



Multi-Material Lightweight Prototype Vehicles Demonstration

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Vehma International

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LM072

Acknowledgement



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Overview



Timeline

- Start Date: 2012-Feb
- End Date: 2014-Dec

Budget

Total Project Funding \$20,288,755

- DOE: \$10,000,000
- Vehma / Ford \$10,288,755

Budget Period 1 Funding \$7,703,413

Expenditure of Funds to Date

- DOE \$1,174,468
- Vehma \$ 518,561
- Ford \$ 655,908

Partners

- Vehma International
- Ford Motor Company

Barriers

The feasibility of achieving the Mach-I vehicle mass reduction objective of 37-40% was impacted by the items listed below:

- FMVSS Regulations - The evolution of FMVSS standards from 2002 to 2012 is estimated to impose a vehicle-level mass reduction penalty of approximately 5% to 7%.
- Donor Vehicle Architecture & Packaging - The Mach-I project scope includes use of a current model year “donor vehicle”, avoiding the time and cost to reengineer and tool a complete new vehicle. Maintaining the current model year “donor vehicle” architecture and packaging constraints imposed a vehicle-level mass reduction penalty of approximately 5%.
- Integration of Optimized Subsystems such as HVAC and Electrical do not provide vehicle-level mass reduction opportunities.
- Project Scope and Funding Level did not permit mass reduction of the transmission.

Project Objectives / Relevance



Project Objectives

1. Design and build Mach-I prototype vehicles, staying within a donor vehicle architectural space, that will obtain a mass reduction of 37-40%, as compared to the 2002 Taurus baseline vehicle. Mach I design shall a) utilize “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-1 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, materials, and process used to manufacture the light weight Mach-I vehicle design is viable for OEM production. (FMVSS, NVH, Durability, and Corrosion)
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.

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 constraints 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
 - Body in White (BIW) & Closures - Multimaterial 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.*

MMLV Milestone Status

(as of 2013-Mar-01)



| Milestone | Component | Scheduled Start Date | Scheduled End Date | % Complete |
|--|---------------------------------------|----------------------|--------------------|------------|
| Mach-I design complete CAE Predictive models complete Vehicle assembly Bill of Materials (BOM) complete | BIW, Closure, Suspension | 01/2012 | 01/15/2013 | 100 |
| Select engine, transmission and driveline combinations to meet performance requirements and Mach-I vehicle mass. | Engine, Transmission, Driveline Combo | 01/2012 | 12/12/2012 | 100 |
| Identify the interior, suspension, seat, and other component candidates for the light weighting to meet the weight targets for the Mach-I design level vehicle | Suspension, Interior, Seats | 01/03/2012 | 12/12/2012 | 85 |
| Mach-I Vehicle integration of unique light weight material designs into current production intent donor vehicle to facilitate full vehicle-level testing and safety validation per FMVSS guidelines. | Vehicle Build | 09/2012 | 06/2013 | 80 |
| Component tooling build release to manufacture the unique light weight material parts based on the Mach-I design concept. | BIW, Closure, Suspension | 01/30/2013 | 06/2013 | 5 |
| Assembly tooling release to manufacture the light weight assembly modules based on the Mach-I design concept | Component | 06/03/2013 | 10/4/2013 | 0 |
| Mach-I Vehicle build integration of light weight vehicle components using current production OEM donor vehicle. | Vehicle | 12/1/2013 | 3/1/2014 | 0 |
| Component testing initiated on Mach-I light weight vehicle components and sub-assemblies | Component | 10/02/2013 | 03/28/2014 | 0 |
| Mach-I initial vehicle build complete and physical testing initiated for NVH, corrosion, durability, and crash to validate design. | Vehicle | 01/16/2014 | 06/27/2014 | 0 |
| Commence Mach-II Design Phase | Vehicle | 03/04/2013 | 9/27/2013 | 0 |



The Mach-I vehicle design architecture is based on the donor vehicle, resulting in limitations in weight reduction due to packaging/space constraints. Design iterations associated with the BIW and closures considered the following:

- Material Substitution from Wrought Steel to Cast & Wrought Aluminum – A significant portion of the Mach-I weight reduction is related to the replacement of steel components with aluminum wrought and cast components. Aluminum stampings and high vacuum die castings comprise the majority of BIW & closure components. Aluminum High Pressure Vacuum Die Castings (HPVDC*) offer an efficient material distribution to achieve the stiffness requirements and maintain the joint stability during a crash event, as well as reducing the number of component parts and associated tooling/assembly costs. Aluminum extrusions were used in areas to utilize the sectional properties of a closed section, providing for weight reduction while maintaining the stiffness requirements.
- Load Path of Impact Requirements – Press Hardened Steel (PHS) was chosen as the material in the major impact load paths for maximum energy absorption and strength considerations (front rail, B-pillar, roof rails).
- Dimensional Stability and Assembly Strategy – The assembly of the BIW was designed for a production intent process that can be adapted to current production facilities. This included the correct slip planes, datum scheme, and process flow to assembly dimensional functional BIW.
- Joining Strategy – Joining dissimilar materials for structural integrity was accomplished by using current industry methods that are currently used, or could be, adapted to higher volume vehicle programs. These include SPR's (Self Piercing Rivets*), one sided FDS (Flow Drill Screws*), structural rivets*, friction stir welding*, and structural adhesive bonding*.
- Corrosion Strategy – Galvanic corrosion is a product of joining dissimilar materials. The process of e-coating all steel components and/or e-coating of assembly modules reduces the possibility of galvanic corrosion. Also, an adhesive will be used in every joint for a barrier between dissimilar materials and for increased joint strength and stiffness.*

Mach-I Technical Approach / Strategy

Other Vehicle Components



Weight reduction design iterations on other vehicle components are as follow:

- Vehicle Chassis – Aluminum Low Pressure Die Castings (LPDC), including hollow castings, offered an efficient material distribution to meet the stiffness & durability requirements for front and rear cradles. A combination of aluminum forgings, castings, and extrusions were used for weight reductions on front and rear suspension links. Lightweight materials and novel architectures were included for wheels, tires, springs, stab bars and rotors for additional weight reductions*.
- Bumper Systems – Aluminum extrusions designed for optimal impact integrity were the primary weight reduction method for the front and rear bumper systems.
- Powertrain – An existing Ford Motor Company 1.0 liter three cylinder GTDi (Gas, Turbocharged, Direct injection) engine was chosen for improved C/D segment vehicle weight reduction. Mach-I design incorporates an advanced aluminum engine block design, cast iron cylinder bore liners, composite oil pan, magnesium transmission case, aluminum transmission plates and planetary carrier.
- Interior and Glazing's – Many different lightweight materials were incorporated into interiors and glazing's for the Mach-I design. The materials include the following: MuCell and chemically foamed plastic, carbon fiber*, magnesium, polycarbonate and chemically toughened glass*.

Mach-II Technical Approach / Strategy



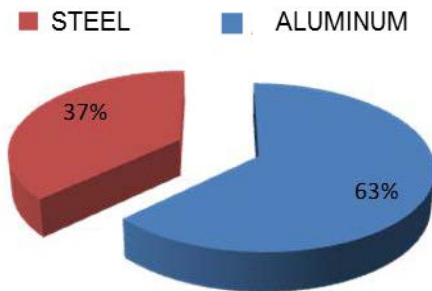
Mach-II design will include a new vehicle architecture, comprised of advanced materials” and joining methods* to achieve the 50% reduction in mass.

- BIW & Closures - The Mach-II BIW and closure design architecture will incorporate the use of advanced material such as magnesium and/or carbon fiber. The areas that are critical to load path and stiffness will remain aluminum and/or PHS steel. Carbon fiber* and magnesium* will be considered for outer panels and/or non structural areas. Magnesium and carbon fiber are two technologies that are not ready for high volume production, but with additional research, could be a possible weight reduction solution for body structures in the future.
- Chassis – Use of cast and wrought magnesium* and/or carbon fiber* will be the main weight reduction method for the chassis components. These advanced materials will be used for weight reductions on front and rear cradles and suspension links. Alternative lightweight materials and novel architectures will be reviewed for wheels, tires, springs, stab bars and rotors for additional weight reductions.
- Powertrain – A new, smaller, higher power density engine, transmission and driveline system is envisioned for the Mach-II design to take advantage of the 50% reduced vehicle weight. Material investigations will include magnesium and carbon fiber above the opportunities identified in Mach-I”. Consideration will be given to reducing vehicle performance to match 2002 levels for 0-60 time and other metrics. Reduced fuel and cooling systems will be included as secondary weight saving opportunities.
- Interiors and Glazings – New concepts such as fixed position seats* and printed wiring harnesses* will be considered along with carbon fiber composites”, structural + aesthetic interior panels, plus lightweight foams* and acoustic materials to further reduce the weight of interior systems. Research level glazing materials” will be considered.

Technical Accomplishments

BIW Structure Mach-I Design

MMLV BIW MATERIAL DISTRIBUTION



● HOT STAMPED STEELS

● STAMPED STEELS

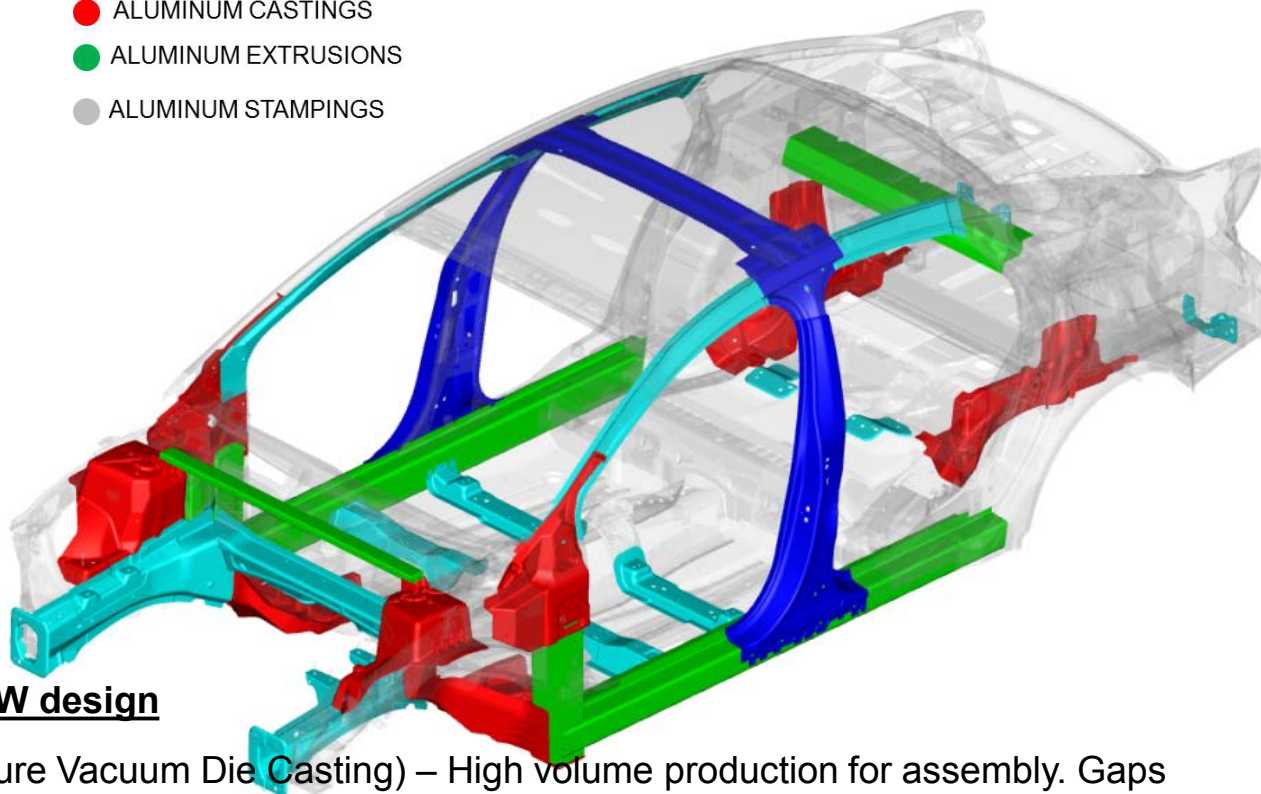
● ALUMINUM CASTINGS

● ALUMINUM EXTRUSIONS

● ALUMINUM STAMPINGS

MMLV CURRENT STATUS – 250 kg
(37% Steel, 63% Aluminum)

(Includes GA Parts, Battery Tray,
and Radiator Reinforcement)



Technology enabler for MMLV BIW design

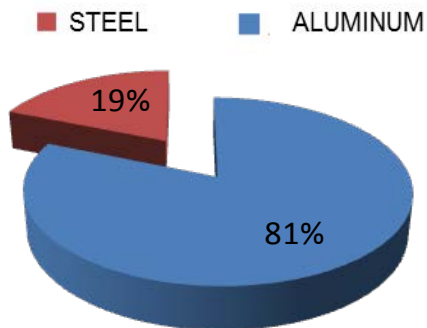
- Aluminum HPVDC (High Pressure Vacuum Die Casting) – High volume production for assembly. Gaps in global capacity exist worldwide. *
- Multi-material Joining - Adhesive, SPR (Self Piercing Rivet), FDS (Flow Drill Screws), and structural rivets implemented for high volume production*
- Assembly & Corrosion Strategy – Subassemblies will be E-coated, allowing integration in current OEM paint lines.

Technical Accomplishments

Closure Structure Mach-I Design



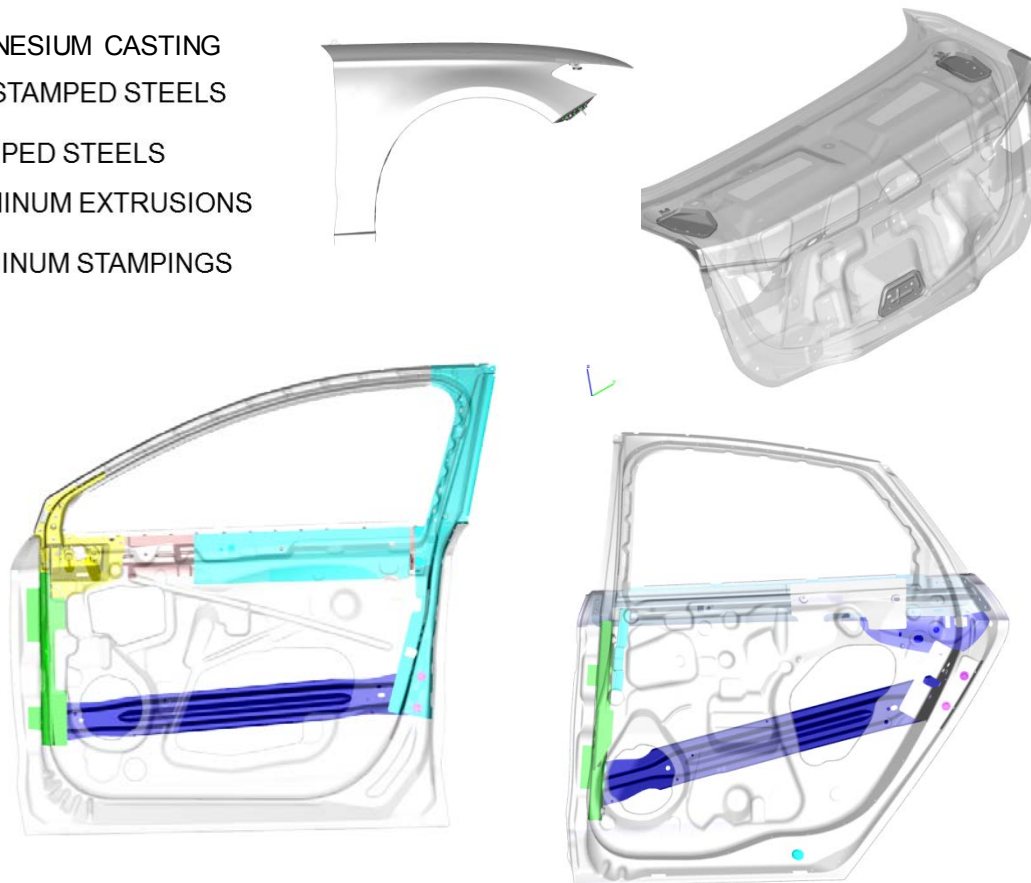
MMLV CLOSURES MATERIAL DISTRIBUTION



- MAGNESIUM CASTING
- HOT STAMPED STEELS
- STAMPED STEELS
- ALUMINUM EXTRUSIONS
- ALUMINUM STAMPINGS

**MMLV CURRENT STATUS – 69 kg
(19% Steel, 81% Aluminum)**

**New Multimaterial Door Design Architecture
incorporating Mg castings, Al stampings, Al
extrusions and steel ***



Technology enabler for MMLV BIW design

- Magnesium HPVDC (High Pressure Vacuum Die Casting*) – High volume production for assembly.
- Multi-material Joining - Adhesive, SPR (Self Piercing Rivet), and structural rivets implemented for high volume production*
- Use of aluminum extrusions for stiffness requirements at hinge areas to allow minimum thickness for inner and outer aluminum panels.

Technical Accomplishments

Joining Methods for BIW & Closures Mach-I Design

Multi-Material Joining

Aluminum to steel materials need to be joined by a mechanical joining method with an structural adhesive median because of the galvanic corrosion concern. SPR's (self-piercing rivets) are the most commonly used method for this type of joint. "

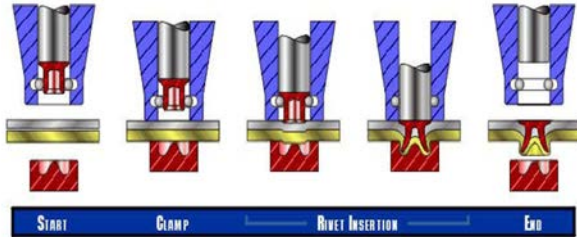
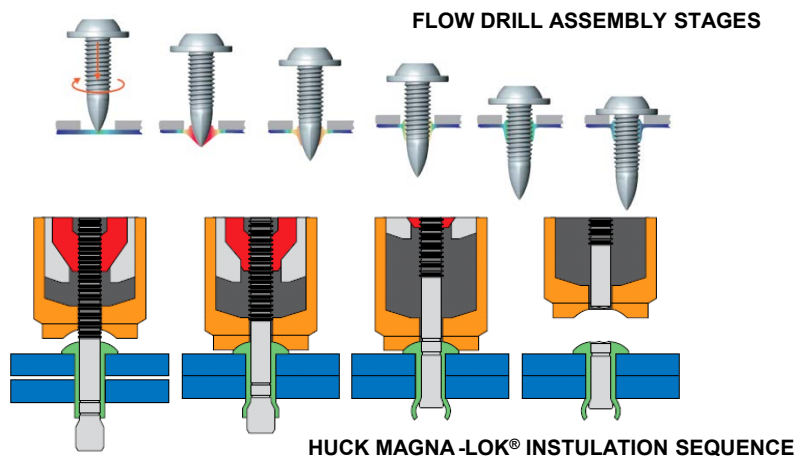


Figure 1: Self Pierce Riveting Process

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



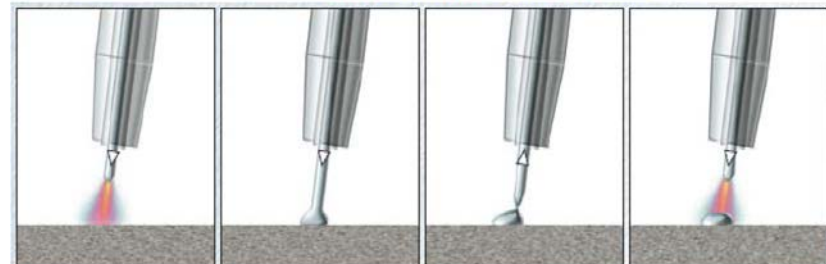
Joint Adhesive

All mechanical fastened joints will have adhesive for increased strength and reduce galvanic corrosion. Two adhesive will be used for this program; Dow Betamate™ 73305, a heat activated adhesive for any modules that will go thru an E-coat process and Dow Betamate™ 73326, an air cured activated adhesive that will be used for the final framer and modules that do not get e-coated.

Aluminum to aluminum spot welding is possible, but cleanliness is a concern because of aluminum's rapid surface oxidation characteristics. For optimum quality and weld performance, expensive cleaning procedures to remove surface oxide are required and the added expense of ensuring a high-quality weld for high volume production was determined to be non-feasible. Because of this reason, SPR's were also used for aluminum to aluminum joints for the BIW & closures design.

In some unique aluminum to aluminum joints, cold metal transfer (CMT) process will be used for the jointing method. In the vehicle build phase of this program, this CMT process will be simulated by TIG welding.

- Alternating process from hot-cold hot-cold hot-cold repeatedly



During the arcing period, the filler metal is moved towards the weld pool.

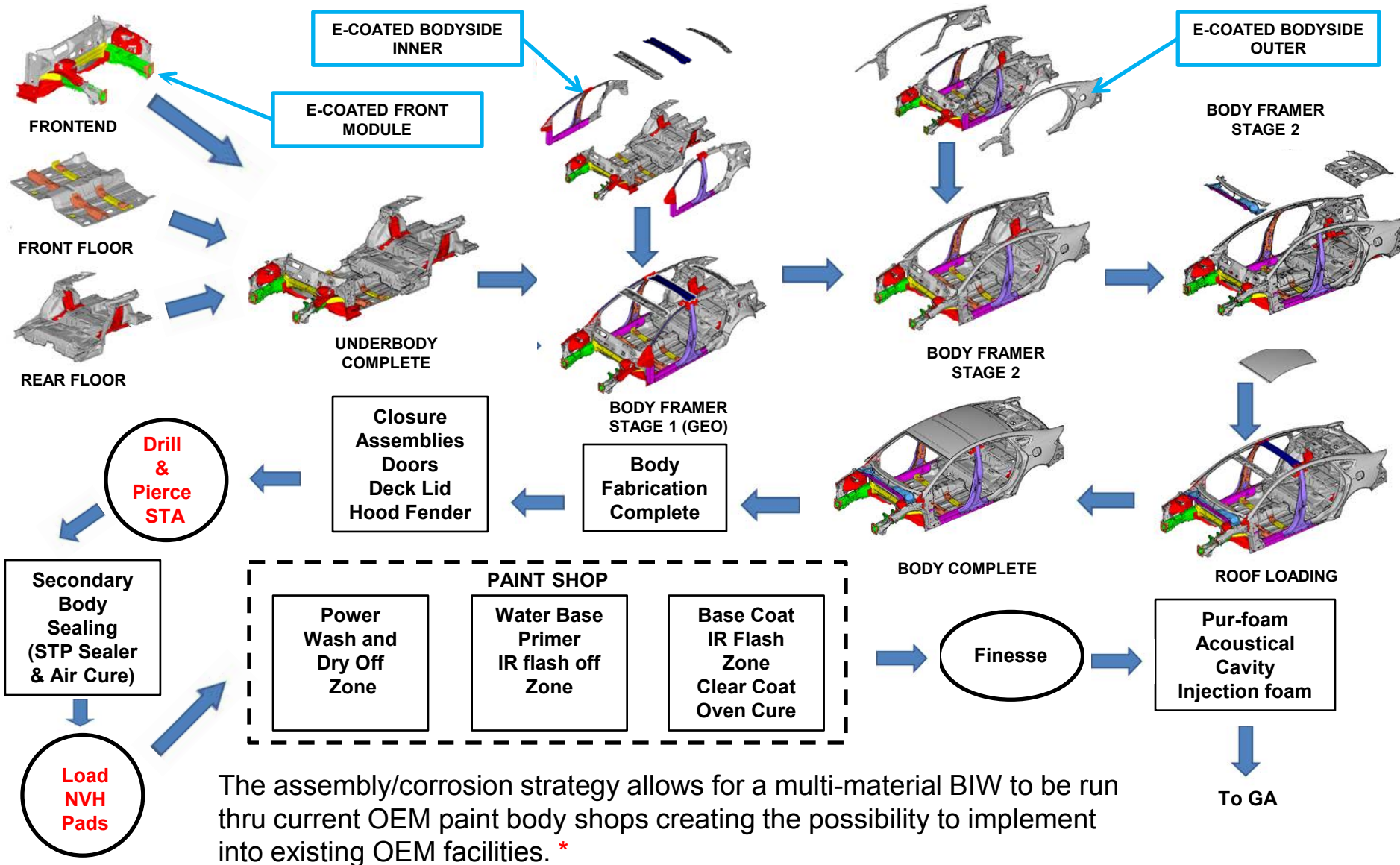
When the filler metal dips into the weld pool, the arc is nearly extinguished. The welding current is reduced

The reverse movement of the wire assists droplet detachment during the short circuit. The short-circuit is kept small.

The wire motion is reversed and the process begins all over again.

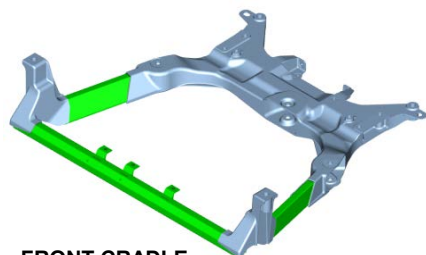
Technical Accomplishments

Assembly Process & Corrosion Strategy – Mach-I Design

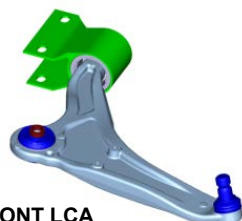


Technical Accomplishments

Chassis Structure & Bumper Systems – Mach I Design

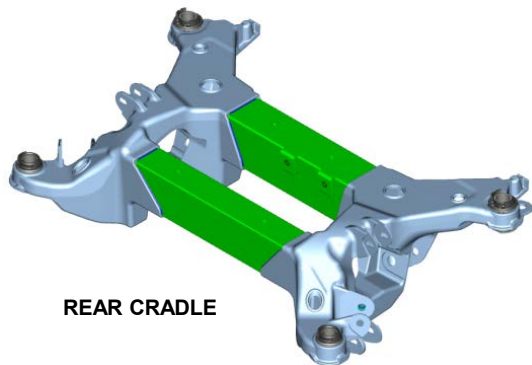


FRONT CRADLE

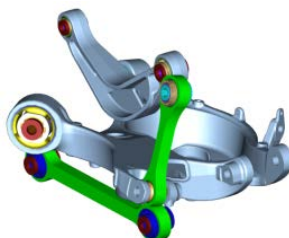


FRONT LCA

- ALUMINUM CASTINGS
- ALUMINUM EXTRUSIONS
- ALUMINUM STAMPINGS



REAR CRADLE



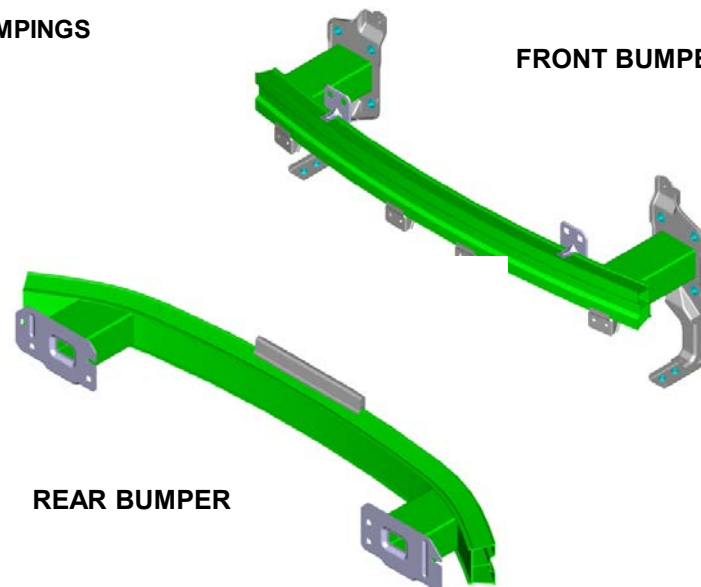
REAR LINKS & LCA

MACH-I TARGET MASS

Suspension - 79 kg
Cradles – 34 kg

MMLV CURRENT STATUS (89% Alum, 11% Steel)

Suspension - 81 kg
Cradles – 30 kg



FRONT BUMPER

REAR BUMPER

MACH-I TARGET MASS 15.27 kg

MMLV CURRENT STATUS – 11.13 kg

Technology enabler for MMLV chassis & bumper design

- Aluminum cast/extrusion welded assemblies exist in low volume production. No gaps exist to make these components in high volume production.
- Aluminum extrusion welded assemblies exist in high volume production. No gaps exist to make these components in high volume production.

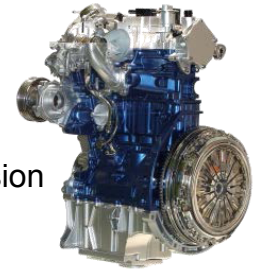
Technical Accomplishments

Vehicle Component Weight Reduction – Mach-I Design



POWERTRAIN – Design Weight 275 kg (24% reduction from 2002 Taurus)

- 1.0 liter three cylinder GTDi (Gas, Turbocharged, Direct injection) engine,
- Automatic 6-speed transmission (under development for future product), FWD (front wheel drive).
- Aluminum engine block, cast Iron cylinder bore liners, magnesium transmission case, aluminum transmission plates and planetary carrier.



SUSPENSION COMPONENTS – Design weight reduction of approximately 30% on these components

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



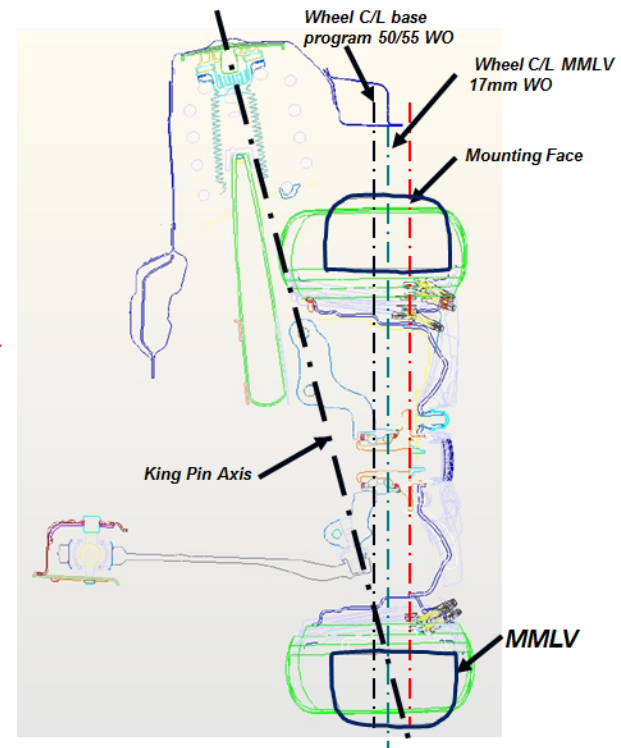
Aluminum brake rotor with thermally sprayed wear resistant coating



prototype lightweight wheels



Evaluate hollow steel and composite coil springs



Technical Accomplishments

Vehicle Component Weight Reduction – Mach-I Design

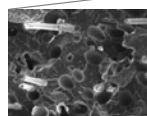


• INTERIOR COMPONENTS

- 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 plastic trim saves 15%



40% weight reduction
improved air insulation



10% weight reduction
improved dimensions



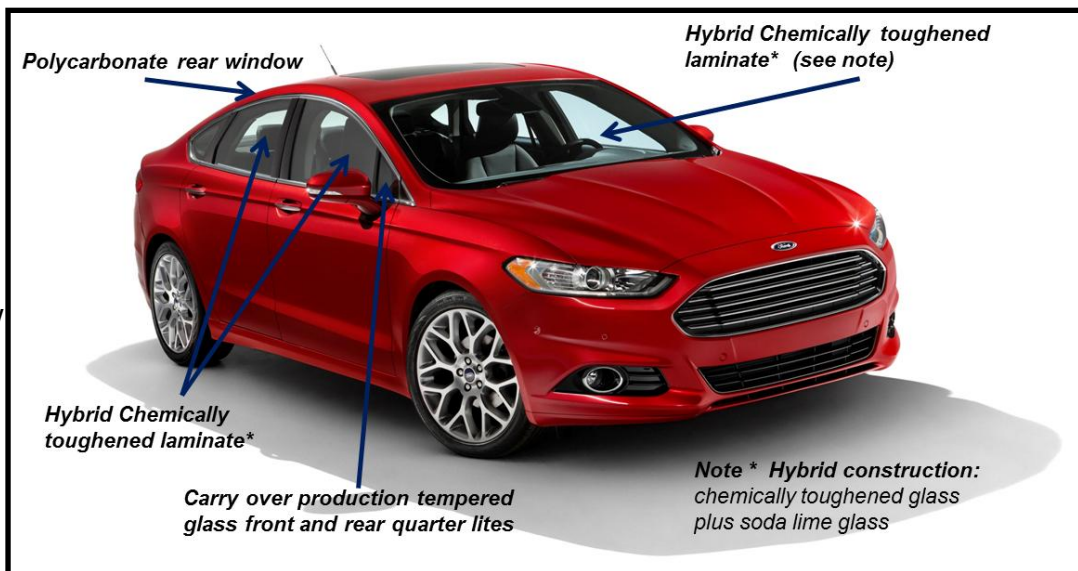
Carbon Fiber
Seat Frame

GLAZINGS -

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



Chemically Toughened Glass
and Polycarbonate"



Technical Accomplishments

Vehicle Mass Tracking – Mach-I



CAE analysis indicates that the Mach-I vehicle design will meet current FMVSS requirements.

The MMLV Mach-I design shows a 22% weight reduction compared to the baseline 2002 Taurus.

| MMLV | | Multi Material Lightweight Vehicle | | | | |
|--|--|---------------------------------------|--------------------------|---|---|--------------------------|
| PMT Description | | 2002 Taurus | MMLV Mach I Target | MMLV Mach I Status as of 3/4/13 | MMLV Mach I % Reduction from Baseline | MMLV Mach I Actual |
| PMT 1 - Body Exterior and Closures (kg) | | 574 | 451 | 456 | 21 | |
| Body-in-White | | n.a. | 243 | 250 | | |
| Closures-in-White | | n.a. | 70 | 69 | | |
| Bumpers | | n.a. | 26 | 25 | | |
| Glazings - Fixed and Movable | | n.a. | 25 | 25 | | |
| Remainder - trim, mechanisms, paint, seals, etc. | | n.a. | 87 | 87 | | |
| PMT 2 - Body Interior and Climate Control (kg) | | 180 | 164 | 161 | 11 | |
| Seating | | n.a. | 42 | 42 | | |
| Instrument Panel | | n.a. | 14 | 14 | | |
| Climate Control | | n.a. | 25 | 25 | | |
| Remainder - trim, restraints, console, etc | | n.a. | 83 | 80 | | |
| PMT 3 - Chassis (kg) | | 352 | 255 | 252 | 28 | |
| Frt & Rr Suspension | | n.a. | 79 | 81 | | |
| Subframes | | n.a. | 34 | 30 | | |
| Wheels & Tires | | n.a. | 64 | 64 | | |
| Brakes | | n.a. | 49 | 49 | | |
| Remainder - steering, jack, etc. | | n.a. | 29 | 29 | | |
| PMT 4 - Powertrain (kg) | | 350 | 285 | 267 | 24 | |
| Engine (dressed) | | n.a. | 89 | 71 | | |
| Transmission and Driveline | | n.a. | 92 | 92 | | |
| Remainder - fuel, cooling, mounts, etc. | | n.a. | 104 | 104 | | |
| PMT 5 - Electrical (kg) | | 67 | 59 | 59 | 12 | |
| Wiring | | n.a. | 25 | 25 | | |
| Remainder - battery, starter, etc. | | n.a. | 34 | 34 | | |
| Total Vehicle (kg) | | 1523 | 1213 | 1195 | 22 | |

Summary

- The Mach-I vehicle was designed as an evolution of the donor vehicle resulting in limitations in weight reduction due to FMVSS requirements, donor vehicle space, and limitations in electrical, HVAC, and transmission.
- Design constraints imposed by the donor vehicle, as well as changes in 2002 vs 2012 FMVSS regulations have resulted in a 22% full vehicle mass reduction the 2002 Ford Taurus.
- The current status Mach-I design mass reduction for the main vehicle components is as follows:
 - BIW = 23%
 - Closures = 30%
 - Bumper systems = 45%
 - Suspension = 30%
 - Powertrain = 24%
 - Interior Trim = 15%
 - Instrument Panel = 35%
 - Interior Seats = 40%
- Technical challenges during the development of the Mach I vehicle development included: manufacturability issues of spot welding aluminum at high volume production, e-coating entire BIW in current OEM facilities, and lack of aluminum HPVDC material property information.

Mach-I Prototype Vehicle Build & Integration, Feb-2014

- Component-level design, incorporate feedback from prototype build and process FEA
- Joint Testing of SPR/bonded joints.
- Manufacture prototype parts
- Procure donor vehicles integration and finalize MMLV Mach-I prototype build content
- Vehicle integration of prototype components and donor vehicles

Mach-1 Component-level & Vehicle-level Testing, March 2014

- Component level testing cradles, closures, and BIW modules (Dec 2013)
- Full vehicle Testing durability, impact, NVH and corrosion testing (Mar-14):
 - Frontal offset deformable barrier (IIHS ODB - 40%)
 - Roof strength (FMVSS 216a)
 - Side impact (FMVSS 214 MDB)
 - Seat pull (FMVSS 207/210)

Mach-II Vehicle Design and Analysis, Mar-2014

- Design of new vehicle architecture capable of achieving a 50% mass reduction, relative to the 2002 Taurus baseline vehicle