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United States Department of Energy
National Energy Technology Lab

DOE Award # DE-EE0005574

Demonstration Project for a Multi-Material Lightweight Prototype Vehicle as Part of the Clean Energy Dialogue with Canada

FINAL SCIENTIFIC REPORT
PROJECT SUMMARY

VEHMA International of America, Inc.
DUNS: 605469048

Project Performance Period

October 01, 2011 to September 30, 2015

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ABSTRACT/EXECUTIVE SUMMARY

The intent of the Multi-Material Lightweight Vehicle ("MMLV") was to assess the feasibility of achieving a significant level of vehicle mass reduction, enabling engine downsizing resulting in a tangible fuel reduction and environmental benefit. The MMLV project included the development of two (2) lightweight vehicle designs, referred to as Mach-I and Mach-II MMLV variants, based on a 2013 Ford production C/D segment production vehicle (Fusion). Weight comparison, life cycle assessment and limited full vehicle testing are included in the project scope. The Mach-I vehicle variant was comprised of materials and processes that are commercially available or previously demonstrated. The 363 kg mass reduction associated with the Mach-I design enabled use of a one-liter, three-cylinder, gasoline turbocharged direct injection engine, maintaining the performance and utility of the baseline vehicle. The full MMLV project produced seven (7) MMLV Mach-I "concept vehicles" which were used for testing and evaluation. The full vehicle tests confirmed that MMLV Mach-I concept vehicle performed approximately equivalent to the baseline 2013 Ford Fusion vehicle thereby validating the design of the multi material lightweight vehicle design. The results of the Life Cycle Assessment, conducted by third party consultant, indicated that if the MMLV Mach-I design was built and operated in North America for 250,000 km (155,343 miles) it would produce significant environmental and fuel economy benefits including a 16% reduction in Global Warming Potential (GWP) and 16% reduction in Total Primary Energy (TPE). The LCA calculations estimated the combined fuel economy of 34 mpg (6.9 l/100 km) associated with the MMLV Mach-I Design compared to 28 mpg (8.4 l/100 km) for the 2013 Ford Fusion.

Lightweight Materials and Technologies – MMLV Mach-I Vehicle

BIW	Al vacuum die casting, Al 6xxx stamping and extrusion, HSLA stamping, Al 5xxx stamping, PHS safety cage
Closures	Al 6xxx outer panel, Al 5xxx inner panel, PHS intrusion beam, Al cast hinge
Bumpers	Al 6xxx extrusion & crush can
Glazing	Hybrid chemically toughened/soda lime laminate front & side, PC rear
Engine	Al cast block, forged Al connecting rod, CF front cover, oil pan & cam carrier
Transmission	Al clutch hub, pump support & bolts, Mg valve body
Chassis	Al cast F/R subframe, hollow steel F/R stabilizer bars FR composite, Ti & hollow steel RR springs Al cast rotors with thermal spray coating

Interior	CF composite seat back and cushion structure
	CF composite IP/cross car beam
Tires	155/70R19 tires
Wheels	CF composite
Electrical	12 VDC Li battery

The Mach-II vehicle design was comprised of advanced materials and manufacturing processes which offer potential for future vehicle lightweighting application and which are not commercially available or previously demonstrated in a high volume application. The Mach-II design was intended to identify future product application areas and highlight technology gaps which need be addressed to enable commercial use of the lightweight material or manufacturing technology. The MMLV Mach-II design realized the 50% mass reduction target compared to the 2002 baseline vehicle. The mass associated with the carbon-fiber and magnesium-intensive Mach-II design was 761 kg (50%) lighter than the 2002 baseline vehicle. While many of the critical performance metrics were assessed, such as roof strength and side impact, the Computer Aided Engineering (CAE) tools used for the performance assessments have not been fully verified relative to physical models. The confidence in the veracity of all the performance assessments is considered low.

Lightweight Materials and Technologies – MMLV Mach-II Vehicle

BIW	Al vacuum die casting, Al 6xxx stamping and extrusion, HSLA stamping,
	Al 5xxx stamping, PHS safety cage
Closures	Al 6xxx outer panel, Al 5xxx inner panel, PHS intrusion beam, Al cast hinge
Bumpers	Al 6xxx extrusion & crush can
Glazing	Hybrid chemically toughened/soda lime laminate front & side, PC rear
Engine	Al cast block, forged Al connecting rod, CF front cover, oil pan & cam carrier
Transmission	Al clutch hub, pump support & bolts, Mg valve body
Chassis	Al cast F/R subframe, hollow steel F/R stabilizer bars
	Composite (epoxy+glass) F/R coil springs
	Al cast rotors with thermal spray coating
Interior	CF composite seat back and cushion structure
	CF composite IP/cross car beam
Tires	155/70R15 tires aramid cords
Wheels	CF composite
Electrical	12 VDC Li battery

Accomplishments

Quantifiable accomplishments during the course of the project include:

<u>Mach-I Design, Vehicle Build & Test</u>

- Joint testing to facilitate CAE predictive modeling
- Component-level CAE predictive modeling
- Full Vehicle CAE Predictive Modeling: NVH, durability and safety
- Tool Fabrication: BIW & chassis castings, stampings, extrusion, IP, seats, tires, wheels, springs
- Manufacture Lightweight Components: castings, stampings, extrusion, IP, seats, wheels, springs, rotors
- Module Subassembly: BIW, closures, bumpers, engine, transmission, subframes, tires/wheels, seats
- Corrosion: Anodize aluminum castings, E-coat subassemblies and BIW assembly

- Vehicle Integration: Teardown and integration of lightweight subassemblies with baseline vehicles
- Component-level Testing: doors, subframes, springs, seats, rotors
- Vehicle-level Testing: Selected corrosion, NVH, durability, fatigue and safety tests

Mach –II Vehicle Design

- BIW - CAE predictive modeling, topology optimisation, modal analysis, local point stiffness, cast Al body structure and CF passenger compartment
- Full Vehicle CAE predictive modeling of NVH, durability and safety
- Closures & Chassis – CAE predictive modeling, Mg sheet and castings
- Engine & Transmission – Naturally aspired 1.0 liter I3 lightweight engine concept with reduced torque lightweight six-speed manual transmission concept.
- Interiors – Structural trim panels, reduced function seats, reduced sound package

Table 1: Mass Summary, MMLV Mach-I and Mach-II

Subsystem Description	2002 Taurus	2013 Fusion	MMLV Mach-I DESIGN FINAL	MMLV Mach-I Prototype Vehicle	MMLV Mach-II DESIGN FINAL
Body Exterior and Closures (kg)	**574**	**594**	**456**	**492**	**308**
Body-in-White	n.a.	326	250	250	171
Closures-in-White	n.a.	98	69	88	51
Bumpers	n.a.	37	25	31	21
Glazings - Fixed and Movable	n.a.	37	25	25	18
Remainder - trim, mechanisms, paint, seals, etc.	n.a.	96	87	97	47
Body Interior and Climate Control (kg)	**180**	**206**	**161**	**191**	**100**
Seating	n.a.	70	42	61	34
Instrument Panel	n.a.	22	14	15	11
Climate Control	n.a.	27	25	27	10
Remainder - trim, restraints, console, etc	n.a.	88	80	88	45
Chassis (kg)	**352**	**350**	**252**	**269**	**165**
Frt & Rr Suspension	n.a.	96	81	85	55
Subframes	n.a.	57	30	44	17
Wheels & Tires	n.a.	103	64	58	42
Brakes	n.a.	61	49	51	34
Remainder - steering, jack, etc.	n.a.	33	29	32	18
Powertrain (kg)	**350**	**340**	**267**	**280**	**160**
Engine (dressed)	n.a.	101	71	83	63
Transmission and Driveline	n.a.	106	92	54	36
Remainder - fuel, cooling, mounts, etc.	n.a.	133	104	142	61
Electrical (kg)	**67**	**69**	**59**	**69**	**29**
Wiring	n.a.	28	25	28	14
Battery	n.a.	14	8	14	5
Remainder - alternator, starter, speakers, etc.	n.a.	27	26	27	9
Total Vehicle (kg)	**1523**	**1559**	**1195**	**1301**	**761**
Weight Save Compared to 2013 Fusion			**23.3%**	**16.5%**	**51.1%**
Weight Save Compared to 2002 Taurus			**21.5%**	**14.6%**	**50.0%**

MMLV Mach-I Design, Prototype Build and Test

The Mach-I vehicle incorporated materials and manufacturing process that are commercially available or have been demonstrated for high volume production The MMLV Mach-I project results are documented in the form of 14 technical papers, published by SAE International, Product Code of PT-170, ISBN of 978-0-7680-8223-4 and are attached in the form of PDF files as part of Appendix A. A copyright release associated with each paper has been granted by SAE.

The Mach-I Design reduced the curb weight to 1195 kg permitting the use of a 1.0 liter, three-cylinder gasoline direct injection turbocharged engine with lightweight material actions. This design, a 23.3% weight savings from the 2013 Fusion, was estimated to reduce Global Warming Potential (GWP) by 16% and reduce Total Primary Energy (TPE) also by 16%. The LCA calculations estimated the combined fuel economy of 34 mpg (6.9 l/100 km) associated with the MMLV Mach-I Design compared to 28 mpg (8.4 l/100 km) for the 2013 Ford Fusion.

The Mach-I Prototype underwent selected critical performance testing including the New Car Assessment Program's (NCAP) 35 mph full-frontal rigid barrier impact and the Insurance Institute for Highway Safety's (IIHS) 40 mph moderate overlap frontal impact. The MMLV prototype also was evaluated according to Ford Motor Company's standard passenger car criteria for rough road durability, corrosion and noise & vibration testing. The details and results of these tests are included Appendix A.

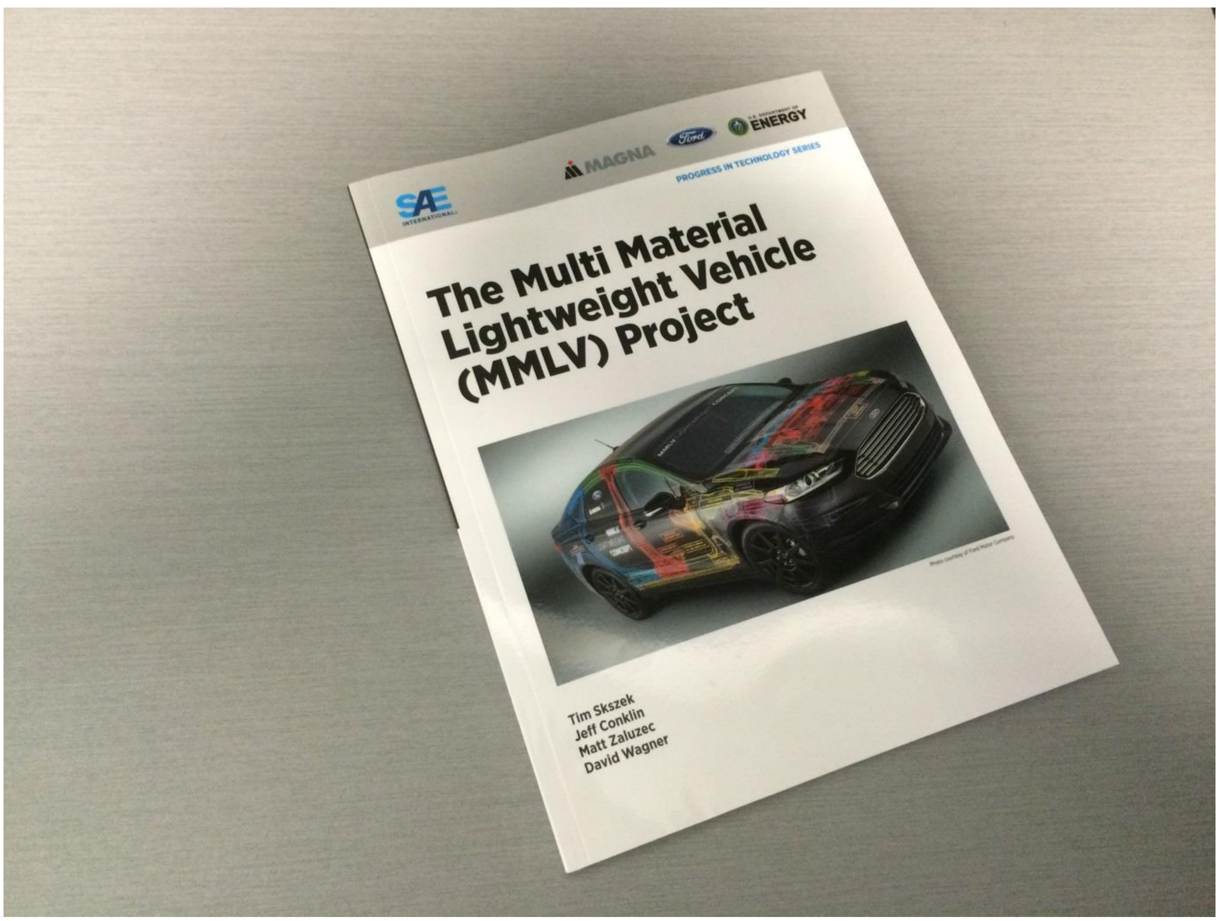


Figure 1: MMLV Mach-I Design Documentation

MMLV Mach-II Design

The MMLV Mach-II design incorporated materials and manufacturing process that "show potential" but are not yet proven commercially viable for high volume production. The Mach-II vehicle was designed without architectural constraints and obtained a mass reduction of 50% as compared to the 2002 Taurus vehicle. Examples include magnesium wrought body components for both Class A surfaces and inner panels, as well as thermoset carbon fiber (CF) reinforced materials for body structure and roof components. The use of magnesium and fiber reinforced composite material poses a significant risk in the area of multimaterial joining and galvanic corrosion.

While the Mach-II vehicle design meets selected safety targets based on CAE analyses, the 50% weight reduction target forced performance reductions in the non-safety related metrics. The noise, vibration and harshness (NVH) of the Mach-II design falls short of the performance of either the 2013 Fusion and 2002 Taurus. Additionally, many of the usual comfort and convenience features customers have come to expect in a vehicle have been eliminated to meet the 50% weight reduction target.

Body Exterior and Closures (276 kg)

Body-In-White - The MMLV Mach-II design contributed 155kg (47.5%) mass reduction relative to 2013 Fusion baseline vehicle. The BIW is comprised of a CF-intensive body structure and roof, vacuum die cast shock towers, stamped aluminum front rails and a press hardened steel safety cage. With the exception of the roof, Class A exterior body panels are warm formed magnesium sheet.

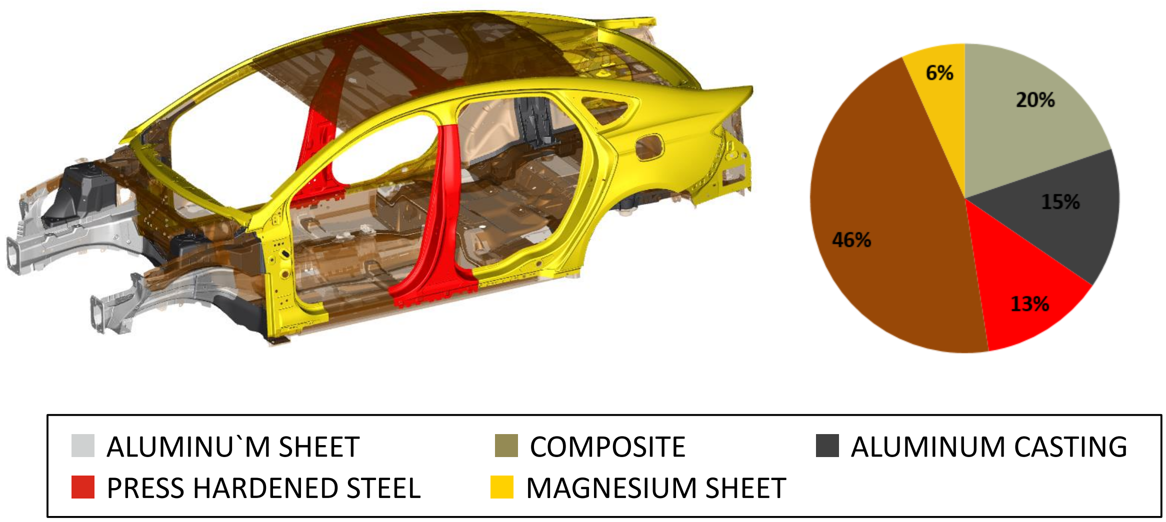
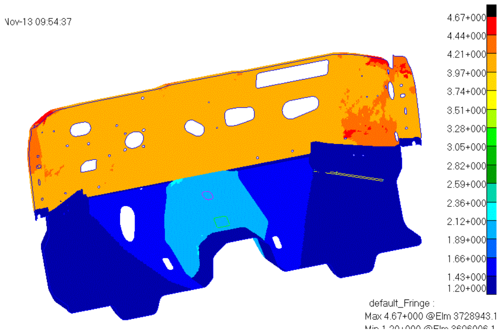


Figure 2 – MMLV Mach-II Body-in-White Material Distribution

- Modal Analysis - All carbon fiber components were optimized using MSC.Nastran™ Topology Optimization software. Lay-up thickness ranged between 1.25 mm and 5.0 mm to achieve the torsional stiffness targets of the BIW. Local reinforcements were added to achieve the targeted NVH modes of the BIW.



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

Figure 3 - Modal Analysis

- Stiffness - Lay-up thicknesses were modified and local reinforcements added to the optimized NVH model to meet the target requirements for stiffness. 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.

Table 2 – Local Stiffness

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

- Performance Simulation - The composite BIW was developed to meet the requirements for FMVSS 214 Deformable Side Impact Barrier, seat belt pull, FMVSS 216a roof crush, and IIHS frontal impact. CAE simulations were conducted for critical crush modes which includes 35 mph full frontal impact, Dynamic side impact and Roof-crush. Crash CAE simulation results are summarized in Figs. 4, 6 and 7. The material properties of the composite materials were limited for LS-Dyna, but aluminum/steel materials were readily available and designed in most of the energy absorbing areas for frontal impact response. The analysis resulted in failure of the composite material at the upper shot gun and good energy absorption from the aluminum front rails. Per CAE results, the overall frontal crush performance of Mach II with multi-material BIW is comparable to Mach I. The Computer Aided Engineering (CAE) tools used for the safety performance assessments have not been fully verified relative to physical models. The confidence in the veracity of all the performance assessments is considered low.

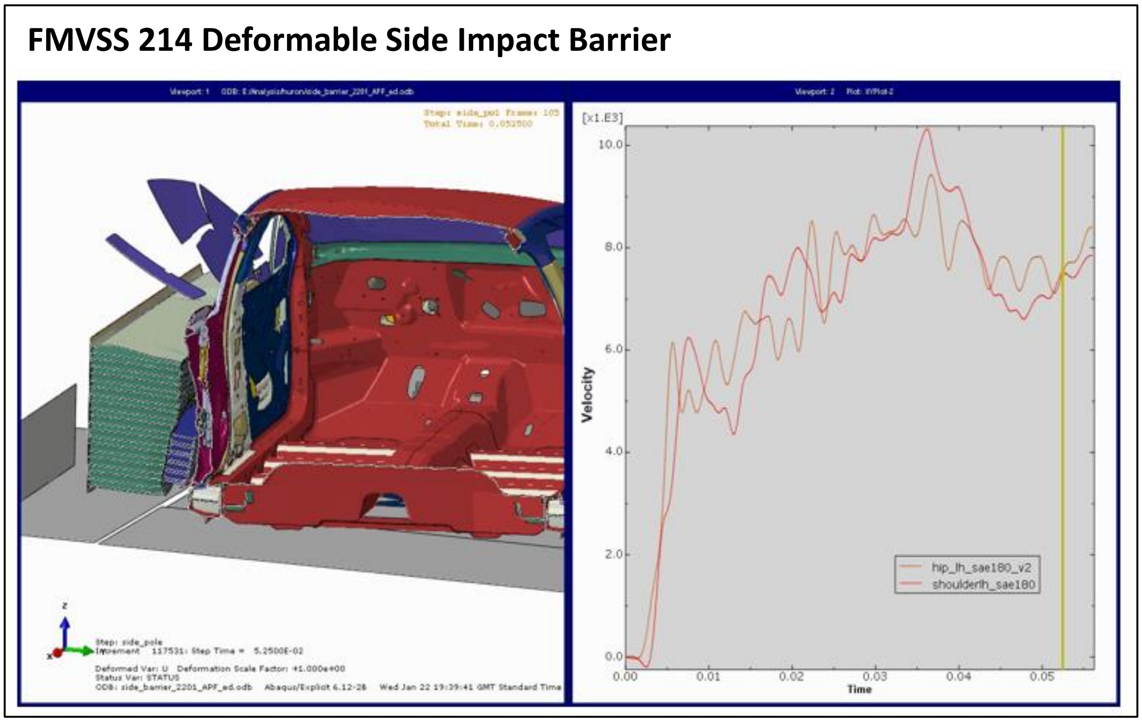


Figure 4 - FMVSS 214 deformable side impact barrier was run with a rationalized “complete” body in white model. Laminates were added for areas of concern and achieved relatively low levels of intrusion.

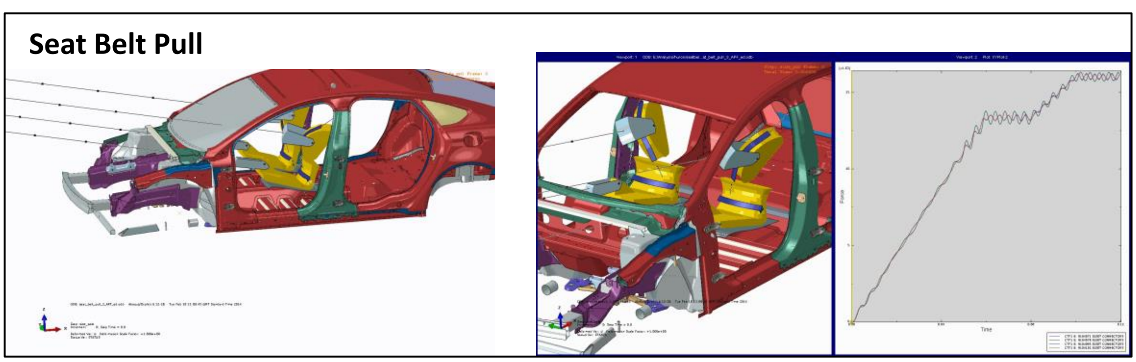


Figure 5 - Seat-belt load were applied to the optimized impact model and local laminate patches were added at seat mount locations. No cohesive failure was observed at the seat cross members.

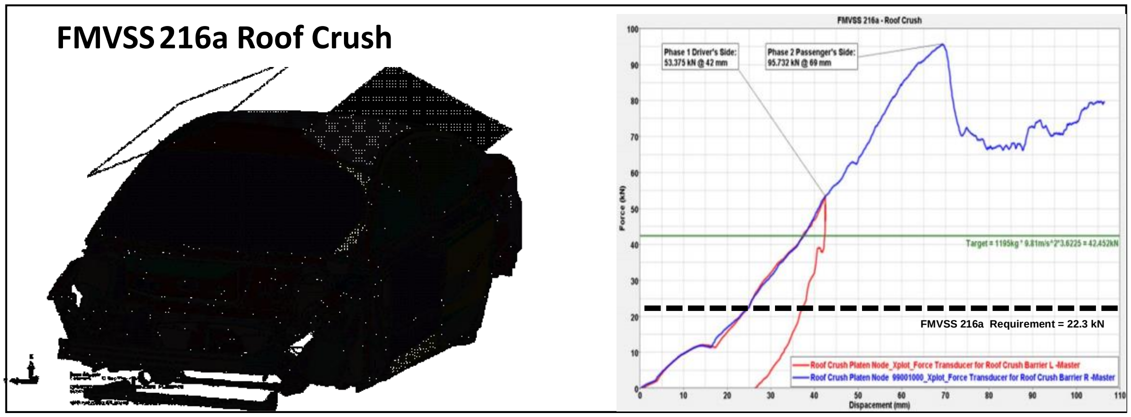


Figure 6 - FMVSS 216a roof crush was run on the optimized impact model. LHS force exceeded both the FMVSS 216a requirement of 3.0 times the unloaded vehicle weight and the IIHS “Good” rating of 4.0 times unloaded vehicle weight per the graph shown and the RHS force is over the target values as well.

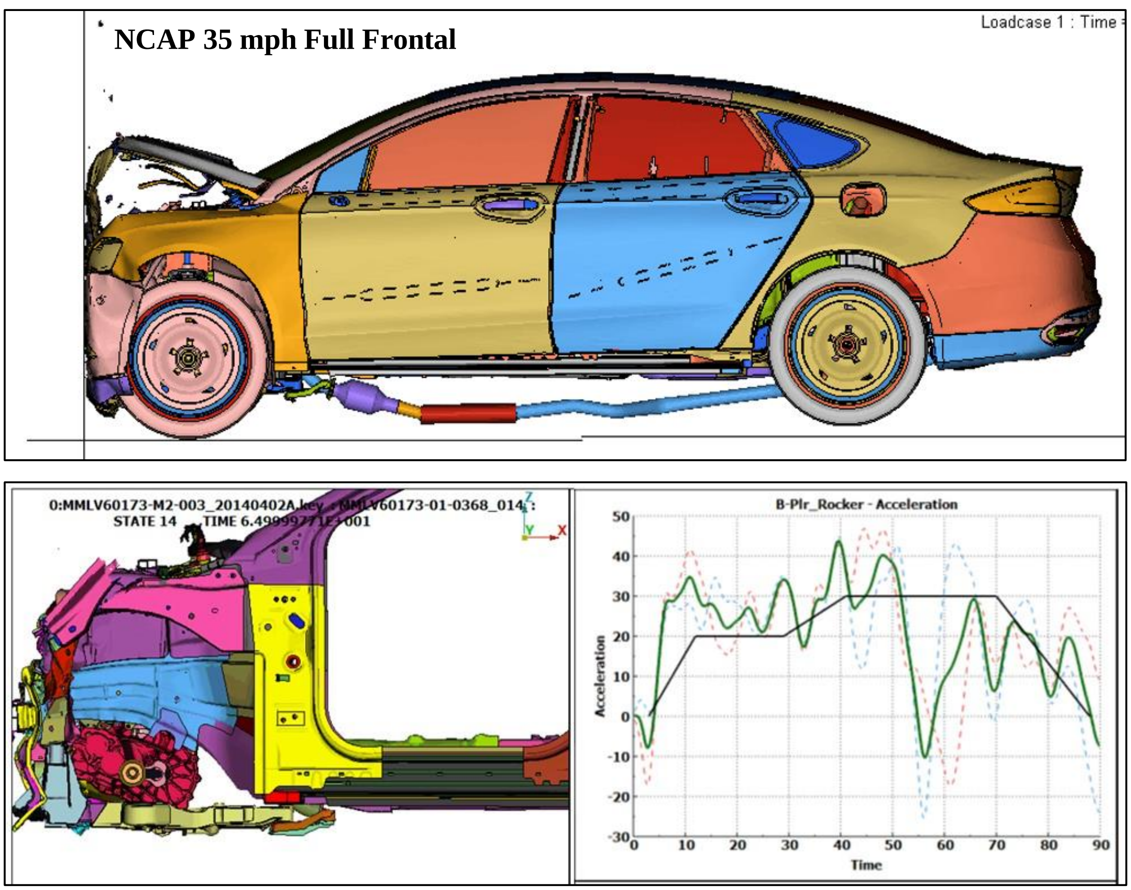


Figure 7 - NCAP front 35 mph rigid wall analysis was reviewed for crush deformation and pulse feedback.

Closures-in-White The Mach-II design provided a 47 kg (48%) mass reduction relative to the baseline vehicle. The multi-material construction includes warm-formed magnesium sheet, aluminum upper structure, cast magnesium mirror support and extruded aluminum mirror reinforcement. The multi-material closures were analyzed to meet oil canning, dent resistance, normal modes, belts stiffness and door sag requirements. Heming of magnesium sheet is identified as a technology gap. For the purpose of this study, hemming of magnesium door outers was assumed to be feasible.

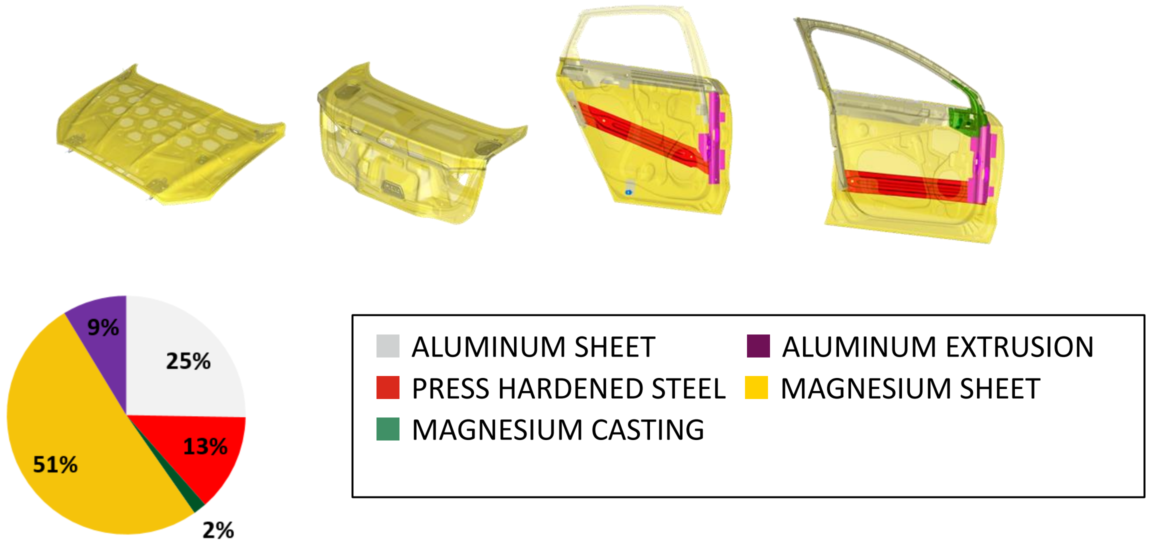


Figure 8 - Closure Material Distribution

Bumpers- The Mach-II bumper design provided 16 kg (46%) mass reduction relative to the baseline vehicle. The construction included an extruded aluminum bumper beam and stamped aluminum attachment brackets.

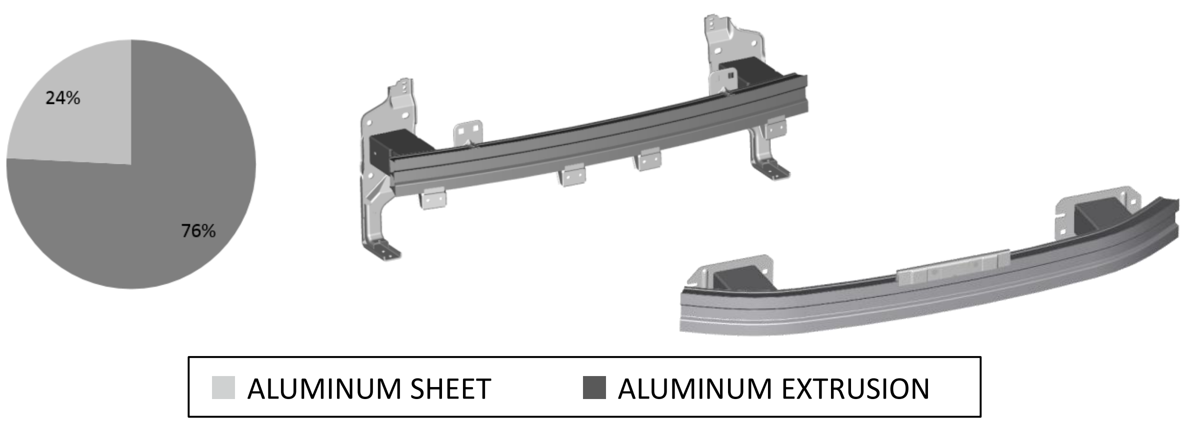


Figure 9 - Bumper Material Distribution

Glazings– The Mach-II glazings provided 19 kg (49%) mass reduction associated with the use of chemically toughened laminated glass for the front windscreen and drop/fixed side glass. In an effort to reduce mass, the rear glass is hinged and is not designed to drop into the door. The Mach-II rear backlight was comprised of polycarbonate.

Body Interior and Climate Control - The Mach-II design contributed 106 kg (51.5%) mass reduction. Lightweighting efforts included carbon fiber (CF) composite seat structures with reduced power adjust functionality and reduced foam padding, CF composite instrument panel and reduced content (bins and console), as well as elimination of the air conditioner.

Chassis – The Chassis subsystem provided 39 kg (47%) mass reduction relative to the baseline vehicle. Subframe materials include vacuum die cast magnesium and extruded magnesium components, while control arms and links were cast aluminum. Stiffness requirements were the main driver for all of the chassis component designs. The reduced Mach II vehicle mass contributed significantly to reduced durability/fatigue targets. The potential for galvanic corrosion between the cast magnesium structural materials, ferrous bushing sleeves and ferrous ball joints components was identified and need be addressed.

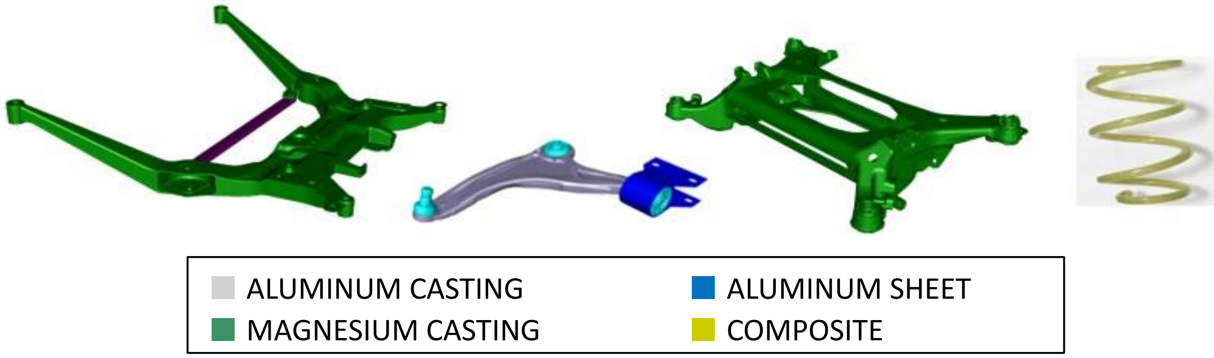


Figure 10 – Chassis Components Material Distribution

The coil springs for both the front and rear suspensions were designed as glass plus epoxy composites and sized to meet the reduced vehicle weight. Similarly the hollow steel stabilizer bars in both the front and rear were sized for the lightweight Mach-II vehicle. The carbon fiber composite wheels and aramid corded narrow tires were designed for 15 inch wheels to further reduce weight. These reduced sized wheels and tires would degrade the ride and handling of the Mach-II vehicle.

Powertrain – Engine and Powertrain modifications contributed a 180 kg (56%) mass reduction potential through deployment of the 1 liter, 3 cylinder engine, excluding the turbocharger, intercooler associated with the Mach-I vehicle. The transmission for the Mach-II Design was a reduced capacity six-speed manual with lightweight material substitutions for the transmission case, clutch housing and differential housing. The Mach-II powertrain development also included material changes associated with most other driveline components.

Figure 11 – Lightweight Downsized Powertrain Components

Technology Assessment / Gap Analysis

MATERIAL ISSUES

Steel Gaps

- There is a need for improved coatings on steels, especially ultra high strength steels, for multi material applications including corrosion mitigation, adhesive compatibility and welding friendliness.

Aluminum Gaps

- There is a need for materials and coatings to increase the die life for aluminum high pressure die castings.
- There is a need for improvements in coatings and processes for incorporating bi-metallic inserts in aluminum dies castings, certainly for low pressure castings and ideally for high pressure die castings as well.
- There is a need for low cost, high volume 7xxx aluminum sheet and extrusions.

Magnesium Gaps

- There is a need for materials and coatings to increase the die life for magnesium high pressure and vacuum assisted high pressure die castings.
- There is a need for improvements in coatings and processes for incorporating bi-metallic inserts in magnesium high pressure die castings.
- There are needs for many advances in magnesium sheet.
    - The automotive industry needs reliable commercial sources for magnesium sheet in the widths typically used in automotive applications, 60 inch widths and greater.
    - There is a need for improved processes and equipment for warm forming of magnesium sheet.
    - Improvements in hemming sheets would enable increased use in closure applications.
    - The surface finish of magnesium sheet needs to be improved, if it is to be used in any panels that are visible by the customer.
    - The corrosion mitigation and adhesive acceptability of the surface treatments on magnesium sheet need to be improved.

Carbon Fiber Composite Gaps

- There is a great need for material characterization and Computer Aided Engineering (CAE) tools for designing and evaluating carbon fiber composite structures for noise, vibration, durability, fatigue, and crashworthiness.
- There is a need for improved surface finish of carbon fiber composite at low cost and high volume, if it is to be used for any parts or panels that are visible to the customer.
- There is a need for improved corrosion mitigation strategies for carbon fiber composite components.
- There is a need for improved joining and assembly processes and techniques for incorporating carbon fiber composite components into multi material systems.
- There is a need for mold-in color and mold-in texture for carbon fiber composite components.
- There is a need for recyclable or reclaimable thermoset carbon fiber material and process systems.

Polymer Gaps

- There is a need for improved adhesives that supply high strength, high stiffness with high ductility and cure quickly at low temperatures (100ºC to 120ºC for less than ten minutes).

- There is a need for improved pump able material that performs the roles of both adhesive and joint sealer to provide the stiffness and strength required for joining as well as the corrosion mitigation, water and air ingress protection for sealing.

MULTI MATERIAL ISSUES

Corrosion Gaps

- There is a need for an improved pretreatment to be applied after body assembly and before painting such as a universal phosphate (or equivalent) and e-coat system that can supply expected corrosion mitigation for a bodies and closures with any mix of steel, aluminum, magnesium and composite.
- There is a need for self-piercing rivets material and coatings that do not act as galvanic corrosion starter sites. This need is greatest for joining multi materials, especially joint stacks that include any magnesium parts.

Joining Gaps

- There is a need for multi material joining methods with corrosion mitigation.
- There is a need for high hardness, high strength self-piercing rivets for joining ultra high strength steel components to multi material components.
- There is a need for "reversible" or "lockable / unlockable" joining methods to reduce the costs and complexity of repairs and disassembly.

Infrastructure Gaps

- There is a need for low cost, high volume vehicle disassembly and sorting materials by type and alloy or grade.

MULTI MATERIAL VEHICLE ISSUES

- There is a need for improved materials and technologies to reduce the weights of electrical components throughout the vehicle. The current trade-offs between low weight and low resistance materials are driving weight into motors, actuators and other components.
- There is a need for improved electrical power distribution and signal passing systems that reduce the weight, complexity and costs of these systems.
- There is a need for low cost, high volume noise vibration and harshness (NVH) treatments for lightweight panels, sheet metal and glazing.
- There is a need for low cost, high volume vehicle disassembly and sorting materials by type and alloy or grade.
- There is a need for lightweight engine architectures that include a bi-metallic (or mixed metallic and polymer) block plus composite "bolt-on" components with integrated cooling and noise mitigation systems.
- There is a need for low cost, high volume carbon fiber composite instrument panel with integrated heating, ventilating, air conditioning systems and structural cross-car plus cowl structure.
- There is a need for a multi material modular subframe system that can accommodate multiple powertrains and driveline configurations with low investment.
- There is a need for a lightweight, low cost complete side door system that meets safety, durability, fatigue, noise and vibration performance with all the currently expected customer features such as power windows, locks, and adjustable side view mirrors, with integrated speakers and interior storage.

PRESENTATIONS/PUBLICATIONS/PATENTS

AWARDS

2015 American Foundry Society Casting of the Year Award. MMLV vacuum die cast Front Kick Down Rail

2015 DOE Vehicle Technologies Office – Distinguished Achievement Award

PUBLICATIONS

TMS 2015

1. Beals, Conklin, Skszek, Wagner, and Zaluzec, "Aluminum High Pressure Vacuum Die Casting Applications for the Multi Materials Lightweight Vehicle (MMLV) Program Body Structure," 2015 TMS 144th Annual Meeting, March 15-19, 2015.
2. Bushi, Skszek, Wagner, Conklin and Zaluzec, "Multi-Material Lightweight Vehicle ("MMLV")," 2015 TMS 144th Annual Meeting, March 15-19, 2015.
3. Bushi, Skszek and Wagner, "Comparative LCA Study of Lightweight Auto Parts of MMLV MACH-I Vehicle as per ISO 14040/44 LCA Standards and CSA Group 2014 LCA Guidance Document for Auto Parts," 2015 TMS 144th Annual Meeting, March 15-19, 2015.
4. Zaluzec, Buschhaus, Jiang, Sabo and Barry, "Multi-Material Light Weight Vehicle (MMLV) – Powertrain Materials," 2015 TMS 144th Annual Meeting, March 15-19, 2015.

SAE WORLD CONGRESS 2015

1. 2015-01-0405 DOE Focuses on Developing Materials to Improve Vehicle Efficiency
   Schutte, Carol: Department of Energy Vehicles Technology
2. 2015-01-0407 MMLV: Project Overview
   Timothy W. Skszek, Magna International; Matthew Zaluzec, Ford Motor Company; Jeff Conklin, Magna International; David Wagner, Ford Motor Company
3. 2015-01-0408 MMLV: BIW Design and CAE
   Jeff Conklin, Randy Beals, Zach Brown, Magna International
4. 2015-01-0409 MMLV: Door Design and Component Testing
   Larry Plourde, Magna International; Michael Azzouz, Jeff Wallace, Ford Motor Co.; Mari Chellman, Magna International
5. 2015-01-1236 MMLV: Lightweight Interiors Systems Design
   John Jaranson, Ford Motor Company; Meraj Ahmed, Eicher Engineering Solutions
6. 2015-01-1237 MMLV: Chassis Design and Component Testing
   Xiaoming Chen, Ford Motor Company; Jeff L. Conklin, Robert M. Carpenter, Magna International; Jeff Wallace, Cynthia Flanigan, David A. Wagner, Vijitha Kiridena, Ford Motor Company; Stephane Betrancourt, Sogefi Group; Jason Logsdon, NHK Spring Group
7. 2015-01-1238 MMLV: Lightweight Engine Design
   Cliff Maki, Kevin Byrd, Bryan McKeough, Ford Motor Co.; Robert G. Rentschler, Ford Casting Operations; Brian J. Nellenbach, Rick L. Williams, James M. Boileau, Ford Motor Co
8. 2015-01-1239 MMLV: Carbon Fiber Composite Engine Parts
   Neal J. Corey, Mark Madin, Rick L. Williams, Ford Motor Co.

9. 2015-01-1240 MMLV: Automatic Transmission Lightweighting
James Kearns, Soon Park, Ford Motor Co.; John Sabo, Dusan Milacic, Magna International

10. 2015-01-0410 MMLV: Corrosion Design and Testing
Kevin Smith, Ying Zhang, Magna International

11. 2015-01-1613 MMLV: Vehicle Durability Design, Simulation and Testing
Nikhil Bolar, Thomas Buchler, Magna International; Allen Li, Jeff Wallace, Ford Motor Co.

12. 2015-01-1614 MMLV: Crash Safety Performance
Yijung Chen, Derek Board, Omar Faruque, Cortney Stancato, James Cheng, Ford Motor Company; Nikhil Bolar, Sreevidhya Anandavally, Magna International

13. 2015-01-1615 MMLV: Vehicle NVH Testing
Yuksel Gur, Ford Motor Company; Jian Pan, Autoneum North America Inc; John Huber, Jeff Wallace, Ford Motor Company

14. 2015-01-1616 MMLV: Life Cycle Analysis
Lindita Bushi, Life Cycle Assessment Consulting; Timothy Skszek, Magna International; David Wagner, Ford Motor Company

WEBSITES(S) OR OTHER INTERNET SITE(S)

Wagner, Zaluzec, Conklin and Skszek, "Mixed Materials Drives Lightweight Vehicle Design," Advanced Materials & Processes, an ASM International Publication, March 2015, Vol. 173, No. 3, pp 18-23.
http://amp.digitaledition.asminternational.org/i/480721-mar-2015

ANNOUNCEMENTS

MMLV Mach-I Media Announcements

Following the delivery of the first drivable Mach-I durability prototype vehicle, upper management at both Vehma/Magna and Ford used the vehicle to make press announcements on the MMLV project and research efforts on lightweight strategies. The announcements were well received and repeated across many media outlets. Here is a partial list of references to MMLV:

Ford Demonstrates Lightweight Fusion Concept
http://www.automobilemag.com/features/news/1406-ford-demonstrates-lightweight-fusion-concept/#14053651510851&188,shopper
by Jake Holmes | United States **Automobile Magazine** | Jun-4-2014

Ford revealed a new lightweight concept version of the Fusion sedan that is nearly 25 percent lighter than the standard car. As a result, the lightweight Fusion weighs as much as the Ford Fiesta hatchback. According to Ford, a 2014 Fiesta weighs 2537-2628 pounds, while a non-hybrid 2014 Ford Fusion tips the scales at 3323-3681 pounds, putting the weight loss somewhere in between 800-900 lbs.

Ford Launches Lightweight Concept
http://www.pistonheads.com/news/default.asp?storyId=30115 *PistonHeads.com*

Ford Unveils Ultra-Light Fusion Sedan Concept http://www.thedetroitbureau.com/2014/06/ford-unveils-ultra-light-fusion-sedan-concept/ *The Detroit Bureau*

Ford's Fusion Lightweight Concept Sheds a Quarter of the Sedan's Bulk http://wallstcheatsheet.com/automobiles/fords-fusion-lightweight-concept-sheds-a-quarter-of-the-sedans-bulk.html/?a=viewall *Wall St. Cheat Sheet*

Ford builds on advanced materials use in all-new F-150 with Lightweight Concept Car » Automotive World http://www.automotiveworld.com/news-releases/ford-builds-advanced-materials-use-new-f-150-lightweight-concept-car/ *Automotive World*

Ford unveils Fusion Lightweight Concept, partners with Samsung on lightweight battery research http://mms.tveyes.com/ExpandGuest.asp?ln=995903 *WJBK-TV (Fox) Channel 2 (Detroit)*

Ford unveils Lightweight Fusion Concept
http://mms.tveyes.com/ExpandGuest.asp?ln=995768 *WXYZ-TV (ABC) Channel 7 (Detroit)*

Ford shows off experimental Fusion 23% lighter than normal
http://www.tweaktown.com/news/38222/ford-shows-off-experimental-fusion-23-lighter-than-normal/index.html
Blog: TweakTown

Ford Unveils Special, Lighter-Weight Fusion
Prototype Is 23% Lighter, Sets Road Map for Next-Generation Weight-Reduction Efforts
by Mike Ramsey | United States
The Wall Street Journal | Jun-4-2014 http://online.wsj.com/articles/ford-unveils-special-lighter-weight-fusion-1401831431?mod=WSJ_qtoverview_wsjlatest

Associated Press Ford unveils lightweight concept car
By Dee-Ann Durbin June 3, 2014
http://www.miamiherald.com/2014/06/03/4155763/ford-unveils-lightweight-concept.html

CNET Ford concept car shows benefits of weight loss
Electrification and efficient drivetrains play a part in increased fuel economy, but making cars lighter delivers the coup de grace.
By Wayne Cunningham June 3, 2014
http://www.cnet.com/news/ford-concept-car-shows-benefits-of-weight-loss/

USA Today Ford shows off lightweight car concept
By Chris Woodyard June 3, 2014
http://www.usatoday.com/story/money/business/2014/06/03/ford-fusion-lightweight/9928467/

The Wall Street Journal
Ford Unveils Special, Lighter-Weight Fusion
Prototype Is 23% Lighter, Sets Road Map for Next-Generation Weight-Reduction Efforts
By Mike Ramsey June 3, 2014
http://online.wsj.com/articles/ford-unveils-special-lighter-weight-fusion-1401831431

San Francisco Chronicle Ford, partners unveil projects to improve cars' efficiency
By David R. Baker June 3, 2014
http://www.sfchronicle.com/business/article/Ford-partners-unveil-projects-to-improve-cars-5526228.php

Jalopnik Ford Just Unveiled A Fusion That Weighs As Little As A Fiesta
By Michael Ballaban June 3, 2014
http://jalopnik.com/ford-just-unveiled-a-fusion-that-weighs-as-much-as-a-fi-1585576176

LA Times Ford Fusion loses 25% of its weight in lightweight concept version
By Charles Fleming June 3, 2014
http://www.latimes.com/business/autos/la-fi-hy-ford-lightweight-concept-car-20140529-story.html

Ubergizmo Ford and Samsung Car Dual-Battery Presented in San Francisco
By Eliane Fiolet June 3, 2014

http://www.ubergizmo.com/2014/06/ford-and-samsung-car-dual-battery-presented-in-san-francisco/

DailyTech Ford Lightweight Concept Removes 800 lbs. from Fusion Midsize Sedan
By Brandon Hill June 3, 2014
http://www.dailytech.com/Ford+Lightweight+Concept+Removes+800+lbs+from+Fusion+Midsize+Sedan/article35006.htm#sthash.V9OcoNRE.dpuf

Detroit Free Press
Ford future technology unveiled in Lightweight Concept
By Alissa Priddle
June 3, 2014
http://www.freep.com/article/20140603/BUSINESS0102/306030181/Ford-Fusion-lightweight-concept-F-150-aluminum-auto

Detroit News Ford reduces Fusion concept's weight 23%
By Karl Henkel June 3, 2014
http://www.detroitnews.com/article/20140603/AUTO0102/306030097/1361/Ford-reduces-Fusion-concept-s-weight-23-

Motor Trend Ford Lightweight Concept First Look
By Frank Markus June 3, 2014
http://www.motortrend.com/future/concept_vehicles/1406_ford_lightweight_concept_first_look/

WardsAuto Ford Concept Car Takes Lightweighting to Extreme
By Byron Pope June 3, 2014
http://wardsauto.com/vehicles-technology/ford-concept-car-takes-lightweighting-extreme

CarAdvice Ford Lightweight Concept Car
By Derek Fung June 3, 2014
http://www.caradvice.com.au/289218/ford-lightweight-concept-car-a-fusionmondeo-that-weighs-as-little-as-a-fiesta/

TheFastLaneCar.com Ford LightWeight Concept turns a Fusion into a Fiesta [Preview]
By Andre Smirnov June 3, 2014
http://www.tflcar.com/2014/06/ford-lightweight-concept-turns-a-fusion-into-a-fiesta-preview/

MotorAuthority Ford Fusion Lightweight Concept Car Goes All-Out with High-Tech Weight Savings:Video
By Nelson Ireson June 3, 2014
http://www.motorauthority.com/news/1092484_ford-fusion-lightweight-concept-car-goes-all-out-with-high-tech-weight-savings-video

Motoring.com Ford's Feather-Weight Fusion June 3, 2014
http://www.motoring.com.au/news/medium-passenger/fords-feather-weight-fusion-43905

TECHNOLOGIES / TECHNIQUES
No technologies/techniques have resulted from the research activities took place during the reporting period.

INVENTIONS, PATENT APPLICATIONS, AND/OR LICENSES
Vehma did not have any inventions, patent applications, and/or licenses as a result of this program.
Ford has identified the following items as a result of the program in the Patent Certification (DOE F 2050.11): Fatigue Life Testing with Water and Alternating Temperatures for Composite Components, Removal of Heat Out of Aluminum Brake Rotor While Protecting Wheel Hub Bearings, Composite Cam Carrier, Bulkhead Insert I Beam Tie Bar, and Brake Rotor Mechanical Roughening.

OTHER PRODUCTS
No other significant products were developed under this project.

APPENDIX 4 – PARTICIPANTS AND OTHER COLLABORATING ORGANIZATIONS

Please provide the following information for each person that qualifies under criteria 1 and/or 2.

Name:	Timothy Skszek
Project Role:	Principal Investigator
Nearest person month worked:	20.5
Contribution to Project:	Project Management and reporting

Name: Project Role:	Buhler, Nikhil Engineer, Lead CAE
Nearest person month worked:	15.0
Contribution to Project:	CAE Analysis

Name: Project Role:	Conklin, Jeff Manager, Department
Nearest person month worked:	18
Contribution to Project:	Project Management and reporting

Please provide the following information for each organization that qualifies.

Organization name:	Ford Motor Company
Location:	Dearborn, Michigan
Contribution to Project:	subcontractor
More detail on partner:	Domestic

APPENDIX 5 – PROJECT IMPACT

Ford Motor Company recently announced that the 2016 Shelby GT350R Mustang will be equipped with carbon fiber composite wheels. The investigations and early testing of the MMLV team on the carbon fiber wheels helped speed the development of the carbon fiber wheels for the Shelby GT350R Mustang.