Multi-Material Lightweight Vehicles

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LM072

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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 – As defined in the 2013 Merit Review, a mass reduction of 364kg was achieved. Further mass reduction was constrained by 2012 FMVSS regulations, donor vehicle architecture, and project scope and funding.

Mach II – The availability of mature material information required for impact and fatigue CAE analysis is limited for the composite materials researched for application development. While many components have been designed at a 50% mass reduction, the full vehicle curb weight target of 50% “full vehicle” mass reduction 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 target mass reduction.

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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 Milestone Status

Milestone (As of March 1)	Component	Start Date	End Date	% Complete
Mach-I Vehicle design complete, CAE Predictive models complete Vehicle assembly Bill of Materials (BOM) complete	BIW, Closure, Suspension, Component	01/2012	01/15/2013	100
Component part build complete – stampings, castings, extrusions complete for assembly build. Vehicle components complete for vehicle integration	Vehicle Build	08/2013	3/15/2014	100
Vehicle Build – completion of BIW modules and final assembly. Integration into full drivable vehicles	BIW, Closures,	010/01/2013	08/06/2014	40
Mach-II Vehicle design – Completion of Bill of materials and design direction for analysis	Vehicle	03/04/2013	05/01/2014	95
Mach-II CAE Predictive Models – Completion of Stiffness and Durability models, FMVSS side impact, roof crush, frontal off-set	Vehicle	10/01/2013	06/01/2014	85
Powertrain prototype components complete	Powertrain	05/01/2013	06/30/2014	60
Component level testing for vehicle integration components	Chassis, Interior	01/30/2013	06/30/2014	40
Component level testing for powertrain components	Powertrain	03/01/2014	09/30/2014	5
Full vehicle durability and corrosion testing	Vehicle	04/30/2014	10/31/2014	0
Full vehicle safety testing	Vehicle	07/15/2014	10/31/2014	0

MMLV Program

Vehicle Lightweighting Project

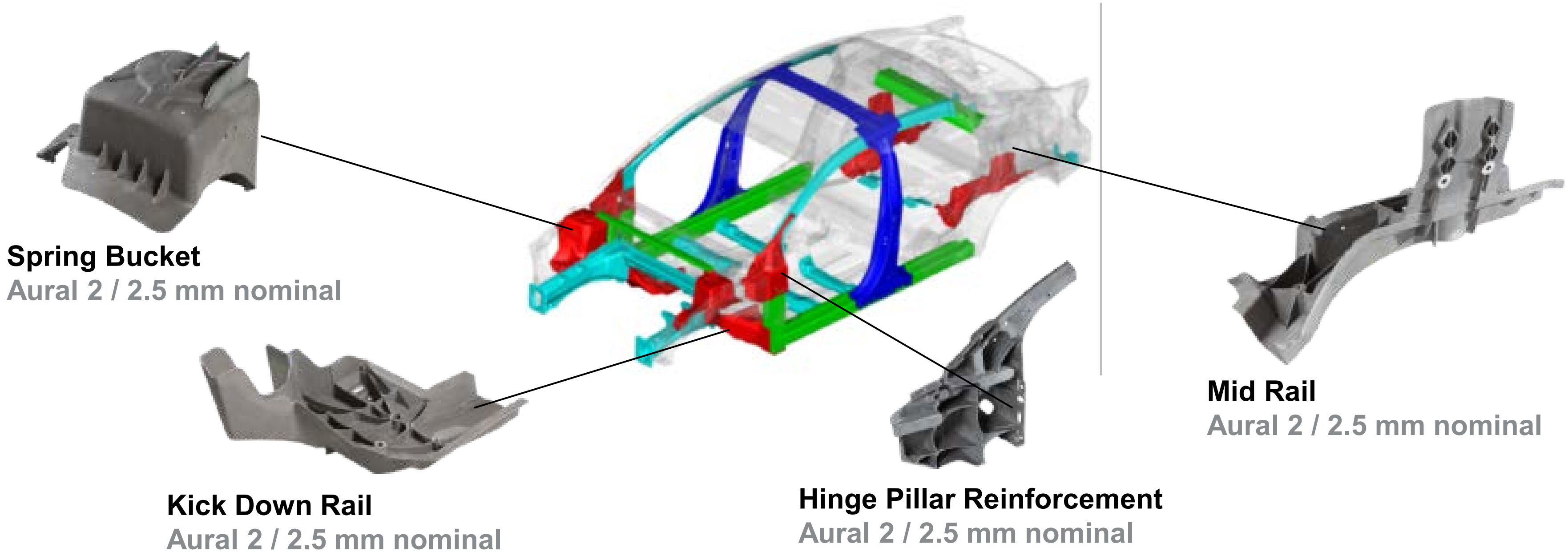
- Baseline Vehicle:
  - 2013 Fusion
- Mach I Vehicle,
  - Existing commercially available materials & production processes
  - Establish a benchmark, without cost considerations
- Mach II Vehicle:
  - Advanced materials & processes
  - Identify technology gaps

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

Technical Accomplishments

Mach-I Prototype Parts



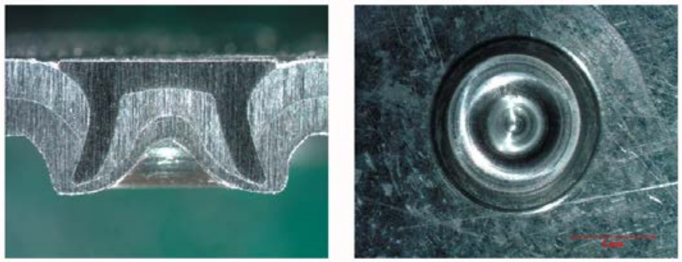
<u>High Pressure Aluminum Die Castings</u>

- Strategically designed to maximize stiffness and part count reduction.
- 7 body castings manufactured as low pressure sand cast with specialized heat treat to simulate production high pressure vacuum die casting process due to cost/timing limitations.
- Body castings will be anodized as pre-treatment for structural adhesive bonding and increased corrosion resistance.
- Front LH rail kick-down manufactured with production intent High Pressure Vacuum Die Cast process. Front LH Rail Kick-down is integral for Front Impact ODB validation and thus the program decision was production intent process for testing.

Technical Accomplishments
Mach-I Prototype Joining

Self Piercing Rivets (SPR) was the main technology used for jointing on the MMLV BIW and closures. * Physical testing to validate joint integrity was conducted for all BIW & Closure joints. SPR joint testing will verified SPR size, die, and gun pressures needed for the specific joint. All of the joint testing is performed with adhesive in the joint to simulation the build process. This joining process is for multi-material joint and aluminum to aluminum joints where gun clearance exists in the design.

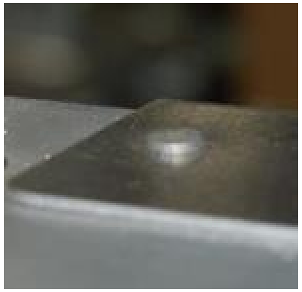
SAMPLE OF SPR JOINT VALIDATION



Ø5 x 5H2 (AS) rivet with DZ09-000 die @ 120/180 Bar

FLOW SCREW

RIV TAC



HUCK RIVET

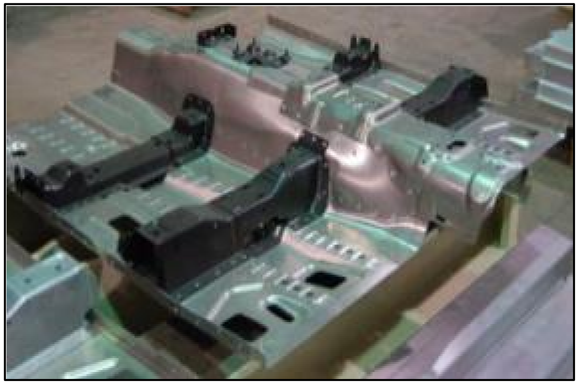
Where SPR's could not be used in the BIW and closure joints due to single side access, insufficient gun clearance, or base material issues, flow screws, Riv-Tac, and Huck rivets were used along with structural adhesive.

All joints where corrosion may form have an adhesive layer between materials to prevent galvanic corrosion and to increase stiffness/durability of the joint. Two adhesive will be used for this program; Dow Betamate™ 73305, a one part heat activated adhesive for any modules that will go thru an E-coat process and Dow Betamate™ 73326, a two part air cured activated adhesive that will be used for the final framer and modules that do not get e-coated.

Technical Accomplishments

Mach-I BIW Modules

FRONT FLOOR



REAR FLOOR

FRONT MODULE

BODY SIDE INNER

Modules include

- E-coated and non-e-coated assemblies
- Aluminum extrusions, aluminum & steel stampings
- Aluminum low pressure sand and high pressure die castings
- Joints
    - SPR
    - Steel Spot Welds
    - Huck Rivets
    - Flow Screws
    - Mig Welding
    - Rivtac
- Air cured and heat cured adhesive at most joints
- Steel to steel weld-thru adhesive at B-Pillar and front rails

Technical Accomplishments
Mach-I BIW Assembly

BIW ASSEMBLY

- Non-E-coated assembly with e-coated steel
- Joints underbody complete with body side outer assemblies
- Aluminum stampings & Steel Stampings
- Joint in Assembly
  - SPR
  - Steel spot weld
  - Huck Rivets
  - Flow Screws
- Air cured adhesive at all joints

Technical Accomplishments

Mach-I FRT Cradle, FRT Bumper, & FRT/RR Doors

FRONT CRADLE

- 6063-T6 Aluminum Extrusions
- Low Pressure Aluminum Castings
- Mid welded assembly
- Post Machined attachments

FRONT BUMPER

- 6063-T6 Aluminum Crush Cans
- 6082-T6 Bumper Beam
- Aluminum Brackets
- Mid welded assembly

REAR DOOR

- 6063-T6 Aluminum Extrusions
- Aluminum Stampings
- Steel Reinforcements
- Magnesium Casting
- Hot Stamping
- Joint in Assembly
  - SPR
  - Steel spot weld
  - Huck Rivets
  - Bolt

FRONT DOOR

Technical Accomplishments

Mach-I Prototype BIW

First Completed Buck

Vehicle builds will have the following MMLV structural content:

- BIW
- LH Front and Rear Doors
- Front Aluminum Cradle
- Front Aluminum Bumper

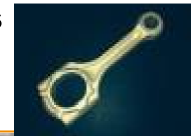
Vehicle builds will have the following carryover structural content:

- Hood (Aluminum)
- Deck Lid
- RH Front and Rear Doors
- Rear cradle and suspension links
- Front & Rear Lower control arms (Aluminum)
- Rear Bumper

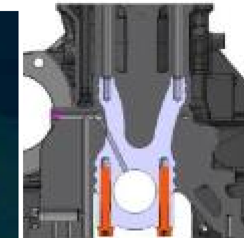
Technical Accomplishments
Mach-I Prototype Powertrain Parts

ENGINE – Weight reduction of 20% to 48% on components

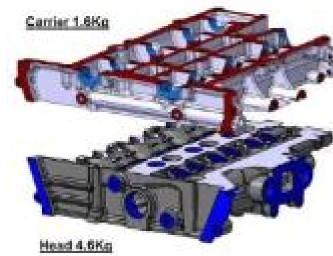
- Cast aluminum engine block for 1.0 liter I3 engine with Powder Metal forged billet crackable bulkhead inserts.
  - saves 48%, 11.8 kg
- Carbon fiber structural oil pan.
  - saves 30%, 1.2 kg
- Carbon fiber front cover with mount.
  - saves 30%, 1.0 kg
- Carbon Fiber + Aluminum cam carrier.
  - saves 20%, 1.3 kg
- Forged aluminum connecting rods.
  - saves 40%, 0.7 kg



Forged Aluminum connecting rods

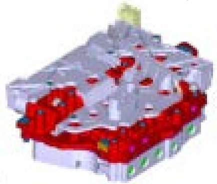


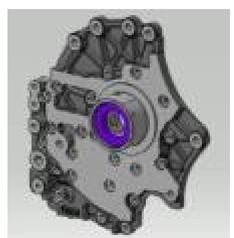
Bulkhead Insert in AL block



Carbon Fiber upper + Aluminum lower Cam carrier

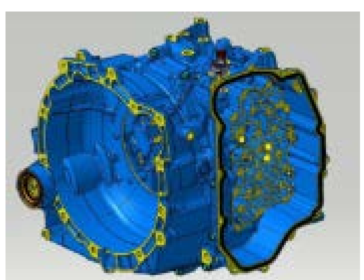
Magnesium valve body





Aluminum pump cover

Aluminum + Steel Clutch Hub



Magnesium case and bell housing

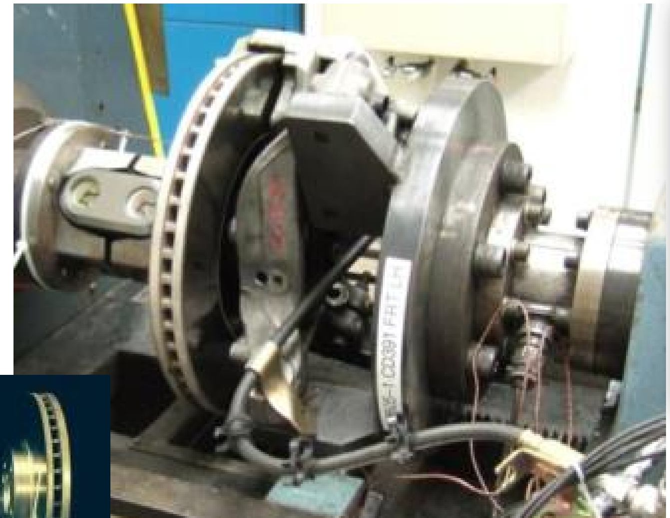
TRANSMISSION – Weight reduction of 30% to 60% on components for reduced torque automatic

- Cast magnesium (AZ91D) case and bell housing
  - saves 30%, 5.0 kg
- Aluminum pump cover
  - saves 55%, 1.8 kg
- Cast magnesium valve body
  - saves 35%, 1.0 kg
- Steel + Aluminum clutch hub (friction spin weld)
  - saves 60%, 0.4 kg

Technical Accomplishments
Mach-I Prototype Suspension Parts

SUSPENSION COMPONENTS – Weight reduction of ~30% on these components

- Tall, Narrow Tires 30% save
  - 155/70R19 new materials and constructions
- Wheels 19 inch x5 inch 30% save
  - cast aluminum or carbon fiber
- Delete Spare Tire/Wheel
- Aluminum Brake Rotors 35% save
  - Cast A356 Al, Thermal Spray Coated
- Coil Springs 35% ~ 55% save
  - hollow micro alloy steel with intensive shot peening, titanium, composite
- Stabilizer Bars 35% ~ 55% save
  - high hardness steel, with internal and external shot peening



Aluminum brake rotor with thermally sprayed wear resistant coating

Carbon fiber wheels

Tall, Narrow Tires

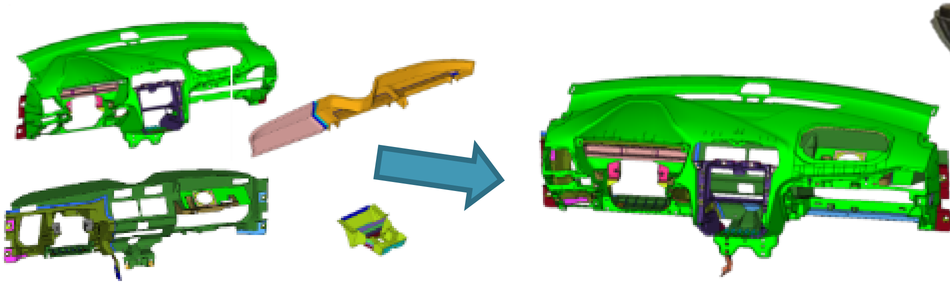
Evaluate composite, hollow steel and titanium coil springs

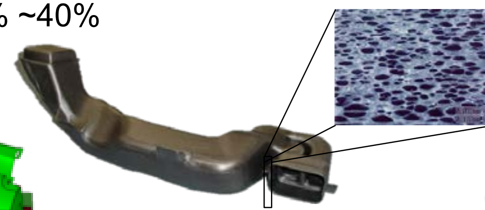
Technical Accomplishments

Mach-I Prototype Parts

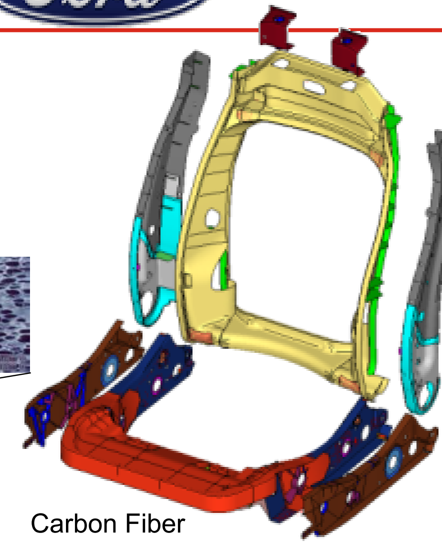
INTERIOR COMPONENTS

- Carbon Fiber Seat designs save ~28 kg, 40%
  (driver -8 kg, passenger -8 kg, rear -12 kg)
- Carbon Fiber (or magnesium) Instrument Panel beam and ducts save ~8 kg, 35%
- MuCell and chemically foamed interior plastic trim saves 15% ~40%





40% weight reduction improved air insulation

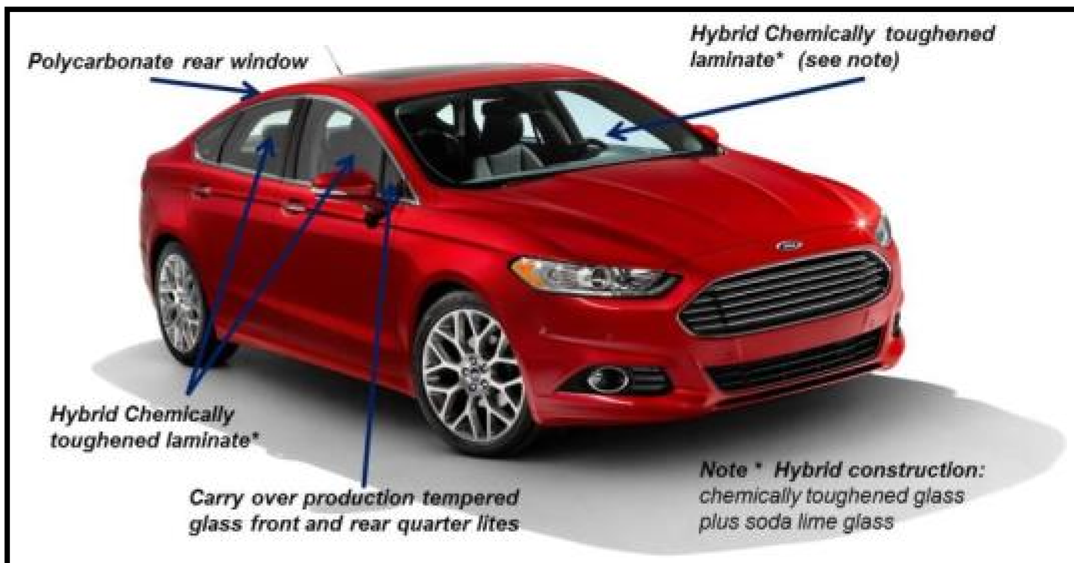


Carbon Fiber Seat Frame

GLAZINGS -

- Mix of Lightweight Glazings saves 14 kg (35%)
- Laminated chemically toughened* windshield,
- Side door movable glazings,
- Polycarbonate Glazing Backlite (Rear Window)

Side Door Glass - Door Slam Durability Test



Vehicle Definitions

MMLV Mach-I Prototype Builds:

1. **Buck:** Body-in-White + Closures + Bumpers + Glazings + Front Subframe
2. **Durability-A:** DRIVABLE, full MMLV content with Fusion powertrain
3. **Corrosion-Traditional:** DRIVABLE, full MMLV content with modified surface treatments and paint process with Fusion powertrain
4. **Corrosion-MMLV Alternative:** DRIVABLE, full MMLV content with MMLV surface treatments and paint process with Fusion powertrain
5. **Safety-A:** NON-Drivable, most MMLV content, without carbon fiber instrument panel, no fluids (fuel, coolant, oil, HVAC, etc.) with Fusion powertrain
6. **Safety-B:** NON-Drivable, most MMLV content, without carbon fiber instrument panel, no fluids (fuel, coolant, oil, etc.) with Fusion powertrain
7. **NVH + Drives:** DRIVABLE, full MMLV content with downsized and boosted powertrain (1.0-liter I3 EcoBoost, gasoline turbocharged direct injection, engine plus six-speed manual transmission)

Timing Plans

MMLV Mach-I Prototype Builds and Test

MMLV Testing Timing 2014 (March '14 update)												
		Mar '14	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec '14	Jan '15
Parts	Component Testing	OOOO	OOOO	X==============X========================X========================X								
Buck #1	NVH + Durability	O	O X====================================X									
Veh #2	Durability		OO	X====================================X								
Veh #3	Corrosion - A MMLV			OO	X===X							
Veh #4	Corrosion - B Traditional			O--	----OO X==X							
Veh #5	Safety - A				OO	X=====================X						
Veh #6	Safety - B					OO	X=====================X					
Veh #7	NVH + Drives						OO Engine Swap		X============================X			
note:	OO Delivery	X====X Testing										

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

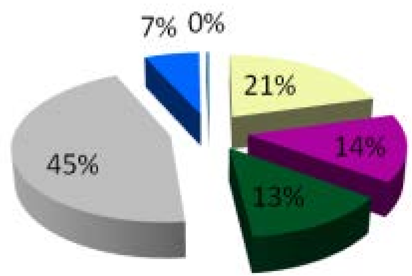
- Recycling of carbon fiber is an area that will need further investigation
- Repair of body components will be an area that will need further investigation

Mach II Design

BIW Status (3-14-14)

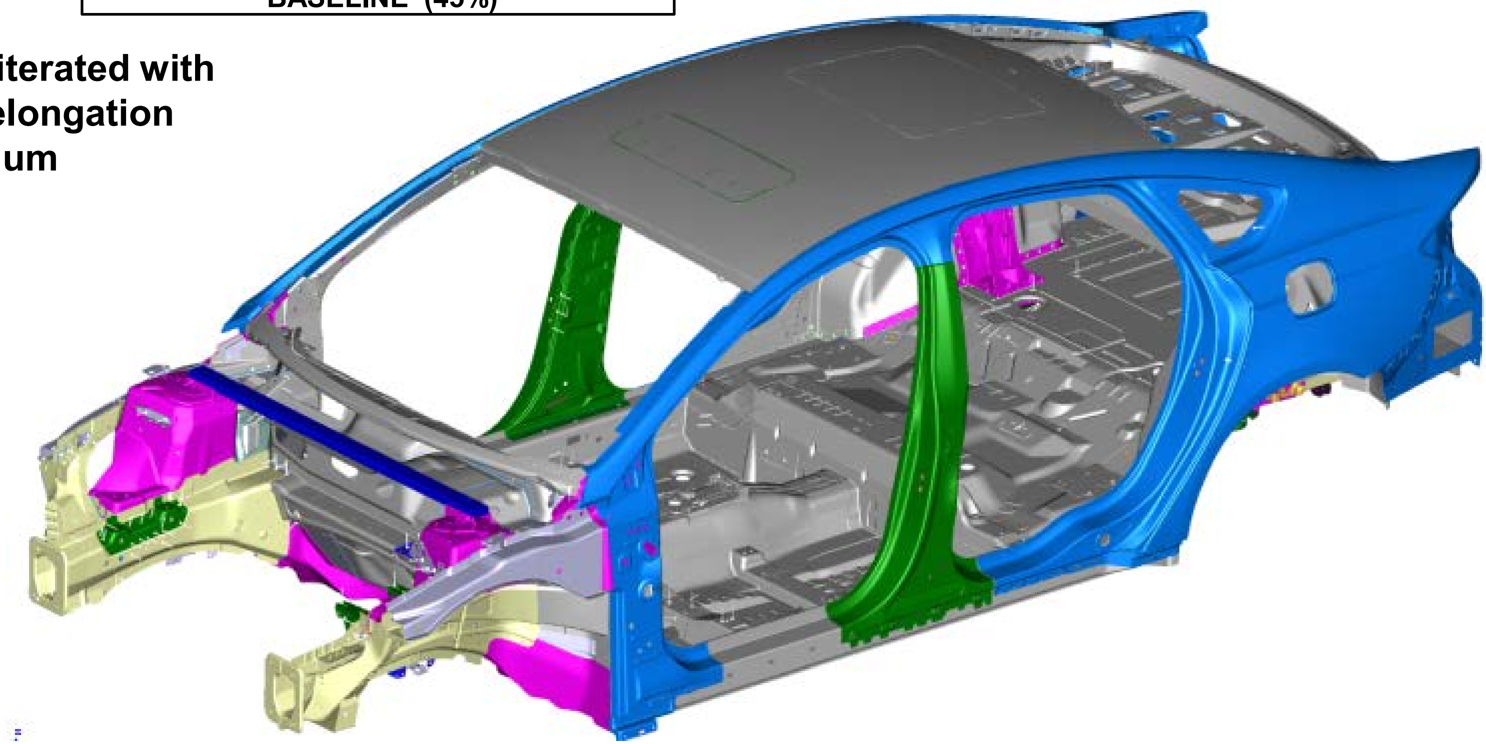
- Aluminum casting
- Steel
- Composite
- Aluminum sheet
- Magnesium
- Aluminum extrusion

MMLV MACH II MATERIAL DISTRIBUTION



144 KG REDUCTION FROM BASELINE (45%)

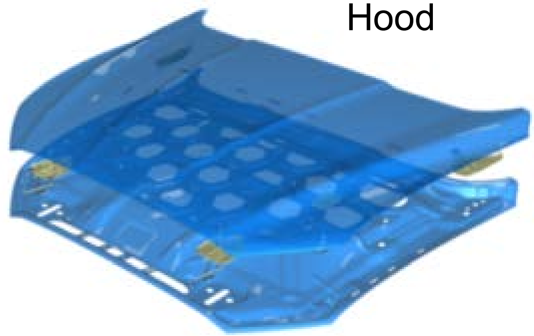
Front Rails will be iterated with 600 MPa UTS, 8% elongation C12Z Alcoa Aluminum



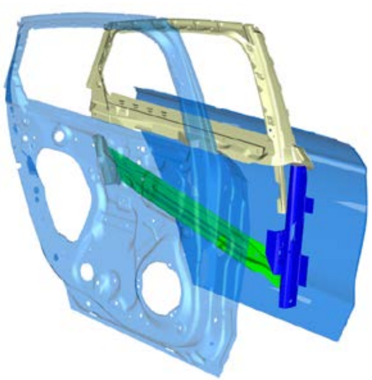
Mach II Design
Closures

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

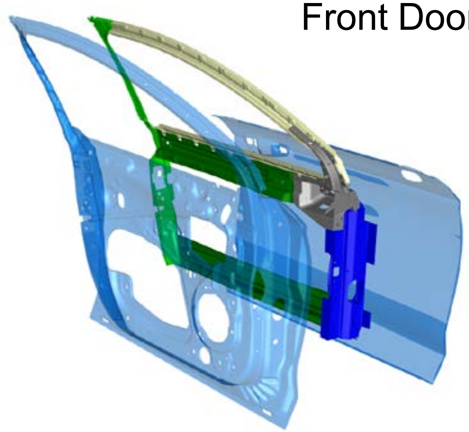
Hood



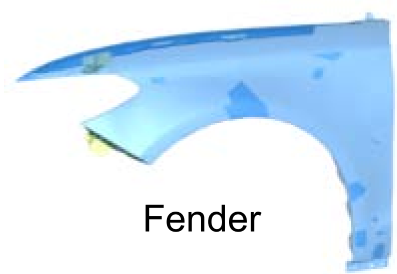
Rear Door



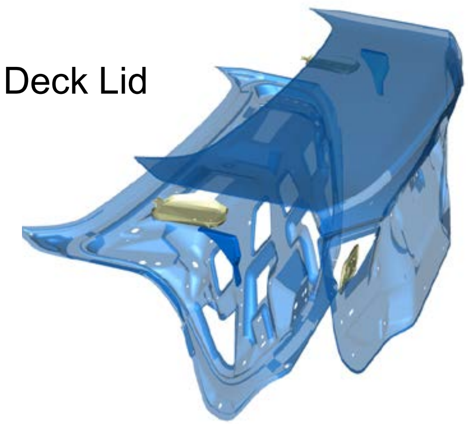
Front Door

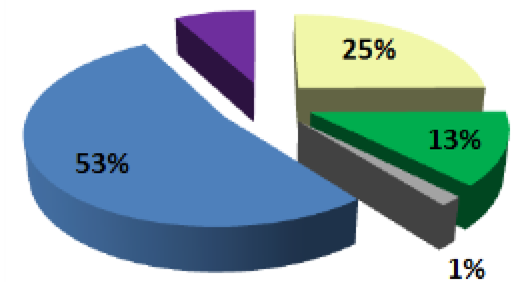


Fender



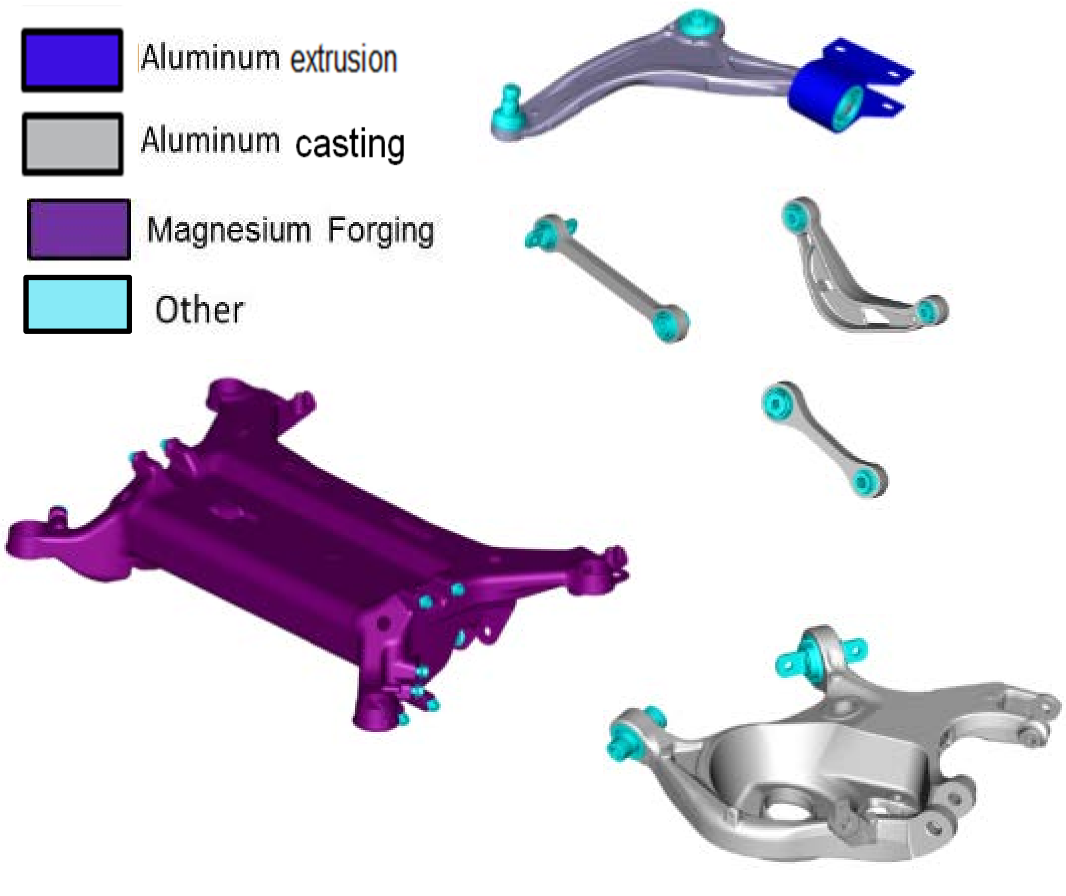
Deck Lid



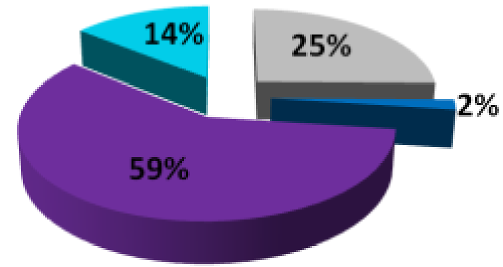


- CAE analysis resulted in increased thickness on door frame header reinforcements due to reduced module magnesium material.
- Panel joints assumed as half-hem with weld or laser warm hemming
- Investigating joint technology for magnesium to steel/aluminum joint

Mach II Design
Chassis



MMLV MACH II MATERIAL DISTRIBUTION



58 KG REDUCTION FROM BASELINE (65%)

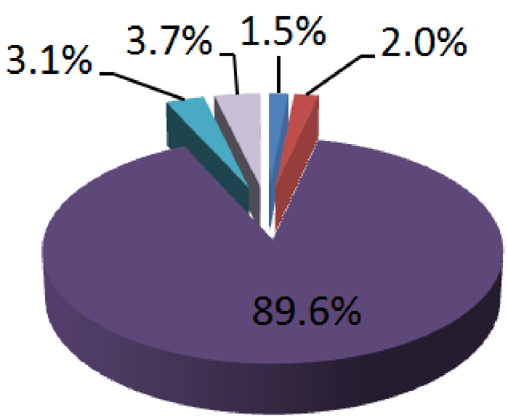
- Bushing assembly sizes were reduced assuming reduction in loads due to lower vehicle weight
- Front cradle is being investigated also as a composite structure

MMLV Structures Weight Comparison

BIW, Closure, Chassis, Bumper

Baseline

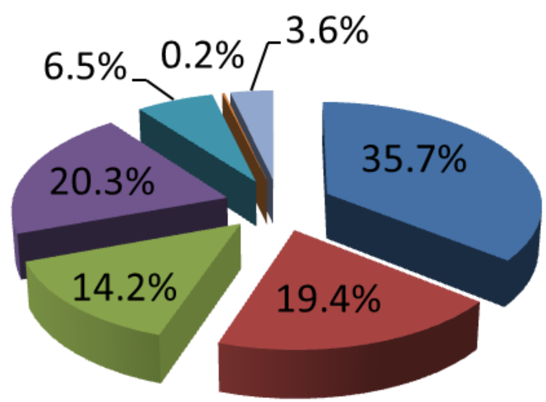
BIW	*316.04*	kg
Closures	*92.17*	kg
Chassis	*89.07*	kg
Bumpers	*20.38*	kg
Totals	*517.66*	kg



MMLV Mach I

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

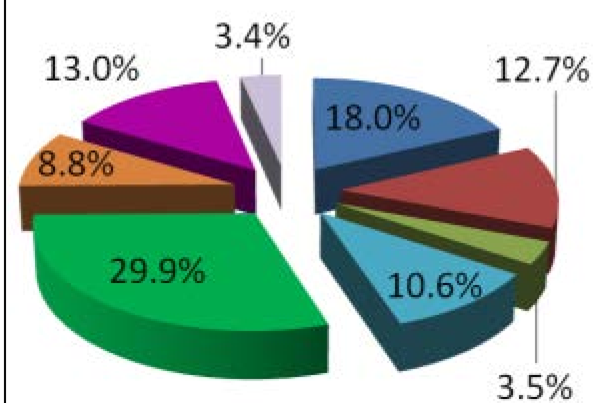
31.9% Reduction



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

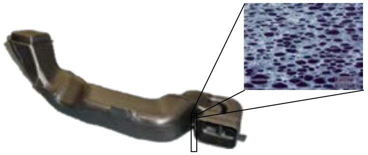
SUSPENSION COMPONENTS – Mix of suspension components

- 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%)

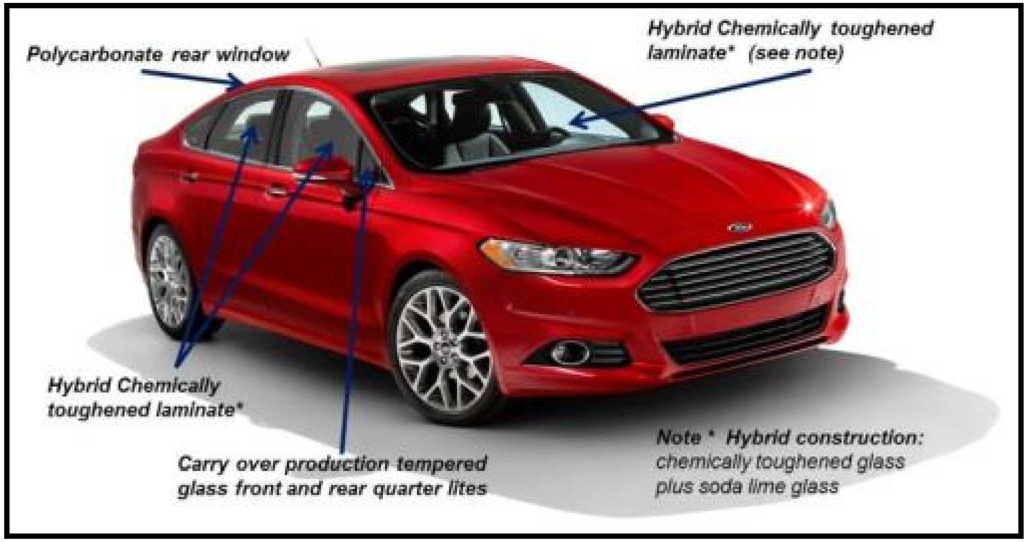
- Reduce Content, i.e., manual driver seat, fixed passenger set, reduce sound absorbing materials, no rear seat pass-through to trunk
- Carbon Fiber Seats with reduced foam (comfort reduction)
- Carbon Fiber Instrument Panel beam and ducts
- Eliminate Air Conditioning (comfort reduction)
- Chemically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

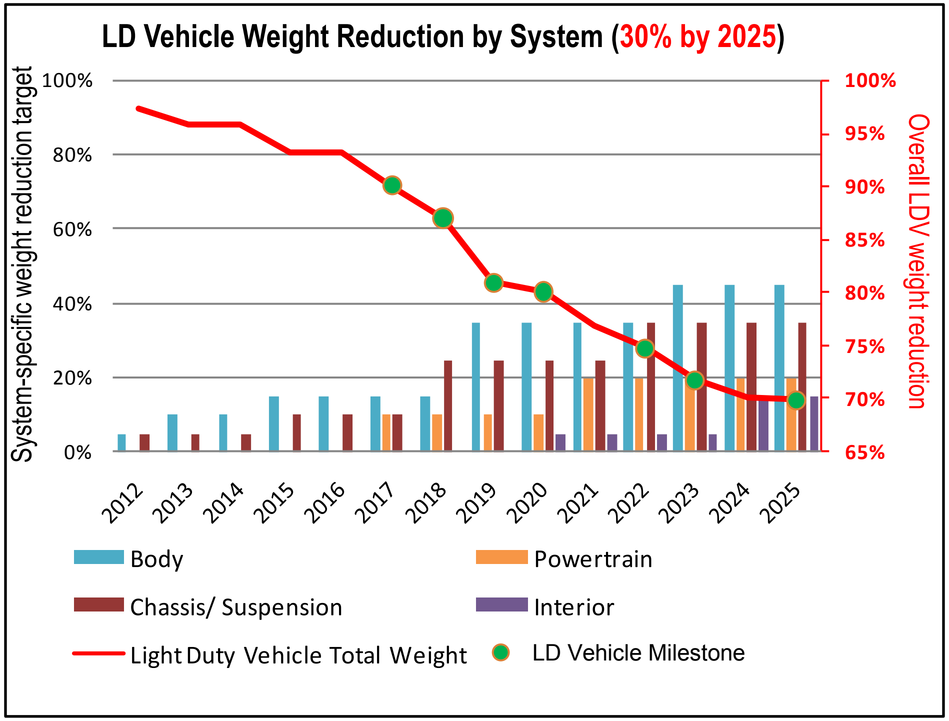
POWERTRAIN 159kg = 47% reduction
Baseline Mass 340 kg
Mach-II Mass 181 kg

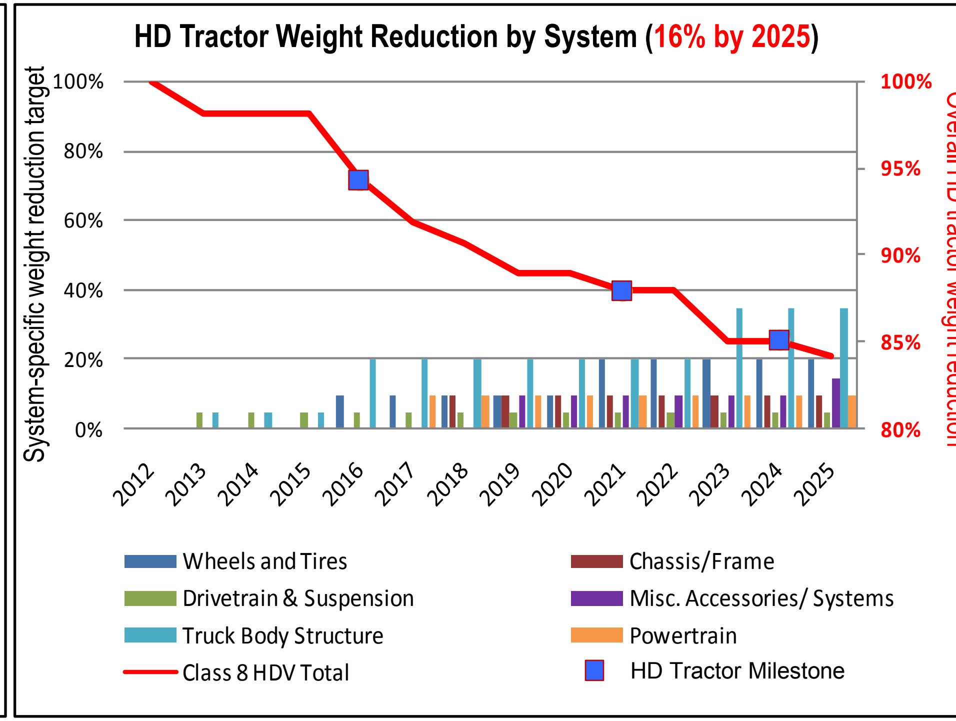
Mach II – Weight STATUS
as of 4 March 2014

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-I vs DOE Roadmap

Mach-I design includes materials and tech which are commercially available.

Vehicle Subsystem	MMLV Mach I Vehicle						DOE Roadmap
	2002 Taurus	2013 Fusion	MMLV Mach I DESIGN	MMLV Mach I (%) Curb	MMLV Mach I (%) save w.r.t. Fusion	Tech Validation Date	
Body Exterior and Closures (kg)	**574**	**594**	**456**	**38.1%**	**23.3%**	**Q4 2014**	**2019 Goal 35%** **2023 Goal 45%**
Body-in-White	n.a.	326	250	20.9%	23.5%		
Closures-in-White	n.a.	98	69	5.8%	29.7%		
Bumpers	n.a.	37	25	2.1%	30.9%		
Glazings - Fixed and Movable	n.a.	37	25	2.1%	32.5%		
Remainder - trim, mech, paint, seals, etc.	n.a.	96	87	7.3%	9.5%		
Powertrain (kg)	**350**	**340**	**267**	**22.4%**	**21.5%**	**Q1 2015**	**2017 Goal 10%**
Engine (dressed)	n.a.	101	71	6.0%	29.7%		
Transmission and Driveline	n.a.	106	92	7.7%	13.8%		
Remainder - fuel, cooling, mounts, etc.	n.a.	133	104	8.7%	21.3%		
Chassis (kg)	**352**	**350**	**252**	**21.1%**	**27.8%**	**Q4 2014**	**2018 Goal 25%** **2022 Goal 35%**
Frt & Rr Suspension	n.a.	96	81	6.8%	15.6%		
Subframes	n.a.	57	30	2.5%	47.6%		
Wheels & Tires	n.a.	103	64	5.4%	37.8%		**2012 Goal 20%**
Brakes	n.a.	61	49	4.1%	19.8%		
Remainder - steering, jack, etc.	n.a.	33	29	2.4%	12.1%		
Body Interior and Climate (kg)	**180**	**206**	**161**	**13.5%**	**21.8%**	**Q4 2014**	**2020 Goal 5%**
Seating	n.a.	70	42	3.5%	40.1%		
Instrument Panel	n.a.	22	14	1.1%	37.0%		
Climate Control	n.a.	27	25	2.1%	5.1%		
Remainder - trim, restraints, console, etc	n.a.	88	80	6.7%	8.7%		
Electrical (kg)	**67**	**69**	**59**	**5.0%**	**14.4%**	**Q1 2015**	
Wiring	n.a.	28	25	2.1%	11.3%		
Battery	n.a.	14	8	0.7%	41.4%		
Remainder - alt, starter, speakers, etc.	n.a.	27	26	2.2%	4.0%		
Total Vehicle (kg)	**1523**	**1559**	**1195**	**100%**	**23.3%**		**2025 Goal 30%**

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%**	**tbd**	**2019 Goal 35%** **2023 Goal 45%**
Body-in-White	n.a.	326	250					
Closures-in-White	n.a.	98	69					
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%**	**tbd**	**2017 Goal 10%**
Engine (dressed)	n.a.	101	71					
Transmission and Driveline	n.a.	106	92					
Remainder - fuel, cooling, mounts, etc.	n.a.	133	104					
Chassis (kg)	**352**	**350**	**252**	**212**	**23%**	**39%**	**tbd**	**2018 Goal 25%** **2022 Goal 35%** **2012 Goal 20%**
Frt & Rr Suspension	n.a.	96	81					
Subframes	n.a.	57	30					
Wheels & Tires	n.a.	103	64					
Brakes	n.a.	61	49					
Remainder - steering, jack, etc.	n.a.	33	29					
Body Interior and Climate (kg)	**180**	**206**	**161**	**116**	**13%**	**44%**	**tbd**	**2020 Goal 5%**
Seating	n.a.	70	42					
Instrument Panel	n.a.	22	14					
Climate Control	n.a.	27	25					
Remainder - trim, restraints, console, etc	n.a.	88	80					
Electrical (kg)	**67**	**69**	**59**	**47**	**5%**	**32%**	**tbd**	
Wiring	n.a.	28	25					
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

Work In Process

Structures Design & Fabrication Mach-I – Vehma (FY14)

- Complete full vehicle Integration of BIW & Components (Q214)

Component & Vehicle Testing Mach-I -Ford (FY14 & FY15)

- Conduct component level testing for prototype parts (1Q-4Q14) including:
  - Door slam and other durability testing,
  - Engine and transmission dynamometer testing,
  - Front subframe durability and vibration testing,

- Conduct full vehicle durability, impact, NVH and corrosion testing to validate MMLV design for production intent (3Q14 – 1Q15). Key vehicle testing includes:
  - Frontal NCAP and frontal offset deformable barrier (IIHS ODB - 40%) impact tests,
  - Full vehicle Rough Road Durability testing,
  - Full vehicle accelerated corrosion testing,
  - Normal mode vibrations, wind noise and engine noise testing.

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.

Oakridge weight assessment and lifecycle assessment Mach I and Mach II (FY15)

✓ Mach I weight
- Mach I life cycle
- Mach II Weight and life cycle