-in-White	n.a.	98	69	88		56
Bumpers	n.a.	37	25	31		24
Glazings - Fixed and Movable	n.a.	37	25	25		21
Remainder - trim, mechanisms, paint, seals, etc.	n.a.	96	87	94		70
Body Interior and Climate Control (kg)	**180**	**206**	**161**	**191**	**137**	**116**
Seating	n.a.	70	42	61		34
Instrument Panel	n.a.	22	14	15		11
Climate Control	n.a.	27	25	27		11
Remainder - trim, restraints, console, etc	n.a.	88	80	88		60
Chassis (kg)	**352**	**350**	**252**	**269**	**144**	**212**
Frt & Rr Suspension	n.a.	96	81	85		66
Subframes	n.a.	57	30	44		19
Wheels & Tires	n.a.	103	64	58		57
Brakes	n.a.	61	49	50		43
Remainder - steering, jack, etc.	n.a.	33	29	32		27
Powertrain (kg)	**350**	**340**	**267**	**299**	**190**	**181**
Engine (dressed)	n.a.	101	71	101		64
Transmission and Driveline	n.a.	106	92	54		38
Remainder - fuel, cooling, mounts, etc.	n.a.	133	104	143		79
Electrical (kg)	**67**	**69**	**59**	**66**	**53**	**47**
Wiring	n.a.	28	25	28		23
Battery	n.a.	14	8	10		8
Remainder - alternator, starter, speakers, etc.	n.a.	27	26	27		17
Total Vehicle (kg)	**1523**	**1559**	**1195**	**1313**	**761**	**911**
Weight save w.r.t. 2013 Fusion			**23.3%**	**15.7%**	**51.2%**	
Weight save w.r.t. 2002 Taurus			**21.5%**	**13.8%**	**50.0%**	

Mach II Design
still 150 kg too heavy, will consider further non-safety attribute degradation, and removing more customer features

Goals for Materials Lightweighting Portfolio (technologically feasible)





2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Develop pathway to 10% weight reduction in HDV Suspension	Validate material technology enabling 10% weight reduction in LDV powertrain.	Validate material technology enabling 25% weight reduction in LDV chassis / suspension	Validate material technology enabling 35% weight reduction in a LDV body	Validate material technology supporting 5% weight reduction in a LDV interior	Develop materials based wheel and tire system to resulting in a 20% weight reduction relative to dual wheel baseline	Validate material technology enabling 35% weight reduction in LDV chassis / suspension	Validate material technology enabling 45% weight reduction in a LDV body	Validate materials enabling 20% weight reduction and 30% improvement in HD Engine efficiency	Demonstrate 30% weight reduction in a LDV at less than target

MMLV Mach-II vs DOE Roadmap

Mach-II design includes materials and technologies which are “early stage”.

Vehicle Subsystem	MMLV Mach II Vehicle							DOE Roadmap
	2002 Taurus	2013 Fusion	MMLV Mach I DESIGN	MMLV Mach II DESIGN as of Mar'14	MMLV Mach II (%) Curb	MMLV Mach II (%) save w.r.t. Fusion	Tech Validation Date	
Body Exterior and Closures (kg)	**574**	**594**	**456**	**355**	**39%**	**40%**		**2019 Goal 35%** **2023 Goal 45%**
Body-in-White	n.a.	326	250					
Closures-in-White	n.a.	98	69				**tbd**	
Bumpers	n.a.	37	25					
Glazings - Fixed and Movable	n.a.	37	25					
Remainder - trim, mech, paint, seals, etc.	n.a.	96	87					
Powertrain (kg)	**350**	**340**	**267**	**181**	**20%**	**47%**		**2017 Goal 10%**
Engine (dressed)	n.a.	101	71				**tbd**	
Transmission and Driveline	n.a.	106	92					
Remainder - fuel, cooling, mounts, etc.	n.a.	133	104					
Chassis (kg)	**352**	**350**	**252**	**212**	**23%**	**39%**		**2018 Goal 25%** **2022 Goal 35%**
Frt & Rr Suspension	n.a.	96	81					
Subframes	n.a.	57	30				**tbd**	
Wheels & Tires	n.a.	103	64					**2012 Goal 20%**
Brakes	n.a.	61	49					
Remainder - steering, jack, etc.	n.a.	33	29					
Body Interior and Climate (kg)	**180**	**206**	**161**	**116**	**13%**	**44%**		**2020 Goal 5%**
Seating	n.a.	70	42					
Instrument Panel	n.a.	22	14				**tbd**	
Climate Control	n.a.	27	25					
Remainder - trim, restraints, console, etc	n.a.	88	80					
Electrical (kg)	**67**	**69**	**59**	**47**	**5%**	**32%**		
Wiring	n.a.	28	25				**tbd**	
Battery	n.a.	14	8					
Remainder - alt, starter, speakers, etc.	n.a.	27	26					
Total Vehicle (kg)	**1523**	**1559**	**1195**	**911**	**100%**	**41.6%**		**2025 Goal 30%**

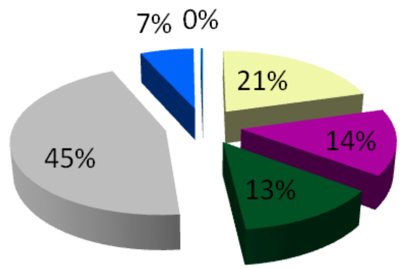
Mach-II design is still under development

Mach II Design

BIW Status (3-14-14)

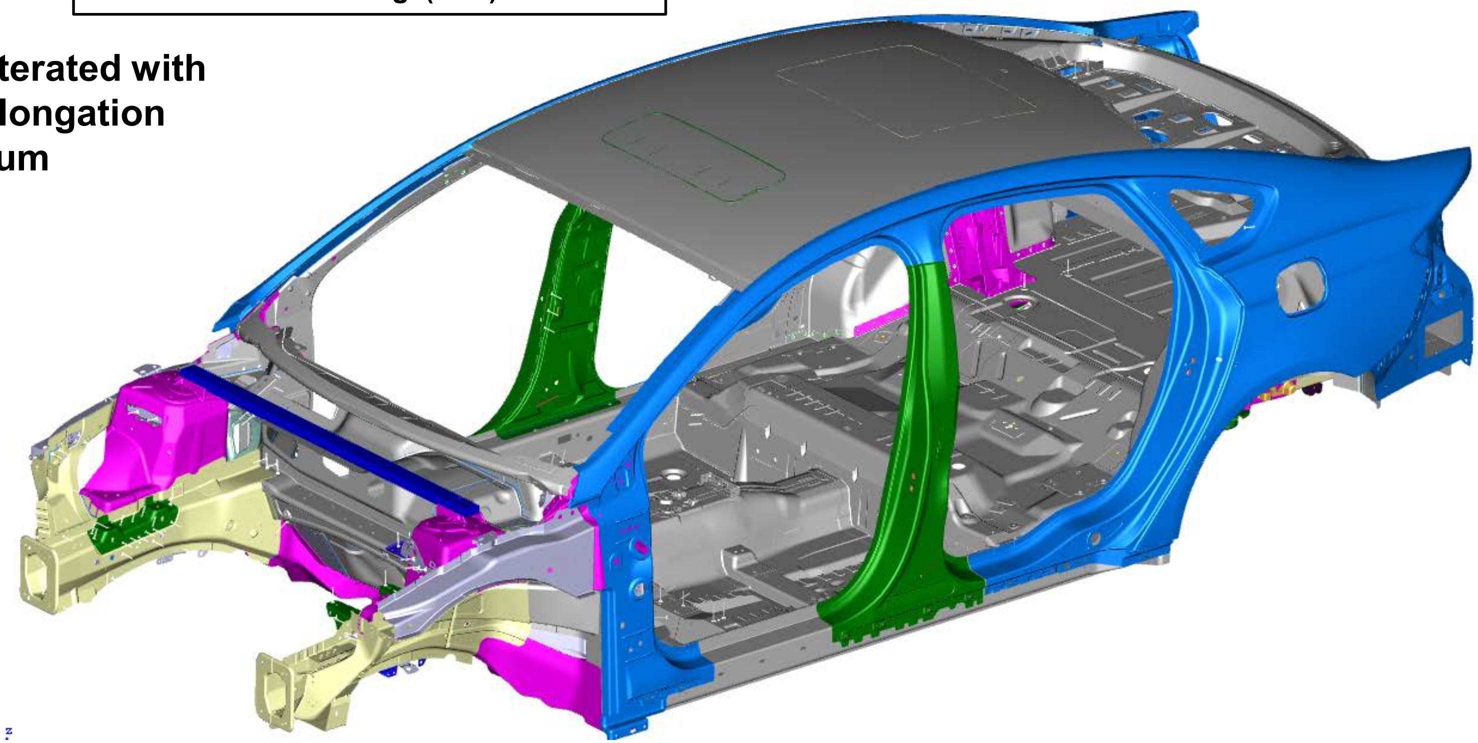
- Aluminum casting
- Steel
- Composite
- Aluminum sheet
- Magnesium
- Aluminum extrusion

MMLV MACH II MATERIAL DISTRIBUTION



BIW
Reduced 145 kg (45%)

Front Rails will be iterated with 600 MPa UTS, 8% elongation C12Z Alcoa Aluminum



Methodology for Carbon Fiber BIW Mach-II Design

BIW Review

- Visual inspection of the model
- Convert where appropriate metallic parts to carbon parts
- Sensitivity of panels to the torsion stiffness
- Sensitivity of section size to torsional stiffness
- Topology optimisation of carbon components
- Practical / manufacturable lay-up development
- Modal analysis and development
- Local Point stiffness

Joint design

- The majority of the joints are a good compromise of strength and stiffness and manufacturing ease. A few joints have been identified as worth investigating for improvement.

Section sizes

- The low density of carbon composite demands that all things being equal, a panel in composite will be thicker, with advantages in panel stability and resistance to buckling. This also allows that we can use larger section sizes, without buckling concerns, improving structural efficiency.

Thickness Variability

- This attribute of a material and production process will be the most important in achieving a lightweight cost effective design.

Material Alignment

- In order to get the maximum benefit from composite use, critical panels will need to be manufactured with a degree of fibre orientation. The effect of structural efficiency is considerable.

Changes to BIW Design

Changes Incorporated into BIW CAE Model

- Deeper sills (30mm)
- Wider B-Pillar (30mm)
- Addition of rear seat back
- Improved attachment at lower B-Pillar / Sill joint
- Improved attachment at lower C-Pillar / Sill joint
- Improved connection of firewall cross member
- Webs added to cast A-pillar lower joint
- More panels converted to carbon composite
- Side impact members
  - Rocker inner webs
  - Floor closer
  - Seat support panel

Material Substitutions

- Carbon panels will need to achieve an equivalent isotropic E property of at least 40,000N/mm2 to be weight efficient over metals. At this value and above as many panels as possible should be made in carbon composite. Just about achievable with a random long fibre architecture.
- Fibre alignment and thickness variation in the manufacturing process leads to greater weight savings
- For panels sized for strength Carbon will provide even greater benefits

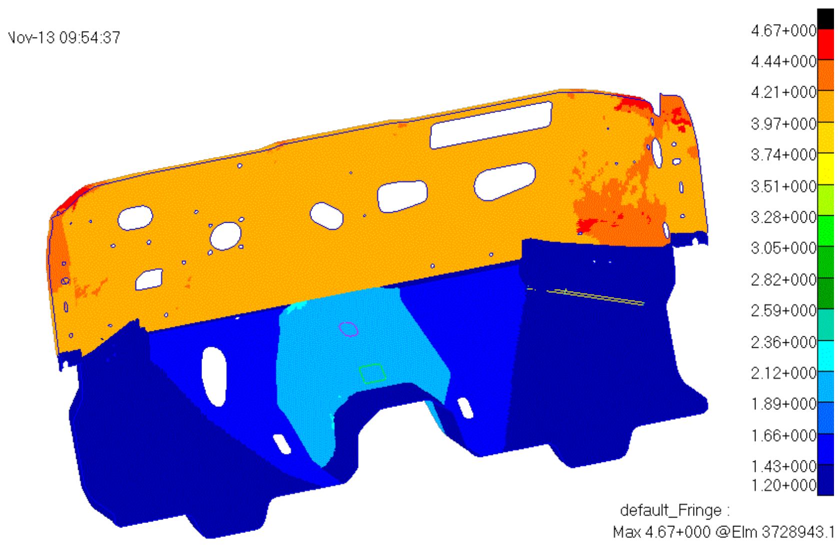
Carbon Fiber Materials

Cost, Speed and Efficiency all influence the selection of the candidate material architectures;

- **Non-Crimp Fabric (NCF) resin infused -** High performance material, highly directional fibre placement and material thickness variation, good formability, good resin flow.
- **Chopped Fibre – Infused/Wet Pressed – P4 or similar -** Low performing material, good thickness variation, low scrap rate.
- **Carbon SMC with/without local UD reinforcement -** Low performing material, complex shapes, incorporation of inserts and stiffening ribs, good thickness variation
- **Braided Infused -** High performing material, less formable than NCF, high impact tolerance

Other Material Considerations

- **Handling Corrosion**
  - Glass Inter Layer
  - Metal Treatments
- **Adhesive Connections**
  - Stiffness vs Damage Tolerance
- **Specific Energy Absorption (SEA)**
  - CFRP x5 better than Steel or Aluminium
  - Geometric Effects



Design Analysis

Thickness Optimization

- Nastran's Topology optimisation routine was used
- Applied to all composite parts
- Used to determine material distribution for each panel
- This information was then used as the foundations for the material lay-up development process.

Lay-up Foundations from Thickness Optimization

- All carbon composite parts except sills were optimised between 1.25mm and 4.0mm
- Sills were optimised between 1.25mm and 5.0mm
- A torsion of 1,714kN/rad was recorded for a mass of 208kg.
- A realistic target for a manufacturable set of panels would be between the above value and the baseline value with rear seat back of 940kN/rad

Lay-up of Structure Panels

- Incorporate all geometric modifications into one model
- Using optimisation results, create a Laminate architecture that best represents the required thickness variation and fibre direction, within the manufacturing methods suggested during phase one.
- Locally reinforce mounting points to achieve required targets

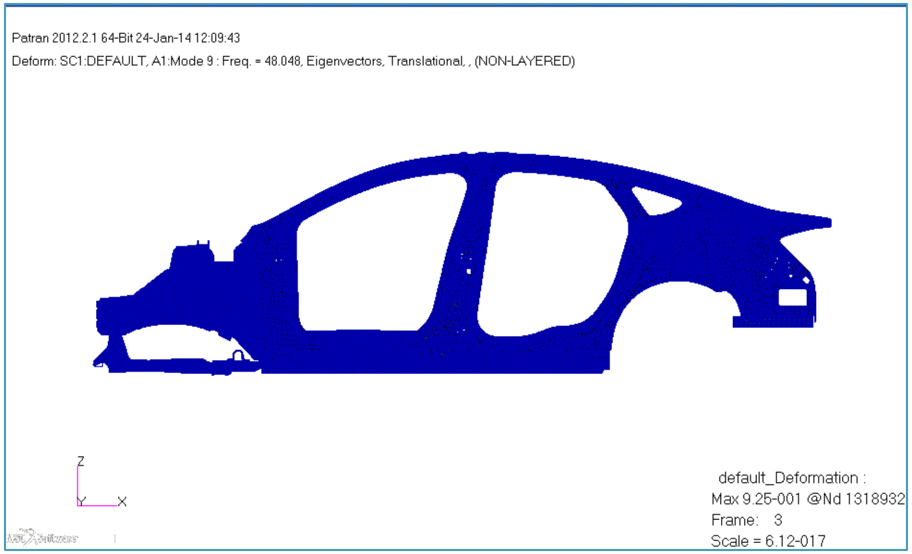
Local Mount Stiffness

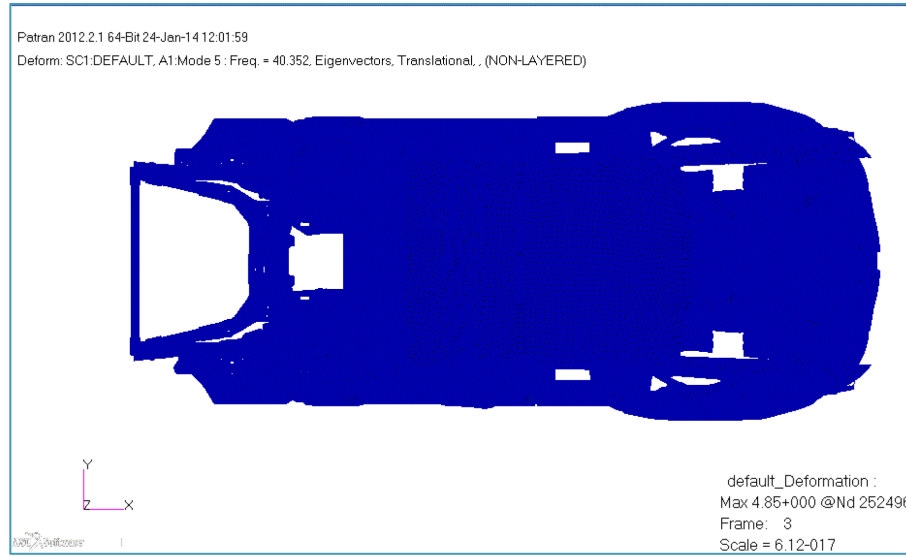
iteration 16e		load	stiffnes target	displacement	stiffness analysis	achieved
front subframe rear mount	X	100	28400	0.0041015	24381.32	0.858497
node 1842285	Y	100	13900	0.0039482	25328	1.822158
	Z	100	7000	0.0086734	11529.5	1.647072
front shock mount RHS	X	100	9400	0.016066	6224.325	0.662162
node 10	Y	100	12100	0.0095286	10494.72	0.867332
	Z	100	9800	0.0065939	15165.53	1.547503
rear subframe front mount	X	100	12000	0.0092505	10810.23	0.900852
node 20 RHS	Y	100	8000	0.015589	6414.78	0.801847
	Z	100	4700	0.011696	8549.932	1.819134
rear subframe rear mount	X	100	12000	0.0094812	10547.19	0.878932
node 22	Y	100	8000	0.0074459	13430.21	1.678776
	Z	100	4500	0.013744	7275.902	1.616867
rear shock mount	X	100	12000	0.0093344	10713.06	0.892755
node 15	Y	100	4800	0.012694	7877.738	1.641195
	Z	100	4800	0.012616	7926.443	1.651342

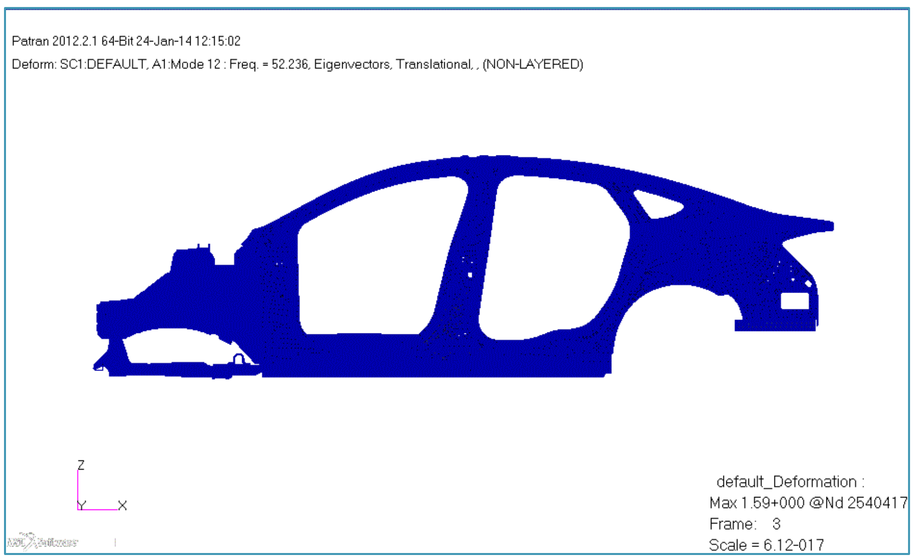
(blue)	greater than 1.0
(green)	between 0.9 and 1.0
(yellow)	between 0.8 and 0.9
(red)	less than 0.8

Stiffness will always be difficult to meet with lower weight vehicles due to the materials used. The higher strength, but lower modulus properties of weight reduction materials will be lower in stiffness unless larger sections can be realized in the design. Designing to keep similar vehicle packaging requirements of the baseline vehicle caused difficulties in using lower weight materials and meeting stiffness requirements.

Mach II BIW Modes



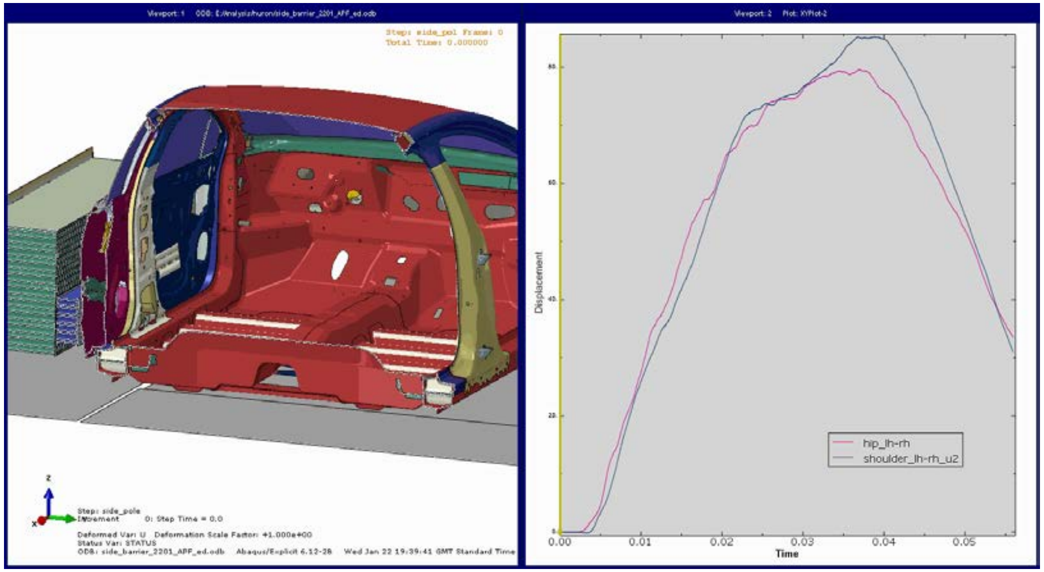


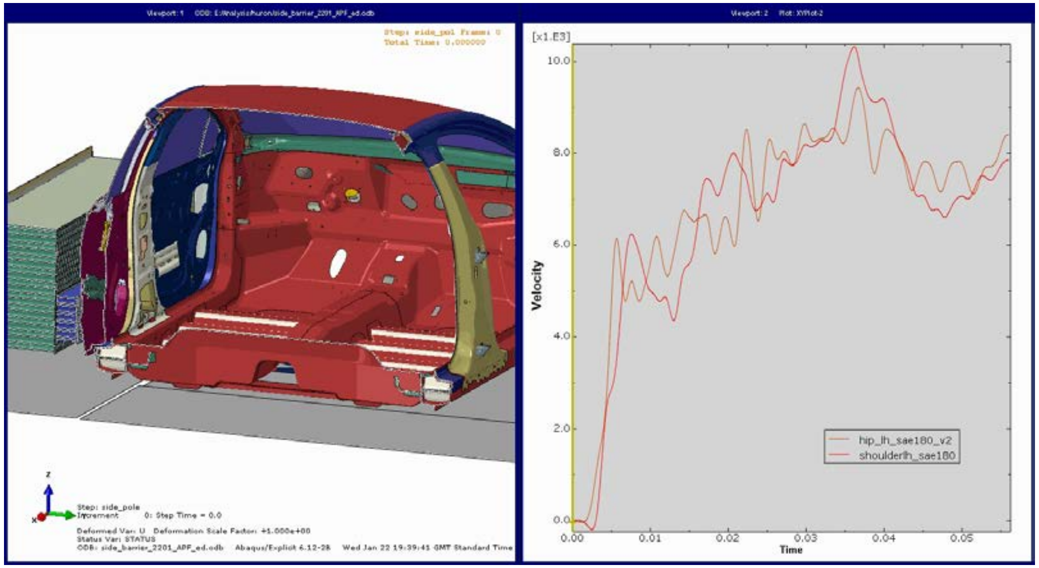


MODE	TARGET (Hz)	MACH II (Hz)
FIRST BENDING	45.1	48
FIRST LATERAL	37.5	40.4
FIRST TORSION	42.9	52.2

Deformable Side Impact Barrier

FMVSS 214





Points tracked on B-Pillar

Intrusion into Vehicle Compartment Acceptable

Analysis & Conclusions

- Rationalised “complete” Body in White model created.
- Laminates from Phase I, incorporating features from Side-Pole impact on Sub-Model, were applied to the BIW model.
- After several rounds of modifications the model still exhibited significant failures in the side barrier impact.
- Final Configuration achieves relatively low level of intrusion and avoids large scale failures.

Roof Crush Simulation

FMVSS 216A

Testing Assumptions

- Platten push on LHS first followed by RHS.
- First push required to exceed 3x GVW (approx. 30kN). 1st platten displacement pre-determined, judged to safely exceed requirement.
- Platten displacement must be <127mm.

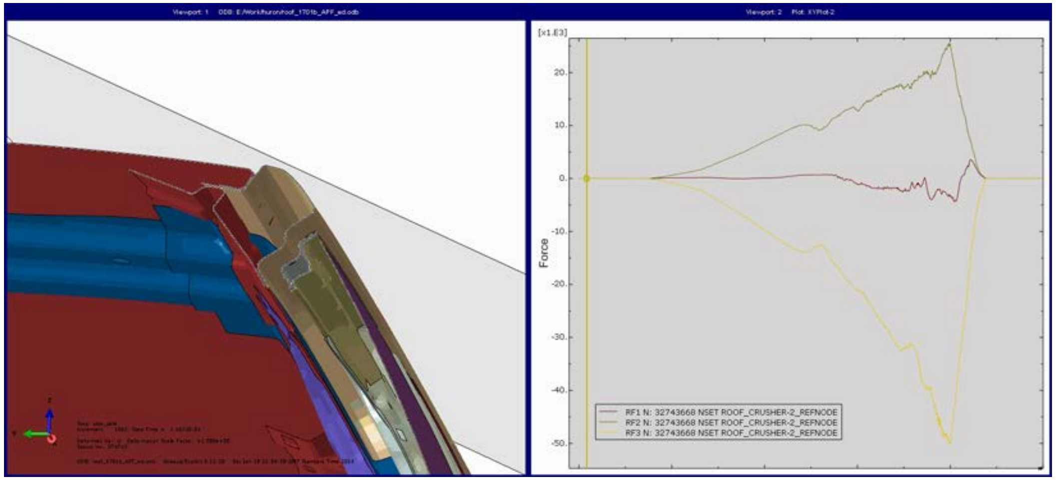
Analysis & Conclusions

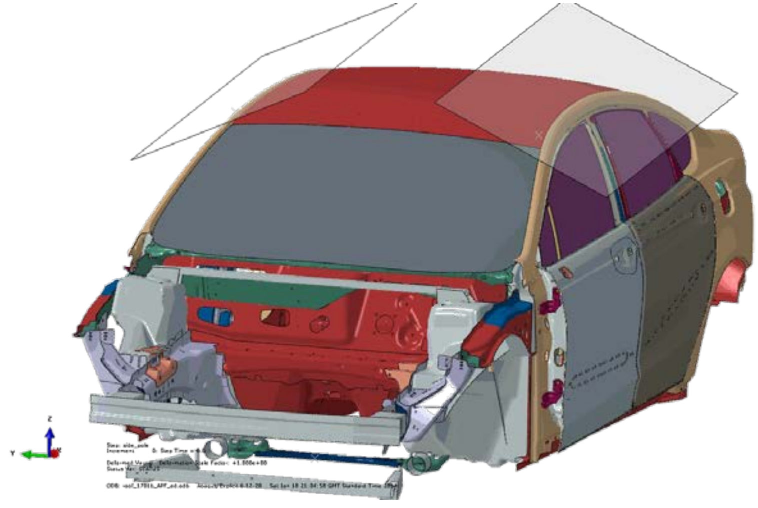
- LHS force easily exceeds requirement without significant composite damage.
- Outer skin flattens and minimal dis-bonding of roof panel edge.
- RHS force closely following LHS.
- Failure in Centre Roof bow and Cant-Rail at around 60kN load.
- RHS force closely following LHS.
    - i.e. effect of 1st side push damage is minimal.
- Platten deflection does not approach 127mm limit.
    - Max for 1st side =50mm
    - Second side deflection =67mm at 70kN load.

Roof Crush Simulation

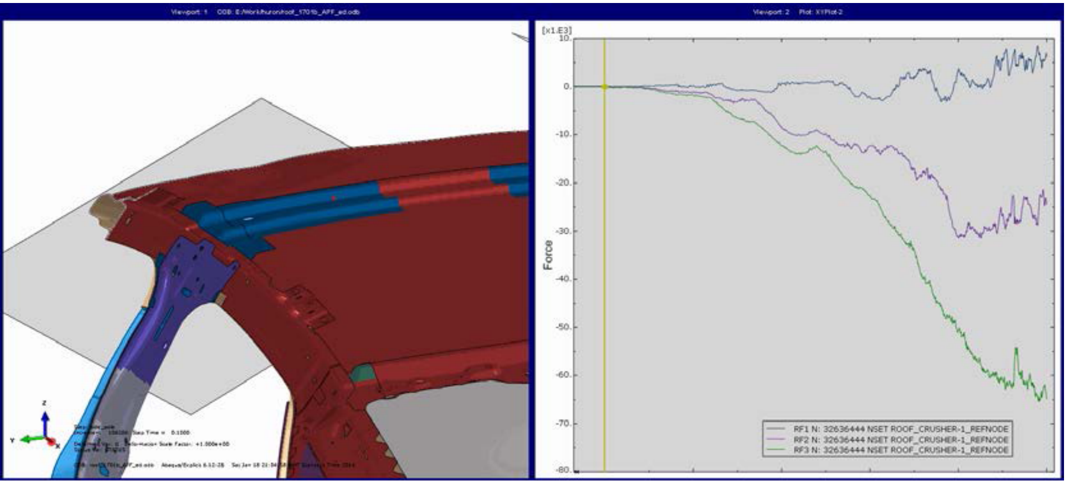
FMVSS 216A

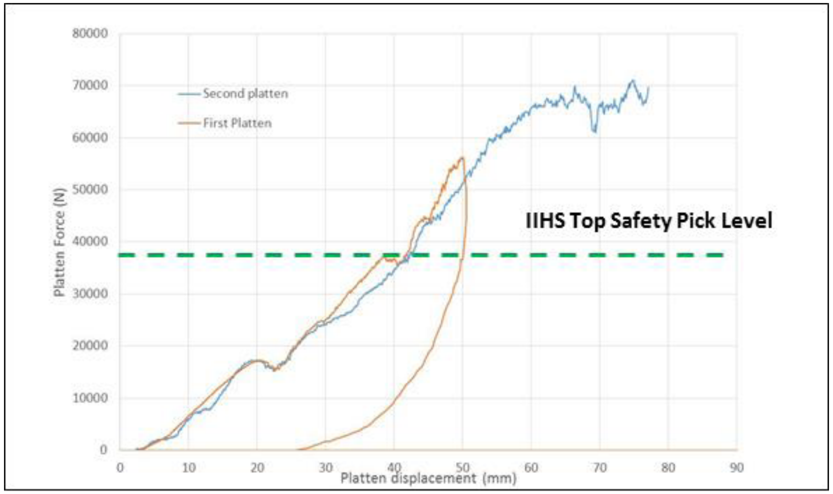
LH SIDE (1ST Loading)



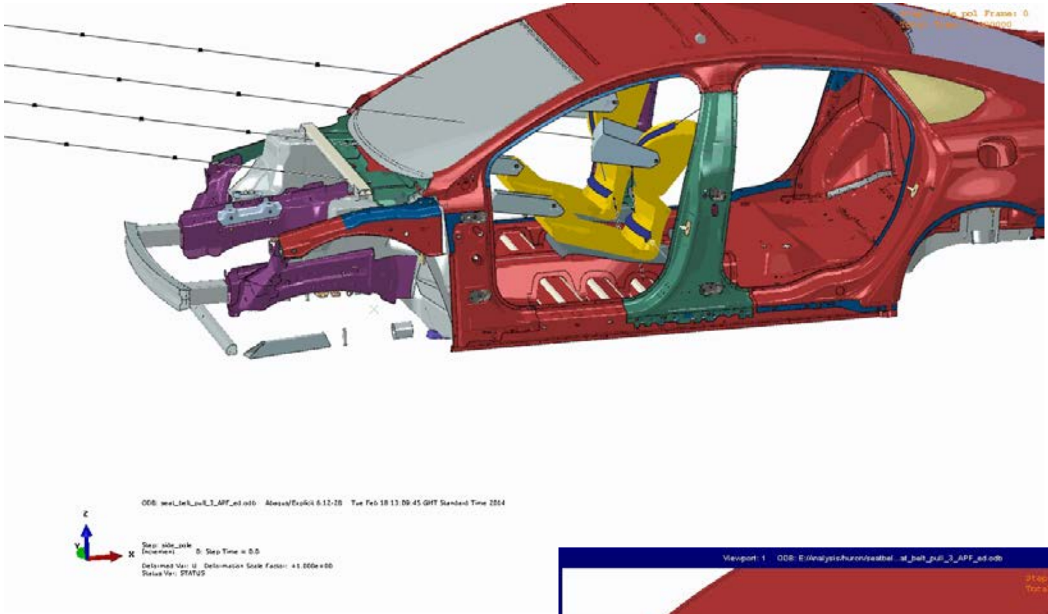


RH SIDE (2nd Loading)



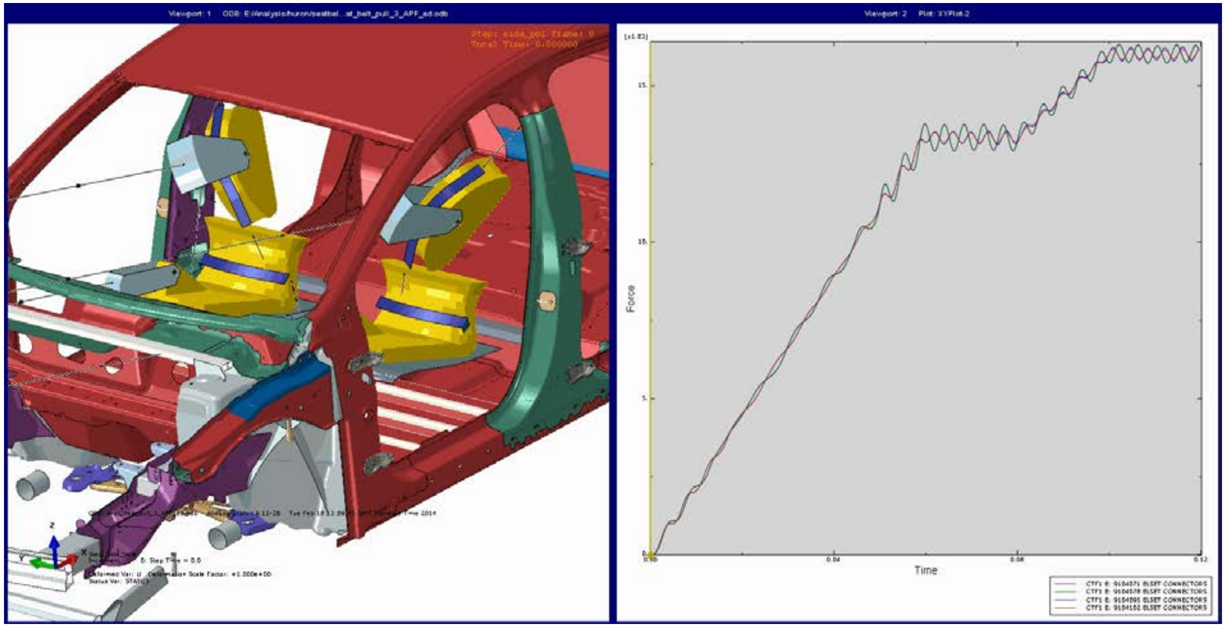


Seat Belt Pull



Analysis & Conclusions

- Local seat attachments used (somewhat pessimistic), but rigid body seat.
- Local patches added at seat mountings.
- No failure in Carbon.
- Very small regions of local ply damage due to transient loading (occurs as load applied dynamically)
- No cohesive failure of seat cross members.



Mach II Design
BIW Technology Issues

Composite Material Information

- Composite material CAE cards for stiffness, durability, and fatigue analysis still not mature for accurate CAE predictions.
- Composite material CAE cards for safety cash analysis still not mature for accurate CAE predictions.
- Composite material and manufacturing infrastructure immature for automotive volumes.
- Critical joint analysis – mechanical fasteners and structural adhesives strategy still not mature for accurate CAE predictions. Joint technology still a gap for composite to steel/aluminum materials.

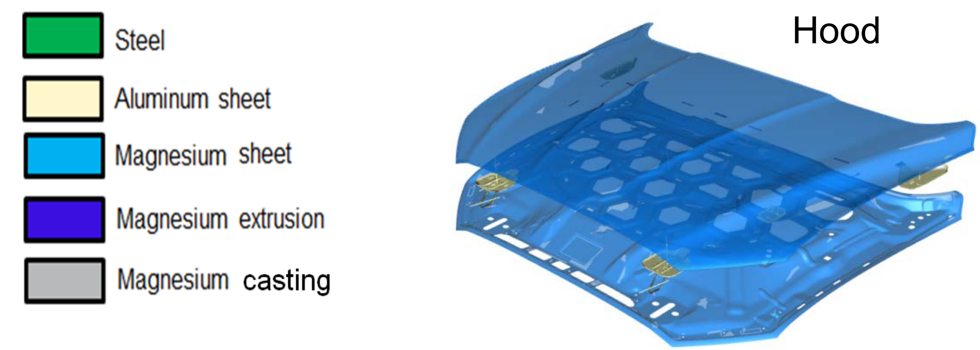
Carbon fiber and composites were deemed not feasible for "class A" panels

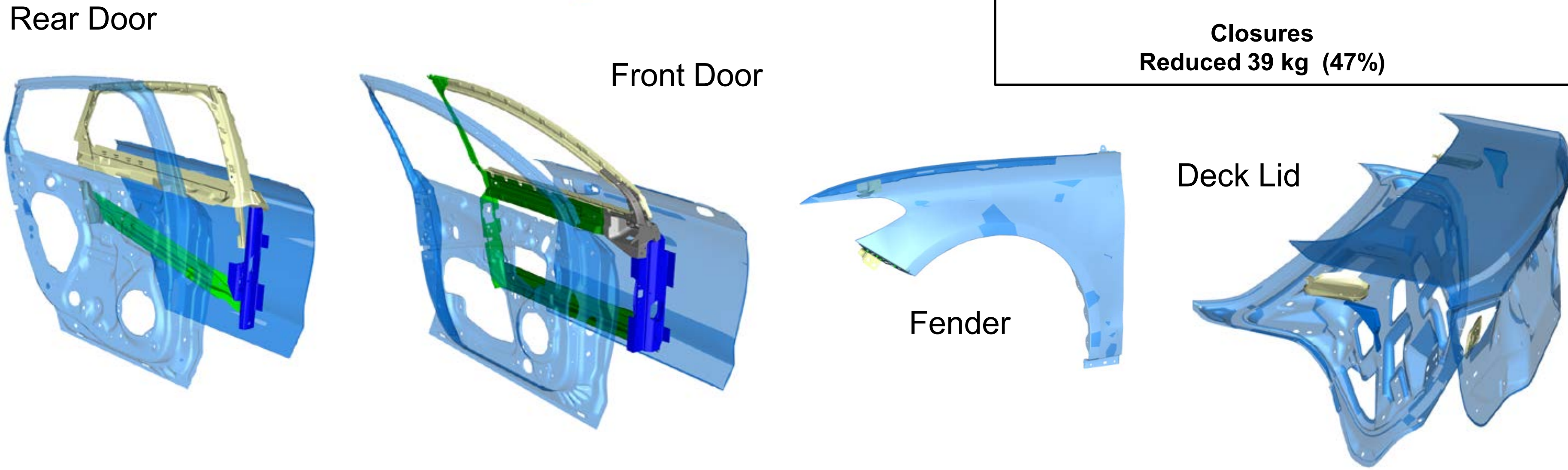
- Requirements for appearance by all OEM's would drive high cycle times to the composite process. Reviewing with many suppliers, it was determined that, even looking at a 2025 timeline, process cycle times would not meet the production volumes of 200,000 units/year with current OEM class be A requirements.
- Class A panels will be designed with aluminum or magnesium sheet products for the BIW and Closure applications.

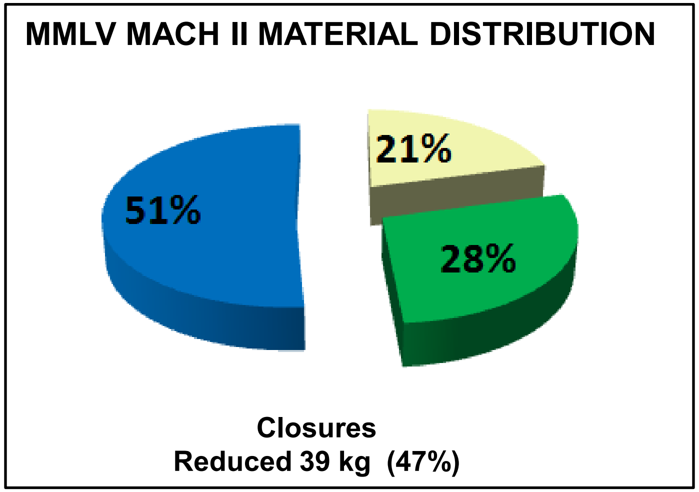
Recyclability and vehicle repair with carbon fiber

- Recycling of carbon fiber is an area that will need further investigation
- Repair of body components will be an area that will need further investigation

Mach II Design
Closures





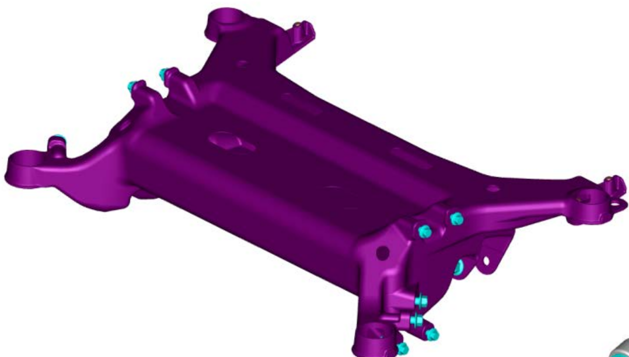


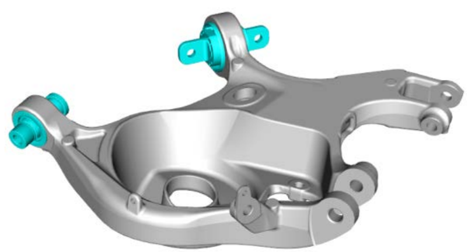
- CAE analysis resulted in increased thickness on door frame header reinforcements due to reduced module magnesium material.
- Panel joints assumed as half-hem with weld or laser warm hemming
- Investigating joint technology for magnesium to steel/aluminum joint

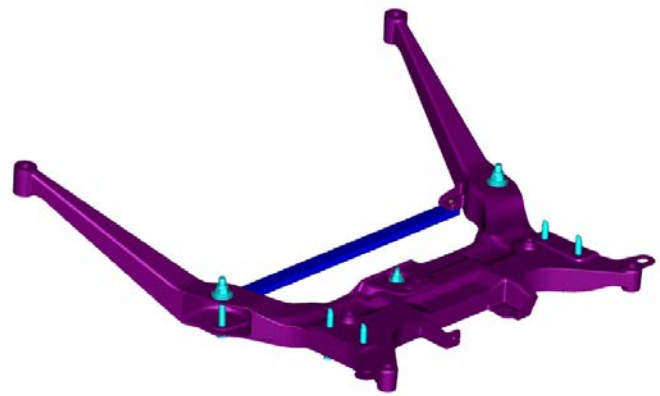
Mach II Design

Chassis

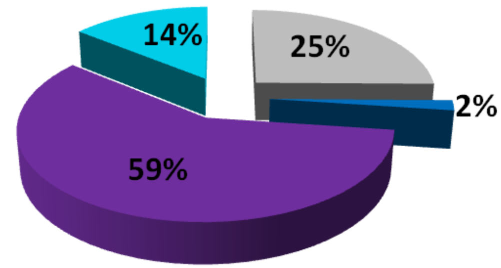
- Aluminum extrusion
- Aluminum casting
- Magnesium casting
- Other







MMLV MACH II MATERIAL DISTRIBUTION



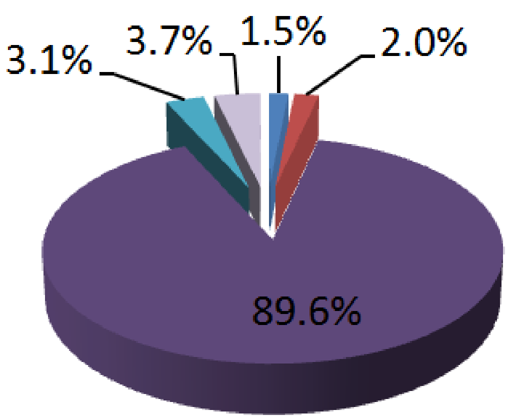
Chassis
Reduced 39 kg (47%)

- Bushing assembly sizes were reduced assuming reduction in loads due to lower vehicle weight
- Front cradle is being investigated also as a composite structure

MMLV Structures Weight Comparison
BIW, Closure, Chassis, Bumper

Baseline

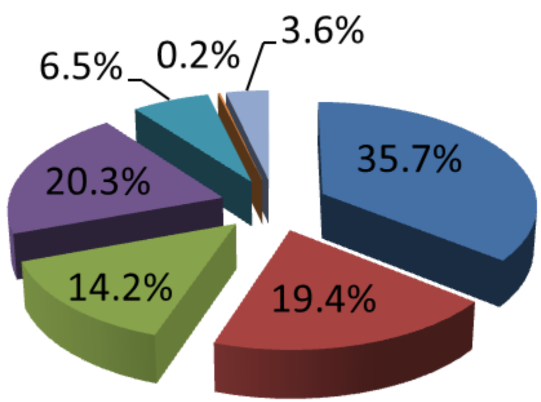
BIW	*316.04*	kg
Closures	*92.17*	kg
Chassis	*89.07*	kg
Bumpers	*20.38*	kg
Totals	*517.66*	kg



MMLV Mach I

BIW	*231.33*	*kg*
Closures	*57.23*	*kg*
Chassis	*52.90*	*kg*
Bumpers	*11.13*	*kg*
Totals	*352.58*	*kg*

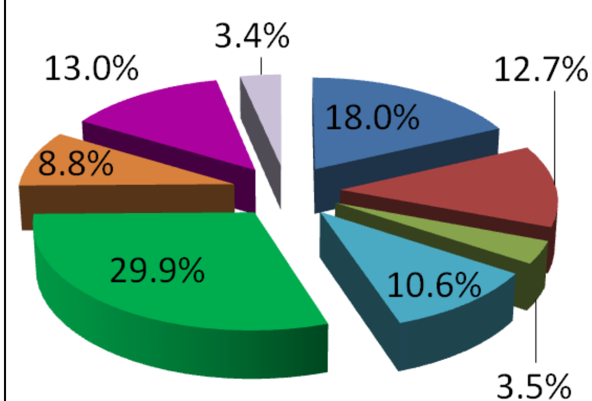
31.9% Reduction



MMLV Mach II

BIW	*172.59*	*kg*
Closures	*45.16*	*kg*
Chassis	*30.80*	*kg*
Bumpers	*11.13*	*kg*
Totals	*259.67*	*kg*

49.8% Reduction



- Aluminum Stampings
- Aluminum Castings
- Aluminum Extrusions
- Steel Stampings
- Hot Stampings
- Fasteners/Sleeves/Other
- COMPOSITE
- MAGNESIUM WARM FORMING
- MAGNESIUM CASTING/FORGING/EXTRUSION

*** CAD WEIGHT**

Mach II – FORD Component Designs

SUSPENSION COMPONENTS – Mix of suspension components

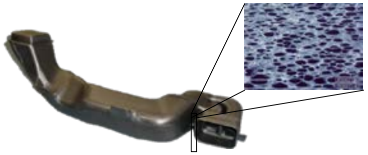
- Tall, Narrow Tires
- CF Wheels
- Delete Spare Tire/Wheel
- Reduced knuckles, calipers
- Aluminum Brake Rotors
- Composite Coil Springs
- Hollow CF Stabilizer Bars



INTERIOR COMPONENTS - Mix of Interior components saves 36 kg (35%)

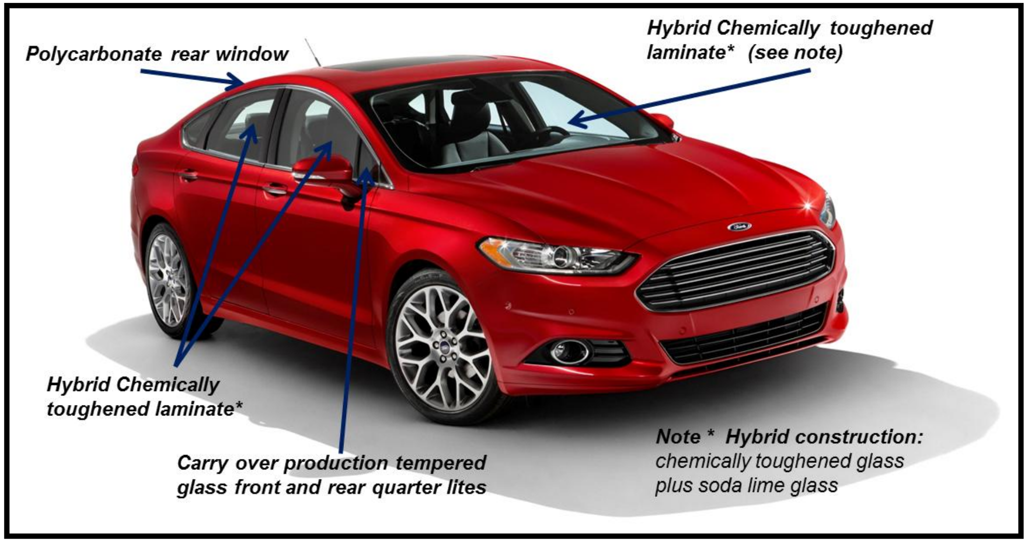
- Reduce Content, i.e., manual driver seat, fixed passenger set, reduce sound absorbing materials, no rear seat pass-through to trunk
- Carbon Fiber Seats with reduced foam (comfort reduction)
- Carbon Fiber Instrument Panel beam and ducts
- Eliminate Air Conditioning (comfort reduction)
- Chemically foamed interior plastic trim saves 50%

10% weight reduction
improved dimensions



40% weight reduction
improved air insulation

GLAZINGS - Mix of Lightweight Glazings saves 15 kg (37%)



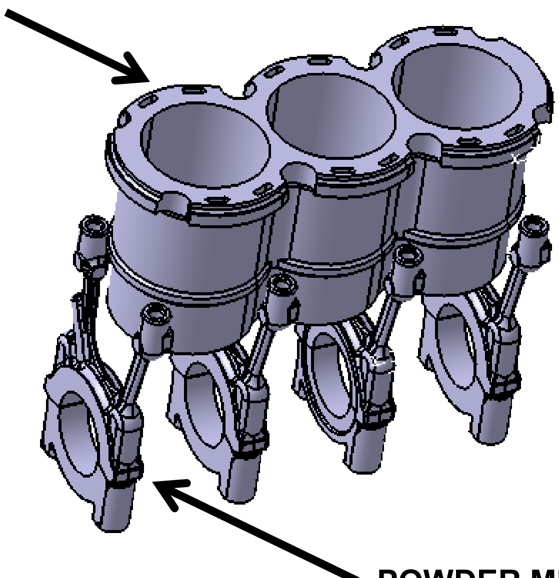
Engine:
1 liter, 3 cylinder DI Naturally Aspirated

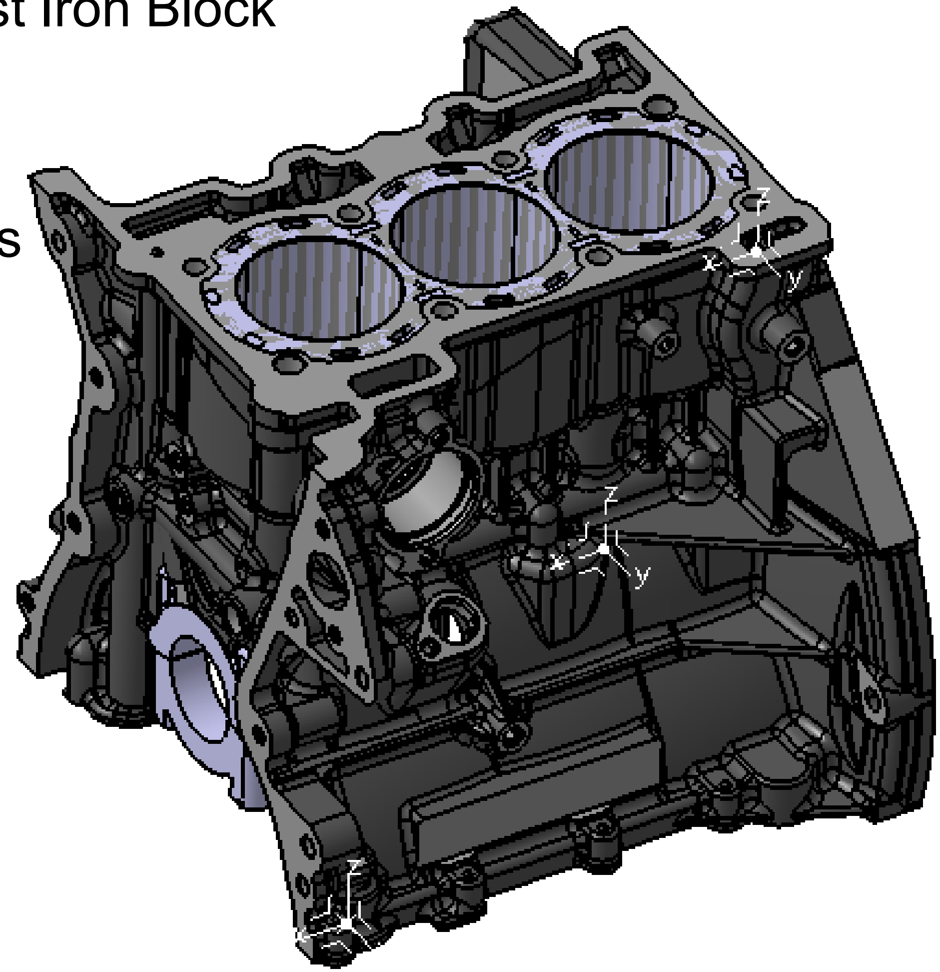
Transmission
6 speed manual w/magnesium case

POWERTRAIN 159kg = 47% reduction
'13 Fusion Mass 340 kg
Mach-II Mass 181 kg

I3 Engine Block for Mach-II

- Multi Material Cylinder Block
  - Saves 13.5 kg (~55%) from Cast Iron Block
  - Composite Block Body
  - Aluminum Sleeves
  - Powered Metal Bulkhead Inserts





Comparisons

	2002 Taurus	2013 Fusion	MMLV Mach-I Design	MMLV Mach-II Design	2013 Honda Fit	1967 VW Beetle	Ariel Atom
							
Curb Weight (kg)	**1523**	**1559**	**1195**	**761 target now 951**	**1135**	**840**	**612**
Passengers (number)	5	5	5	5	5	4	2
Doors (number)	4	4	4	4	5 - Hatchback	2	0
Cargo Vol (liters) seats up	481	453	453	453	580	280	0
Overall Length (mm)	5019	4872	4872	4872	4105	4079	3406
Overall Width (mm)	1854	1852	1852	1852	1694	1539	1798
Engine	3.0 liter V6 Nat Asp OHV	1.6 liter I4 GTDI	1.0 liter I3 GTDI	1.0 liter I3 Nat Asp DI	1.5 liter I4 SOHC - iVTEC	1.5 liter OHV H4	2.0L Honda i-VTEC, or 3.0L Ariel V8
Transmission	4-spd Automatic	6-spd Automatic	6-spd Automatic	6-spd Manual	5-spd Manual	4-spd Manual	6-spd Manual
Drive	Front Wheel Drive	FWD Std - AWD Opt	Front Wheel Drive	Front Wheel Drive	Front Wheel Drive	Rear Wheel Drive	Rear Wheel Drive
Power:Weight Ratio (W/kg)	76	83	77	74	76	47	290 to 600
Safety Systems	Seat Belts Front & Side Air Bags	Advanced Seat Belts Front & Side Air Bags Knee Bolster Bags	Advanced Seat Belts Front & Side Air Bags Knee Bolster Bags	Advanced Seat Belts Front & Side Air Bags Knee Bolster Bags	Advanced Seat Belts Front & Side Air Bags Knee Bolster Bags	Front Seat Belts	Front Seat Belts (no rear seat)
SAFETY IIHS ODB Front	Good	Good	Good CAE	Good CAE	Good		
NCAP Front	5-star	5-star (new)	Structural at 5-star	Structural at 5-star	4-star (new)	not tested	not tested
NCAP Side	3-star	4-star (new)	Structural at 4-star	Structural at 4-star	4-star (new)		
Roof Strength to Curb Wt	over 1.5 : 1	over 4 : 1	over 4 : 1	over 4 : 1	over 4 : 1		
Power Steering	Yes	Yes	Yes	Yes	Yes	No	No
Power Brakes	Yes - ABS	Yes - ABS	Yes - ABS	Yes - ABS	Yes - ABS	No - Manual	No - Manual
Air Conditioning	Yes	Yes	Yes	No	Yes	No	No
Power Windows	Yes	Yes	Yes	No	Yes	No	No
Power Front Seats	Yes	Yes	Yes	No	Yes	No	No
Carpet Padding (Sound Insulation)	Yes - Moderate	Yes - High	Yes - High	None	Yes - High	Yes - Little	None
Entertainment System	AM / FM	AM / FM / Sat CD / USB	AM / FM / Sat CD / USB	None	AM / FM / Sat CD / USB	AM Radio	None
Spare Tire/Wheel	Yes - mini	Yes - mini	No - Inflator Kit	No - Inflator Kit	Yes - mini	Yes - full	No

Mach-II Design: Work In Process

Mach-II Vehicle Design and Analysis (FY14)

- Complete Mach-II vehicle design to achieve a 50% weight reduction.
- Mach-II design will include reduced and eliminated comfort and convenience content such as air conditioning, entertainment system, power seats and windows.
- Focusing on Body Exterior and Chassis systems to further reduce weight.
- Chassis Opportunities:
  - Reduce wheel and tire size (degrade ride and handling)
  - Reduce bushing weight (degrade ride and handling and interior vibrations)
  - Reduce steering system weight (degrade responsiveness and vibration)
- Body Exterior Opportunities:
  - Reduce body-in-white weight (degrade stiffness, ride, vibration, quietness)
  - Reduce or eliminate trim (degrade appearance, water ingress, quietness)
  - Reduce mechanism weights (degrade durability, convenience)