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16. Abstract

NHTSA contracted EDAG, Inc., to conduct a weight reduction feasibility and cost study of a full-size pickup truck using high-volume manufacturing processes available in MYs 2020 to 2030. The goal was to determine maximum feasible weight reduction while maintaining performance, safety, and crash rating. Furthermore, the retail price of the light-weighted vehicle must be within 10 percent of the original price. Based on production volume, market share, 5-star crash rating, and the most up-to-date vehicle on the market, the MY 2014 Chevrolet Silverado was chosen as the baseline vehicle. The light-weighted vehicle must also maintain or improve vehicle functionalities compared with the baseline vehicle, including NCAP frontal, side, side pole and IIHS test programs, and all advanced design, material, technologies and manufacturing processes must be realistically available for fleet-wide production. Advanced high-strength materials (steels, aluminum, magnesium and plastics), manufacturing processes (stamping, hot stamping, die-casting, extrusions, hydroforming and roll-forming) and assembly methods (spot-welding, laser welding, riveting and adhesive bonding) were studied. However, additional research can provide more insight to the future of vehicle weight reduction, including creating a detailed design for other platforms with alternate powertrains (e.g., battery electric subcompact car).

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1 Executive Summary

The Department of Transportation National Highway Traffic Safety Administration awarded a contract to an automotive design and engineering company EDAG, Inc., to conduct vehicle weight reduction feasibility and cost study of a full-size pickup truck. The light weighted version of full-size pickup truck (LWT) will use manufacturing processes available in MYs 2020-2030 and capable of high-volume production.[1] The team's goal was to determine the maximum feasible weight reduction while maintaining the same vehicle functionalities, such as performance, safety, and crash rating, as the baseline vehicle. Furthermore, the retail price of the LWT must be within +10 percent of the original baseline vehicle.[2]

Based upon its production volume, market share, 5-star crash rating, and the most up to date vehicle on the market, the team selected the MY 2014 Chevrolet Silverado as its baseline vehicle. Because a lighter vehicle needs less power, vehicle powertrain was downsized but limited to the same naturally aspirated engine. Any advanced powertrain study such as hybrid electric vehicle was outside the scope of this project. Other major boundary conditions for this project include the followings.

1. Maintain or improve vehicle size compared with the baseline vehicle.
2. Maintain retail price parity (±10% variation) with the baseline vehicle.
3. Maintain or improve vehicle functionalities compared with the baseline vehicle, including maintaining comparable performance in NHTSA's NCAP frontal, side, side pole and IIHS test programs through appropriate crash simulations.
4. All advanced design, material, technologies and manufacturing processes must be realistically projected to be available for fleet wide production in time frame of MYs 2020-2030 and capable of high-volume production (200,000 units per year).
5. Achieve the maximum feasible amount of mass reduction within the constraints.

After conducting a full teardown and benchmarking of the baseline vehicle, a detailed CAE LSDYNA3D model of the baseline vehicle was created and correlated with the available crash test results. The project team then used state-of-the-art computer modeling and optimization techniques to design the light-weighted pickup truck and optimized the vehicle structure to achieve the maximum amount of mass reduction while achieving comparable vehicle performance as the baseline vehicle. Only the technologies and materials projected to be available for large-scale production and available within two to three design generations (e.g., MY 2020, 2025 and 2030) were chosen for the LWT design. The recommended materials (advanced high-strength steels, aluminum, magnesium and plastics) manufacturing processes, (stamping, hot stamping, die casting, extrusions, hydroforming and roll-forming) and assembly methods (spot-welding, laser welding, riveting and adhesive bonding) are at present used, some to a lesser degree than others. These technologies can be fully developed within the normal product design cycle using the current design and development methods used by automotive manufacturers. The process parameters for manufacturing with advanced materials

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[1] Annual production volume of 200,000 (1,000,000 over 5 years production)

[2] 10 percent of the baseline MSRP is $3,805 based on 2014 Chevrolet Silverado 1500 window sticker shown in Figure 10

can be supported by computer simulation. This approach eliminated those material and technology options that would likely be unrealistic or overly aggressive to implement in mass production by MYs 2020-2030.

The team began the investigation by measuring, evaluating, and modeling the baseline vehicle 2014 Chevrolet Silverado1500. They also investigated possible material choices and manufacturing technologies for each vehicle sub-system. For the major systems with the most mass saving potential, such as the vehicle cab, pickup box, chassis frame, closures, bumpers, and suspensions, EDAG created a design to fully optimize the mass savings, using the latest CAE optimization techniques. For those components that are often purchased by the OEM, EDAG interviewed the leading suppliers to determine their future plans for weight reduction and cost targets. For the components that were re-designed by EDAG, a technical cost modeling approach was used that calculated the direct manufacturing costs of the components. For the components that are purchased by OEMs, the team obtained the anticipated mass reduction technologies and the corresponding estimated cost to the OEM (including supplier mark-ups) for the year 2025 from the leading component suppliers.

These cost estimates were also validated using EDAG/Intellicosting[3] internal cost estimating expertise. The two cost assessment methods allowed the team to calculate the OEM Manufacturing Cost' including the purchased costs of all the supplier parts for the baseline Silverado and the LWT. The indirect manufacturing costs were addressed by applying the retail price equivalent multiplier of 1.45,[4] to determine the manufacturer suggested retail price of the vehicle.

In the baseline vehicle, the body structure (cab, pickup box, chassis frame) accounts for 34 percent of the vehicle weight (818 kg) and was a key focus of this study because of its weight reduction potential, importance to crash safety and effect on compounded weight reduction for other sub-systems. Based upon its strength, cost effectiveness, manufacturing volumes, and production timeframe, the team selected to design the chassis frame using advanced high-strength steel. The LWT cab and pickup box structure was designed using the latest grades of aluminum, similar to the newly released 2015 Ford F-150. Although other materials, such as carbon fiber reinforced polymer offer greater weight savings, their cost premium and large scale manufacturing limitations prevented the team from choosing them for the cab and chassis frame structures. Other components in the vehicle did use some of these advanced materials and others including aluminum, magnesium, and glass fiber reinforced polymer. Overall, the complete LWT achieved a total weight savings of 16.8 percent (409 kg) compared with the baseline vehicle (2432 kg) at an incremental manufacturing cost increase of $1,424 or $3.48 per kg.

To achieve the same vehicle performance as the baseline vehicle, the size of the engine for LWT was proportionally reduced from 5.3L/355 HP to 5.0L/335 HP. Without the mass and cost reduction allowance for the powertrain (engine and transmission), the mass saving for the 'glider' is 20 percent (359 kg) at a mass saving cost premium of $4.10 per kg of mass saved.

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[3] www.intellicosting.com

[4] RPE of 1.45 for General Motors used for this study; Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers," EPA report EPA-420-R-09-003, February 2009.

The design of the LWT was verified, through CAE modeling, that it meets all relevant crash tests performance. The LS-DYNA finite element software used by the EDAG team is an industry standard for crash simulation and modeling. The researchers modeled the crashworthiness of the LWT design under the NCAP Frontal, Lateral Moving Deformable Barrier, and Lateral Pole tests, along with the IIHS Roof, Lateral Moving Deformable Barrier, and Frontal Offset (40% and 25%) tests. All the modeled test results were comparable to the actual crash tests performed on the 2014 Silverado. Furthermore, the FMVSS No. 301 rear impact test was modeled and it showed no damage to the LWT fuel system.

This high-level approach helps the final design meet the project objectives within the boundary conditions, and ideally provides the government and industry a production feasible vehicle design to use for future studies and analysis. The results of this work will provide a basis for helping to estimate some of the impacts of future CAFE standards for MYs 2020-2030.

EDAG believe that the rigorous engineering approach applied to this project balanced various factors and produced a LWT that had the greatest weight savings while meeting the baseline vehicle functionalities, cost, and manufacturing targets for year 2020-2030; however additional research can provide more insight to the future of vehicle weight reduction. This can include creating a detailed design for other platforms with alternate powertrains (e.g., battery electric subcompact car). Using similar engineering approach or creating another lightweight vehicle design with a longer time horizon (2030 and beyond). The generated LSDYNA models may also be helpful for conducting future vehicle to vehicle crash analysis studies, to assess the safety performance of lower mass vehicles.

2 Definitions and Acronyms

3D – three dimensional

3G – geometry, gauge, and grade of material, term used for computer optimization

4WD (or 4x4) – 4-wheel drive

5th percentile female –population representing a small-framed woman who averages 152 cm.; 95 percent of women are larger than a 5th percentile female.

99th percentile male –population representing a large-framed man who averages 183 cm.; a man of this size would be larger than 98 percent of the male population.

A-arm – An automotive suspension system contains a control arm (sometimes referred to as an A-arm, A- frame, or wishbone). It is triangular-shaped and nearly flat. Functionally, it pivots in two places; the broad end of the triangle attaches at the frame and pivots on a bushing. The narrow end attaches to the steering knuckle and pivots on a ball joint.

ABC – activity-based costing

ABS – antilock braking system that prevents wheels from locking up or ceasing to rotate while braking to avoid skidding. It offers enhanced vehicle control and decreased stopping distances on dry and slippery surfaces for most drivers.

ABS (material) – acrylonitrile butadiene styrene, a common synthetic thermoplastic used to make light, rigid, injection-molded and extruded products

A/C – air conditioning; see HVAC

ADAMS – Automated Dynamic Analysis of Mechanical Systems

AHSS – advanced high-strength steel

A-pillar – The A-pillar of a vehicle is the first pillar of the driver and passenger sides of the vehicle located vertically at both sides of the vehicle's windshield area. It has structural responsibility for protecting the occupants in the case of a roll-over. From a design perspective, it provides a point of reference following successive letters in the alphabet (B-pillar, C-pillar, etc.).

ATD – anthropomorphic test device, also called a crash test dummy

AWD – all-wheel drive - a system that powers all four wheels of a vehicle at all times by locking all the wheels to rotate at the same velocity. AWD is much less capable in off-road settings and inferior to 4WD in such situations.

belt line – The belt line lies horizontally underneath the side windows of the car. It starts from the hood and runs to the trunk. It separates the glass area from the lower body.

BH steel – bake hardenable steel, an advanced processing technique to produce low-carbon steels used for car bodies. The process provides high strength through an optimized batch annealing treatment necessary in order to have enough carbon in solution required for bake hardening. This makes automotive bodies, and panels, strengthened after paint-baking treatment.

BIW – body-in-white, the stage in automotive manufacturing in which the vehicle's body sheet metal components have been welded together. It is before components such as doors, hood, deck lid, fenders, etc., have been added prior to paint.

BLS – Bureau of Labor Statistics

BMSB – blow-molded seat back (also known as “blow forming”). This manufacturing process creates hollow, plastic components, from thermoplastic. In general, three primary processes are extrusion molding, injection molding, and stretch blow-molding.

BOM – bill of materials

B Segment – Refers to a vehicle classification used in Europe. It is the equivalent to an American subcompact car.

BSFC – brake specific fuel consumption - measure of fuel efficiency within a shaft reciprocating engine. It is the rate of fuel consumption divided by the power produced. BSFC allows the fuel efficiency of different reciprocating engines to be directly compared.

CAA – Clean Air Act

CAD – computer-aided design

CAE – computer-aided engineering

CAFE – Corporate Average Fuel Economy

CARB – California Air Resources Board

CCA (or CCAW) – copper clad aluminum (wire), used as conductor for high-quality coils such as the voice coils in headphones, portable loudspeakers or mobile coils in other applications.

center stack –the center portion of the instrument panel containing the sound system, HVAC controls, and the navigation system screen.

CFM – cubic feet per minute

CFRP – carbon fiber reinforced polymer

CFTF – carbon fiber technology facility

CG – center of gravity

Class A surface –automotive design term to describe the surface area most easily seen by the customer. These areas have a higher standard for appearance and quality in the automotive industry.

CO – carbon monoxide

CO2 – carbon dioxide

composite – material in which two or more distinct, structurally complementary substances like metals, ceramics, glasses, and polymers are combined to produce structural or functional properties not present in any individual component, such as fiberglass or steel-reinforced concrete.

CSA – cross sectional area

C Segment –vehicle classification used in Europe equivalent to an American compact car.

cut and sew – process for creating automotive seat covers by cutting/trimming material from fabric sheets. The separate selected pattern sections are joined by sewing them together.

CUV – crossover utility vehicle - vehicle built on a car platform and combines features of an SUV with features from a passenger vehicle

CVT – continuously variable transmission – vehicle transmission that shifts seamlessly through an infinite number of effective gear ratios between maximum and minimum values. The flexibility of a CVT allows the driving shaft to maintain a constant angular velocity over a range of output velocities. This can provide better fuel economy than other transmissions by enabling the engine to run at its most efficient RPM for a range of vehicle speeds.

CVW – curb vehicle weight

DFS – design for serviceability

DLO – daylight opening, automotive industry term for glassed-in areas of a vehicle's cabin

DP (or DPS) – dual phase steel, high-strength steel that has a ferrite and martensitic microstructure. This results in a microstructure consisting of a soft ferrite matrix containing islands of martensite as the secondary phase (martensite increases the tensile strength). Due to these properties DPS is often used for automotive body panels, wheels, and bumpers.

EC – European Commission, the executive branch of the European Union (EU), and operates as a “cabinet government” responsible for proposing legislation, implementing decisions, upholding the Union's treaties, and the general day-to-day running of the EU.

EGR – exhaust gas recirculation, a nitrogen oxide (NOx) emissions reduction technique used in most gasoline and diesel engines. EGR works by recirculating a portion of an engine's exhaust gas back to the engine cylinders.

EISA – Energy Independence and Security Act

EPA – United States Environmental Protection Agency

EPB – electric parking brake

EPCA – Energy Policy and Conservation Act

EPDM – ethylene propylene diene monomer, a synthetic rubber containing a saturated chain of the polyethylene used in a range of applications

EPP – expanded polypropylene, a foam form of polypropylene, used in a variety of applications. It also has very good impact characteristics due to its low stiffness; this allows EPP to resume its shape after impacts.

ESP or ESC – electronic stability program or electronic stability control - computerized technology that may potentially improve the safety of a vehicle's stability by detecting and minimizing skids.

Euro V – The EU defines the acceptable limits for exhaust emissions of new vehicles sold in Europe. Euro VI is scheduled to supersede V in 2013.

EVA – ethylene vinyl acetate - the copolymer of ethylene and vinyl acetate thT approaches elastomeric materials in softness and flexibility but it can be processed like other thermoplastics. The material has good clarity, gloss, barrier properties, low-temperature toughness, stress-crack resistance, hot-melt adhesive water proof properties, and resistance to UV radiation. EVA has little or no odor and is competitive with rubber and vinyl products in many electrical applications.

FBCC – front bumper and crush can

FEA – finite element analysis

FEM – front end module

FLD – forming limit diagram - an empirical curve showing the biaxial strain levels beyond which failure may occur in sheet metal forming.

FMVSS –Federal Motor Vehicle Safety Standard; provides the minimum standard for motor vehicle performance, or motor vehicle equipment performance, which is practicable, which meets the need for motor vehicle safety, and which provides objective test criteria. FMVSS norms are administered by NHTSA.

FRP – fiber-reinforced polymer (also fiber-reinforced plastic) - a composite material made of a polymer matrix reinforced with fibers such as fiberglass.

Frt – front

FSV – future steel vehicle

FWD – front wheel drive

GAWR – gross axle weight rating - the maximum distributed weight that may be supported by an axle of a road vehicle. A vehicle's GAWR is the specific weight determined by the manufacturer to be the maximum allowable weight that can be placed on an individual axle. Typically GAWR is followed by either the letters F, FR, R or RR which indicate front or rear axles.

GDP – Gross Domestic Product

GFRP – glass fiber-reinforced polymer

GHG – greenhouse gas

GVW (or GVWR) – gross vehicle weight rating - the maximum allowable total weight of a road vehicle or trailer when loaded - i.e., including the weight of the vehicle itself plus fuel, passengers, cargo, and trailer tongue weight.

H-Arm – A type of suspension control arm that attaches to the frame or body at two points and to the wheel carrier or knuckle at two points.

HC – hydrocarbon

HD – hot dip (galvanized steel)

HDPE – high-density polyethylene - a strong, relatively opaque form of polyethylene having a dense structure with few side branches off the main carbon backbone.

HIC – head injury criterion - a measure of the likelihood of head injury arising from an impact. The HIC can be used to assess safety related to vehicles.

HP – horsepower

HPA – hydraulic power assistance - specifies that pressurized hydraulic fluid is used to increase the manual force being applied in a mechanical system.

HSLA – high-strength low alloy – a type of alloy steel that provides better mechanical properties or greater resistance to corrosion than carbon steel

HSS – high-strength steel - low carbon steel with minute amounts of molybdenum, niobium, titanium, and/or vanadium. Is sometimes used to refer to high-strength low alloy steel or to the entire group of engineered alloys of steels developed for high strength.

HVAC – heating, ventilating, and air conditioning

IC – internal combustion

ICE – internal combustion engine

ICE – in-car entertainment - audio and/or audio/visual entertainment, as well as automotive navigation systems.

IEM – integrated exhaust manifold - the integration of the exhaust manifold with the cylinder head as used in the Lotus SABRE project.

IIHS – Insurance Institute for Highway Safety

I/P – instrument panel

IRD – impact reference distance (IIHS side impact crash test)

ISOFIX – The international standard for attachment points for child safety seats in passenger cars. It is also known as LATCH (Lower Anchors and Tethers for Children) in the United States and as LUAS (Lower Universal Anchorage System) or Canfix in Canada. It has also been called the Universal Child Safety Seat System or UCSSS.

IVT – infinitely variable transmission

LATCH – Lower Anchors and Tethers for Children. See ISOFIX.

LCA – lower control arm. See A-Arm.

LCD – liquid crystal display

LED – light-emitting diode

LEP – light emitting polymer

LF – left front

LH – left hand

LS-DYNA – Livermore Software finite element simulation program

LUAS – Lower Universal Anchorage System. See ISOFIX.

LWB – laser welded blank (stamping process)

LWR – lower

LWT – lightweight truck

MAP – microwave-assisted plasma (new technology being developed to produce carbon fibers)

MDB – moving deformable barrier (crash test)

MIG – metal inert gas (welding method)

mJ – milli joules.

MMC – metal matrix composite

monocoque – A metal structure in which the skin absorbs all or most of the stresses to which the body is subjected. Unibody, or unitary construction, is a related construction technique for automobiles in which the body is integrated into a single unit with the chassis rather than having a separate body-on-frame. The welded "unit body" is the predominant automobile construction technology today.

MPa – mega Pascal

MPV – multi-purpose vehicle

MS – mild steel – also called carbon steel or plain carbon steel, is steel where the main alloying constituent is carbon.

MSRP – manufacturer's suggested retail price

MY – model year

NAIAS – North American International Auto Show held in Detroit, MI

NAICS – North American Industry Classification System

NCAC – National Crash Analysis Center

NCAP – New Car Assessment Program (also called Euro NCAP) - a European car safety performance assessment program founded in 1997 by the Transport Research Laboratory for the U.K. Department for Transport and now the standard throughout Europe.

NETL – National Energy Technology Laboratory

NOx – generic term for mono-nitrogen oxides (NO and NO2)

NPI – new product introduction

NPRM – Notice of Proposed Rulemaking – the first step in the Federal Government's informal rulemaking process. This is normally published in the Federal Register and is followed by public comment.

NVH – noise, vibration, and harshness - also known as noise and vibration (N&V). It is the study and modification of the noise and vibration characteristics of vehicles, particularly cars and trucks.

OEL – organic electro luminescence

OEM – original equipment manufacturer

OLED – organic light emitting diode - a light-emitting diode whose emissive electroluminescent layer is composed of a film of organic compounds

ORNL – Oak Ridge National Laboratory

OTR – outer

PA – polyamide

PC – polycarbonate

PCCB – Porsche ceramic carbon brakes. Carbon-ceramic brakes are optional on all Ferraris, most Lamborghinis and Porsches, and the Bentley Continental GT Diamond. These cars are priced above $133,000. Their high cost limited them to exotic performance cars. A new manufacturing process could make them affordable for even budget-minded enthusiasts.

PE – predictive engineering

PEHD – polyethylene high density - a strong, relatively opaque form of polyethylene having a dense structure with few side branches off the main carbon backbone.

PHEV – plug-in hybrid electric vehicle - a hybrid vehicle with batteries that can be recharged by connecting a plug to an electric power source. It shares the characteristics of both traditional hybrid electric vehicles, having an electric motor and an internal combustion engine, and of battery electric vehicles, also having a plug to connect to the electrical grid (it is a plug-in vehicle).

PM – particulate matter

PNNL – Pacific Northwest National Laboratory

PP – polypropylene or polypropene - a thermoplastic polymer used in a variety of applications.

PPE – poly (p-phenylene ether) - a high-temperature thermoplastic. It is rarely used in its pure form due to difficulties in processing. It is mainly used as blend with polystyrene, high-impact styrene-butadiene copolymer or polyamide.

PPO – poly (p-phenylene oxide) - a high-temperature thermoplastic. It is rarely used in its pure form due to difficulties in processing. It is mainly used as blend with polystyrene, high-impact styrene-butadiene copolymer or polyamide.

PRNDL – Park, Reverse, Neutral, Drive, and Low - the automatic transmission gear selector

PSA – pressure sensitive adhesive (tape)

PSAT – powertrain system assessment toolkit

PU (or PUR) – polyurethane – a polymer used in various resins, tough chemical-resistant coatings, adhesives, and foams. Most polyurethanes are thermosetting polymers that do not melt when heated, but thermoplastic polyurethanes are also available.

PVC – polyvinyl chloride - the third most widely used thermoplastic polymer after polyethylene and polypropylene.

Rad – radiator

Reinf – reinforcement

RF – right front

RH – right hand

ROM – rough order of magnitude - a general term that is often used in analysis equating to “Estimate'

RPE – retail price equivalent

RR – rear

RSW – resistance spot-welding

RTM – resin transfer molding – a method of fabricating composite parts

R-Value –measure of thermal resistance.

RWD – rear wheel drive - a form of engine/transmission layout used in motor vehicles, where the engine drives the rear wheels only. Often seen is vehicles that fall into the sports car category.

SCF – super critical fluid

SG & A – selling, general, and administrative (costs)

SLA – short long arm - a suspension design also known as an unequal length double wishbone

SLC – super light car – European Union multi-material automotive body structure study

SPR – self-piercing rivet

SSF – static stability factor (vehicle rollover assessment) - distance between the centers of the right hand and left hand tires along the axle divided by 2 times the vertical center of gravity height

STL – stereo lithography

sub-system – A smaller assembly living within a larger assembly

SWR – strength-to-weight ratio (IIHS roof crush test)

system – Several separate system categories were created to include all vehicle components. These systems are as follows: body structure, closures, front/rear bumpers, glazing, interior, chassis, air conditioning, electrical, and powertrain.

TCM – technical cost modeling

TIG – tungsten inert gas (welding method)

TRB – tailor rolled blank (stamping process)

TRIP steel – transformation induced plasticity - a high-strength steel that is typically incorporated in the automotive industry. TRIP steel has a triple phase microstructure consisting of ferrite, bainite, and retained austenite. During plastic deformation and straining, the metastable austenite phase is transformed into martensite. This transformation allows for enhanced strength and ductility.

TRL – technology readiness level - the degree to which a technology is considered feasible for volume production at the inception of a new vehicle program, i.e., approximately 3 years prior to start of production. The technology may be proven at the time of the new vehicle program start or is expected to be proven early in the production design process so that there is no risk anticipated at the targeted timing for production launch.

TSD – Traffic Safety Division

UCSSS – Universal Child Safety Seat System. See ISOFIX.

ULSAB-AVC – ultra-light steel auto body – advanced vehicle concepts

UTS – ultimate tensile strength

UV – ultraviolet

VI – vacuum injection

VR – virtual reality - a computer technology which allows a user to simulate physical presence in the real world or in the imaginary world.

YS – yield strength (or yield point) - defined in engineering and materials science as the stress point in which a predetermined amount of permanent deformation occurs.

3 Introduction and Scope of Work

3.1 Purpose

The purpose of this project is to design a lightweighted light-duty pickup truck[5] that can, at minimum, meet the performance functions[6] of the original baseline vehicle while controlling for both direct and indirect cost to maintain affordability.[7] EDAG,[8] the prime contractor for this project chose a baseline vehicle (2014 Chevrolet Silverado 1500) that best represents automotive industry's expectation of the light-duty pickup truck fleet for MY 2021. EDAG then performed a comprehensive teardown study to establish the baselines for engineering analysis that included manufacturing technology assessment, material utilization and cost analysis for comparison with the lightweighted design. Data from the baseline vehicle teardown was also used to build detailed finite element analysis simulation models. The EDAG team then used advanced design, material, and manufacturing processes that will likely be available during MYs 2020-2030 to develop a lightweighted pickup truck (LWT) concept vehicle that is capable of high-volume production. The LWT concept vehicle information included an engineering design with sufficient detail such that computer aided engineering analysis could be performed to demonstrate crashworthiness from that design. The EDAG team then developed a comprehensive direct manufacturing incremental cost estimate for the LWT concept vehicle, including both detailed direct manufacturing and indirect cost estimates for tooling and equipment investment.

3.2 Background

NHTSA has been issuing Corporate Average Fuel Economy standards under the Energy Policy and Conservation Act for the last 40 years. EPCA requires DOT to establish average fuel economy standards for passenger cars and light trucks at "the maximum feasible average fuel economy level that the Secretary [of DOT] decides the manufacturers can achieve in that model year." When setting "maximum feasible" fuel economy standard, DOT is required to "consider technological feasibility, economic practicability, the effect of other motor vehicle standards of the Government on fuel economy, and the need of the United States to conserve energy." The Energy Independence and Security Act was enacted on December 19, 2007, and amended EPCA. In addition to passenger car and light truck standards being set at the maximum feasible level in each model year, EISA mandated that the MYsMY 2011-2020 CAFE standards be set sufficiently high to ensure that the industry-wide average of all new passenger cars and light trucks, combined, be not less than 35 mpg by MY 2020.

In fulfillment of its EPCA and EISA requirements and in response to President Obama's directive to create a coordinated and harmonized national program for motor vehicle efficiency

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[5] Light-duty pickup trucks are defined as trucks with GVWR ranging from 6,001 to 8,500 pounds.

[6] Vehicle performance functions include safety, fuel economy, vehicle utility/performance (towing, acceleration, etc.), NVH, manufacturability, aesthetics, ergonomics, durability, and serviceability.

[7] Affordability is defined as maintaining overall vehicle retail price parity with the baseline vehicle with ±10 percent variation.

[8] EDAG, see Section 3.4

and emissions standards, NHTSA published a final rule with the EPA. This final rule set CAFE standards under EPCA/EISA and greenhouse gas standards under the Clean Air Act for passenger cars and light trucks manufactured in MYs 2017-2025 for GHG and 2017-2021 for CAFE. NHTSA will develop final CAFE standards for MYs 2022-2025 as part of a future new rulemaking, considering the findings of a "mid-term evaluation" to be conducted jointly with EPA and the California Air Resources Board.[9] The CAFE standards increase annually in stringency, and for MY 2021, are currently estimated to require a combined industry-wide fleet fuel economy of 40.3 to 41.0 mpg.

Based on NHTSA's discussions with manufacturers about how they plan to comply with CAFE standards in those MYs, the agency anticipates that the industry will make use of vehicle mass reduction as a means for reducing vehicle fuel consumption in the future. NHTSA's recent rulemaking analyses have employed mass reduction as a technology option for compliance modeling purposes. Specifically, in order to ensure that a compliance path for industry exists that would be safety neutral at a societal level, NHTSA applied more mass reduction in the CAFE rulemaking analysis to larger vehicles, such as pickup trucks and minivans, and less or even zero mass reduction to smaller vehicles, such as subcompact and compact cars. For example, in the analysis for MYs 2017-2025 Notice of Proposed Rulemaking, the CAFE model was configured to allow up to 20 percent mass reduction per vehicle as a way for manufacturers to achieve compliance, with greater amounts of mass reduction being available for heavier vehicle subclasses. The agency took this approach for consistency with NHTSA's analysis of safety effects for vehicle mass reduction, which found that mass reduction, can occur in a safety neutral, or perhaps even a safety beneficial, manner if it occurs in the heaviest of vehicles, while the contrary may be true for lighter vehicles.[10]

In support of the recent rulemaking for MYs 2017-2025, NHTSA funded a mass reduction study on mid-size passenger cars based on a MY 2011 Honda Accord. In that project, the vehicle achieved 20 percent mass reduction with a cost increase. Due to the functionality differences between passenger cars and light trucks, the agency is very interested in exploring the potential differences in mass reduction approaches for these vehicles, and believes further research would be helpful to this objective.

NHTSA has recently noticed many OEMs announcing more and more complicated types of mass reduction, often in the interest of improving fuel economy. As the agency looks ahead to the future rulemaking to develop final standards for MYs 2022-2025, we expect that more mass reduction technologies will be applied and that the baseline fleet may migrate to lighter vehicles overall. The mass reduction technologies and materials used on baseline vehicles in previous lightweighting studies are different from those

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[9] The final rule was issued on August 28, 2012, and was published in the Federal Register on October 15, 2012, at www.gpo.gov/fdsys/pkg/FR-2012-10-15/pdf/2012-21972.pdf . A copy is also available on NHTSA's website at www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/2017-25_CAFE_Final_Rule.pdf

[10] See Chapter IX of NHTSA's Preliminary Regulatory Impact Analysis of the Corporate Average Fuel Economy Standards for MYs 2017-2025 Passenger Cars and Light Trucks, available at www.nhtsa.gov/fuel-economy

that will be employed in the fleet representing the on-road vehicles closer to the time when the future rulemaking is conducted. Some future lightweighted vehicles will also have downsized powertrains, consistent with the design in the mid-size passenger car mass reduction project and the agency's assumptions in the recent rulemaking for MYs 2017-2025. As the 2012-2016 CAFE rule is phasing out during the next few years and OEMs are preparing to comply with the MYs 2017-2021 CAFE final rule, OEMs already have started applying more mass reduction technologies in the fleet. This might change the material usage and manufacturing technology usage for the baseline for MYs 2022-2025 rule. The agency is interested in updating the baseline mass reduction technologies for on-road vehicle material and manufacturing technology usage, in confirming and validating the mass compounding effect of downsizing a vehicle powertrain, and in confirming the mass reduction potential for the overall vehicle.

3.3 Specific Tasks

The following activities were undertaken as part of this project:

3.3.1 Task 1: Baseline Vehicle Teardown and Finite Element Analysis Modeling

3.3.1.1 Decision on the Baseline Truck Build and Model

Full-size pickup trucks offered by major OEM's are typically available with three styles of driver and passenger cab designs and three sizes of load carrying pickup boxes. These vehicles offer flexibility to carry up to six passengers in comfort and safety with payload carrying capacities up to 3,120 lbs (1,415 kg) and towing capacity over 11,300 lbs (5,126 kg).[11] The off-road capability of these vehicles with easy and open access to the pickup box makes them a good choice for farmers, construction industry work-crews, emergency responders, snow and debris removal crews and heavy-equipment transporters as well as suburbanites hauling recreational gear on vacation. To accommodate such diverse customer base and performance requirements, these vehicles are available with options of several powertrains, 4-wheel drive, heavy-duty towing and up to 36-gallon fuel tanks for a driving range of over 700 miles between fill-ups. With consideration of these diverse requirements, the project team identified the make, model and configuration of the baseline light-duty truck using the following main criteria.

- Assessment of light-duty pickup trucks on the market by each OEM
- Preliminary assessment of light-duty pickup trucks – range of options on each platform
- Platform sharing with other vehicles
- Annual sales volume
- The vehicle model introduction year
- Results of crash tests performed by NHTSA and IIHS
- Timely availability of the vehicles for the teardown and benchmark studies

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[11] 2013 Ford F-150 sales brochure. The illustrations and numbers quoted in this proposal are for 2013 Ford F-150 range of trucks. The F-150 has been the highest selling truck in the United States for the past 35 years.

The baseline vehicle needed to be a segment leader in terms of technologies and sales volume in the U.S. market for MY 2020 with representative vehicle functionalities,[12] configuration, and sales volume. Also taken into consideration was both General Motor and Ford's intention of releasing their next generation pickup trucks in 2014 with significant amounts of mass reduction compared to prior models. Ford, for example, has redesigned the next generation F-150 to be 700 pounds lighter when it is released in 2014.[13] GM has also announced their intentions that the new Silverado pickup truck be lighter weight, with higher content of advanced high-strength steel extensive aluminum and magnesium applications and a smaller V8 engine compared to previous models. This new truck went into production in 2013[14] as a 2014 model year vehicle.

EDAG chose the 2014 Chevrolet Silverado 1500 as the baseline vehicle to best represent the trend of fuel economy technologies during the time frame of the future rulemaking to develop final standards for MYs 2022-2025. Part of the rationale for selecting this vehicle is the variety of complex configurations of the Silverado 1500 such as: different cab sizes (standard, quad and crew cab), box sizes (short, standard, and long bed), 2WD vs. 4WD, different powertrain configurations and tire/wheel sizes. Some of the components for the light-duty truck (class 2A, Silverado 1500) are shared with medium duty trucks (such as 2B and 3B, Silverado 2500 and 3500 respectively). Any systems shared among all configurations have to be considered, so that the component sharing scenarios can be taken in to account in the final optimized lightweighted design. The selection of the 2014 Chevrolet Silverado 1500 baseline vehicle also forms a good foundation of how results can be applicable to the light-duty pickup trucks built on shared platforms and how the results can be applied to the future pickup fleet. For further discussion on the choice of the baseline vehicle, see Section 4 of this report.

3.3.1.2 Baseline Vehicle Teardown and Finite Element Analysis LS-DYNA Model

EDAG team performed a comprehensive teardown/benchmarking (see Section 5) of the baseline vehicle for engineering analysis that included manufacturing technology assessment, material utilization and complete vehicle geometry scanning. The baseline vehicles' overall mass, center of gravity and all key dimensions were determined as shown in Figure 270. The geometry and material test data from the baseline vehicle tear down was used to build detailed finite element analysis simulation models suitable for crash worthiness using LS- DYNA simulation program. Before the vehicle teardown, laboratory torsional stiffness tests, bending stiffness tests and normal modes of vibration tests were performed on the baseline vehicle CAB and Frame, so that these results can be compared with the CAE models of the lightweighted design. The FEA LS-DYNA models based on the teardown information and necessary material properties, such as the stress-strain curve, were based on test results and information from other available databases or CAE models. In the interest of transparency, all information used for the FEA model is releasable to the general public.

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[12] Vehicle functionalities include safety, fuel economy, vehicle utility/performance (e.g., towing, acceleration, etc), NVH, manufacturability, aesthetics, ergonomics, durability and serviceability

[13] www.thecarconnection.com/news/1078027_next-ford-f-150-to-get-aluminum-body-for-better-gasmileage

[14] www.digitaltrends.com/cars/2014-chevrolet-silverado-coming-in-december/

An FEA LS-DYNA model was created and correlated to the baseline vehicle crash results, which include FMVSS, NCAP, and IIHS tests, as follows.

- NCAP frontal
- NCAP side
- NCAP side pole
- FMVSS No. 216
- FMVSS No. 301
- IIHS offset
- IIHS side impact
- IIHS small overlap: This load case may not have real vehicle test data to which to correlate. In this case, the contractor shall find other applicable vehicle test results to reference.

EDAG developed the baseline vehicle CAE models and identified the lightweighting strategies that the vehicle manufacturer used in designing the baseline vehicle. The 2014 Silverado 1500 was also compared to the previous generation of light-duty pickup trucks to identify the strategies that are expected to be in widespread application in the MY 2021 baseline fleet.

3.3.1.3 Cost Model for Baseline Vehicle

A cost model was developed for the baseline light duty pickup truck and will be used to derive the incremental cost for the newly designed lightweighted pickup truck. The cost model and processes are documented in Section10 of this report.

3.3.2 Task 2: Design and Optimization for the Lightweighted Pickup Truck

After completing the tasks for the baseline vehicle, the EDAG team designed a lightweighted light-duty pickup truck suitable for high-volume production (around 200,000 units per year) for MYs 2020-2030 while maintaining the overall vehicle retail price parity within ±10 percent variation relative to the baseline vehicle. This task was divided into three steps. First, initial research and documenting the general approaches that will be used for design, optimization, engineering analyses, and cost analyses for the light-weighted vehicle. Second, based on the approaches agreed upon by NHTSA the EDAG team provided a preliminary design-of-concept of the light- weighted pickup truck. Third, EDAG finalized the design of the lightweighted pickup truck and provide to NHTSA the final design report, detailed FEA LS-DYNA models of the light weighted concept vehicle, and the cost model.

3.3.2.1 Computer Modeling and Optimization of the Light-Weighted Vehicle

The EDAG team used state-of-art modern computer modeling and optimization techniques to design the light-weighted pickup truck and optimize the vehicle structure to achieve the maximum amount of mass reduction while achieving comparable vehicle performance (including safety and durability performance) as the baseline vehicle. The process employed factored in advanced design, computer optimization, advanced materials and manufacturing processes projected to be available in the time frame of MYs 2020-2030. A MY 2025 was used as target production year for the lightweighted design. Available advanced design, material and manufacturing processes selected for the model were based upon the EDAG's technical expertise, literature review, and/or consultation with industry experts, and were deemed reasonable for adoption by vehicle manufacturers for high-volume production for MYs 2020-2030. The design was not limited only to material substitution; material usage, optimization, manufacturing process, and assembly processes were all also be practicable for high-volume production vehicles for MYs 2020-2030 timeframe, taking into consideration the limited number of redesign cycle of the vehicle between now and the timeframe of the future rulemaking.

3.3.2.2 Engineering and Functionality Analysis

The finalized design report includes detailed engineering analyses and documentation to prove that the functionality of the LWT is maintained or improved within the ±10 percent retail price variation relative to the baseline vehicle. It shows that the proposed design is commercially feasible for high-volume production (around 200,000 units per year). The report details engineering analyses and documentation showing how the functionalities for the lightweighted vehicle are maintained or improved compared with the baseline vehicle. These functionalities include safety, fuel economy, vehicle utility/performance (e.g., towing, acceleration, etc.), noise vibration and harshness, vehicle dynamics (e.g., vehicle weight distribution, rollover stability, etc.), manufacturability, aesthetics, ergonomics, durability and serviceability.

Appropriate CAE tools as used by OEMs for this vehicle class were used when comparing baseline vehicle functionalities to the lightweighted design, such as for safety, NVH, powertrain performance, towing, durability, etc.

3.3.2.3 Powertrain Selection

The mass of the powertrain has a significant role on the weights of the body structure, chassis, suspension, tire and wheel, etc., all downstream from the engine and required to support the powertrain system. A lighter powertrain might lead to lighter downstream components, i.e., more secondary mass savings, yet when multiple powertrain choices exist on the vehicle platform, some of the downstream components need to be designed to handle the worst-case scenario, which would be the heaviest powertrain. The project team examined the different strategies employed by various OEMs and the mass differences between a lighter naturally-aspirated engine and a downsized turbo-charged engine that could achieve the same fuel economy, towing, acceleration performance, and NVH characteristics, and selected the new powertrain configuration based upon that detailed analysis. For the lightweighting analysis, the project team investigated the lightweighting technologies for major powertrain components, such as engine parts, transmission parts, axles, transfer cases, etc. These lightweighting technologies were as cost-effective as other lightweighting technologies applied to other vehicle systems, such as body, closures, etc. The powertrain of this concept vehicle was properly sized to match the newly designed lightweighted vehicle, maintaining vehicle acceleration and towing capacity compared with the baseline vehicle. Incremental mass and cost differences between the powertrain chosen for the lightweighted vehicle and the baseline powertrain were also calculated.

3.3.2.4 Impact of Future Technologies

The design of the concept vehicle included mass reduction technologies that are not mature or that are currently limited to small volume production. In such cases there are risks associated with including these developmental technologies as part of the planned vehicle design (e.g., the probability that these technologies will be available for fleet-wide production in the time frame studied). For each technology chosen for this work, the project team listed the technology readiness (mature, mid-term, long term) and the associated risks if the technology is still in the developmental stage. In particular, this report discusses when these developing technologies will be mature and applicable to mass production. In choosing technologies, factors such as the capacity and capability of industry and/or its suppliers to produce products or materials in sufficient quantities and in the specific geometry (shape) to support the vehicle design were considered.

3.3.2.5 Crashworthiness Analysis

When performing vehicle crashworthiness analysis, the vehicle CAE models demonstrated good correlation of structural performance to FMVSS No. 208 Occupant Protection, FMVSS No. 214 Side Impact Protection, and in NHTSA's NCAP frontal, side, and side pole test programs. For each of these rating tests, the project team conducted an appropriate crash simulation and compared the crash acceleration and occupant compartment intrusion against test results of the baseline vehicle. The occupant compartment acceleration was evaluated in terms of peak acceleration and relevant intrusion measurements for the crash mode. The vehicle models also demonstrated compliance with FMVSS No. 216, Roof crush resistance, and FMVSS No. 301, Fuel system integrity. The project team also conducted a crash simulation to evaluate the structural performance requirements of the IIHS frontal offset, side impact, and frontal small overlap test programs.

The designed vehicle obtained at least equivalent ratings in each of the structural or intrusion ratings performed by IIHS of the baseline vehicle. The project team also considered other global safety programs such as the European NCAP, as vehicles may be designed for global requirements and information programs. The CAE vehicle models are compatible with available finite element analysis models from George Washington University and are suitable for frontal vehicle-to-vehicle crash simulation.

3.3.2.6 Incremental Cost Study

Cost is frequently a constraint when vehicle manufacturers decide which fuel-saving technology to apply to a vehicle. Incremental cost analysis for all the new technologies applied to reduce mass of the light-duty full-size pickup truck designed were calculated. The cost estimates include variable costs as well as non-variable costs, such as the manufacturer's investment cost for tooling etc. The cost models are detailed datasets using Microsoft Excel 2010 showing cost breakdowns of each component and related subsystem, including the total sum for each vehicle subsystem (by system level) and the overall vehicle cost. The cost estimates include all the costs directly related to manufacturing the components. For example, for a stamped sheet metal part, the cost models estimate the costs for each of the operations involved in the manufacturing process, starting from blanking the steel from coil through the final stamping operation to fabricate the component. The final estimated total manufacturing cost and assembly cost are a sum total of all the respective cost elements including the costs for material, tooling, equipment, direct labor, energy, building and maintenance. This report in Section 10 details description of the methodologies used in the cost estimates, the factors included in the cost estimates, and the database structure for the cost breakdown, including the specific cost estimates used for each individual cost element.

The information from the cost model was used to establish cost curves for various levels of mass reduction, from zero percentage to the maximum amount feasible. The cost curves from the NHTSA mid-size sedan study were also reviewed and updated with knowledge gained from this project. Cost sensitivity of major vehicle systems to material cost and production volume variations was also conducted.

3.3.3 Optional Requirement "Mass Reduction for Other Light-Duty Vehicles"

In addition to the lightweight truck design, the EDAG team considered how the mass reduction technologies evaluated for this vehicle could be applied to other types of light-duty passenger vehicles. Those other types of light-duty vehicles include the following.

- Subcompact passenger cars
- Compact passenger cars
- Large passenger cars
- Minivans
- Small CUV/SUV/trucks
- Midsize CUV/SUV/trucks
- Large CUV/SUV/light-duty trucks

As documented in the MYs 2012-2016 final rule[15] and the preceding NPRM[16] for purposes of applying fuel-saving technologies, NHTSA's modeling analysis considered 12 technology subclasses of passenger cars and light trucks (subcompact passenger cars, subcompact performance passenger cars, compact passenger cars, etc.). NHTSA understands that the relationship between mass reduction and size is not linear, as there is a certain fixed mass needed to comply with FMVSS and consumer information programs, i.e., more mass can likely be taken out of large vehicles than small vehicles. The EDAG team provided feasible mass reduction estimates for each vehicle subclass used in the CAFE Volpe model, along with supporting documentation.

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[15] www.nhtsa.gov/Laws+&+Regulations/CAFE+-+Fuel+Economy/Model+Years+2012-2016:+Final+Rule

[16] www.nhtsa.gov/Laws+&+Regulations/CAFE+-+Fuel+Economy/Model+Years+2012-2016:+Notice+of+Proposed+Rulemaking+(NPRM)

The EDAG team provided details about the amount of mass reduction that is feasible for each of the vehicle subclasses stated above which were used in the CAFE model and phase-in caps for amount of mass reduction for each subclass for MYs 2017-2025. The conclusions are supported with detailed analysis and are provided as Section 11 of this report.

3.4 Project Team

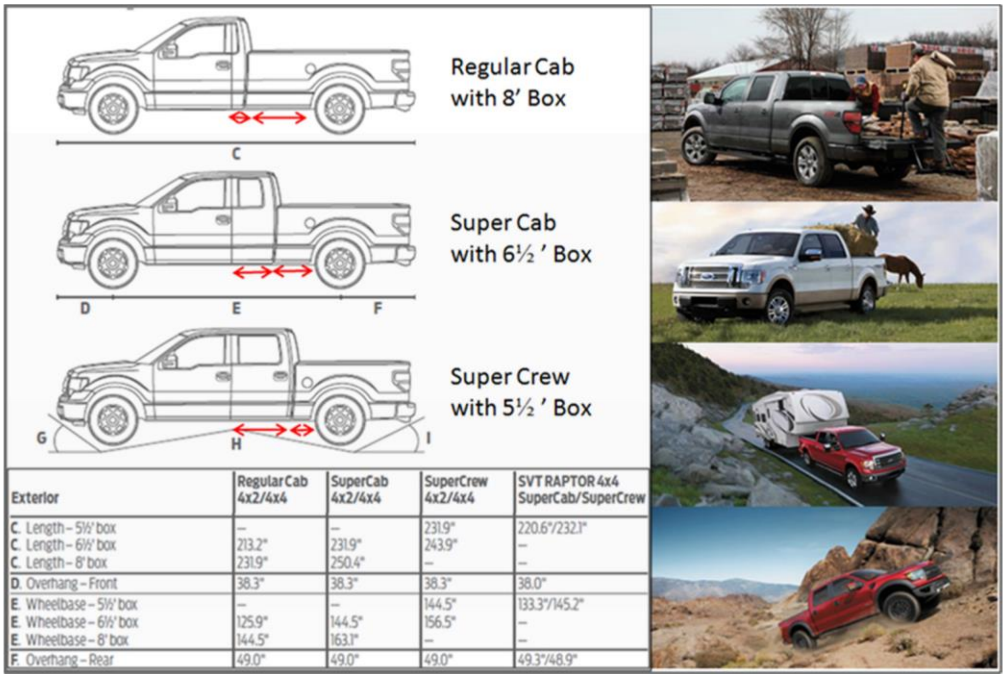
This project was completed by EDAG The EDAG team has extensive experience in the areas of automotive engineering, development and vehicle crash test modeling and analysis. EDAG was the prime contractor and technical lead on optimizing the lightweight vehicle design, performing the cost modeling, and examining advanced manufacturing techniques as well as vehicle crash modelling, correlation and analysis.

EDAG Group, the world's largest independent vehicle development partner, designs, engineers and develops customized concepts and solutions, optimized for production, to meet the mobility needs of the future. The design and development of complete modules, motor vehicles, derivatives and production systems belongs to the range of EDAG's services just as much as the construction of CAE models, prototypes and special vehicles and small-series production. In addition to the product development, EDAG Group offers the realization of complete production systems for vehicle construction and vehicle assembly from a single source. EDAG has had vast experience for many years in providing tooling for body shops and assembly lines as part of our manufacturing development services. Customers have included major OEM's like GM as well as smaller companies for single and multiple tools. EDAG has the capability to provide tooling design, at its facility in Troy, Michigan. At the request of the customer, the installation and tuning of the tool/s can also be installed by EDAG/FFT in their assembly line.

4 Baseline Benchmarking Vehicle Selection

4.1 Full-Size Pickup Truck Vehicle Selection Overview

Full-size pickup trucks offered by major OEM’s are typically available with three styles of driver and passenger cab designs and three sizes of load carrying pickup boxes as shown in Figure 1. These vehicles offer flexibility to carry up to six passengers in comfort and safety with payload carrying capacities up to 3,120 lbs (1,415 kg) and towing capacity over 11,300 lbs (5,126 kg).[17] The off-road capability of these vehicles with easy and open access to the pickup box makes these vehicles a good choice for farmers, construction industry work-crews as well as suburbanites who require occasional towing and the convenience of pickup box for load carrying. The uses of these vehicles range from transport of farmyard feed stocks and equipment to and from worksites in multitude of industries. To accommodate such diverse customer base and performance requirements these vehicles are available with options of several powertrains, 4-wheel drive, heavy-duty and fifth-wheel towing and up to 36-gallon fuel tanks for driving range of over 700 miles between fill-ups.



Exterior	Regular Cab 4x2/4x4	SuperCab 4x2/4x4	SuperCrew 4x2/4x4	SVT RAPTOR 4x4 SuperCab/SuperCrew
C. Length – 5½' box	–	–	231.9"	220.6"/232.1"
C. Length – 6½' box	213.2"	231.9"	243.9"	–
C. Length – 8' box	231.9"	250.4"	–	–
D. Overhang – Front	38.3"	38.3"	38.3"	38.0"
E. Wheelbase – 5½' box	–	–	144.5"	133.3"/145.2"
E. Wheelbase – 6½' box	125.9"	144.5"	156.5"	–
E. Wheelbase – 8' box	144.5"	163.1"	–	–
F. Overhang – Rear	49.0"	49.0"	49.0"	49.3"/48.9"

Figure 1: Full-size pickup truck[1] – design variations

The full-size trucks available in class 2A, 2B and 3 also share some components and systems. This sharing of components could influence the mass of the class 2A vehicles. For example 2014 Ford F150 (class 2A) and 2014 Ford F250 (class 2B) are both available with 6.2L V8 engine.

The baseline vehicle selection criteria setup for this project is that the baseline vehicle has to have a significant market share and be a representative vehicle for the segment. Besides these, to accommodate the diversity of the options, EDAG team created the following additional criteria

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[17] 2013 F-150 sales brochure - The F-150 has been the highest selling truck in the United States for the past 35 years

so that the complexity for pickup truck design can be fully considered to make the final design as realistic as possible within the funding and timing constraints of this project.

1. Style of Cab: Regular/Super Cab/Super Crew
2. Pickup Box Size: 5 ½ ft/6 ½ ft/8 ft referred to as short, standard and long respectively
3. Range of available engines, 3 sizes required
4. Drive: 4x2/4x4
5. Availability of heavy-duty drive package
6. Availability of regular and max towing package
7. Fuel tank size

The major constraint for deciding which vehicle to be used as baseline vehicle for this project is the possible time for the next CAFE rulemaking. In order to meet the major deadlines,[18] the project should be finished by April 2016 to support the next CAFE rulemaking, mid-term review.

4.2 Candidates for the Baseline Vehicle:

Five OEMs manufacture light duty pickup trucks as shown in Figure 2.

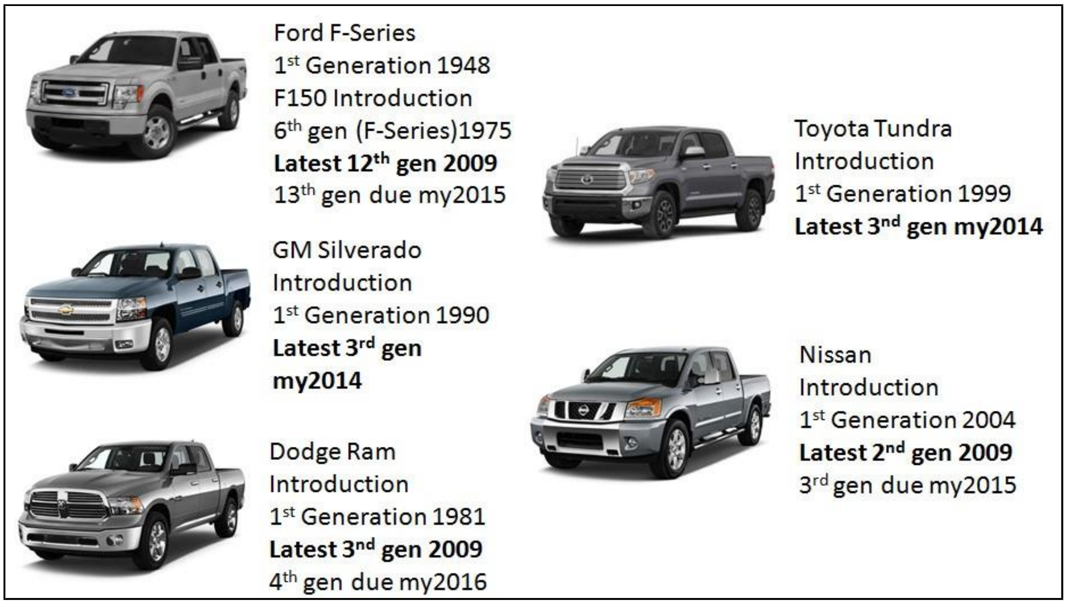

Figure 2: Pickup Truck Introduction Dates and History

For the vehicles shown in Figure 2, the model release dates range from 2009 to 2014 with a design date possibly 2 to 3 years prior to these release dates.

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[18] Issue TAR by November 15, 2017, and line up with the timeline for EPA to make the decision for rulemaking by April 1, 2018

Ford F-150
The Ford F-Series was introduced in 1948 with the first F-150 being introduced in late 1996 with a complete ground-up redesign. The current F-150 (12th generation of the F-Series) was introduced for the MY 2009 with major updates to the full-size truck platform. Ford will release the 13th generation F-150 for MY 2015 with new engines, cab, and pickup box design. As of 2014 the F-150 is sold in the United States, Canada, Mexico, the Middle East, and Iceland.

Chevrolet Silverado/GMC Sierra 1500
The first generation Silverado/Sierra was released as a MY 1990 vehicle, built on the then all-new GMT800 platform. The current third generation 2014 Silverado/Sierra began production in April 2013, with the change from the GMT800 to the K2XX platform. Changes included the introduction of GM's EcoTec3 family of engines as well as changes to the frame, cab, and pickup box. In January 2014, the Silverado received the North American International Auto Show truck-of-the-year award. As of 2014, the Silverado/Sierra is sold in the United States, Canada, Mexico, the Middle East, and Venezuela.

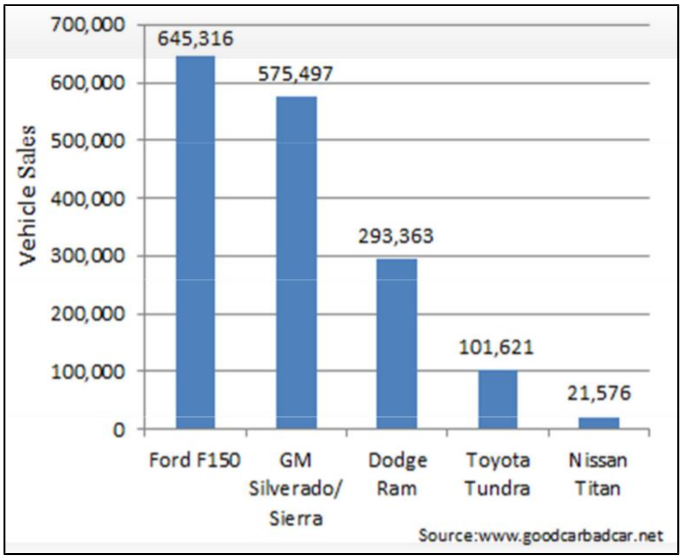
Dodge Ram 1500
The Dodge Ram truck was first introduced in 1981 as the Dodge Ram models B and D. The Dodge Ram truck was then redesigned for MY 1994. The Ram 1500 was introduced in 2002. The current Ram 1500 was introduced for MY 2009 with improved drivetrain and capacities. As of 2014, the Ram 1500 is sold in the United States, Canada, Mexico, the Middle East, and Brazil.

Toyota Tundra
The Toyota Tundra first generation was introduced in May 1999, sharing drivetrain with the Toyota T100 and Tacoma. The third generation was introduced in February 2013 as a MY 2014 vehicle, with redesigns to the interior cab and exterior trim. The Tundra for 2014 is only sold in NAFTA regions.

Nissan Titan
The Nissan Titan was introduced in 2004 sharing the F-Alpha platform with the Nissan Armada and Infiniti QX56 SUV, but unlike all the other vehicles in this study, the Titan has only one engine option. The Titan for 2014 is only sold in NAFTA regions.

4.2.1 Annual Sales

The full-size pickup market is currently dominated by the domestic OEMs: Ford F-Series, GM Silverado/Sierra, and Dodge Ram. Together these account for approximately 78 percent of total pickup truck sales (2012), and 13.4 percent of total U.S. vehicle sales, car and truck combined. To complete the selection process, two additional known OEM pickup trucks were selected for comparison, the Toyota Tundra and the Nissan Titan. See Figure 3 below for 2012 U.S. sales. The F-150 has the highest vehicle sales with 645,316 for 2012, with the combined Silverado and Sierra sales second at 575,497. Sales numbers for each of these two vehicles alone are higher than the combined Dodge, Toyota, and Nissan vehicle sales.



Source:www.goodcarbadcar.net

Figure 3: U.S. Vehicle Sales in the Full-Size Pickup Truck Category for MY2012[19]

4.2.2 Style of Cab

Ford, Chevrolet/GMC, Dodge, and Toyota all offer three cab types; regular for 3 passengers, double/extended, and crew cab for 6 passengers. The Nissan Titan has only a double cab (known as a king cab) and a crew cab. A regular cab is not available.

4.2.3 Pickup Box Length

As with the style of cab, Ford, Chevrolet/GMC, Dodge, and Toyota each have a 5 ½ ft., known as a short box, a 6 ½ ft. standard box and an 8 ft. long box. Nissan has a short and standard box and a shorter 7 ft. long box. Not all box sizes are available for all cab styles. An example of this is the Ford F-150 where the 8 ft. long box is not available on the crew cab. Figure 4 shows available combinations of cabs and pickup boxes.

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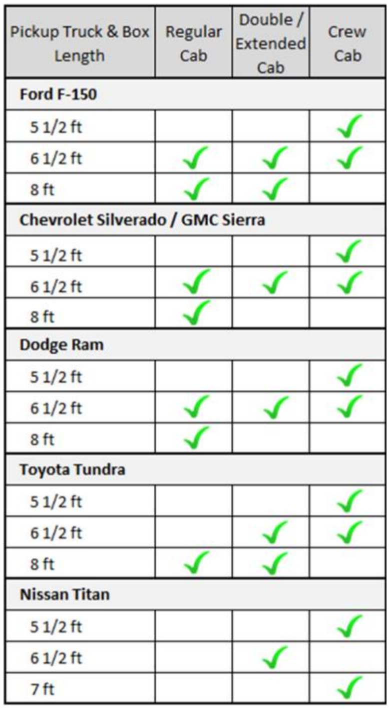
[19] Goodcarbadcar.net Vehicle market sales MY2012

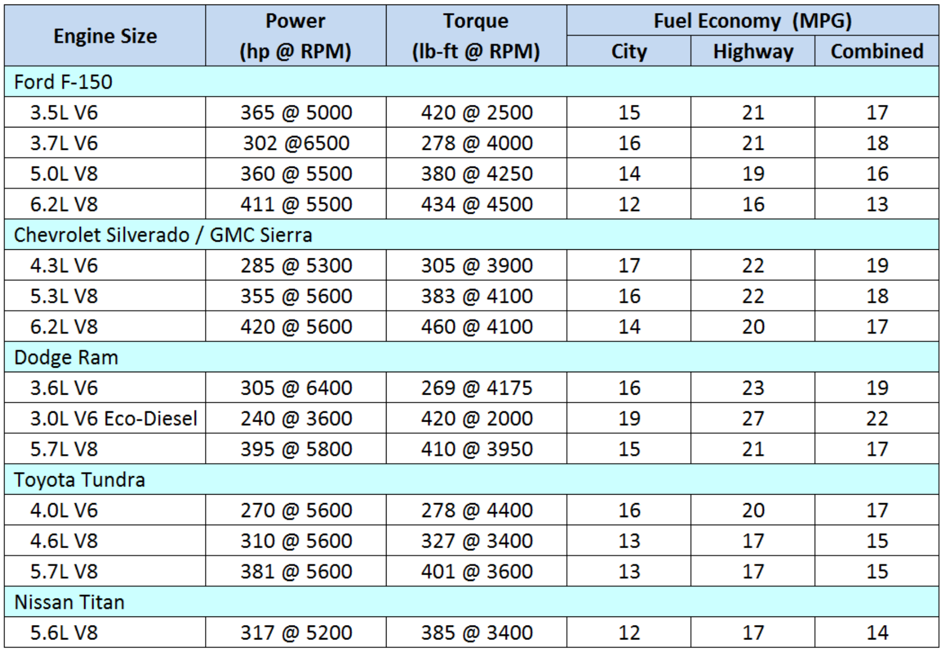


Pickup Truck & Box Length	Regular Cab	Double / Extended Cab	Crew Cab
Ford F-150			
5 1/2 ft			✓
6 1/2 ft	✓	✓	✓
8 ft	✓	✓	
Chevrolet Silverado / GMC Sierra			
5 1/2 ft			✓
6 1/2 ft	✓	✓	✓
8 ft	✓		
Dodge Ram			
5 1/2 ft			✓
6 1/2 ft	✓	✓	✓
8 ft	✓		
Toyota Tundra			
5 1/2 ft			✓
6 1/2 ft		✓	✓
8 ft	✓	✓	
Nissan Titan			
5 1/2 ft			✓
6 1/2 ft		✓	
7 ft			✓

Figure 4: Available Cab and Pickup Box Size Configurations

4.2.4 Engine Size

The MY2014 Ford F-150 has four engine sizes ranging from the 3.5L-V6 Eco Boost to a 6.2L-V8. The Chevrolet Silverado is offered with three engine sizes: 4.3L-V6, 5.3L-V8 and 6.2L-V8; all are EcoTec3 generation. However, the GMC Sierra only uses the 5.3L-V8 and 6.2L-V8 EcoTec3 engines. The Dodge Ram is currently available with three engine sizes: 3.6L-V6 Pentastar, 3.0L-V6 Eco-Diesel and a 5.7L-V8. Currently the Toyota Tundra has three engine sizes: 4.0L-V6, 4.6L-V8 and 5.7L-V8. Nissan has one engine available for the Titan, a 5.6L-V8, but is planning to introduce a 5.0L-V8 Turbo-Diesel for the next generation of Titan in 2015. Figure 5 show a summary of available engines, power, torque, and fuel economy for each truck.



Engine Size	Power (hp @ RPM)	Torque (lb-ft @ RPM)	Fuel Economy (MPG)		
			City	Highway	Combined
Ford F-150					
3.5L V6	365 @ 5000	420 @ 2500	15	21	17
3.7L V6	302 @6500	278 @ 4000	16	21	18
5.0L V8	360 @ 5500	380 @ 4250	14	19	16
6.2L V8	411 @ 5500	434 @ 4500	12	16	13
Chevrolet Silverado / GMC Sierra					
4.3L V6	285 @ 5300	305 @ 3900	17	22	19
5.3L V8	355 @ 5600	383 @ 4100	16	22	18
6.2L V8	420 @ 5600	460 @ 4100	14	20	17
Dodge Ram					
3.6L V6	305 @ 6400	269 @ 4175	16	23	19
3.0L V6 Eco-Diesel	240 @ 3600	420 @ 2000	19	27	22
5.7L V8	395 @ 5800	410 @ 3950	15	21	17
Toyota Tundra					
4.0L V6	270 @ 5600	278 @ 4400	16	20	17
4.6L V8	310 @ 5600	327 @ 3400	13	17	15
5.7L V8	381 @ 5600	401 @ 3600	13	17	15
Nissan Titan					
5.6L V8	317 @ 5200	385 @ 3400	12	17	14

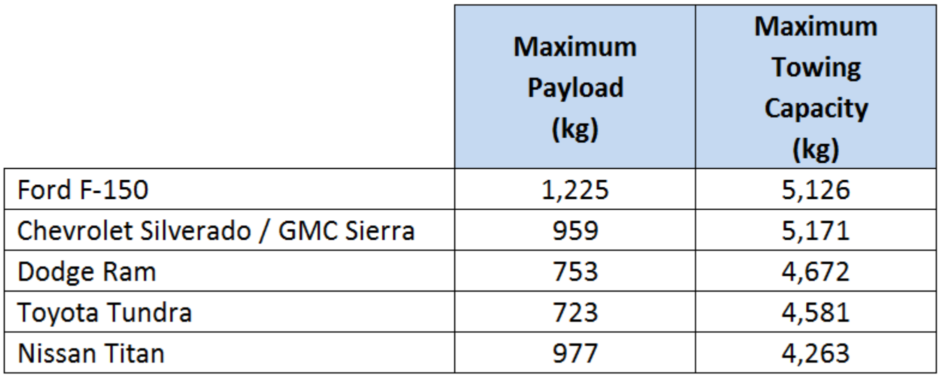
Figure 5: Engines Available for 2014 Full-Size Pickup Trucks

4.2.5 Drive Options

All the selected OEM's offer 4x4 drives with switchable 4x2 modes. Ford and Chevrolet/GMC have 6-speed automatic transmissions with overdrive, with tow/haul modes, and heavy-duty packages. The MY 2014 Dodge Ram is equipped with an 8-speed automatic transmission or an optional 6-speed automatic for the 5.7L-V8 engine. Toyota and Nissan are each equipped with 5-speed automatic transmissions with overdrive.

4.2.6 Heavy-Duty Drive and Towing Package

Only Ford and Chevrolet/GMC offer heavy-duty drives and towing packages. Ford's package includes all-terrain tires, heavy-duty suspension shock absorbers, and upgraded coil springs, plus an upgraded radiator and auxiliary transmission oil radiator. The rear axle is fitted with a 9.75" gear set and a 3.73 limited slip gear ratio. The Chevrolet/GMC package includes a 9.76" rear axle with a 3.73 axle ratio, heavy-duty rear leaf springs, and upgraded suspension shock absorbers. Also included is an upgraded cooling radiator. See Figure 6 for a summary of maximum payloads for each of the trucks.



	Maximum Payload (kg)	Maximum Towing Capacity (kg)
Ford F-150	1,225	5,126
Chevrolet Silverado / GMC Sierra	959	5,171
Dodge Ram	753	4,672
Toyota Tundra	723	4,581
Nissan Titan	977	4,263

Figure 6: Maximum Payload and Towing Capacities for 2014 Full-Size Pickup Trucks

4.2.7 Towing Package

All the selected OEM's offer a towing package, which includes the trailer hitch and associated wiring and connectors. Ford and Chevrolet/GMC also include additional upgrades.
Ford's additional upgrades include a Class IV trailer hitch receiver for towing over 2,268 kg, an upgraded radiator, auxiliary oil radiator and Ford's Select Shift automatic transmission.
Chevrolet/GMC additional upgrades include an automatic locking rear differential and 7-pin plus 4-pin connectors. Both Ford and Chevrolet/GMC offer a trailer brake controller. A summary of maximum towing capacities for each of the trucks can be seen in Figure 6

4.2.8 Fuel Tank Capacity

Ford offers 26- and 36-gallon fuel tank, where Chevrolet/GMC has 26- and 34-gallon fuel tank capacity. The Dodge Ram fuel tanks are 26 and 32 gallons. The fuel tank sizes are dependent on cab and pickup box configurations. Toyota and Nissan offer one fuel tank size. The Toyota Tundra fuel tank has a 26.4-gallon capacity and the Nissan Titan's is 28 gallons.

4.2.9 Occupant Safety

The 2014 Chevrolet Silverado1500 obtained an overall 5-star safety rating in NHTSA's NCAP, as seen in Figure 7.

Year/Make/Model	Overall	Frontal Crash	Side Crash	Rollover
2014 Chevrolet Silverado 1500 FWD	★★★★★	★★★★★	★★★★★	★★★★☆

Figure 7: 2014 Chevrolet Silverado 1500 NHTSA Safety Ratings[20]

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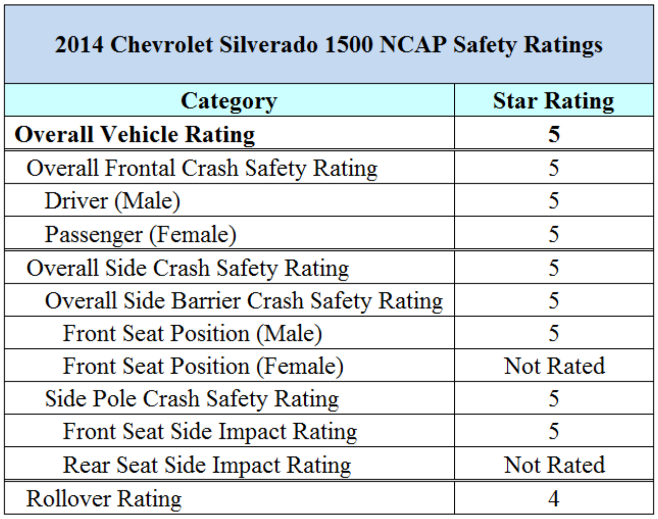
[20] NHTSA web site, "5-Star Safety Rating," www.safercar.gov/

The Overall Vehicle Rating is determined by combining the results of the ratings from the frontal crash tests, side crash tests, and roll over resistance into a single summary score between 1 and 5 stars.[21] The Silverado 1500 achieved the NHTSA 5-star Overall Vehicle Rating based upon 5 stars in overall frontal crash, 5 stars in overall side crash and 4 stars for rollover. For a more detailed breakdown of the crash ratings, see Figure 8.



2014 Chevrolet Silverado 1500 NCAP Safety Ratings

Category	Star Rating
Overall Vehicle Rating	**5**
Overall Frontal Crash Safety Rating	5
Driver (Male)	5
Passenger (Female)	5
Overall Side Crash Safety Rating	5
Overall Side Barrier Crash Safety Rating	5
Front Seat Position (Male)	5
Front Seat Position (Female)	Not Rated
Side Pole Crash Safety Rating	5
Front Seat Side Impact Rating	5
Rear Seat Side Impact Rating	Not Rated
Rollover Rating	4

Figure 8: 2014 Chevrolet Silverado 1500 NCAP Star Rating Breakdown
(safercar.gov)

4.3 Decision for Baseline Vehicle Selection

From the 5 OEM's selected for review based upon sales volumes, the two vehicles below were selected as candidates for this study.

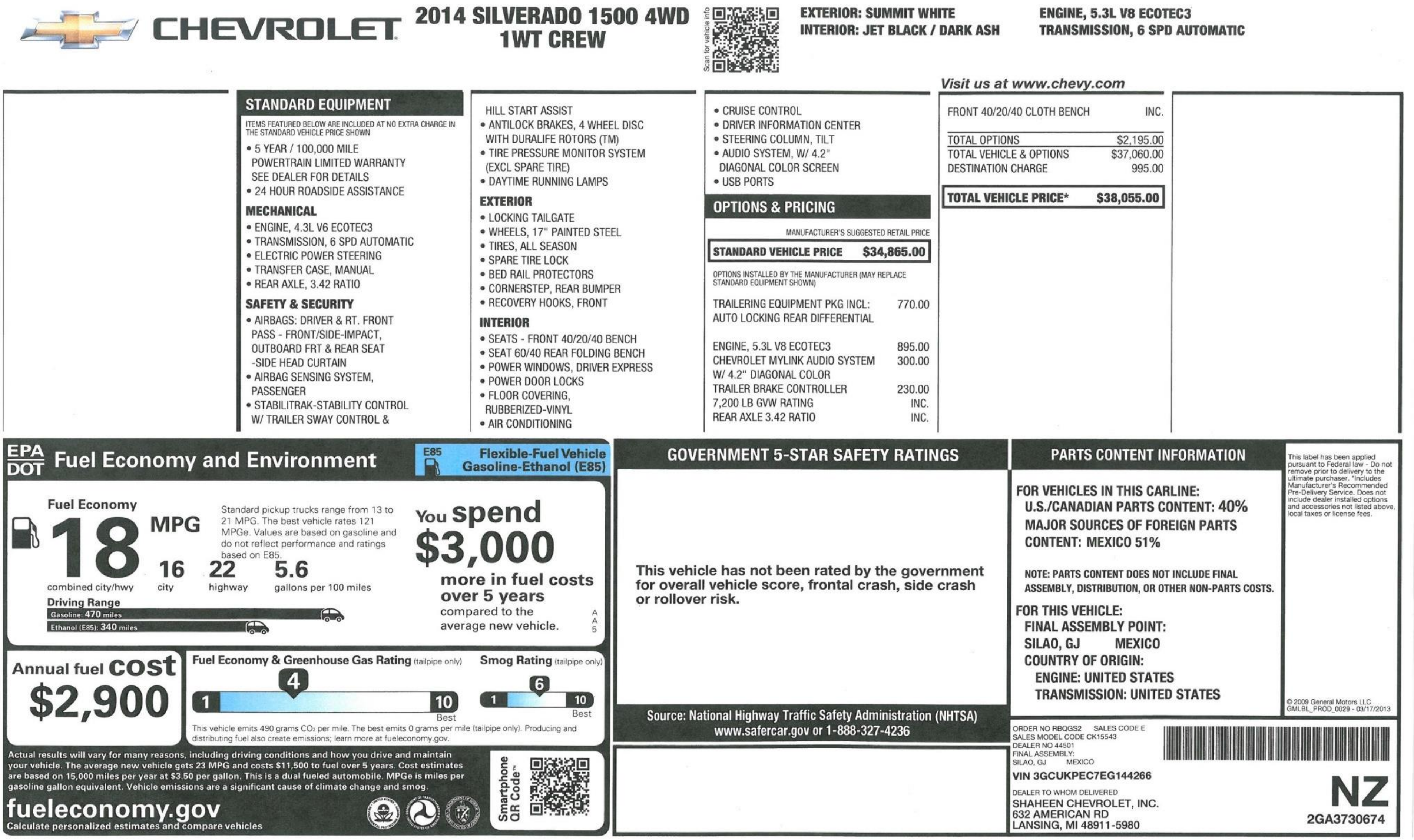
- 2014 Ford F-150 1500, redesigned for MY 2009
- 2014 Chevrolet Silverado 1500, with new design for MY 2014

Both vehicles have high sales volumes and a significant market share in the full-size pickup segment. Both have similar functionalities, payload, and towing capacities, similar powertrain combinations, fuel economy ratings, and body/cab configurations. One factor favoring the Chevrolet Silverado is that the 2014 model is based upon the major redesign for MY2014, with the design work most likely completed during 2010. The 2014 Ford F-150 was based upon the MY2009 redesign for which the design work was possibly completed in 2006. Due to these redesign dates, the Ford F-150 is deemed to be an "older design" when representing a baseline vehicle for mid-term review for MY2022-2025.

Currently the 2014 Chevrolet Silverado has a NHTSA 5-star safety rating, whereas the 2014 Ford F-150 with the same configuration has a 4-star safety rating. Ford has announced that a redesigned F-150 using an aluminum-intensive cab and pickup box will be released for MY2015. However, at time of making this decision (November 2013), the exact release date and vehicle cost are unknown, as is the time frame when NCAP and IIHS test data for the 2015 F-150 will be available.

Taking all these factors into consideration, the baseline full-size pickup truck selection for this study was chosen to be MY2014 Chevrolet Silverado 1500, Crew Cab with Short Box (5 ½ ft.), 5.3L-V8 Ecotec3 engine with a 4x4 drivetrain, trim level 1WT. The chosen model configuration is the most popular and similar to the model configuration that would be used for NCAP testing. This vehicle shown in Figure 9 and Figure 10 shows the Monroney window sticker for the baseline vehicle.

Figure 9: Baseline 2014 Chevrolet Silverado 1500



CHEVROLET

2014 SILVERADO 1500 4WD
1WT CREW

Scan for vehicle info

EXTERIOR: SUMMIT WHITE
INTERIOR: JET BLACK / DARK ASH

ENGINE, 5.3L V8 ECOTEC3
TRANSMISSION, 6 SPD AUTOMATIC

STANDARD EQUIPMENT

ITEMS FEATURED BELOW ARE INCLUDED AT NO EXTRA CHARGE IN THE STANDARD VEHICLE PRICE SHOWN

- 5 YEAR / 100,000 MILE POWERTRAIN LIMITED WARRANTY SEE DEALER FOR DETAILS
- 24 HOUR ROADSIDE ASSISTANCE

MECHANICAL

- ENGINE, 4.3L V6 ECOTEC3
- TRANSMISSION, 6 SPD AUTOMATIC
- ELECTRIC POWER STEERING
- TRANSFER CASE, MANUAL
- REAR AXLE, 3.42 RATIO

SAFETY & SECURITY

- AIRBAGS: DRIVER & RT. FRONT PASS - FRONT/SIDE-IMPACT, OUTBOARD FRT & REAR SEAT -SIDE HEAD CURTAIN
- AIRBAG SENSING SYSTEM, PASSENGER
- STABILITRAK-STABILITY CONTROL W/ TRAILER SWAY CONTROL & HILL START ASSIST
- ANTILOCK BRAKES, 4 WHEEL DISC WITH DURALIFE ROTORS (TM)
- TIRE PRESSURE MONITOR SYSTEM (EXCL SPARE TIRE)
- DAYTIME RUNNING LAMPS

EXTERIOR

- LOCKING TAILGATE
- WHEELS, 17" PAINTED STEEL
- TIRES, ALL SEASON
- SPARE TIRE LOCK
- BED RAIL PROTECTORS
- CORNERSTEP, REAR BUMPER
- RECOVERY HOOKS, FRONT

INTERIOR

- SEATS - FRONT 40/20/40 BENCH
- SEAT 60/40 REAR FOLDING BENCH
- POWER WINDOWS, DRIVER EXPRESS
- POWER DOOR LOCKS
- FLOOR COVERING, RUBBERIZED-VINYL
- AIR CONDITIONING
- CRUISE CONTROL
- DRIVER INFORMATION CENTER
- STEERING COLUMN, TILT
- AUDIO SYSTEM, W/ 4.2" DIAGONAL COLOR SCREEN
- USB PORTS

OPTIONS & PRICING

MANUFACTURER'S SUGGESTED RETAIL PRICE

STANDARD VEHICLE PRICE	**$34,865.00**

OPTIONS INSTALLED BY THE MANUFACTURER (MAY REPLACE STANDARD EQUIPMENT SHOWN)

TRAILERING EQUIPMENT PKG INCL: AUTO LOCKING REAR DIFFERENTIAL	770.00
ENGINE, 5.3L V8 ECOTEC3	895.00
CHEVROLET MYLINK AUDIO SYSTEM W/ 4.2" DIAGONAL COLOR	300.00
TRAILER BRAKE CONTROLLER	230.00
7,200 LB GVW RATING	INC.
REAR AXLE 3.42 RATIO	INC.
FRONT 40/20/40 CLOTH BENCH	INC.
TOTAL OPTIONS	$2,195.00
TOTAL VEHICLE & OPTIONS	$37,060.00
DESTINATION CHARGE	995.00
TOTAL VEHICLE PRICE*	**$38,055.00**

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EPA DOT Fuel Economy and Environment

E85 **Flexible-Fuel Vehicle Gasoline-Ethanol (E85)**

Fuel Economy

18 MPG combined city/hwy

16 city **22** highway **5.6** gallons per 100 miles

Standard pickup trucks range from 13 to 21 MPG. The best vehicle rates 121 MPGe. Values are based on gasoline and do not reflect performance and ratings based on E85.

Driving Range

Gasoline: **470** miles

Ethanol (E85): **340** miles

You **spend $3,000** **more in fuel costs over 5 years** compared to the average new vehicle.

A A 5

Annual fuel cost $2,900

Fuel Economy & Greenhouse Gas Rating (tailpipe only) **4** (1 – 10 Best)

Smog Rating (tailpipe only) **6** (1 – 10 Best)

This vehicle emits 490 grams CO_2 per mile. The best emits 0 grams per mile (tailpipe only). Producing and distributing fuel also create emissions; learn more at fueleconomy.gov.

Actual results will vary for many reasons, including driving conditions and how you drive and maintain your vehicle. The average new vehicle gets 23 MPG and costs $11,500 to fuel over 5 years. Cost estimates are based on 15,000 miles per year at $3.50 per gallon. This is a dual fueled automobile. MPGe is miles per gasoline gallon equivalent. Vehicle emissions are a significant cause of climate change and smog.

fueleconomy.gov
Calculate personalized estimates and compare vehicles

Smartphone QR Code™

GOVERNMENT 5-STAR SAFETY RATINGS

This vehicle has not been rated by the government for overall vehicle score, frontal crash, side crash or rollover risk.

Source: National Highway Traffic Safety Administration (NHTSA)
www.safercar.gov or 1-888-327-4236

PARTS CONTENT INFORMATION

FOR VEHICLES IN THIS CARLINE:
U.S./CANADIAN PARTS CONTENT: 40%
MAJOR SOURCES OF FOREIGN PARTS CONTENT: MEXICO 51%

NOTE: PARTS CONTENT DOES NOT INCLUDE FINAL ASSEMBLY, DISTRIBUTION, OR OTHER NON-PARTS COSTS.

FOR THIS VEHICLE:
FINAL ASSEMBLY POINT:
SILAO, GJ MEXICO
COUNTRY OF ORIGIN:
ENGINE: UNITED STATES
TRANSMISSION: UNITED STATES

This label has been applied pursuant to Federal law - Do not remove prior to delivery to the ultimate purchaser. *Includes Manufacturer's Recommended Pre-Delivery Service. Does not include dealer installed options and accessories not listed above, local taxes or license fees.

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GMLBL_PROD_0029 - 03/17/2013

ORDER NO RBQGS2 SALES CODE E
SALES MODEL CODE CK15543
DEALER NO 44501
FINAL ASSEMBLY:
SILAO, GJ MEXICO

VIN 3GCUKPEC7EG144266

DEALER TO WHOM DELIVERED
SHAHEEN CHEVROLET, INC.
632 AMERICAN RD
LANSING, MI 48911-5980

NZ
2GA3730674

Figure 10: Window Sticker for Baseline 2014 Chevrolet Silverado 1500

4.4 Additional Benchmark Vehicles

To review and determine the impact of other models within the Silverado 1500 vehicle range, two supplemental models were selected to cover the additional selection criteria specified in the Statement of Work. These vehicles will be subjected to limited teardown.

- MY2014 Chevrolet Silverado 1500, Regular Cab with Standard Box (6 ½ ft.), 4.3L-V6 EcoTec3 engine with 4x2 drivetrain, trim level 1WT, with 24-gallon fuel tank
- MY2014 Chevrolet Silverado 1500, Double Cab with Standard Box (6 ½ ft.), 6.2L-V8 EcoTec3 engine with 4x4/4x2 drivetrain, trim level LTZ, with maximum towing package and 26-gallon fuel tank

Figure 11 shows features of these benchmark vehicles.

Chevrolet Silverado 1500 (MY2014)

Additional Benchmark Vehicles

Feature	Model 1WT	Model LT
Cab Style	Regular	Double
Pickup Box	Standard (6 ½ft)	Standard (6 ½ ft)
Engine	4.3L V6 EcoTec3	6.2L V8 EcoTec3
Drive	2WD	4x4 with 4x2
Rear Axle Ratio	3.23	3.73
Fuel Tank Capacity (Gallons)	24	26
Max Payload (lb/kg)	2,059/934	1,823/827
Max Convention Towing (lb/kg)	6,300/2,858	11,800/5,352

Figure 11: Supplemental Benchmark Vehicle Configurations[22]

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[22] www.chevrolet.com/silverado-1500/specs/capabilities

5 Baseline Vehicle Teardown and Technical Assessment

5.1 Vehicle Teardown and Geometry Scan

Prior to scanning and teardown, the baseline 2014 Chevrolet Silverado 1500 was weighed using four-point weigh scales. The mass of the Silverado 1500 with a full gas tank was 2,432 kg. The front axle was measured to have 58 percent of the weight and the rear axle had 42 percent. This weight distribution is common in a 4-wheel drive vehicle; the higher mass in the front is from the weight of the engine and drivetrain, while the rear has fewer drivetrain components. See Figure 12 for Silverado weight distribution and Figure 13 for Silverado dimensions and weights.

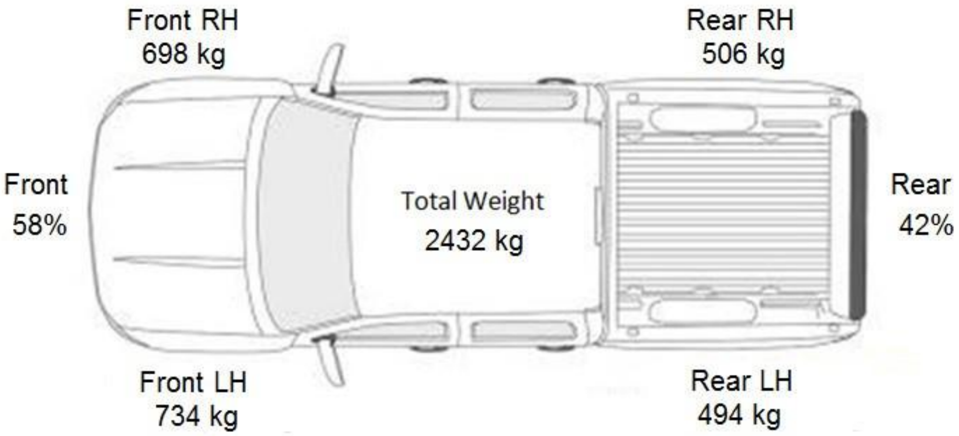
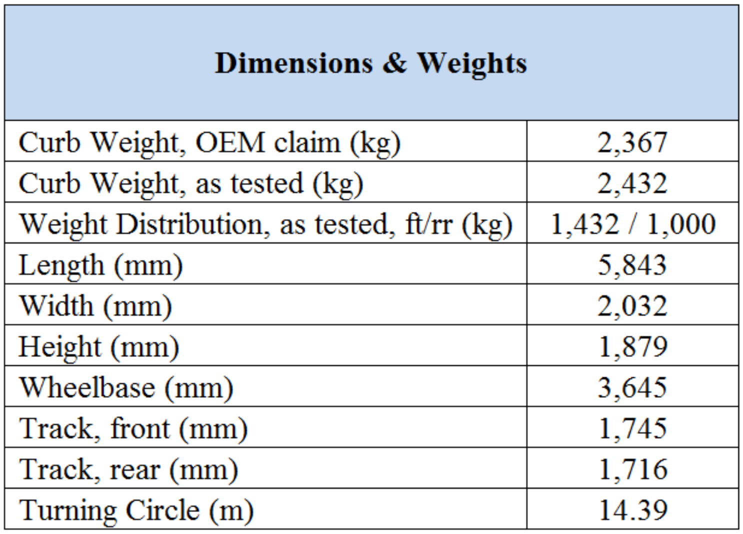


Figure 12: Silverado 1500 Weight Distribution



Dimensions & Weights	
Curb Weight, OEM claim (kg)	2,367
Curb Weight, as tested (kg)	2,432
Weight Distribution, as tested, ft/rr (kg)	1,432 / 1,000
Length (mm)	5,843
Width (mm)	2,032
Height (mm)	1,879
Wheelbase (mm)	3,645
Track, front (mm)	1,745
Track, rear (mm)	1,716
Turning Circle (m)	14.39

Figure 13: Silverado Dimensions and Weights

An exterior and interior white-light scan of the entire vehicle was then completed. A scanning fringe pattern is projected onto the vehicle or component surfaces using a white light projector.

These patterns are then recorded by two cameras mounted on the scanning head. The system self-checks its calibration relative to the ambient conditions. Software then calculates the high-precision 3D coordinates of up to 4 million object points per measurement. In addition to the surface, the system also provides trim edges plus hole and slot information. Each measurement is transformed automatically into a common XYZ coordinate system. The complete 3D data sets are then exported into standard format, stereo lithography for further processing to CAD data. Refer to Figure 14 for photographs of the Silverado 1500 prior to exterior vehicle scanning and Figure 15 for the Silverado prior to interior vehicle scanning.

Figure 14: Silverado 1500 Prior to Exterior Scanning

Figure 15: Silverado 1500 Prior to Interior Scanning

Due to the camera optics, the body is sprayed using a removable white talc spray to eliminate reflections from the painted surface. The Silverado 1500 prepared with talc spray for the white light scanning process is shown in Figure 16. The grey interior is also sprayed with talc, as shown in Figure 17, since any polished surface will reflect white light while dark surfaces absorb the light. Either of these occurrences will not produce a satisfactory scan image.

Figure 16: Silverado 1500 Exterior Prepared for White Light Scanning

Figure 17: Silverado 1500 Interior Prepared for White Light Scanning

Reference point decals are added to allow multiple scan patches to be made, manipulated and aligned to a three-dimensional XYZ axis, creating a single-point cloud file with a common point of origin. After completing all the scans and the subsequent data processing, the resulting 3D data is converted to an STL data file that is comprised of a series of small-triangulated surfaces. The STL data is further converted to a CAD data file Unigraphics format. Examples of the Silverado 1500 converted STL files from the 3D scan to workable CAD data are shown in Figure 18 and Figure 19.

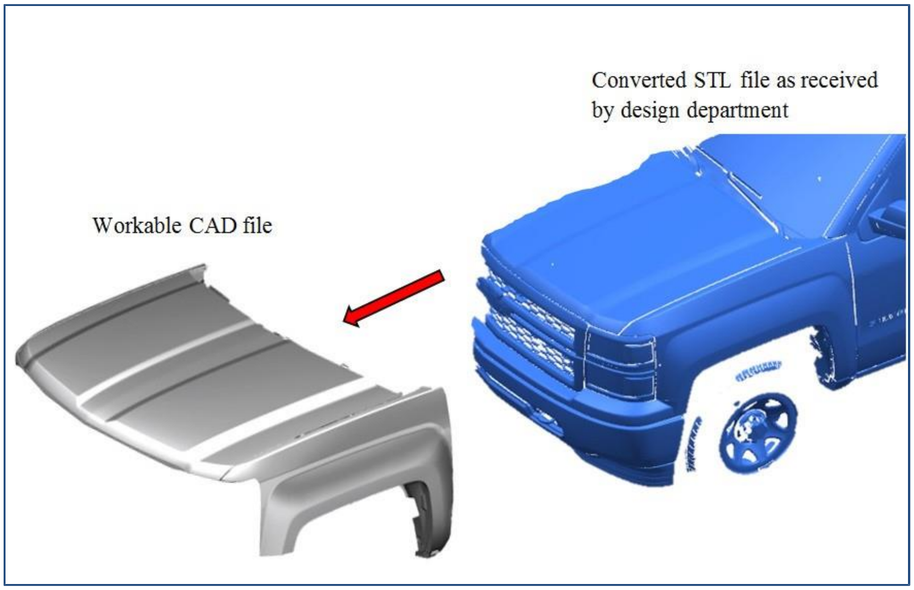


Figure 18: Body Structure Scanned Surfaces STL to CAD Data

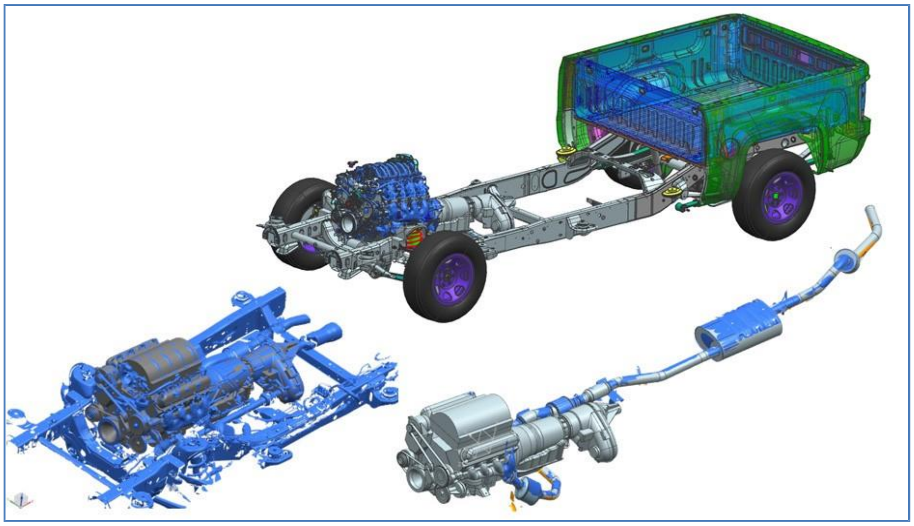


Figure 19: Powertrain Scanned Surfaces to Geometry CAD Data

Areas scanned on the complete vehicle prior to teardown included:

- Vehicle exterior to minimum 200mm past vehicle center,
- Engine bay with hood open,
- Complete underbody with wheels removed, and
- Complete interior.

The Silverado 1500 underwent a complete vehicle teardown to the individual component or sub- assembly level. All closures, front/rear doors, hood, tailgate, pickup box, and cab, were removed from the body structure. Teardown of the left-hand front and rear doors plus hood and tailgate were then completed. Figure 20 shows a flowchart of the teardown process for the baseline vehicle.

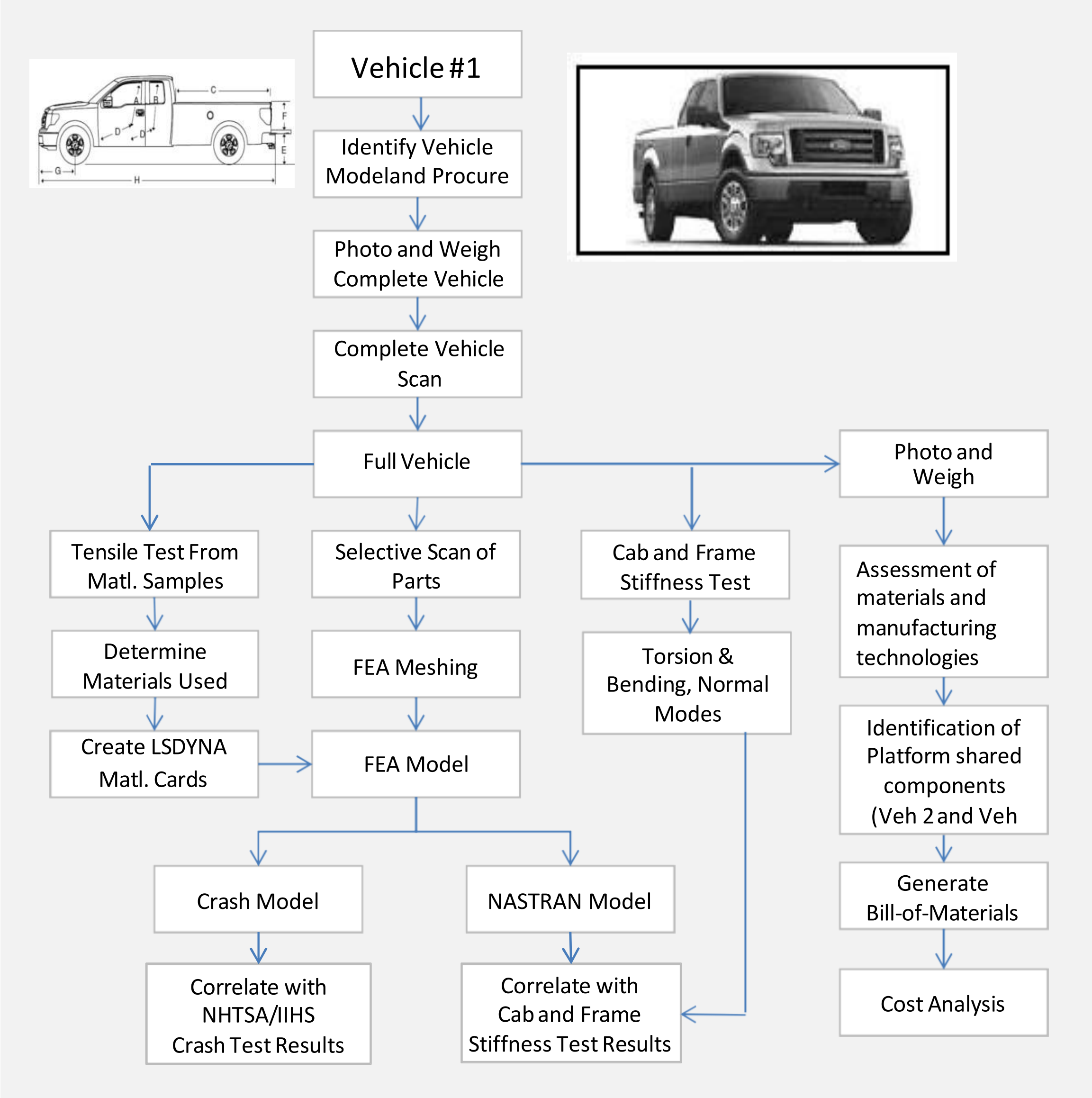


Figure 20: Silverado 1500 Teardown Flow Chart

After the vehicle teardown, additional scans were made on the following components and sub-assemblies in order to create 3D CAD model data required to evaluate these sub- systems for packaging and design studies and weight reduction.

- Front and rear door inner surfaces
- Hood and tailgate inner surfaces
- Entire chassis with powertrain
- Chassis stripped down to frame
- Front bumper assembly
- Rear bumper assembly with trailer hitch

After teardown of the body structure and additional scanning were completed, the body structure underwent static torsion and bending testing, plus modal testing to determine the baseline stiffness criteria for the LWT. An external source, Defiance Testing &Engineering, was engaged to complete these tests.

For these tests, the front windshield and rear glass were not removed from the body, and the instrument panel cross-car beam was re-assembled into the body structure, as these components contribute to the overall vehicle stiffness.

Each individual component part or sub-assembly was weighed, photographed, and weight information of each part was collected. This information was added to a parts database.

5.2 Body Structure and Chassis Frame Part Count

5.2.1 Body Structure Part Count

Several steps were performed to ensure that all components of the Silverado 1500 body structure were completely accounted for, as shown in Figure 21 and Figure 22. The Silverado 1500 body structure assembly was analyzed to determine the assembly sequence of the major sub-assemblies. In addition, a body structure bill of materials was generated and a spot-weld count was made. From the assembly analysis it was determined that there are 305 parts that make up the Silverado 1500 Body-In-white prior to the paint process. The BIW includes the body structure and closures.

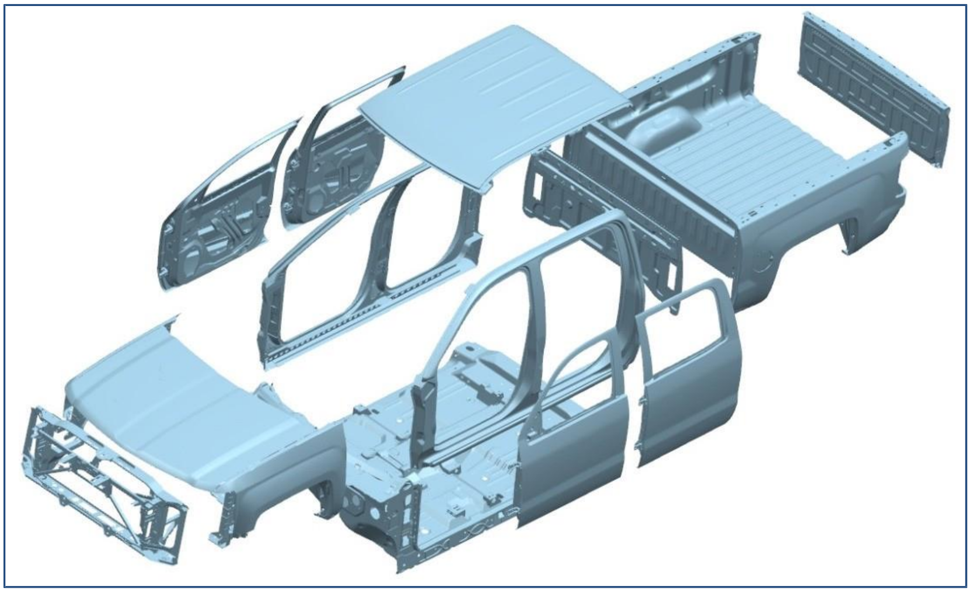
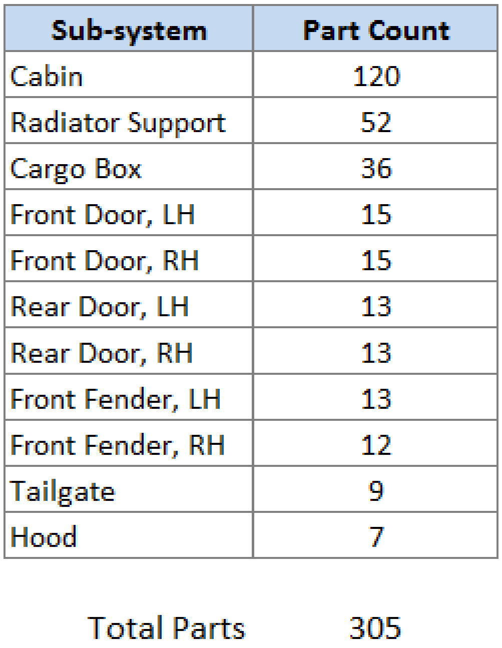


Figure 21: Body Structure Sheet Metal Assemblies



Sub-system	Part Count
Cabin	120
Radiator Support	52
Cargo Box	36
Front Door, LH	15
Front Door, RH	15
Rear Door, LH	13
Rear Door, RH	13
Front Fender, LH	13
Front Fender, RH	12
Tailgate	9
Hood	7

Total Parts 305

Figure 22: Body-in-White Part Count by Sub-System

5.2.2 Silverado 1500 Chassis Frame

The Silverado 1500 chassis frame assembly was analyzed to determine the assembly sequence of the major sub-assemblies. In addition, a bill of materials was generated and weld count was made. From the assembly analysis it was determined that there are 134 parts that make up the Silverado 1500 chassis frame prior to the paint process. The chassis frame includes the frame, bumpers and trailer hitch. See and Figure 24 for the Silverado 1500 part count per sub-system.

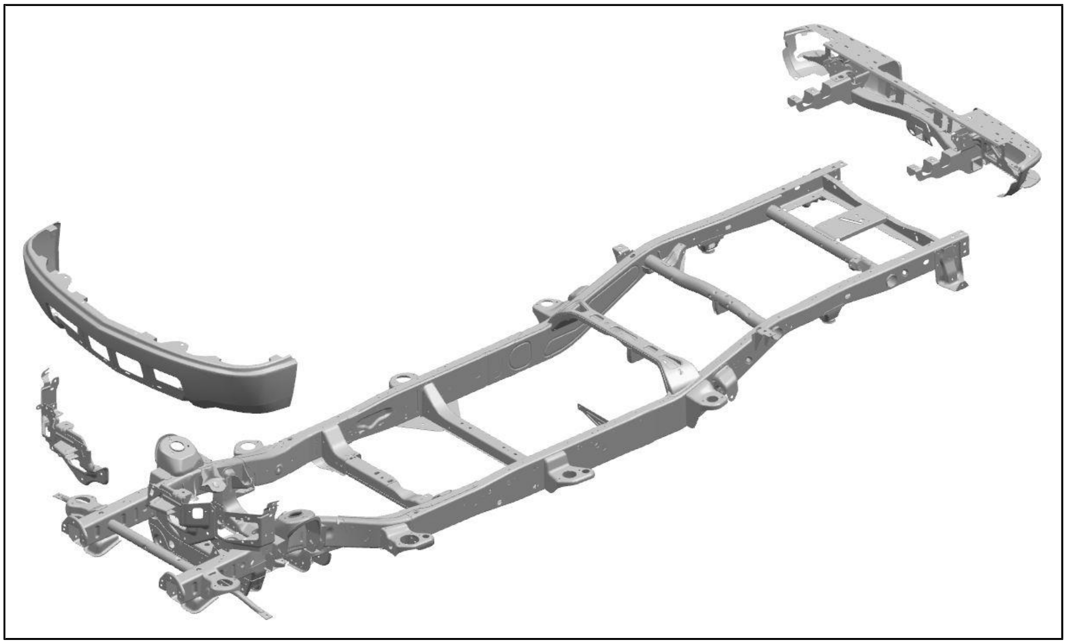
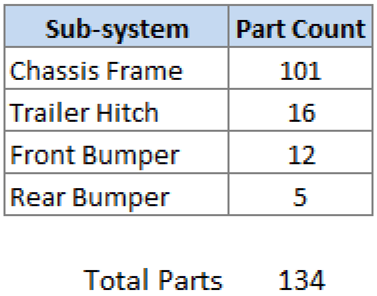


Figure 23: Chassis Frame,
(Source: EDAG CAD Model)



Sub-system	Part Count
Chassis Frame	101
Trailer Hitch	16
Front Bumper	12
Rear Bumper	5

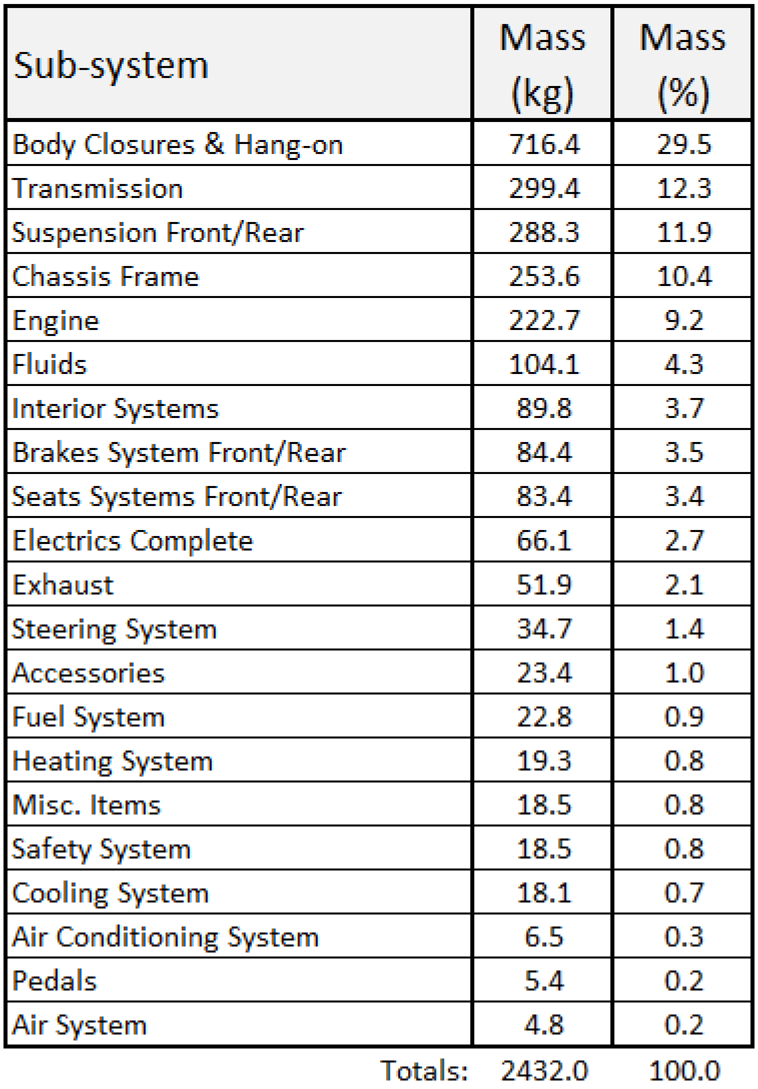
Total Parts 134

Figure 24: Chassis Frame Count by Sub-System

5.3 Vehicle, Sub-system and Component Mass and Material Assessment

5.3.1 Mass and Material Distribution

The body structure, which includes all closures plus front fenders and other add-on parts, accounts for 29.5 percent of the vehicle's mass, making it the largest individual contributor. The front and rear suspensions account for approximately 22.3 percent of the vehicle's overall weight while the powertrain, including the engine and the transmission, accounts for 21.9 percent of the vehicle weight. See Figure 25 and Figure 26 for mass distribution. Appendix A provides a complete vehicle parts list showing sub-system mass.



Sub-system	Mass (kg)	Mass (%)
Body Closures & Hang-on	716.4	29.5
Transmission	299.4	12.3
Suspension Front/Rear	288.3	11.9
Chassis Frame	253.6	10.4
Engine	222.7	9.2
Fluids	104.1	4.3
Interior Systems	89.8	3.7
Brakes System Front/Rear	84.4	3.5
Seats Systems Front/Rear	83.4	3.4
Electrics Complete	66.1	2.7
Exhaust	51.9	2.1
Steering System	34.7	1.4
Accessories	23.4	1.0
Fuel System	22.8	0.9
Heating System	19.3	0.8
Misc. Items	18.5	0.8
Safety System	18.5	0.8
Cooling System	18.1	0.7
Air Conditioning System	6.5	0.3
Pedals	5.4	0.2
Air System	4.8	0.2
Totals:	2432.0	100.0

Figure 25: Vehicle Mass Distribution (kg and %)

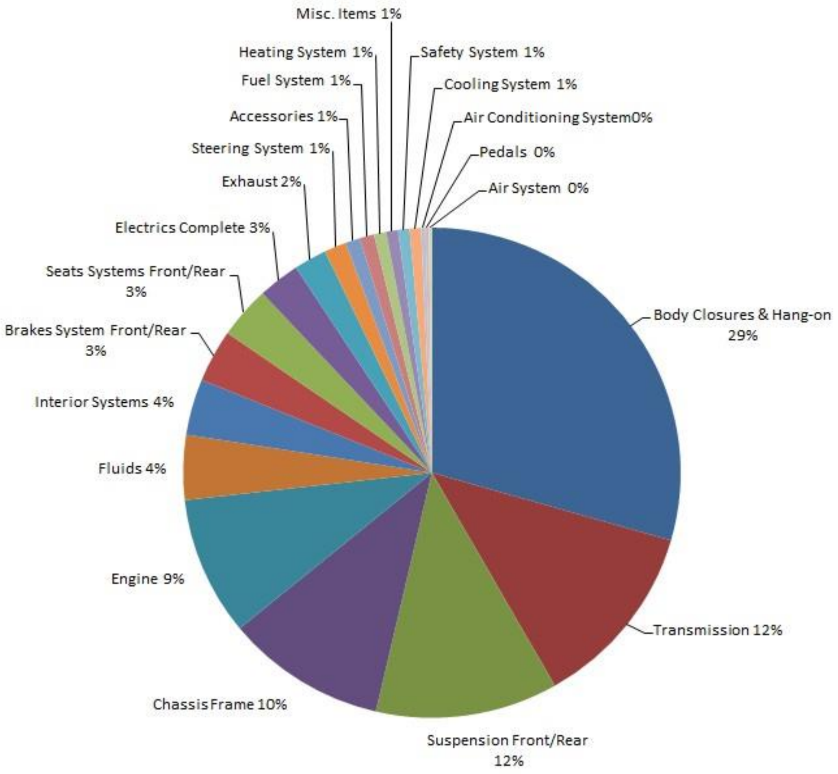


Figure 26: Vehicle Mass Distribution (%)

5.4 Vehicle Material Usage Analysis for Major Vehicle Systems

For the Chevrolet Silverado 1500 sub-system weights see Appendix A.

5.4.1 Vehicle Material usage

Material utilization for the 2014 Silverado is shown in Figure 27. Steel usage for the total vehicle 46% is predominantly sheet steel used for the body structures shown in Figure 28 and chassis frame assembly inclusive front and rear bumpers and towing hitch shown in Figure 43.

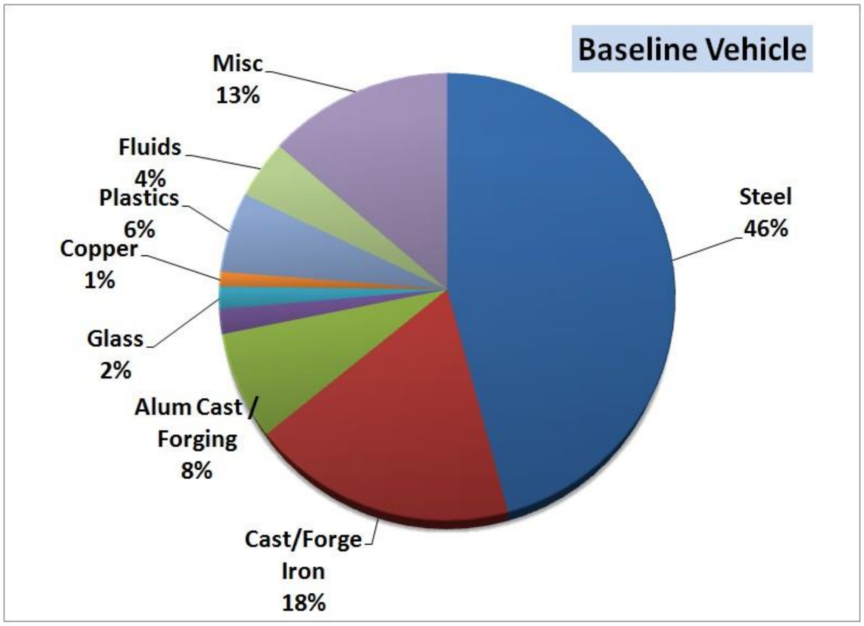


Figure 27: Material distribution for the 2014 Silverado 1500

The body-in-white and the following major sub-systems in the baseline vehicle were reviewed to determine the material distribution.

- Front seat assembly
- Instrument panel
- Center console/middle front seat
- Steering sub-system
- Chassis frame, front and rear bumper assemblies, and hitch
- Front suspension module
- Rear suspension module

Each of these systems is described in detail below.

5.4.2 Body-in-White

The complete body-In-white includes the cab structure, closures (front/rear doors, hood, and tailgate), front fenders, pickup box and radiator core support. These were benchmarked to determine the weight and material composition of each component. Figure 28 shows the BIW components. The weight of individual BIW components reflects the condition of the BIW assembly as received by the final assembly shop after it leaves the paint shop. The BIW of the 2014 Chevrolet Silverado 1500 includes paint, sealer, anti-flutter adhesive and some NVH measures added prior to the paint process. The BIW is constructed of steel and some aluminum alloys, with the exception of the paint, sealer and anti-flutter adhesive. Figure 29 shows the part weight distribution for the BIW structure, while Figure 30 shows the material distribution. The closures (front and rear doors, hood, and tailgate) also include hem and anti-flutter adhesive.

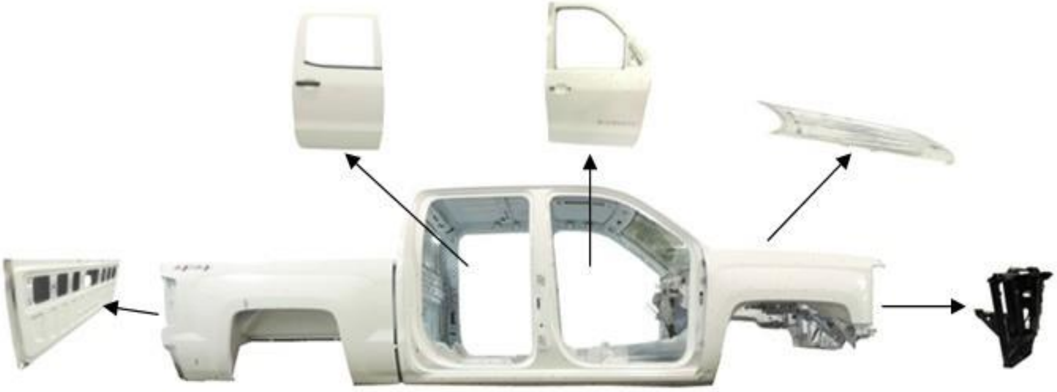


Figure 28: Body-in-White Structure Components

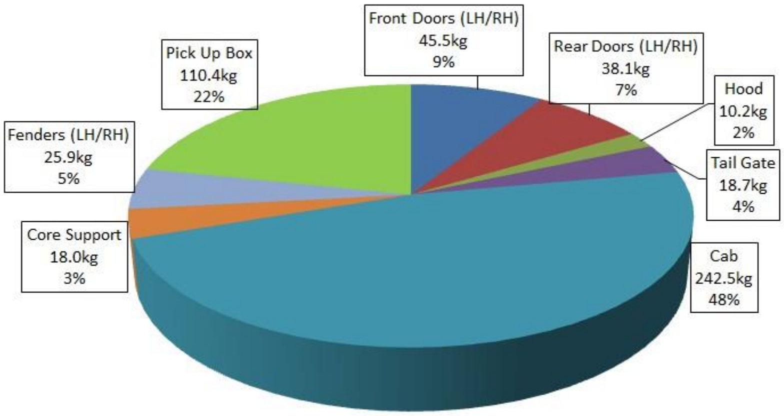


Figure 29: Part Weight Distribution for the Chevrolet Silverado Body-in-White Structure

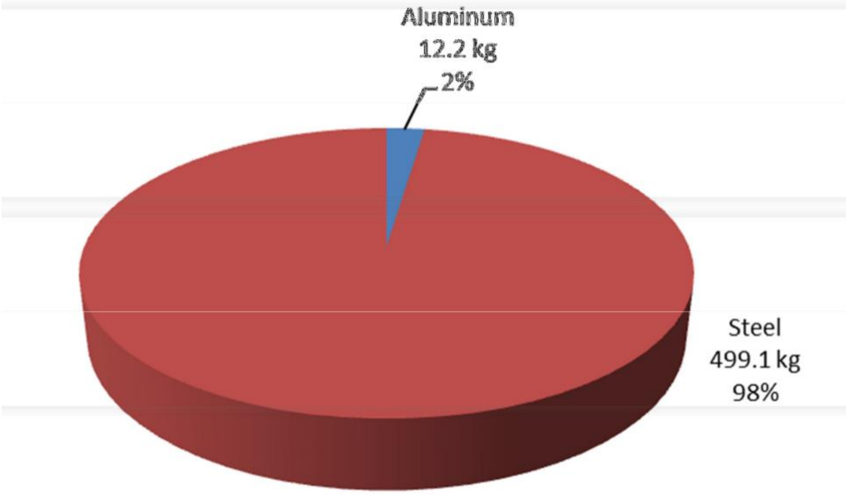


Figure 30: Material Distribution for Chevrolet Silverado 1500 Body-in-White Structure

5.4.3 Front Seat Assembly

The front seat assembly on the baseline Chevrolet Silverado 1500 is the manual seat model. The front seat is composed primarily of steel with the highest weight proportion (64%) from the seat frame, with a weight of 27.8 kg. The foam cushions account for 15 percent at 6.5 kg, followed by 12 percent attributed to various plastics at 5.2 kg and 6 percent (2.5 kg) from the fabric covering. For the components that make up the front seat assembly, see Figure 31. The material and weight distribution for the front seat is shown in Figure 32.

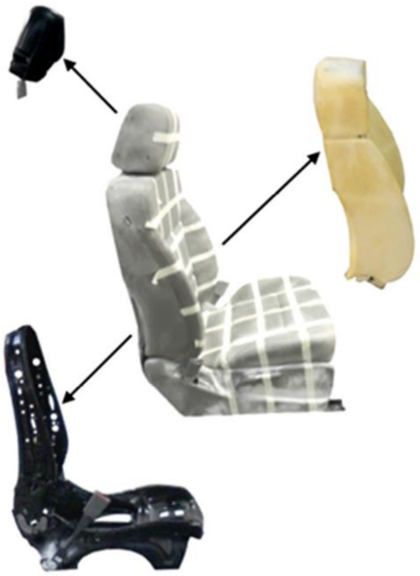


Figure 31: Front Seat Assembly

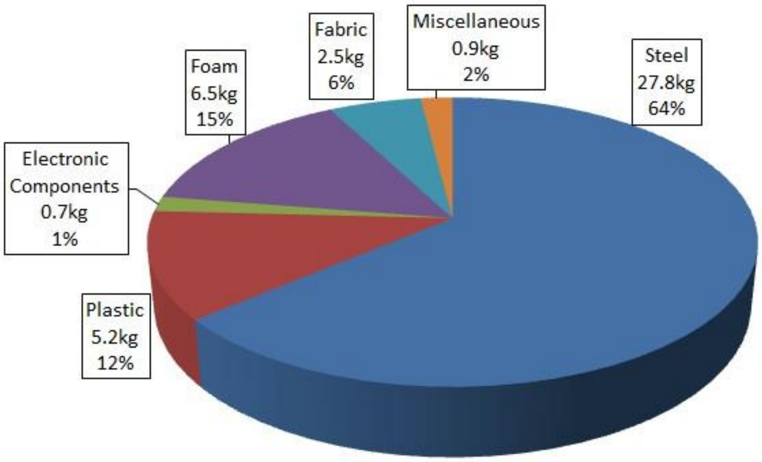


Figure 32: Material Distribution for the Silverado 1500 Front Seat Assembly

5.4.4 Center Console/Middle Front seat

The center console sub-assembly for the 2014 Chevrolet Silverado 1500 consists of the seat frame, arm rest/back support, storage compartment and all subsequent trim parts. This is standard for the crew cab model; the 40/20/40 split of the front bench seat allows three people to be seated, while also providing electronic USB connections and additional storage. See Figure 33 for the center console basic components.

Figure 33: Center Console Assembly With Basic Components

The majority of the center console weight is the steel frame at 46 percent (7.01 kg). Plastic components make up the next 36 percent (5.47 kg) of the weight while the remaining 18 percent (2.63 kg) is foam, fabric, and leather. See Figure 34 for the material distribution.

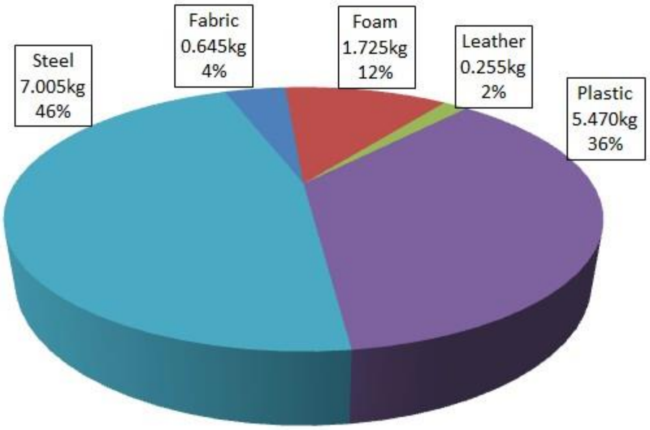


Figure 34: Center Console Material Distribution

5.4.5 Rear Seat Assembly

The rear seat assembly of the baseline 2014 Chevrolet Silverado 1500 is the bench seat model, with fold-up seats for more stowing capacity. The rear bench is comprised of three sitting positions, split 1/3 seat on the passenger side and 2/3 seat on the driver's side. The center rear seat has a fold out armrest with cup holders. The rear seat is composed primarily of steel with the highest weight proportion,74 percent, from the seat frame, with a weight of 29.6 kg. The foam cushions account for 15 percent at 6.0 kg, followed by 8 percent attributed to fabric covering at 3.2 kg. Finally, 3 percent (1.2 kg) are from the various plastics. For the components that make up the rear seat assembly, see Figure 35. The material and weight distribution for the rear seat is shown in Figure 36.

Figure 35: Rear Seats Assembly

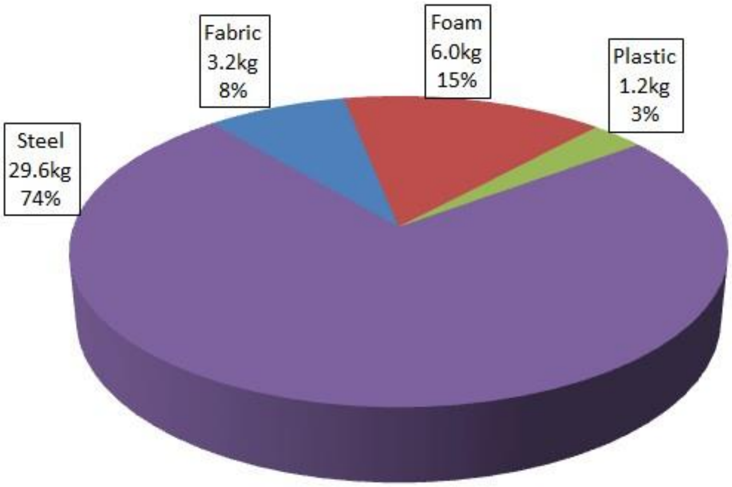


Figure 36: Rear Seats Material Distribution

5.4.6 Instrument Panel

The instrument panel contains three main material groups: (1) various types of plastics, (2) steel, which is mostly concentrated in the instrument panel cross-car beam, and (3) electronic components. The Silverado 1500 includes plastic in the dash cover and dashboard, subsequent trim pieces, and the dual glove boxes, which comprise the far right third of the IP. The plastic weight accounts for 50 percent (16.33 kg) of the mass for the entire IP. The cross-car beam assembly constructed from steel accounts for 39 percent (12.68 kg) of the total IP weight. The electronics include the instrument cluster, radio, heater controls, center display and all instrument panel-mounted control modules, accounting for 11 percent of the weight. For the major components that make up the instrument panel assembly see Figure 37. The IP material and weight distribution is shown in Figure 38.

Figure 37: Instrument Panel Components

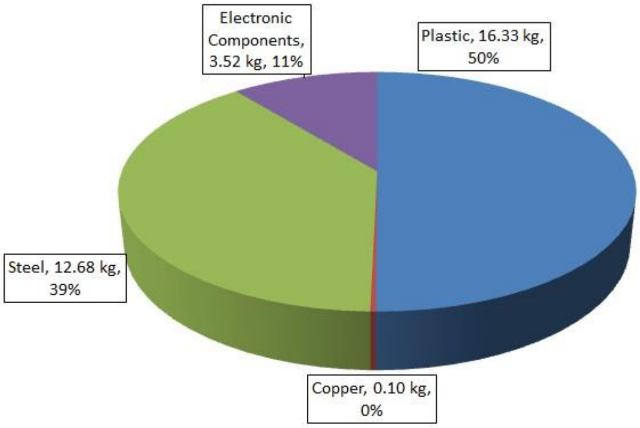


Figure 38: Instrument Panel Material Distribution

5.4.7 Steering Sub-System

The steering sub-system comprises the steering rack with electric motor, column and steering wheel, plus all related trim parts that attach to the steering column. For the basic components that make up the steering sub-system, see Figure 39. At 37 percent (12.66 kg), aluminum alloy is the primary material used in the steering sub-system. The secondary material is steel, which makes up 28 percent (9.84 kg) of the steering assembly. Electronic components account for 24 percent (8.31 kg), plastics 10 percent (3.56 kg) and miscellaneous materials the remaining 1 percent (1.56 kg) of the steering sub-system. This breakdown by material can be seen in Figure 40 while a breakdown by component is shown in Figure 41.

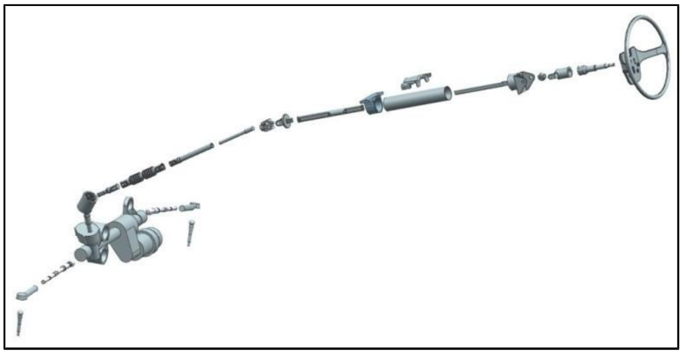


Figure 39: Steering Sub-System Assembly Components

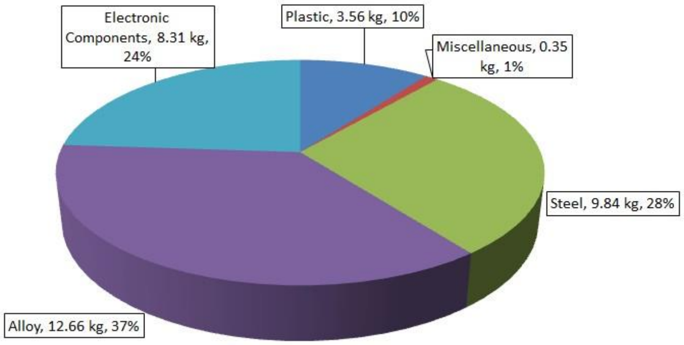


Figure 40: Steering Sub-System Material Distribution

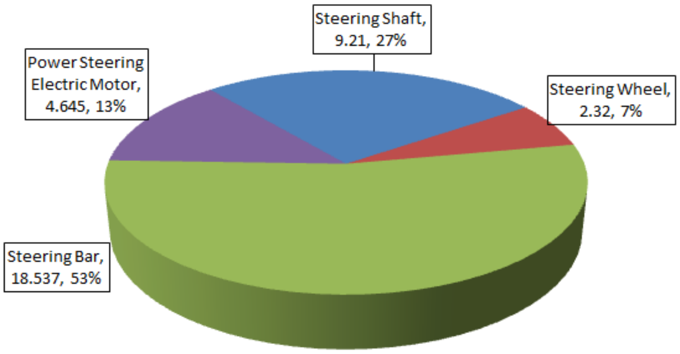


Figure 41: Steering Sub-System Mass Breakdown of Components

5.4.8 Chassis Frame Module With Front and Rear Bumper Assemblies

The chassis frame for the Silverado 1500 is a steel ladder frame with a hydro-formed front rails. The chassis frame is of steel construction and contributes 10.4 percent (253.6 kg) of the overall vehicle weight. The front and rear bumpers are constructed of steel with plastic trim parts, which account for more than 2 percent (56.3 kg) of the vehicle weight. The towing hitch support is of steel construction and accounts for less than 1 percent (16.6 kg) of vehicle weight. The chassis frame, bumpers and hitch components are shown in Figure 42. The weight distribution of chassis frame, bumpers and trailer hitch are shown in Figure 43, while a material breakdown for all parts can be seen in Figure 44.

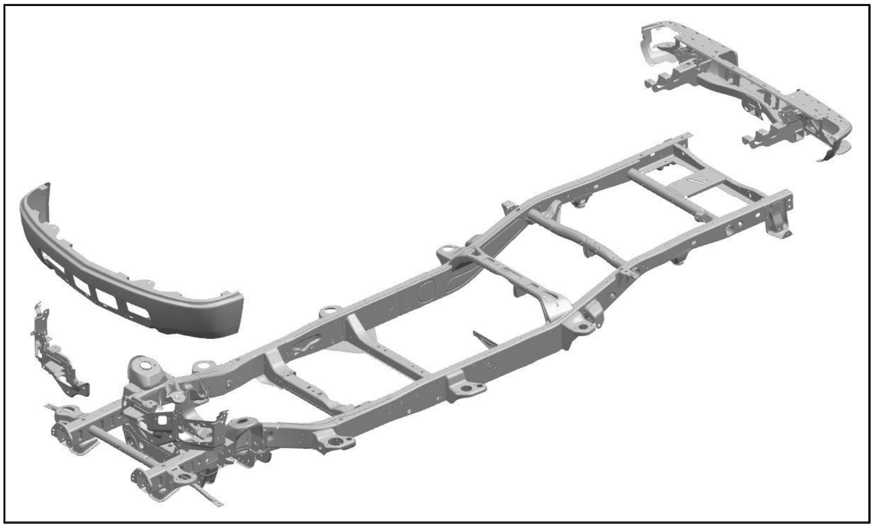


Figure 42: Chassis Frame, Bumpers, and Hitch Components for Silverado 1500

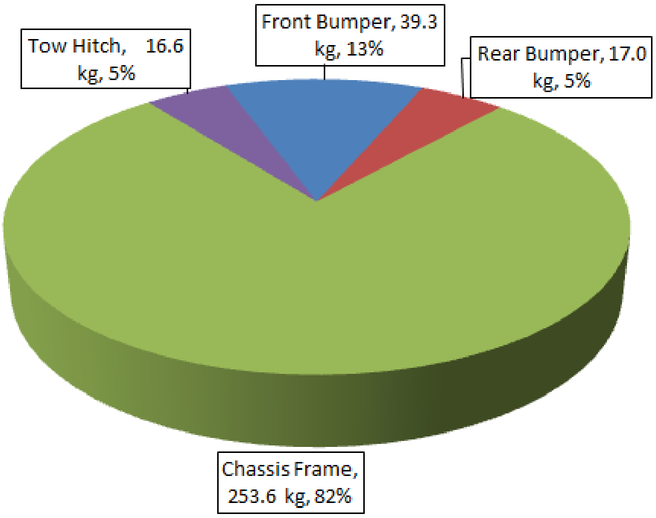


Figure 43: Chassis Frame, Bumpers, and Trailer Hitch Weight Distribution

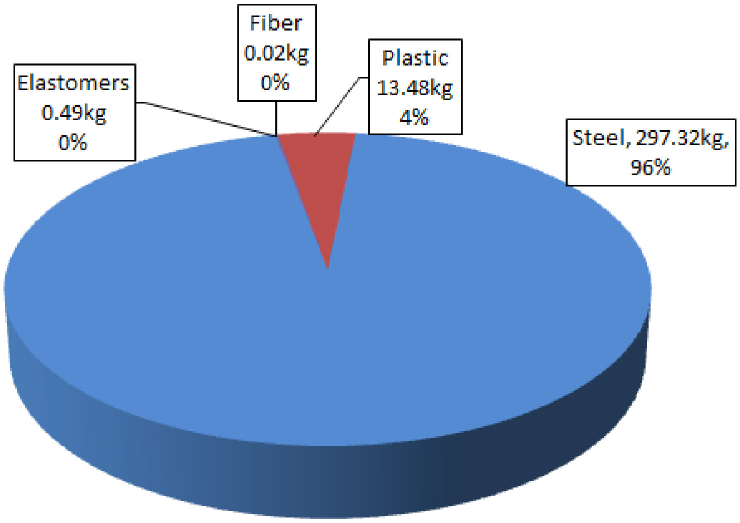


Figure 44: Chassis Frame, Bumpers, and Hitch Material Distribution

5.4.9 Front Suspension Module

The front suspension of the 2014 Chevrolet Silverado 1500 is a double-wishbone suspension, also known as "double A-arms." This is an independent suspension design using two wishbone control arms to position each front wheel and sustain the wheel in a perpendicular geometry to the road surface, providing minimum camber change adjustment to bump or rebound conditions. This suspension is preferable to the Macpherson strut suspension, offering a better quality ride and adjustability. Conversely, the cost of manufacturing is higher and weight is increased due to additional components.[23] The Silverado 1500 front suspension module is comprised of shock absorbers, upper and lower wishbone control arms, steering knuckle, stabilizer bar, and other miscellaneous parts, as exhibited in Figure 45.

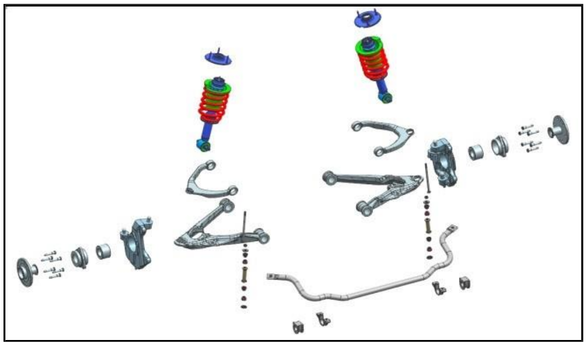


Figure 45: Front Suspension Module Components

The part weight distribution of the major components for the front suspension module is shown in Figure 46. The largest weight component of the front suspension module is the shock absorber

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[23] http://auto.howstuffworks.com/car-suspension4.htm

and coil spring assembly, which is primarily comprised of 94 percent steel construction. The lower and upper control arms (triangles), make up 26 percent of the front suspension weight, and are manufactured using aluminum alloy.

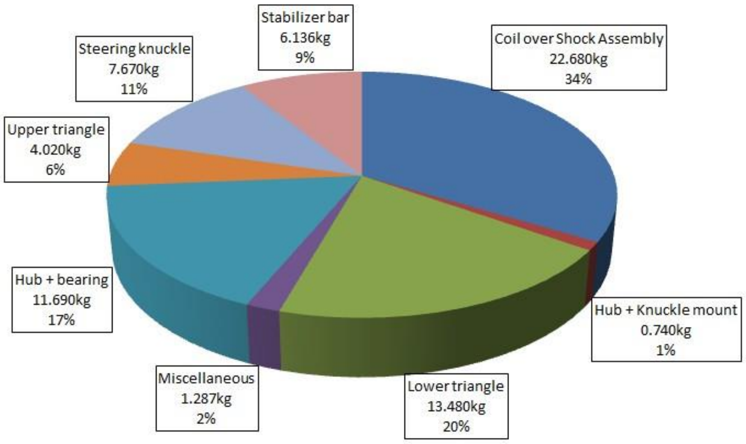

Figure 46: Part Weight Distribution of the Front Suspension Module

Regarding materials, the front suspension module is approximately 59 percent steel construction, 37 percent aluminum alloy construction, and the remaining 4 percent consists of elastomers, various plastics and miscellaneous materials. This is shown in Figure 47.

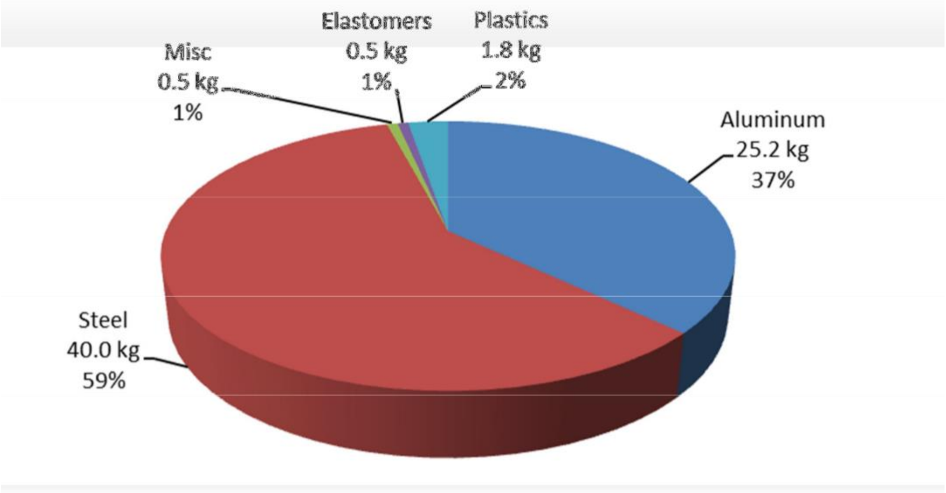

Figure 47: Front Suspension Module Material and Weight Distribution

5.4.10 Rear Suspension Module

The Chevrolet Silverado 1500 rear suspension is a solid axle, semi-elliptical leaf spring system. The ends of the leaves attach directly to the chassis and the axle is clamped to the leaf springs along with the shocks. This module is prevalent in trucks, as the leaf spring distributes the weight of a load more widely over the vehicle's chassis in contrast to the coil spring that locates weight to a single point. Manufacturing this system is uncomplicated and relatively inexpensive in comparison with the solid axle with coil spring system or the beam axle system.[24] The Silverado 1500 rear suspension consists of spring (leaf) blades, spring mounts, shock absorbers, and miscellaneous parts, as shown in Figure 48.

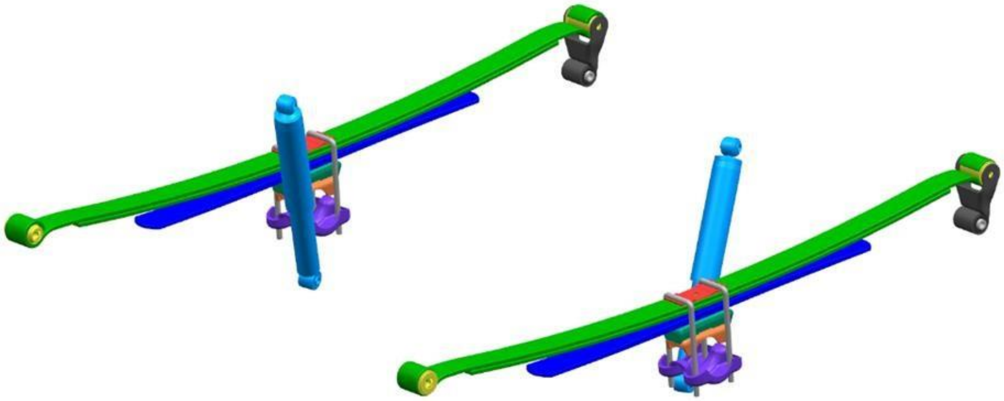

Figure 48: Rear Suspension Module Components

The largest contributors to the Silverado 1500 rear suspension weight at 85 percent (53.17 kg) are the spring (leaf) blades, which are of steel construction. See Figure 49 for the rear suspension module part weight distribution and Figure 50 for the rear suspension module material distribution.

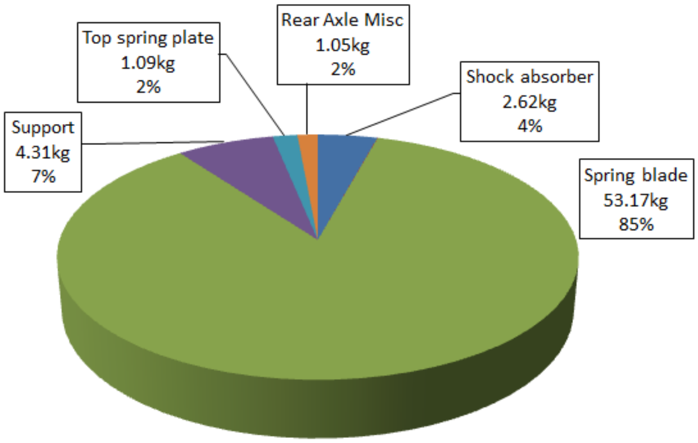

Figure 49: Rear Suspension Module Part Weight Distribution

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[24] http://trucks.about.com/od/recallsmaintenance1/p/rear_suspension.htm

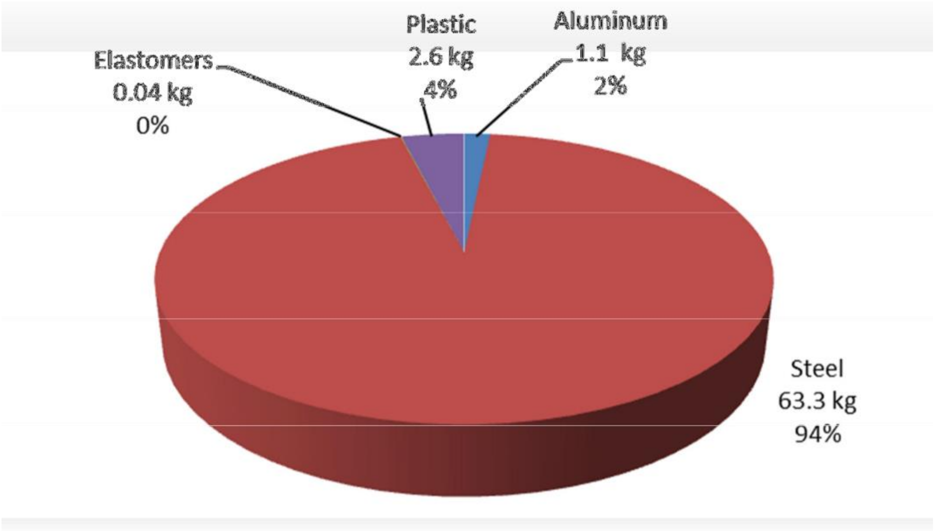

Figure 50: Rear Suspension Module Material Distribution

5.4.11 Engine

The Chevrolet Silverado 1500 is available in three engine configurations: a V-6 4.3L EcoTec3 engine, a V-8 5.3L EcoTec3 engine and a V-8 6.2L EcoTec3 engine.[25] The baseline Silverado 1500 was selected with the EcoTec3 5.3 L V-8 engine with aluminum block and heads. An image of the engine can be seen in Figure 51. The FlexFuel, direct-injection engine with active fuel management was rated at 355 hp at 5,600 rpm and 383 lb-ft torque at 4,100 rpm when operating with gasoline. The overall mass of the engine is 222.74 kg. The highest weight contributor to the engine is steel at 46 percent (101.3 kg), followed closely by aluminum at 43.0 percent (96.0 kg). The material distribution of the engine mass can be seen in Figure 52.

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[25] https://www.chevrolet.com/silverado-1500-pickup-truck/specs/powertrain.html

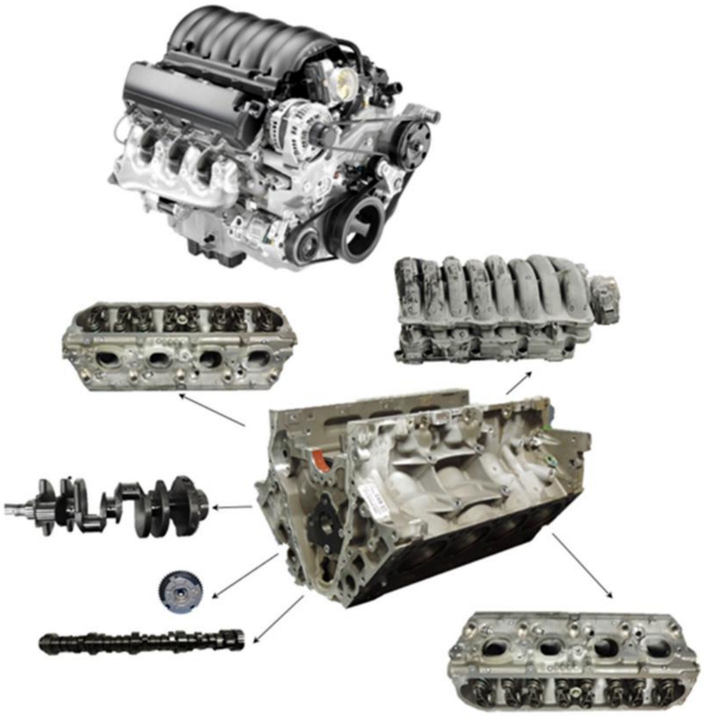

Figure 51: EcoTec3 5.3L V-8 L83 Engine

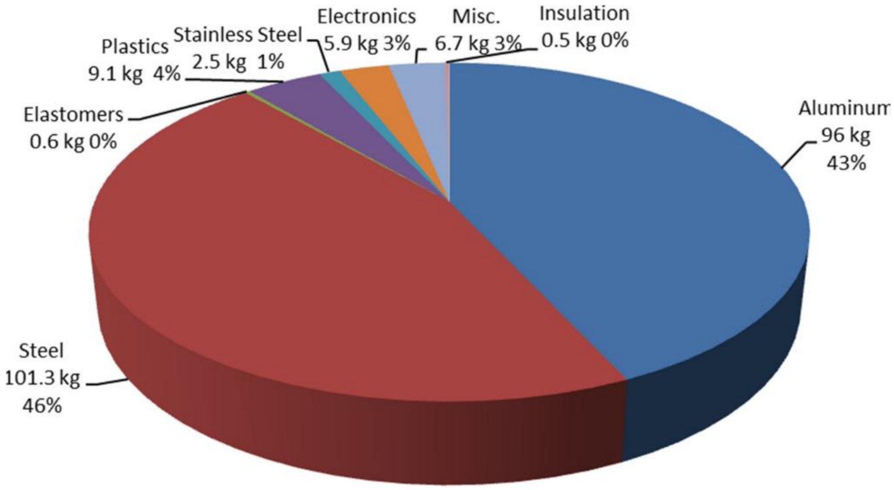

Figure 52: Engine Material Distribution

5.4.12 Transmission

The only transmission available for the 2014 Chevrolet Silverado 1500 is the automatic 6-speed Hydra-Matic 6L80. This transmission is electronically controlled with automatic overdrive, electronic engine grade braking, and tow/haul mode. The maximum torque is 439 lb-ft (592.65 N-m).[26] An image of the transmission can be seen in Figure 53.

Figure 53: Transmission Assembly

Figure 54 shows details of the baseline automatic transmission gear and final drive ratios.

Figure 55 shows the material distribution for the transmission assembly. The largest weight contributors are steel at 59 percent (51.7 kg) and aluminum alloy at 24 percent (21.6 kg). The total weight for the transmission is 88.5 kg.

Gear Ratio	
1st	4.0
2nd	2.4
3rd	1.5
4th	1.2
5th	0.9
6th	0.7
Reverse	3.1
Final Drive Ratio	3.42

Figure 54: Silverado 1500 Automatic6L80 Transmission Ratios[27]

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[26] www.gmfleetorderguide.com/NASApp/domestic/graytabcontroller.jsp?graytabtype=2&rpoid=40293&vehicleid=14682&section=engineAxle

[27] Ibid

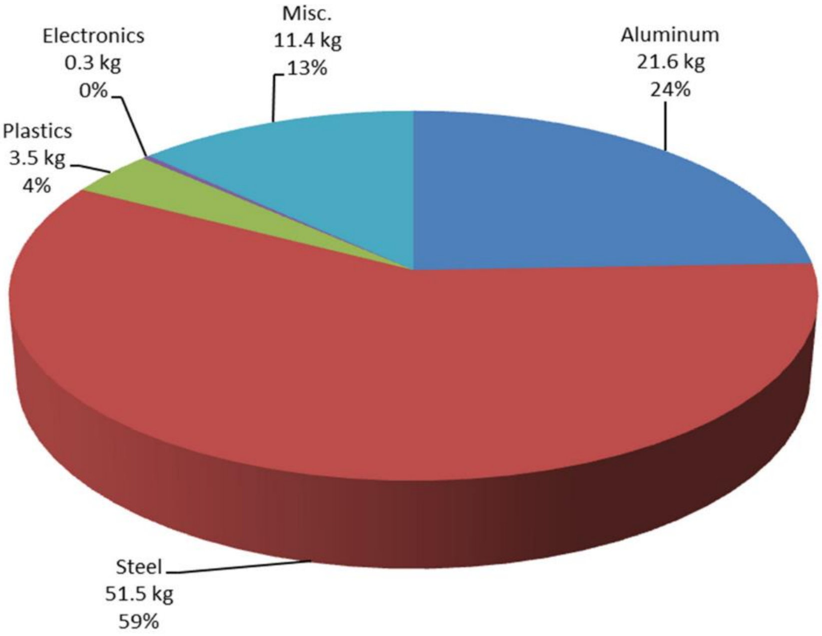

Figure 55: Transmission Material Distribution

5.4.13 Power Transfer Case

The Silverado 1500 comes with two drive options: 2WD and 4WD. The baseline vehicle has a 4WD option, which requires a power transfer case. The transfer case is pictured in Figure 56. The primary materials that comprise the transfer case are steel at 66 percent (22.4 kg) and aluminum alloy at 33 percent (11.0 kg). Figure 57 depicts the material distribution for the overall weight of the transfer case at 33.7 kg.

Figure 56: Transfer Case Assembly

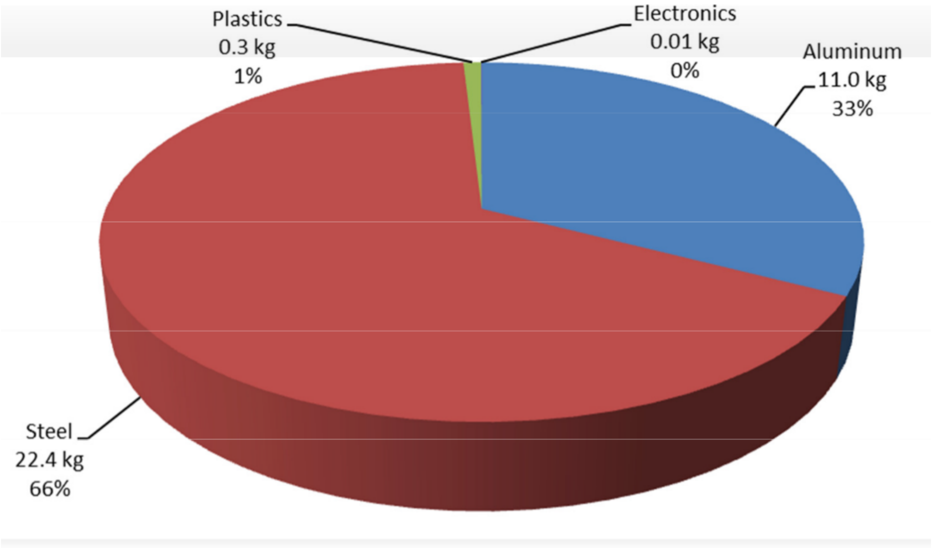

Figure 57: Transfer Case Materials Distribution

5.4.14 Front Differential

The weight of the front differential is mainly contributed by steel at 68 percent, or 29 kg. The aluminum casing contributes 12.5 kg or 30 percent of the weight. Elastomers and miscellaneous components make up 2 percent of the overall mass of the front differential. The total mass of the front differential is 42.4 kg. An image of the front differential can be seen in Figure 58. The material distribution can be seen in Figure 59.

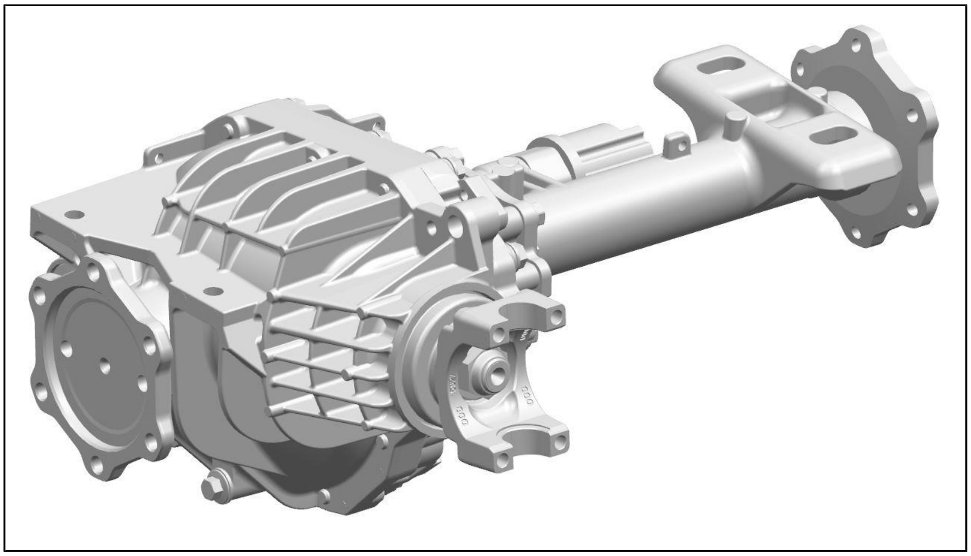

Figure 58: Front Differential Assembly

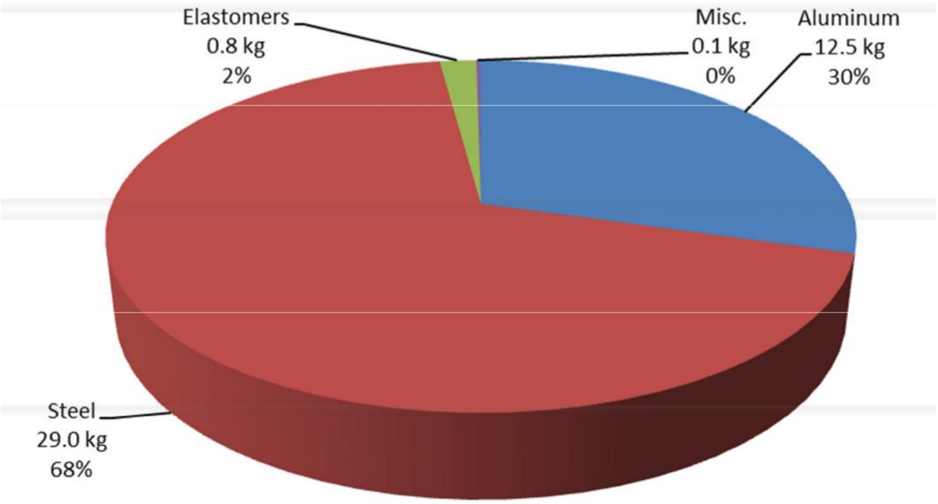

Figure 59: Front Differential Material Distribution

5.4.15 Drive Shafts

The total weight for all drive shafts - front, intermediate, and rear - is 53.74 kg. A diagram of the drive shafts can be seen in Figure 60. The primary drive shaft is the rear intermediate drive shaft that connects the power transfer case to the rear differential. The total mass for this drive shaft is 8.62 kg; it is comprised of aluminum with two steel yokes. The front and rear shafts, plus the front intermediate shaft, are all of steel construction. The material distribution for the drive shafts can be seen in Figure 61. The majority of weight contribution is steel at 87 percent (46.8 kg). Aluminum contributes 11 percent (6.1 kg) and elastomers add about 2 percent (0.9 kg) to the overall drive shaft mass.

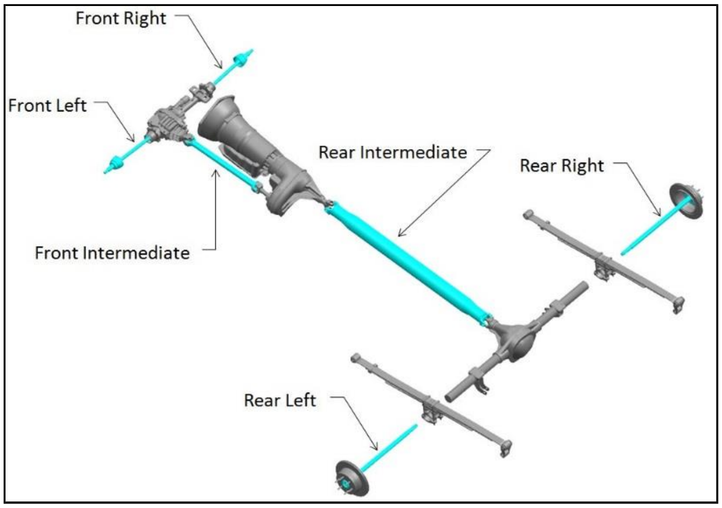

Figure 60: Drive Shafts

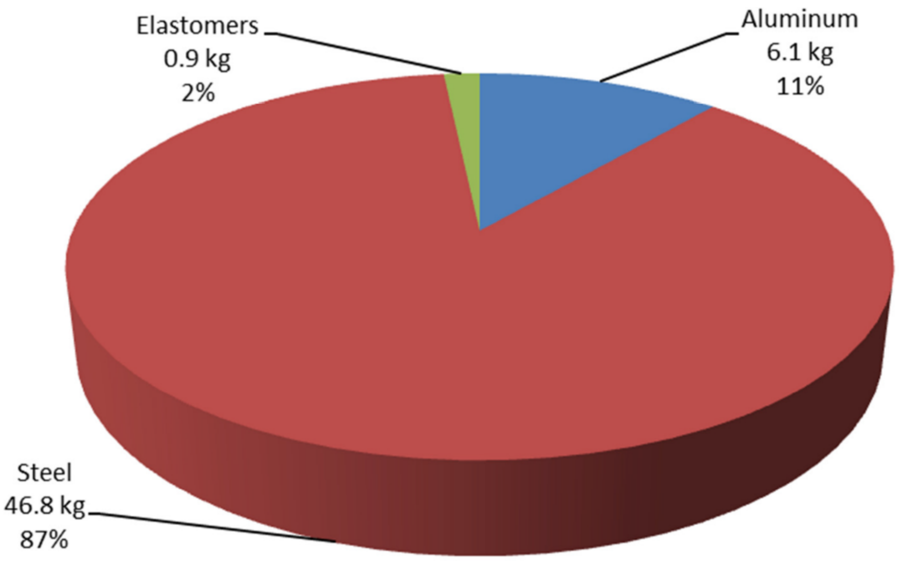

Figure 61: Drive Shaft Material Distribution

5.5 Baseline Vehicle Performance and Functionality

5.5.1 Acceleration, Braking and Maximum Speed

Performance data for the baseline 2014 Chevrolet Silverado 1500 were not available from GM. The data that follows have been compiled from various independent sources, including Consumer Reports,[28] Edmunds.com,[29] Motor Trend,[30] Car and Driver,[31] TopSpeed.com,[32] and ZeroTo60Times.com.[33] The vehicles evaluated were all comparable to our baseline, but not exactly the same. Baseline vehicle 2014 Silverado 1500 Crew Cab, Short Box 1WT with 5.3L-V8, 4WD, 17-inch wheels and P255/70R17 tires. Consumer Reports evaluated the 2014 Silverado 1500 Crew Cab, Short Box LT with 5.3L-V8, 4WD, 18-inch wheels and P265/65R18 tires. Edmunds.com evaluated the 2014 Silverado 1500 Crew Cab, Short Box LT Z71 with 5.3L-V8, 2WD, 18-inch wheels and P265/55R18 tires. Motor Trend evaluated the 2014 GMC Sierra 1500 Crew Cab, Short Box SLT Z71 with 5.3L-V8, 4WD and undefined wheels/tires. Car and Driver evaluated the 2014 Silverado 1500 Crew Cab, Short Box LTZ Z71

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[28] www.consumerreports.org/cro/chevrolet/silverado-1500/ratings-and-specs.htm

[29] www.edmunds.com/car-reviews/track-tests/2014-chevrolet-silverado-1500-z71-lt-track-tested.html

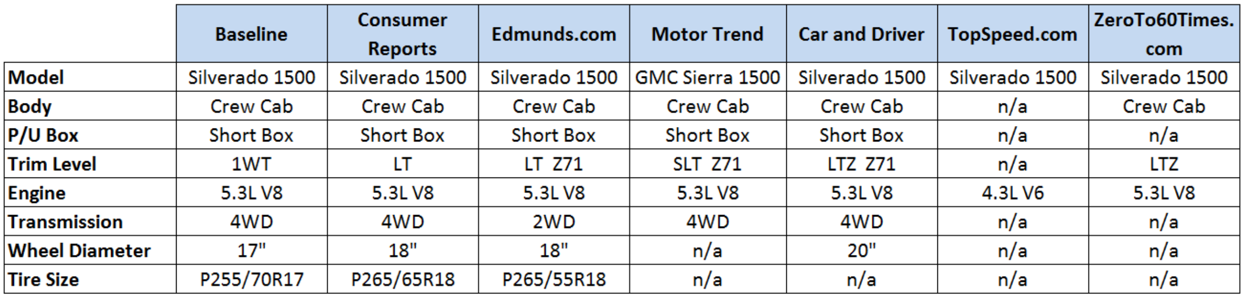
[30] www.motortrend.com/roadtests/trucks/1308_2014_gmc_sierra_1500_slt_4wd_crew_cab_first_test/

[31] www.caranddriver.com/chevrolet/silverado-1500#

[32] www.topspeed.com/cars/chevrolet/2014-chevrolet-silverado-ar130323.html

[33] www.zeroto60times.com/Chevrolet-Chevy-0-60-mph-Times.html

with 5.3L-V8, 4WD and 20-inch wheels. TopSpeed.com evaluated a 2014 Silverado 1500 with 4.3L-V6. The body style, box length, trim level, drive type, wheels and tires were not defined. ZeroTo60Times.com evaluated the 2014 Silverado 1500 Crew Cab LTZ with 5.3L-V8. The box length, drive type, wheels and tires were not defined. Figure 62 compares the models reviewed.



	Baseline	Consumer Reports	Edmunds.com	Motor Trend	Car and Driver	TopSpeed.com	ZeroTo60Times.com
Model	Silverado 1500	Silverado 1500	Silverado 1500	GMC Sierra 1500	Silverado 1500	Silverado 1500	Silverado 1500
Body	Crew Cab	Crew Cab	Crew Cab	Crew Cab	Crew Cab	n/a	Crew Cab
P/U Box	Short Box	Short Box	Short Box	Short Box	Short Box	n/a	n/a
Trim Level	1WT	LT	LT Z71	SLT Z71	LTZ Z71	n/a	LTZ
Engine	5.3L V8	5.3L V8	5.3L V8	5.3L V8	5.3L V8	4.3L V6	5.3L V8
Transmission	4WD	4WD	2WD	4WD	4WD	n/a	n/a
Wheel Diameter	17"	18"	18"	n/a	20"	n/a	n/a
Tire Size	P255/70R17	P265/65R18	P265/55R18	n/a	n/a	n/a	n/a

Figure 62: Comparison of Vehicles Reviewed for Performance Data

The following information for the acceleration, braking and maximum speed of the 2014 Silverado 1500 is a compilation of data obtained during independent evaluation and performance testing completed by the previously mentioned sources. These performance results are summarized in Figure 63. The values included in the figure are those most representative of our baseline vehicle. The maximum speed of 100 mph is imposed by the OEM through the use of a governor. Restricting the maximum speed to a particular limit is an OEM decision based upon marketing, safety and other considerations. Vehicle performance characteristics of the LWT are comparable to those of the baseline vehicle.

Test	Results
Acceleration, 0-30 mph (sec)	2.8
0-45 mph (sec)	4.5
0-60 mph (sec)	6.8
0-60 mph with 1 foot of rollout (sec)	6.5
0-75 mph with Traction Control off (sec)	10.2
0-100 mph (sec)	18.4
5-60 mph (sec)	7.3
45-65 mph (sec)	3.7
1/4 mile (sec @ mph)	15.3 @ 92.0
Braking, 30-0 mph (ft)	32
60-0 (dry surface) (ft)	138
60-0 (wet surface) (ft)	164
70-0 (dry surface) (ft)	178
Slalom (mph)	55.4
Skid Pad (lateral g)	0.76
Max Speed, Limited by Governor (mph)	100
Engine Speed @ 70 mph (rpm)	1,750

Figure 63: 2014 Chevrolet Silverado 1500 Performance Test Results

5.5.2 Towing and Payload

The baseline Silverado is equipped with the optional trailering package and trailer brake controller. This provides a trailer hitch platform with integrated 7-pin and 4-pin connectors, an automatic locking rear differential and a 3.42 rear axle ratio, giving the vehicle a maximum conventional trailering capacity of 4,354 kg (9,600 lb.) or a maximum payload of 888 kg (1,957 lb.). The maximum trailering capacity for the Silverado 1500 is 5,307 kg (11,700 lbs.) with a crew cab, standard box, 4WD, 6.2L EcoTec3 engine and the Max Trailering package. The LWT structure will be capable of performing maximum towing functions similar to the baseline vehicle with the 6.2L engine.

5.5.3 Total Driving Range

The baseline Silverado is fitted with a 26.0-gallon (98.4 L) fuel tank. EPA estimates of 16 mpg (city), 22 mpg (highway) and 18 mpg (combined) yield driving ranges of 416, 572 and 468 miles, respectively. The Ecotec3 5.3L-V8 is a flex fuel engine, capable of operating with gasoline or E85. The LWT is also designed to have a range of at least 468 miles under combined driving conditions with gasoline to maintain the same functionality as the baseline vehicle, using the combined miles per gallon predicted for the LWT. It should be noted that the regular cab, long box version of the Silverado is equipped with a 34-gallon (128.7 L) fuel tank. The frame design for the LWT can also accommodate a larger capacity fuel tank.

5.5.4 Minimum Turning Circle

The Silverado 1500 Crew Cab with short box has a minimum turning circle of 14.39 m (47.2 ft.). As this is an important feature when maneuvering the vehicle in tight spaces, this is maintained on the LWT.

5.5.5 Sun Roof

The crew cab is the only version of the Silverado 1500 that can be equipped with an OEM sunroof, which is available in the LTZ, LTZ Z71 and High Country trim levels. Therefore, the LWT crew cab structure is designed with provisions for a sunroof.

5.5.6 Seating

The front seat in the baseline Silverado 1500 is a cloth, three-passenger bench equipped with a folding center console that provides storage space. With the console in its stowed position, the seating is a 40/20/40 configuration. The cloth rear seat is a 60/40 folding bench with a stowable center armrest. The seat backs are stationary while the bottoms may be folded up, creating additional cargo space inside the cab when needed. There is also stowage space inside the rear armrest. These capabilities are maintained in the LWT design. Front and rear seating are shown in Figure 64.

Figure 64: Baseline Silverado 1500 Front and Rear Seating

5.5.7 Wheels and Tires

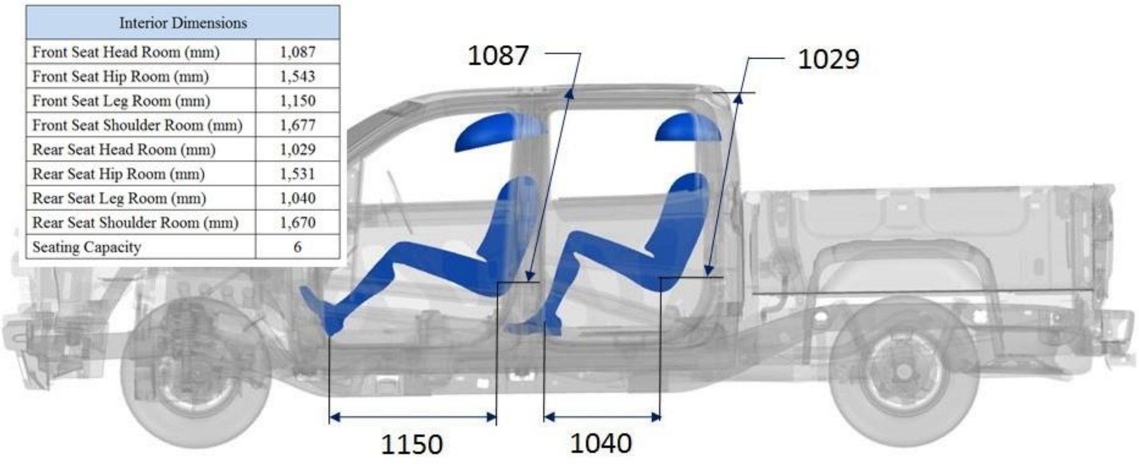
The baseline Silverado is fitted with 17-inch painted steel wheels and Bridgestone Dueler H/T P255/70R17 all-season black wall tires (shown in Figure 65). The full-size spare, mounted under the box, uses the same tire on an aluminum rim.

Figure 65: Baseline Silverado 1500 Wheel and Tire

Up-level trim packages (LT, LT Z71, LTZ, LTZ Z71 and High Country) are able to accommodate wheels as large as 22-inch diameter with P285/45R22 tires. On the LWT design the front and rear suspension, the body structure and spare tire stowage is package protected to accommodate these larger wheels and tire sizes.

5.5.8 Interior Space/Packaging

The Silverado 1500 Crew Cab is a full-size, light duty pickup truck with a seating capacity of six including the driver and five passengers. Figure 64 shows the seating configuration for the baseline vehicle and Figure 66 lists the interior dimensions. Comparable interior dimensions will be maintained for the LWT.



Interior Dimensions	
Front Seat Head Room (mm)	1,087
Front Seat Hip Room (mm)	1,543
Front Seat Leg Room (mm)	1,150
Front Seat Shoulder Room (mm)	1,677
Rear Seat Head Room (mm)	1,029
Rear Seat Hip Room (mm)	1,531
Rear Seat Leg Room (mm)	1,040
Rear Seat Shoulder Room (mm)	1,670
Seating Capacity	6

Figure 66: Baseline Silverado 1500 Interior Dimensions[34]

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[34] www.chevrolet.com/silverado-1500-pickup-truck/specs/dimensions.config%3Dcrew_cab_short_box.html

6 Vehicle Crashworthiness Safety and Structural Performance Targets

6.1 Introduction

The lightweighted light-duty pickup truck (LWT) at minimum must meet the performance functions of the original baseline vehicle. This section of the report identifies the structural performance targets for the LWT design. These targets were based upon test results for the baseline or an equivalent vehicle and/or based upon the results obtained from the baseline correlated CAE models. The LWT design maintained vehicle size and performance functionalities comparable to the baseline vehicle in the following areas.

1. Crashworthiness Safety

   Vehicle test results from NHTSA's New Car Assessment Program (NCAP) and IIHS ratings tests are used to establish the deceleration pulses and occupant compartment intrusion values as targets for the following crash load cases.

   - NCAP frontal
   - NCAP side
   - NCAP side pole
   - FMVSS No. 216
   - FMVSS No. 301
   - IIHS offset
   - IIHS side impact
   - IIHS small overlap

2. Structural Stiffness and NVH

   The baseline vehicle structure (frame, cab and pickup box) was tested for normal modes of vibration and torsion and bending stiffness. The LWT uses these values as targets to maintain vehicle performance for NVH compared to the baseline vehicle.

   - Noise, vibration and harshness

3. Other vehicle functions

   The LWT design maintained vehicle performance functionalities compared to the baseline vehicle for the following.

   - Serviceability and Repairability
   - Durability and Reliability
   - Ride and Handling
   - Towing

6.2 Crashworthiness Safety

Crashworthiness is the ability of a vehicle to protect its occupants during an impact. This protection is provided in several ways. Inside the vehicle, an effective restraint system consisting of seat belts, frontal and side air bags, head rests, and cushioning materials limits the crash forces exerted on the occupants. The vehicle structure itself absorbs and manages crash energy through selective deformations and redirections of the crash forces. The structure of the occupant compartment is carefully designed to maintain its integrity to the highest degree possible, providing an environment in which the restraint systems can perform their function and controlling the forces exerted on the occupant either directly by contact with the vehicle interior or indirectly through interactions with the restraint systems.

The scope of this project included reducing the overall mass of a full-size pickup truck while retaining a current, equivalent level of occupant safety. This current level of safety is provided by the vehicle structure, the restraint systems, and effective interaction between them. Because the restraint systems make up a very small part of the overall vehicle mass (less than 1%), and because the development and validation of these systems requires a great deal of time and resources, this project did not attempt to develop alternatives to the occupant restraints; the current designs were used on the LWT. The scope and allocated resources of this study were focused on optimizing the structure of the LWT, reducing its mass while maintaining adequate strength and stiffness to protect the occupants.

6.2.1 NCAP Frontal Rigid Barrier Impact Test

The NCAP Frontal Rigid Barrier Impact Test applies a full-width impact load to the front of the vehicle. Two fully instrumented anthropomorphic test devices (ATD) are placed into the vehicle; a 50th percentile male in the driver's seat and a 5th percentile female in the front passenger seat. The vehicle is crashed head-on into a rigid concrete load cell barrier at a velocity from 55.5 to 57.1 km/h (34.5 - 35.5 mph). During the collision, instruments in the ATDs measure the severity of the impact to the bodies of the occupants. Following the collision, measurements are taken at multiple points on the vehicle and compared with corresponding pre-test measurements to assess the effect of the crash on the vehicle structure.

The 2014 Chevrolet Silverado 1500 underwent an NCAP frontal barrier impact test on July 30, 2013.[35] The crash was conducted by MGA Research Corporation in Burlington, Wisconsin, at an impact velocity of 56.6 km/h (35.2 mph). Figure 67 shows the load cell barrier and the post-crash vehicle for the NCAP frontal test.

While the front end of the vehicle was heavily damaged in the crash, the post-test observations of the occupant compartment indicated no damage to the windshield or windows, no changes to the door opening apertures, and no other notable effects. Both the driver and passenger side doors remained closed during the impact and were operable afterward. The maximum static crush of the vehicle was measured at 665 mm at the vehicle centerline. Driver compartment intrusions

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[35] Test Number 8316, NHTSA, *Final Report of New Car Assessment Program Frontal Impact Testing of 2014 Chevrolet Silverado 1500 4WD LT Crew Cab*, Report No. NCAP-MGA-2014-008

were evaluated at six points, with the dimensional difference between pre-test and post-test measurements being mostly negligible as shown in Figure 68.

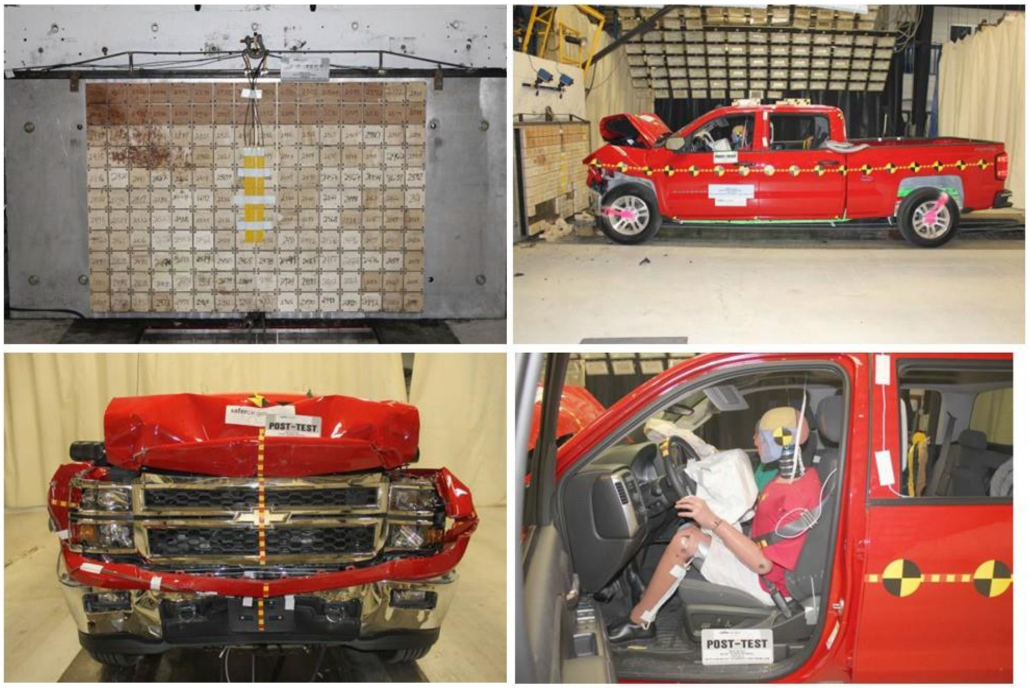

Figure 67: Load Cell Barrier and Post-Crash 2014 Silverado NCAP Frontal Crash Test[36]

In subsequent analysis NHTSA awarded the Silverado the highest safety rating, “5-star,” for the NCAP Frontal Impact test.[37] An in-depth investigation of the restraint systems and injury criterion readings of the ATD is beyond the scope and funds of this project. Instead the dynamic accelerations and static intrusion response of the baseline structure will be used to correlate the baseline and LWT design CAE models. The acceleration measured by the accelerometers mounted on the driver and passenger side cab structure (cross member adjacent to B-pillar) in the longitudinal direction will be used. The crash pulse of the 2014 Silverado 1500 is shown in Figure 69.

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[36] Test Number 8316, NHTSA, *Final Report of New Car Assessment Program Frontal Impact Testing of 2014 Chevrolet Silverado 1500 4WD LT Crew Cab*, Report No. NCAP-MGA-2014-008.

[37] NHTSA web site, “5-Star Safety Rating,” www.safercar.gov/.

Item	Description	Units	Pre-Test	Post-Test	Difference
AB	Door Opening (Inside Window Jam)	mm	772	772	0
CX	Left Knee Bolster to X	mm	288	291	-3
DX	Right Knee Bolster to X	mm	298	285	13
EX	Brake Pedal to X	mm	555	590	-35
FX	Foot Rest to X	mm	646	650	-4
GX	Center of Steering Column Wheel Hub to X	mm	107	117	-10

X = Front of Seat Track (stationary)

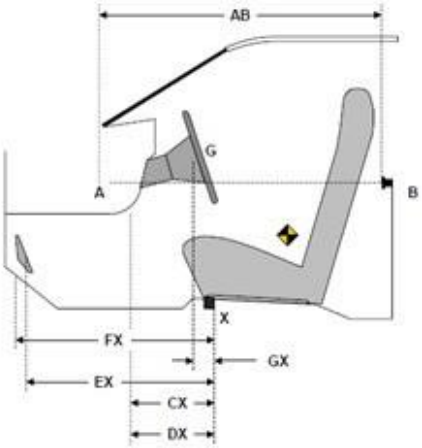

Figure 68: Vehicle Intrusion Measurements 2014 Silverado 1500 NCAP Frontal Impact Test

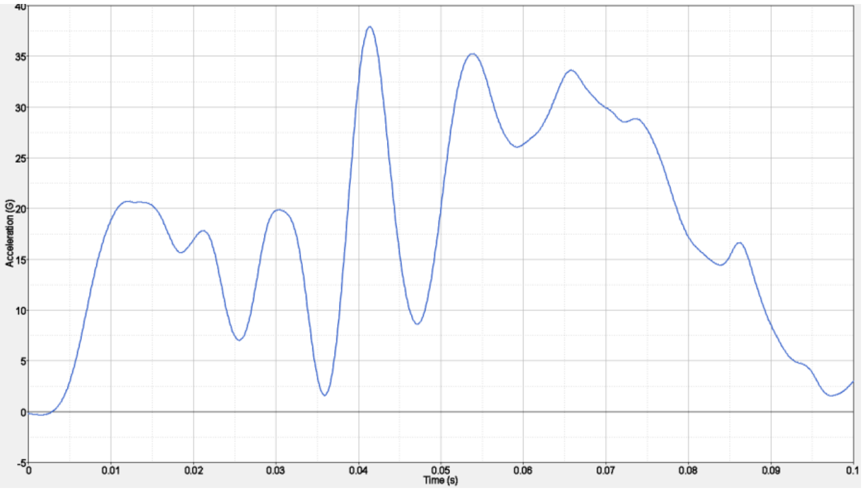

Figure 69: Accelerometer Data: NCAP Frontal Impact Test of 2014 Silverado 1500

6.2.2 NCAP Side Impact Moving Deformable Barrier Test

The NCAP Side Impact Moving Deformable Barrier Test is designed to simulate a 90-degree side impact in which both vehicles are moving. It is performed by impacting the driver's side of a stationary test vehicle with a moving deformable barrier at a velocity of 61.1 - 62.7 km/h (38.0 - 39.0 mph). Because the test vehicle is stationary, the MDB's velocity and orientation are adjusted to simulate the condition in which both vehicles are in motion. The wheels of the MDB are crabbed at 27 degrees to its forward line of motion and it strikes the test vehicle, which is positioned at an angle of 63 degrees to the line of forward motion, as shown in Figure 70. The total mass of the MDB, including impact face, can range from 1,356.5 to 1,365.5 kg. During the collision, instrumented ATDs measure the severity of the impact on the bodies of the occupants. A requirement of this test is that any doors of the vehicle, which are struck by the MDB, shall not separate totally from the vehicle. Any doors, which are not struck by the MDB, must meet the following.

- The door shall not disengage from the latched position
- The latch shall not separate from the striker, and the hinge components shall not separate from each other or from their attachment to the vehicle
- Neither the latch nor the hinge systems of the door shall pull out of their anchorages

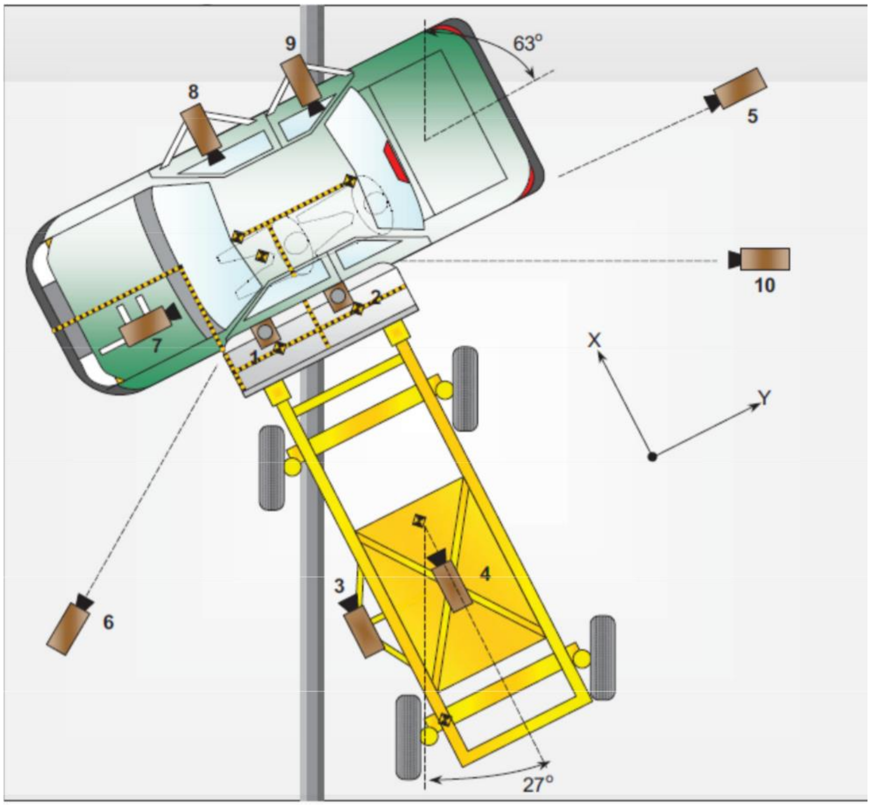

Figure 70: Orientation of Test Vehicle and MDB
(NHTSA Report SINCAP-MGA-2014-007)

The 2014 Chevrolet Silverado 1500 crew cab pickup was subjected to the NCAP moving deformable barrier side impact test on July 30, 2013.[38] The crash was conducted by MGA Research Corporation with the barrier moving at an impact velocity of 62.4 km/h. A 50th percentile male ATD was positioned in the driver's seat and a 5th percentile female ATD was positioned in the rear seat directly behind the driver. The two doors on the impacted, driver's side of the vehicle did not separate from the body at the hinges or latches, and the opposite side doors did not open during the impact event. Figure 71 shows the MDB and the post-test vehicle.

Figure 71: MDB and Post-Test Vehicle 2014 Silverado 1500 NCAP Side Impact Test
(NHTSA Report SINCAP-MGA-2014-007)

Vehicle exterior crush measurements were recorded following the MDB side impact testing and compared with the pre-test measurements. The vertical reference locations measured are identified as Level 1 (Sill Top), Level 2 (Mid-Door), Level 3 (Occupant Hip Point), Level 4 (Window Sill) and Level 5 (Window Top). The results of these measurements can be seen in Figure 72 and Figure 73. A graph of the results is shown in Figure 74.

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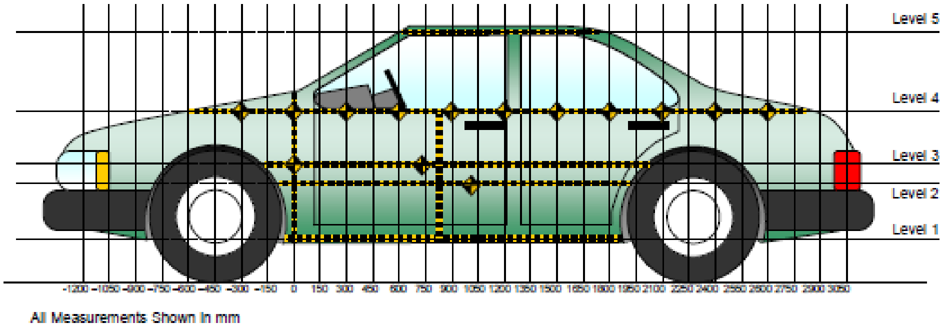
[38] MGA Research Corporation, *New Car Assessment Program (NCAP) Moving Deformable Barrier Side Impact Test 2014 Silverado 1500,* Report No. SINCAP-MGA-2014-007, 5000 Warren Road, Burlington, WI 53105, July 30, 2014.

Test Vehicle: 2014 Chevrolet Silverado 1500 1WT Crew Cab NHTSA No. M20140105
Test Program: NCAP Side MDB Impact Test Test Date: 7/30/2013



LEFT SIDE VIEW

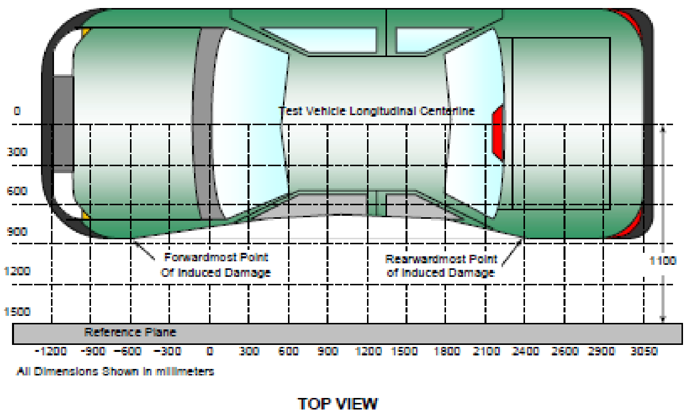
MAXIMUM EXTERIOR CRUSH MEAUREMENTS

Level	Measurement Description	Height Above Ground (mm)	Maximum Exterior Static Crush	Distance from Impact
1	Sill Top	420	360	1800
2	Mid Door	832	353	1650
3	Occupant Hip Point	860	352	1650
4	Window Sill	1201	268	1650
5	Window Top	1735	102	750

Note: The measurements are taken along the vertical impact reference line.
Vehicle measurements forward of the vertical impact reference line are negative.

Figure 72: Exterior Crush Measurements From NCAP Side Impact With MDB Test
(NHTSA Report SINCAP-MGA-2014-007)

Test Vehicle: 2014 Chevrolet Silverado 1500 1WT Crew Cab NHTSA No. M20140105
Test Program: NCAP Side MDB Impact Test Test Date: 7/30/2013



DAMAGE PROFILE DISTANCES

DPD	Distance from Impact Point (mm)	Pre-Test (mm)	Post-Test (mm)	Max. Static Crush (mm)
1	3900	149	193	44
2	2930	148	212	64
3	1910	188	520	332
4	880	181	466	285
5	-75	182	254	72
6	-1050	245	255	10

Figure 73: Exterior Crush Measurements From NCAP Side Impact With MDB Test
(NHTSA Report SINCAP-MGA-2014-007)

Test Vehicle: 2014 Chevrolet Silverado 1500 1WT Crew Cab NHTSA No. M20140105
Test Program: NCAP Side MDB Impact Test Test Date: 7/30/2013

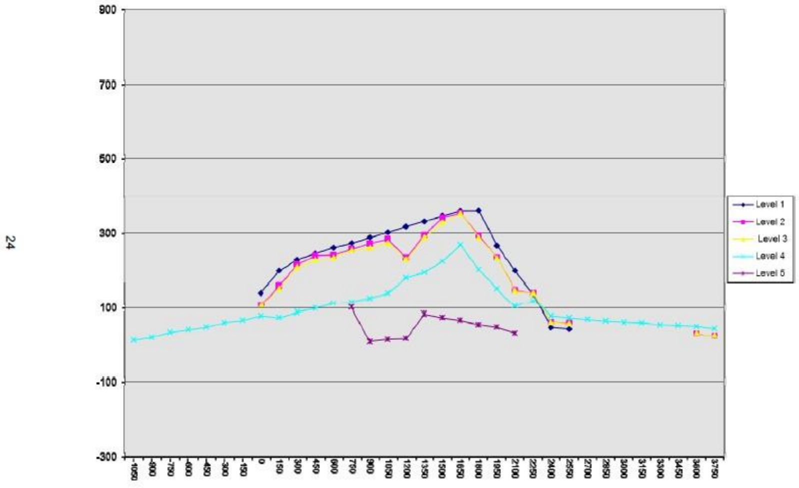


Figure 74: Exterior Crush Measurements From NCAP Side Impact With MDB Test

In subsequent analysis, the Chevrolet Silverado 1500 was awarded a 5-star safety rating for the NCAP side impact MDB test.[39] The baseline vehicle CAE model was subjected to a computer simulation of the NCAP side impact MDB test, correlating with the results from this test. The LWT finite element model was also subjected to these loads and the results compared with those of the baseline Silverado, verifying that the LWT is able to achieve a 5-star rating for NCAP side impact with MDB. Refer to Section 9.2 of this report for a full description of this analysis.

6.2.3 NCAP Side Impact Rigid Pole Test

The NCAP Side Impact Rigid Pole test subjects the test vehicle to a side door impact with a fixed, rigid pole 254 mm (10 inches) in diameter, at a speed of 32.2 km/h (20 mph). The test vehicle is towed into the pole at a 75° angle. Figure 75 shows the test set-up while Figure 76 shows the rigid pole. The only ATD used in this test is a fully instrumented 5th percentile female, positioned in the driver's seat. During the collision, instruments in the ATD measure the severity of the impact on the body of the occupant. A requirement of this test is that any side door of the vehicle, which is struck by the pole, shall not separate totally from the vehicle. Any doors, which are not struck by the pole, must meet the following criteria.

- The door shall not disengage from the latched position
- The latch shall not separate from the striker, and the hinge components shall not separate from each other or from their attachment to the vehicle
- Neither the latch nor the hinge systems of the door shall pull out of their anchorages

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[39] NHTSA web site, "5-Star Safety Rating," www.safercar.gov/.

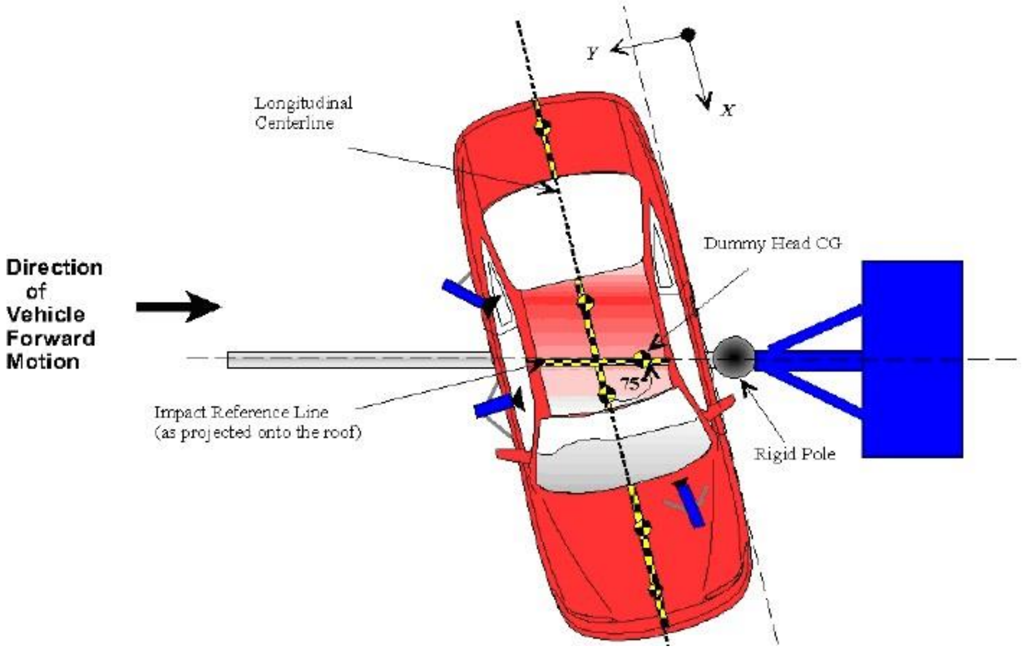

Figure 75: Test Set-Up for NCAP Side Impact Rigid Pole Test[40]

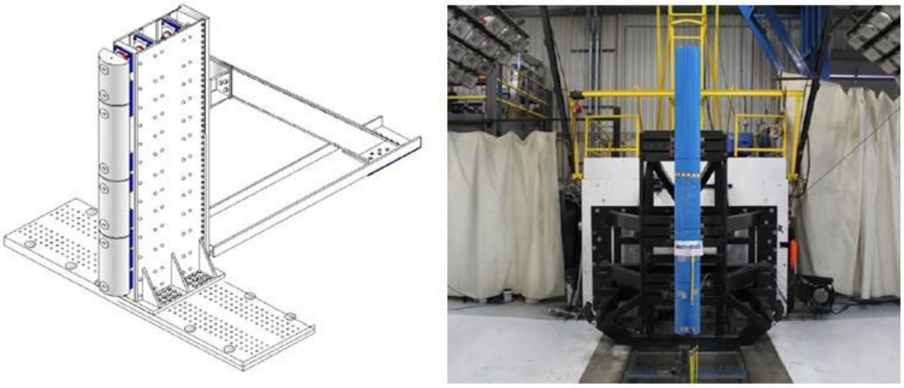

Figure 76: Fixed, Rigid Pole Used for NCAP Side Impact Pole Test[6]

The 2014 Chevrolet Silverado 1500 crew cab pickup was impacted in the side by a rigid pole on July 31, 2013.[41] The test was conducted by MGA Research Corporation in Burlington, Wisconsin. The impact velocity was 32.1 km/h and the maximum exterior crush of 424 mm occurred at the vehicle mid-door (Level 2). A 5th percentile female ATD was positioned in the

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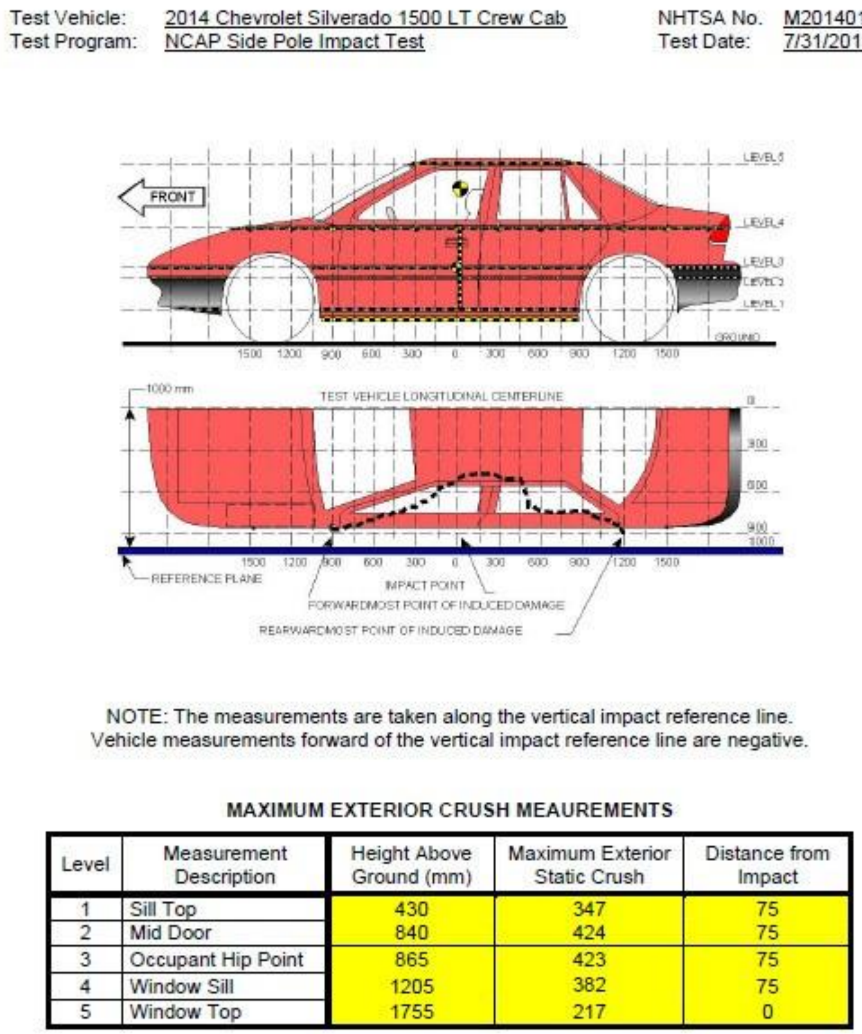
[40] National Highway Traffic Safety Administration, *Laboratory Test Procedure for the New Car Assessment Program Side Impact Rigid Pole Test*, September 2012, Washington DC 20590.

[41] NHTSA, *Final Report of New Car Assessment Program Side Impact Pole Testing of a 2014 Chevrolet Silverado 1500 LT Crew Cab*, Report No. SPNCAP-MGA-2014-009, Washington DC 20590, August 22, 2013.

left front (driver's) seat. The two doors on the struck side of the vehicle did not separate from the body at the hinges or latches, and the two doors on the opposite side of the vehicle did not open during the impact. Figure 77, Figure 78, and Figure 79 show the vehicle exterior crush measurements.



Test Vehicle: 2014 Chevrolet Silverado 1500 LT Crew Cab
Test Program: NCAP Side Pole Impact Test
NHTSA No. M20140104
Test Date: 7/31/2013

NOTE: The measurements are taken along the vertical impact reference line. Vehicle measurements forward of the vertical impact reference line are negative.

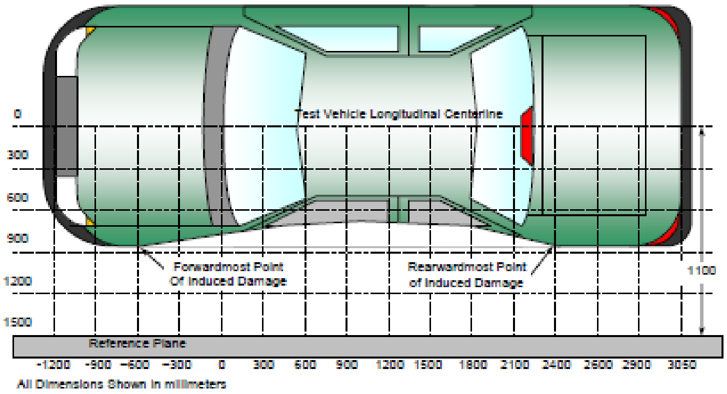
MAXIMUM EXTERIOR CRUSH MEAUREMENTS

Level	Measurement Description	Height Above Ground (mm)	Maximum Exterior Static Crush	Distance from Impact
1	Sill Top	430	347	75
2	Mid Door	840	424	75
3	Occupant Hip Point	865	423	75
4	Window Sill	1205	382	75
5	Window Top	1755	217	0

Figure 77: Maximum Exterior Crush Measurements From NCAP Side Impact Pole Test

Test Vehicle: 2014 Chevrolet Silverado 1500 LT Crew Cab
Test Program: NCAP Side Pole Impact Test

NHTSA No. M20140104
Test Date: 7/31/2013



TOP VIEW

DAMAGE PROFILE DISTANCES

DPD	Distance from Impact Point (mm)	Pre-Test (mm)	Post-Test (mm)	Max. Static Crush (mm)
1	3900	223	190	-33
2	2930	190	327	137
3	1910	186	394	208
4	880	156	687	531
5	-75	110	525	415
6	-1050	178	147	-31

Figure 78: Damage Profile Distances From NCAP Side Impact Pole Test

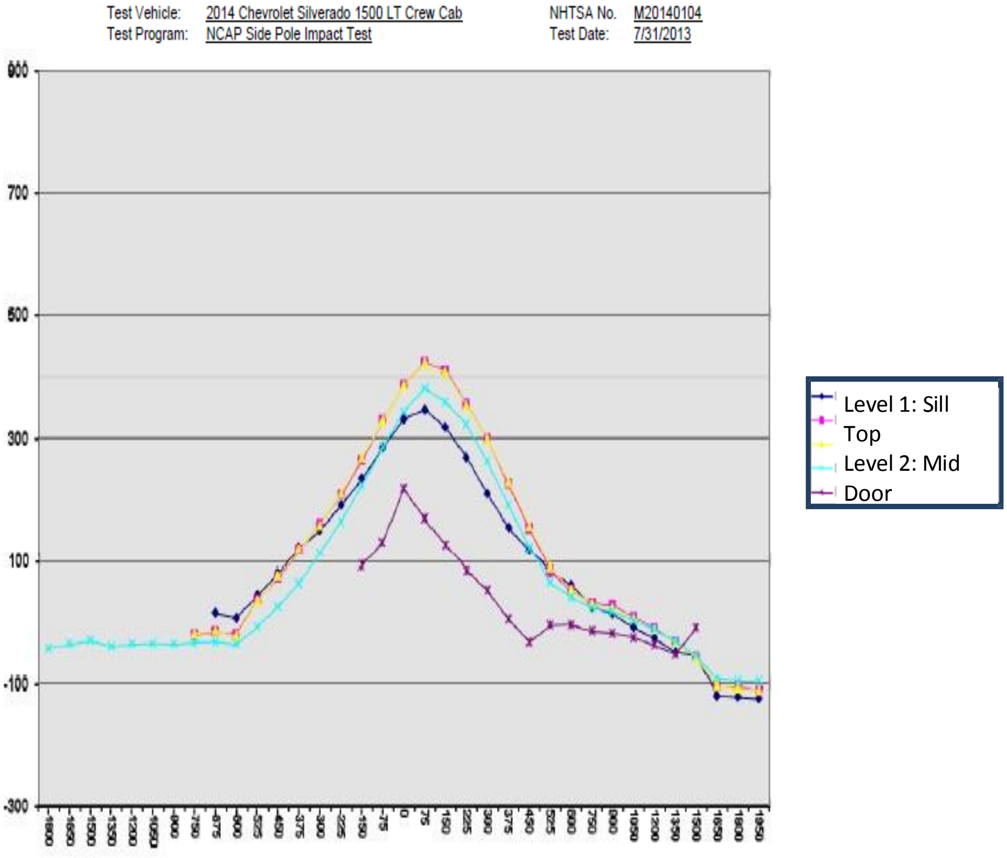


Figure 79: Exterior Crush Measurements From NCAP Side Impact Pole Test

The 2014 Chevrolet Silverado 1500 was awarded a 5-star safety rating for this NCAP side impact, rigid pole test.[42] The EDAG finite element model of the baseline Silverado will be subjected to a computer simulation of the NCAP side impact pole test, correlating the FEA results with the physical test results. The LWT finite element model will also be subjected to these loads. The results will be compared with the baseline Silverado values, verifying that the LWT is able to achieve a 5-star rating for NCAP side pole impact.

6.2.4 IIHS Roof Strength Test

The IIHS Roof Strength Test applies a crushing load to one outboard edge of the test vehicle's roof (either driver's side or passenger's side) to measure the maximum force it can sustain prior to deforming 127 mm (5 in). The test system can be seen in Figure 80. The maximum force is divided by the vehicle's measured curb weight to determine the strength weight ratio, which is used to rate the vehicle's rollover protection. The IIHS rating system is as follows:

Good: $\text{SWR} \geq 4.00$
Acceptable: $3.25 \leq \text{SWR} < 4.00$

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[42] NHTSA web site, "5-Star Safety Rating," www.safercar.gov/.

Marginal: 2.50 ≤ SWR < 3.25
Poor: SWR < 2.50

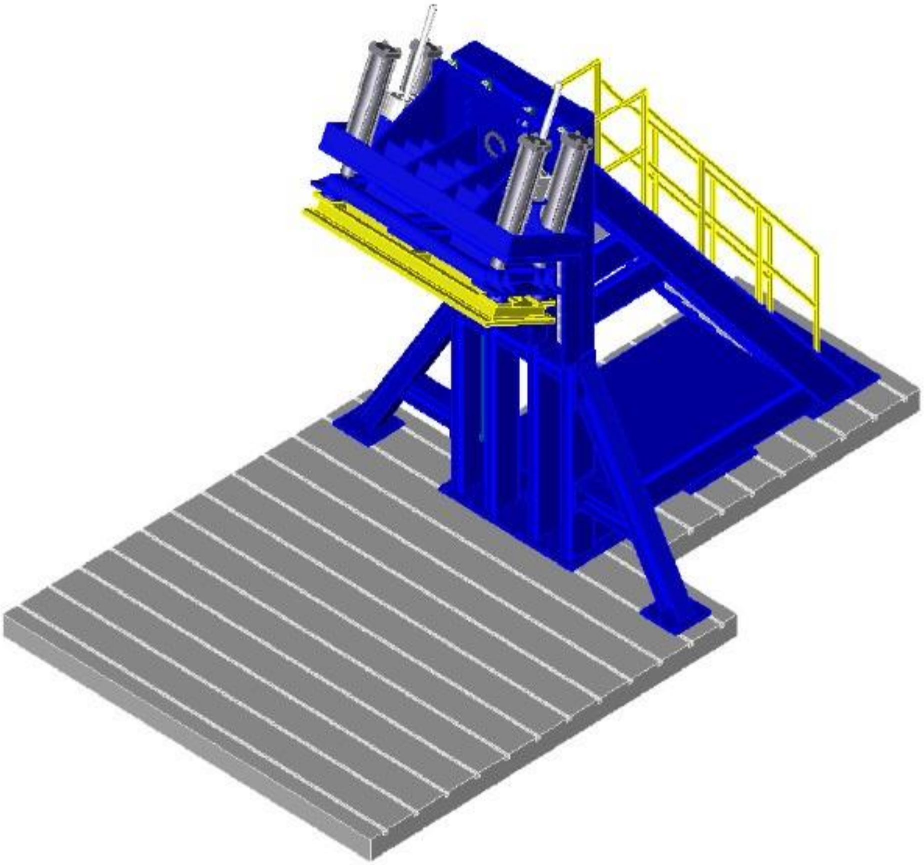

Figure 80: IIHS Roof Strength Test System[43]

Roof strength test data is not currently available for the 2014 Chevrolet Silverado 1500. The most recent model year for which test data is available is 2011. That test was run on April 14, 2011 on a 2011 Chevrolet Silverado crew cab pickup.[44] The vehicle in the test fixture can be seen in Figure 81. Figure 82 shows the vehicle in a pre-test state while Figure 83 shows it in a post-test state.

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[43] IIHS, *Crashworthiness Evaluation Roof Strength Test Protocol (Version II)*, 1005 North Glebe Road, Arlington, VA 22201, December 2012.

[44] Insurance Institute for Highway Safety, *Roof Strength Test Report – 2011 Chevrolet Silverado (SWR 1125)*, 1005 N Glebe Road, Arlington, VA 22201, April 14, 2011

Figure 81: 2011 Chevrolet Silverado in IIHS Roof Strength Test Fixture

Figure 82: Pre-Test Photo of 2011 Chevrolet Silverado Roof Strength Test

Figure 83: Post-Test Photo of 2011 Chevrolet Silverado Roof Strength Test[45]

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[45] Insurance Institute for Highway Safety, *Roof Strength Test Report – 2011 Chevrolet Silverado (SWR 1125)*, 1005 N Glebe Road, Arlington, VA 22201, April 14, 2011

The roof side structure was able to sustain a peak load of 16,134 lbf during the 127 mm (5 in) deformation. The measured curb weight of the vehicle was 5,151 lb., giving an SWR of 3.1. This is a rating of Marginal, as shown in **Figure 84**. Significant improvements have been made to the roof side rail and body side structure of the 2014 Chevrolet Silverado crew cab compared with the 2011 model. The results for the 2014 Silverado are expected to be higher SWR values and a higher IIHS roof strength rating. One such improvement is the usage of hot-stamped high-strength steel in the roof rails, A-pillars and B-pillars[46] as shown in Figure 92.

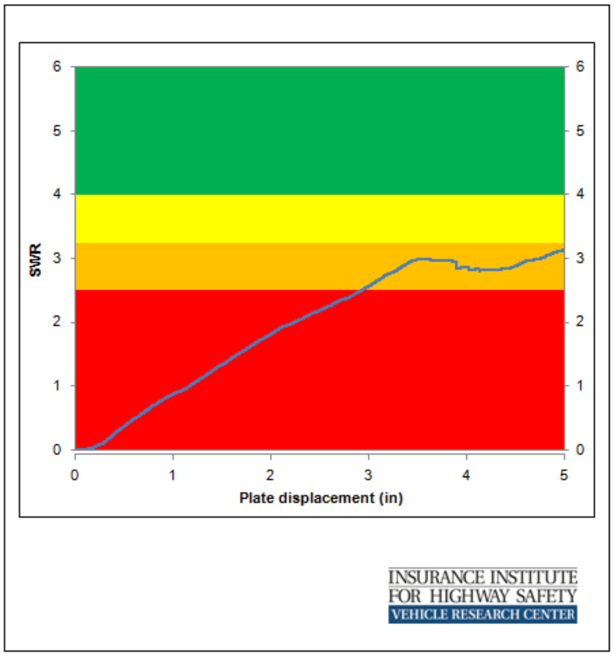

Figure 84: Test Rating for 2011 Chevrolet Silverado IIHS Roof Strength Test[47]

The EDAG finite element model of the baseline 2014 Silverado will be subjected to a computer simulation of the IIHS roof strength test. The SWR will be calculated and the rating determined. The LWT finite element model will also be subjected to these loads, verifying that it is able to achieve as high of a rating as the baseline 2014 Silverado 1500 CAE results. The results for the LWT will also be compared with test results for the 2015 Ford F-150[48]. The 2015 Ford F-150 achieved an SWR of 5.9

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[46] http://media.gm.com/media/us/en/chevrolet/news.detail.html/content/Pages/news/us/en/2012/Dec/1213-2014-silverado.html

[47] IIHS, *Roof Strength Test Report – 2011 Chevrolet Silverado (SWR 1125)*, 1005 N Glebe Road, Arlington, VA 22201, April 14, 2011

[48] IIHS Crashworthiness Evaluation; Roof Strength Test Report 2015 Ford F-150 (SWR1505)

6.2.5 IIHS Side Impact Crash Test

The IIHS Side Impact Crash Test consists of a stationary test vehicle struck on the driver’s side by a moving deformable barrier (MDB), a crash cart fitted with an IIHS deformable aluminum barrier element. The 1,500 kg MDB, shown in Figure 85, has an impact velocity of 50 km/h (31.1 mi/h) and strikes the test vehicle on the driver’s side at a 90-degree angle. The longitudinal impact point of the barrier on the side of the test vehicle is determined based upon on the vehicle’s wheelbase. The impact reference distance (IRD) is defined as the distance rearward from the test vehicle’s front axle to the centerline of the deformable barrier when it first contacts the vehicle (Figure 86). For the 2014 Silverado baseline, the IRD is 1,648 mm.

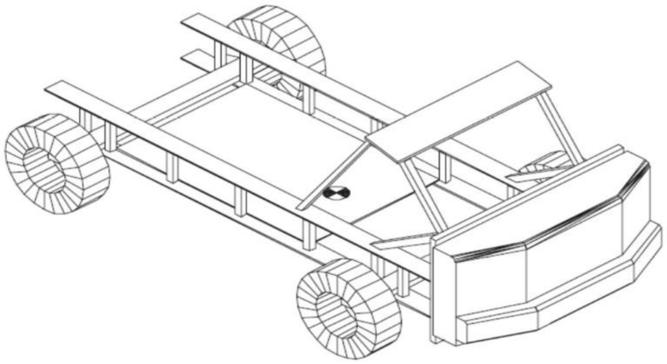

Figure 85: Moving Deformable Barrier Used in IIHS Side Impact Test[49]

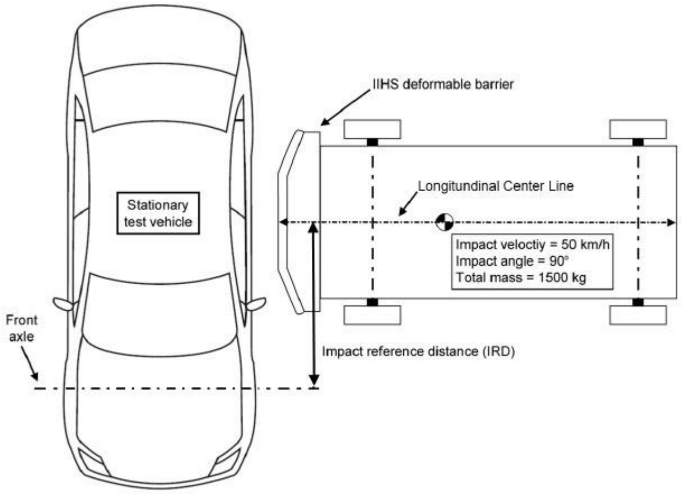

Figure 86: IIHS Moving Deformable Barrier Alignment With Test Vehicle[14]

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[49] IIHS, *Side Impact Crashworthiness Evaluation: Crash Test Protocol (Version VI)*, 1005 N. Glebe Road, Arlington, VA 22201, December 2012.

Two fully instrumented ATDs, both 5th percentile females, are placed into the test vehicle, one in the driver's seat and one in the rear passenger seat directly behind the driver. During the collision, instruments in the ATDs measure the severity of the impact on the bodies of the occupants.

IIHS side impact crash test data was yet not available for the 2014 Chevrolet Silverado 1500 crew cab pickup. The most recent data available was for a 2010 Chevrolet Silverado 1500 crew cab pickup. This vehicle was tested by IIHS on August 27, 2009.[50] Figure 87 shows the pre-test vehicle, Figure 88 shows the impact event and Figure 89 shows the vehicle after the impact.

Figure 87: 2010 Chevrolet Silverado 1500 Prior to IIHS Side Impact Test

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[50] IIHS, *Side Impact Crashworthiness Evaluation Crash Test Report 2010Chevrolet Silverado 1500,* Report No. CES0921, 1005 N. Glebe Road, Arlington, VA 22201, Crash Test Date August 27, 2009.

Figure 88: 2010 Chevrolet Silverado 1500 at Time of IIHS Side Impact

Figure 89: 2010 Chevrolet Silverado 1500 Following IIHS Side Impact Test

All doors remained closed during the crash and there was no separation of the door latches from their strikers. The B-pillar structure remained intact and attached to the body. The maximum intrusion of the B-pillar's interior surface was 5.0 cm outboard of the driver's seat centerline (pre-crash position) and 49.7 cm outboard of the longitudinal centerline of the vehicle. Figure 90 shows the pre-crash and post-crash positions of the B-pillar. As shown in Figure 91, this earned the vehicle an Acceptable rating from IIHS.

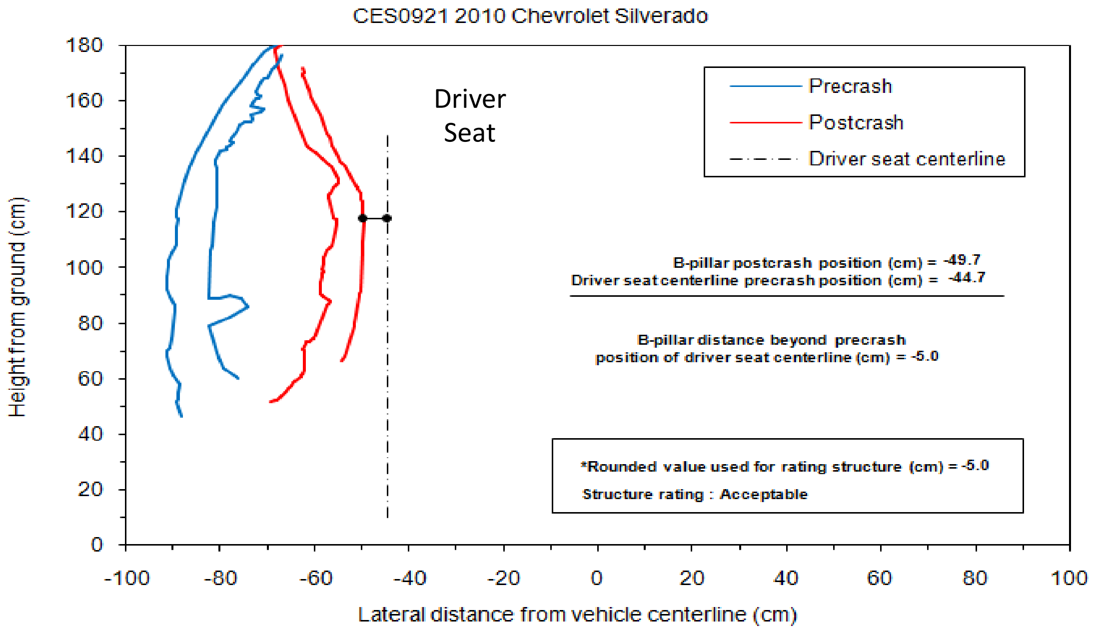

Figure 90: B-Pillar Exterior and Interior Profiles – 2010 Chevrolet Silverado 1500

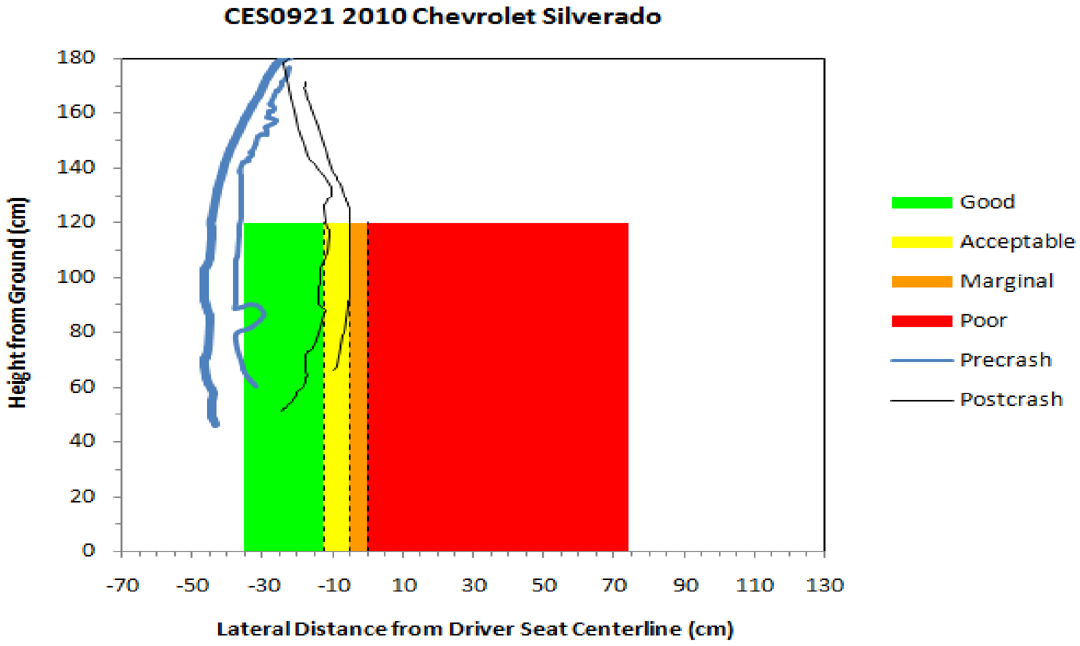

Figure 91: IIHS Side Impact Crash Test Rating – 2010 Chevrolet Silverado 1500

Compared with the 2007-2013 Silverado models, the body structure of the 2014 Chevrolet Silverado 1500 crew cab pickup is considerably improved through the insertion of new, structural B-pillars and the use of high-strength and ultra-high strength steel in the A-pillars, B-pillars, rockers and roof rails as shown in Figure 92. The expectation is that the 2014 Silverado will have side impact crash test ratings better than the 2010 model.

Figure 92: 2014 Chevrolet Silverado 1500 Improved Cab Structure[51]

The EDAG finite element model of the 2014 baseline Silverado will be subjected to a computer simulation of the IIHS side impact test, and the results evaluated in a manner comparable to those of the 2010 test. The LWT finite element model will also be subjected to these loads and the results compared with those of the baseline 2014 Silverado 1500, verifying that the LWT is able to achieve as high of a rating as the baseline CAE model results.

6.2.6 IIHS Moderate Overlap Frontal Crash Test

The IIHS Moderate Overlap Frontal Crash Test subjects the test vehicle to a partial frontal impact into a stationary deformable barrier. The test vehicle is aligned such that the right edge of the barrier is offset from the horizontal centerline of the vehicle by 10±1 percent of the vehicle width (defined in SAE J1100 – Motor Vehicle Dimensions) as shown in Figure 93. In this way 40 percent of the test vehicle's front face is impacted in the crash. The deformable barrier is shown in Figure 94.

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[51] http://media.gm.com/media/us/en/chevrolet/news.detail.html/content/Pages/news/us/en/2013/May/Silverado-May-5/0505-silverado-body.html

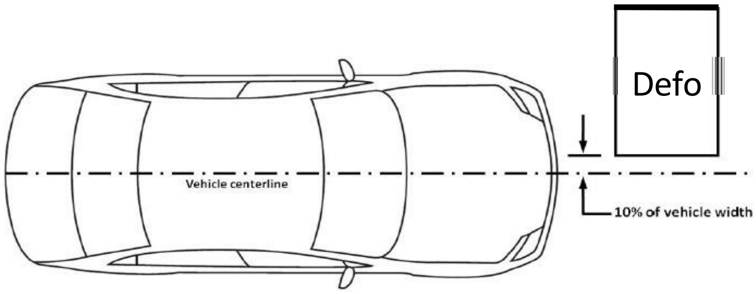

Figure 93: Orientation of Test Vehicle With IIHS Deformable Barrier[52]

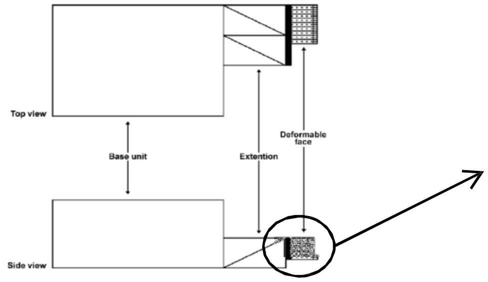

Figure 94: IIHS Deformable Barrier for Moderate Overlap Frontal Crash Test

The test is conducted at an impact velocity of 64.4±1 km/h (40±0.6 mph). One ATD, a 50th percentile male with instrumented lower legs, is positioned in the driver's seat of the vehicle. During the collision, instruments in the ATD measure the severity of the impact on the body of the occupant. A total of 14 locations on the driver side interior and exterior of the vehicle are measured before and after the test to determine intrusion into the occupant compartment of the vehicle.

Based upon testing performed by GM, the 2014 Chevrolet Silverado 1500 has been given a "Good" rating for moderate overlap frontal crash by the IIHS. Though the actual test data was not available to the LWT team, the EDAG finite element models of the baseline Silverado and the LWT will be subjected to computer simulations of the IIHS moderate overlap frontal crash test and compared with each other, verifying that the LWT provides as high a level of protection as the 2014 baseline[53].

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[52] IIHS, *Moderate Overlap Frontal Crashworthiness Evaluation Crash Test Protocol (Version XIV),* 1005 N. Glebe Road, Arlington, VA 22201, December 2012.

[53] www.iihs.org/iihs/ratings/vehicle/v/chevrolet/silverado-1500#Frontal1914

6.2.7 FMVSS No. 301 Rear Impact Test

Federal Motor Vehicle Safety Standard (FMVSS) No. 301 specifies a rear-impact test. The rear-impact test is designed to promote crashworthiness of the body structure, protect the fuel tank from damage, and hence avoid fuel leakage and possible fires. In this test, a moveable deformable barrier (MDB) impacts at 80 km/h (50 mph) into the rear of a stationary vehicle with an overlap of 70 percent as shown in Figure 95. The MDB used in the rear-impact test weighs 1380 kg. The baseline 2014 Silverado and the LWT design CAE models will be assessed for this load case to make certain that there is no damage to the safety critical components related to the fuel tank of the vehicles.

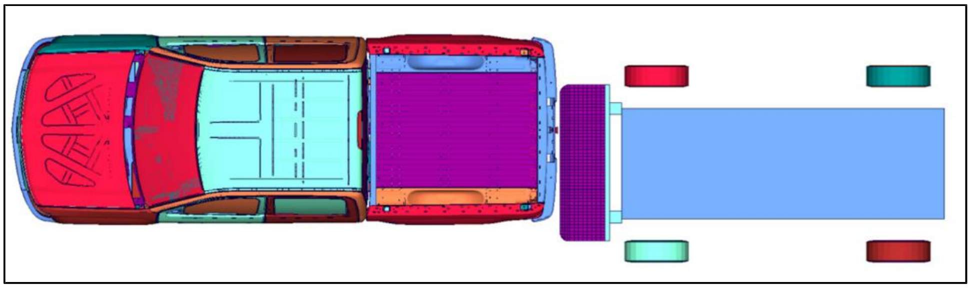

Figure 95: Test Setup for FMVSS No. 301

6.2.8 IIHS Small Overlap Frontal Barrier Test

The IIHS small overlap frontal barrier test is designed to reproduce what happens when the front corner of a vehicle hits another vehicle or an object like a tree or utility pole. Because occupants move both forward and toward the side of the vehicle, the small overlap test is also a trial for some safety belt and air bag designs. In this test, a vehicle travels at 40 mph toward a 5-foot tall rigid steel barrier. A Hybrid III dummy representing an average-size man is positioned in the driver seat. Twenty-five percent of the total width of the vehicle strikes the barrier on the driver side. Figure 96 illustrates the test setup from a top view and the barrier. The orientation of the tested vehicle to the barrier is shown in Figure 97.

Figure 96: Configuration of the IIHS small overlap frontal barrier test

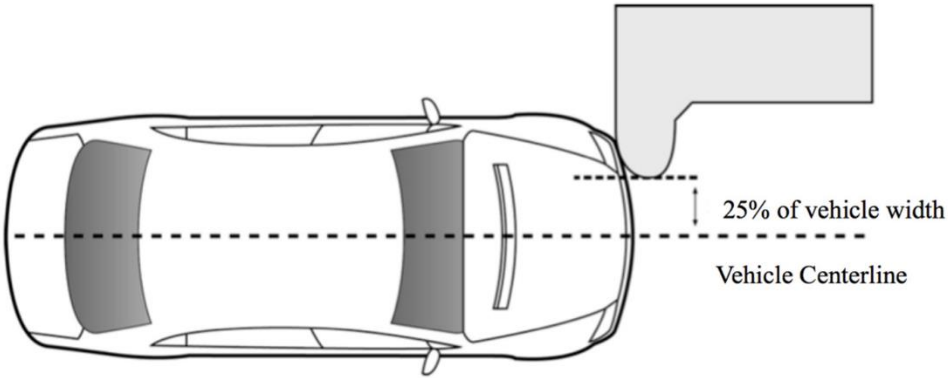

Figure 97: Vehicle overlay on flat 150mm radius small overlap barrier

To measure intrusion after the IIHS small overlap frontal barrier test, the locations shown in Figure 98 are examined for the amount of residual movement about the occupant compartment of the driver.

Vehicle performance in the IIHS small overlap frontal barrier test is determined by three categories: restraint and dummy kinematics, dummy injury measures, and vehicle structural performance. The structural rating is based on (1) the movement of seven points on the vehicle interior plus (2) the movement of three points along the door frame as shown in Figure 98.

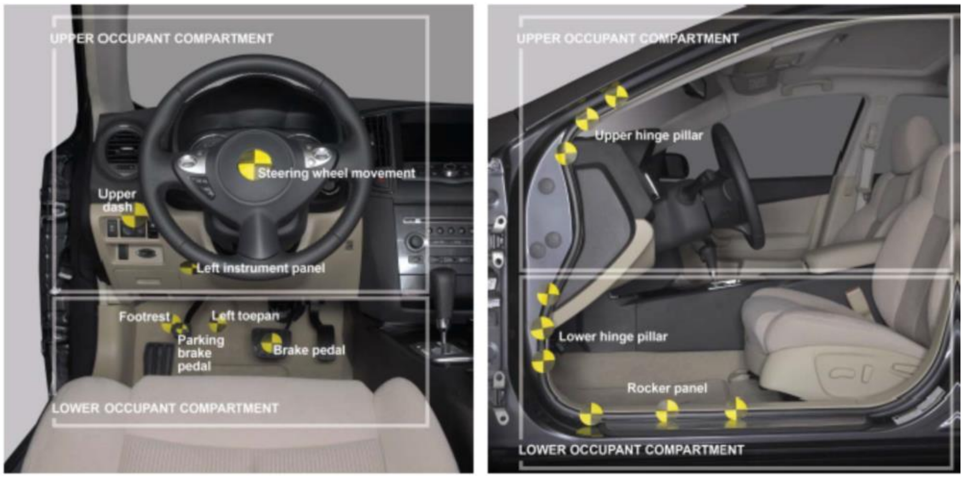

Figure 98: Locations used for measuring vehicle intrusion

The CAE results for the baseline and the LWT models will also be compared with the IIHS test conducted on the 2015 Ford F-150.[54]

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[54] IIHS Crashworthiness Evaluation; 2015 Ford F-150 (CEN1512) Small Overlap Front

6.2.9 Summary of Baseline Chevrolet Silverado Crash Tests

Figure 99 summarizes the dynamic and static (crush and intrusion) crash test results of the MY 2014 Chevrolet Silverado 1500 crew cab pickup. In assessing the relative safety performance of the LWT with the baseline Silverado, the safety elements in the table will be employed.

Test	Dynamic Results	Static Results
NCAP Frontal Rigid Barrier Impact	Peak acceleration and pulse time plots from NCAP testing	Driver compartment intrusion shown in Figure 68 and NHTSA Rating = 5 Star
NCAP Side Impact Moving Deformable Barrier	Peak acceleration and pulse time plots from NCAP testing	Vehicle crush measurements shown in Figure 72, 92 and 93 NHTSA
NCAP Side Impact Rigid Pole	Peak acceleration and pulse time plots from NCAP testing	**Vehicle crush measurements shown in** Figure 77, 98 and 99 NHTSA Rating = 5 Star
IIHS Roof Strength	Strictly a static test and not a dynamic examination	SWR = 3.13(2011Silverado data) Baseline CAE results (2014 Silverado) IIHS Rating = Marginal
IIHS Side Impact Crash	Dynamic test data not available	Occupant compartment intrusion shown in **Figure 90** and 95 IIHS Rating = Acceptable **2010 Silverado data** Baseline CAE results (2014 Silverado)
IIHS Moderate Offset (40%) Frontal Crash	Proprietary GM test data not available to LWT team	IIHS Rating = Good **Based upon GM test data**
Federal Motor Vehicle Safety Standard (FMVSS) No. 301	Plastic strains in fuel tank material during the impact time	No damage to fuel tank – structural intrusion in the vicinity of fuel tank
IIHS small overlap frontal barrier test	Acceleration and the pulse time width?	Occupant compartment intrusions

Figure 99: Structural Response of the 2014 Chevrolet Silverado 1500 Crew Cab Pickup

6.3 Vehicle Structural Stiffness and NVH Targets

The body structure torsion and bending stiffness, as well as the modal properties, are signatures of a vehicle's structural performance. Vehicles with higher stiffness are generally associated with refined ride and handling qualities. A rigid vehicle structure helps to minimize noise, vibration and harshness in the passenger compartment, improving the vehicle's ride quality, comfort and interior quietness. After the baseline 2014 Chevrolet Silverado 1500 crew cab pickup truck was completely disassembled at EDAG, the structure underwent testing for the normal modes of vibration, torsion stiffness and bending stiffness, as will be discussed in the following sections. The frame, pickup box and body structure (with windshield, back glass and instrument panel cross-car beam assembled in place), were made available to Exova Defiance in Troy to complete the tests. The results of these tests are discussed below, while the complete final test reports prepared by Exova Defiance are included in Appendix B of this report. The LWT was designed to maintain the torsional and bending stiffness as well as the modal properties of the baseline Silverado.

6.3.1 Normal Modes Frequency Testing

A normal mode of a body structure is a pattern of motion in which all parts of the system move in phase and with the same frequency. The normal mode frequencies of a body system are known as its natural frequencies or resonant frequencies. A vehicle body/cab has a set of normal modes that depend upon its structure, materials and boundary conditions. The objective of this test was to determine the modal properties of a 2014 Chevrolet Silverado 1500 crew cab pickup truck BIW (including front end sheet metal, front and rear glass and instrument panel beam) in the 0 to 100 Hz frequency range. The major resonance frequencies of the body/cab structure which are likely to be excited by the out-of-balance forces from the engine and wheels are within this range. It is important to identify these frequencies and make certain they are separated from the engine and wheel forcing frequencies. For the test setup, the Silverado BIW cab was supported by four rubber air bags at four locations to give an approximation of "free-free' boundary conditions where no constraints are applied to the body structure that could influence the test results. The air pressure in the air bags was reduced as much as possible to minimize the interference of these supports on the lowest flexible modes of the structure while still providing the appropriate boundary conditions. Two modal shakers provided excitation to the structure while tri-axial accelerometers were attached to selected geometry points. The vehicle setup for the normal modes test is shown in Figure 100 and Figure 101.

Figure 100: 2014 Silverado With Shaker and Air bag Support for Cab Modal Testing

Figure 101: 2014 Silverado 1500 With Tri-Axial Accelerometer for Cab Modal Testing[55]

The results from the modal test for the baseline 2014 Chevrolet Silverado 1500 are shown in Figure 102. These values are used to generate targets for the LWT body structure, as shown in Figure 103. Refer to Appendix B for the full modal test report.

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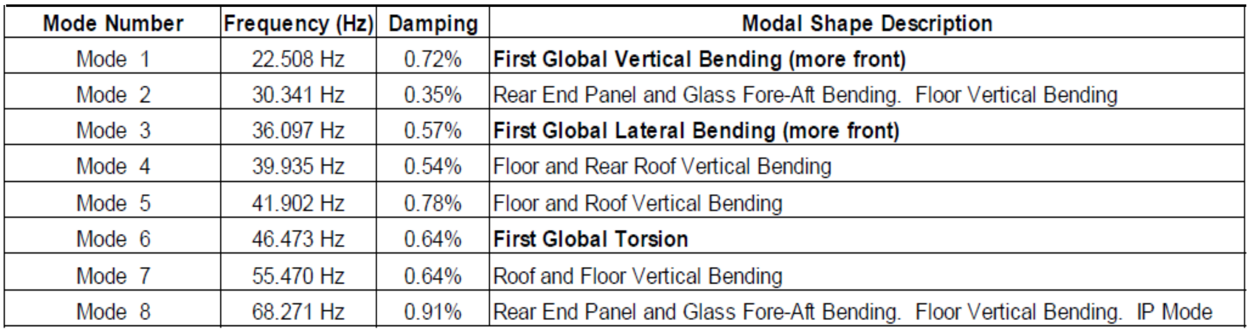
[55] Exova Defiance, *Chevy Silverado Cab BIW Modal Test*, Report No. 107429, 1154 Maplelawn, Troy, MI.



Mode Number	Frequency (Hz)	Damping	Modal Shape Description
Mode 1	22.508 Hz	0.72%	**First Global Vertical Bending (more front)**
Mode 2	30.341 Hz	0.35%	Rear End Panel and Glass Fore-Aft Bending. Floor Vertical Bending
Mode 3	36.097 Hz	0.57%	**First Global Lateral Bending (more front)**
Mode 4	39.935 Hz	0.54%	Floor and Rear Roof Vertical Bending
Mode 5	41.902 Hz	0.78%	Floor and Roof Vertical Bending
Mode 6	46.473 Hz	0.64%	**First Global Torsion**
Mode 7	55.470 Hz	0.64%	Roof and Floor Vertical Bending
Mode 8	68.271 Hz	0.91%	Rear End Panel and Glass Fore-Aft Bending. Floor Vertical Bending. IP Mode

Figure 102: 2014 Silverado 1500 Modal Results

	BASELINE CHEVROLET SILVERADO 1500	LWT TARGET
First Bending Mode (Hz)	22.5	22.5
Front End Lateral Mode (Hz)	36.1	36.1
First Torsion Mode (Hz)	46.5	46.5

Figure 103: Modal Test Results and Targets

6.3.2 Torsional Stiffness

Torsional stiffness of a vehicle is determined by applying a static moment to the frame at the front shock towers while constraining the frame at rear close to the rear axle center, as shown in Figure 104.

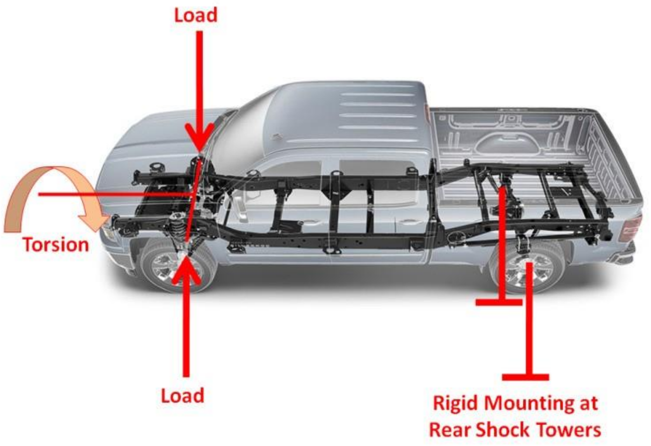


Figure 104: Vehicle Load and Mounting for Torsional Stiffness Test

The torsion angle is defined as the resulting deformation angle between the front and rear shock towers. The corresponding torsional stiffness is calculated as the ratio of the applied static moment to the torsion angle. Increasing the torsional stiffness value results in a stiffer vehicle; this provides a better ride characteristic. In the case of a pickup truck, the vehicle is tested in four configurations.

- Frame with cab and pickup box
- Frame with cab only
- Frame with pickup box only
- Frame only

Figure 105 shows the test set-up for the first configuration, frame with cab and pickup box. The cab includes the windshield, rear glass and the instrument panel cross-car beam. Figure 106 shows the test set-up for the third configuration, frame with pickup box only. One of the rear constraints is shown in Figure 107. Torsional stiffness test results are shown in Figure 111. The detailed torsion test report with all results can be seen in Appendix B.

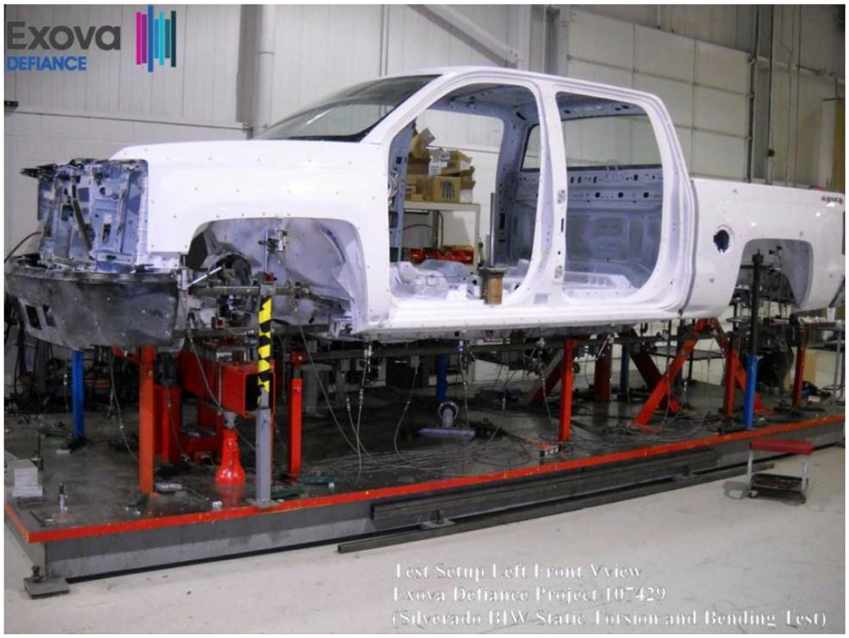


Figure 105: 2014 Silverado 1500 Set-Up for Static Bending and Torsion Testing of Frame, Cab, and Pickup Box

Figure 106: 2014 Silverado 1500 Set-Up for Static Bending and Torsion Testing of Frame With Pickup Box

Figure 107: 2014 Silverado 1500 Left Rear Constraint for Static Bending and Torsion Testing

6.3.3 Bending Stiffness

Vehicle bending stiffness is measured using the same test set-up as that used for torsion testing, and with the same four vehicle configurations: frame with cab and pickup box; frame with cab only; frame with pickup box only; and frame only. The vehicle is constrained at the front and rear shock towers while loads are applied at locations between the front and rear constraints, as shown in Figure 108. Two different load cases evaluated are frame loaded bending and sill loaded bending. For a frame loaded bending test, brackets are welded to the left and right frame rails halfway between the front and rear constraints. These brackets are connected by a bar to which vertical forces up to a maximum of 8,896 N (2,000 lbs.) are applied as shown Figure 109. For a sill loaded bending test, dead weights up to 2,224 N (500 lbs.) are applied to the left and right sills for a total of 4,448 N (1,000 lbs.) as shown in Figure 110.

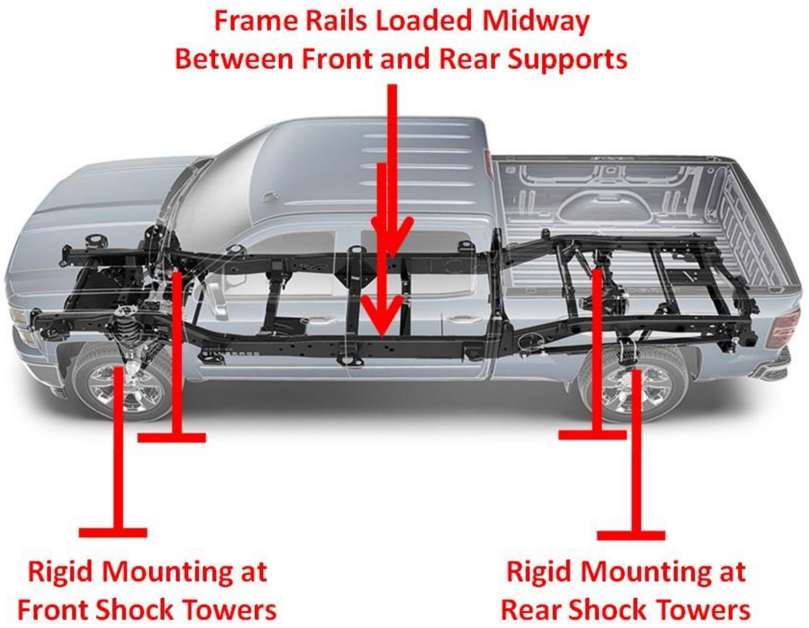


Figure 108: Vehicle Load and Mounting for Frame Loaded Bending Test

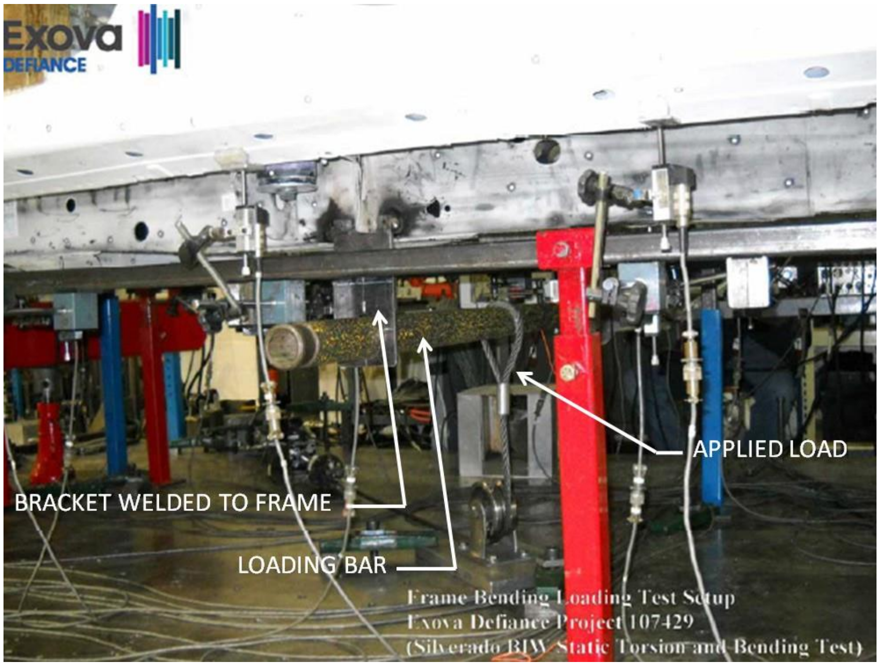
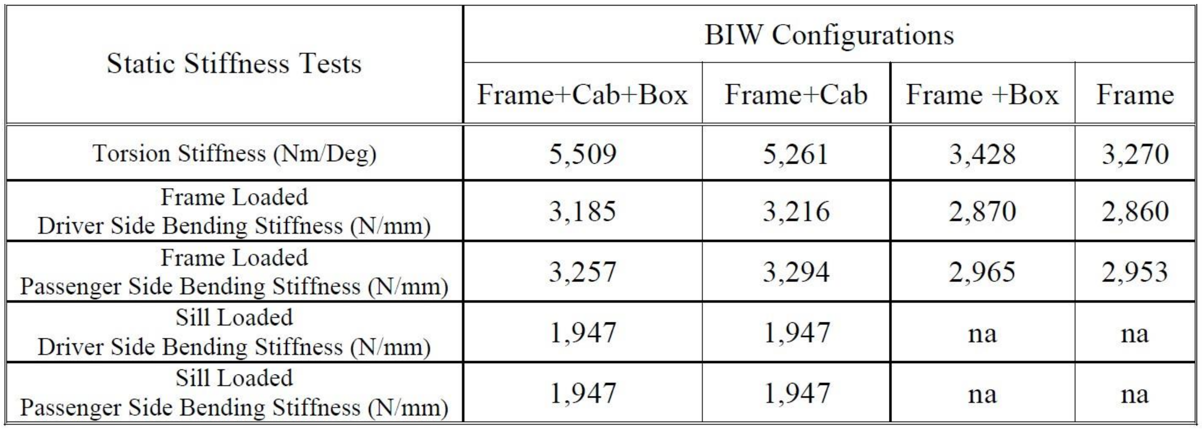


Figure 109: 2014 Silverado Frame Loaded Bending Test

Figure 110: 2014 Silverado Sill Loaded Bending Test

Bending stiffness is calculated based upon the ratio of the applied load to the maximum deflection along the rocker panel and tunnel. Excessive amounts of deflection under bending loads can lead to unacceptable relative movements between components, a possible cause of squeaks and rattles or even premature structural failures. The bending stiffness results are shown in Figure 111.

A summary of the static bending and torsion test results shown in Figure 111 are target values for the LWT design. The complete static bending and torsion test report is included in Appendix B.



Static Stiffness Tests	BIW Configurations			
	Frame+Cab+Box	Frame+Cab	Frame +Box	Frame
Torsion Stiffness (Nm/Deg)	5,509	5,261	3,428	3,270
Frame Loaded Driver Side Bending Stiffness (N/mm)	3,185	3,216	2,870	2,860
Frame Loaded Passenger Side Bending Stiffness (N/mm)	3,257	3,294	2,965	2,953
Sill Loaded Driver Side Bending Stiffness (N/mm)	1,947	1,947	na	na
Sill Loaded Passenger Side Bending Stiffness (N/mm)	1,947	1,947	na	na

Figure 111: 2014 Silverado 1500 Static Torsion and Bending Stiffness Summary

6.4 Other Vehicle Considerations

6.4.1 Serviceability and Repairability

All OEMs have documented guidelines for serviceability design in one form or another. The guidelines address the issues associated with corrective and preventive maintenance, and with the ability to perform system diagnostics. Design for serviceability takes into account part accessibility and repair costs, which include assessment of labor, parts and repair times. This type of detailed analysis is outside the scope of this program, given that it requires extensive amounts of investigation into every serviceable component in the vehicle. In addition, the impact of such studies on the mass of the vehicle would be very limited. For the LWT, serviceability and repairability were given due care engineering consideration during the design stage of all proposed solutions, but a devoted serviceability analysis was not performed.

6.4.2 Durability and Reliability

Vehicle durability refers to the long-term performance of a vehicle subjected to extended usage and repetitive loading from driving, towing and other operating conditions in all types of weather and environments. One major area of concern is stress and fatigue-related durability. Under normal operating conditions, tires and suspensions experience road loads, the engine and transmission produce vibrations and loads, and even the vehicle entertainment system produces significant vibrations. All these loads and vibrations cascade throughout the vehicle body and frame, producing a cyclic load spectrum which can degrade structural members and joints. The transfer and distribution of loads varies with the structural, inertial, and material attributes of the vehicle, and are manifested as repetitive loads on the systems and components. These repetitive loads can cause fatigue damage, and the accumulation of this damage often results in crack initiation, crack propagation, and system or part failure. To address these fatigue damage concerns, OEMs conduct extensive mathematical analyses and physical durability tests with identified load cycles and durations. The physical tests are run in laboratories, simulating multiple life cycles, on test tracks and on public roads under actual driving conditions. Another major durability concern is resistance to corrosion and material degradation due to weather, salt spray, chemicals, contaminants, etc. Corrosion and material degradation occur when materials come into contact with reactive agents; whether salt spray acting on unprotected metals, petroleum products acting on plastics, dissimilar metals coming into contact with each other, or a myriad of other interactions. The durability of materials facing such degradation is similarly validated by OEMs through analyses and testing. When making material selections during the design phases it is crucial to consider where a component is located in the vehicle, what other components are in the proximity and the environment in which the components will operate.

The 2014 Chevrolet Silverado is an all-new design, so real-world history on its durability does not yet exist. Results of development testing performed by GM on the baseline vehicle were not available to the LWT team during the preparation of this report. An indication of the long term durability may be reflected in the durability of the previous generation Silverado, which was in production from MY2007-2013. The Consumer Reports reliability data for this platform[56] shows that, for the three categories most applicable to durability (paint/trim, squeaks and rattles and body hardware), the ratings in the first few model years were below average to average. The ratings improved each year until by the 2013 model year they were all above average. A study of J. D. Power reliability data[57] reached similar conclusions.

The LWT was designed with attention to durability concerns, employing finite element analyses and industry best practices to ensure adequate long term reliability. However, full assessment of the durability of the LWT was outside the scope of this program as this normally requires Road Load’ test data derived from instrumented prototype vehicles. Therefore, the LWT was assessed by using basic durability load cases generated from an Automatic Dynamic Analysis of Mechanical Systems ride and handling mathematical model. ADAMS multi-body dynamics software is an analysis tool used to create and test virtual prototypes of mechanical systems and to study the dynamics of moving parts, how loads and forces are distributed, and to improve and optimize the performance of vehicle designs.

The LWT was analyzed for the following durability road load cases.

- Pot hole (vertical loads transmitted from the suspension)
- 0.7 G cornering (lateral loads transmitted from the suspension)
- 0.8G forward braking (fore and aft loading during braking)

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[56] www.consumerreports.org/cro/cars/models/used/chevrolet/silverado-1500/reliability.htm

[57] http://autos.jdpower.com/research/Truck/index.htm?make_facet=Chevrolet&sortBy=year%20desc&year=2007

For these load cases the LWT durability life cycle targets was based upon typical OEM requirements. The number of cycles seen during the lifetime of the vehicle, assuming 200,000 miles, is equivalent to one severe (not extreme) pothole every 20 miles, one very hard cornering event every 2 miles and one emergency braking event every 2 miles.

- Pot hole (10,000 cycles)
- 0.7 G cornering (100,000 cycles)
- 0.8G forward braking (100,000 cycles)

6.4.3 Drivability, Ride and Handling

The targets for drivability are not based upon any benchmark vehicle measurements. The baseline Silverado and the LWT will be assessed using an ADAMS mathematical simulation model in order to confirm the suspension characteristics. The ride and handling tests which will be analyzed are:

- NCAP Fishhook Maneuver Test, and
- Double Lane Change Maneuver (ISO 3888-1).

The Fishhook test was used in conjunction with the Static Stability Factor (SSF) to rate the propensity for vehicle rollover. The SSF is calculated with the following equation.

$$SSF = T/2H$$

T is the vehicle’s track width (distance between the centers of the right hand left hand tires along the axle) and H is the height of the vehicle’s vertical center of gravity. A typical SSF for an SUV is in the 1.0 – 1.3 range while a typical SSF for a passenger car is in the 1.3 – 1.5 range. The SSF for the baseline Silverado is 1,716/(2*720.6) = 1.2. This value will be maintained or improved in the LWT.

6.4.4 Towing

The baseline Silverado is equipped with the optional trailering package and trailer brake controller. This provides a trailer hitch platform with integrated 7-pin and 4-pin connectors, an automatic locking rear differential and a 3.42 rear axle ratio, giving the vehicle a maximum conventional trailering capacity of 4,354 kg (9,600 lb.) or a maximum payload of 888 kg (1,957 lb.). The maximum trailering capacity for the Silverado 1500 is 5,307 kg (11,700 lbs.) with a crew cab, standard box, 4WD, 6.2L EcoTec3 engine and the Max Trailering package.

In order to make sure the LWT structure will be capable of performing maximum towing functions similar to the baseline vehicle with the 6.2L engine, the LWT CAE model of the chassis frame and the tow hitch structure will be subjected to towing loads as specified in SAE J684 specifications and the results (predicted stresses and deflections) compared to correlated CAE baseline model when subjected to same loads.

7 LWT System Technology Assessment and Selection

7.1 Introduction

The options for lightweighting technologies and the solutions applied to the LWT were based on detailed assessment of several baseline vehicle systems. Suitable choices of materials and manufacturing technologies were identified for each system. Each option was rated for its mass saving potential and cost of implementation in terms of cost per kg mass saving. The team reviewed each sub-system and a suitable mass reduction for each component was determined based upon similar applications in use and based upon the EDAG team's experience with vehicle design and engineering. The percentage mass reduction applied to each system took into account the current manufacturing technology of the system and future potential technologies classed as "Mid-Term" or "Mature" and their suitability for cost effective high-volume production. The baseline vehicle systems with their corresponding masses are shown in Figure 112.

As an example, the vehicle cab structure (system number 1 in Figure 112) is a stamped steel structure with above average use of AHSS. For this cab structure, the following four options were considered.

1. Increased content of future AHSS with mass saving potential of 46.50 kg at an additional cost of $2.01 per kg mass saving
2. An aluminum construction similar to the newly released 2015 Ford F-150. Mass saving potential 93.0 kg at a cost increase of $6.72 per kg mass saving
3. A hybrid structure constructed from AHSS and aluminum similar to 2015 Cadillac CT6. Mass saving potential 69.8 kg at a cost increase of $5.15 per kg mass saving
4. A composite/multi-material construction similar to the BMWi3 with mass saving potential 101.3 kg at a cost increase of $26.31 per kg mass saving

After reviewing the above four options, option 2 was selected for the LWT cab design. The cab structure was designed using various grades of aluminum. A similar approach was applied to all the other systems shown in Figure 112. For all the systems, the chosen cost effective lightweighting options formed the basis of the detailed design and optimization resulting in an engineering solution' for the entire LWT vehicle. The geometry of all major structural systems was redesigned to be suitable for the chosen material and its related manufacturing and assembly process.

Vehicle System		2014 Silverado System Mass (kg)	Percentage of Vehicle Mass
1	Cab	242.5	10.0%
2	Front Door Frames (per vehicle)	46.3	1.9%
3	Rear Door Frames (per vehicle)	42.4	1.7%
4	Hood Frame	11.4	0.5%
5	Tailgate Frame	22.4	0.9%
6	Front End Sheet Metal (per vehicle)	32.8	1.3%
7	Radiator Support Structure	21.0	0.9%
8	Pickup Box	109.9	4.5%
9	Front Bumper	30.1	1.2%
10	Rear Bumper	15.0	0.6%
11	Chassis Frame	244.1	10.0%
12	Towing Hitch	15.7	0.6%
13	Front Suspension (per vehicle)	68.0	2.8%
14	Rear Suspension (per vehicle)	66.9	2.7%
15	Wheels and Tires (per vehicle)	159.0	6.5%
16	Front Seat and Center Console	57.0	2.3%
17	Rear Seat	40.4	1.7%
18	Instrument Panel	32.7	1.3%
19	Engine	200.7	8.3%
20	Transmission	230.1	9.5%
21	Drive Shafts	53.7	2.2%
22	Fuel System	22.2	0.9%
23	Trim	86.1	3.5%
24	Exhaust	51.9	2.1%
25	Brake System	84.4	3.5%
26	HVAC	30.7	1.3%
27	Water Cooling	18.0	0.7%
28	Electrical	38.2	1.6%
29	Battery	19.6	0.8%
30	Fluids	38.3	1.6%
31	Fuel	65.8	2.7%
32	Glazings	39.6	1.6%
33	Air Bags and Seatbelts	18.5	0.8%
34	Steering System	34.7	1.4%
35	Wiper System	5.2	0.2%
36	Misc. latches/fasteners/mirrors	136.9	5.6%
Total Baseline Vehicle Mass		2432.0	100%

Figure 112: Baseline Vehicle System Mass and Percentage of Vehicle Mass

7.1.1 Cost and Mass Assessment of Technology Options

For each of the recommended technology options for the construction material and manufacturing technologies, the associated estimated mass savings were first identified. For each design option, an increase or decrease in the cost compared with the baseline vehicle was then calculated. This cost number was used to establish a preliminary cost for mass savings (calculated in cost per kg of mass saved) to assess the effectiveness of each option at reducing mass in a cost-effective manner. The option considered to be the most cost-effective, while remaining consistent with the other parameters of the study during the proof of concept stage, was incorporated into the LWT design. For the final Silverado LWT design, the project team performed a detailed incremental cost analysis.

The estimated cost developed for each design option was based upon the substitution of material from the current baseline vehicle design with AHSS, aluminum, magnesium, composite, etc. along with appropriate manufacturing process factors developed through EDAG team experience and feedback from the respective material/technology specialist. The following methodology was used to make the initial cost estimations of the different design options:

1. Material Cost and Scrap Return Premiums – For the majority of the materials referenced in this report, the base prices were obtained from published sources and consultations with material suppliers or buyers. The average costs of the different material grades were established based upon discussions with the respective material suppliers. The material grades distribution of the baseline vehicle body structure was used to calculate the average steel material cost for the high-strength steel grades (up to 590 MPa) and the AHSS grades (greater than 590 MPa). The prices for gray iron and SMC are not available through published sources, and hence were established based upon consultation with industry experts including data from manufacturers of components using the specific material. The scrap return premiums were obtained from MetalPrices.com.[58]

2. The Manufacturing Process Scrap (%) is the typical scrap rate of the predominant manufacturing process for the respective material in the automotive industry (such as stamping for steel). The Material Cost with Manufacturing ($/kg) is the effective material price after also taking into consideration the manufacturing process scrap and scrap return premium. The Manufacturing Difficulty Factor takes into account considerations such as cycle time and the feasibility of the technology for high-volume production.[59] These parameters were established based upon consultation with industry experts including data from manufacturers of components using the specific materials.

The material cost and manufacturing factors assumed for the initial cost estimates are summarized in Figure 113. The cost analysis of the final LWT design for each assembly was refined as the design matured from the proof of concept stage to the final design release. The material costs and manufacturing factors shown in Figure 113 were used in the proof of

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[58] www.metalprices.com/introduction/description_of_serviceshtm

[59] A typical annual production of 200,000 used for this study

concept stage and only for the preliminary cost assessment of the different options. LWT costs were calculated based upon the design of the vehicle after the design was finalized.

Material	Material Cost ($/kg)	Reference	Material Cost With Manu-facturing ($/kg)	Manu-facturing Process Scrap	Manu-facturing Difficulty	Scrap Return Premium $/kg
Steel up to 590 MPa Strength - Average	**1.03**	**Platts - WorldAutoSteel**	**1.32**	**0.45**	**1.00**	**0.38**
Steel AHSS Average	**1.47**	**Platts - WorldAutoSteel**	**2.16**	**0.45**	**1.10**	**0.38**
Aluminum Sheet	**3.93**	**Platts**	**6.69**	**0.45**	**1.40**	**2.05**
Aluminum Cast	**2.23**	**Platts**	**2.91**	**0.03**	**1.30**	**1.89**
Magnesium Cast	**4.98**	**Platts**	**6.57**	**0.03**	**1.30**	**2.44**
Vinyl Ester Compound	**5.22**	**PlasticsNews.com**	**6.32**	**0.10**	**1.10**	**0.00**
Fiber Glass	**1.50**	**Supplier**	**2.70**	**0.20**	**1.50**	**0.00**
Carbon Fiber	**17.31**	**Warren, Oak Ridge, 2010**	**41.54**	**0.20**	**2.00**	**0.00**
Gray Iron/steel	**1.50**	**Supplier**	**2.02**	**0.05**	**1.30**	**0.38**
SMC	**3.00**	**Supplier**	**4.10**	**0.05**	**1.30**	**0.00**
Sound Insulation	**3.00**	**Supplier**	**4.10**	**0.05**	**1.30**	**0.00**

Figure 113: Material Costs and Manufacturing Factors[60]

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[60] Used only for the preliminary cost assessment of the different options

7.2 Cab Assembly

The cab assembly consists of the cab structure, front-end sheet metal (FESM) and radiator support, as shown in Figure 114. The cab structure is the occupant compartment containing the seats, console, instrument panel, etc. The FESM includes the fenders and any supporting structure associated with them. On the baseline vehicle, the left hand right hand FESM assemblies are bolted on to the cab structure. The radiator support structure is bolted to the front of the FESM.

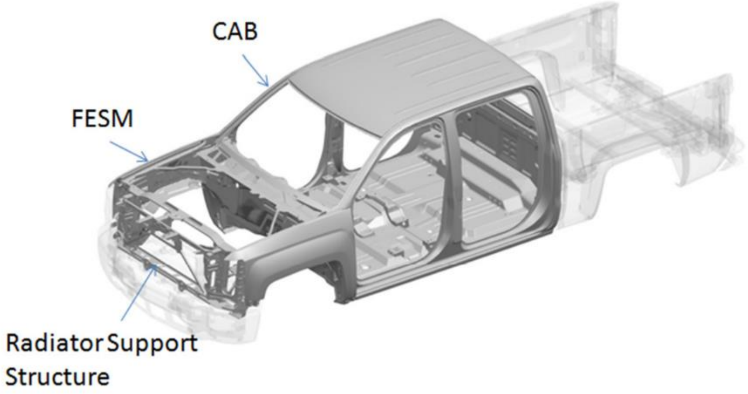

Figure 114: Baseline Chevrolet Silverado 1500 Cab Assembly

7.2.1 Cab Structure

7.2.1.1 Overview

The mass of any system generally is predetermined by the choice of material, manufacturing technology and the selected design methodology. The choices for the body/cab structure for high-and low volume production are illustrated in Figure 115. For high-volume production vehicles (over 100,000 annual), the economic choices for material are generally steel and Advanced High-Strength Steel (AHSS), with spot-welding the preferred (accepted) method of panel assembly.

Another way that mass may be predetermined is through the fact that new vehicle designs are most often based upon existing platforms. For example, the Chevrolet Silverado shares its platform with several other light-duty GM pickups and SUVs (such as the Chevrolet Tahoe and Suburban, and the GMC Sierra, Yukon and Yukon XL). Due to some of the required compromises inherent in platform sharing, since a platform has to work for all vehicle models built upon it, this generally leads to solutions which permit reduced research, development and tooling costs, but leads to inefficient higher mass.

Usage of aluminum is most common in high-performance, high-premium cost vehicles, though more current pickups such as the 2015 Ford F-150 are incorporating aluminum structures. The assemblies of these structures make greater use of adhesive bonding and self-piercing rivets. These, coupled with laser welding, lead to increased structural performance and hence lower structure mass.

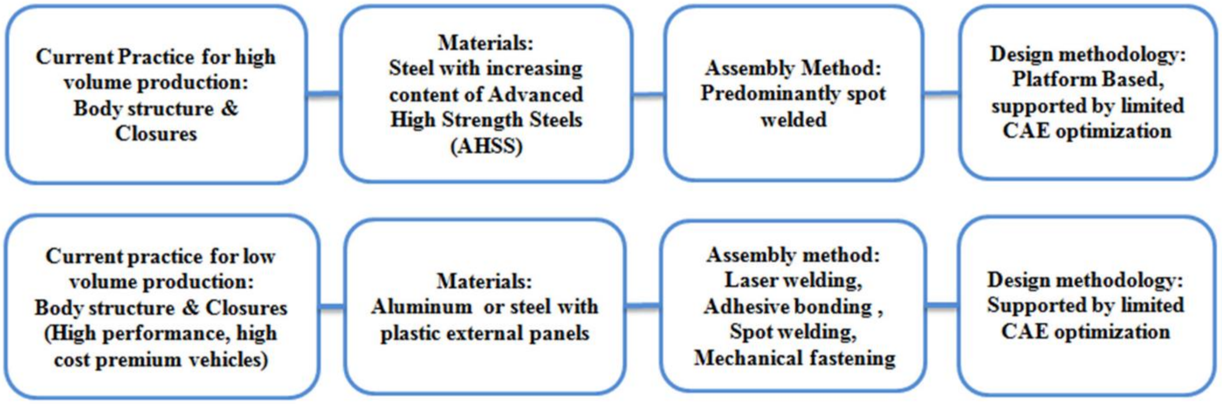

Figure 115: Material, Assembly and Design Methodology for Body Structures

The baseline 2014 Chevrolet Silverado 1500 body structure is a modern unibody monocoque structure constructed primarily from high-strength steel. The mass of the painted cab structure including paint, sealer, anti-flutter adhesive and some NVH measures added prior to the paint process was weighed to be 242.5 kg. This is 10 percent of the total weight of the baseline Silverado. The fenders, front end sheet metal, radiator support, windshield, and rear glass are not included in this weight as they are covered elsewhere in this report. Previously published data by GM in Figure 92 shows the HSS usage on the 2014 Chevrolet Silverado cab.

Most current pickup trucks are offered in three basic body styles; regular cab, extended cab and crew cab. To commonize as many parts as possible while still accommodating these variations, OEM's use the same structure for the front end and rear end of all models, making up the different lengths by changing the mid-body structure, as illustrated in Figure 116. This commonization of parts was taken into account in all design decisions for the LWT.

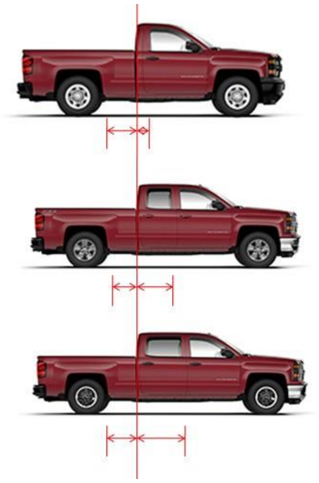

Figure 116: Full-Size Pickup Truck Design Variations

7.2.1.2 Selection of Technology for Cab Structure

The cab structure being evaluated in this section consists of the body side structure, outer panels, floor, roof, front-of-dash panel and back panel, as shown in Figure 117.

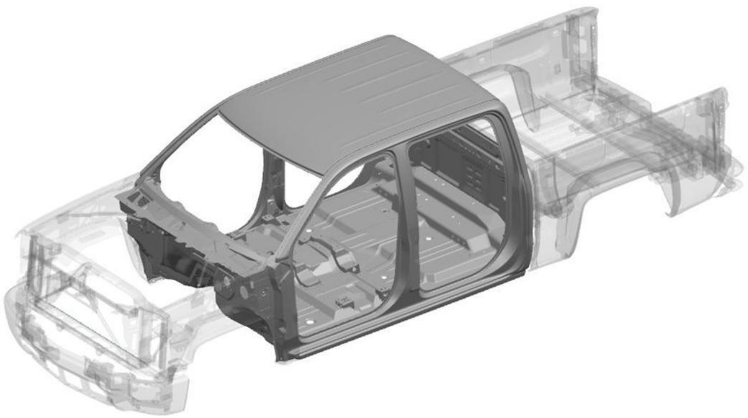

Figure 117: 2014 Chevrolet Silverado Cab Structure

7.2.1.3 Cab Option 1: Advanced High-Strength Steel

One possibility for reducing mass is maximizing the use of AHSS in the cab structure. Increasing the strength of the steel allows the gages to be reduced, resulting in a corresponding reduction in mass. However, as the metal becomes thinner it allows more sound to penetrate the cab, requiring additional acoustic insulation (refer to Section 7.7.3). As the cab structure is subject to several high-energy absorption crash requirements (high-speed side impacts and roof crush), advanced ultra-high-strength steels with extremely high-tensile strength (up to 1,500 MPa) offer a good solution at low cost premiums. This has led to a significant growth in the use of AHSS for automotive applications as shown in Figure 118.[61]

Some of the UHSS grade alloys considered for the LWT:

- Transformation Induced Plasticity
- Complex Phase Steel
- Recovery Annealed Steel
- Martensitic Steel
- Boron Steel for Hot-Stamping
- Dual Phase Steel

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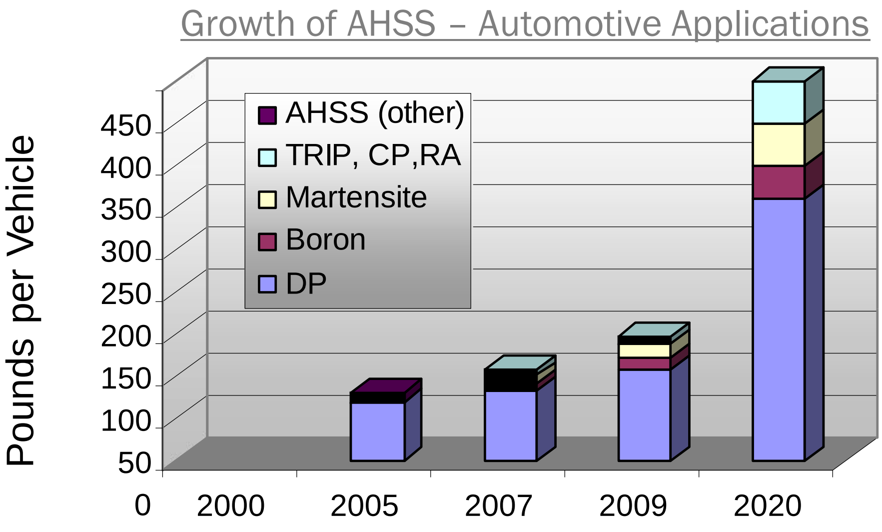
[61] Ducker Worldwide (2009)



Source: *Ducker Worldwide (2009)*

Figure 118: Use of AHSS for Automotive Applications

The baseline 2014 Chevrolet Silverado makes use of several types of steel in the cab structure: mild, bake harden-able, HSLA, dual-phase/multi-phase and press hardened. Advantage can be taken of much higher grades of steel in areas of the cab structure that are designed to reach high loads, such as the upper structure for roof crush and the side structure for side impact loads. Based upon research by World Auto Steel on the Future Steel Vehicle, with the use of ultra high-strength grades and hot-stamping manufacturing techniques, the average tensile strength of steel can be increased to over 700 MPa, with a mass saving potential of 25 percent.[62] A recent study by ArcelorMittal in which these types of AHSS grades were used to redesign the structure of a crew cab pickup truck demonstrated a 28 percent mass savings for the cab, radiator support and front end sheet metal structure.[63]

Further reductions in weight can be achieved beyond what is described in Option 1 above (that is, simply maximizing usage of AHSS in the cab structure) by filling selected structural components/sections with structural foams and thinning the gauge of the steel material used in that component. Henkel, Dow Chemical, and BASF are among several companies that provide plastic structural foam and insert solutions. These solutions were not proposed for the LWT cab structure due to concerns about difficulty with end-of-life recycling for such materials. Foams and other plastic materials used for this application are completely captured inside closed structural members and cannot easily be removed from the scrapped vehicle for recycling. Even though there are currently no regulatory requirements for recycling in the United States, there are requirements in other markets, such as Europe and Japan. If a vehicle is designed for multiple markets, the OEM would likely try to avoid any technologies which violate those requirements.

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[62] WorldAutoSteel – FutureSteelVehicle www.worldautosteel.org/projects/future-steel-vehicle/

[63] "Mass Reduction for Steel Pickup Truck Structures," Tom Wormald, Nicolas Schneider, Elie Gibeau of ArcelorMittal, presented at International Automotive Body Congress Dearborn 2014

For Option 1, a 20 percent reduction of the cab steel mass can be achieved by increasing the usage of AHSS, leading to an overall mass reduction of 19.2 percent when paint and adhesive is included in the calculation (it is assumed that the same amount of paint and adhesive will be used on the LWT as was used on the baseline). This equates to a projected weight of the LWT cab structure of 196.0 kg, as shown in Figure 119. Compared with the baseline Silverado cab weight of 242.5 kg, this represents a mass savings of 46.5 kg. This mass reduction estimate takes into account the fact that AHSS is already used in the 2014 Silverado B-pillar. AHSS, with its high tensile strength, offers a good solution at a comparatively low cost premium. From a cost perspective, Option 1 would result in an increase of $2.01 per kg saved for direct manufacturing cost, or an overall incremental increase of $93.65 per each cab structure.

	CAB Structure Material	2014 Silverado Mass (kg)	Cab Structure				
			Mass Reduction			Cost Increase	
			%	LWT Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 1	AHSS	242.52	19.2%	196.02	46.50	93.65	2.01
	Steel	232.52	20.0%	186.02	46.50	93.65	2.01
	Paint	10.00	0.0%	10.00	0.00	0.00	

Figure 119: Cab Structure Option 1 (AHSS) – Mass and Cost Summary

7.2.1.4 Cab Option 2: Aluminum Intensive

Another mass reduction alternative is to maximize the use of aluminum throughout the cab structure. Previous studies have shown the mass reduction potential of aluminum compared with steel for the main body structure of a vehicle can be up to 40 percent. A cost comparison study from 2001[64] showed that the increased cost of an aluminum body structure compared with a steel structure was typically $600 for the manufacturing and assembly. This is also a rule of thumb often used in the industry by body design engineers.

The newly released 2015 Ford F-150 makes extensive use of aluminum for all body structures, including the cab, pickup box and all closures as shown in Figure 120. This resulted in a mass savings of 40 percent compared with the 2012 F-150.[65]

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[64] Kelkar et al: Automobile Bodies: Can Aluminum Be an Economical Alternative to Steel? August 2001 Issue of JOM., 53 (8) (2001)pp. 28-32

[65] A2Mac1 Data

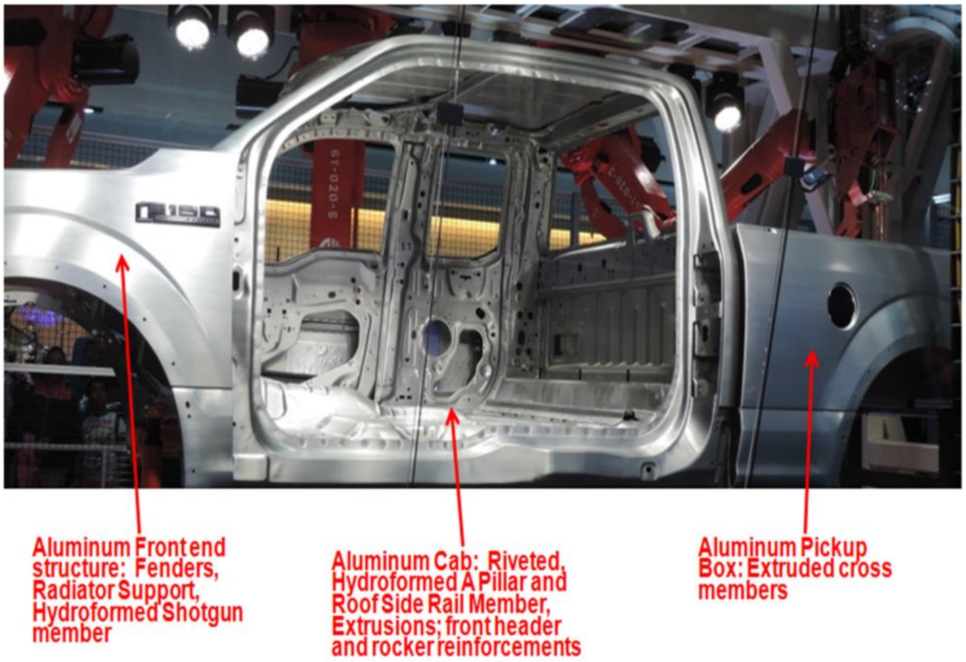

Figure 120: 2015 Ford F-150 Aluminum Structure

The 2011 Audi A8 body structure, illustrated in Figure 121, is constructed of an aluminum space-frame.[66] The actual space-frame consists of a combination of aluminum extruded sections, stampings and castings that are welded to each other. Several grades of aluminum are used in the construction of the structure including 3000, 5000 and 6000 series. For maximum recyclability benefits, an end-of-life process must be put in place to separate the various grades of aluminum prior to re-usage of the material. Otherwise, the resulting recycled aluminum is only suitable for low grade castings.[67] Jaguar Land Rover incorporated an all-aluminum monocoque body structure on its 2013 Range Rover, reducing mass by 39 percent compared with the previous steel version.[68] The vehicle is being built at a new aluminum production facility in Solihull, UK, as seen in Figure 122.

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[66] 12th International Car Body Benchmark Conference “EuroCarBody 2010”

[67] Material Transactions, Vol. 46, No. 12 (2005) pp. 2641 to 2646, Special Issue on Growth of Ecomaterials as a Key to Eco-Society II, 2005 The Japan Institute of Metals, Hiroshi Nishikawa, Kouhei Seo;*, Seiji Katayama and Tadashi Takemoto

[68] http://autoweek.com/article/car-news/2013-land-rover-range-rover-sheds-weight-all-aluminum-unibody-us- market-wont-get

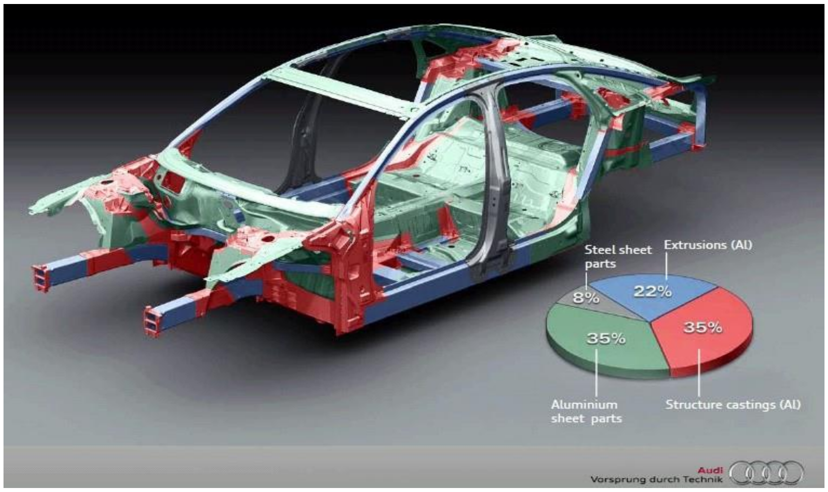

Figure 121: Audi A8 Aluminum Intensive Body Structure[69]
(Total Weight of Body-In-white without Doors, Closures, and Fenders = 231 kg)

Figure 122: 2013 Range Rover Being Built at New Aluminum Assembly Facility[70]

The calculated weight for the LWT cab structure for Option 2 is 149.5 kg, as shown in Figure 123. The 38 percent weight saving is equivalent to 93 kg mass reduction when compared with the baseline 2014 Chevrolet Silverado. From a mass reduction standpoint, an aluminum intensive approach provides an attractive alternative to AHSS as it achieves an additional 46.5 kg mass savings compared with Option 1. However, the cost of the aluminum cab structure is $625.33 higher than the baseline structure. This is equivalent to a cost of $6.72 per kg mass savings.

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[69] 12th International Car Body Benchmark Conference "EuroCarBody 2010"

[70] http://autoweek.com/article/car-news/2013-land-rover-range-rover-sheds-weight-all-aluminum-unibody-us- market-wont-get

	CAB Structure Material	2014 Silverado Mass (kg)	Cab Structure				
			Mass Reduction			Cost Increase	
			%	LWT Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 2	Aluminum	242.5	38.4%	149.5	93.0	625.33	6.72
	Steel to Aluminum	232.5	40.0%	139.5	93.0	625.33	6.72
	Paint	10.0	0.0%	10.0	0.00	0.00	

Figure 123: Cab Structure Option 2 (Aluminum) – Mass and Cost Summary

7.2.1.5 Cab Option 3: AHSS + Aluminum

A more cost effective mass reduction solution is selectively replacing some of the baseline steel components with AHSS and some with lower density materials. Candidates for the lower density components are the roof, floor and outer cab panels. Aluminum roof panels, for example, have been used on vehicles such as BMW's 7-series[71] and the Range Rover Evoque.[72] The integration of an aluminum panel into a steel cab structure cannot be accomplished with welding technologies due to the dissimilar metals involved. Instead, it must be done using mechanical attachments and adhesive bonding. This can create its own complications during the vehicle manufacturing process. For example, if the roof is bonded to the cab structure in the body shop prior to painting, the unequal coefficients of thermal expansion between steel and aluminum can present problems with rippling of the class-A surface of the roof panel. On the BMW 7-series, the roof panel went through the paint shop un-attached to the body structure, and was adhesively bonded to the structure in the vehicle assembly shop after painting. This may be acceptable for a high-cost and low volume production vehicle such as the BMW 7-series, but on very high production volume assemblies, this type of a bonding operation could lead to quality issues and, therefore, is not desirable. On the Range Rover Evoque, the roof panel was bonded prior to entering the paint shop. Land Rover solved the thermal expansion problem through development of special adhesive and mechanical fastenings and by optimizing the process parameters through computer simulations.[73]

The concept of using alternate lower density materials for the floor and outer panels of the cab has also been implemented in production for such vehicles as the Audi A8.[74] Steel support structure will still be required in this concept, but the panels are good candidates for material substitution. Some potential replacement materials considered for these cab panels are aluminum, glass-filled polypropylene and carbon fiber composite. As was discussed with the roof panel, there are difficulties with joining aluminum panels to steel structural members, but these can be overcome. Glass-filled polypropylene is very attractive for its low density, but these

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[71] 12th International Car Body Benchmark Conference "EuroCarBody 2010"

[72] Ibid

[73] Ibid

[74] Ibid

areas of the cab must provide protection from impacts such as road debris hitting the floor and shifting cargo in the bed impacting the rear wall. The amount of additional reinforcement and panel thickness which would need to be added to provide adequate protection from these impacts would likely nullify the weight savings. Carbon fiber composites can provide protection along with weight savings, but are more effective as a comprehensive panel/structure design than as discrete composite panels attached to metal structure. This comprehensive design will be considered later in this section as Option 4. As with any multi-material approach, an effective end-of-life strategy must be considered and solutions implemented for maximum recyclability. Separating the various materials to allow recycling must be technically and economically feasible.

The 2016 Cadillac CT6, which began production at the end of 2015, is based upon an all-new GM architecture employing a mixed-material approach, which includes eleven different materials, innovative joining techniques and has generated twenty-one patents.[75] The body structure of the CT6 is aluminum intensive (64% including all exterior body panels) and features thirteen high-pressure aluminum castings along with aluminum sheets and extrusions. The front and rear impact zones are composed of a combination of high strength steel and aluminum while high-strength aluminum is used for a rear impact bar. The structural portion of the B-pillar is entirely high-strength steel, as are carefully chosen reinforcements and close-out panels in the lower structure. This mixed-material structure, shown in Figure 124, reduces vehicle mass by 90 kg compared with a similar steel structure while achieving the highest torsional rigidity of any Cadillac and providing a quiet cabin without the need for additional sound insulation. Advanced joining methods are used on the CT6 including GM proprietary aluminum spot-welding technology, laser welding, aluminum arc welding, steel spot-welding, flow drill fasteners, self-piercing rivets, and advanced structural adhesives.

Figure 124: 2016 GM Cadillac CT6 Body Structure (General Motors)

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[75] More information on Cadillac appears at www.cadillac.com Cadillac's media website with information, images and video can be found at media.cadillac.com

A newly developed aluminum hybrid construction process was used on the 2014 Mercedes C-Class sedan that reduced the BIW mass by 70 kg compared with the previous model.[76] The new structure uses nearly 50 percent aluminum while the previous model used 9 percent. Usage of hot formed steel and high-strength steel is also increased on the new C-Class. The structure includes nine primary cast components as well as stampings and hydroformed tubes. Most exterior panels, including the doors, roof and hood, are aluminum. Because steel and aluminum cannot be welded together, Mercedes-Benz has become the world's first automaker to use the ImpAcT (impulse accelerated tacking) joining process, in which a rivet is driven through the aluminum and steel components at high speed, bonding them. Self-piercing rivets, self-tapping screws and clinching are other joining techniques used. Figure 125 shows the body structure of the new C-Class.

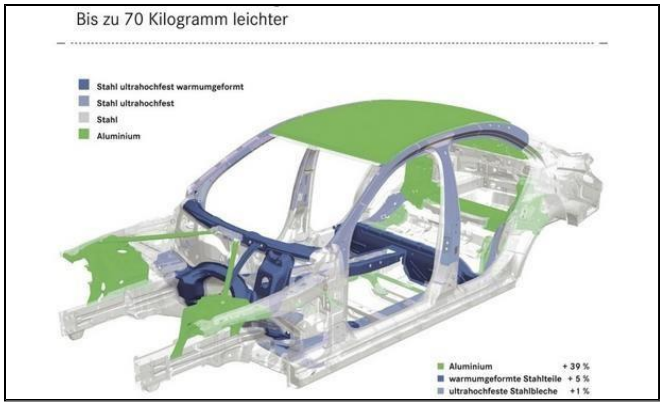

Figure 125: 2014 Mercedes C-Class Body Structure

Option 3 uses a multi-material design composed of AHSS and aluminum. Materials are applied to the areas where their properties are most appropriate, as can be seen in Figure 126. AHSS is used on the floor panels, front and rear body panels, plenum and reinforcements to provide stiffness and noise insulation. Aluminum is used for the roof and body side panels, roof beams, and overhead console bracket. The A-, B-, and C-pillars, roof rails and rocker beam are composed of a hybrid aluminum/AHSS structure similar to that shown in Figure 127. As can be seen in Figure 128, the calculated mass of the Option 3 cab is 172.76, a 28.8 percent reduction compared with the baseline. This mass reduction comes at an incremental cost of $359.49, equivalent to $5.15 per kg mass saving.

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[76] www.mercedes-benz.jp/news/release/2014/20140711_1_e.pdf

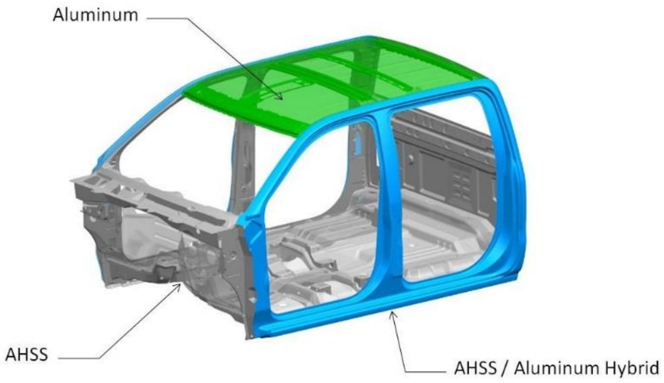

Figure 126: Option 3 AHSS + Aluminum Cab Structure

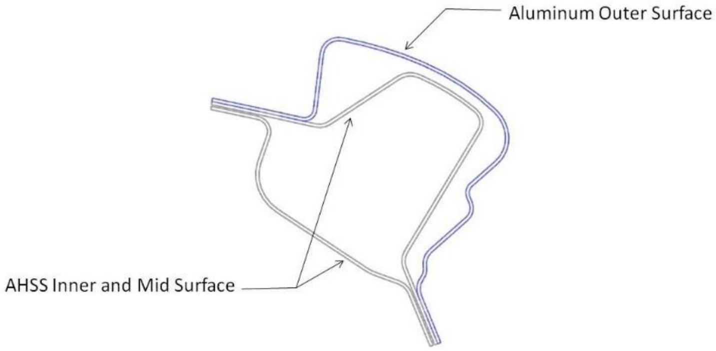

Figure 127: Option 3 AHSS + Aluminum Cab A-Pillar Cross Section

	CAB Structure Material	2014 Silverado Mass (kg)	Cab Structure				
			Mass Reduction			Cost Increase	
			%	LWT Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 3	AHSS + Aluminum	242.5	28.8%	172.7	69.7	359.49	5.15
	Steel -> AHSS	116.2	20.0%	93.0	23.2	46.82	2.01
	Steel -> Alum	116.2	40.0%	69.7	46.5	312.66	6.72
	Paint	10.0	0.0%	10.0	0.0	0.00	

Figure 128: Cab Structure Option 3 (AHSS + Aluminum) – Mass and Cost Summary

7.2.1.6 Cab Option 4: Carbon Fiber Composite

Composites offer many advantages compared with traditional materials, such as significant mass reduction and superior corrosion resistance. Nevertheless, it is still believed by many in the industry that for automotive applications a good understanding of composites at the engineering level is lacking. In the teams' opinion, implementation of composites on a large scale basis for high-volume production requires four major breakthroughs.

- Cost of the carbon fiber has to be reduced by almost a factor of 3
- The manufacturing cycle time has to be reduced by a factor of 4, to approximately 2 minutes per part
- There needs to be better understanding of structural behavior in crashes
- Methods have to be developed to assess low speed impact damage and repair methods for damaged structures

Much work is currently being done to reduce the cost of producing carbon fiber. The U.S. Department of Energy, as part of its Lightweight Materials R&D Program, contracted the Oak Ridge National Laboratory to "construct and operate a highly flexible, highly instrumented low-cost carbon fiber technology demonstration facility for demonstrating and evaluating new low-cost manufacturing technologies at a pilot scale."[77] The resulting Carbon Fiber Technology Facility was made operational in March 2013. Further work under this program is being done by ORNL and RMX Technologies including "development of a higher speed, lower cost oxidative stabilization process and development of a Microwave-Assisted Plasma (MAP) carbonization method."[78] By the end of 2015 these processes are expected to be advanced to the point where the researchers will have a 25 ton/year plasma oxidation module in operation on an advanced technology pilot line. On a laboratory bench scale, MAP carbonization has already been proven effective. In addition to this, Zoltek Companies, Inc., and Weyerhaeuser Company have a contract under this same U.S. Department of Energy program to "develop and commercially validate a low cost carbon fiber (using) innovative, patent pending technology for wet-spinning of Lignin/PAN blended polymer precursor fibers combined with modifications to existing commercial precursor and carbon fiber manufacturing processes."[79] This method has been used to produce prepreg tape from which composite test panels were fabricated. Results of testing on these panels are not yet available in the public sector.

Many companies are working to reduce the cycle time required to fabricate structural composite parts, aiming at a goal of one-minute cycle times. Partnerships between OEMs and composite suppliers are common, such as GM/Teijin, Ford/DowAksa, BMW/SGL, Chrysler/Quantum and Daimler/Toray Industries. One consortium, ACOMPLICE (**A**ffordable **COMP**osites for **LI**ghtweight **C**ar structur**E**s) includes Umeco, Aston Martin Lagonda, Delta Motorsport, ABB Robotics and Pentangle Engineering Services.[80] "ACOMPLICE aims to significantly reduce the cost of composite body-in-white vehicle structures for the mainstream automotive sector. The

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[77] http://energy.gov/sites/prod/files/2014/04/f15/2013_lightweight_materials_apr.pdf

[78] Ibid

[79] Ibid

[80] Ibid

partners plan to develop pre-impregnated broad application materials suitable for robotic lamination and fast cure technologies."[81]

Another consortium, MAI Carbon, has seventy-two members from the business, educational and research fields, including Audi, BMW, Premium AEROTEC, Eurocopter, Voith, SGL Group, IHK Schwaben, Technische Universität München, and Carbon Composites e.V. The stated objective of MAI Carbon is "to make the substance carbon fit for volume production and to turn the Munich-Augsburg-Ingolstadt region into a European competence center for CFRP lightweight construction."[82]

Momentive Specialty Chemicals has developed a "snap cure" epoxy resin, which "reportedly cures within two minutes."[83] Teijin Ltd. announced in 2011 that its "press forming process combined with intermediate prepreg materials made of thermoplastic resin instead of conventional thermosetting resin (achieved) a cycle time of less than one minute."[84]

Crash behavior of composite automotive components is being studied under the U.S. Department of Energy Lightweight Materials R&D program. Ford Motor Company Research and Innovation Center, General Motors R&D Center, and the National Energy Technology Laboratory have been contracted to "validate physics-based crash models for simulating primary load carrying automotive structures made of production-feasible carbon fiber composites for crash energy management. This will include the two Automotive Composites Consortium/USAMP developed meso-scale models from the University of Michigan and Northwestern University as well as existing composite crash material models in four major commercial crash codes (LS-DYNA, RADIOSS, PAM-CRASH and ABAQUS)."[85] As of the most recent progress report (2013), a production steel front bumper and crush can was selected for this study and analyzed using the physics-based crash models. A physical crash was conducted and the results were in the process of being compared with the predictions. Following completion of this, ten composite FBCC concepts will be evaluated and one chosen to be modeled, built and crash tested. The crash test results will be compared with the models to validate their predictive capabilities.

Predictions of design properties are also being studied by the U.S. Department of Energy. The Pacific Northwest National Laboratory and the NETL are working to "advance the predictive engineering tool to accurately predict fiber orientation and length distributions in injection-molded long-carbon fiber thermoplastic composites for optimum design of automotive structures using these materials to meet weight and cost reduction requirements."[86]

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[81] www.reinforcedplastics.com/view/26365/uk-project-to-develop-lower-cost-lightweight-composite-vehicle-structures/

[82] www.germaninnovation.org/research-and-innovation/centers-of-innovation/center-of-innovation?id=7ce94712-9d2a-e211-9fb3-000c29e5517f

[83] www.compositesworld.com/articles/composite-leaf-springs-saving-weight-in-production-suspension- systems

[84] www.compositesworld.com/news/teijin-announces-60-second-carbon-fiber-composite-manufacturing- process

[85] http://energy.gov/sites/prod/files/2014/04/f15/2013_lightweight_materials_apr.pdf

[86] Ibid

Industry experts agree that the assessment and repair of damaged CFRP parts is a serious concern and that a satisfactory solution is not yet readily available for high-volume vehicles. The primary issues are:

- How to determine the extent of damage to CFRP structures?
- How to decide whether to repair or replace the damaged structures?
- What is the appropriate repair method and material?

Many methods can be employed to determine the extent of the damage, including visual inspection, CT scan, ultrasound, electrical resistance, thermography, UV dye and acoustic emission. However, most of these require large, costly equipment, highly trained analysts and significant time to complete the analysis. In aerospace applications this is acceptable, but it cannot be expected that every automotive repair facility will have this equipment and expertise available, or that the cost of this analysis will be acceptable to consumers.

Once the damage has been assessed, the preferred repair solution is to replace any parts that are damaged. Mike Shinedling, Viper program manager at Chrysler, stated that, "replacing the part will be the best solution every time."[87] Of course, this is not always feasible. For small damages it is possible to patch the damaged area or install large overlap splices. McLaren's MP4-12C supercar includes a one-piece, all CFRP passenger cell they call a MonoCell as shown in Figure 129. Their approach is to avoid damage to this component by isolating it with front and rear aluminum crash cans. High-speed crash testing has shown the approach to be effective.[88]

Figure 129: McLaren MP4-12C[89]

Lamborghini's Aventador LP700-4 shown in Figure 130 has a one-piece all CFRP space frame coupled to a rigid aluminum sub-frame. In addition, the rear engine deck-lid, air scoops and vertical body panels are CFRP. Lamborghini's repair approach is that in the event of serious

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[87] www.compositesworld.com/articles/automotive-cfrp-repair-or-replace

[88] Ibid

[89] McLaren Automotive, Ltd.

damage, “one of its specially trained technicians is dispatched to repair the car. The automaker calls this elite group of four technicians its “flying doctors” and says they are on call 24/7/365 to travel to any location where an Aventador’s composite structure has been damaged.”[90] This approach is very impressive but not feasible for a mid-priced, high-volume vehicle.

Figure 130: Lamborghini Aventador LP700-4[91]

The 2014 BMW i3, in which the entire passenger compartment shell, or Life Module, is constructed of CFRP (shown in Figure 131), cannot employ the repair philosophies used by McLaren or Lamborghini. “Manuel Sattig, the communications manager for BMW I, explained: If the car is involved in a minor accident, only the exterior plastic parts are damaged. These are easily replaced by clicking out the damaged parts and replacing them with new ones. In case of a higher impact the carbon fiber will possibly be damaged.’"[92] Chuck Vossler, writing in BMWBLOG says, “Once a carbon fiber piece is broken, there just is no repairing of it. The entire part/body panel must be replaced. Nonetheless BMW knew the implication of building a car of CFRP and thus designed specific cut away sections in the i3. These are defined segments that when cut will allow the technician to remove the damaged CFRP piece and then bond the new CFRP segment back in with glue. These are located at the top of the A, B, C pillars as well as forward and aft of the floor pan.”[93]

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[90] www.automotive-iq.com/PDFS/Repair%20of%20composites_P3.pdf

[91] Automobili Lamborghini SpA

[92] www.automotive-iq.com/PDFS/Repair%20of%20composites_P3.pdf

[93] www.bmwblog.com/2014/07/11/learn-bmw-i3-repair-process/#

Figure 131: 2014 BMW i3 – Composite and Aluminum Structure[94]

At this point, though the producers of high price, low volume supercars have established methods of determining and repairing damage to CFRP vehicles, those methods are not feasible for mid-price, high-volume vehicles like the Silverado. Institutions such as the University of Bristol – Advanced Composites Centre for Innovation and Science[95] and the Fraunhofer Research Institution for Polymeric Materials and Composites[96] are performing research to advance these methods, and companies such as Abaris[97] are training technicians, but it does not appear that acceptable solutions will be available in the foreseeable future, particularly in the 2020-2030 time frame.

Through these various efforts progress is being made by the composites industry. By 2030 the price of carbon fiber is projected to decrease 45-67 percent[98] and the one-minute cycle time should be a reality. However, high-volume implementation is unlikely to occur over two to three vehicle design cycles (by MY 2025). The application of composites to date has been limited to a few premium vehicles with low production volume. This will hold true through 2030, with extensive applications of carbon fiber structural parts occurring in low volume luxury vehicles and premium electric vehicles (approximately 1% of all vehicles). The BMW i3 has created a great deal of excitement in this field. As of 30 June 2015, there were 27,735 i3's sold globally since the vehicle began production in September 2013.[99] BMW claims a mass savings potential of 50 percent over conventional steel construction by using the CFRP in the i3.

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[94] A2Mac1 Data

[95] www.bristol.ac.uk/engineering/media/accis/cdt/news/tolladay.pdf

[96] www.processexcellencenetwork.com/presentations/repair-and-recycling-of-automotive-composites/

[97] www.abaris.com/2014/07/31/abaris-completes-first-automotive-composite-repair-class/

[98] Heuss, R., Müller, N., van Sintern, W., Starke, A., Tschiesner, A., "Lightweight, Heavy Impact: How Carbon Fiber and Other Lightweight Materials Will Develop Across Industries and Specifically in Automotive," February 2012.

[99] http://en.wikipedia.org/wiki/BMW_i3#Global_sales

Calculations of the Option 4 cab structure yields an estimated mass of 141.2 kg, a reduction of 41.8 percent compared with the baseline Silverado (see Figure 132). The incremental cost of the carbon fiber cab structure is $2,663.94 higher than that of the baseline Silverado cab.

	CAB Structure Material	2014 Silverado Mass (kg)	Cab Structure				
			Mass Reduction			Cost Increase	
			%	LWT Mass (kg)	Mass Saving (kg)	Incre-mental ($)	Mass Saving Premium ($/kg)
Option 4	Composite Carbon Fiber	242.5	-41.8%	141.2	101.2	2663.94	26.31
	Steel -> CFRP	232.5	-50.0%	116.2	116.2	2563.64	22.05
	Paint	10.0	0.0%	10.0	0.0		
	Reinforcements Aluminum			15.0	-15.0	100.30	

Figure 132: Cab Structure Option 4 (Composites) – Mass and Cost Summary

Another possibility for weight reduction of cab structures is a more aggressive multi-materials approach, similar to Concept 3 but with a wider range of materials. This would be a hybrid structure made from several readily available materials like AHSS, aluminum, magnesium and composites. It would require innovations in joining dissimilar materials, some of which have been used in low volume production levels, but not yet in high volume, and a different vehicle end-of-life recycling infrastructure. The European Union Super Light Car (SLC) multi-material body structure study demonstrated a mass saving of 37 percent over a steel benchmark for the body structure, which was achieved at a cost premium of 7.80 € per kg mass saving for the body structure only[100]. This increase in cost is due to the higher price of the material used and the joining methods. The joining methods implemented on the SLC add 2.00 € per kg mass saving. A 2012 Lotus study also explored this approach using the 2009 Toyota Venza CUV as a baseline.[101] Body mass was reduced 141 kg (37%) at a cost in excess of $723.00 ($5.13 per kg of mass saved). When manufacturing and assembly complexity reduction due to lower part count and tooling costs were taken into account, the cost penalty decreased to $239.00, or $1.69 per kg.

Option 4 has a much higher mass saving cost premium than this because CFRP is used for the entire cab structure. Taking into consideration the 10 percent increase limit in retail cost of the proposed LWT, this option would be too expensive to implement and is unlikely to be a viable solution for high volume production 2020-2030 model year vehicles.

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[100] Dr.-Ing, Marc Steihlin: Volkswagen AG, SuperLIGHT-Car project – An integrated research approach for lightweight car body innovations. Lightweight Vehicle Structure Conference, Wolfsburg, Germany - May 2009

[101] "Evaluating the Structure and Crashworthiness of a 2020 Model-Year, Mass-Reduced Crossover Vehicle Using FEA Modeling," Lotus Engineering, Contract #09-621, August 31, 2012

7.2.1.7 Risks and Trade-Offs of Cab Structure Options

All materials used in a high-volume production manufacturing setting have their own risks and trade-offs. AHSS is no different. The risks for AHSS, however, are small in comparison to the other material options listed above. From a process standpoint, AHSS is more difficult to work with, in part because of its low ductility. For instance, it requires more robust stamping equipment to bend it into the desired shape. The varieties of AHSS do exhibit high formability, but in entirely different ways from traditional stamping materials. Stamping forming simulation must be used extensively to determine forming parameters at the tool design stage to determine the narrow forming window required for the AHSS. The cab structure is subjected to several high-energy absorption crash requirements (side high-speed impacts, and roof crush). Using AHSS materials with extremely high tensile strengths (up to 1,500 MPa) offers a structurally safe solution at fairly low cost premiums.

Aluminum has a low processing risk as it can be formed with similar tooling and manufacturing processes as the baseline steel components, though there are some processing limitations such as draw depth and processing times. The mass savings are greater than AHSS, but the material cost is also greater.

A combination of AHSS and aluminum offers very good mass savings at a reasonable cost premium, but in addition to the previously mentioned risks, it incurs additional risk due to the difficulties of joining and processing dissimilar materials.
The greatest mass savings can be realized through the use of carbon fiber composites, but the cost is extremely high compared with any of the other options investigated. There are also the additional risks previously mentioned regarding manufacturing cycle times, crash behavior and repair methodologies.

The different cab structure weight reduction options are summarized in Figure 133.

Compone	Technology Options	Benefits	Risks and Trade-Offs
Cab Structure	Option 1: AHSS and ultra high-strength steel	Weight savings up to 20%; low cost	Manufacturing limitations; spring back
	Option 2: Aluminum	Weight savings up to 40%	Higher costs; manufacturing and assembly limitations
	Option 3: AHSS + aluminum	Weight savings 20% to 30%; moderate	Manufacturing and assembly limitations; end-of-life recycling
	Option 4: Composites/multi-material	Weight savings up to 50%	High cost of material; manufacturing and assembly; further development needed for high volume production

Figure 133: Summary of Body Structure Weight Reduction Options

7.2.1.8 Cab Structure Selection

The LWT uses an aluminum intensive design for the cab structure (Option 2). Proper design with this choice of materials provides equivalent structural integrity with the baseline and offers a 38.4 percent mass savings. The cost premium is higher than Options 1 and 3, but because the cab structure represents such a large portion of the total vehicle mass, the team feels this system warranted a more aggressive approach and a larger percentage of the allowable cost increase. This approach avoided many of the difficulties with joining dissimilar metals that the other design options would have presented as well as many of the concerns about end of life recycling infrastructure. Although Option 4 offered the greatest mass savings, the incremental cost increase ($2,663.94) was too high for it to be a viable candidate for the LWT. To put the cost values into perspective, the overall cost limit of this study is 10 percent parity with the baseline vehicle MSRP, or $3,805.50 for the entire vehicle. Mass and cost summaries of all four-design options are shown in Figure 134.

	CAB Structure Material	2014 Silverado Mass (kg)	Cab Structure				
			Mass Reduction			Cost Increase	
			%	LWT Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 1	AHSS	242.5	19.2%	196.0	46.50	93.65	2.01
Option 2	Aluminum	242.5	38.4%	149.5	93.01	625.33	6.72
Option 3	AHSS + Aluminum	242.5	28.8%	172.7	69.76	359.49	5.15
Option 4	Composite (Carbon Fiber)	242.5	41.8%	141.2	101.26	2663.94	26.31

Figure 134: Body Structure Weight Reduction Options – Mass and Cost Summary

7.2.2 Front End Sheet Metal - Fenders

7.2.2.1 Baseline

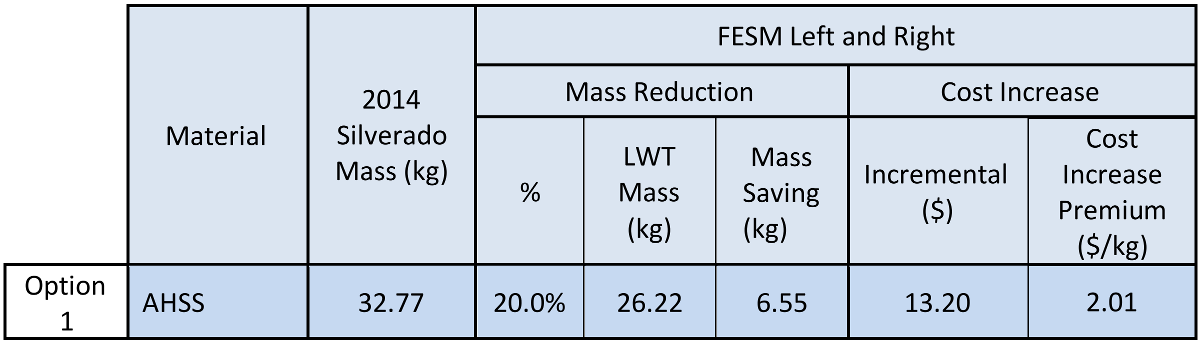
The FESM assemblies on the baseline 2014 Chevrolet Silverado are built primarily from cold rolled sheet steel. They are each composed of an inner and outer panel, reinforcements, brackets, supports, fasteners, liner and insulation. The left hand fender also has a battery tray. With the exception of the liners and insulation, all these components are constructed of steel. The combined masses of both left hand right hand fender assemblies are 38.3 kg, of which 32.8 kg are from the fender structural components (inner and outer panel, reinforcements, brackets, miscellaneous supporting structures and fasteners) and 5.6 kg are from the liners and insulation. This section of the report will focus on the 32.8 kg of primary structure, as the liners and insulation will be covered in other sections of the report. Figure 135 shows the right FESM primary structure while Figure 136 shows an exploded view of all the parts in the assembly.

Figure 135: Baseline Right FESM Assembly

Figure 136: Baseline Left FESM Parts

7.2.2.2 FESM Technology Option 1: AHSS

Up to 20 percent mass reduction is possible by use of AHSS for structure constructed from moderate strength steels such as the FESM assemblies, this leads a mass saving of 6.55 kg compared with the baseline mass. The incremental cost increase to manufacture the FESM in AHSS is $13.20 per vehicle, for a cost increase premium of $2.01 per kg mass saving as shown in Figure 137. Manufacturing of the Option 1 fender can be accomplished using the same production presses and fabrication sequences as the baseline fender.

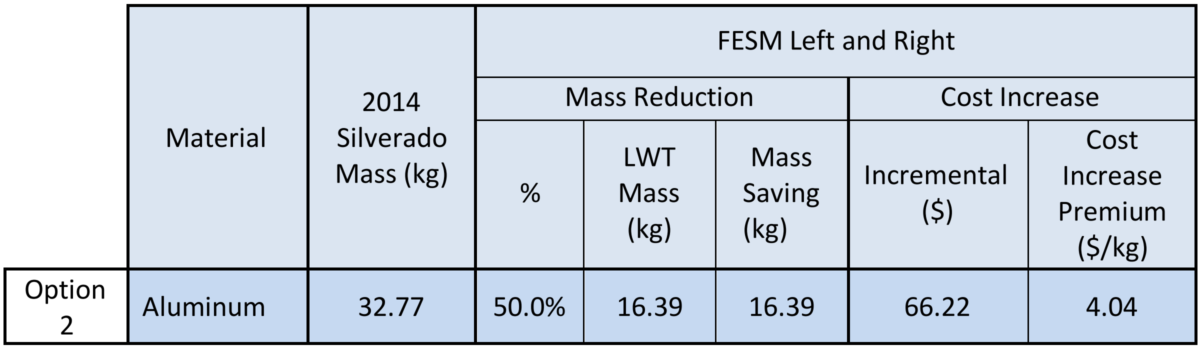


	Material	2014 Silverado Mass (kg)	FESM Left and Right				
			Mass Reduction			Cost Increase	
			%	LWT Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Option 1	AHSS	32.77	20.0%	26.22	6.55	13.20	2.01

Figure 137: FESM Option 1 (AHSS) – Mass and Cost Summary

7.2.2.3 Option 2: Aluminum

The Option 2 fender construction replaces the steel stampings with aluminum. The mass of the Option 2 fender design is 16.39 kg, a mass saving of 16.39 kg per vehicle (50%) over the baseline construction. The incremental cost increase to produce the Option 2 fender is $66.22 per vehicle, which represents a cost increase premium of $4.04 per kg mass saving as shown in Figure 138. As with the Option 1 design, the Option 2 fender can be produced using the same presses as the baseline vehicle fender.



	Material	2014 Silverado Mass (kg)	FESM Left and Right				
			Mass Reduction			Cost Increase	
			%	LWT Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Option 2	Aluminum	32.77	50.0%	16.39	16.39	66.22	4.04

Figure 138: FESM Option 2 (Aluminum) – Mass and Cost Summary

7.2.2.4 Option 3: Aluminum + AHSS

The Option 3 design uses an aluminum stamping for the outer panel and AHSS for the inner panel and all other structural components. The aluminum outer panel weighs 5.83 kg, 50% less than the baseline panel's mass of 11.65 kg. The total weight of the Option 3 fender structural components is 22.72 kg per vehicle, 10.05 kg (31%) less than the baseline 32.77 kg. The incremental cost of the Option 3 fender is $32.05 per vehicle, or $3.19 per kg of mass saved as shown in Figure 139.

	Material	2014 Silverado Mass (kg)	FESM Left and Right				
			Mass Reduction			Cost Increase	
			%	LWT Mass (kg)	Mass Saving (kg)	Incre-mental ($)	Cost Increase Premium ($/kg)
Option 3	Aluminum + AHSS	32.77	30.7%	22.72	10.05	32.05	3.19
	Outer Stamping (Alum)	11.65	50.0%	5.83	5.83	23.54	4.04
	Inner Stamping (AHSS)	8.99	20.0%	7.19	1.80	3.62	2.01
	Misc. Mountings (AHSS)	12.13	20.0%	9.70	2.43	4.89	2.01

Figure 139: FESM Option 3 (Aluminum+AHSS) – Mass and Cost Summary

7.2.2.5 Option Selection

As can be seen in Figure 140 the Option 2 aluminum design has the highest incremental cost at $66.22, but also provides the greatest mass savings at 16.39 kg per vehicle. Option 1 has the lowest cost, but provides less than half the mass savings at only 6.55 kg per vehicle. The Option 3 concept is approximately half the incremental cost of Option 2, but offers 6.34 kg less mass savings. For the LWT program, Option 2 was chosen. As with the cab structure, the team felt that the fenders are large enough components that the additional mass savings, as well as avoiding issues with joining and recycling dissimilar materials, justified the higher costs.

			FESM Left and Right				
			Mass Reduction			Cost Increase	
	Material	2014 Silverado Mass (kg)	%	LWT Mass (kg)	Mass Saving (kg)	Incre-mental ($)	Cost Increase Premium ($/kg)
1	AHSS	32.77	20.0%	26.22	6.55	13.20	2.01
2	Aluminum	32.77	50.0%	16.39	16.39	66.22	4.04
3	Aluminum + AHSS	32.77	30.7%	22.72	10.05	32.05	3.19

Figure 140: Mass and Cost Summary of FESM Design Options

7.2.3 Radiator Support

7.2.3.1 Baseline

The baseline radiator support on the 2014 Chevrolet Silverado, shown in Figure 141, is primarily constructed of stamped steel elements spot-welded together. The mass of the baseline radiator support is 19.98 kg, which includes 18.96 kg of stampings and 1.0 kg of miscellaneous mountings.

Figure 141: Baseline Chevrolet Silverado Radiator Support

7.2.3.2 Radiator Support Technology Options

Four design options offering mass saving potential were considered for the radiator support.

7.2.3.3 Option 1: AHSS

The Option 1 design replaces the stamped steel radiator support elements with AHSS. Mass and cost summary for AHSS radiator support assembly is shown in Figure 142. The combined mass of the AHSS radiator support 17.14 kg per vehicle. This is a mass saving of 2.84 kg (14%) compared with the baseline mass of 19.98 kg. The incremental cost to manufacture the radiator support in AHSS is $9.68 per vehicle, for a cost premium of $3.40 per kg mass saving. Manufacturing of the Option 1 radiator support can be accomplished using the same production presses and fabrication sequences as the baseline parts.

	Component	2014 Silverado Mass (kg)	Radiator Support Structure				
			Mass Reduction			Cost Increase	
			%	LWT Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Option 1	AHSS	19.98	14.2%	17.14	2.84	9.68	3.40
	Stamping	18.96	15.0%	16.12	2.84	9.68	3.40
	Misc. Mountings	1.02	0.0%	1.02	0.00	0.00	0.00

Figure 142: Radiator Support Option 1(AHSS) – Mass and Cost Summary

7.2.3.4 Option 2: Aluminum Stampings

The Option 2 radiator support construction replaces the steel with aluminum. Mass and cost summary for aluminum radiator support assembly is shown in Figure 143. The mass of the Option 2 design is 14.29 kg, a mass saving of 5.69 kg per vehicle (28.5%) over the baseline construction. The incremental cost increase to produce the Option 2 radiator support is $63.67 per vehicle, which represents a cost increase premium of $11.19 per kg mass reduction.

	Component	2014 Silverado Mass (kg)	Radiator Support Structure				
			Mass Reduction			Cost Increase	
			%	LWT Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Option 2	Aluminum	19.98	28.5%	14.29	5.69	63.67	11.19
	Stampings and Extrusions	18.96	30.0%	13.27	5.69	63.67	11.19
	Misc. Mountings	1.02	0.0%	1.02	0.00	0.00	0.00

Figure 143: Radiator Support Option 2 (Aluminum) – Mass and Cost Summary

7.2.3.5 Option 3: Aluminum + Magnesium

The Option 3 design uses aluminum for the upper and lower support structure and magnesium casting for the main support, as shown in Figure 144. The one-piece magnesium casting takes the place of several steel stampings in the baseline design, providing a reduction in complexity as well as material density. The aluminum upper and lower supports, brackets and reinforcements are a combination of stampings, extrusions and hydroformed parts. The total mass of the Option 3 radiator support structure is 13.34 kg, a savings of 6.64 kg compared with the baseline, at an incremental cost increase of $56.68, which represents a cost increase premium of $8.54 per kg mass reduction as shown in Figure 145.

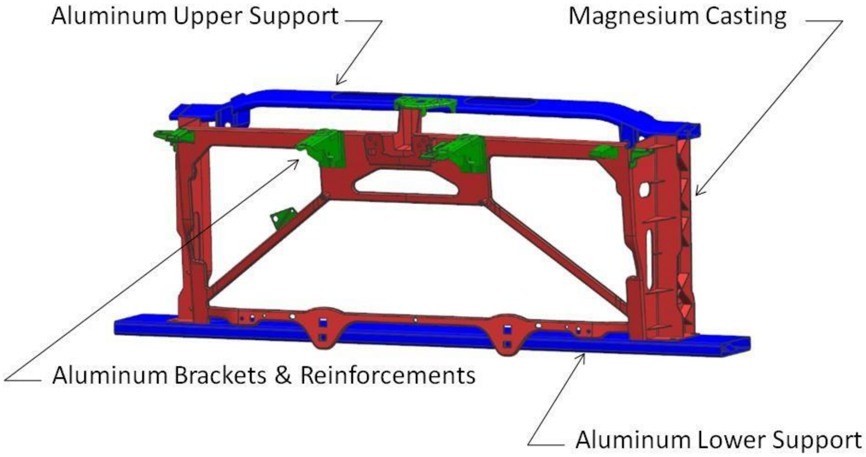


Figure 144: Option 3 Radiator Support Structure

	Material	2014 Silverado Mass (kg)	Radiator Support Structure				
			Mass Reduction			Cost Increase	
			%	LWT Mass (kg)	Mass Saving (kg)	Incre-mental ($)	Cost Increase Premium ($/kg)
Option 3	Magnesium and Alum	19.98	33.2%	13.34	6.64	56.68	8.54
	Magnesium Casting	9.48	40.0%	5.69	3.79	24.85	6.55
	Aluminum Members	9.48	30.0%	6.64	2.84	31.83	11.19
	Misc Mountings	1.02	0.0%	1.02	0.00	0.00	0.00

Figure 145: Radiator Support Option 3 (Mag and Alum) – Mass and Cost Summary

7.2.3.6 Option Selection

Figure 146 summarizes the masses and costs of the radiator support design options. Option 1 has the lowest cost, but also the lowest mass savings at only 2.84 kg per vehicle. Concept 3 uses aluminum for the upper and lower supports, brackets and reinforcements, which reduces the problems, associated with attaching the magnesium casting to the front-end body structure. For the LWT program, Option 3 was chosen. This design offers the benefits of replacing multiple parts with one magnesium casting, provides a simple attachment scheme through the aluminum supporting structure and reduces vehicle mass by an estimated 6.64 kg at a cost of $56.68 per vehicle.

	Material	2014 Silverado Mass (kg)	Radiator Support Structure				
			Mass Reduction			Cost Increase	
			%	LWT Mass (kg)	Mass Saving (kg)	Incre-mental ($)	Cost Increase Premium ($/kg)
1	AHSS	19.98	14.2%	17.14	2.84	9.68	3.40
2	Aluminum	19.98	28.5%	14.29	5.69	63.67	11.19
3	Magnesium and Alum	19.98	33.2%	13.34	6.64	56.68	8.54

Figure 146: Mass and Cost Summary of Radiator Support Design Options

7.2.4 Cab Assembly Final Optimized Design

The chosen design options previously discussed for the cab, FESM and radiator support are summarized in Figure 147. These mass saving and incremental costs were estimated using EDAG team engineering experience and were used to identify the starting point for detailed design and optimization for the LWT.

	CAB Structure Material Options	2014 Silverado Mass (kg)	CAB Assembly – LWT Estimated Mass and Incremental Cost				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
	Cab Assembly	295.27	39.3%	179.24	116.03	748.23	6.45
CAB	Aluminum	242.52	38.4%	149.51	93.01	625.33	6.72
FESM	Aluminum	32.77	50.0%	16.39	16.39	66.22	4.04
Rad Support	Magnesium + Alum	19.98	33.2%	13.34	6.64	56.68	8.54

Figure 147: Cab Assembly Mass and Cost Summary Estimate

The final optimized cab assembly incorporated the chosen design options previously discussed for the cab, FESM and radiator support, but also took advantage of additional design changes to make the structure lighter, stronger and easier to manufacture and assemble. The structure supporting the fenders and radiator support were integrated into the cab structure rather than being part of the fender assemblies, as shown in Figure 148. This reduced the complexity of the supporting structure and allowed the fender design to be a simple 3-piece bolt on construction. The baseline radiator-support structure was redesigned to magnesium casting shown in red in Figure 148.

Some of the baseline FESM and radiator-support structure elements are incorporated into the LWT cab structure. While the cost of the fenders and radiator support were reduced in the LWT that of the cab structure was increased. The mass of the final redesigned LWT cab assembly 169.6 kg, as can be seen in Figure 149 compares very well with the original estimate of 179.24 kg as shown in Figure 147.

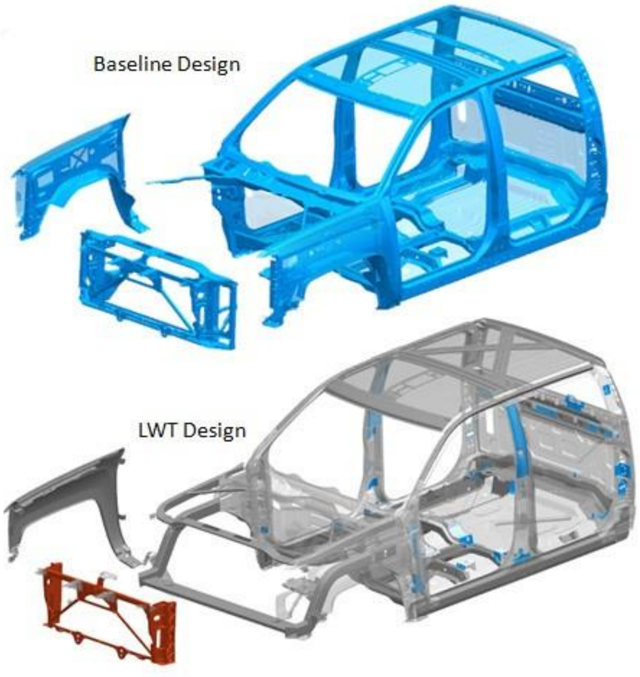


Figure 148: Baseline and LWT Cab Assembly Structure Design

The mass of the final redesigned LWT cab assembly is 169.61 kg, represents a mass savings of 125.66 kg (42.6%) compared with the baseline cab assembly. These savings were partly due to replacing steel with lower density aluminum and magnesium, but also was a result of an optimized design. The LWT cab assembly results in an overall incremental cost increase $726 for the cab assembly, or $5.78 per kg of mass saved.

	CAB Structure Material Options	2014 Silverado Mass (kg)	CAB Assembly – LWT Design Solution				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
	Cab Assembly	295.27	42.6%	169.61	125.66	726.01	5.78
CAB	Aluminum and Steel Reinforcements	242.52	37.5%	151.51	91.01	830.02	9.12
FESM	Aluminum	32.77	68.1%	10.44	22.33	-74.42	-3.33
Radiator Support	Magnesium and	19.98	61.6%	7.66	12.32	-29.59	-2.40

Figure 149: Final LWT Cab Assembly Mass and Cost Summary

7.3 Pickup Box

7.3.1 Baseline

The baseline 2014 Chevrolet Silverado pickup box is shown in Figure 150 and Figure 151. The pickup box front panel and sides are made of stamped steel inner panels spot-welded to stamped steel outer panels. The floor structure is made of a roll-formed panel spot-welded to roll-formed and stamped cross members. The four sub-assemblies are spot-welded together to make up the pickup box assembly. The entire pickup box assembly weighs 109.90 kg

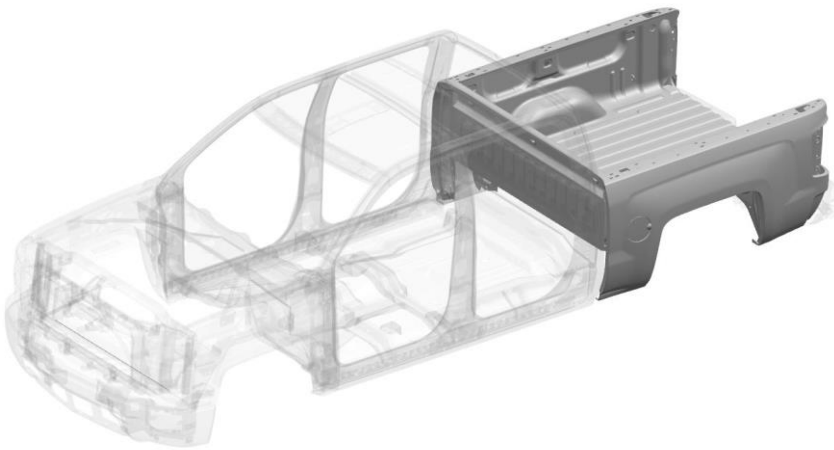
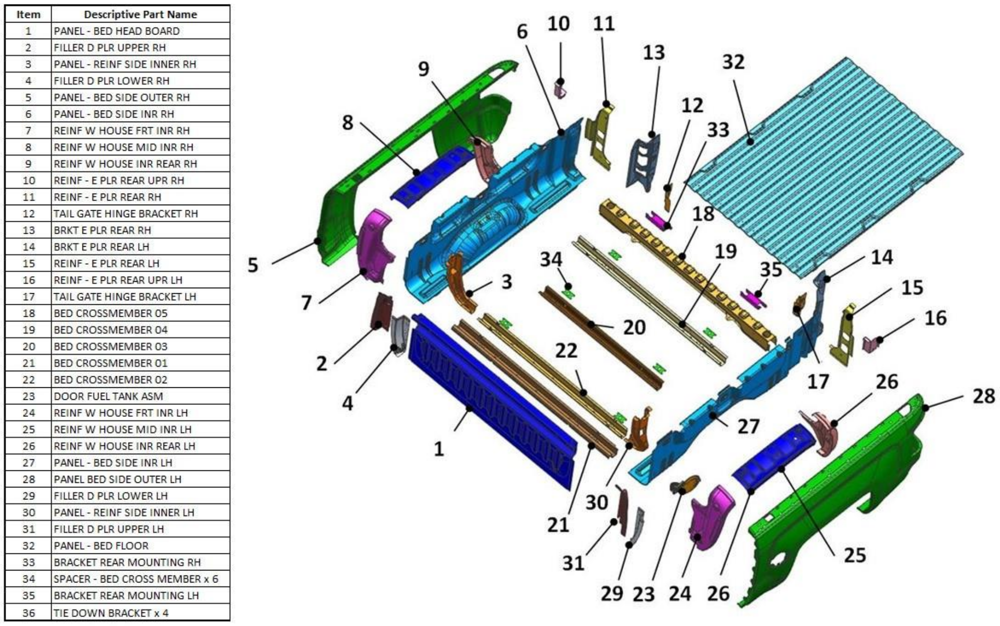


Figure 150: 2014 Chevrolet Silverado Pickup Box



Item	Descriptive Part Name
1	PANEL - BED HEAD BOARD
2	FILLER D PLR UPPER RH
3	PANEL - REINF SIDE INNER RH
4	FILLER D PLR LOWER RH
5	PANEL - BED SIDE OUTER RH
6	PANEL - BED SIDE INR RH
7	REINF W HOUSE FRT INR RH
8	REINF W HOUSE MID INR RH
9	REINF W HOUSE INR REAR RH
10	REINF - E PLR REAR UPR RH
11	REINF - E PLR REAR RH
12	TAIL GATE HINGE BRACKET RH
13	BRKT E PLR REAR RH
14	BRKT E PLR REAR LH
15	REINF - E PLR REAR LH
16	REINF - E PLR REAR UPR LH
17	TAIL GATE HINGE BRACKET LH
18	BED CROSSMEMBER 05
19	BED CROSSMEMBER 04
20	BED CROSSMEMBER 03
21	BED CROSSMEMBER 01
22	BED CROSSMEMBER 02
23	DOOR FUEL TANK ASM
24	REINF W HOUSE FRT INR LH
25	REINF W HOUSE MID INR LH
26	REINF W HOUSE INR REAR LH
27	PANEL - BED SIDE INR LH
28	PANEL BED SIDE OUTER LH
29	FILLER D PLR LOWER LH
30	PANEL - REINF SIDE INNER LH
31	FILLER D PLR UPPER LH
32	PANEL - BED FLOOR
33	BRACKET REAR MOUNTING RH
34	SPACER - BED CROSS MEMBER x 6
35	BRACKET REAR MOUNTING LH
36	TIE DOWN BRACKET x 4

Figure 151: Baseline Pickup Box Exploded View

7.3.2 Pickup Box Technology Options

Four design options were considered for mass saving potential of the pickup box assembly. The rationale behind a proposed LWT concept was to best exemplify mass savings while taking into account manufacturing and cost considerations. The selected design was further developed through more advanced design and analysis efforts, verifying its feasibility and demonstrating its ability to match or exceed all the safety and performance requirements of the baseline pickup box.

7.3.3 Option 1: AHSS

The Option 1 pickup box design maintains the basic geometry of the original design, but substitutes AHSS for the baseline steel, allowing the metal gauges to be reduced. This material substitution results in a pickup box mass of 87.92 kg for a mass savings of 21.98 kg (20%) over the baseline 109.90 kg. This result compares well with a 2014 study by ArcelorMittal[102] in which a similar pickup box was redesigned using AHSS and laser welded blanks, achieving a mass savings of 22 percent. The incremental cost impact to produce the Option 1 pickup box is an increase of $44.26, or $2.01 per kg.

7.3.4 Option 2: Aluminum

The Option 2 pickup box design replaces the baseline steel with aluminum. This reduces the mass to 65.94 kg, a mass saving of 43.96 kg (40%) compared with the baseline pickup box. The incremental cost increase for the Option 2 pickup box is $295.56, a cost increase premium of

$6.72 per kg. Manufacturing of all aluminum pickup box can also be performed with the same presses and processing sequences as the baseline steel design, though joining will require adhesive bonding and self-piercing rivets.

7.3.5 Option 3: Aluminum + AHSS

The Option 3 pickup box design uses aluminum for the inner and outer side panels and AHSS for the bed head board and floor where higher impact resistance is required as shown in Figure 152. All other parts are also constructed of AHSS. This result in a pickup box mass of 74.79 kg, a reduction of 35.11 kg (32%) compared with the baseline. A breakdown of the mass and cost for each component of this assembly is shown in Figure 153. The incremental cost of this concept is $115.06, or $3.28 per kg saved. Manufacturing the Option 3 pickup box can also be performed with the same presses and processing sequences as the baseline steel design, though joining of dissimilar metals will require adhesive bonding and self-piercing rivets.

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[102] "Mass Reduction for Steel Pickup Truck Structures," Tom Wormald, Nicolas Schneider, and Elie Gibeau of ArcelorMittal, presented at International Automotive Body Congress, Dearborn, 2014

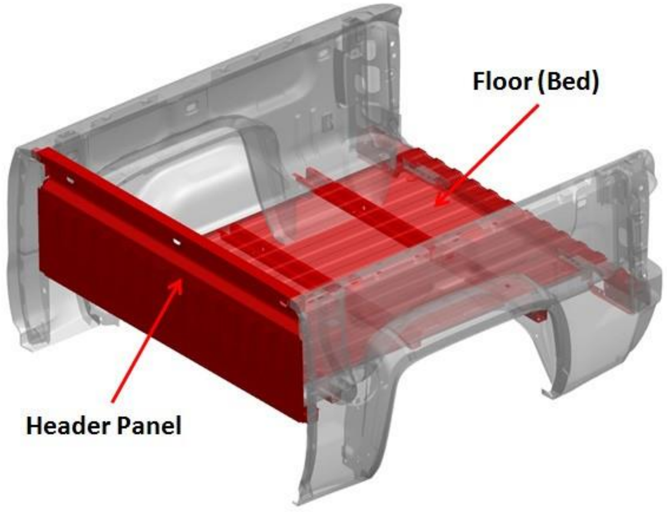

Figure 152: Pickup Box Option 3: Aluminum + AHSS (Red)

	Material	2014 Silverado Mass (kg)	Pickup Box				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 3	Aluminum + AHSS	109.90	31.9%	74.79	35.11	115.06	3.28
	Outer Panel Wheelhouse (Alum)	21.72	50.0%	10.86	10.86	43.89	4.04
	Inner Panel Wheelhouse (Alum)	22.04	50.0%	11.02	11.02	44.54	4.04
	Floor Panel (AHSS)	17.50	20.0%	14.00	3.50	7.05	2.01
	Header Pnl (AHSS)	9.05	20.0%	7.24	1.81	3.64	2.01
	Other Parts (AHSS)	39.59	20.0%	31.67	7.92	15.94	2.01

Figure 153: Pickup Box Option 3 (Aluminum + AHSS) – Mass and Cost Summary

7.3.6 Option 4: Carbon Fiber Reinforced Polymer

The Option 4 pickup box made from carbon fiber composites with aluminum inserts for mountings. The mass of the Option 4 pickup box is estimated to be 57.95 kg, for a mass savings of 51.95 kg (47%) over the baseline steel pickup box. As was discussed in Section 7.2.1.6, the production costs and manufacturing cycle times for fabricating composite structures are very high. The incremental cost increase for the Option 4 pickup box design is estimated to be $1,101.44, representing a cost increase premium of $21.20 per kg.

Manufacturing the Option 4 pickup box would require entirely different equipment, processes and facilities than those used on the baseline vehicle, as well as a revised fastening strategy. In addition, technologies are still being developed to understand crash behavior and repair methods for composite automotive components.

7.3.7 Option Selection

A summary of the pickup box design options can be seen in Figure 154. The Option 4 composite design offers the greatest mass saving potential of all the designs considered at 51.95 kg, but it also has an extremely high cost increase at $1,101.44 per vehicle. Fiber reinforced composite parts have been discussed previously in this report. While they do offer significant mass savings, the team does not believe the technology is mature enough yet for high-volume production applications such as Chevrolet Silverado, nor will it be mature enough in the 2020-2030 period.

The AHSS design (Option 1) has the lowest incremental cost premium at $2.01 per kg, but offers the lowest mass savings at 21.98 kg. Option 3, in which the side inner and outer panels are aluminum while the remaining parts are AHSS, offers less mass savings than the aluminum intensive option, but at a much lower cost increase. The pickup box, like the cab structure, represents a significant percentage of the total vehicle mass and, therefore, a significant percentage of the potential vehicle mass savings. The additional mass savings provided by Option 2 aluminum justify the higher incremental cost. For these reasons, the aluminum intensive design (Option 2) was chosen for the LWT.

			Pickup Box				
			Mass Reduction			Cost Increase	
	Material	2014 Silverado Mass (kg)	%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 1	AHSS	109.90	20.0%	87.92	21.98	44.26	2.01
Option 2	Aluminum	109.90	40.0%	65.94	43.96	295.56	6.72
Option 3	Aluminum + AHSS	109.90	31.9%	74.79	35.11	115.06	3.28
Option 4	CFRP	109.90	47.3%	57.95	51.95	1101.44	21.20

Figure 154: Summary of Pickup Box Design Options

The final, optimized LWT pickup box design weighs 66.10 kg. This represents a mass savings of 43.80 kg (39.9%) compared with the baseline Silverado. The incremental cost increase is $297.11, or $6.78 per kg of mass saved. These mass and cost numbers for the mass and cost are comparable to the original estimates for the Option 2 as shown in Figure 154.

7.4 Closures

The closures on a pickup truck are defined as the doors, hood and tailgate (see Figure 155). The structural mass of these assemblies, as shown in Figure 156, includes only the primary load carrying components such as the inner and outer panels, reinforcements, brackets, support beams, hinges, regulator guides and window frames. The structural mass does not include glass, mirrors, electrical components, mechanisms, locks, latches, linkages, seals, trim and fasteners, which are accounted for elsewhere in this report. The structural mass of the closures is 121.75 kg, making up 5 percent of the total vehicle mass (2,432 kg).

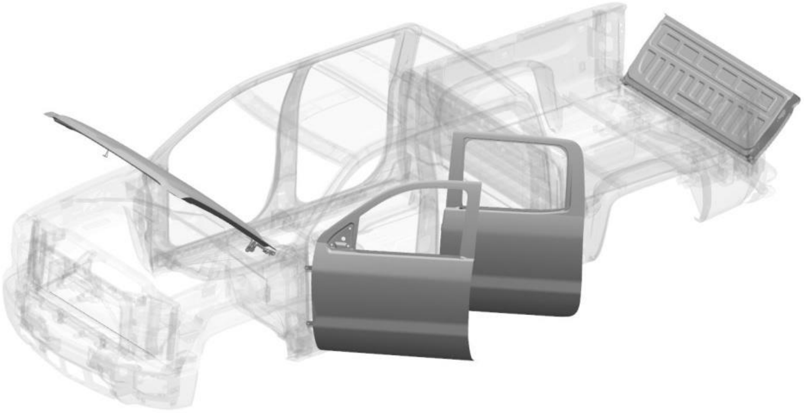

Figure 155: 2014 Chevrolet Silverado Closures

Component	Structural Mass (kg)	Construction
Front Doors (combined LH & RH)	45.46	Steel Stamping Outer & Laser Welded Blank Inner
Rear Doors (combined LH & RH)	42.44	Steel Stamping Outer & Laser Welded Blank Inner
Hood	11.42	Aluminum Stamping Outer & Inner
Tailgate	22.43	Steel Stamping Outer & Laser Welded Inner
Total	**121.75**	

Figure 156: Summary of Baseline Closures Mass

The use of AHSS theoretically provides the potential for approximately 25 percent mass savings in vehicle structures. However, this may not be attainable for closures because the benefit offered by AHSS is its increased tensile strength, not stiffness (the modulus of elasticity is unchanged from that of standard steel). While the design of cab structures and frames are mostly dependent upon the tensile strength of the material, closures are more dependent upon the stiffness. One closure application that does rely upon tensile strength, however, is the side door intrusion beam. Compliance with the FMVSS No. 214 "Side Impact Protection" side door intrusion test requires a very high-strength beam member built into the door structure. For this component, AHSS may provide a cost effective solution with significant mass savings.

The closures are smaller and less complex assemblies than the cab structure, and there are more choices of mature technologies currently available that can offer significant mass reduction opportunities. For example, stamped aluminum doors are used on the Audi A6 and A8, the BMW 5 series and the Jaguar XJ8. The use of magnesium castings for rear closures (e.g., the 2010 Lincoln MKT liftgate) and door inner panels could lead to mass savings up to 50 percent on some structural components of these assemblies. These options will be discussed below.

Carbon fiber hoods are used on some premium, low volume vehicles such as the Corvette ZR1, Chrysler Viper, and Lexus LFA. Carbon fiber construction has a tremendous mass saving advantage over steel structures. Carbon fiber is stronger per unit mass than steel, and its unique construction method provides much greater flexibility in part designs, allowing for the manufacture of intricate parts that are both stronger and lighter than their steel counterparts. However, fabrication of composite parts is labor intensive with high production costs, long cycle times and complex integration of manufacturing processes and materials. Currently, resin transfer molding and vacuum injection are the principal processes used for automotive applications of composite materials. In these processes the reinforcing materials (carbon fibers, fiberglass, etc.) can be inserted into the mold in sheets and have the thermoset or thermoplastic resin injected into the closed mold to be cured. Alternatively, chopped fibers can be fed into the mold along with the resin. The complete manufacturing process from basic components to finished part is measured in minutes or hours for composites, as opposed to seconds for stamped metal designs. For that reason, this method is still generally used for low volume, high-priced vehicles rather than high-volume, medium priced programs. The price of carbon fiber remains high compared with other automotive materials (nearly six times that of steel and more than four times that of aluminum), though it is expected to drop at least 45 percent by 2030.[103] Other factors to consider are that energy consumption of composite processing is higher than that of stamping presses, and the End of Life recycling of composite parts is still a great challenge with only limited facilities available, particularly for thermoset parts. Until this technology matures to the point where raw material prices and manufacturing cycle times are reduced, composite material is not a good candidate for high-volume production vehicles such as the Chevrolet Silverado within the 2020-2030 period.

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[103] Heuss, R., Müller, N., van Sintern, W., Starke, A., Tschiesner, A., "Lightweight, Heavy Impact: How Carbon Fiber and Other Lightweight Materials Will Develop Across Industries and Specifically in Automotive," February 2012.

7.4.1 Front Doors

7.4.1.1 Baseline

The front doors of the baseline 2014 Chevrolet Silverado are constructed of cold rolled sheet steel of various bake-hardenable (BH) and HSS grades. The front door frame is shown in Figure 157. The major components of the complete door assembly include the frame (inner and outer panels, intrusion beam, regulator guides and various reinforcements), glass, mirror, lock, latch, handles, hinges, electrical components (switches, speakers, wiring, etc.), trim panels, seals, and fasteners. Many of these are shown in Figure 158. The combined mass of both complete front door assemblies is 91.93 kg, as shown in Figure 159.

Figure 157: Baseline Front Door Frame

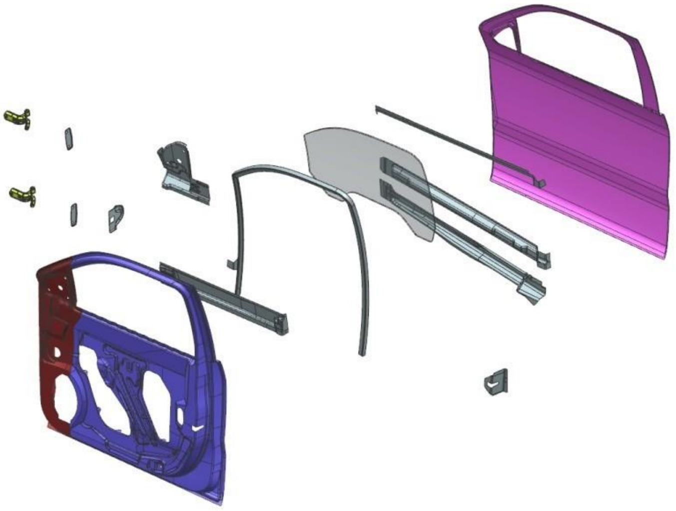

Figure 158: Baseline Front Door Exploded View

Baseline Door Component	Mass (kg)
Frame	45.46
Glass	10.05
Glass Regulator	2.34
Sealing System	6.51
Wiring Harness	1.32
Speakers	1.41
Hinges and Latch	6.18
Outside Mirrors	4.31
Trim	10.60
Fasteners and Miscellaneous	3.75
Total	**91.93**

Figure 159: Baseline Front Door Mass – Combined Driver and Passenger

The combined mass of the LH and RH door frame components is 45.46 kg. The laser welded inner panel carries the glass actuation hardware and the interior trim. The outer panel has a class A' surface that must be resistant to surface dents. The two panels are joined together through a process known as "roller hemming' without the use of any welding that would be visible from the outside of the vehicle.

7.4.1.2 Front Door Technology Options

Four design options were considered for mass saving potential of the front doors. The chosen design was further developed using more advanced design and analysis efforts, verifying its feasibility and demonstrating its ability to match or exceed all the safety and performance requirements of the baseline door.

During the preliminary concept phase, the door frame structure (inner and outer panels, reinforcements, brackets, support beams, regulator guides and window frames) was the principal focus, as it would primarily drive the selection of the option to be selected for the LWT. Other components of the door assembly such as the glass, seals, electrical components and trim offer mass reduction potential and will be discussed in other sections of this report. The savings for these components were similar for all the options and did not affect the selection of the LWT front door option. The cost and time required to redesign and validate some components, such as the door lock/latch/striker system and the hinges, exceed the mass reduction benefits expected. Therefore, they were carried over from the baseline to the LWT.

The materials and manufacturing processes that were investigated for mass and cost of the doorframe components are shown in Figure 160.

Technology Options	Benefits	Risks/Trade-offs
Option 1: Advanced High Strength Steel (AHSS)	Weight savings approximately 25% Existing production stamping presses can be used	Safe choice Conventional technology
Option 2: AHSS Beam + Aluminum for All Other Components	Weight savings 35% to 45% Existing production stamping presses can be used	Higher material costs Limitations in manufacturing & assembly
Option 3: Aluminum Outer Panel + AHSS for All Other Components	Weight savings 30% to 40% Existing production stamping presses can be used	Higher material costs Limitations in manufacturing & assembly
Option 4: Magnesium Casting for Inner Panel + Aluminum Stamping for Outer Panel + AHSS Beam	Weight savings 40% to 50% Modularity of parts Outer panel can be stamped using existing stamping presses	High material cost Inner panel requires over 2,500 Ton capacity High-Pressure Die Casting Press Limitations in manufacturing and assembly Further development needed for high-volume production

Figure 160: Front Door Frame Construction Options

7.4.1.3 Option 1: AHSS

The Option 1 front door frame design is essentially the same as that of the baseline door except for the material used. The primary structure consists of a two-piece stamped inner door panel and a laser welded blank that is roller hemmed to a stamped outer door panel. The doorframe, including intrusion beam, brackets and reinforcements, is constructed entirely of AHSS. The use of AHSS allows the door panel thicknesses to be reduced from those of the steel baseline door, resulting in the mass reduction. Due to the decreased thickness, additional sound insulation is added to compensate. For this preliminary estimate, it is assumed that 0.4 kg of additional sound insulation will be adequate. As shown in

Figure 161, the estimated mass of the AHSS front door frames (both LH and RH) is 34.70 kg, a 10.76 kg reduction per vehicle from the baseline mass of 45.46 kg (24% decrease). The incremental cost increase for the Option 1 front door is $15.48 per vehicle. This is equivalent to a cost increase premium of $1.44 per kg mass saving.

	Material	2014 Silverado Mass (kg)	Front Door Frames (per vehicle)				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 1	AHSS	45.46	23.7%	34.70	10.76	15.48	1.44
	AHSS Stampings	41.42	25.0%	31.07	10.36	12.22	1.18
	Intrusion Beam (AHSS)	4.04	20.0%	3.23	0.81	1.63	2.01
	Additional sound insulation			0.40	-0.40	1.64	

Figure 161: Front Door Frame Option 1 (AHSS) – Mass and Cost Summary

Manufacturing processes for this option would be consistent with those for the baseline door because existing baseline door production presses, roller hemming equipment and construction sequences can be used to produce the Option 1 door components.

7.4.1.4 Option 2: Aluminum Stampings With AHSS Beam

The Option 2 front door design uses aluminum stampings instead of the baseline steel stampings. The stamped inner door structure, including the inner beltline and hinge reinforcement panels, the outer panel, and the outer beltline reinforcement stampings are all aluminum. The intrusion beam is AHSS to provide adequate side impact protection. As with Option 1, additional sound insulation is added to compensate for the thickness reduction in the door panels. The result, shown in Figure 162 is a combined (LH and RH) mass of 28.58 kg for the door frames, yielding a mass saving of 16.88 kg per vehicle over the 45.46 kg baseline (a 37% decrease). The incremental cost increase over the baseline steel door is $115.08 per vehicle, representing a $6.82 per kg mass saved.

	Material	2014 Silverado Mass (kg)	Front Door Frames (per vehicle)				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 2	Aluminum with AHSS Beam	45.46	37.1%	28.58	16.88	115.08	6.82
	Aluminum Stampings	41.42	40.0%	24.85	16.57	111.40	6.72
	Intrusion Beam (AHSS)	4.04	20.0%	3.23	0.81	1.63	2.01
	additional sound insulation			0.5	-0.5	2.05	

Figure 162: Front Door Frame Option 2 (Alum + AHSS Beam) – Mass and Cost Summary

Manufacturing of the Option 2 design could be accomplished using the same stamping presses as the baseline door. As with the baseline and Option1 designs, the inner and outer door panels would be joined using existing roller hemming equipment.

7.4.1.5 Option 3: Aluminum Outer Panel + AHSS

The Option 3 front door design features a stamped aluminum outer panel, all other door frame parts constructed of AHSS, and sound insulation added. This door design weighs 29.93 kg per vehicle, 15.53 kg less than the baseline Silverado door (34%). The incremental cost increase over the baseline steel door is $35.00 per vehicle ($2.25 per kg mass saved). The mass and cost summary is shown in Figure 163.

	Material	2014 Silverado Mass (kg)	Front Door Frames (per vehicle)				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 3	Aluminum + AHSS	45.46	34.2%	29.93	15.53	35.00	2.25
	Other Parts (AHSS)	27.45	30.0%	19.21	8.23	5.13	0.62
	Intrusion Beam (AHSS)	4.04	20.0%	3.23	0.81	1.63	2.01
	OuterPanel (Alum)	13.97	50.0%	6.99	6.99	28.24	
	additional sound insulation			0.50	-0.50	2.05	

Figure 163: Front Door Frame Option 3 (Aluminum + AHSS) – Mass and Cost Summary

As with the previous designs, manufacturing of the Option 3 door could be accomplished using the same stamping presses and hemming processes as the baseline door.

7.4.1.6 Option 4: Magnesium + Aluminum + AHSS

The Option 4 front door design features an inner door structure consolidating several parts, such as brackets and reinforcement elements, together into a one-piece magnesium casting. The outer door panel and beltline reinforcement are stamped aluminum, while the hinges, intrusion beam and door lock striker are AHSS. 0.50 kg of sound insulation is added. The total estimated mass of the Option 4 doors is 25.81 kg per vehicle, 19.65 kg (43%) less than the 45.46 kg baseline doors, as shown in Figure 164.

	Material	2014 Silverado Mass (kg)	Front Door Frames (per vehicle)				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 4	Alum + Mag Solution	45.46	43.2%	25.81	19.65	94.84	4.83
	Inner Casting (Mag)	27.45	45.0%	15.10	12.35	62.94	5.09
	Outer Stamping (Alum)	13.97	50.0%	6.99	6.99	28.24	4.04
	Intrusion Beam (AHSS)	4.04	20.0%	3.23	0.81	1.63	2.01
	additional sound insulation			0.50	-0.50	2.05	

Figure 164: Front Door Frame Option 4 (Aluminum + Magnesium) – Mass and Cost Summary

The magnesium casting requires the use of a high tonnage (approximately 2,500 tons), high-pressure die casting press. Currently the manufacturing base capacity of high-pressure die casting presses in North America is not sufficient to support such high-volume production. Overall, the incremental cost increase of the Option 4 front door is $94.84 per vehicle, or $4.84 per kg of mass saved.

Like the baseline design and previous options, the Option 4 inner and outer door panels are joined with the existing roller hemming equipment. The assembly process is greatly simplified due to the one-piece cast magnesium inner door structure that combines several inner door elements into a single module. This is the major contributing factor making this design the lightest of the four options. The baseline stamping presses can be used for the aluminum outer panel, but new tooling, equipment and processes are required for the magnesium casting.

7.4.1.7 Option Selection

The mass and cost results of the front door design options are summarized in Figure 165. The Option 3 design (stamped aluminum outer panel, everything else AHSS) was selected for the LWT front door design. While the incremental cost of Option 1 (AHSS) is much lower ($15.48 vs. $25.65 per vehicle), the additional mass savings of Option 3 make this the more cost effective design.

	Material	2014 Silverado Mass (kg)	Front Door Frames (per vehicle)				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 1	AHSS	45.46	23.7%	34.70	10.76	15.48	1.44
Option 2	Aluminum with AHSS Beam	45.46	37.1%	28.58	16.88	115.08	6.82
Option 3	Aluminum + AHSS	45.46	34.2%	29.93	15.53	35.00	2.25
Option 4	Alum + Mag Solution	45.46	43.2%	25.81	19.65	94.84	4.83

Figure 165: Summary of Front Door Frame Design Options

The mass of the LWT front door frames final optimized design is 31.43 kg, 14.03 kg (30.9%) less than the baseline Silverado front door frames. This mass savings comes at an incremental cost increase of $17.62, or $1.26 per kg of mass saved. These mass and cost numbers for the final optimized design are comparable to the original estimates for the Option 3 as shown in Figure 165. The results of the CAE analysis for the recommended design are shown in Section 9.3.10 of this report.

7.4.2 Rear Doors

7.4.2.1 Baseline

The rear doors of the baseline 2014 Chevrolet Silverado (shown in Figure 166) are, like the front doors, constructed of bake-hardenable and HSS, cold rolled sheet steel. The major components of the complete rear door assembly are the frame (including inner and outer panels, intrusion beam, regulator guides, brackets and reinforcements), glass, lock, latch, handles, hinges, electrical components (switches, wiring, etc.), trim panel, seals, and fasteners. Some of these components are shown in the Figure 167 exploded view. The combined mass of both complete rear doors is 78.50 kg (refer to Figure 168).

Figure 166: Baseline Rear Door

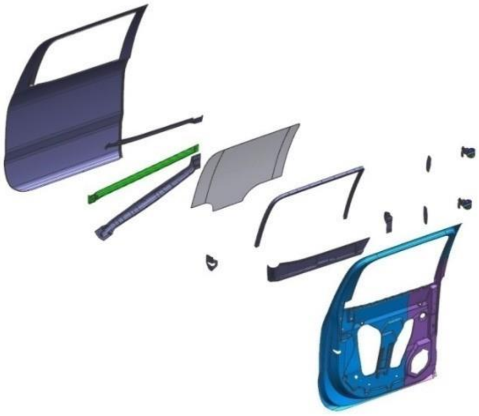

Figure 167: Baseline Rear Door Exploded View

Baseline Rear Door Component	Mass (kg)
Frames	42.44
Glass	8.86
Glass Regulator s	2.34
Sealing System	3.95
Wiring Harnesses	1.00
Speakers	1.20
Hinges and Latches	5.33
Trim	9.25
Fasteners and Miscellaneous	4.13
Total	**78.50**

Figure 168: Baseline Rear Door Mass - Combined Driver and Passenger

The construction of the rear door frame is much as was described for the front door, with the laser welded inner panel joined to the outer panel by roller hemming. The structural components of the rear door frame are all constructed of roll-formed or stamped steel.

7.4.2.2 Rear Door Technology Options

Four design options were considered for mass saving potential of the rear doors. The rationale for selecting one of them for the LWT was the same as it was for the front doors, which is to best exemplify mass savings while taking into account manufacturing and cost considerations. The process that was used to develop the rear doors is exactly the same as that of the front doors. The option selection was followed by a detailed design and analysis phase optimizing the structure and verifying that it meets or exceeds the safety and performance requirements of the baseline doors.

As was discussed in the front door section, the mass reduction efforts in this section of the report were focused on the door frame structure, as this drives the option selection and also offers the greatest mass reduction potential. Other components, such as the glass, seals, electrical components and trim will be evaluated in other sections of this report and incorporated where feasible. Again, the door hinges and lock/latch/striker system were carried over from the baseline to the LWT. The materials and manufacturing processes investigated for mass and cost of the rear door frame components were the same as those for the front (refer to Figure 160). Modularity of design and assembly were also investigated to achieve the most mass efficient solutions.

7.4.2.3 Option 1: AHSS Rear Door

The Option 1 rear door construction follows the same approach as that of the front door, in which AHSS stampings provide direct replacements for the baseline stampings. The door frame, including intrusion beam, brackets and reinforcements, is constructed entirely of AHSS, allowing steel gauges and mass to be reduced. Sound insulation is added to compensate for the thinner gauges. The hinges and door lock striker are carried over from the baseline. The combined mass of the LH and RH AHSS rear door frames is calculated to be 30.83 kg, as can be seen in Figure 169. This is a reduction of 10.07 kg per vehicle, a 24% decrease in mass compared with the baseline door frame mass of 42.44 kg. The incremental cost increase for the Option 1 rear door is $14.46 per vehicle, a cost increase premium of $1.44 per kg mass saving.

	Material	2014 Silverado Mass (kg)	Rear Door Frames (per vehicle)				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incre-mental ($)	Mass Saving Premium ($/kg)
Option 1	AHSS	42.44	23.7%	32.37	10.07	14.46	1.44
	AHSS Stampings	39.60	25.0%	29.70	9.90	11.68	1.18
	Intrusion Beam (AHSS)	2.84	20.0%	2.27	0.57	1.14	2.01
	Additional sound insulation			0.40	-0.40	1.64	

Figure 169: Rear Door Frame Option 1 (AHSS) – Mass and Cost Summary

Manufacturing of the Option 1 rear door would be consistent with the baseline door because, as with the front doors, existing baseline door production presses, roller hemming equipment and construction sequences can be used. As was mentioned previously, increases in total tooling costs associated with using the AHSS material have been incorporated into the cost increase figures used to evaluate the door frame construction options.

7.4.2.4 Option 2: Aluminum Stampings With AHSS Beam

The Option 2 rear door design uses aluminum stampings in place of the baseline mild steel for most of the door frame components. The inner door structure, inner beltline, reinforcement panels, outer panel and outer beltline reinforcement are aluminum stampings. The intrusion beam and hinge reinforcement plates are AHSS, while the hinges and door lock striker are carried over from the baseline. Additional sound insulation is provided. The result is a combined mass of 26.53 kg per vehicle for the door frames; a mass saving of 15.91 kg per vehicle from the 42.44 kg baseline (a 37.5% decrease). The incremental cost over the baseline mild steel door is $109.69 per vehicle, representing a $6.90 per kg cost increase pre. The mass and cost summary can be seen in Figure 170.

	Material	2014 Silverado Mass (kg)	Rear Door Frames (per vehicle)				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incre-mental ($)	Mass Saving Premium ($/kg)
Option 2	Aluminum with AHSS Beam	42.44	37.5%	26.53	15.91	109.69	6.90
	Aluminum Stampings	39.60	40.0%	23.76	15.84	106.50	6.72
	Intrusion Beam (AHSS)	2.84	20.0%	2.27	0.57	1.14	2.01
	additional sound insulation			0.50	-0.50	2.05	

Figure 170: Rear Door Frame Option 2 (Alum + AHSS Beam) – Mass and Cost Summary

Manufacturing of the Option 2 design can be accomplished using the same stamping presses, roller hemming equipment and fabrication sequences as the baseline door. Increased tooling maintenance costs and the need for new tooling for the inner door panel stamping have been incorporated into the cost increase premium over the baseline design.

7.4.2.5 Option 3: Aluminum Outer Panel + AHSS

The Option 3 rear door design features a stamped aluminum outer panel, all other rear door frame components constructed of AHSS, and additional sound insulation. This door design weighs 30.68 kg per vehicle, 11.76 kg less than the baseline Silverado door (27.7%). As can be seen in Figure 171. The incremental cost increase over the baseline steel door is $25.20 per vehicle ($2.14 per kg mass saved).

As with the previous designs, manufacturing of the Option 3 door could be accomplished using the same stamping presses and hemming processes as the baseline door.

	Material	2014 Silverado Mass (kg)	Rear Door Frames (per vehicle)				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium
Option 3	Aluminum + AHSS	42.44	27.7%	30.68	11.76	25.20	2.14
	Other Parts (AHSS)	32.43	25.0%	24.32	8.11	9.56	1.18
	Intrusion Beam (AHSS)	2.84	20.0%	2.27	0.57	1.14	2.01
	Outer Panel (Alum)	7.17	50.0%	3.59	3.59	14.50	4.04
	additional sound insulation			0.50	-0.50	2.05	

Figure 171: Rear Door Frame Option 3 (Aluminum + AHSS) – Mass and Cost Summary

7.4.2.6 Option 4: Magnesium + Aluminum + AHSS

The Option 4 rear door design features the magnesium casting approach described in the front door section, in which multiple parts are incorporated into the one-piece inner door module. The outer door panel and beltline reinforcement are stamped aluminum, while hinges, intrusion beam and door lock striker are AHSS. Figure 172 shows the mass and cost summary for Option 4.

	Material	2014 Silverado Mass (kg)	Rear Door Frames (per vehicle)				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 4	Alum + Mag Solution	42.44	43.0%	24.19	1825	92.03	5.04
	Inner Casting (Mag)	32.43	45.0%	17.83	14.59	74.35	5.09
	Outer Stamping (Alum)	7.17	50.0%	3.59	3.59	14.50	4.04
	Intrusion Beam (AHSS)	2.84	20.0%	2.27	0.57	1.14	2.01
	additional sound insulation			0.50	-0.50	2.05	-4.10

Figure 172: Rear Door Frame Option 4 (Alum + Magnesium) – Mass and Cost Summary

As was discussed in the front door section, the manufacturing process for the Option 4 rear door frame is simplified compared with the baseline. As a result, this option features the lowest mass of all the rear door options. The baseline stamping presses and roller hemming equipment can be used for the aluminum outer panel, but new tooling, equipment and processes are required for the magnesium casting.

7.4.2.7 Option Selection

The mass and cost results of the rear door frame design options are summarized in Figure 173. Option 3 (stamped aluminum outer panel, all other frame components AHSS) was chosen for the LWT rear door. Option 3 provides the best balance of significant mass savings and reasonable incremental cost. Options 1, 2 and 3 can all be produced using much of the same stamping sequences and equipment as the baseline design, avoiding additional capital investment. Option 4 requires new tooling, processes and increased press capability for the magnesium inner casting.

	Material	2014 Silverado Mass (kg)	Rear Door Frames (per vehicle)				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 1	AHSS	42.44	23.7%	32.37	10.07	14.46	1.44
Option 2	Aluminum with AHSS Beam	42.44	37.5%	26.53	15.91	109.69	6.90
Option 3	Aluminum + AHSS	42.44	27.7%	30.68	11.76	25.20	2.14
Option 4	Alum + Mag Solution	42.44	44.7%	23.48	18.96	87.24	4.60

Figure 173: Summary of Rear Door Frame Design Options

The final optimized design of the LWT rear doorframes weighs 30.83 kg. This is 11.61 kg (27.4%) less than the baseline. The incremental cost increase for the LWT rear door frame is $15.09, or $1.30 per kg of mass saved. These mass and cost numbers are comparable to the original estimates for the Option 3 as shown in Figure 173. The results of the CAE analysis for the recommended design are shown in Section 9.3.10 of this report.

7.4.3 Hood

7.4.3.1 Baseline

The inner and outer panels of the baseline 2014 Chevrolet Silverado hood are constructed of aluminum stampings, as are the reinforcements. The inner panel is joined to the outer panel by roller hemming. The hinges, latch and associated hardware are made of high-strength steel. The total mass of the hood assembly, shown in Figure 174, is 14.54 kg, of which 11.42 kg is the frame structure (inner and outer panels and reinforcements). An exploded view of the hood assembly can be seen in Figure 175.

Figure 174: Baseline Hood Assembly

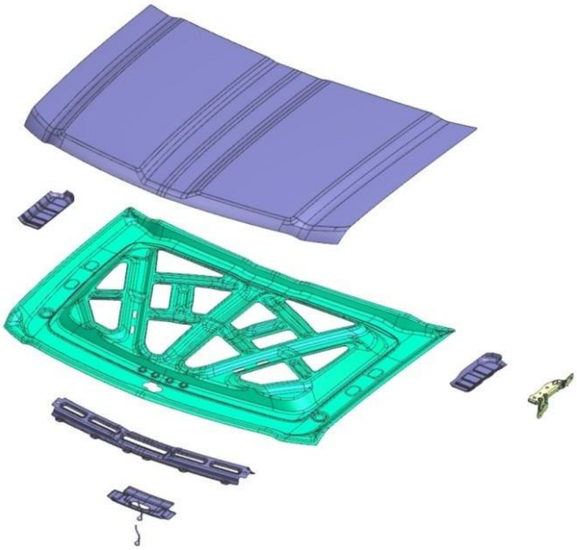

Figure 175: Baseline Hood Exploded View

7.4.3.2 Hood Technology Options

Two design options were considered for mass saving potential of the hood. The inner and outer hood panels, including reinforcements, account for 70 percent of the hood mass. They were targeted in mass reduction efforts on this assembly.

7.4.3.3 Option 1: Aluminum

The mass of the baseline aluminum hood frame is 11.42 kg. Aluminum hoods are common on several vehicles, and are already implemented on the baseline 2014 Silverado 1500 and its competitor vehicles.

7.4.3.4 Option 2: Carbon Fiber Reinforced Polymer (CFRP)

The Option 2 concept replaces the aluminum inner panel, outer panel and reinforcements with carbon fiber reinforced polymer. As with fenders, carbon fiber hoods are used on some premium, low volume vehicles such as the Corvette ZR1, Dodge Viper and Lexus LFA. The CFRP inner panel consolidates several parts into one molding, simplifying the manufacturing process and reducing mass. The hinges and latch are carried over from the baseline. The total mass of the Option 2 hood frame is estimated to be 9.14 kg, 2.28 kg less than that of the 11.42 kg baseline (20%) at an incremental cost of $303.19. This represents a mass saving premium of $132.74 per kg as shown in Figure 176.

	Material	2014 Silverado Mass (kg)	Hood Frame				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 2	CFRP	11.42	20.0%	9.14	2.28	303.19	132.74
	Inner (CFRP)	5.70	20.0%	4.56	1.14	151.20	132.74
	Outer Panel (CFRP)	5.73	20.0%	4.58	1.15	151.99	132.74

Figure 176: Hood Option 2 (CFRP) – Mass and Cost Summary

While carbon fiber hoods and fenders are used on some premium, low volume vehicles resulting in mass savings, the technology is not yet mature enough for high-volume production applications such as the Chevrolet Silverado. The team does not anticipate that it will be sufficiently mature in the 2020-2030 time frame to use on the LWT due to the long cycle times and complex integration of manufacturing processes and material cost.

7.4.4 Tailgate

7.4.4.1 Baseline

Like the doors, tailgate of the 2014 Chevrolet Silverado is composed of a laser welded inner panel roller hemmed to the stamped outer panel. A removable access panel is bolted to the inner panel. The total mass of the tailgate frame is 22.43 kg. The tailgate structure can be seen in Figure 177 while an exploded view is shown in Figure 178.

Figure 177: Baseline Tailgate Assembly

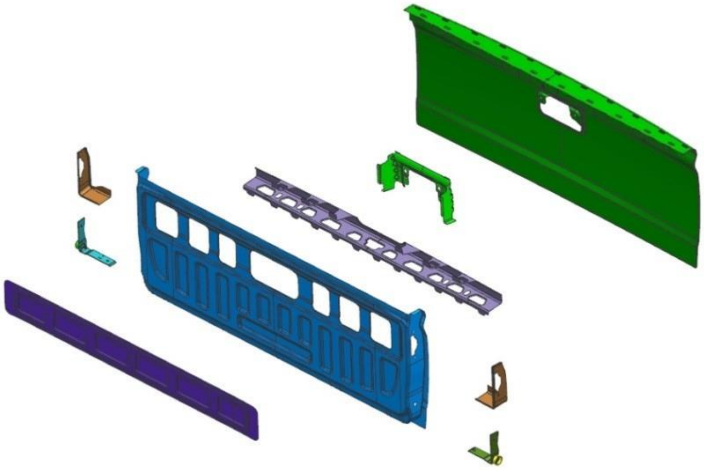

Figure 178: Baseline Tailgate Exploded View

7.4.4.2 Tailgate Technology Options

Two design options were considered for mass saving potential of the tailgate. The option chosen for the LWT was that which best exemplified mass saving while taking into account manufacturing and cost considerations. That concept was further developed through more advanced design and analysis efforts, resulting in a new, completely developed tailgate. The cost of developing and validating lower weight replacement hinges, latch/lock and striker assemblies was not justified by the combined potential mass savings of less than 1 kg. Therefore, those components are being carried over to the LWT from the baseline.

7.4.4.3 Option 1: AHSS

The Option 1 tailgate design replaces the baseline steel stampings with AHSS, allowing for reduced material thicknesses resulting in mass savings. The tailgate hinges, latch/lock mechanism and striker, constructed of steel, are carried over from the baseline. The mass of the AHSS tailgate frame is 17.94 kg, which is a 4.49 kg mass saving (20%) over the conventional mild steel baseline design of 22.43 kg (refer to Figure 179). The incremental cost increase for the Option 1 design is $9.03, a cost increase premium of $2.01 per kg.

	Material	2014 Silverado Mass (kg)	Tailgate Frame				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 1	AHSS	22.43	20.0%	17.94	4.49	9.03	2.01
	AHSS Stampings	20.15	20.0%	16.12	4.03	8.12	2.01
	Access panel	2.28	20.0%	1.82	0.46	0.92	2.01

Figure 179: Tailgate Option 1 (AHSS) – Mass and Cost Summary

Manufacturing the AHSS tailgate would be performed with the same production presses and techniques as the baseline tailgate.

7.4.4.4 Option 2: Aluminum

The Option 2 tailgate replaces the baseline steel stampings with aluminum for the outer panel, inner panel, access panel and reinforcements. As with Option 1 the hinges, latch/lock and striker are carried over from the baseline. The mass of this design is estimated to be 14.58 kg, providing a 7.85 kg mass savings (35%) over the conventional steel design of the baseline vehicle. The incremental cost increase for the Option 2 construction is $67.82, for a cost increase premium of $8.64 per kg. Figure 180 shows the mass and cost summary for Option 2. As with the AHSS design, the same production presses and techniques can be used for the aluminum tailgate as were used for the baseline.

	Material	2014 Silverado Mass (kg)	Tailgate Frame				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 2	Aluminum	22.43	35.0%	14.58	7.85	67.82	8.64
	Aluminum Stampings	20.15	35.0%	13.10	7.05	60.93	8.64
	Access panel	2.28	35.0%	1.48	0.80	6.89	8.64

Figure 180: Tailgate Option 2 (Aluminum) – Mass and Cost Summary

7.4.4.5 Option Selection

Option 2 using aluminum stampings was chosen for the LWT. Option 2 provides the greatest mass savings (7.85 kg) of the two options, though the incremental costs are also the highest at $67.82, equivalent $8.64 per kilogram mass saving. The team feels that, considering the objectives of this study, the additional mass savings justifies the additional costs. The parts for both of the options can be produced using the same stamping equipment as the baseline design, avoiding additional capital investment.

The mass of the final optimized design of the tailgate is 15.27 kg, 7.16 kg less than the baseline for a 32 percent mass savings. The incremental cost increase for the LWT tailgate is $21.73 ($3.03 per kg of mass saved).

7.5 Chassis System

The 2014 Silverado 1500 chassis is composed of the frame, bumpers, towing hitch, front and rear suspension, tires and wheels, brakes and steering system, as shown in Figure 181.

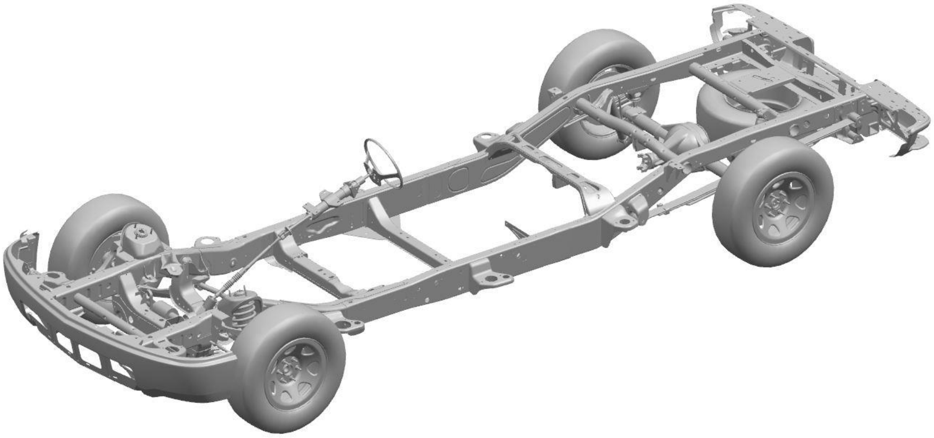

Figure 181: 2014 Chevrolet Silverado Chassis System

7.5.1 Chassis Frame

The chassis frame assembly, shown in Figure 182, is constructed primarily of high-strength steel with a total mass of 242.1 kg. The frame assembly is composed of frame rails, cross members, reinforcements, brackets, shock tower panels and cab isolators (mounts) as can be seen in Figure 183. The frame front rails are hydroformed steel while the cross members, brackets, reinforcements and shock tower panels are stamped steel. The mounts are made of a combination of steel and elastomers.

Figure 182: Baseline Chevrolet Silverado Frame

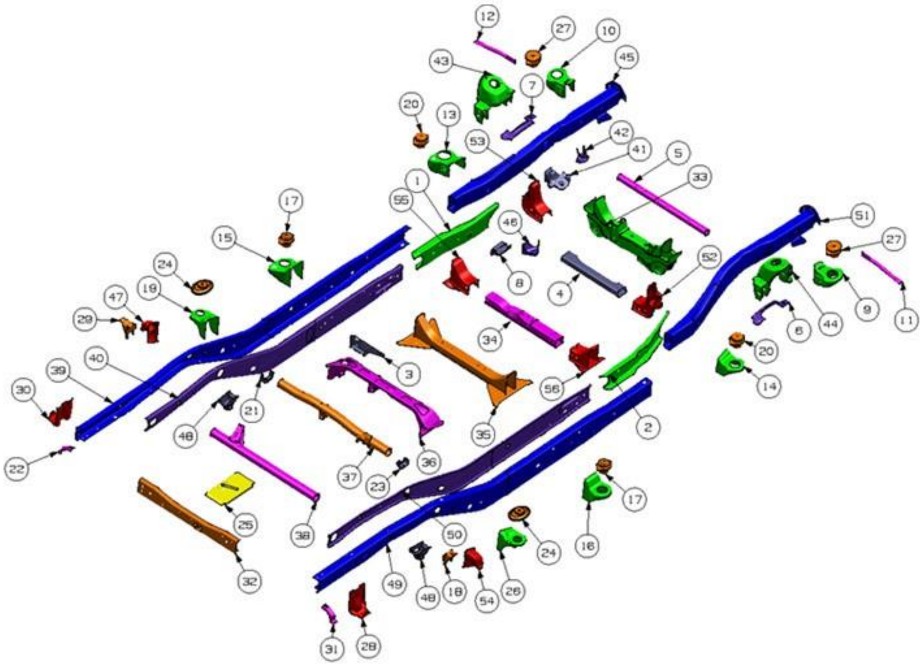

Figure 183: Baseline Chevrolet Silverado Frame Exploded View

7.5.1.1 Frame Technology Options

Three design options were considered for mass saving potential of the frame assembly. The chosen design was further developed through more advanced design and analysis efforts to verify its feasibility and to demonstrate its ability to match or exceed all the safety and performance requirements of the baseline frame assembly.

7.5.1.2 Option 1: AHSS

The Option 1 frame design maintains the basic geometry of the original design, but substitutes AHSS for the baseline steel, allowing the metal gauges to be reduced. This material substitution results in a total frame mass of 219.29 kg for a mass savings of 22.81 kg (9.4%) over the baseline 242.1 kg, as can be seen in Figure 184. The incremental cost impact to produce the Option 1 frame is an increase of $141.06, or $6.18 per kilogram saved.

Manufacturing of the Option 1 design can be done using the same production presses and processes as the baseline steel frame design.

	Material	2014 Silverado Mass (kg)	Chassis Frame				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 1	AHSS	242.10	9.4%	219.29	22.81	141.06	6.18
	Frame Rails (AHSS)	124.13	10.0%	111.72	12.41	76.76	6.18
	Cross Members (AHSS)	56.36	10.0%	50.72	5.64	34.85	6.18
	Reinforc. and Bkts (AHSS)	38.19	10.0%	34.37	3.82	23.62	6.18
	Shock Tower Panels (AHSS)	9.42	10.0%	8.48	0.94	5.83	6.18
	Isolators	7.00	0.0%	7.00	0.00	0.00	0.00
	Paint + Misc.	7.00	0.0%	7.00	0.00	0.00	

Figure 184: Frame Option 1 (AHSS) – Mass and Cost Summary

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7.5.1.3 Option 2: Aluminum

The Option 2 frame design replaces the baseline steel with aluminum. This reduces the mass to 196.48 kg, a mass saving of 45.62 kg (18.8%) compared with the baseline frame. The incremental cost increase for the Option 2 frame is $918.47, a cost increase premium of $20.13 per kg. The Option 2 mass and cost summary is shown in Figure 185.

As with Option 1, manufacturing can be performed with the same presses and processing sequences as the baseline frame.

	Material	2014 Silverado Mass (kg)	Chassis Frame				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 2	Aluminum	242.10	18.8%	196.48	45.62	918.47	20.13
	Frame Rails (Alum)	124.13	20.0%	99.30	24.83	499.82	20.13
	Cross Members (Alum)	56.36	20.0%	45.09	11.27	226.94	20.13
	Reinforc. and Bkts (Alum)	38.19	20.0%	30.55	7.64	153.78	20.13
	Shock Tower Panels (Alum)	9.42	20.0%	7.54	1.88	37.93	20.13
	Isolators	7.00	0.0%	7.00	0.00	0.00	0.00
	Paint + Misc.	7.00	0.0%	7.00	0.00	0.00	

Figure 185: Frame Option 2 (Aluminum) – Mass and Cost Summary

7.5.1.4 Option 3: AHSS + Carbon Fiber Reinforced Polymer

The Option 3 frame is made from a combination of AHSS and carbon fiber composites, consolidating parts where possible to reduce part complexity as well as mass. The front and rear portions of the frame use AHSS to provide impact resistance and address concerns with the repair of damaged CFRP. The center section of the frame is replaced with CFRP, as shown in Figure 186. The Option 3 frame weighs 192.91 kg, for a mass savings of 49.19 kg (20.3%) over the baseline steel frame (see Figure 186). The production costs and manufacturing cycle times for fabricating composite structures are high. The incremental cost increase for the Option 3 frame design is $955.64, representing a cost increase premium of $19.43 per kilogram saved.

Manufacturing the Option 3 frame would require entirely different equipment, processes and facilities than those used on the baseline vehicle, as well as a revised fastening strategy. In addition, technologies are still being developed to understand crash behaviour and repair methods for composite automotive components.

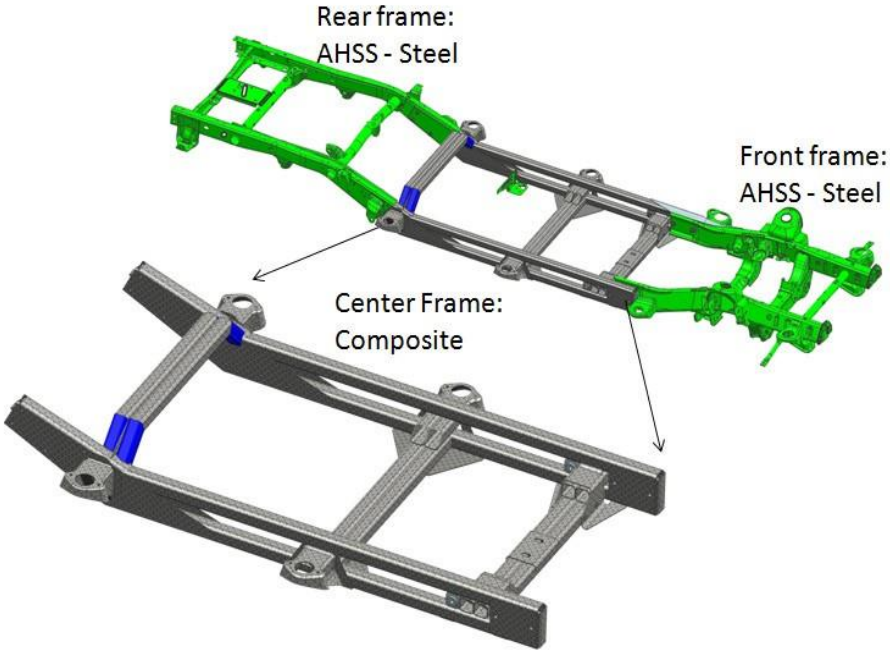


Figure 186: Frame Option 4 (AHSS + CFRP)

	Material	2014 Silverado Mass (kg)	Chassis Frame				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 3	Carbon Fiber Reinf. Polymer	242.10	20.3%	192.91	49.19	955.64	19.43
	Front Frame (AHSS)	95.47	10.0%	85.92	9.55	59.04	6.18
	Mid Frame (CFRP)	75.37	45.0%	41.45	33.92	861.19	25.39
	Rear Frame (AHSS)	57.26	10.0%	51.53	5.73	35.41	6.18
	Isolators	7.00	0.0%	7.00	0.00	0.00	0.00
	Paint + Misc.	7.00	0.0%	7.00	0.00	0.00	

Figure 187: Frame Option 4 (AHSS + CFRP) – Mass and Cost Summary

7.5.1.5 Option Selection

Figure 188 gives a summary of the frame design options. The greatest mass saving potential of all the designs considered are provided by the Option 3 composite design at 49.19 kg, but it also has an extremely high cost increase at $955.64 per vehicle. The AHSS design (Option 1) has the lowest incremental cost premium at $6.18 per kg, but offers the lowest mass savings at 22.81 kg. The most cost effective design for the frame is Option 1, AHSS, and this has been selected for the LWT.

	Material	2014 Silverado Mass (kg)	Chassis Frame				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 1	AHSS	242.10	9.4%	219.29	22.81	141.06	6.18
Option 2	Aluminum	242.10	18.8%	196.48	45.62	918.47	20.13
Option 3	Carbon Fiber Reinf. Polymer	242.10	20.3%	192.91	49.19	955.64	19.43

Figure 188: Summary of Frame Design Options

The final LWT optimised frame design has a mass of 222.70 kg. This represents a 19.40 kg mass savings (8%) compared with the baseline at an incremental cost increase of $75.76, equivalent to $3.90 per kg of mass saved. The LWT frame is designed to meet the IIHS narrow offset barrier test, requiring additional design features and hence higher mass of the frame, in comparison to the baseline vehicle 2014 Silverado 1500 frame structure.

7.5.2 Front and Rear Bumpers

7.5.2.1 Baseline Designs

The bumper system on the baseline 2014 Chevrolet Silverado is composed of stamped steel bumper panels attached to the frame with steel brackets. The front bumper assembly shown in Figure 189 also includes the plastic front grill for reference, while an exploded view of the front bumper system itself is shown in Figure 190. This system, weighing 30.09 kg, includes the front bumper panel (14.32 kg) and the brackets (15.77 kg). The rear bumper system and exploded view, shown in Figure 191, are made up of the rear bumper panel (10.30 kg) and brackets (4.74 kg), for a total of 15.04 kg.

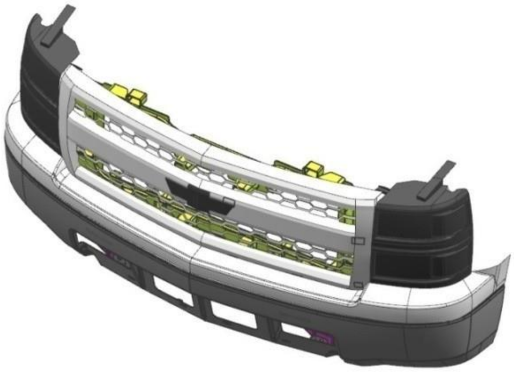


Figure 189: Baseline Front Bumper Assembly (Grill Also Shown)

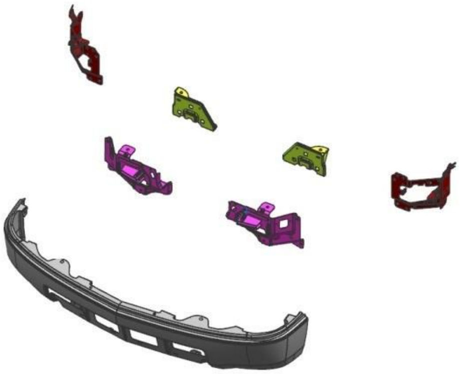


Figure 190: Baseline Front Bumper System Exploded View

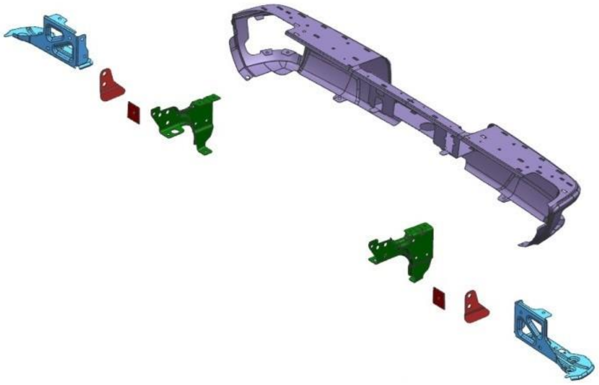


Figure 191: Baseline Rear Bumper System Exploded View

7.5.2.2 Bumper Technology Options

Four design options were considered for mass saving potential of the front and rear bumpers. The rationale behind the proposed LWT concepts was to best exemplify mass savings while taking into account manufacturing and cost considerations. The selected design was further developed through more advanced design and analysis efforts, verifying its feasibility and demonstrating its ability to match or exceed all the safety and performance requirements of the baseline bumpers.

7.5.2.3 Option 1: AHSS

The Option 1 front and rear bumper designs maintain the basic geometry of the original baseline designs, but substitute AHSS for the baseline steel, allowing the metal gauges to be reduced. The mass and cost summaries for the front and rear bumpers are shown in Figure 192 and Figure 193.

	Material	2014 Silverado Mass (kg)	Front Bumper				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 1	AHSS	30.09	15.0%	25.58	4.51	15.36	3.40
	Bumper Panel (AHSS)	14.32	15.0%	12.17	2.15	7.31	3.40
	Bumper Frame (AHSS)	15.77	15.0%	13.40	2.37	8.05	3.40

Figure 192: Front Bumper Option 1 (AHSS) – Mass and Cost Summary

	Material	2014 Silverado Mass (kg)	Rear Bumper				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 1	AHSS	15.04	15.0%	12.78	2.26	7.68	3.40
	Bumper Panel (AHSS)	10.30	15.0%	8.76	1.55	5.26	3.40
	Bumper Step Bkt (AHSS)	2.34	15.0%	1.99	0.35	1.19	3.40
	Bumper Mtg Bkt (AHSS)	2.40	15.0%	2.04	0.36	1.23	3.40

Figure 193: Rear Bumper Option 1 (AHSS) – Mass and Cost Summary

Manufacturing of the Option 1 design can be accomplished using the same production presses and processes as the baseline steel bumper design.

7.5.2.4 Option 2: Aluminum

The Option 2 front and rear bumper designs replace the baseline steel stampings with aluminum. This reduces the mass to 22.57 kg for the front bumper and 11.28 kg for the rear. See Figure 194 and Figure 195 for more details.

	Material	2014 Silverado Mass (kg)	Front Bumper				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 2	Aluminum	30.09	25.0%	22.57	7.52	111.10	14.77
	Bumper Panel (Alum)	14.32	25.0%	10.74	3.58	52.87	14.77
	Bumper frame (Alum)	15.77	25.0%	11.83	3.94	58.23	14.77

Figure 194: Front Bumper Option 2 (Aluminum) – Mass and Cost Summary

	Material	2014 Silverado Mass (kg)	Rear Bumper				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 2	Aluminum	15.04	25.0%	11.28	3.76	55.53	14.77
	Bumper Panel (Alum)	10.30	25.0%	7.73	2.58	38.03	14.77
	Bumper Step Bkt (Alum)	2.34	25.0%	1.76	0.59	8.64	14.77
	Bumper Mtg Bkt (Alum)	2.40	25.0%	1.80	0.60	8.86	14.77

Figure 195: Rear Bumper Option 2 (Aluminum) – Mass and Cost Summary

As with Option 1, manufacturing can be performed with the same presses and processing sequences as the baseline steel bumper design.

7.5.2.5 Option 3: Carbon Fiber Reinforced Polymer

The Option 3 front and rear bumpers are made from carbon fiber composites. Mass and cost summaries of these can be seen in Figure 196 and Figure 197.

	Material	2014 Silverado Mass (kg)	Front Bumper				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 3	CFRP	30.09	40.0%	18.05	12.04	406.07	33.74
	Bumper Panel (CFRP)	14.32	40.0%	8.59	5.73	193.25	33.74
	Bumper frame (CFRP)	15.77	40.0%	9.46	6.31	212.82	33.74

Figure 196: Front Bumper Option 3 (CFRP) – Mass and Cost Summary

	Material	2014 Silverado Mass (kg)	Rear Bumper				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 3	CFRP	15.04	40.0%	9.02	6.02	202.97	33.74
	Bumper Panel (CFRP)	10.30	40.0%	6.18	4.12	139.00	33.74
	Bumper Step Bkt (CFRP)	2.34	40.0%	1.40	0.94	31.58	33.74
	Bumper Mtg Bkt (CFRP)	2.40	40.0%	1.44	0.96	32.39	33.74

Figure 197: Rear Bumper Option 3 (CFRP) – Mass and Cost Summary

Manufacturing the Option 3 bumpers would require entirely different equipment, processes and facilities than those used on the baseline vehicle, as well as a revised fastening strategy. In addition, technologies are still being developed to understand crash behavior and repair methods for composite automotive bumper systems.

7.5.2.6 Option Selection

A summary of the front and rear bumper design options can be seen in Figure 198. The Option 3 composite design offers the greatest mass saving potential of all the designs considered, with 40 percent for both the front and rear bumpers, but it also has the highest cost increase premium at $33.74 per kg for mass saved. As was discussed previously in this report, the technology of supplying carbon fiber reinforced composite parts for a high-volume production vehicle is not yet mature enough, nor will it be mature enough in the 2020-2030 time frame. The AHSS design (Option 1) has the lowest incremental cost premium at $3.40 per kg, but offers the lowest mass savings at 15 percent. Option 2, aluminum stampings/extrusions, provides higher mass savings than Option 1 but at significantly higher cost premium of $16.20 per kg mass saved.

	Material	2014 Silverado Mass (kg)	Front Bumper				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 1	AHSS	30.09	15.0%	25.58	4.51	15.36	3.40
Option 2	Aluminum	30.09	25.0%	22.57	7.52	111.10	14.77
Option 3	CFRP	30.09	40.0%	18.05	12.04	406.07	33.74

	Material	2014 Silverado Mass (kg)	Rear Bumper				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 1	AHSS	15.04	15.0%	12.78	2.26	7.68	3.40
Option 2	Aluminum	15.04	25.0%	11.28	3.76	55.53	14.77
Option 3	CFRP	15.04	40.0%	9.02	6.02	202.97	33.74

Figure 198: Summary of Front and Rear Bumper System Design Options

The mass of the final LWT bumper designs is 23.7 kg for the front and 13.11 kg for the rear. This provides a mass savings of 6.3 kg and 1.93 kg, respectively (21% and 12.8%). The incremental cost saving for the LWT bumper designs of $10.20 for the front and cost increase of $3.15 for the rear (-$2.45 and $1.63 per kg of mass saved). The higher mass savings for the front bumper leads to a cost saving, although slightly higher strength steel grades are used.

7.5.3 Towing Hitch

The Chevrolet Silverado towing hitch assembly, shown in Figure 199, has a total mass of 15.81 kg and is composed of the main hitch tube, hitch receiver and various reinforcements and brackets (see Figure 200). These parts are constructed from roll-formed or stamped HSS steel.

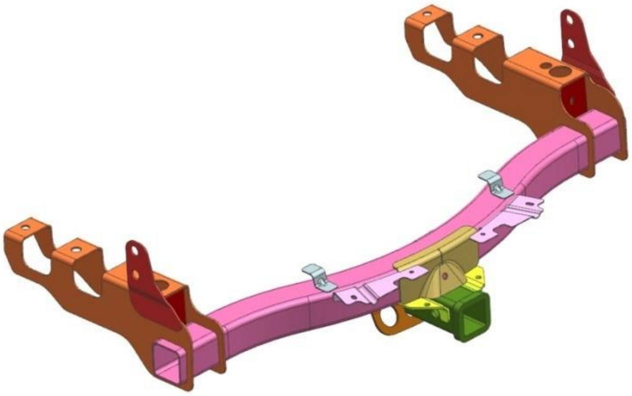


Figure 199: Baseline Rear Towing System

Item	Descriptive Part Name
1	Bracket- U Hitch Mount LH
2	Bracket- U Hitch Mount RH
3	Bracket- Outer Hitch Mount LH
4	Bracket- Outer Hitch Mount RH
5	Filler- Hitch Mount LH
6	Filler- Hitch Mount RH
7	Tube - Main Hitch
8	Reinf - Upper Center Brkt
9	Plate- Rear Center Reinf
10	Receiver - Hitch
11	Bracket - Receiver Reinf LH
12	Bracket - Receiver Reinf RH
13	Bracket - Bumper LH
14	Bracket - Bumper RH
15	Bracket - Z LH
16	Bracket - Z RH

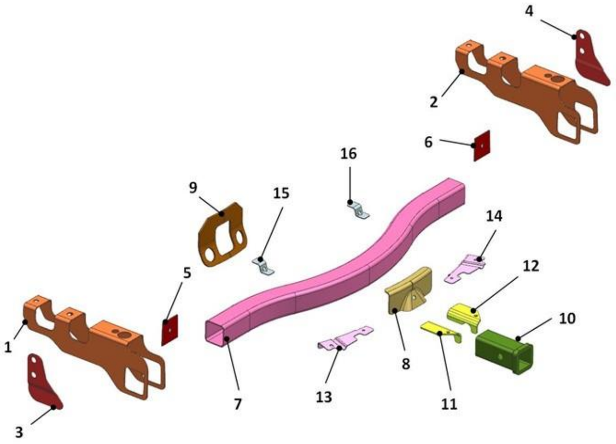


Figure 200: Baseline Rear Towing System Part Breakdown

Two design options were explored for this assembly, as can be seen in Figure 201. Option 1 replaced all the steel parts in the towing hitch assembly with AHSS, resulting in a mass savings of 1.40 kg per vehicle. Option 2 replaced the material with aluminum, reducing the mass by 3.14 kg. The incremental cost increase premium for AHSS solution is $6.18, and Aluminum solution $20.13 per kg mass saved. Based upon this evaluation, Option 1 has been chosen for the LWT towing hitch.

	Material	2014 Silverado Mass (kg)	Towing Hitch				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Mass Saving Premium ($/kg)
Option 1	AHSS	15.81	8.8%	14.41	1.40	8.65	6.18
	Main Hitch Tube (AHSS)	6.91	10.0%	6.22	0.69	4.27	6.18
	Hitch Receiver (Carryover)	1.71	0.0%	1.71	0.00	0.00	0.00
	Brackets (AHSS)	4.70	10.0%	4.23	0.47	2.91	6.18
	Reinforcements (AHSS)	2.38	10.0%	2.14	0.24	1.47	6.18
	Misc.	0.11		0.11		0.00	
Option 2	Aluminum	15.81	19.9%	12.67	3.14	63.22	20.13
	Main Hitch Tube	6.91	20.0%	5.53	1.38	27.82	20.13
	Hitch Receiver	1.71	20.0%	1.37	0.34	6.89	20.13
	Brackets	4.70	20.0%	3.76	0.94	18.93	20.13
	Reinforcements	2.38	20.0%	1.90	0.48	9.58	20.13
	Misc.	0.11		0.11		0.00	

Figure 201: Summary of Towing Hitch Design Options

The mass of the LWT towing hitch final design, shown in Figure 202 is 13.83 kg, a savings of 1.98 kg (12.5%) compared with the baseline. This savings comes at an incremental cost saving of $0.85.

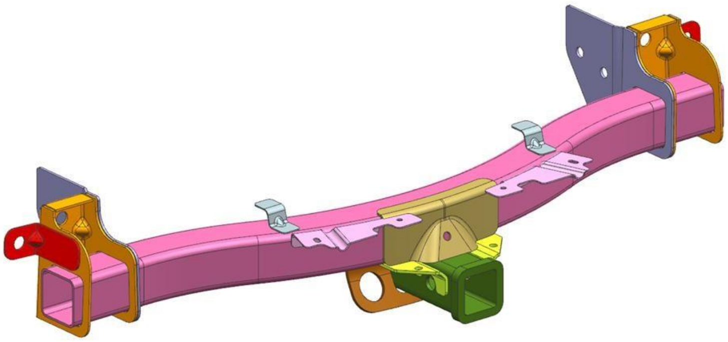


Figure 202: LWT Towing Hitch Final Design

7.5.4 Front Suspension

7.5.4.1 Baseline Design

The front suspension of the baseline 2014 Chevrolet Silverado is a standard coil-over-shock, double wishbone design consisting of the shock absorbers, coil springs, upper and lower control arms, steering knuckles, hub/bearing assemblies, stabilizer bar and other miscellaneous parts, as shown in Figure 203. The combined mass of these components, listed in Figure 204, is 67.95 kg per vehicle. This mass is comprised of 45 percent steel, 37 percent aluminum and 18 percent plastics, elastomers and other materials. The principle steel components are the coil springs (11.05 kg), stabilizer bar (6.94 kg) and hub/bearings (12.92 kg), while the principle aluminum components are the upper control arms (4.02 kg), lower control arms (13.48 kg) and steering knuckles (7.67 kg).

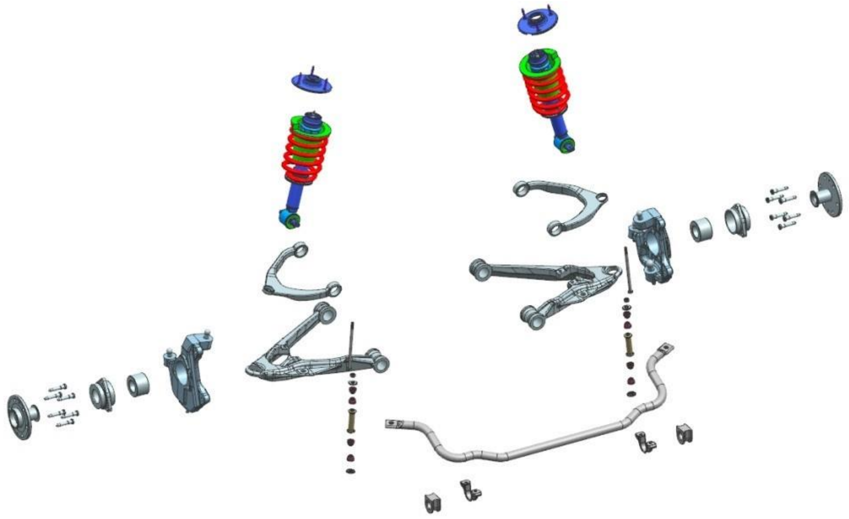


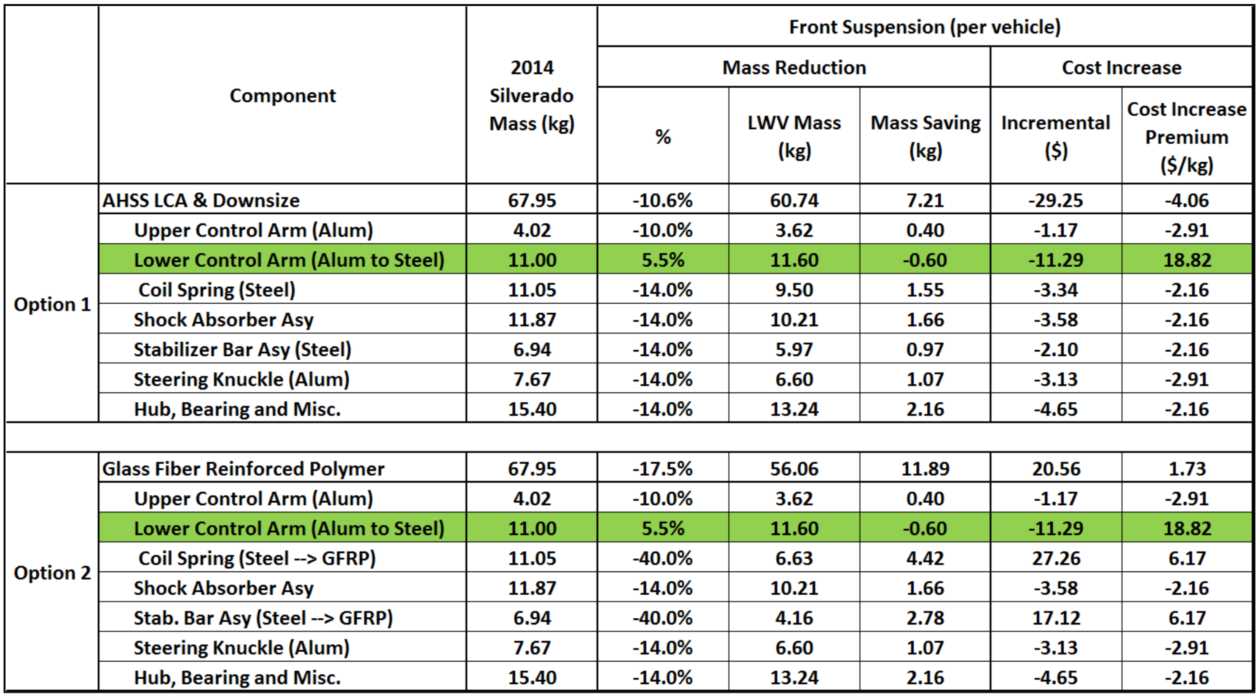
Figure 203: Baseline Front Suspension Exploded View
(EDAG CAD Model)

Item (material)	**Mass (kg)**
Control Arms – Upper Control Arm (aluminum)	4.02
Control Arms – Lower Control Arm (aluminum)	11.00
Shock Absorber Assy (various)	11.87
Coil Springs (steel)	11.05
Steering Knuckles (aluminum)	7.67
Stabilizer Bar (steel)	6.94
Hubs, Bearings and Misc. (steel)	15.40
Total:	**67.95**

Figure 204: Baseline Front Suspension Parts Mass Breakdown (per vehicle)

7.5.4.2 Front Suspension Technology Options

Options for saving mass in the front suspension assembly are limited because the baseline design already has many lightweighting technologies incorporated. The control arms and steering knuckle are aluminum and the stabilizer bar is a hollow steel tube construction. The reduction of the overall mass of the LWT compared with the baseline vehicle reduces the loads on the suspension components, allowing them to be downsized without degrading performance. Option 1 takes advantage of this downsizing while maintaining the baseline material selections, except in the case of the lower control arm that has been redesigned using AHSS. As can be seen in Figure 205, this provides a mass savings of 7.21 kg at a cost savings of $29.25.



	Component	2014 Silverado Mass (kg)	Front Suspension (per vehicle)				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Option 1	AHSS LCA & Downsize	67.95	-10.6%	60.74	7.21	-29.25	-4.06
	Upper Control Arm (Alum)	4.02	-10.0%	3.62	0.40	-1.17	-2.91
	Lower Control Arm (Alum to Steel)	11.00	5.5%	11.60	-0.60	-11.29	18.82
	Coil Spring (Steel)	11.05	-14.0%	9.50	1.55	-3.34	-2.16
	Shock Absorber Asy	11.87	-14.0%	10.21	1.66	-3.58	-2.16
	Stabilizer Bar Asy (Steel)	6.94	-14.0%	5.97	0.97	-2.10	-2.16
	Steering Knuckle (Alum)	7.67	-14.0%	6.60	1.07	-3.13	-2.91
	Hub, Bearing and Misc.	15.40	-14.0%	13.24	2.16	-4.65	-2.16
Option 2	Glass Fiber Reinforced Polymer	67.95	-17.5%	56.06	11.89	20.56	1.73
	Upper Control Arm (Alum)	4.02	-10.0%	3.62	0.40	-1.17	-2.91
	Lower Control Arm (Alum to Steel)	11.00	5.5%	11.60	-0.60	-11.29	18.82
	Coil Spring (Steel --> GFRP)	11.05	-40.0%	6.63	4.42	27.26	6.17
	Shock Absorber Asy	11.87	-14.0%	10.21	1.66	-3.58	-2.16
	Stab. Bar Asy (Steel --> GFRP)	6.94	-40.0%	4.16	2.78	17.12	6.17
	Steering Knuckle (Alum)	7.67	-14.0%	6.60	1.07	-3.13	-2.91
	Hub, Bearing and Misc.	15.40	-14.0%	13.24	2.16	-4.65	-2.16

Figure 205: Summary of Front Suspension Design Options

Option 2 incorporates this same lower control arm and downsizing, but also replaces the steel coil springs and stabilizer bar with glass fiber reinforced polymer (GFRP). Audi is currently implementing the GFRP concept on the coil springs of an upper mid-size model, achieving a 40 percent mass saving on those components.[104] Chevrolet has been using GFRP leaf springs on the Corvette since 1981.[105] Replacing the steel coil springs with GFRP on the LWT will reduce the mass from 11.05 kg to 6.63 kg per vehicle at a cost of $27.26. The same change to the stabilizer bar will reduce the mass from 6.94 kg to 4.16 kg at a cost of $17.12. This reduces the total mass of the front suspension from 67.95 kg to 56.06 kg, a reduction of 11.89 kg (17.5%). The incremental cost of this option is $20.56 per vehicle.

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[104] www.greencarcongress.com/2014/06/20140630-audi.html

[105] www.compositesworld.com/articles/composite-leaf-springs-saving-weight-in-production-suspension- systems

The business cases for Option 1 and Option 2 are reasonably close. However, the team was not able to find any performance data for GFRP coil springs used on a vehicle that will be operating off-road under heavy loading conditions. This introduces an uncertain amount of risk for durability, damage assessment and repair. Operation of the vehicle under challenging conditions is a defining characteristic of this type of vehicle that cannot be compromised. It is this uncertain risk that makes Option 1 the design choice for the LWT. In time, when more data is generated for GFRP front suspension components, this option should be re-evaluated.

7.5.5 Rear Suspension

7.5.5.1 Baseline

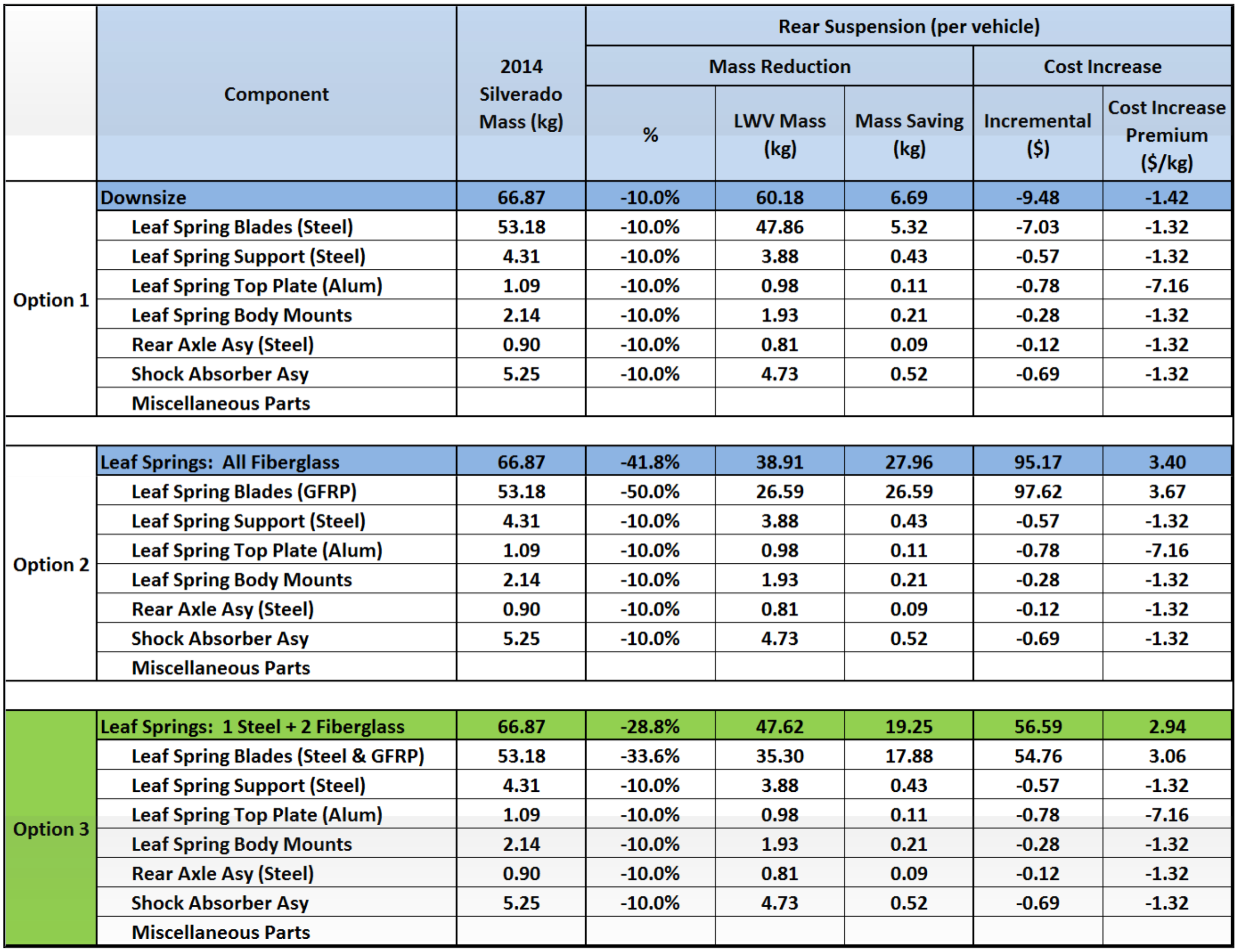
The baseline 2014 Chevrolet Silverado uses a semi-elliptical, 2-stage multi-leaf spring rear suspension, shown in Figure 206. The major components of the rear suspension are the leaf spring blades, supports, mounts and shock absorbers. The total mass of the system is 66.87 kg per vehicle. Steel is the primary material used in the rear suspension module with the exception of the leaf spring top plate (aluminum, 1.1 kg) and a small amount of elastomeric material.

Figure 206: Baseline Leaf Spring Rear Suspension Exploded View

7.5.5.2 Rear Suspension Technology Options

The same design philosophy as was discussed for the front suspension also applies to the rear. Option 1 downsizes all the components due to the lower overall weight of the LWT, resulting in a rear suspension mass of 60.18 kg, compared with the 66.87 kg baseline, a savings of 10%. This also provides an incremental cost savings of $9.48 per vehicle. Option 2 similarly downsizes the components, but in addition replaces all the steel leaf spring blades with GFRP.

This reduces the mass of the leaf spring assembly from 53.18 kg to 26.59 kg, or 50%. The mass of the entire rear suspension is 38.91 kg, a savings of 27.96 kg compared with the baseline, at an incremental cost increase of $95.17 per vehicle ($3.40 per kg of mass saved). Option 3 replaces the lower two leaf spring blades with GFRP but keeps the top blade steel. Since the top blade includes the body mounts (eyes), this option avoids the complications of redesigning these mounts and incorporating them into a GFRP structure. The top spring blade and other components are downsized as in the previous options, resulting in a total mass of 47.62 kg for the Option 3 rear suspension, a savings of 19.25 kg (29%). The incremental cost increase of Option 3 is $56.59, or $2.94 per kg of mass saved. Figure 207 shows the mass and cost summary for each of these options.



	Component	2014 Silverado Mass (kg)	Rear Suspension (per vehicle)				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Option 1	**Downsize**	**66.87**	**-10.0%**	**60.18**	**6.69**	**-9.48**	**-1.42**
	Leaf Spring Blades (Steel)	53.18	-10.0%	47.86	5.32	-7.03	-1.32
	Leaf Spring Support (Steel)	4.31	-10.0%	3.88	0.43	-0.57	-1.32
	Leaf Spring Top Plate (Alum)	1.09	-10.0%	0.98	0.11	-0.78	-7.16
	Leaf Spring Body Mounts	2.14	-10.0%	1.93	0.21	-0.28	-1.32
	Rear Axle Asy (Steel)	0.90	-10.0%	0.81	0.09	-0.12	-1.32
	Shock Absorber Asy	5.25	-10.0%	4.73	0.52	-0.69	-1.32
	Miscellaneous Parts						
Option 2	**Leaf Springs: All Fiberglass**	**66.87**	**-41.8%**	**38.91**	**27.96**	**95.17**	**3.40**
	Leaf Spring Blades (GFRP)	53.18	-50.0%	26.59	26.59	97.62	3.67
	Leaf Spring Support (Steel)	4.31	-10.0%	3.88	0.43	-0.57	-1.32
	Leaf Spring Top Plate (Alum)	1.09	-10.0%	0.98	0.11	-0.78	-7.16
	Leaf Spring Body Mounts	2.14	-10.0%	1.93	0.21	-0.28	-1.32
	Rear Axle Asy (Steel)	0.90	-10.0%	0.81	0.09	-0.12	-1.32
	Shock Absorber Asy	5.25	-10.0%	4.73	0.52	-0.69	-1.32
	Miscellaneous Parts						
Option 3	**Leaf Springs: 1 Steel + 2 Fiberglass**	**66.87**	**-28.8%**	**47.62**	**19.25**	**56.59**	**2.94**
	Leaf Spring Blades (Steel & GFRP)	53.18	-33.6%	35.30	17.88	54.76	3.06
	Leaf Spring Support (Steel)	4.31	-10.0%	3.88	0.43	-0.57	-1.32
	Leaf Spring Top Plate (Alum)	1.09	-10.0%	0.98	0.11	-0.78	-7.16
	Leaf Spring Body Mounts	2.14	-10.0%	1.93	0.21	-0.28	-1.32
	Rear Axle Asy (Steel)	0.90	-10.0%	0.81	0.09	-0.12	-1.32
	Shock Absorber Asy	5.25	-10.0%	4.73	0.52	-0.69	-1.32
	Miscellaneous Parts						

Figure 207: Summary of Rear Suspension Design Options

Option 3 was selected for the LWT because of the significant mass savings at a modest cost increase premium of $2.94 per kg mass saved. The concern with GFRP that was expressed regarding the front suspension coil springs is not as significant for the rear leaf springs due to the large amount of performance data available on GFRP leaf springs dating back more than thirty years.

7.5.6 Wheels/Tires

7.5.6.1 Baseline Design

The baseline wheel and tire system consists of four wheels, four tires, a spare wheel/tire, jack, spare tire mounting and tools. The baseline wheel and tire can be seen in **Figure 208**. The mass of the entire system is 158.96 kg, as shown in **Figure 209**. The tires are standard tubeless tires while the wheel rims and jack are steel. The spare tire is the same as the road tire, but the spare rim is aluminum rather than steel.

Figure 208: 2014 Chevrolet Silverado Baseline Wheel/Tire

Item	Mass (kg)
4 Wheels	58.20
4 Tires	66.36
Spare Tire/Wheel	26.76
Jack and Tools	5.24
Spare Tire Hanger Assy and Misc.	2.40
Total	**158.96**

Figure 209: Baseline Wheel/Tire System Parts Mass Breakdown

7.5.6.2 Wheels/Tires Technology Options

Reducing the wheel and tire size to a smaller series was one mass reduction possibility considered. However, the wheels and tires on a vehicle are seen to enhance its appearance, as well as being very critical for adequate grip during acceleration, cornering, braking and trailering. Therefore, the baseline P255/70R17 wheel and tire sizes were maintained for the LWT.

Another possibility investigated was eliminating the spare tire, wheel and jack by replacing the conventional tires with run-flat tires or providing an aerosol canned tire repair kit. This approach is being used on many passenger cars in current production. However, it was judged that neither of these options would be acceptable to consumers of light duty pickup trucks, particularly with trailering packages, and would be considered a serious downgrading of the vehicle content and a loss of functionality. Therefore, these options were eliminated for the LWT.

Revising the wheel rim material from steel to aluminum, magnesium or carbon fiber composite was considered. Each of these would reduce mass by using lower density materials compared with the baseline. The baseline spare uses the same tire as the rest of the vehicle, but with an aluminum rim that weighs 4.38 kg less than the steel rim. Using this aluminum rim throughout the vehicle produces a savings of 17.52 kg at a cost increase of $50.03. Magnesium rims are commonly available and can reduce the vehicle weight by 26.19 kg, but the cost increase is $125.72. Carbon fiber composite wheels present the greatest mass reduction potential, up to 29.10 kg per vehicle, but at a large cost increase approaching $800 per vehicle. This technology is not yet advanced to the point where it can supply a high-volume program like the Chevrolet Silverado in a cost effective manner, and the team does not anticipate that it will be sufficiently advanced for that purpose in the 2020-2030 period.

Lacks Wheel Trim Systems, LLC, offers a product called the eVOLVE Hybrid Wheel in which both mass and drag coefficient are reduced, contributing to an increased fuel economy of approximately 1 mpg.[106] Analysis by Lacks has determined that more than 10 percent of a typical wheel's mass is due to aerodynamic and aesthetic requirements rather than structural. The eVOLVE wheel is composed of a cast aluminum structural "backbone" bonded to a lightweight polymer composite "design surface" as can be seen in Figure 210. The backbone is optimized to the smallest mass and geometry needed to meet the structural requirements while the design surface provides the necessary aerodynamic and aesthetic attributes. Lacks has demonstrated the ability to reduce the mass of a standard aluminum wheel more than 10 percent with the eVOLVE technology. Replacing the baseline Silverado steel wheels with appropriate eVOLVE wheels would reduce vehicle mass by an estimated 25.25 kg at an additional cost of $40.80 per vehicle. In addition, the baseline Silverado wheel is a very basic wheel from a styling point of view, while the eVOLVE wheel presents a premium level appearance. While that is not the goal of this option, as a side benefit it does provide the consumer with a perceived upgrade in vehicle content.

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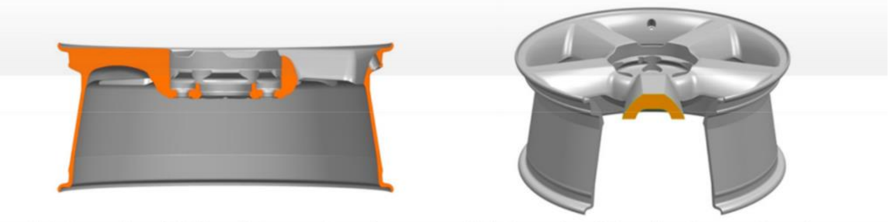
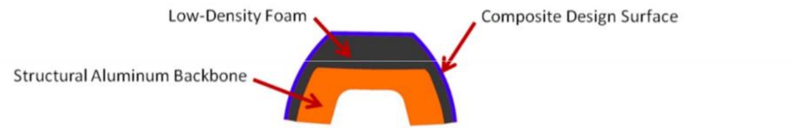
[106] www.evolvehybrid.com/



(a) Standard Wheel Cross-Section (b) Standard Spoke Cross-Section

(c) eVOLVE™ Wheel Cross-Section (d) eVOLVE™ Spoke Cross-Section



(e) eVOLVE™ Spoke Detail

Figure 210: Standard Wheel vs. eVOLVE Composite Construction Wheel
(Lacks Wheel Trim Systems, LLC)

A search of the current market was conducted to determine if there are tires available with lower mass and equivalent performance to the baseline tires. While tire suppliers are working on developing lightweight tires,[107] not much data has been presented to date. A search of currently available tires identified a Yokohama Geolander H/T G056 that is 1.17 kg lighter than the baseline Bridgestone Dueler H/T (15.42 kg vs. 16.59 kg). Replacing the five tires on the LWT with the Yokohama tire reduces the combined mass by 5.85 kg (7%) at an estimated cost of $95.00 per vehicle.

Figure 211 shows the mass and cost summary for Option 1 (steel rims). All the components except the tire pressure sensors are downsized to take advantage of the overall lighter mass of the LWT. The total mass of the wheel/tire system is 143.07 kg, a savings of 15.89 kg compared with the baseline (10% mass reduction). This option results in an incremental savings of $11.66 per vehicle.

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[107] http://energy.gov/sites/prod/files/2014/03/f13/vss083_donley_2013_o%2520.pdf

	Component	2014 Silverado Mass (kg)	Wheels & Tires (per vehicle)				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Option 1	Steel Rims + Spare Tire	158.96	-10.0%	143.07	15.89	-11.66	-0.73
	Rims (Steel)	58.20	-10.0%	52.38	5.82	-7.70	-1.32
	Tires	66.36	-10.0%	59.72	6.64	0.00	0.00
	Tire Pressure Sensors	0.06	0.0%	0.06	0.00	0.00	0.00
	Spare Rim (Aluminum)	10.17	-10.0%	9.15	1.02	-2.96	-2.91
	Spare Tire	16.59	-10.0%	14.93	1.66	0.00	0.00
	Spare Wheel Hanger Assy	2.34	-10.0%	2.11	0.23	-0.31	-1.32
	Car Jack & Tools	5.24	-10.0%	4.72	0.52	-0.69	-1.32

Figure 211: Wheels/Tires Option 1 (Steel Rims) – Mass and Cost Summary

- Options 2, 3, 4 and 5 are identical to Option 1 with the exception of the rim material. Option 2 (aluminum rims) provides 31.66 kg mass savings (127.30 total vehicle mass). Replacing all five rims with magnesium (Option 3) gives a combined wheel/tire mass of 121.17 kg per vehicle (a savings of 37.79 kg), while replacing them with CFRP reduces the combined mass to 117.25 kg per vehicle (41.71 kg mass savings). The eVOLVE wheel, Option 5, weighs 123.64 kg per vehicle (35.32 kg mass savings). Figure 212 shows a summary of the five design options considered for the LWT. Each of these options includes the same downsized components in addition to the rim material change. The option selected for the LWT is the Option 5 eVOLVE rims, providing a 22.2 percent mass reduction. In addition, as was previously mentioned, the composite technology is not yet mature enough to support high-volume production. The Option 1 and Option 2 rims generate cost savings for the vehicle, but do not provide nearly as much mass savings. As the focus of this study is mass reduction, the Option 5 eVOLVE rims provide the best mass savings for a reasonable cost.

	Component	2014 Silverado Mass (kg)	Wheels & Tires (per vehicle)				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Option 1	Steel Rims + Spare Tire	158.96	-10.0%	143.07	15.89	-11.66	-0.73
Option 2	Aluminum Rims + Spare Tire	158.96	-19.9%	127.30	31.66	132.31	4.18
Option 3	Magnesium Rims + Spare Tire	158.96	-23.5%	121.68	37.28	366.70	9.84
Option 4	CFRP Rims + Spare Tire	158.96	-26.2%	117.25	41.71	838.09	20.09
Option 5	eVOLVE™ Rims + Spare Tire	158.96	-22.2%	123.64	35.32	164.30	4.65

Figure 212: Wheels/Tires Design Options Mass and Cost Summary

7.5.7 Brakes

7.5.7.1 Baseline design

The baseline Chevrolet Silverado features a conventional 4-wheel antilock disc brake system. This system includes the master cylinder, hydraulic lines, discs, calipers, brake pads, parking brakes, ABS and various shields, brackets and sensors. The total mass of this system, as shown in Figure 213, is 84.35 kg per vehicle.

Item	Mass (kg)
Master Cylinder	5.60
Front Discs	23.59
Front Calipers	10.17
Front Pads	2.34
Rear Discs	19.25
Rear Calipers	3.77
Rear Pads	1.38
Park Brake to EPB	2.02
ABS System	4.66
Brake Lines	0.88
Caliper Supports	9.20
Miscellaneous	1.49
Total:	**84.35**

Figure 213: Baseline Brake System Parts Mass Breakdown

7.5.7.2 Brakes Technology Options

As has been discussed on other vehicle systems, the overall reduced mass of the LWT allows the brake system to be downsized. The master cylinder, calipers, pads, and discs could be reduced in size without degrading vehicle performance. In addition, the cast iron brake discs and front calipers can be replaced with aluminum discs and calipers. The performance and production capability of aluminum calipers has been demonstrated through usage on several vehicles over time. For example, in the 2009 MY alone at least 12 production vehicles used aluminum brake calipers, including Audi A7, BMW X6, Cadillac CTS and DTS, Chevrolet Camaro, Ford Mustang, Infiniti FX45, Opel Insignia, Pontiac Vibe, Porsche 911 and Cayenne, and Toyota Highlander.[108] The baseline 2014 Chevrolet Silverado is already using aluminum for the rear brake calipers. Aluminum brake discs are in use by many racing teams where mass

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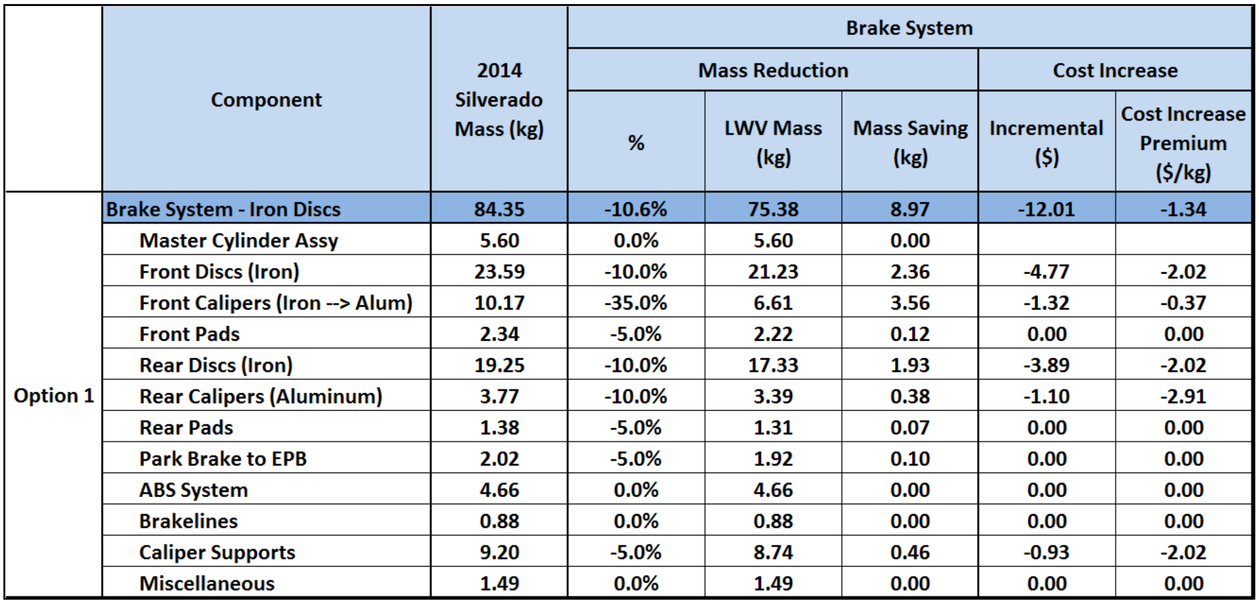
[108] http://aluminumintransportation.org/applications/applications/brake-calipers

savings are critical. Metal matrix composites have been studied as a replacement material for cast iron brake discs[109] offering up to 60 percent mass savings and improved performance, particularly at high temperatures. While some specialty vehicles, such as the 1996-98 Lotus Elise, have used MMC brake discs, this technology is still being developed and may not be available for high-volume production in the 2020-2030 time frame.

Another opportunity for mass reduction in the brake systems is to replace the mechanical parking brake with an electric system in which the pedal and linkages are replaced by a small switch, wiring and an actuator. This would reduce the mass of the system from 2.02 kg to 1.92 kg, a 5 percent (0.10 kg) weight savings. Electric parking brake systems are already available and being used on several products such as Cadillac, Audi, Subaru, BMW, Renault, Opel, Lincoln, VW, Chevrolet, and Buick. They are less expensive to manufacture and install than the mechanical system and thus offer a cost decrease. In use since 2001, the reliability of this technology has been proven and many consumers are already comfortable with it, so the risk associated with it is low.

Option 1 replaces the front calipers with aluminum and incorporates the downsizing previously mentioned (see Figure 214). This results in a total brake system mass reduction of 8.97 kg (from 84.35 kg to 75.38 kg) and saves $12.01 per vehicle. Option 2 (see Figure 215) makes those same changes, but also replaces the iron brake discs with aluminum for an additional 10.71 kg mass savings compared with Option 1. This reduces the mass of the brake system to 64.67 kg, 19.68 kg less than the baseline. The incremental cost of Option 2 is $72.18 per vehicle, or $3.67 per kg.



	Component	2014 Silverado Mass (kg)	Brake System				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Option 1	**Brake System - Iron Discs**	84.35	-10.6%	75.38	8.97	-12.01	-1.34
	Master Cylinder Assy	5.60	0.0%	5.60	0.00		
	Front Discs (Iron)	23.59	-10.0%	21.23	2.36	-4.77	-2.02
	Front Calipers (Iron --> Alum)	10.17	-35.0%	6.61	3.56	-1.32	-0.37
	Front Pads	2.34	-5.0%	2.22	0.12	0.00	0.00
	Rear Discs (Iron)	19.25	-10.0%	17.33	1.93	-3.89	-2.02
	Rear Calipers (Aluminum)	3.77	-10.0%	3.39	0.38	-1.10	-2.91
	Rear Pads	1.38	-5.0%	1.31	0.07	0.00	0.00
	Park Brake to EPB	2.02	-5.0%	1.92	0.10	0.00	0.00
	ABS System	4.66	0.0%	4.66	0.00	0.00	0.00
	Brakelines	0.88	0.0%	0.88	0.00	0.00	0.00
	Caliper Supports	9.20	-5.0%	8.74	0.46	-0.93	-2.02
	Miscellaneous	1.49	0.0%	1.49	0.00	0.00	0.00

Figure 214: Brake System Option 1 - Mass and Cost Summary

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[109] Adebisi, A. A., Maleque, M. A., Rahman, M. M. 2011. "Metal Matrix Composite Brake Rotor: Historical Development and Product Life Cycle Analysis." International Journal of Automotive and Mechanical Engineering (IJAME), Volume 4, pp.471-480, July-December 2011.

	Component	2014 Silverado Mass (kg)	Brake System				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Option 2	Brake System - Aluminum Discs	84.35	-23.3%	64.67	19.68	72.18	3.67
	Master Cylinder Assy	5.60	0.0%	5.60	0.00		
	Front Discs (Iron --> Alum)	23.59	-35.0%	15.33	8.26	41.59	5.04
	Front Calipers (Iron --> Alum)	10.17	-35.0%	6.61	3.56	-1.32	-0.37
	Front Pads	2.34	-5.0%	2.22	0.12	0.00	0.00
	Rear Discs (Iron --> Alum)	19.25	-35.0%	12.51	6.74	33.94	5.04
	Rear Calipers (Aluminum)	3.77	-10.0%	3.39	0.38	-1.10	-2.91
	Rear Pads	1.38	-5.0%	1.31	0.07	0.00	0.00
	Park Brake to EPB	2.02	-5.0%	1.92	0.10	0.00	0.00
	ABS System	4.66	0.0%	4.66	0.00	0.00	0.00
	Brakelines	0.88	0.0%	0.88	0.00	0.00	0.00
	Caliper Supports	9.20	-5.0%	8.74	0.46	-0.93	-2.02
	Miscellaneous	1.49	0.0%	1.49	0.00	0.00	0.00

Figure 215: Brake System Option 2 - Mass and Cost Summary

7.5.7.3 Option Selection

While the additional mass savings offered by the aluminum brake discs are attractive, there are concerns with using them on a vehicle that can be expected to experience long duration brake usage and large GCWR, such as a fully loaded vehicle towing a trailer on a long downgrade. The amount of heat dissipation provided by the aluminum discs may not be adequate to prevent overheating of the braking system. In addition, standard cast aluminum begins to lose strength at fairly low temperatures (480˚F or 250˚C). The vehicles currently using aluminum discs are generally high-performance racing vehicles with average to minimal braking durations. Recent research on aluminum-ceramic composite brake discs[110] and high-temperature aluminum alloys[111] is promising, but at this time there is insufficient data demonstrating the performance capability of aluminum brake discs on heavily loaded vehicles such as the Silverado. For that reason the team selected Option 1 for the LWT.

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[110] www.designnews.com/author.asp?dfpPParams=ind_183%2Cindustry_auto%2Cindustry_gov%2Cbid_27%2Caid_239090&dfpLayout=blog&doc_id=239090&page_number=1

[111] www.mtu.edu/news/stories/2010/october/miracle-diet-for-brake-rotors-high-strength-high-temp-aluminum.html

7.5.8 Steering

7.5.9 Baseline Steering System

The baseline Chevrolet Silverado uses an electric power steering system consisting of the steering column assembly, steering wheel, rack and electric motor, as shown in Figure 216. The total weight of the system is 34.72 kg.

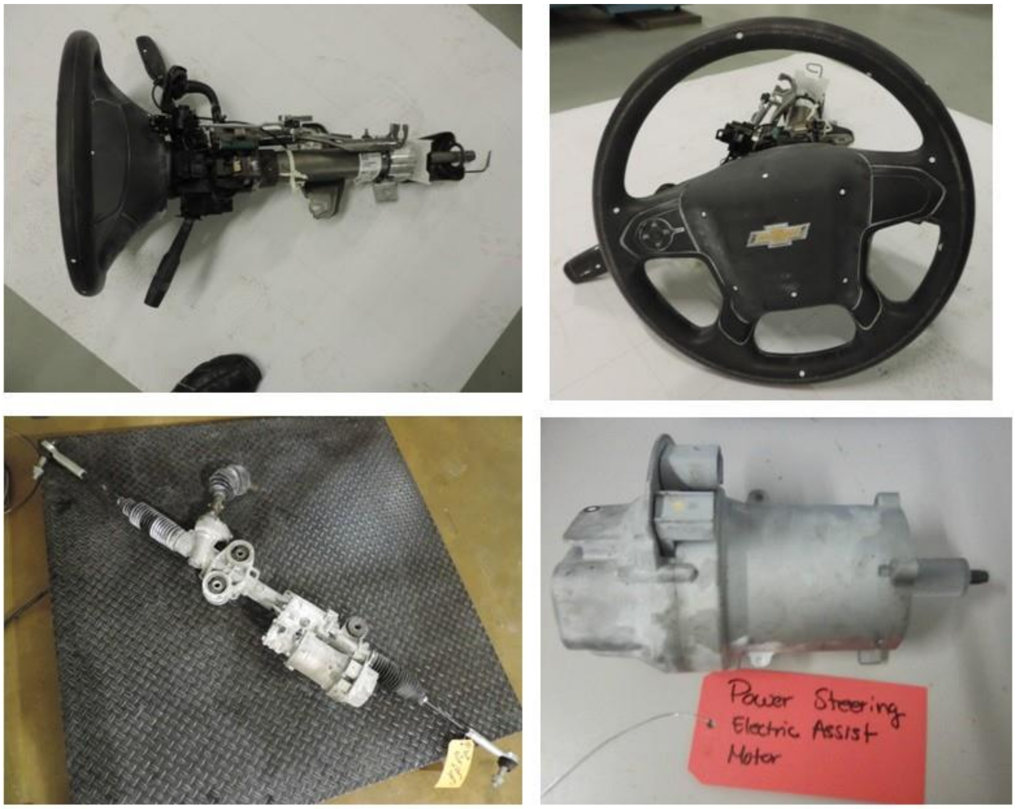


Figure 216: Baseline Steering System Assembly

7.5.10 Steering Column and Rack

The steering column is a tubular steel structure surrounded by plastic trim, designed to provide support for the steering wheel and controls while collapsing during a frontal impact to absorb energy, lessening the load to the driver. The steering column has a total mass of 9.21 kg. The steel assembly was replaced by a magnesium casting, reducing the mass to 5.99 kg, a savings of 35% due to the lower density material and complexity reduction. The incremental cost of this change is $15.33, or $4.76 per kg.

The steering rack, with a mass of 18.54 kg, is composed primarily of steel castings and rods, with some elastomers. This, like other systems in the LWT, can be scaled down due to the reduced weight of the vehicle without affecting vehicle performance, resulting in a mass of

17.61 kg, a savings of 0.93 kg. The cost impact of this change includes savings due to material reductions ($3.45).

7.5.11 Steering Wheel

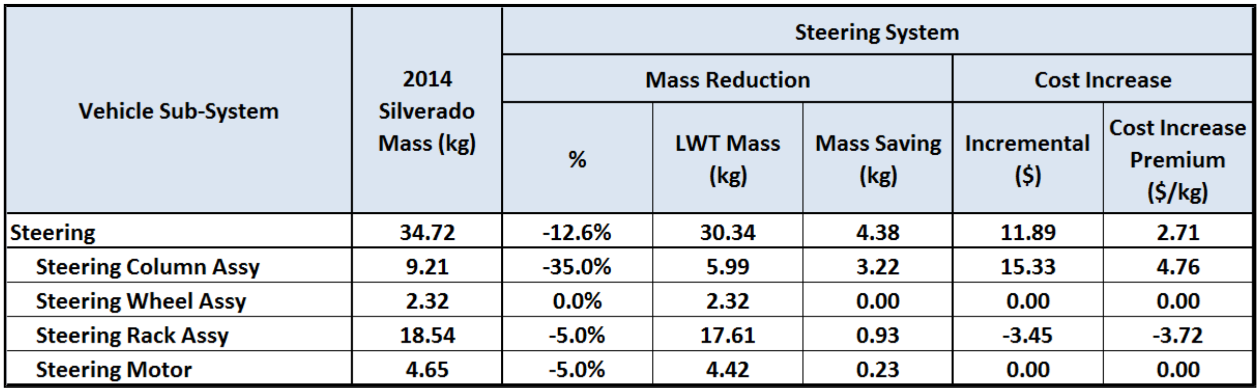
The steering wheel of the baseline Chevrolet Silverado is constructed of a magnesium casting covered with a nylon overwrap and the air bag assembly. The mass of the steering wheel is 2.32 kg, while that of the air bag assembly is 1.05 kg. The design of the air bag assembly has been highly refined through years of development and testing. These components are restricted by FMVSS requirements and cannot be modified in a cost effective manner. The mass reduction potential for the remainder of the steering wheel through re-design or material substitution is low compared with the cost increase involved. Therefore the entire steering wheel assembly was carried over to the LWT.

7.5.12 Power Steering

The baseline electric power steering motor was slightly downsized from 4.65 kg to 4.42 kg due to the reduced vehicle mass. This is a cost neutral change.

7.5.13 Steering System Technologies Summary

Figure 217 summarizes the changes to the steering system. The overall effect is to reduce the mass of the system from 34.72 kg to 30.34 kg, a drop of 4.38 kg (13%) at a cost increase of $11.89 per vehicle ($2.71 per kg).



Vehicle Sub-System	2014 Silverado Mass (kg)	Steering System				
		Mass Reduction			Cost Increase	
		%	LWT Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Steering	**34.72**	**-12.6%**	**30.34**	**4.38**	**11.89**	**2.71**
Steering Column Assy	**9.21**	**-35.0%**	**5.99**	**3.22**	**15.33**	**4.76**
Steering Wheel Assy	**2.32**	**0.0%**	**2.32**	**0.00**	**0.00**	**0.00**
Steering Rack Assy	**18.54**	**-5.0%**	**17.61**	**0.93**	**-3.45**	**-3.72**
Steering Motor	**4.65**	**-5.0%**	**4.42**	**0.23**	**0.00**	**0.00**

Figure 217: Steering System Mass and Cost Summary

7.6 Powertrain

The baseline Chevrolet Silverado powertrain system is composed of the engine, transmission, front differential, transfer case, rear axle/differential, drive shafts, fuel system, exhaust system and engine cooling system as shown in Figure 218. The total mass of the powertrain system is 614.15 kg (refer to Figure 219). It should be noted that the baseline vehicle is a 4WD vehicle; 2WD vehicles will not have the front differential, transfer case, or front drive shafts.

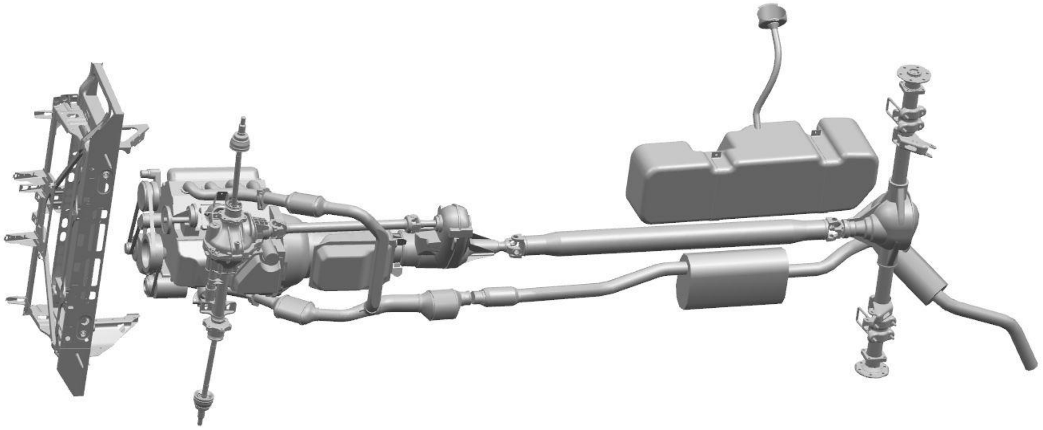


Figure 218: 2014 Chevrolet Silverado Powertrain Systems

Item	Mass (kg)
Engine	222.70
Transmission Assy	75.00
Front Differential Assy	42.30
Transfer Case Assy	33.47
Rear Axle/Differential Assy	81.41
Drive Shafts	53.71
Fuel System	22.19
Exhaust System	51.91
Engine Cooling System	18.00
Miscellaneous	13.46
Total:	**614.15**

Figure 219: Powertrain System Mass Breakdown

7.6.1 Engine

7.6.1.1 Baseline

The engine used in the baseline 2014 Chevrolet Silverado is an aluminum block 5.3 liter Ecotec3 V8 (see Figure 220). The FlexFuel, direct injection engine with active fuel management is rated at 265 kW at 5600 rpm (355 hp) and 519 Nm torque at 4100 rpm (383 lb-ft) when operating with gasoline. With E85 fuel, the power rating is 283 kW (380 hp) and 564 Nm torque (416 lb-ft). The mass of the engine is 222.70 kg.

Figure 220: Baseline Chevrolet Silverado 5.3L V8 Engine
(http://media.gm.com, © General Motors)

7.6.1.2 Engine Technology Options

The baseline Chevrolet Silverado 5.3 liter all-aluminum engine is already a very lightweight design and does not offer many mass reduction opportunities. As a reference the 2015 Ford F150 engine (shown in Figure 221) was downsized from the previous 5.0 liter to a 2.7 liter EcoBoost, with twin turbos, saving approximately 11 kg. Because the overall weight of the LWT is less than that of the baseline, the LWT engine was downsized from the baseline (5.3L) 200.73 kg to (5.0 L) 193.3 kg as shown in Figure 222. This represents a mass reduction of 7.43 kg (3.7%) and a cost savings of $19.77 due to less materials being required. Engine size calculations are shown in Section 9.7

Figure 221: 2015 Ford 2.7L Twin Turbo EcoBoost Engine
(https://media.ford.com)

Vehicle Sub-System	2014 Silverado Mass (kg)	Engine				
		Mass Reduction			Cost Increase	
		%	LWT Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Engine Assembly	200.73	-3.7%	193.30	7.43	-19.77	-2.66
Fuel Injection System	12.81	-2.6%	12.48	0.33	-1.69	-5.13
Engine Block	49.85	-3.0%	48.37	1.48	-5.23	-3.53
Engine Mounts	8.84	-4.5%	8.45	0.39	-0.61	-1.56
Cylinder Head	49.56	-3.0%	48.09	1.48	-3.70	-2.51
Crankshaft System	51.02	-5.6%	48.16	2.85	-5.38	-1.89
Front Engine System	0.80	-3.2%	0.78	0.03	-0.04	-1.47
Lubrication System	18.90	-3.2%	18.30	0.60	-2.06	-3.45
Cooling System	7.01	-3.2%	6.78	0.22	-0.70	-3.14
Style Cover	1.94	-2.9%	1.88	0.06	-0.35	-6.32

Figure 222: Engine Mass and Cost Summary

7.6.2 Transmission, Transfer Case, Front Differential, Rear Axle/Differential

7.6.2.1 Baseline

The baseline 2014 Chevrolet Silverado comes equipped with a 6-speed automatic transmission with overdrive and manually switched 4WD. The mass of the transmission, shown in Figure 223, is 75.00 kg. The transfer case assembly, highlighted in Figure 224, has a mass of 33.47 kg. The front differential, with a mass of 42.30 kg, can be seen in Figure 225. All these components are constructed in a similar manner with an aluminum housing surrounding hardened steel internal components. The rear axle/differential assembly (shown in Figure 226) has a mass of 81.41 kg. The housing is constructed of cast steel with hardened steel used for the differential and other internal components.

Figure 223: Baseline Chevrolet Silverado Transmission

Figure 224: Transfer Case

Figure 225: Front Differential

Figure 226: Rear Axle/Differential

7.6.2.2 Transmission Technology Options

As with the engine, the baseline transmission, transfer case and front differential are lightweight designs with aluminum housings and high-strength steel components. The same rationale that was used for the LWT engine downsizing applies to these components. The rear axle housing is cast steel that can be replaced by aluminum as well as downsized. The result is a combined mass reduction of 23.17 kg, from the baseline 230.08 kg to the LWT 206.91 kg. This provides an incremental cost of $13.01. Another option considered is to replace the housings with cast magnesium, resulting in a mass reduction of 31.63 kg (14%). The incremental cost of this design is $104.12, or $3.29 per kg mass saved. The mass and cost summary of both options can be seen in Figure 227.

	Components	2014 Silverado Mass (kg)	Transmission				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Option 1	Downsize; Rear Diff. Housing to Alum	230.08	-10.1%	206.91	23.17	13.01	0.56
	Automatic Gearbox	74.65	-5.4%	70.61	4.03	-8.36	-2.07
	Shift Lever Mechanism	2.22	0.0%	2.22	0.00		
	Front Drive Shaft / Differential	42.71	-5.6%	40.34	2.37	-4.16	-1.75
	Intermediate Transmission	0.00	0.0%	0.00	0.00	0.00	0.00
	Rear Drive Shaft / Differential	70.94	-20.7%	56.28	14.65	29.40	2.01
	Transfer Case	38.02	-5.5%	35.92	2.10	-3.88	-1.84
	4x4 Activation System	1.54	0.0%	1.54	0.00		
Option 2	Downsize; Magnesium Housings	230.08	-13.7%	198.44	31.63	104.12	3.29
	Automatic Gearbox	74.65	-9.8%	67.33	7.32	28.90	3.95
	Shift Lever Mechanism	2.22	0.0%	2.22	0.00	0.00	#DIV/0!
	Front Drive Shaft / Differential	42.71	-10.8%	38.12	4.60	20.83	4.53
	Intermediate Transmission	0.00	0.0%	0.00	0.00	0.00	0.00
	Rear Drive Shaft / Differential	70.94	-20.7%	56.28	14.65	29.40	2.01
	Rear Drive Shaft / Diff. (Electronic &	0.26	0.0%	0.26	0.00	0.00	0.00
	Transfer Case	38.02	-13.3%	32.96	5.06	24.99	4.94
	4x4 Activation System	1.54	-0.3%	1.53	0.01	-0.01	-1.32

Figure 227: Transmission Components Mass and Cost Summary

7.6.3 Drive Shafts

7.6.3.1 Baseline

The baseline Chevrolet Silverado is a four-wheel drive vehicle with a manual transfer case. This system includes six drive shafts, as shown in Figure 228, with a total mass of 53.71 kg (listed in Figure 229). The rear intermediate drive shaft is constructed of tubular aluminum while the front intermediate shaft is tubular steel. The remaining four drive shafts are conventional steel bar construction.

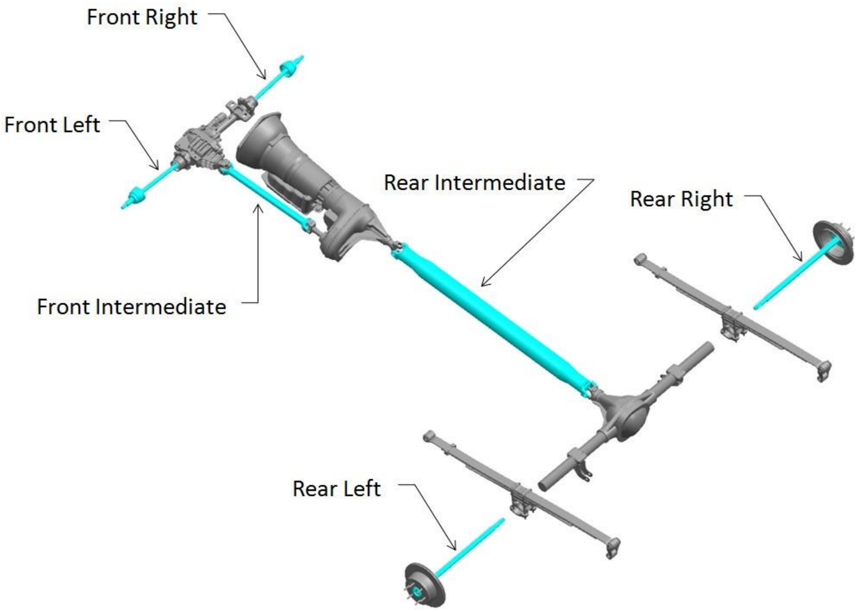


Figure 228: Baseline Chevrolet Silverado Drive Shafts

Item	Mass (kg)
Front Left Drive Shaft (steel rod)	8.58
Front Right Drive Shaft (steel rod)	8.58
Front Intermediate Drive Shaft (steel tube)	6.61
Rear Intermediate Drive Shaft (alum. tube)	8.62
Rear Left Drive Shaft (steel rod)	10.66
Rear Right Drive Shaft (steel rod)	10.66
Total:	**53.71**

Figure 229: Baseline Drive Shaft Masses

7.6.3.2 Drive Shaft Technology Options

Lightweighting the drive shafts could be done through material substitution by replacing the baseline materials with AHSS, aluminum or carbon fiber composites. All these options have been studied by transmission suppliers and OEMs. Aluminum drive shafts have been used on Corvettes and Firebirds. Carbon fiber drive shafts are in use on the Nissan 370Z, Aston Martin Rapide, Mercedes-Benz SLS AMG and Mazda RX8. Carbon fiber drive shafts are normally only considered for certain types of products such as high-performance and racing vehicles. In these vehicles, the low rotational mass, increased vibration dampening and lower torsional spring rate of carbon fiber drive shafts result in increased horsepower and allow the engine to run at higher RPMs, offering competitive advantages. In addition, these vehicles place such a high priority on mass reduction that large cost increases are acceptable. Four wheel drive and rear wheel drive cars and trucks have multiple or long drive shafts, offering the potential of significant mass reduction by replacing steel with aluminum or composite. Front wheel drive midsize vehicles have very short drive shafts, so the mass saved through material substitution does not offset the cost increase. Based upon current industry surveys, aluminum drive shafts cost approximately 1.5 times more than steel while carbon fiber is 2.5 to 4 times the cost of steel.

Option 1 for the LWT drive shafts is to maintain the baseline materials but scale down the size, taking advantage of the overall lower mass of the LWT. This results in a 5 percent reduction in drive shaft weights, from 53.71 kg to 51.02 kg, as shown in Figure 230. This also provides a cost savings of $7.74 per vehicle. Option 2 replaces all the drive shafts with CFRP, reducing the mass to 31.70 kg, a savings of 22.01 kg compared with the baseline. The incremental cost increase of the CFRP drive shafts is $684.48, or $31.09 per kg mass saved. While the CFRP drive shafts save 19.32 kg more mass than Option 1, this design is not feasible from a cost perspective. Therefore, Option 1 has been chosen for the LWT.

	Component	2014 Silverado Mass (kg)	Drive Shafts				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Option 1	Downsize	53.71	-5.0%	51.02	2.69	-7.74	-2.88
	Front Drive Shafts (Steel)	17.16	-5.0%	16.30	0.86	-1.85	-2.16
	Interm. Drive Shaft, Frt (Steel)	6.61	-5.0%	6.28	0.33	-0.71	-2.16
	Interm. Drive Shaft, RR (Alum)	8.62	-5.0%	8.19	0.43	-2.88	-6.69
	Rear Drive Shafts (Steel)	21.32	-5.0%	20.25	1.07	-2.30	-2.16
Option 2	CFRP	53.71	-41.0%	31.70	22.01	684.48	31.09
	Front Drive Shafts (CFRP)	17.16	-45.0%	9.44	7.72	212.93	27.57
	Interm. Drive Shaft, Frt (CFRP)	6.61	-45.0%	3.64	2.97	82.02	27.57
	Interm. Drive Shaft, RR (CFRP)	8.62	-20.0%	6.90	1.72	124.98	72.50
	Rear Drive Shafts (CFRP)	21.32	-45.0%	11.73	9.59	264.55	27.57

Figure 230: Drive Shaft Mass and Cost Summary

7.6.4 Fuel System

7.6.4.1 Baseline

The baseline Chevrolet Silverado fuel system is composed of a 26-gallon (98.4 liter) plastic fuel tank, tank protection and supports, filler pipe, filler cap, charcoal canister and fuel lines. The mass of the entire fuel system (not including fuel) is 22.19 kg, of which the tank itself accounts for 15.42 kg as shown in Figure 231. The mass of 26 gallons of gasoline is approximately 70 kg and is discussed in the Fluids section of this report.

Component	Mass (kg)
Fuel Tank and Protector	15.42
Fuel Tank Support	2.03
Filler Pipe and Support	0.84
Filler Cap	0.08
Fuel Lines	1.36
Charcoal Canister	2.46
Total:	**22.19**

Figure 231: Baseline Fuel System Material and Mass

7.6.4.2 Fuel System Technology Options

The primary method of reducing mass in the fuel system is to reduce the capacity of the fuel tank. This will reduce the mass of the fuel carried while also reducing the mass of the tank itself. The performance criterion that must be maintained is the vehicle range provided by a tank of gas. Because the LWT is lighter than the baseline 2014 Chevrolet Silverado, vehicle fuel economy is improved, allowing the vehicle to travel the same distance using less fuel. The baseline vehicle has an EPA stated average fuel economy of 18 mpg, giving it a range of 470 miles with the 26.0-gallon fuel tank. A number studies have shown that 10 percent reduction in vehicle weight leads to a gain of 3.5 percent to 6.5 percent in fuel economy[112]. The lower increase of 3.5 percent is if the powertrain is not resized to maintain the same vehicle performance, 6.5 percent fuel economy improvement is for resized powertrain. The powertrain for the LWT is resized to main the towing performance or to maintain the same GVWR to horsepower ratio as the baseline vehicle. The fuel economy the LWT is calculated to be 19.7 mpg based on 5.0 percent fuel economy improvement for 10 percent reduction in vehicle mass. This allowed the fuel tank to be reduced in size proportionately, from 15.42 kg to 14.34 kg, a 7 percent mass savings. Less material was required to fabricate the smaller fuel tank, resulting in a cost savings of $6.82 per vehicle. The manufacturing process is unchanged compared with that of the baseline tank. The baseline fuel tank is made of high-density polyethylene with a density of 0.977 g/cm^3. Tanks constructed from coated steels or stainless steel are generally higher mass than the HDPE tanks. Therefore, no material substitutions were made for this component.

7.6.5 Exhaust

7.6.5.1 Baseline

The baseline Chevrolet Silverado uses a conventional exhaust system composed of manifolds, exhaust pipes, catalytic converter, muffler, heat shields, seals and hangers, as shown in Figure

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[112] Wohlecker, R., Johannaber, M., and Espig, M., "Determination of Weight Elasticity of Fuel Economy for ICE, Hybrid and Fuel Cell Vehicles," SAE Technical Paper 2007-01-0343, 2007, doi:10.4271/2007-01-0343.

232. Most of the components are steel with the exception of the hangers (a combination of rubber and steel) and the inner components of the catalytic converter. The total mass of the exhaust system is 51.91 kg.

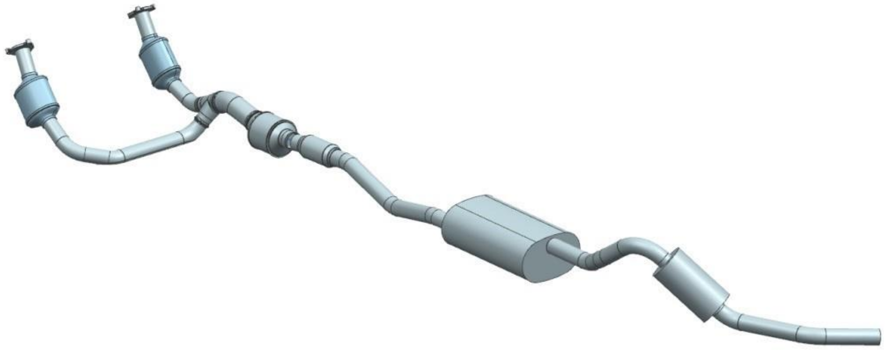
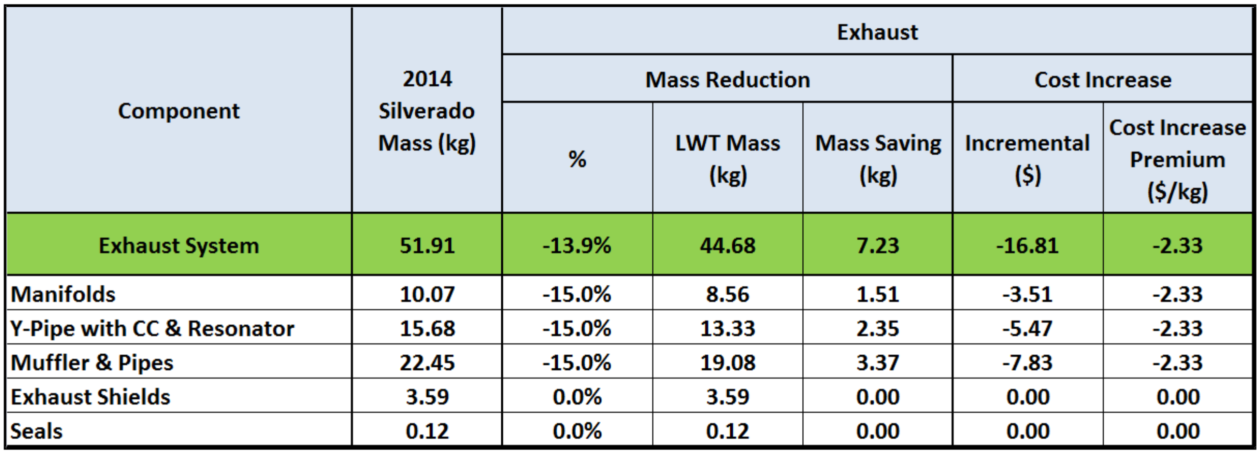


Figure 232: Baseline Exhaust System

7.6.5.2 Exhaust System Technology Options

As was done with the engine cooling system, the exhaust system can take advantage of the lower vehicle mass and smaller engine/transmission to reduce the sizes of its components, as shown in Figure 233.



Component	2014 Silverado Mass (kg)	Exhaust				
		Mass Reduction			Cost Increase	
		%	LWT Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Exhaust System	**51.91**	**-13.9%**	**44.68**	**7.23**	**-16.81**	**-2.33**
Manifolds	**10.07**	**-15.0%**	**8.56**	**1.51**	**-3.51**	**-2.33**
Y-Pipe with CC & Resonator	**15.68**	**-15.0%**	**13.33**	**2.35**	**-5.47**	**-2.33**
Muffler & Pipes	**22.45**	**-15.0%**	**19.08**	**3.37**	**-7.83**	**-2.33**
Exhaust Shields	**3.59**	**0.0%**	**3.59**	**0.00**	**0.00**	**0.00**
Seals	**0.12**	**0.0%**	**0.12**	**0.00**	**0.00**	**0.00**

Figure 233: Exhaust System Mass and Cost Summary

Substituting lower density materials, such as aluminum or composite, was not feasible in this application due to the high-temperature requirements. The baseline 409 stainless steel for its ability to maintain structural properties during extended periods in temperatures as high as 700˚F. Substituting a material unable to meet this requirement would seriously compromise vehicle performance. Currently there are no other known technology improvements under development that offer mass saving potential in the 2020-2030 time frame.

The final LWT exhaust system has a combined mass of 44.68 kg, 7.23 kg less than the baseline 51.91 kg. The cost effect is a reduction of $16.81 per vehicle due to the need for less material.

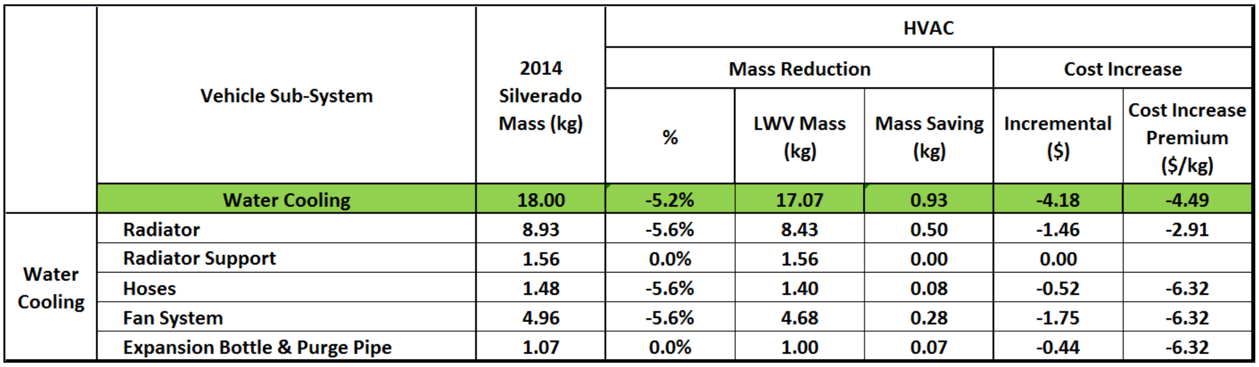
7.6.6 Engine Cooling System

7.6.6.1 Baseline

The 2014 Chevrolet Silverado uses a conventional water cooled engine with a radiator, water pump, fan, thermostat, hoses and fittings. The mass of the water pump has been included with that of the engine, and the mass of the engine coolant has been included in the Fluids section.

7.6.6.2 Cooling System Technology Options

With the reduction of vehicle mass and engine/transmission sizes, the engine cooling components were also scaled down as shown in Figure 234. This resulted in an overall mass savings of 0.93 kg per vehicle (5.2%) compared with the baseline, and a cost savings of $4.18 per vehicle.



	Vehicle Sub-System	2014 Silverado Mass (kg)	HVAC				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
	Water Cooling	**18.00**	**-5.2%**	**17.07**	**0.93**	**-4.18**	**-4.49**
Water Cooling	Radiator	8.93	-5.6%	8.43	0.50	-1.46	-2.91
	Radiator Support	1.56	0.0%	1.56	0.00	0.00	
	Hoses	1.48	-5.6%	1.40	0.08	-0.52	-6.32
	Fan System	4.96	-5.6%	4.68	0.28	-1.75	-6.32
	Expansion Bottle & Purge Pipe	1.07	0.0%	1.00	0.07	-0.44	-6.32

Figure 234: Engine Cooling System Mass and Cost Summary

7.7 Interior Systems

The baseline Chevrolet Silverado interior is primarily composed of steel, plastics, fabric and foam (insulation and carpeting will be covered in another section of this report). As can be seen in Figure 235, plastics account for 30 percent of the interior mass (44.37 kg), making this an ideal candidate for mass reduction. Plastics in general are very low density materials, making it difficult to achieve mass savings. However, recent technologies from Trexel, Inc. (MuCell) and Wittmann Battenfeld (Cellmould) offer promising opportunities to reduce significant mass with little or no cost penalty.

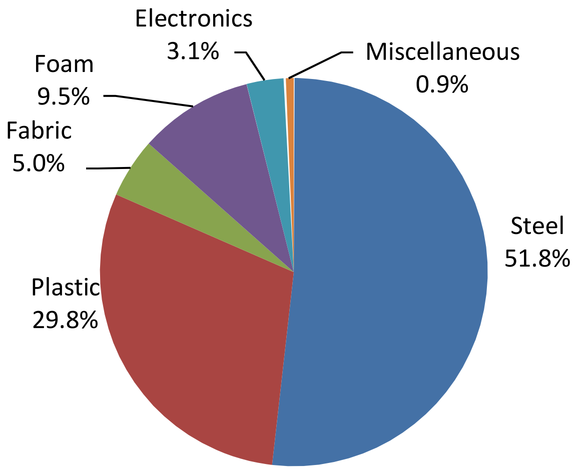


Figure 235: Baseline Chevrolet Silverado Interior Materials Distribution

Many automotive plastic parts can benefit from the application of foaming plastic technologies like MuCell and Cellmould. With MuCell, a supercritical fluid (SCF) like nitrogen or CO_2 is dissolved and uniformly dispersed into the molten polymer during the injection process. In the mold, the lower pressure allows the SCF to nucleate, or foam, producing a microcellular material with a lower density than the basic polymer. This technology, currently available and in use by Audi, Porsche, Volkswagen and Mercedes-Benz, can reduce part mass by 5 percent with a simple material substitution or as much as 25 percent if the part is redesigned to take full advantage of the MuCell process. These optimizations include redesigning ribs, bosses, wall thicknesses and gate locations with the MuCell process in mind. In the future, part costs could possibly be reduced through shorter processing times, less required raw material, smaller molding machines and improved product quality. It should be noted that, due to surface appearance concerns, MuCell material is generally not recommended for use on Class A surfaces, though work is currently underway by Trexel to improve this. For the LWT project, MuCell is only recommended for components and surfaces, which are out of the consumer's view. Some examples of current MuCell automotive applications are the Volkswagen Touran interior trim, Ford Escape I/P and carrier, and BMW fan shrouds.

Wittmann Battenfeld's Cellmould process directly injects either chemical or physical foaming agents during molding to create a sandwich-type structure with a low density foam core inside of a compact shell. This produces a part that is lightweight, rigid and has little warpage. When variothermic mold tempering (careful control of the mold temperature to optimize it for each phase of the molding cycle) is employed during this process, the surface quality of parts can be improved enough for them to be used for Class A surfaces. The expected mass savings for these parts is estimated at 30 percent[113].

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[113] www.apn.com.sg/resource-centre/item/410-wittmann-battenfeld-showcases-cellmould- structured-foam-process-at-k2013

Interior trim panels, ducting, I/P retainers and bezels are ideal candidates for this technology, though care must be taken to ensure integrally molded snap-fit locking features have acceptable insertion/retention properties. For the LWT, the part cost is assumed to be neutral based on supplier feedback.

7.7.1 Instrument Panel

7.7.1.1 Baseline

The baseline 2014 Chevrolet Silverado instrument panel assembly, which can be seen in Figure 236, is constructed of a cross-car beam, carrier, upper and lower covers, HVAC vents, glove box and door, electronics (instrument cluster, radio, GPS, HVAC controls, center display, and various control modules), inflatable restraint system, bezels, brackets and mounts. The mounting brackets allow for the attachment of the cross-car beam to the body structure and instrument panel assembly, in addition to providing attachment points for the steering column and passenger air bag module. The cross-car beam, brackets and mounts are steel, while most of the other components, aside from electronics and inflatable restraint system, are various types of plastics. The mass of the entire baseline I/P assembly (except for the inflatable restraint system, which is covered in another section of this report) is 32.71 kg as detailed in Figure 237.

Figure 236: Baseline I/P

Item (material)	Mass (kg)
Cross-Car Beam Asy (steel)	12.27
I/P Carrier (plastic)	4.53
Upper Skin (plastic)	3.85
Lower Cover (plastic)	0.74
Air Vent Asy (plastic)	0.91
IP Cluster (various)	1.07
Audio Controls (various)	0.35
GPS	0.55
Heater Control	1.02
Dashboard Cover Asy (plastic)	1.25
Passenger Side Storage (plastic)	1.22
AshTray (plastic)	0.80
Cluster Trim (plastic)	1.07
Glove Box Assy (various)	1.62
Headlight Switch (various)	0.37
Multifunction Control (various)	0.24
Bezels (metal and plastic)	0.69
Dashboard Clips (various)	0.16
Total:	**32.71**

Figure 237: Baseline Instrument Panel Material and Mass

7.7.1.2 Instrument Panel Technology Options

The backbone of the baseline I/P assembly is the tubular steel cross-car beam with multiple steel brackets and mounts welded to it, shown in Figure 238. The mass of this assembly is 12.27 kg. Lightweight options for this assembly illustrating the estimated mass and cost effects can be seen in Figure 239. The LWT replaced this baseline steel cross-car beam assembly with a one-piece magnesium casting, such as that produced by Lunt Magnesium Die Casting for the BMW E70 (see Figure 240).[114] This beam created 50 percent mass savings and received the American Foundry Society Best-In-Class award in 2007. For the LWT, the brackets and mounts are incorporated into the basic casting, reducing the complexity and part count significantly and improving geometric tolerance. Magnesium castings have been successfully used as cross-car beams in automotive I/P applications for several years on such programs as the GM full-size

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[114] www.lunt.com/news1021.html

trucks, Jeep Grand Cherokee, and Ford GT. Honda designed and implemented a cast magnesium instrument panel on its 2008 FCX, documenting a 40 percent mass savings[115].

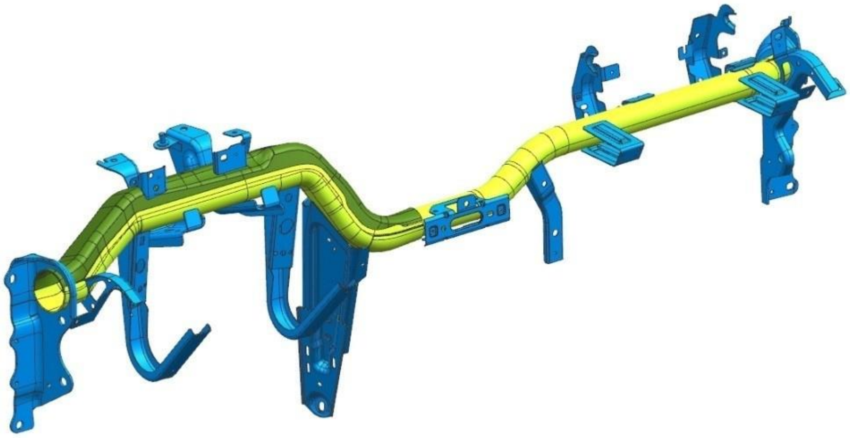

Figure 238: Baseline 2014 Chevrolet Silverado I/P Cross-Car Beam Assembly

	Material	2014 Silverado Mass (kg)	Instrument Panel				
			Mass Reduction			Cost Increase	
			%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Cross-Car Beam	AHSS	12.27	-15.0%	10.43	1.84	3.83	2.08
	Aluminum Tubes & Stampings	12.27	-20.0%	9.82	2.45	37.28	15.19
	Aluminum Casting	12.27	-25.0%	9.20	3.07	12.62	4.11
	Magnesium Casting	12.27	-45.0%	6.75	5.52	26.51	4.80

Figure 239: I/P Cross-Car Beam Options – Mass and Cost Summary

Figure 240: BMW E70 Cast Magnesium I/P Beam
(www.lunt.com/news1021.html)

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[115] (ref. Kuwano, Y., Sakamoto, Y., Ayumu, U., Hata, T., Endo, T., Atkin, S., "CAE Analysis for Development of Magnesium Cross-Car Beam," Honda R&D Technical Review, April 2008, Vol. 20, No. 1, eISBN 978-0-7680-5733-1)

The various parts in the I/P structure containing plastic have a combined mass of 17.36 kg, of which 14.36 kg is plastic that was replaced with MuCell or Cellmould technology, depending upon whether it is a Class A surface or not (MuCell is not recommended for Class A surfaces). The I/P upper skin was replaced with Cellmould and a lower density foam, the lower cover is Cellmould and the remaining plastic parts MuCell. The incremental cost of the MuCell and Cellmould technology is neutral, as has been discussed previously, but the lower density foam in the upper skin has an incremental cost increase of $15.43 per vehicle. This represents an overall cost increase premium of $5.30 per kg for these plastic components.

The total mass of the LWT instrument panel assembly with all the proposed improvements and redesigned IP beam in magnesium casting is 24.42 kg. This represents a mass savings of 8.44 kg per vehicle (25.4%) at an incremental cost of $19.23, or $2.32 per kg of mass saved.

7.7.2 Seats

7.7.2.1 Front Seats - Baseline

The baseline 2014 Chevrolet Silverado 40/20/40 split bench front seats (see Figure 241) are of a conventional design with respect to materials and construction. They each consist of a frame, base, tracks, riser, recline and lumbar adjustment mechanisms, safety restraints, seatbelt attachment anchors, foam cushioning, fabric cover and plastic garnishments. Fore and aft, recline and lumbar support adjustments for the front seats (driver and passenger) are manually operated.

Figure 241: Baseline Front Seats and Center Console

The front seat frame is constructed of stamped, cold rolled sheet steel, as are the base, tracks and riser. The cushioning is molded polyurethane foam, the cover is knit fabric and the garnish trim is polypropylene. The combined masses of the complete driver and passenger seat assemblies and center console are 57.02 kg (refer to Figure 242).

Item (material)	Mass (kg)
Seat Frame and Mechanisms (steel)	24.71
Seat Cushions (foam)	6.45
Seat Covers (fabric)	2.50
Center Console Frame (steel)	7.75
Center Console Cushion (foam)	1.73
Center Console Cover (fabric)	0.64
Garnish Trim (plastics)	4.41
Miscellaneous Parts and Fasteners	8.83
Total:	**57.02**

Figure 242: Baseline Front Seat Material and Mass
(Combined Driver, Passenger and Center Console)

7.7.2.2 Rear Seat – Baseline

The rear seat assembly, shown in Figure 243 consists predominantly of foam cushioning, cloth cover and plastic garnish trim backed by mild steel stampings with a tubular steel frame. The mass of the complete rear seat assembly is 40.43 kg, as can be seen in Figure 244.

Figure 243: Baseline Rear Seat Assembly

Item (material)	Mass (kg)
Frame and Mechanisms (Steel)	27.73
Cushions (foam)	5.60
Covers (Fabric)	3.19
Garnish trim (plastics)	1.14
Miscellaneous – Locking Mechanisms and	2.77
Total:	**40.43**

Figure 244: Baseline Rear Seat Materials and Mass

7.7.2.3 Seats – Technology Options

7.7.2.4 Seat Frame Construction

The Chevrolet Silverado seat frames use a conventional stamped steel design. This is a proven approach from both performance and cost effectiveness perspectives. Figure 245 shows portions of the rear seat frame, revealing the materials and construction methods. A typical automotive steel seat frame design generally includes the seat base, adjustment rails and the seat back structure. For this program, the team collaborated with one of the largest Tier 1 seating suppliers to examine the future trends in seat frame construction.

Figure 245: Baseline Chevrolet Silverado Rear Seat Frame

For the next generation of seat construction (MY 2016-2018), the team believes that replacing the steel seat frame material with Advanced High Strength Steel is a cost effective solution. This allows for smaller gauge sizes, resulting in a lighter design. The use of AHSS provides for improvements in structural strength and less deformation during crash events. One area in particular that would benefit from the use of high strength steel is the seatback "hoop." This is a stamped tubular design that could be optimized through hydroforming with high-strength steels. The seat risers, tracks and adjustment mechanisms are finely tuned to provide smooth movement of the seat with no binding, as well as positive locking with no rattling or slippage. Modifications of these parts would require significant development time and testing resources to maintain the current level of safety and performance. Similarly, reducing mass in the electrical and safety components of the seat assembly would require a great deal of engineering, design and testing to develop them to the point at which they could meet performance and regulatory requirements. While there is time before the 2020-2030 time frame to develop these systems, the amount of mass that could be saved is less than 2 kg and does not justify the investment costs. Therefore, these components will be carried over from the baseline to the LWT.

Lear Corporation has developed an advanced seating system called the Evolution Seat[116] shown in Figure 246. The Evolution Seat incorporates several technologies that reduce seat weight up to 11 kg compared to conventional seats without sacrificing strength or safety. The combined Lear technologies in the Evolution Seat significantly reduce weight and trim costs. Lear claims that the Evolution Seat structures are as much as 30 percent lighter than conventional structures because they integrate lightweight mechanisms and rails, and avoid the use of exotic metals.

Figure 246: The Evolution Seat by Lear Corporation
(http://articles.sae.org/8268/)

Other seat frame construction materials reviewed were cast aluminum, cast magnesium and composites. Incorporating cast magnesium or aluminum for the seat frame bottom is a lightweight option for the 2018-2020 time frame. Cast magnesium seat frames have been used in various Mercedes, Fiat, Hyundai Azera, and Jaguar vehicles. The Mercedes-Benz SLZ magnesium frame, which weighs 2.05 kg, is shown in Figure 247. The use of magnesium casting of this type is equivalent to a mass saving of 45 percent compared with similar steel structure.

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[116] www.sae.org/mags/aei/inter/8268

Figure 247: Magnesium Seat Back – Mercedes-Benz SLZ (Lear)

Dow Automotive has developed a new design, material and technology that enable the entire seatback structure to be made of plastic composite, further reducing weight while meeting all safety and other regulatory requirements.[117] The seatback is molded from a polycarbonate and acrylonitrile butadiene styrene polymer blend and includes a built-in head restraint and provisions for mounting a side air bag as shown in Figure 248. With this approach, the tooling costs for blow molding are much lower than tooling costs for steel and other metal-based systems. Prototyping is simplified and relatively fast, thereby leading to quicker turnaround times for component optimization. This technology provides a 2.3 kg mass reduction as well as a $4.00 cost savings per vehicle. With an ABS seat frame design, many components could be integrated into a single, easy to form ergonomic part, reducing part count and manufacturing complexity. As an example, the head restraint can be molded into the seatback and surfaces requiring trim can be reduced. Additionally, the ABS seat structures can be tuned to help absorb energy during impact events.

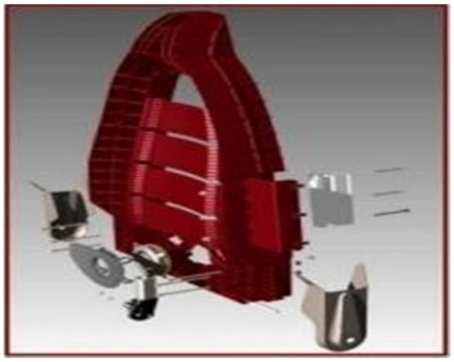

Figure 248: Dow Automotive Plastic Composite Seatback (SAE Paper No. 299-51528)

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[117] SAE Paper No. 299-51528

Composites offer an attractive design possibility for the 2020-2030 time frame. Fiber-reinforced composite rear seat structures achieve even greater mass reduction than magnesium, aluminum or ultra-high-strength steels, providing the lowest mass design, but at higher costs. These structures can also be designed to meet the same requirements as the baseline steel structure. The benefits of composite seat structures, as shown in Figure 249 are:

- Up to 50 percent mass reduction compared to steel,
- Less complex parts and fewer process steps reduce development and manufacturing time, and
- Structural behavior and crash strength equivalent to current production seats.

Figure 249: Fiber-Reinforced Composite Rear Seat Back (JCI)[118]

7.7.2.5 Seat Foam

Seating suppliers have developed seat foams of varying levels of density to reduce the volume of foam required to cover a seat frame, while offering all the ergonomic support that is needed to meet consumer expectations. These foams offer lighter weight and provide design flexibility for appealing contours and shapes. One seat supplier is using a system of overlapping structural foam shapes to eliminate the traditional steel springs and other support structures used in the base and back of auto seats. The combination of the advanced low volume/high-density foams with a composite seat frame structure offers the greatest benefit for weight reduction. The Woodbridge Group, a provider of foam technologies for automotive seating, has developed a lightweight seating system using structural foam as an alternative to the metal wire frame that is commonly used in seat cushions and backs.[119] Typical weight savings achieved for rear seat cushions were in the range of 20-40 percent. The technology was patented and trademarked with the name StructureLite and is currently available in two types of foam: polyurethane or expanded polypropylene.

7.7.2.6 Seat Fabrics

Tier 1 automotive suppliers are developing seat fabrics that can be woven to provide similar support characteristics as steel springs when applied over seat frame structures. Combined with

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[118] www.johnsoncontrols.com/publish/etc/medialib/jci/ae/naias_2011/pds_seating.Par.0943.File.dat/modular_rear_seat_structure_composite_concept_en.pdf)

[119] SAE Paper2011-01-0424 Published04/12/2011

structural foam, this approach has the potential to eliminate or reduce the steel support springs used in a traditional seat design, while also lowering costs. Other developments in the field are eco-friendly fabrics with up to 100 percent recycled content, leading to conservation of natural resources, lower energy usage for production and reduced landfill content.

7.7.2.7 Risks and Trade-offs

The seat system designs explained above all have potential risks and trade-offs. For example, material substitution may very well lower mass, but could adversely affect performance. To bring these design concepts to production, they first need to be validated by finite element model analysis followed by in-vehicle dynamic testing to tune the designs to the particular dynamics of the vehicle under development. Seat designs need to be evaluated for their ability to limit whiplash injury and retain structural integrity during impact events. The seating system designed for a particular application would have to be analyzed with respect to safety standards FMVSS No. 201 (Occupant Protection in Interior Impact), FMVSS No. 202 (Head Restraints), FMVSS No. 207 (Seating Systems) and FMVSS No. 210 (Seat Belt Assembly Anchorages). As was discussed previously, the LWT seat risers, tracks and adjustment mechanisms are being carried over from the baseline to minimize risk in these components. Finally, any low mass designs must be subjectively evaluated for comfort and ergonomics. It is possible to design a seating system that meets all the performance requirements but lacks the aesthetic appeal customers expect. In these cases, it may be necessary to add materials that would result in a shape or style more acceptable to the customer. The seating sub-system weight reduction technologies are summarized in Figure 250.

Component	Technology	Benefits	Risks/Trade-offs
Seat Frame	Advanced High Strength Steel Hydro-formed seat back Die-cast Mg/Al Blow-molded seat back Composites	Lower mass and costs Lower mass and costs Lower mass Lower mass and costs Lower mass	Higher costs Higher costs High-volume manufacturing
Seat Foam	Multi-density foam	Lower system mass	Complexity/costs
Seat Fabric	Advanced fabric-weaving technology	Lower mass, system costs	Complexity, Customer acceptance

Figure 250: Seating Sub-System Weight Reduction Technologies

7.7.2.8 Seat Technologies Summary

The following future automotive seat technologies matrix (Figure 251) was developed through discussion with major seat suppliers.

	Baseline 2014 Chevrolet Silverado		Next Generation 2016 - 2018		Generation 2 2018 - 2020		Generation 3 2020 - 2030	
	1st Row	2rd row	1st Row	2rd row	1st Row	2rd row	1st Row	2rd row
Mass (kg)	57.02	40.43	-10%	-10%	-20%	-20%	-30%	-30%
Cost Incr.	n/a	n/a	+5%	+5%	+10%	+10%	+15%	+15%
	Technologies		TRIP steels used in structural components		Composite frame structures (Lanxess type process)		Biominic structure (composite structural components)	
			Natural material impregnated plastics (wood)		Aluminum structures with glass fiber PP		Lightweight plastic composites – PP with wood filling	
			Increased natural polyols (15%) in foam (soy, castor, palm)		Increase natural polymers (20%+) in foam		TPU replacement for PU foam	
			Add inert gases to foam (CO_2)		New fabric materials to include trim and laminate		Aluminum mechanism	
			Expanded Polypro pellets as structure and replacement for PU foam		Digital printing to reduce wire harness		Nano generation within components	
			Composite seat backs – aluminum with fiber board		Aluminum/steel structural components		Natural material – with fiber structural components	

Figure 251: Seating Technologies Matrix

Based upon the Seating Technologies Matrix, the calculated mass and cost for the LWT front and rear seats[120] are shown in Figure 252. For year 2030, it is estimated that the baseline vehicle seating mass of 97.45 kg can be reduced by 30 percent, equivalent to a mass savings of 29.24 kg. The increase in cost over the baseline vehicle is $137.70 per vehicle.

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[120] Based on feedback from leading seat suppliers

Time Frame	Chevrolet Silverado Mass (kg)	LWT Mass (kg)	Mass Savings (kg)	Mass Savings (%)	Cost Increase ($)
Next Generation 2016 - 2018	97.45	87.71	9.74	10.0	45.90
Generation 2 2018 - 2020	97.45	77.96	19.49	20.0	91.80
Generation 3 2020 - 2030	97.45	68.21	29.24	30.0	137.70

Figure 252: LWT Seating Mass and Cost Summary

The mass of the final LWT seat designs (front seat, rear seat and center console combined) is 68.50 kg per vehicle. This is a mass savings of 28.95 kg (29.7%) compared with the baseline Silverado at an incremental cost increase of $137.70 ($4.76 per kg of mass saved). The LWT seat designs are assumed to meet all the regulatory, ergonomic and structural performance goals met by the baseline seats. However, it is important to note that the scope of this study does not allow full design and validation of the seat concepts selected for the LWT. Seat design is complicated and must meet many safety standards; simple material substitution without full validation and testing simulations as performed by the seat suppliers might not conform to the standards or meet customer satisfaction. Due to time and resource limitation, the team relied upon the expertise of knowledgeable suppliers.

7.7.3 Trim

Automotive OEMs are turning to “green” natural fibers and other organic biodegradable materials for use in automotive interior components such as headliners, seat foam, carpet and interior trim. These are usually mixed with traditional trim materials in some percentage to produce parts that lessen demand on petroleum use and minimize the impact on the environment. These materials are not expected to have a significant effect on part mass. Replacing injection molded plastic parts with MuCell or Cellmould can provide mass savings from 5 percent to 25 percent on interior trim and other molded components, depending upon how much the parts are engineered to take advantage of the molding processes. Trim components that are constructed of a combination of plastic and other materials may also be able to benefit from the lower density plastics, though with less mass impact on the component. At this time, the conservative estimate of 5 percent mass savings will be used for these parts.

The Chevrolet Silverado exterior trim consists of moldings, weather-stripping, garnish, air dams/spoilers, bumper trim, splash shields, etc. Many of these parts are Class A surfaces, so it is not recommended to use MuCell technology on them. It may be possible to use Cellmould technology on the Class A parts if the sandwich-type construction is able meet the strength, flexibility and durability requirements, particularly for spoilers and air dams. The team felt that assuming a mass reduction of 5 percent by using Cellmould on many of these parts was a conservative estimate for preliminary design.

The baseline floor covering is rubberized vinyl material. It is anticipated that future floor coverings will be able to achieve equivalent performance at lower mass, but at this time no data was found on these upcoming materials. The headliner is made of pressed fiber covered with fabric and backed by foam. As with the floor covering, mass reductions are anticipated but not supported by current data. For the LWT preliminary design it was conservatively estimated that 5 percent mass savings is achievable in the 2020-2030 time frame for the floor covering, headliner and other miscellaneous trim materials.

The interior insulation in the baseline Chevrolet Silverado consists of conventional cotton fiber batting with a total mass of 17.40 kg. This insulation is located in the front of dash, floor and overhead (closures insulation was previously addressed in the closures section of this report). The reduction of metal thickness in the LWT cab makes it necessary to increase the amount of sound insulation to maintain the quietness of the baseline Silverado. Three lower mass options were considered as potential replacements for the baseline insulation to offset this increase. 3M offers a product called Thinsulate that has been used on such vehicles as the Toyota Prius and up-level Honda Accord models. This is a non-woven polypropylene blend that can reduce the mass of conventional insulation by as much as 40 percent while maintaining the same or better acoustic protection.[121] In addition, this is a hydrophobic material eliminating the need for waterproofing barriers and resisting mold and mildew growth. CTA Acoustics provides a glass fiber based insulation called QuietBlend that can reduce mass by as much as 25-30 percent with no drop-off in acoustic or thermal protection. Several vehicle manufacturers, such as Mercedes--Benz, GM, Ford, Chrysler, Nissan and Toyota have successfully incorporated QuietBlend materials. Faurecia, as part of their “Light Attitude” program, has developed a lightweight dash mat composed primarily of polyurethane that can reduce the mass by as much as 30 percent. All these materials are in current use and are excellent candidates for high-volume production. The design direction for the LWT was to replace the baseline insulation with Thinsulate and to engineer this material to meet or exceed the acoustic level of the baseline Silverado. The expected effect of replacing the baseline material with Thinsulate is a 2.61 kg increase (15%) per vehicle at a cost increase of $10.69.

The overall effect of these interior and exterior trim changes is a mass savings of 6.36 kg per vehicle with a cost increase of $10.69 as shown in Figure 253.

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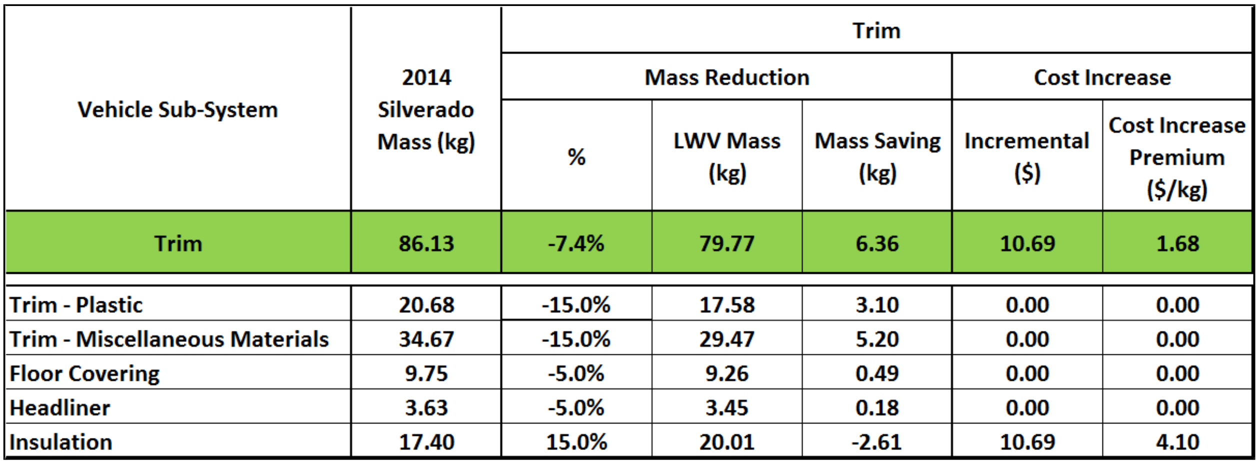
[121] http://articles.sae.org/9160/



Vehicle Sub-System	2014 Silverado Mass (kg)	Trim				
		Mass Reduction			Cost Increase	
		%	LWV Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Trim	**86.13**	**-7.4%**	**79.77**	**6.36**	**10.69**	**1.68**
Trim - Plastic	20.68	-15.0%	17.58	3.10	0.00	0.00
Trim - Miscellaneous Materials	34.67	-15.0%	29.47	5.20	0.00	0.00
Floor Covering	9.75	-5.0%	9.26	0.49	0.00	0.00
Headliner	3.63	-5.0%	3.45	0.18	0.00	0.00
Insulation	17.40	15.0%	20.01	-2.61	10.69	4.10

Figure 253: Interior Trim Mass and Cost Summary

7.7.4 Entertainment

The baseline Chevrolet Silverado is equipped with the optional MyLink 4.2" diagonal color radio system that includes a conventional AM/FM/CD radio, six speakers, and GPS (see Figure 254). The total mass of this system is 4.56 kg, as shown in Figure 255.

Figure 254: Baseline Chevrolet MyLink Audio System

Component	Mass (kg)
Audio Control Unit	0.34
Antenna	0.22
Receiver	0.47
Navigation Unit	0.56
Speakers – Front Doors	1.41
Speakers – Rear Doors	1.20
Speakers – Instrument Panel	0.36
Total	**4.56**

Figure 255: Baseline Audio System Mass

Some of the mass reduction strategies applicable to entertainment/navigation systems are:

- Replacing metal housings with low density MuCell or Cellmould material,
- Low mass speakers,
- LCD and LED head unit systems that eliminate mechanical controls and incorporate thin displays,
- Eliminating the CD player and including only an iPod/MP3 input jack with the radio, and
- Replacing the GM audio system with a lighter mass aftermarket audio system.

The housings in the baseline Chevrolet Silverado audio system are constructed of lightweight plastic and the baseline speaker system is already a very lightweight system, so these did not present mass reduction opportunities. Introducing an LCD or LED faceplate could reduce the mass of the knobs and tuning mechanism, but these components make up a very small fraction of the head unit mass while the CD player and electronics account for the majority. There are no indications of significant mass reductions in these components in the near future. Eliminating the CD player would likely be seen as an unacceptable loss of content by the consumer, so this option was ruled out. While there is a possibility that CD players could be phased out by the 2020-2030 time frame, the team decided that there is not enough certainty of that possibility to include it in the LWT. Replacing the baseline GM audio system with an aftermarket system presents compatibility issues with the GM MyLink system. In addition, the aftermarket systems available that fit the 2014 Chevrolet Silverado had metal housings and higher masses than the baseline.

A new technology concept being developed by a partnership between Johnson Controls and Bongiovi Acoustics is called Lightweight Audio.[122] Traditional speakers are eliminated from the doors, I/P and trim panels and replaced by lightweight transducers in the headliner and trim panels. The interior trim itself becomes the speakers, providing a surround-sound effect that is more acoustically accurate than the current speaker systems. An additional benefit is that it removes a cut-out from the door structure, reducing sound and water intrusion. The amount of mass savings provided by this system was not yet available, but could be roughly approximated for the LWT by subtracting the mass of the speakers (2.97 kg) and adding in the transducers and digital amplifier required by the system (possibly 0.5 – 1.0 kg), giving a potential mass savings of 2.0 – 2.5 kg per vehicle. The cost of this new system was also not available at this time. Because of the early stage of development and the uncertainties with Lightweight Audio, this was not proposed for the LWT, but should be kept in mind as a future possibility.

No mass reduction opportunities for the entertainment system were identified that appeared to be ready for high-volume production in the 2020-2030 time frame, so the LWT will carry over the baseline system.

7.7.5 Control Systems

The Chevrolet Silverado control systems include the accelerator pedal, brake pedal, parking brake lever, gear selector handle and housing assembly, transfer case handle and housing assembly, linkages, brackets and switches. In a previous section of this report it was proposed to replace the mechanical parking brake with an electric system, where a small switch, actuator, and wiring replaces the conventional pedal and linkages. Making this type of change to the accelerator and brake pedals would not be readily accepted by consumers due to their comfort level with the long standing operator interface. Therefore, changes to those components would be limited to replacing the materials with lower mass alternatives. As the total mass of the accelerator pedal, brake pedal and linkages is 5.44 kg, the potential mass savings to cost ratio is not beneficial. Electric gear shifters are used on some motorcycles, but are not currently considered for automotive applications. The LWT has carried over these components from the baseline.

7.7.6 HVAC

The air conditioning system is the single largest auxiliary load on a vehicle by nearly an order of magnitude. The peak cabin soak temperature must be reduced if a smaller air conditioning system is to be used. Advanced glazing and cabin ventilation during soak conditions are effective ways to reduce the peak cabin temperature. HVAC systems are engineered by Tier 1 suppliers to a particular vehicle's cabin volume and specific operating criteria established by an OEM. HVAC system suppliers have already engineered the major components of their HVAC system for optimal efficiency, mass, material usage and chlorofluorocarbon emissive refrigerant type as regulated by law.

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[122] www.youtube.com/watch?v=jvxGJ-d0OC0

The best opportunity for mass reduction in the HVAC system is to introduce low density plastics, such as MuCell or Cellmould, wherever possible. Because the functionality of the HVAC unit and compressor have already been engineered and optimized, as mentioned in the previous paragraph, this can be done by replacing the metal housings with low density plastic, achieving 5 percent mass savings on these components while preserving their performance. The ducting offers the greatest possibility of mass reduction as advantages available with foaming plastic technology (optimizing rib, wall and boss dimensions and injection gate locations, etc.) can be incorporated along with the density savings for a 20 percent mass reduction. The tubes, hoses, connectors and fasteners will be carried over from the baseline. The total mass savings for these HVAC components is estimated to be 2.16 kg per vehicle (7%) compared with the baseline with a cost savings of $2.87.

7.8 Electrical System

7.8.1 Battery

The baseline Chevrolet Silverado uses a standard lead-acid automotive battery with a mass of 19.55 kg. Cables, supports and cover add another 3.39 kg to this mass. Lithium-Ion (Li-Ion) batteries suitable for automotive use have been recently developed offering significant mass savings, but at a hefty cost premium. Braille Battery[123] currently offers several Li-Ion batteries that could be used in the Silverado with masses ranging from 4.5 kg to 8.8 kg. The retail costs of these batteries range from $1,469 to $2,604, while the cost of the baseline Silverado battery is approximately $175.00 at retail auto supply stores. As the overall cost limit of this study is 10 percent parity with the baseline vehicle MSRP, or $3,805.50, the current prices of Li-Ion batteries do not present an acceptable business case for the purposes of this project. Industry experts anticipate the price of Li-Ion batteries dropping by as much as 64 percent by the year 2020,[124] improving the business case for Li-Ion. Average values from Braille Battery indicate that replacing the baseline battery with Li-Ion can reduce the LWT mass from 19.55 kg to 6.47 kg, a drop of 67 percent. Using industry projections of future prices to extrapolate from current Braille Battery prices, the cost of this replacement in 2020 is $526 per vehicle ($40.21 per kg of mass saved). However, even with these projected cost reductions, the Li-Ion battery is too expensive for the LWT. Therefore, the LWT uses a current technology lead-acid battery that is scaled down in size to take advantage of the lighter vehicle mass. This assumes that the LWT mass of the cables, supports and cover are the same as the baseline. The resulting battery mass is estimated to be 18.00 kg, 1.55 kg (8%) less than the baseline. The cost effect is neutral. Figure 256 shows the mass and cost summary of these options.

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[123] www.braillebattery.com/

[124] http://green.autoblog.com/2013/11/08/li-ion-battery-prices-headed--down-180-kwh/

	Component	2014 Silverado Mass (kg)	Electrical				
			Mass Reduction			Cost Increase	
			%	LWT Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Option 1	Battery (Lead-Acid)	19.55	-7.9%	18.00	1.55	0.00	0.00
Option 2	Battery (Li-Ion)	19.55	-66.9%	6.47	13.08	526.00	40.21

Figure 256: Battery Mass and Cost Summary

7.8.2 Wiring and Wire Harness

The baseline 2014 Chevrolet Silverado uses conventional insulated copper wiring in all its harnesses. The most promising mass reduction alternative to that is copper clad aluminum wiring, in which a layer of pure copper surrounds an aluminum core, resulting in mass and cost reductions with no loss in performance. Although the electrical conductivity of aluminum is only 66 percent that of copper, the density is less than a third (2.7 g/cm^3 compared with 8.9 g/cm^{3}for copper). Therefore, the aluminum wire bundles must be larger in diameter than copper to carry the same current, but mass savings are still achievable. GM electrical strategies do not allow the usage of CCA wiring in external or engine compartment applications, and other applications may be subject to spacing constraints. The total wiring harness mass of the 2014 Silverado baseline is 28.48 kg, of which 14.68 kg are engine compartment or exterior applications. Of the remaining 13.80 kg, the team conservatively estimates that 50 percent, or 6.90 kg can be replaced with CCA wiring without violating spacing constraints. This replacement results in a mass saving of 1.38 kg and an incremental cost saving of $28.07, as shown in Figure 257. Compared with the entire wiring harness, this represents a mass savings of 4.8 percent.

Component	2014 Silverado Mass (kg)	Electrical				
		Mass Reduction			Cost Increase	
		%	LWT Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Wiring (Copper Clad Aluminum)	6.90	-20.0%	5.52	1.38	-28.07	-20.33
Wiring (Copper)	21.58	0.0%	21.58	0.00	0.00	0.00

Figure 257: Wiring Mass and Cost Summary

Two issues affecting the application of aluminum to automotive wiring are galvanic corrosion between the cable and end connections, and methods of crimping the cable to the end connections. Delphi has addressed both of these issues, developing and successfully demonstrating the usage of aluminum wiring in a variety of on-road applications.

Another promising technology is multiplexing, in which a single data wire sends control data signals back and forth between several different systems, reducing the amount of wiring required in the vehicle. However, this technology is still in its early stages for automotive applications and will likely not be available for high-volume usage in the 2020-2030 time frame.

7.8.3 Lighting

The baseline 2014 Chevrolet Silverado uses standard lighting components throughout the vehicle (see Figure 258). Many OEMs are incorporating LED lighting systems as they offer increased design flexibility and reduced energy consumption compared with conventional incandescent lighting. The 2008 Audi A8 became the world’s first car in which all exterior lighting functions of the head lamp and tail lamp (low/high beam, turn signal, daytime running lights, position lights, rear stop lamp and vehicle lighting) were realized using LED technology. While LED systems offer many improvements in performance, styling and energy consumption, from a purely weight saving perspective, LED systems generally have higher mass and cost than incandescent systems. Therefore, for the purpose of this study we will not consider the option of replacing the baseline head lamps and tail lamps with LED.

Figure 258: Baseline Chevrolet Silverado Head Lamp and Tail Lamp

A typical exterior head lamp or tail lamp is composed of a plastic lens (usually polycarbonate), reflector (usually metalized polycarbonate), bezels (often polycarbonate or polypropylene carbonate), housing (commonly polypropylene) and various electrical components, seals and fasteners. Material changes to the lens, reflector or bezels are not recommended as they are subject to stringent photometric, thermal and styling requirements; the extensive validation required would not justify the small mass savings. The housing, generally accounting for nearly half the weight of the lamp, is a good candidate for low density plastics like MuCell and

Cellmould. The baseline Chevrolet Silverado head lamp assemblies have a mass of 7.68 kg per vehicle, while the tail lamp assemblies have a mass of 2.00 kg per vehicle, as can be seen in Figure 259. The LWT has replaced the housings with MuCell. It is estimated that this will reduce the mass of the headlamps to 6.14 kg and that of the tail lamps to 1.60 kg, a savings of 1.54 kg and 0.40 kg, respectively (1.94 kg per vehicle). This material substitution is assumed to be cost neutral.

Component	2014 Silverado Mass (kg)	Electrical				
		Mass Reduction			Cost Increase	
		%	LWT Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Head Lamps (MuCell® Housings)	**7.68**	**-20.0%**	**6.14**	**1.54**	**0.00**	**0.00**
Tail Lamps (MuCell® Housings)	**2.00**	**-20.0%**	**1.60**	**0.40**	**0.00**	**0.00**

Figure 259: Lighting Mass and Cost Summary

7.8.4 Summary of Electrical System

Incorporating all these design changes into the LWT reduced the electrical system mass to 52.85 kg, a savings of 4.87 kg (8.4%) and resulted in a cost reduction of $28.07 per vehicle, as can be seen in Figure 260.

	Component	2014 Silverado Mass (kg)	Electrical				
			Mass Reduction			Cost Increase	
			%	LWT Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Option 1	**Electrical - Lead-Acid Battery**	**57.72**	**-8.4%**	**52.85**	**4.87**	**-28.07**	**-5.77**
	Wiring (Copper Clad Aluminum)	**6.90**	**-20.0%**	**5.52**	**1.38**	**-28.07**	**-20.33**
	Wiring (Copper)	**21.58**	**0.0%**	**21.58**	**0.00**	**0.00**	**0.00**
	Battery (Lead-Acid)	**19.55**	**-7.9%**	**18.00**	**1.55**	**0.00**	**0.00**
	Head Lamps (MuCell® Housings)	**7.68**	**-20.0%**	**6.14**	**1.54**	**0.00**	**0.00**
	Tail Lamps (MuCell® Housings)	**2.00**	**-20.0%**	**1.60**	**0.40**	**0.00**	**0.00**
Option 2	**Electrical - Li Ion Battery**	**57.72**	**-28.4%**	**41.32**	**16.40**	**497.93**	**30.37**
	Wiring (Copper Clad Aluminum)	**6.90**	**-20.0%**	**5.52**	**1.38**	**-28.07**	**-20.33**
	Wiring (Copper)	**21.58**	**0.0%**	**21.58**	**0.00**	**0.00**	**0.00**
	Battery (Li-Ion)	**19.55**	**-66.9%**	**6.47**	**13.08**	**526.00**	**40.21**
	Head Lamps (MuCell® Housings)	**7.68**	**-20.0%**	**6.14**	**1.54**	**0.00**	**0.00**
	Tail Lamps (MuCell® Housings)	**2.00**	**-20.0%**	**1.60**	**0.40**	**0.00**	**0.00**

Figure 260: Electrical System Mass and Cost Summary

7.9 Other Components

7.9.1 Glazings – Baseline

The glazings on the baseline Chevrolet Silverado include the windshield, front door glass, rear door glass and rear window (backlite). The total mass of these components is 39.59 kg per vehicle. The baseline windshield, shown in Figure 261, is constructed of inner and outer layers of conventional soda lime float glass laminated around a center layer of polyvinyl butyral (PVB). The 5 mm thick windshield has a mass of 15.23 kg. The front door glazing is a single layer of tempered glass with a thickness of 5 mm and a combined (left hand right hand doors) mass of 10.05 kg per vehicle. The rear door and backlite glazings, are 4 mm thick, single layer tempered glass. The combined mass of the rear door glazings is 8.86 kg per vehicle while that of the backlite is 5.45 kg.

Figure 261: Baseline Windshield, Backlite and Doors Glass

7.9.2 Glazings – Technology Options

The overall length, width and shape of the glass components on the LWT have remained the same as the baseline. Possibilities considered for mass reductions were:

- Reduce the thicknesses of the current glazings, keeping the baseline material,
- Replace the baseline glass with lower density materials, and
- Replace the baseline glass with toughened glass, enabling thickness reductions.

Simply reducing the thickness of the glazings while keeping the baseline material the same is not feasible. In addition, the thickness of the glass is a major factor in controlling noise intrusion; reducing the thickness allows more noise into the cabin, just as happens when the thickness of sheet metal is reduced. It is fairly simple to add insulation to sheet metal components to compensate for this, but not so with glass. Automotive glazings are finely optimized by OEMs to meet the acoustic specifications of each vehicle. Any lightweighting technologies applied to automotive glass must incorporate features that provide the same level of acoustic insulation as the baseline.

Some of the alternate materials considered for the LWT were chemically toughened float glass, polycarbonate, Gorilla Glass from Corning and SGS dBCONTROL acoustic glazing from Saint-Gobain Sekurit. Chemical toughening, in which a conventional glass sheet undergoes a sodium and potassium ion exchange in a high-temperature salt bath, increases the flex strength and impact resistance of the glass, allowing the thickness to be reduced. However, the cost of laminated glazings using this material is more than three times that of conventional laminated glazings. More importantly, the processing time required to produce chemically toughened glass is commonly from 8 to 16 hours,[125] making it an unacceptable choice for production of high-volume vehicles such as the Chevrolet Silverado.

Polycarbonate, with a density of 1.2 g/cm^3 (compared with the 2.5 g/cm^3 of conventional laminated or tempered glass) offers significant mass reduction possibilities. However, replacing the windshield with PC is not feasible due to FMVSS 205 regulations that require laminated glazings in frontal glass. The movable windows on the side doors are not good candidates for polycarbonate because the stiffness of PC is much less than that of conventional glass, leading to potential problems with the window operation. The lower modulus PC can flex under compressive loading while the window is being operated, binding and possibly damaging the window run channels, regulator and mechanisms. Research is underway to improve door modules such that they can be successfully integrated with the less stiff PC windows, but these are not expected to reach production capability within the 2020-2030 time frame.[126] Polycarbonate is a possibility for the backlite, provided it can meet light transmission and abrasion resistance requirements defined in FMVSS 205 and UNECE R-43 and is sized properly to match the acoustic insulation properties of the baseline.

Gorilla Glass from Corning is created using Corning's proprietary Fusion Manufacturing Process[127] and then chemically strengthened. The increased strength of this glass allows the thickness to be reduced, resulting in mass savings. The surface toughness is more damage resistant than polycarbonates. Currently Gorilla Glass is used primarily as touch screens on electronic devices, such as smart phones and tablet computers. Work is being done to produce Gorilla Glass suitable for automotive applications. When it appears likely that this material can meet the cost and timing needs of high-volume production, FMVSS and UNECE regulations, and acoustic requirements, the feasibility of using Gorilla Glass in the LWT can be re-evaluated.

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[125] http://abrisatechnologies.com/specs/Glass%20Strengthening%20-%20Tech%20Document%2012_11.pdf

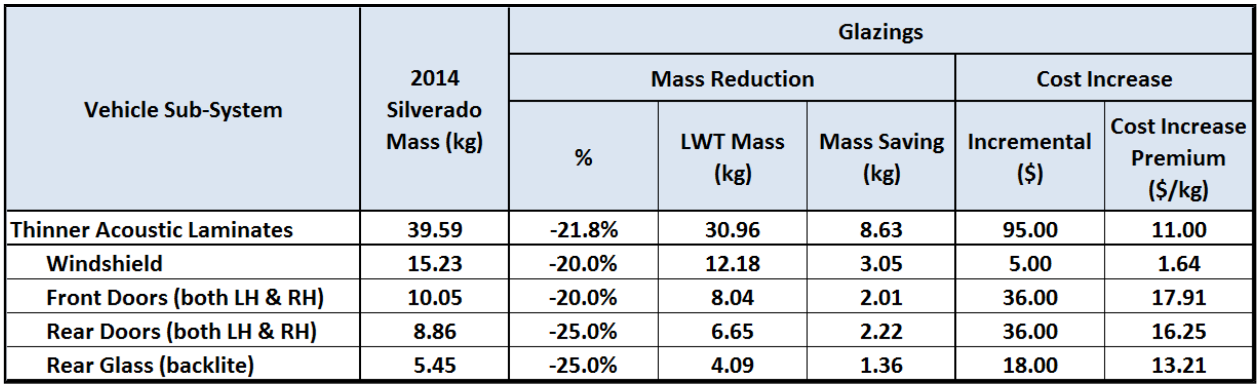
[126] www.just-auto.com/analysis/polycarbonate-auto-glazing-offers-designers-new- vision_id94895.aspx

[127] www.corninggorillaglass.com/news-events/What-Makes-Corning%C2%AE-Gorilla%C2%AE-Glass-So-Tough

Saint-Gobain Sekurit's SGS dBCONTROL[128] uses a specially developed acoustic PVB layer in laminated glazings to effectively suppress both low frequency (engine) and high-frequency (aerodynamic and wind) noises. The outer layers of the laminate are standard glass sheets, so stiffness and durability characteristics are the same as baseline glazings. SGS dBCONTROL allows the use of thinner glazings while maintaining acceptable noise levels in the cabin.

7.9.2.1 Glazings Selection

The most feasible lightweight alternative to the baseline glazings is the SBS dBCONTROL produced by Saint-Gobain Sekurit. Replacing the 5 mm laminated windshield with a 4 mm SGS dBCONTROL windshield in the LWT would reduce the mass from 15.23 kg to 12.18 kg. Similarly, the baseline 5 mm thick tempered glass in the front doors could be replaced by 4 mm laminated SGS dBCONTROL, producing a mass savings of 2.01 kg (from 10.05 kg to 8.04 kg). The baseline 4 mm thick tempered rear door glass and backlite could be replaced with 3 mm thick SGS dBCONTROL, reducing the mass from 8.86 kg to 6.65 kg for the rear doors, and from 5.45 kg to 4.09 kg for the backlite. Replacing the baseline glazings with SGS dBCONTROL would provide an estimated mass savings of 8.63 kg per vehicle (21.8%), as is shown in Figure 262. The cost of making this change was not available at the time of preparing this report, making a business case assessment difficult. This option should be revisited when more precise data are available.



Vehicle Sub-System	2014 Silverado Mass (kg)	Glazings				
		Mass Reduction			Cost Increase	
		%	LWT Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Thinner Acoustic Laminates	**39.59**	**-21.8%**	**30.96**	**8.63**	**95.00**	**11.00**
Windshield	**15.23**	**-20.0%**	**12.18**	**3.05**	**5.00**	**1.64**
Front Doors (both LH & RH)	**10.05**	**-20.0%**	**8.04**	**2.01**	**36.00**	**17.91**
Rear Doors (both LH & RH)	**8.86**	**-25.0%**	**6.65**	**2.22**	**36.00**	**16.25**
Rear Glass (backlite)	**5.45**	**-25.0%**	**4.09**	**1.36**	**18.00**	**13.21**

Figure 262: Mass and Cost Summary for SGS dBControl Glazings

Though the 8.63 kg mass savings are significant, the uncertainty about the cost increase premium introduces an unknown amount of risk. Considering the 10 percent cost limit for this project, there is not a strong enough business case to support making this design change until cost information is available. Therefore, the baseline glazings are being carried over to the LWT.

7.9.3 Outside Mirrors

Replacing the outside mirror housings with low density plastic such as Cellmould was considered, but the anticipated mass savings of 0.20 kg per vehicle did not justify the risk of degrading the surface quality on such a highly visible Class A surface.

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[128] www.saint-gobain-sekurit.com/glazingcatalouge/product

Therefore, outside mirrors on the LWT are being carried over from the baseline vehicle.

7.9.4 Wipers

The windshield washing/wiping system is composed of the wiper arms/blades, motor, pump, reservoir, tubes and fluid. The components of this system are well developed, optimized and common to many product lines, allowing few opportunities for mass reduction. The most likely option would be to reduce the size of the windshield washer reservoir, decreasing the mass of the fluid and the reservoir itself. However, this requires the consumer to re-fill the reservoir more frequently and increases the possibility of running out of fluid. This would be seen by the consumer as a degradation of the system's performance; the likelihood of displeasing the consumer exceeds the value of potential mass reduction. Therefore the baseline wiper/washer system is being carried over to the LWT.

7.9.5 Spare Tire/Tools

Refer to Section 7.5.6 for a discussion of mass reduction options for the spare tire and jack.

7.9.6 NVH Insulation

Refer to Section 7.7.3 for a discussion of mass reduction options relating to insulation.

7.9.7 Safety Systems

Automotive safety restraints (seatbelts and air bags) are constantly evolving to take advantage of new technologies and to meet updated Federal safety regulations. Safety restraint suppliers are under pressure to reduce mass, as are all automotive component suppliers. This is achieved through design and material changes that must be cost effective. The majority of materials used in seatbelts and air bags are lightweight polyester and nylon. These materials are mounted to control surfaces and pyrotechnic devices, such as air bag inflators, that are typically constructed of steel to withstand the forces and heat generated during deployment.

The safety systems in the Chevrolet Silverado are conventional designs as described above. The combined masses of the driver, passenger and curtain air bag systems are 7.95 kg, while those of all seat belt systems are 10.01 kg. Modifying the components in the restraint system would involve significant design, engineering and validation efforts to ensure that there is no degradation of safety levels and that all Federal regulations are still being met. The potential mass savings from this effort are anticipated to be no more than 2-3 kg per vehicle and do not present a positive business case. In addition, the current safety systems are common throughout the GM global portfolio; any modifications would need to be validated for all affected vehicle lines. Therefore, the LWT restraints are being carried over from the baseline Silverado.

7.9.8 Fluids

The basic approach to fluids was that the overall reduction in vehicle mass will lead to lower fluid volumes being required. Therefore the masses of all fluids in the vehicle except the air conditioning gas and windshield washer fluid (as were discussed previously in this report) could be scaled back. The initial estimate for this effect was a 10 percent reduction of most fluid masses, resulting in an overall mass savings of 9.81 kg per vehicle.

The fluid needs were further evaluated using more advanced design and analysis efforts to verify or correct the initial estimate. The results of this analysis are shown in Figure 263. The final LWT design fluids have a combined mass of 36.60 kg, a mass savings of 1.71 kg compared with the baseline. The cost decrease from the fluid mass savings is a part of the dealer cost (included in indirect cost) and is considered cost neutral to the vehicle manufacturer. In addition, the fuel mass was reduced by 6.71 kg (refer to the fuel tank discussion in Section 7.6.4.2). This reduction in fuel does provide a cost savings of $7.91 per vehicle, assuming a fuel price of $3.00 per gallon.

Vehicle Sub-System	2014 Silverado Mass (kg)	Fluids and Fuel				
		Mass Reduction			Cost Increase	
		%	LWT Mass (kg)	Mass Saving (kg)	Incremental ($)	Cost Increase Premium ($/kg)
Fluids	**38.31**	**-4.5%**	**36.60**	**1.71**	**0.00**	**0.00**
Engine Oil	5.52	-5.6%	5.21	0.31	0.00	0.00
Transmission Oil	9.09	-5.6%	8.58	0.51	0.00	0.00
Coolent	12.20	-5.6%	11.52	0.68	0.00	0.00
Brake Fluid	0.87	0.0%	0.87	0.00	0.00	0.00
Power Steering Fluid	0.89	0.0%	0.89	0.00	0.00	0.00
Air Conditioning Gas	0.74	0.0%	0.74	0.00	0.00	0.00
Windshield Washer Fluid	5.28	0.0%	5.28	0.00	0.00	0.00
Front Differential Oil	1.10	-5.6%	1.04	0.06	0.00	0.00
Rear Differential Oil	1.50	-5.6%	1.42	0.08	0.00	0.00
Transfer Case	1.12	-5.6%	1.06	0.06	0.00	0.00
Fuel	**65.77**	**-10.2%**	**59.06**	**6.71**	**-7.91**	**-1.18**

Figure 263: Fluids Mass and Cost Summary

7.10 Summary of Selected Technologies

From the various technologies that were reviewed for future mass saving potential, four different vehicle built scenarios with low to high mass saving potential are shown in Figure 264. The four light weighting vehicle build options range from a vehicle mass saving of 10.5 percent to 22.9 percent.

1. An all advanced high strength steel intensive design, including cab, pickup box, closures, chassis frame, seat frames and instrument panel beam structures. This option leads to total vehicle mass saving of 10.5 percent.
2. Design with AHSS chassis frame structure and aluminum cab, pickup box, closures, and multi-material seats, achieves a mass saving of 16.8 percent.
3. An aluminum intensive solution, using aluminum for body structure, closures, chassis frames and magnesium for seats leads to a mass saving of 17.8 percent
4. An advanced carbon fiber and multi-material solution, using carbon fiber reinforced composite body structure, CFRP/magnesium/aluminum closures, aluminum chassis frames and magnesium/composite seat structures, achieves a total vehicle mass saving of 22.9 percent.

To achieve same vehicle performance as the baseline vehicle the size of the engine is proportionally reduced from the baseline 5.3L (355 HP) to 5.0L (335HP) for the LWT. In the mass calculations, all four options include the same powertrain a 5.0L (335 HP) engine with 6 speed automatic transmission. The costs for these options are reported in Section 10.10 of this report.

Vehicle System	2014 Silverado System Mass (kg)	EDAG LWT AHSS Frame and Alum Cab, Pickup Box		AHSS Intensive Frame, Cab, Pickup Box and Closures		Aluminium Intensive Frame and Alum Cab, Pickup Box and Closures		CFRP Intensive Frame, Cab, Pickup Box and Li ion Battery	
		Delta Mass Reduc-tion (kg)	Mass Reduc-tion	Delta Mass Reduc-tion (kg)	Mass Reduc-tion	Delta Mass Reduc-tion (kg)	Mass Reduc-tion	Delta Mass Reduc-tion (kg)	Mass Reduc-tion
Cab Structure	242.52	91.01	38%	46.50	19%	91.01	38%	101.26	42%
FESM	32.77	22.33	68%	6.55	20%	22.33	68%	18.80	57%
Radiator Supt Structure	19.98	12.32	62%	2.84	14%	5.69	28%	12.32	62%
Front Door Frames	45.46	14.03	31%	10.76	24%	16.88	37%	19.65	43%
Rear Door Frames	42.44	11.61	27%	10.07	24%	15.91	37%	18.25	43%
Hood Frame	11.42	0.00	0%	0.00	0%	0.00	0%	2.28	20%
Tailgate Frame	22.43	7.85	35%	4.49	20%	7.85	35%	6.82	30%
Pickup Box	109.90	43.80	40%	21.98	20%	43.80	40%	51.95	47%
Front Bumper	30.09	6.39	21%	6.39	21%	7.52	25%	12.04	40%
Rear Bumper	15.04	1.93	13%	1.93	13%	3.76	25%	6.02	40%
Chassis Frame	242.10	19.40	8%	19.40	8%	45.62	19%	49.19	20%
Towing Hitch	15.81	1.98	13%	1.98	13%	3.14	20%	3.14	20%
Front Suspension	67.95	7.21	11%	7.21	11%	7.21	11%	11.89	17%
Rear Suspension	66.87	19.25	29%	6.69	10%	6.69	10%	27.96	42%
Wheels and Tires	158.96	35.32	22%	15.89	10%	31.66	20%	41.71	26%

Vehicle System	2014 Silverado System Mass (kg)	EDAG LWT AHSS Frame and Alum Cab, Pickup Box		AHSS Intensive Frame, Cab, Pickup Box and Closures		Aluminium Intensive Frame and Alum Cab, Pickup Box and Closures		CFRP Intensive Frame, Cab, Pickup Box and Li ion Battery	
		Delta Mass Reduction (kg)	Mass Reduction	Delta Mass Reduction (kg)	Mass Reduction	Delta Mass Reduction (kg)	Mass Reduction	Delta Mass Reduction (kg)	Mass Reduction
Front Seat and Ctr Console	57.02	16.98	30%	5.70	10%	16.98	30%	16.98	30%
Rear Seat	40.43	11.97	30%	4.04	10%	11.97	30%	11.97	30%
Instrument Panel	32.71	8.44	26%	4.75	15%	5.98	18%	8.44	26%
Engine	200.73	7.43	4%	7.43	4%	7.43	4%	7.43	4%
Transmission	230.08	23.17	10%	23.17	10%	23.17	10%	31.63	14%
Drive Shafts	53.71	2.69	5%	2.69	5%	2.69	5%	22.01	41%
Fuel System	22.19	1.08	5%	1.08	5%	1.08	5%	1.08	5%
Trim	86.13	6.36	7%	6.36	7%	6.36	7%	6.36	7%
Exhaust	51.91	7.23	14%	7.23	14%	7.23	14%	7.23	14%
Brake System	84.35	8.97	11%	8.97	11%	19.68	23%	19.68	23%
HVAC	30.66	2.16	7%	2.16	7%	2.16	7%	2.16	7%
Water Cooling	18.00	0.93	5%	0.93	5%	0.93	5%	0.93	5%
Electrical	38.17	3.32	9%	3.32	9%	3.32	9%	3.32	9%
Battery	19.55	1.55	8%	1.55	8%	1.55	8%	13.08	67%
Fluids	38.31	1.71	4%	1.71	4%	1.71	4%	1.71	4%
Fuel	65.77	6.71	10%	6.71	10%	6.71	10%	6.71	10%
Glazings	39.59	0.00	0%	0.00	0%	0.00	0%	8.63	22%
Air Bags and Seatbelts	18.47	0.00	0%	0.00	0%	0.00	0%	0.00	0%
Steering System	34.72	4.38	13%	4.38	13%	4.38	13%	4.38	13%
Wiper System	5.19	0.00	0%	0.00	0%	0.00	0%	0.00	0%
Misc: latches/fasteners/mirrors	140.58	0.00	0%	0.00	0%	0.00	0%	0.00	0%
Total - With Powertrain	2,432	409	16.8%	255	10.5%	432	17.8%	557	22.9%
Total - Without Powertrain	1,790	359	20.1%	206	11.5%	382	21.4%	480	26.8%

Figure 264: Vehicle Build Technology Options for LWT

From the four options above the design with AHSS chassis frame structure and aluminum cab, pickup box and multi-material seats and closures, is selected to be the most likely to be implemented for production years 2025 to 2030. The selected technologies for the LWT are summarized in Figure 265. These technology options were included in the detail design and comprehensive CAE performance assessment of the complete LWT design. The recommended design for LWT achieved a vehicle mass saving of 16.8 percent (409 kg). To achieve same vehicle performance as the baseline vehicle the size of the engine is proportionally reduced from the baseline 5.3L (355 HP) to 5.0L (335HP) for the LWT. Without the mass and cost reduction allowance for the powertrain, the mass saving for the LWT “glider” is 20.1 percent (359 kg).

Vehicle System	2014 Silverado System Mass (kg)	Mass Reduction (kg)	Mass Reduction %	Lightweighting Implemented Technology
Cab[129]	242.52	91.01	38%	Aluminum
FESM (per vehicle)	32.77	22.33	68%	Aluminum
Radiator Supt Structure	19.98	12.32	62%	Magnesium
Front Door Frames	45.46	14.03	31%	Aluminum + AHSS
Rear Door Frames	42.44	11.61	27%	Aluminum + AHSS
Hood Frame	11.42	0.00	0%	Aluminum
Tailgate Frame	22.43	7.85	35%	Aluminum
Pickup Box	109.90	43.80	40%	Aluminum
Front Bumper	30.09	6.39	21%	AHSS
Rear Bumper	15.04	1.93	13%	AHSS
Chassis Frame	242.10	19.40	8%	AHSS
Towing Hitch	15.81	1.98	13%	AHSS
Front Suspension	67.95	7.21	11%	Downsize
Rear Suspension	66.87	19.25	29%	Leaf Springs:2 Fiberglass
Wheels and Tires	158.96	35.32	22%	eVOLVE Rims + S Tire
Front Seat and Cntr Console	57.02	16.98	30%	Multi-Material Solution
Rear Seat	40.43	11.97	30%	Multi-Material Solution
Instrument Panel	32.71	8.44	26%	Magnesium Casting
Engine	200.73	7.43	4%	Engine Re-Size
Transmission	230.08	23.17	10%	Rear Diff. Housing to Alum
Drive Shafts	53.71	2.69	5%	Downsize
Fuel System	22.19	1.08	5%	Fuel Tank/System
Trim	86.13	6.36	7%	Trim
Exhaust	51.91	7.23	14%	Exhaust System
Brake System	84.35	8.97	11%	Brake System - Iron Discs
HVAC	30.66	2.16	7%	HVAC
Water Cooling	18.00	0.93	5%	HVAC
Electrical	39.17	3.32	9%	Copper clad alum
Battery	19.55	1.55	8%	Lead Acid
Fluids	38.31	1.71	4%	Fluids
Fuel	65.77	6.71	10%	Fuel
Glazings	39.59	0.00	0%	Carryover Baseline
Air Bags and Seatbelts	18.47	0.00	0%	Air Bags and Seatbelts
Steering System	34.72	4.38	13%	Steering System
Wiper System	5.19	0.00	0%	Wiper System
Misc: latches/fastners/mirrors	121.03	0.00	0%	
Total - With Powertrain	2432.0	409	16.8%	
Total - Without Powertrain	1789.6	359	20.1%	Powertrain: Engine, Transmission, Fuel Sys, Exhaust , Fuel, coolant

Figure 265: Technologies Selected for LWT

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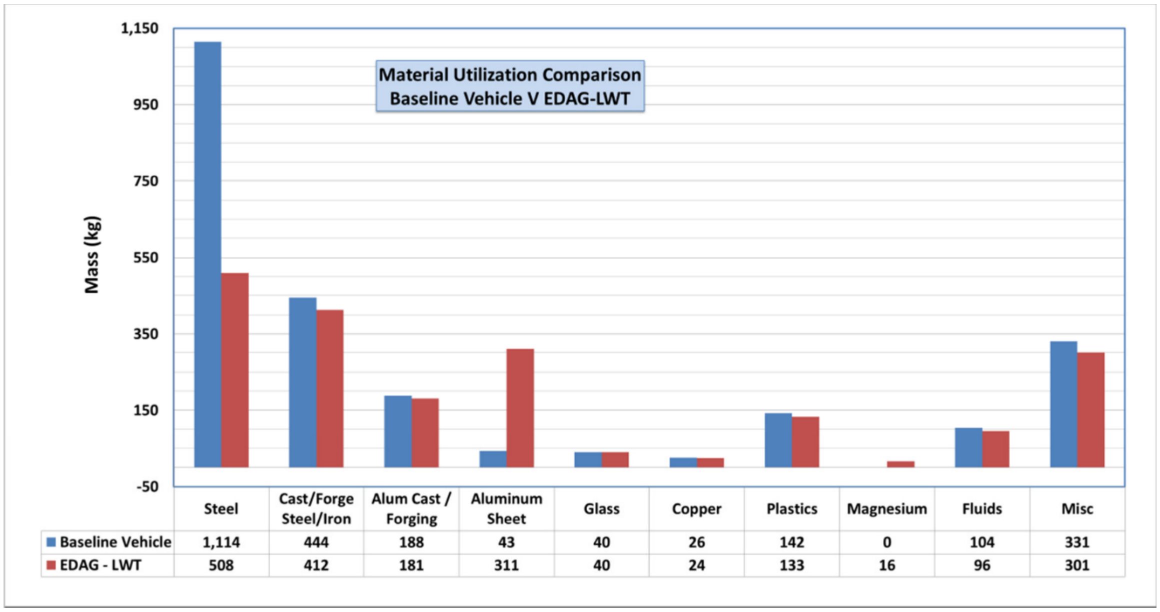
[129] Explanation for the higher mass savings shown for the FESM and rad support. The cab, FESM and radiator support structure were redesigned with different assembly approach, bolt-on radiator support, and bolt-on fenders. Some of the FESM and rad support parts are consolidated into the LWT cab structure.

The material usage and comparison with the baseline 2014 Silverado 1500, for the lightweighting design options for LWT for year 2025 - 2030 shown in Figure 266. Compared with the baseline vehicle the usage of steel was reduced by 606 kg per vehicle from 1,114 kg in the baseline vehicle to 508 kg in the LWT. Cast/forged iron was reduced from 444 kg to 412 kg. Usage of cast aluminum decreased from 188 kg to 181 kg, while sheet aluminum increased to 311 kg in the LWT from 43 kg used in the baseline vehicle. No changes were made to the glazing, so usage of glass was constant at 40 kg. Copper usage was reduced from 26 kg to 24 kg. Plastics, which amounted to 142 kg in the baseline vehicle, were reduced to 133 kg in the LWT. Magnesium was not used in the baseline vehicle, but 16 kg used in the LWT. Fluid mass dropped from 104 kg to 96 kg due to the reduced fuel tank capacity. Figure 266 shows the impact of the LWT design modifications on each of these materials, while Figure 267 shows how the distribution of materials has changed from the baseline vehicle to the LWT, in terms of total mass.



	Steel	Cast/Forge Steel/Iron	Alum Cast / Forging	Aluminum Sheet	Glass	Copper	Plastics	Magnesium	Fluids	Misc
🟦 Baseline Vehicle	1,114	444	188	43	40	26	142	0	104	331
🟥 EDAG - LWT	508	412	181	311	40	24	133	16	96	301

Figure 266: Material Changes From Baseline to LWT

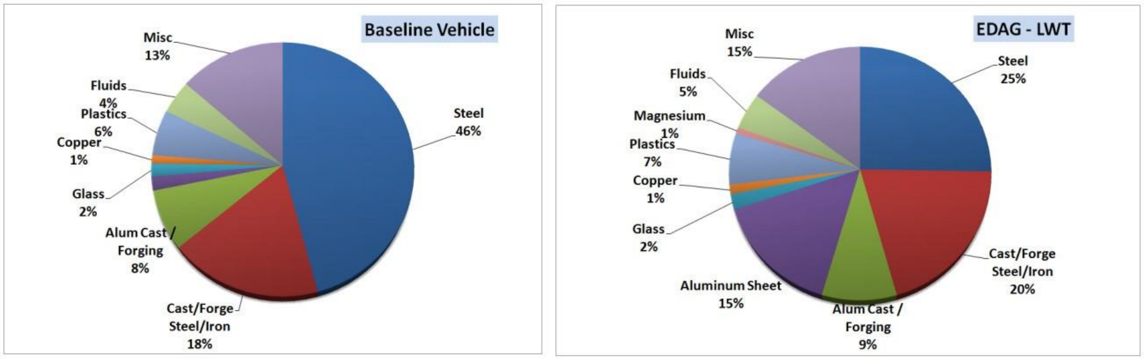


Figure 267: Material Percentages for Baseline and LWT

When considering the future high-volume production outlook of the LWT, it is important to note that most of the material changes have been reductions in quantity. The materials that experienced an increase in usage, aluminum sheet and magnesium, are readily available with current technology. The increased quantities would not present procurement difficulties in today’s marketplace, let alone that of 2025-2030. Therefore, the feasibility of high-volume production of the LWT is not at risk due to unavailability of material.

8 Lightweight Pickup Truck Design Approach

8.1 Key Assumptions

NHTSA has been issuing Corporate Average Fuel Economy standards under the Energy Policy and Conservation Act for the last 30 years. As part of its work on fuel economy standards for MYs 2017-2025, NHTSA released a project solicitation[130] with the purpose of designing a lightweighted light-duty pickup truck that can, at minimum, meet the performance functions of the original baseline vehicle while controlling for both direct and indirect cost to maintain affordability.

The LWT shall use advanced design, material and manufacturing processes that will likely be available in the time frame of MYs 2020-2030 for high-volume production (around 200,000 units per year) to develop an engineering design with sufficient detail such that computer aided engineering analysis can be performed to demonstrate crashworthiness of the vehicle concept. This request for proposal established that the vehicle design shall achieve the maximum feasible amount of mass reduction, as defined in the solicitation, while meeting the following the baseline requirements and assumptions.

- The target vehicle shall maintain retail price parity (meaning direct cost plus Retail Price Equivalent [131] markup) with the baseline vehicle within ±10% variation[132]

- The design shall maintain vehicle size and performance functionalities compared with the baseline vehicle, including:

    - Safety,
    - Noise, vibration and harshness,
    - Towing,
    - Acceleration,
    - Manufacturability,
    - Aesthetics,
    - Ergonomics,
    - Durability, and
    - Serviceability.

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[130] Contract Number DTNH22-13-R-00669 Vehicle Weight Reduction Feasibility and Cost Study-Full-Size Pickup Truck

[131] RPE of 1.45 for General Motors used for this study; Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers," EPA report EPA-420-R-09-003, February 2009

[132] 10 percent of the baseline MSRP is $3,805 based on 2014 Chevrolet Silverado 1500 window sticker shown in Figure 10

- Using crash simulations, the target vehicle model shall demonstrate structural performance in NHTSA's NCAP frontal, side, and side pole test programs equivalent to or better than the baseline vehicle. It will also obtain at least equivalent ratings to the baseline vehicle in the each of the structural or intrusion ratings for the following.
    - NCAP frontal
    - NCAP side
    - NCAP side pole
    - FMVSS No. 216
    - FMVSS No. 301
    - IIHS offset
    - IIHS side impact
    - IIHS small overlap

8.2 Introduction

Our approach to meet the program objective of identifying mass saving potential for the baseline vehicle during MYs 2020-2030 is to investigate possible material choices and manufacturing technologies for each vehicle sub-system. The systems with the greatest mass saving potential, such as the vehicle cab, pickup box, closures (doors, hood and tailgate), chassis frame, bumpers, and suspensions, were investigated for the most relevant materials and manufacturing technologies, and their detail designs were properly sized using the latest computer aided engineering optimization techniques. It was verified that the recommended designs for these systems met all the relevant FMVSS crash requirements and achieved comparable crash performance for NCAP and IIHS tests compared with the baseline vehicle by using LS-DYNA finite element analysis simulations. The generated LS-DYNA models may also be helpful for conducting future vehicle-to-vehicle crash analysis studies to assess the safety performance of lighter mass vehicles in a future fleet simulation study.

Assessment of all other vehicle systems (e.g., interior, glazing, HVAC, electrical, powertrain) were based upon technologies expected to be available and mature in the time frame of MY2025, and the components were resized as appropriate to meet the performance goals of the projected lightweight vehicle. The overall LWT project methodology is illustrated in Figure 268 below.

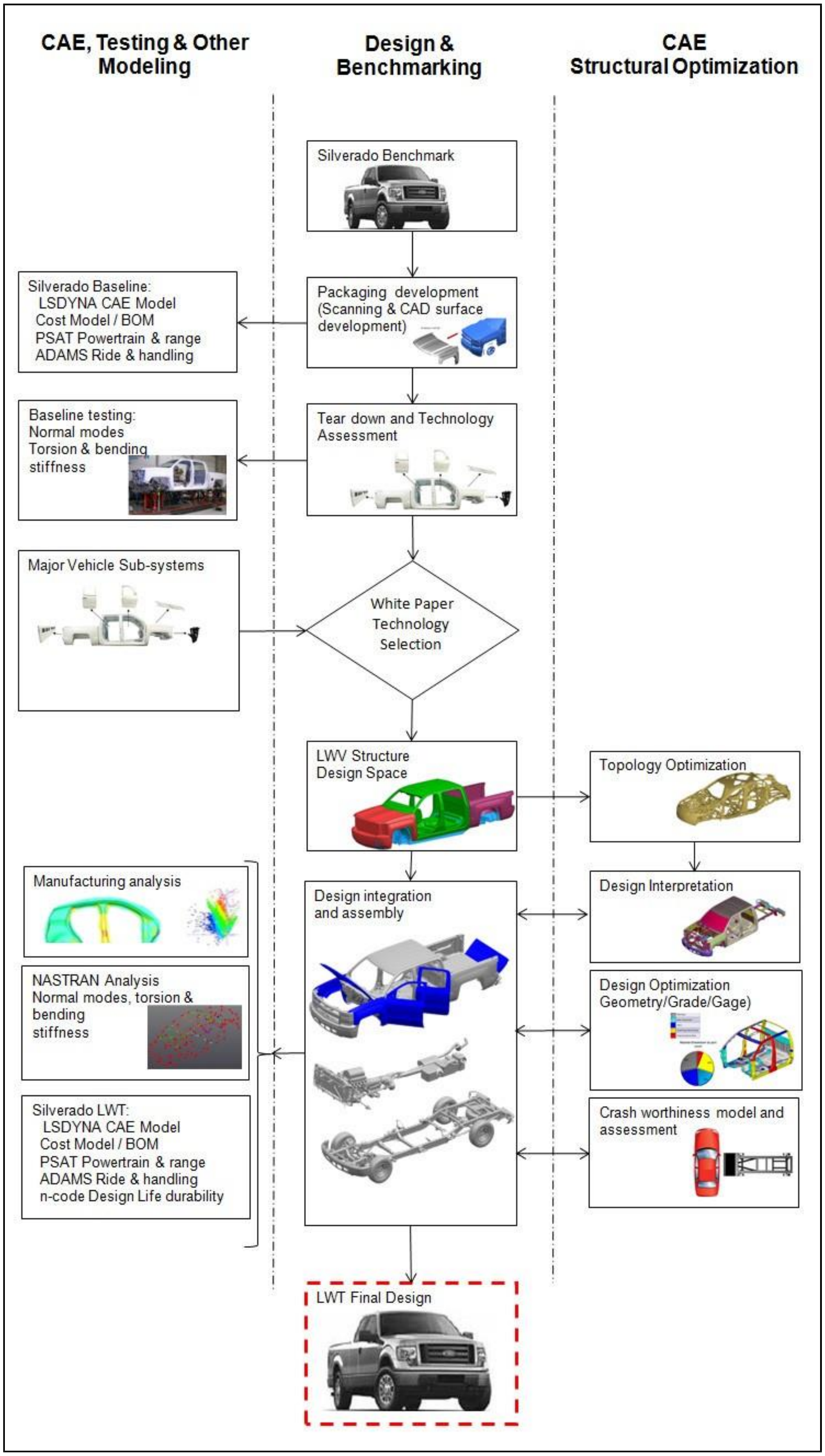

Figure 268: Light Weight Truck Program Approach

8.3 Vehicle Packaging Requirements

The vehicle packaging space for occupants and volume allocated to payload was determined by the 2014 Chevrolet Silverado 1500 baseline vehicle. The laser scanned surfaces of the interior form the basis of the key interior dimensions related to occupant seating positions, such as head clearances to the interior surfaces, H-point, legroom and critical vision angles for visibility. This approach was also applied to maintain the same ease of entry and egress from the vehicle and the same payload volume of the pickup box. To achieve the same utility/functionality in terms of driving the vehicle on typical road surfaces, the LWT is designed with same ground clearances as the baseline vehicle. The baseline vehicle interior and the external scanned surfaces are shown in Figure 269.

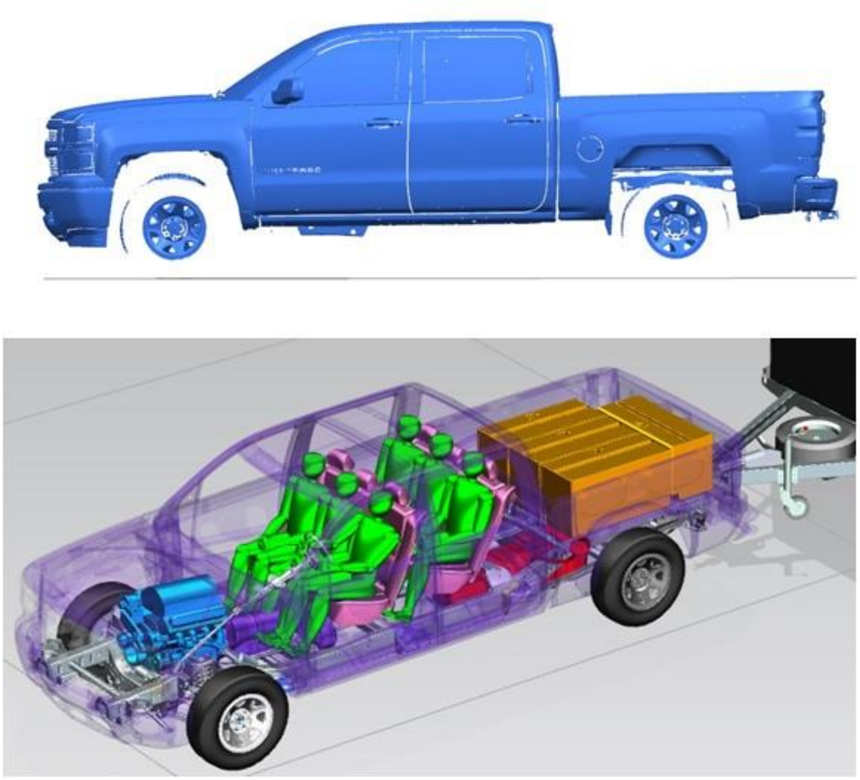

Figure 269: Vehicle Package Space Based on Scanned Surfaces

The external dimensions of the baseline vehicle shown in Figure 270 were also maintained for the LWT design. The wheelbase and front overhang, and hence the total vehicle length, depend on the choice/size of the powertrains. If the powertrain is assumed to be ICE-based, the front end of the vehicle can be a common design. Due to the fact that the LWT will be a low mass vehicle, it will require lower power to maintain the same performance as the baseline vehicle. The size of the powertrain unit will also be physically smaller. The engine and the transmission are almost solid blocks and do not crush; a smaller block will free up space for additional crush and this would lead to a slightly smaller front end over-hang while still maintaining similar amount of crush distance as the baseline vehicle.

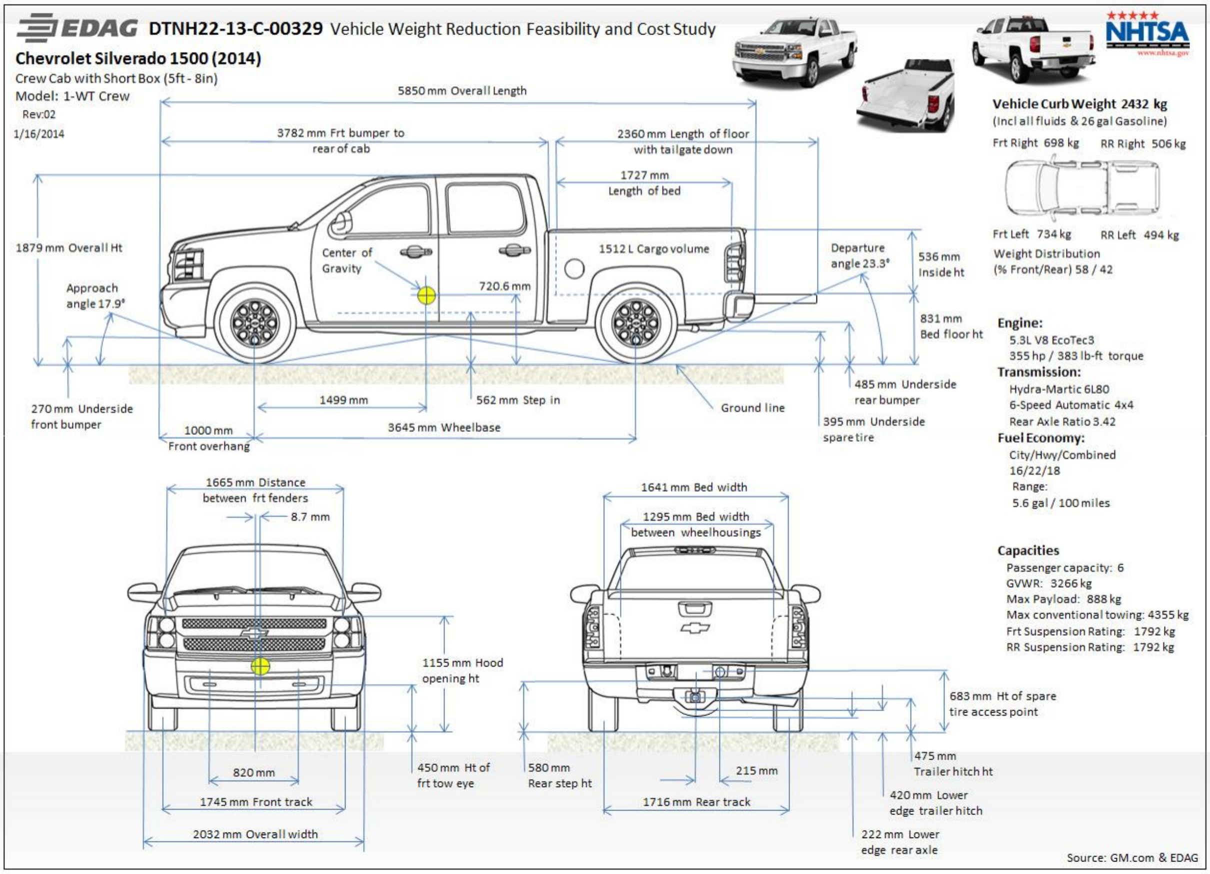

Figure 270: 2014 Chevrolet Silverado 1500 Exterior Dimensions

8.4 Design Strategy for the LWT

Full-size pickup trucks offered by major OEM's are typically available with three styles of cab designs and three sizes of pickup boxes as shown in Figure 1. These vehicles offer flexibility to carry up to six passengers in comfort and safety with payload carrying capacities up to 879kg (1,937 lbs[133]) and towing capacity over 4,883kg (10,700 lbs[134]). The off-road capability of these vehicles with easy and open access to the pickup box makes these vehicles a good choice for the agricultural and construction industry as well as suburbanites who require occasional towing and the convenience of a pickup box for load carrying. The uses of these vehicles range from transport of materials and equipment to and from worksites in multitude of industries. To accommodate such diverse customer base and performance requirements these vehicles are available with options of several powertrains, 2- or 4-wheel drive, heavy duty and fifth-wheel towing, and up to 36-gallon fuel tanks for driving range of over 700 miles.

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[133] 2013 Silverado 1500 sales brochure

[134] Ibid

	REGULAR CAB STANDARD BOX	REGULAR CAB LONG BOX	DOUBLE CAB STANDARD BOX	CREW CAB SHORT BOX	CREW CAB STANDARD BOX
OVERALL LENGTH (MM)	5221.5	5700.5	5842.8	5842.8	6085.1
WHEELBASE (MM)	3022.6	3378.2	3644.9	3644.9	3886.2

Figure 271: Full size pickup truck[135] – design variations

To combine all of the often-conflicting requirements and variables, the approach to the design of these vehicles is significantly different from the design approach applied to passenger cars. As illustrated in Figure 271, the front end and rear ends of the full range of the variants are common designs. The longer cabs and longer pickup boxes are designed in such a way as to increase the central length of the vehicle. On some variants, the increase in length of the cab is balanced by use of correspondingly shorter length pickup box or vice-versa. For variants requiring longer cabs and longer pickup boxes, the wheel base length of the vehicle is increased. This require the frame to be designed in segments along the length, such that by keeping the front and rear segments common amongst several variants, the central segments are designed to accommodate the required length variations as shown in Figure 272. The 2014 Silverado range of trucks requires four different lengths and four different wheel bases to accommodate all variants as shown in Figure 271.

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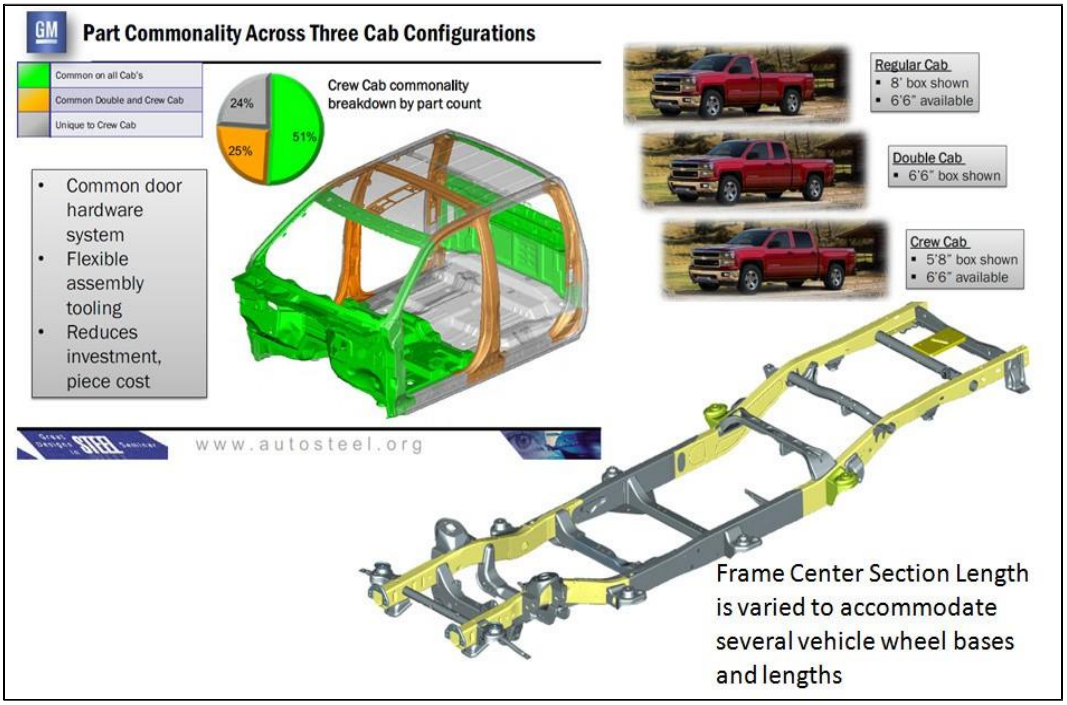
[135] 2013 Silverado 1500 sales brochure
The illustrations and numbers quoted in this proposal are for 2013 Chevrolet Silverado 1500 range of trucks



Part Commonality Across Three Cab Configurations

- 🟩 Common on all Cab's
- 🟧 Common Double and Crew Cab
- ⬜ Unique to Crew Cab

Crew Cab commonality breakdown by part count

- Common door hardware system
- Flexible assembly tooling
- Reduces investment, piece cost

Regular Cab
- 8' box shown
- 6'6" available

Double Cab
- 6'6" box shown

Crew Cab
- 5'8" box shown
- 6'6" available

Frame Center Section Length is varied to accommodate several vehicle wheel bases and lengths

Figure 272: 2014 Silverado 1500 Vehicle Cab and Frame Common Parts[136]

The design strategies applied to body-on-frame vehicles are different from those used on monocoque/unibody based car structures. Both monocoque and body-on-frame vehicle structures have to strike a balance between intended vehicle function and affordability. Each approach has certain benefits and ultimately determines the functionality and characteristics of the vehicle. The monocoque structure offers a lighter mass efficient design which is a plus for fuel efficiency. In addition, with higher structural stiffness it is a better choice for performance oriented passenger vehicles. The heavier ladder frame based vehicles are better than the monocoque for carrying heavy loads and towing heavier trailers. They also offer greater flexibility for accommodating different cab styles on existing proven chassis platforms, leading to significantly lower engineering development costs. Typically, the re-design cycle for the chassis frame system is 10 years versus restyled cab and pickup box every 5 years. The isolated passenger cab (rubber-mounted) offers a quieter environment with reduced vibrations. Vehicles with ladder chassis frames are easier to repair after damage.

It is generally easier to incorporate crash crumple zones into a vehicle with a monocoque body design with integrated load paths consisting of front rails, front uppers (shot guns) and the engine cradle. For the body-on-frame vehicle, frontal and rear crash loads are predominantly handled by the chassis frame structure with very small contributions from the cab and pickup box structures. The cab structure, however, does play a key role for the side impact and roof strength requirements.

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[136] Some information in this slide is from: Thomas Grabowski General Motors Company, Great Designs in Steel 2013

The CAE optimization techniques that were used for the NHTSA mid-size sedan monocoque structure are also applied to the light weighted truck structures (cab, ladder frame and pickup box) with the appropriate boundary constraints and representative interfaces within the three systems. The design of the LWT structure accommodated all the vehicle variants with maximum component commonality and common assembly processes, so that the variants can be assembled on the same plant assembly lines. The cab and pickup box part commonality for the LWT is illustrated in Figure 273. The chassis frame part commonality is shown in Figure 274.

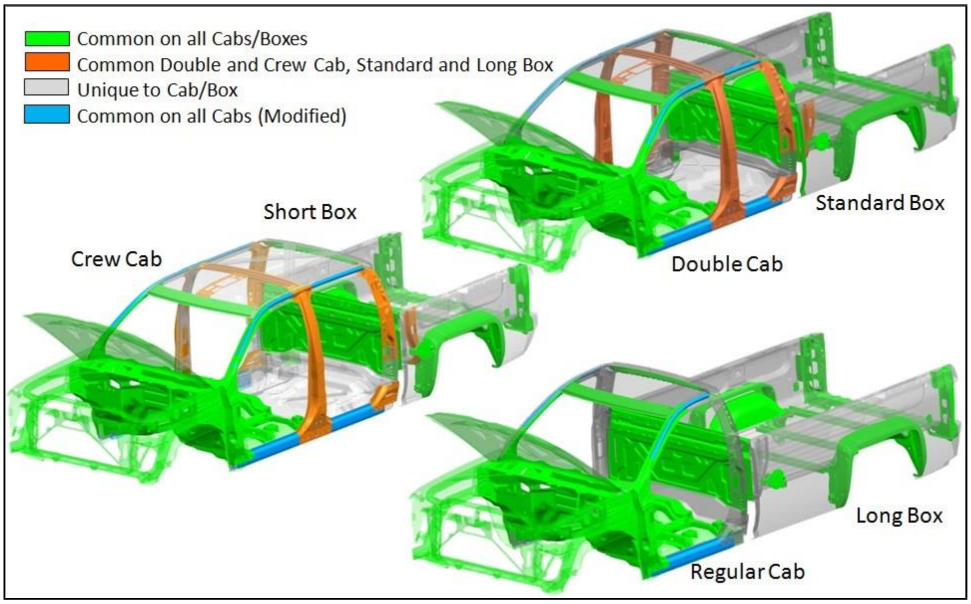


Figure 273: LWT Cab and Pickup Box Common Parts

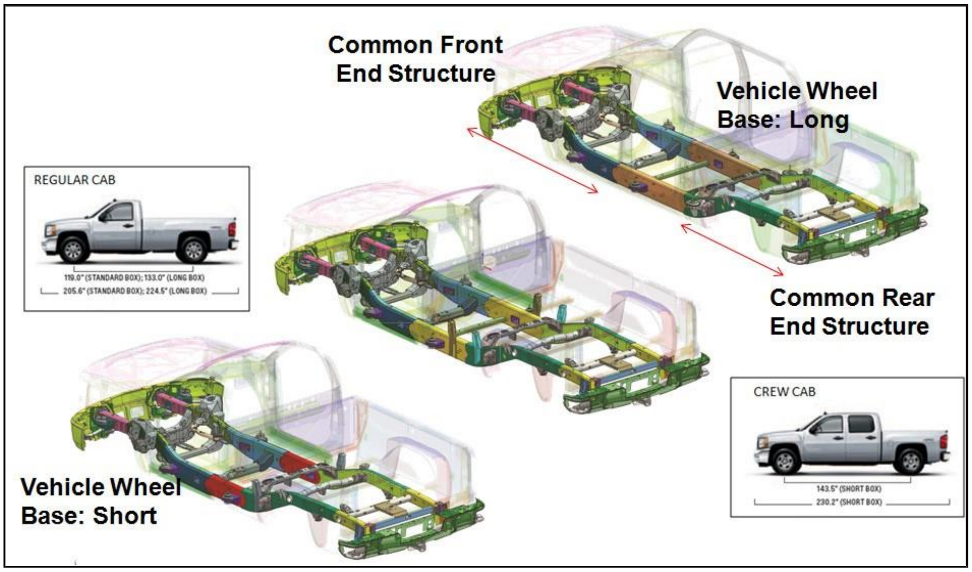


Figure 274: LWT Chassis Frame Common Parts

8.5 Material and Manufacturing Technologies for the LWT

The manufacture of vehicle systems encompasses a number of manufacturing processes and technologies unique and specific to the automotive industry. These are determined by the vehicle volume per year, the materials used and the availability of manufacturing technologies related to the year of production. This section gives an overview of the technologies that have been considered for the manufacture of the LWT for the years 2020-2030. The topics include:

- Material and manufacturing technologies overview and maturity, and
- Assembly Technologies.

8.5.1 Material and manufacturing technologies overview and maturity

For the LWT design, the choices for materials with their corresponding manufacturing technologies were reviewed for availability and readiness for high volume production for MYs 2014 and 2025 - 2030. The materials considered include:

1. Steel,
2. Aluminum,
3. Magnesium,
4. Plastics, and
5. Composites such as FGRP and CFRP.

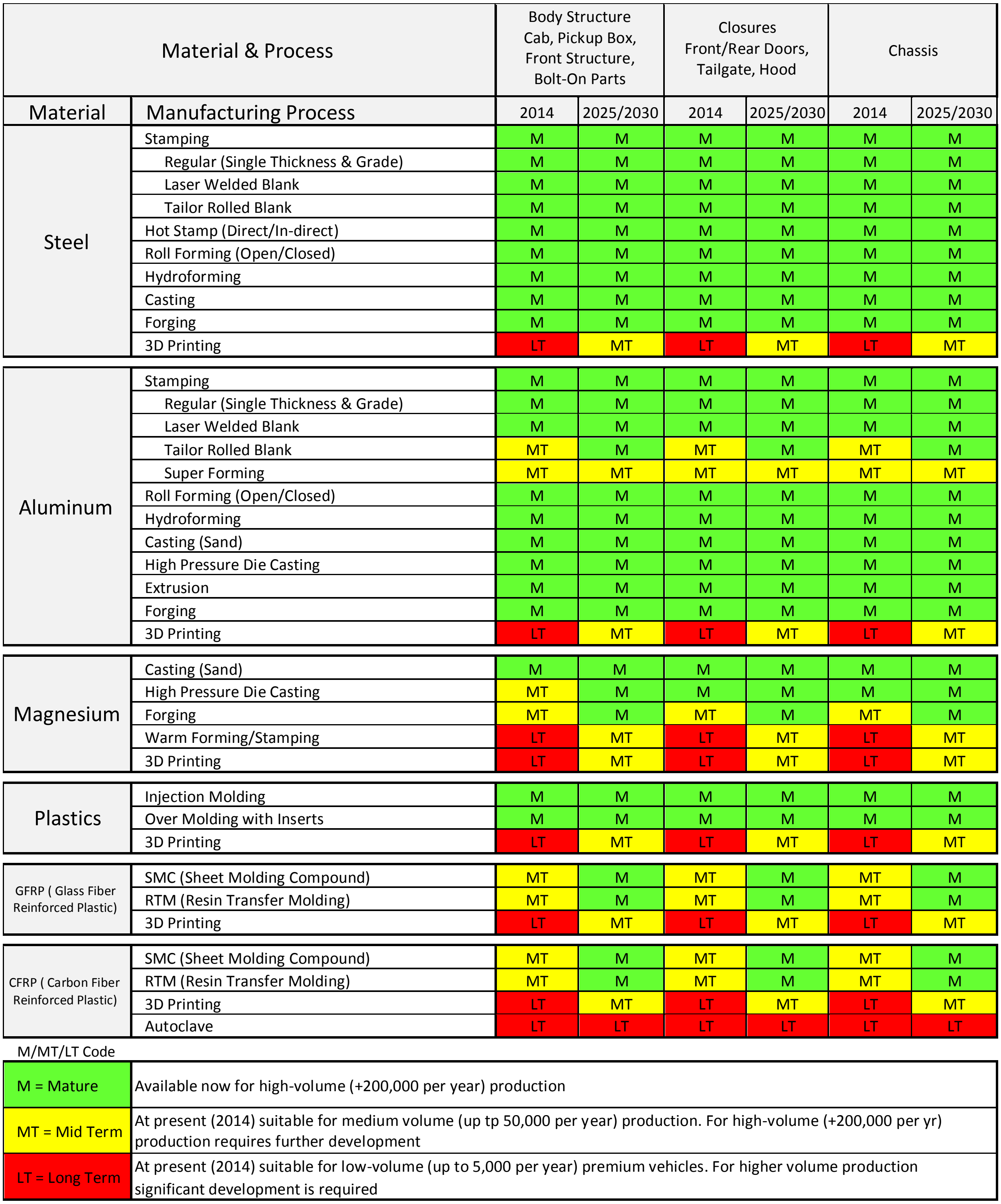
The suitability and maturity of each material for major vehicle systems, body structure, closures, chassis frame are shown in Figure 275 for the MY 2014 and MY 2025-2030 time frame. Manufacturing and assembly technologies are classified as:

- **Mature** – Mature technologies are those materials and manufacturing technologies that are currently suitable for high-volume production (200,000+ products per year)

- **Mid-Term** – Mid-term technologies are those technologies that are currently suitable for low-volume production (up to 50,000 per year) and are mainly used on premium-priced products. But given time and development, these technologies could become a mature technology by MY 2025

- **Long Term –** Long-term technologies are those technologies that are currently suitable for very low-volume production (up to 5,000 per year) and are mainly used on high-priced products. In this case, materials and technologies tend to be labor- and time-intensive, resulting in a somewhat “hand-built” product. Materials and processes must be further developed to the point that they are capable of high production volumes at affordable costs in order to take advantage of these long-term technologies.

For the LWT systems only materials and manufacturing technologies that are classed as M (Mature) and MT (Mid-Term) at present are specified.



Material & Process		Body Structure Cab, Pickup Box, Front Structure, Bolt-On Parts		Closures Front/Rear Doors, Tailgate, Hood		Chassis	
Material	Manufacturing Process	2014	2025/2030	2014	2025/2030	2014	2025/2030
Steel	Stamping	M	M	M	M	M	M
	Regular (Single Thickness & Grade)	M	M	M	M	M	M
	Laser Welded Blank	M	M	M	M	M	M
	Tailor Rolled Blank	M	M	M	M	M	M
	Hot Stamp (Direct/In-direct)	M	M	M	M	M	M
	Roll Forming (Open/Closed)	M	M	M	M	M	M
	Hydroforming	M	M	M	M	M	M
	Casting	M	M	M	M	M	M
	Forging	M	M	M	M	M	M
	3D Printing	LT	MT	LT	MT	LT	MT
Aluminum	Stamping	M	M	M	M	M	M
	Regular (Single Thickness & Grade)	M	M	M	M	M	M
	Laser Welded Blank	M	M	M	M	M	M
	Tailor Rolled Blank	MT	M	MT	M	MT	M
	Super Forming	MT	MT	MT	MT	MT	MT
	Roll Forming (Open/Closed)	M	M	M	M	M	M
	Hydroforming	M	M	M	M	M	M
	Casting (Sand)	M	M	M	M	M	M
	High Pressure Die Casting	M	M	M	M	M	M
	Extrusion	M	M	M	M	M	M
	Forging	M	M	M	M	M	M
	3D Printing	LT	MT	LT	MT	LT	MT
Magnesium	Casting (Sand)	M	M	M	M	M	M
	High Pressure Die Casting	MT	M	M	M	M	M
	Forging	MT	M	MT	M	MT	M
	Warm Forming/Stamping	LT	MT	LT	MT	LT	MT
	3D Printing	LT	MT	LT	MT	LT	MT
Plastics	Injection Molding	M	M	M	M	M	M
	Over Molding with Inserts	M	M	M	M	M	M
	3D Printing	LT	MT	LT	MT	LT	MT
GFRP (Glass Fiber Reinforced Plastic)	SMC (Sheet Molding Compound)	MT	M	MT	M	MT	M
	RTM (Resin Transfer Molding)	MT	M	MT	M	MT	M
	3D Printing	LT	MT	LT	MT	LT	MT
CFRP (Carbon Fiber Reinforced Plastic)	SMC (Sheet Molding Compound)	MT	M	MT	M	MT	M
	RTM (Resin Transfer Molding)	MT	M	MT	M	MT	M
	3D Printing	LT	MT	LT	MT	LT	MT
	Autoclave	LT	LT	LT	LT	LT	LT

M/MT/LT Code

M = Mature	Available now for high-volume (+200,000 per year) production
MT = Mid Term	At present (2014) suitable for medium volume (up tp 50,000 per year) production. For high-volume (+200,000 per yr) production requires further development
LT = Long Term	At present (2014) suitable for low-volume (up to 5,000 per year) premium vehicles. For higher volume production significant development is required

Figure 275: Material and Manufacturing Technologies Maturity Level

8.5.2 Joining Technologies for the LWT

There are a number of joining methods generally available to complete the vehicle structure assembly. Figure 276 shows the available joining methods that are used on the existing Chevrolet Silverado and those selected for the LWT.

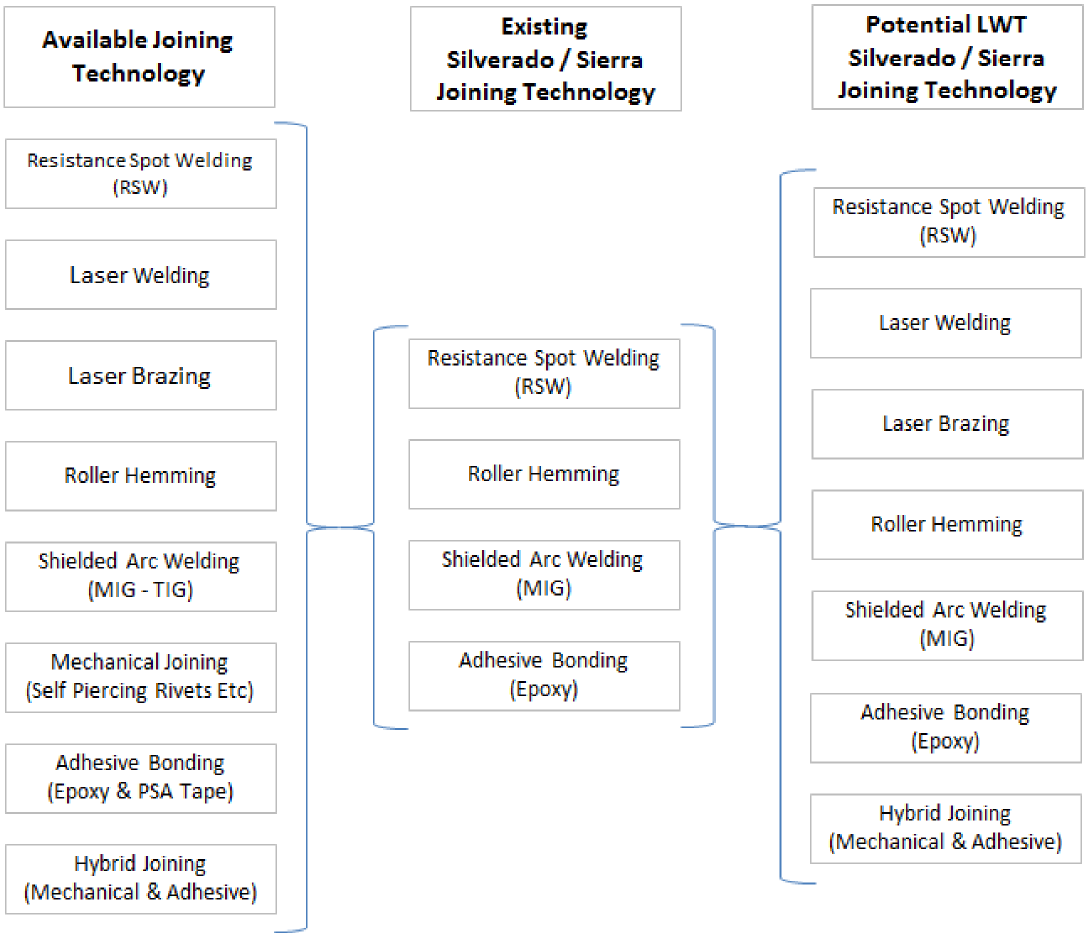


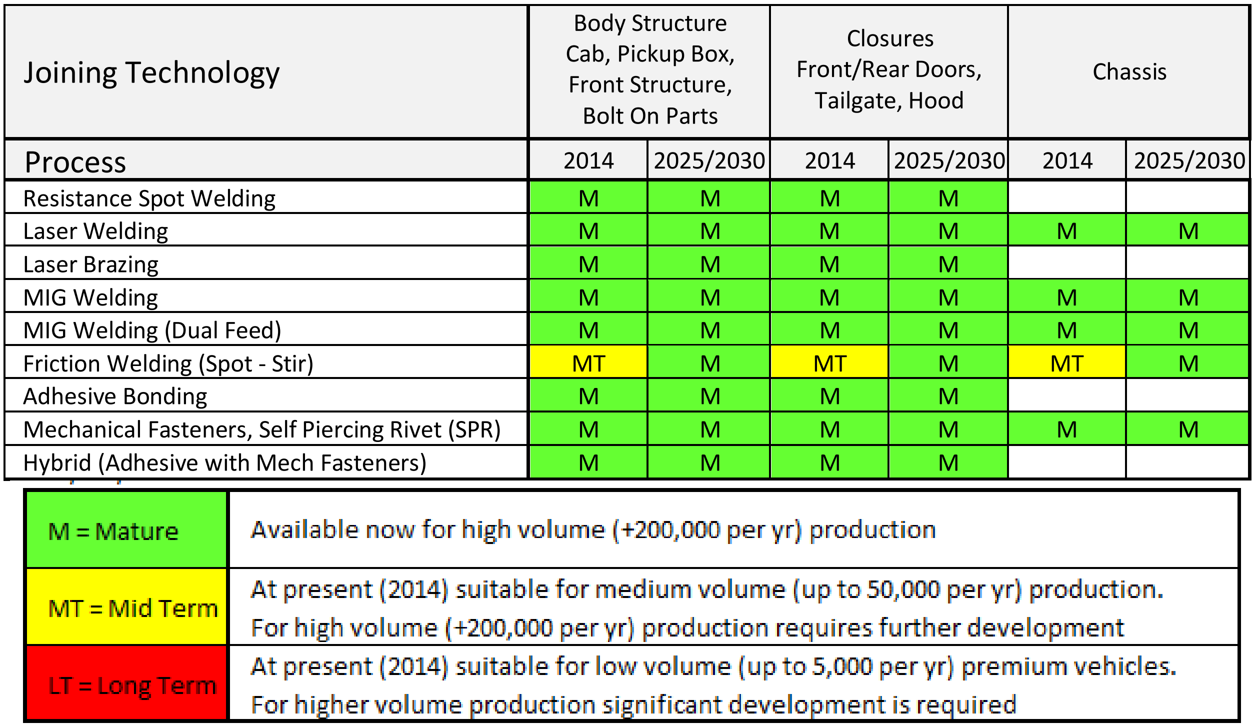
Figure 276: Available Joining Methods

From the eight available joining methods, four are used on the 2014 Silverado 1500 and seven joining methods are considered for the LWT. Shielded arc welding (MIG welding) is still the preferred method for the chassis frame. Laser welding is also an option for the LWT whether the structure is of a steel construction or all aluminum. For the LWT, aluminum solution, the following joining methods were adopted.

- Roller Hemming (Closures)
- Resistance Spot-Welding (Front/Rear Bumpers, Chassis Frame, Trailer Hitch)
- Shielded Arc Welding, MIG. (Chassis Frame, Trailer Hitch)
- Hybrid Joining (Cab-Front End Structure, Pickup Box, Closures)

- Adhesive (Structural and Anti-Flutter)
- Mechanical (Self-Piercing Rivets and Flow Drill Screws)

The joining method maturity levels are shown Figure 277.



Joining Technology	Body Structure Cab, Pickup Box, Front Structure, Bolt On Parts		Closures Front/Rear Doors, Tailgate, Hood		Chassis	
Process	2014	2025/2030	2014	2025/2030	2014	2025/2030
Resistance Spot Welding	M	M	M	M		
Laser Welding	M	M	M	M	M	M
Laser Brazing	M	M	M	M		
MIG Welding	M	M	M	M	M	M
MIG Welding (Dual Feed)	M	M	M	M	M	M
Friction Welding (Spot - Stir)	MT	M	MT	M	MT	M
Adhesive Bonding	M	M	M	M		
Mechanical Fasteners, Self Piercing Rivet (SPR)	M	M	M	M	M	M
Hybrid (Adhesive with Mech Fasteners)	M	M	M	M		

M = Mature	Available now for high volume (+200,000 per yr) production
MT = Mid Term	At present (2014) suitable for medium volume (up to 50,000 per yr) production. For high volume (+200,000 per yr) production requires further development
LT = Long Term	At present (2014) suitable for low volume (up to 5,000 per yr) premium vehicles. For higher volume production significant development is required

Figure 277: Joining Technologies Maturity Level

Vehicles with steel bodies are constructed by welding together separate parts that have been stamped from steel sheet materials. This process of manufacturing body structures using steel has been extensively refined and optimized over the years for high speed and low cost. A steel stamped part can be produced in approximately 10 to 15 seconds when using a conventional stamping die and approximate 5 seconds for a progressive die. With production volumes of 200,000 units or more, part costs are kept low which makes steel the OEM's preferred material for a vehicle body structure. However, with the OEM's striving to reduce the weight of the vehicle the use of aluminum is becoming more popular. This is especially true for vehicle closures, hood, doors, and tailgate/liftgate.

Aluminum intensive body structures are produced by a process similar to a steel vehicle body either welded together or using mechanical fasteners with adhesives to complete the assembly of the structure. An advantage of the stamped aluminum structure approach is that existing steel presses can be used with modified tooling. This keeps capital investment costs low for the OEMs and allows for higher production volumes. Stamped aluminum parts can also be manufactured in approximately 15 seconds each using the same stamping process as that used for steel. The stamping cycle time for aluminum is generally higher than a steel stamping partly due to aluminum having lower elongation than steel.

8.6 CAE Optimization and Manufacturing Assessment

8.6.1 Topology Optimization

Topology optimization is a computer simulation method to determine optimized structural load paths in a pre-specified three-dimensional space. This analysis is conducted using the optimization program, Optistruct,[137] developed by Altair Engineering, Inc. The vehicle package created from the scanned surfaces of the baseline Silverado 1500 was used as the basis for the LWT Topology Optimization Model shown in Figure 278.

The following load cases were used to identify optimized structural load paths for the LWT.

- Stiffness Bending and Torsion
- Frontal NCAP Full Barrier
- IIHS 40 Percent ODB Front Crash
- IIHS Side
- FMVSS No. 214 (Pole Impact)
- FMVSS No. 301 (Rear Crash)
- FMVSS No. 216 (Roof Crush)

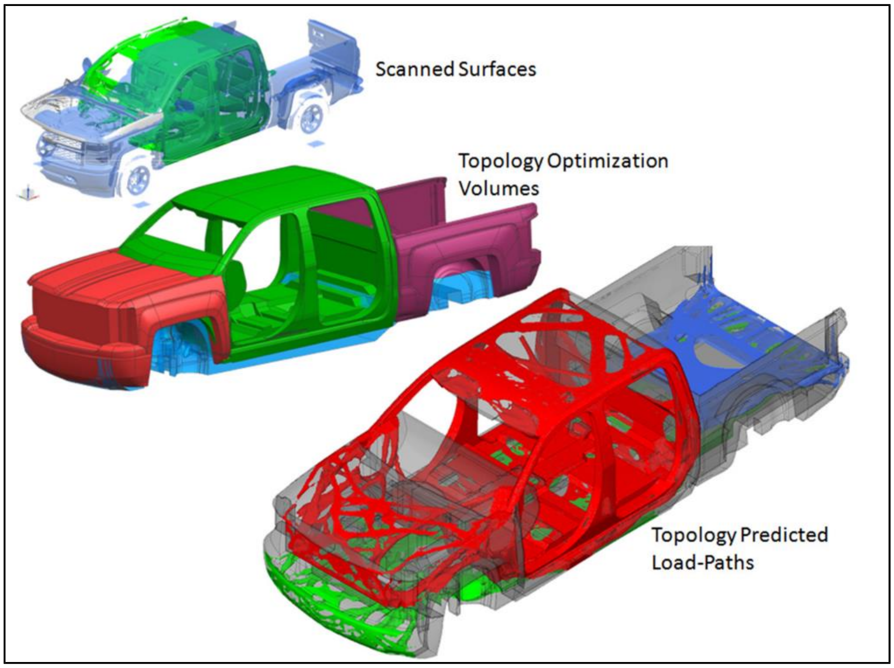


Figure 278: LWT Topology Optimization Model

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[137] www.altairhyperworks.com/HWTemp3Product.aspx?product_id=19&item_name=Benefits&top_nav_str=1&AspxAutoDetectCookieSupport=1

All major load cases for front, side, and rear impact are taken into account. The result of this task is a better understanding of the critical load paths for each of the main load cases and identification of computer optimized load paths. Computer-based topology optimization is an advanced CAE technique that yields unique unconventional solutions to structural load paths, because the solutions are purely based on mathematics without engineer's preconception. Load paths identified by this technique are very organic as found in nature, however, require design interpretation to convert the identified shapes to manufactureable design. The load paths predicted by topology optimization for the cab structure are illustrated as blue color are superimposed on the final chosen design gray color are shown in Figure 279.

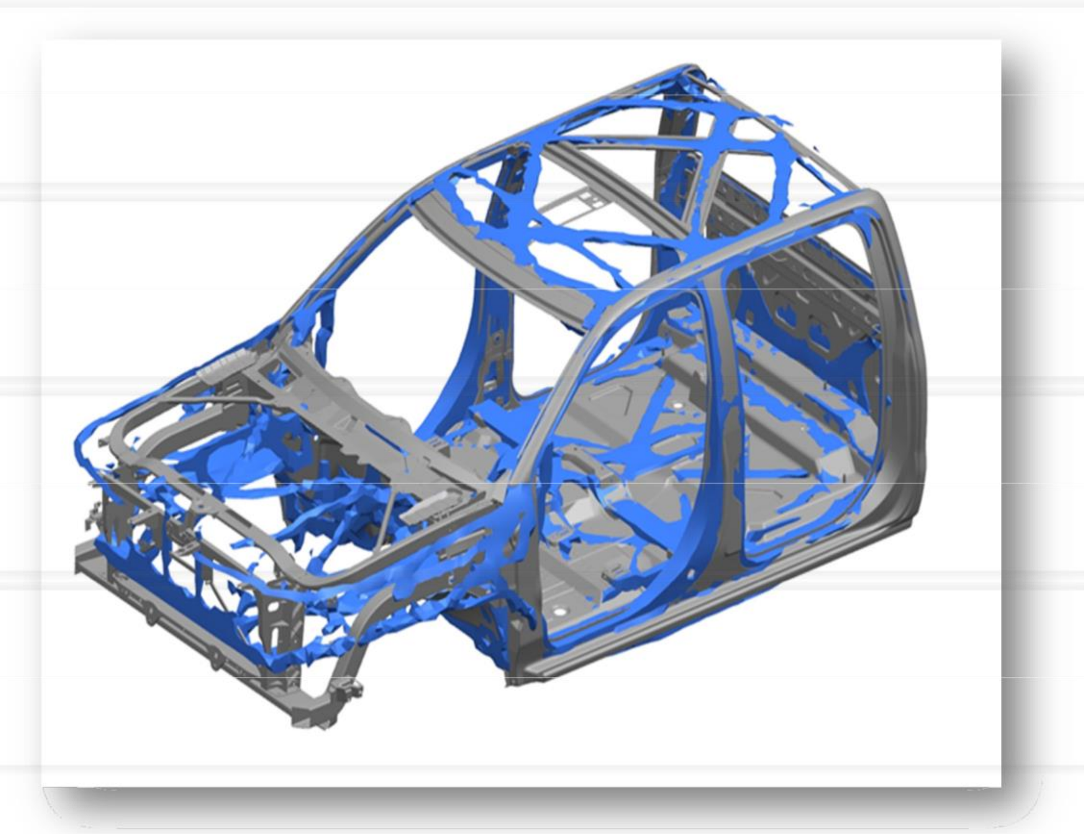

Figure 279: LWT Cab Design and Topology Results

Topology load path results superimposed on baseline 2014 Silverado 1500 structure geometry, shown in Figure 280, show remarkable similarity to the baseline design. This is indicative of the fact that GM designed the 2014 Silverado using similar advanced analysis techniques. The topology predicted load paths for the radiator support, fender assembly, and hood show very similar pattern as used on the baseline vehicle. This is also true for the cab front floor shown in Figure 280. The front floor reinforcement panels shown in color green are almost an exact match predicted by topology optimization.

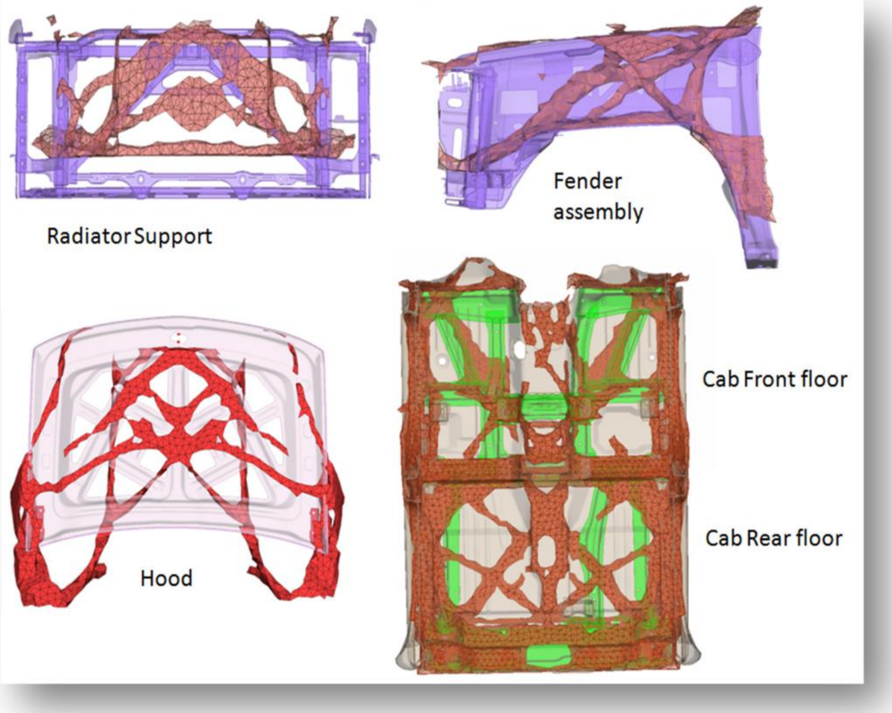

Figure 280: Topology Optimization Results – Overlaid on Baseline Vehicle Structure

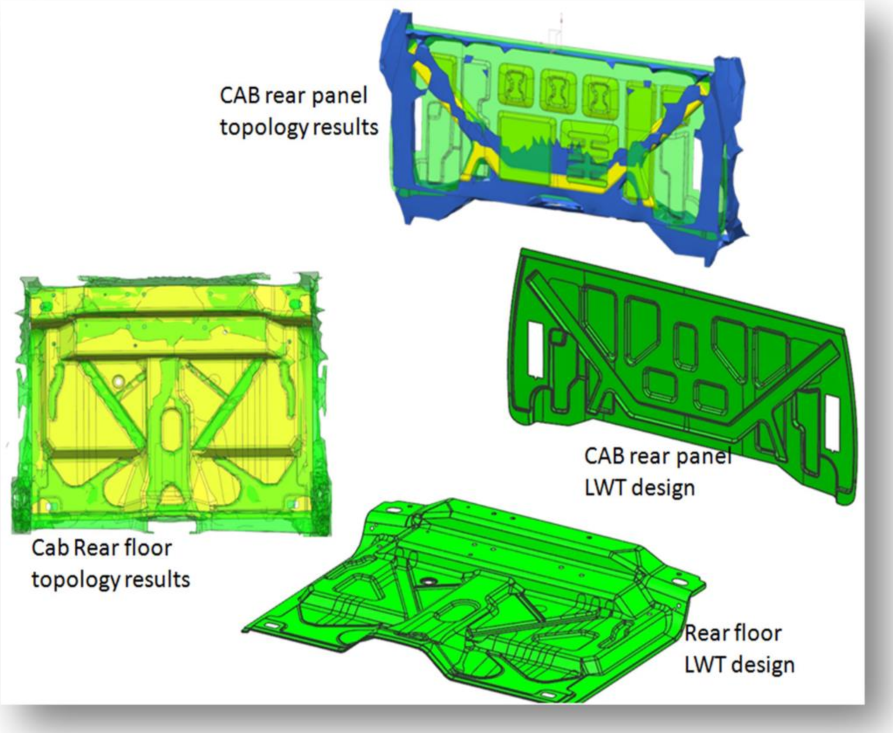

Figure 281: Topology Optimization Results and Interpreted Design Examples

As explained above, the structural load paths identified by Topology Optimization must be interpreted by technical experts for design, engineering and manufacturing in order to ensure that component shapes consistent with the optimization can be manufactured. The areas of the baseline design that did not conform to the load paths predicted by Topology Optimization were identified and redesigned for the LWT structure. Two examples of such structure; cab rear floor and cab rear panel are shown in Figure 281. These panels were redesigned for the LWT to follow the predicted load paths as accurately as possible, keeping in mind the manufacturing process constraints, in this case the stamping process for these two panels. The entire cab design was built panel by panel using similar method. The LWT cab although maintaining the outer styling surface of the baseline design, is completely new design and construction using aluminum with local steel reinforcements as shown in Figure 282.

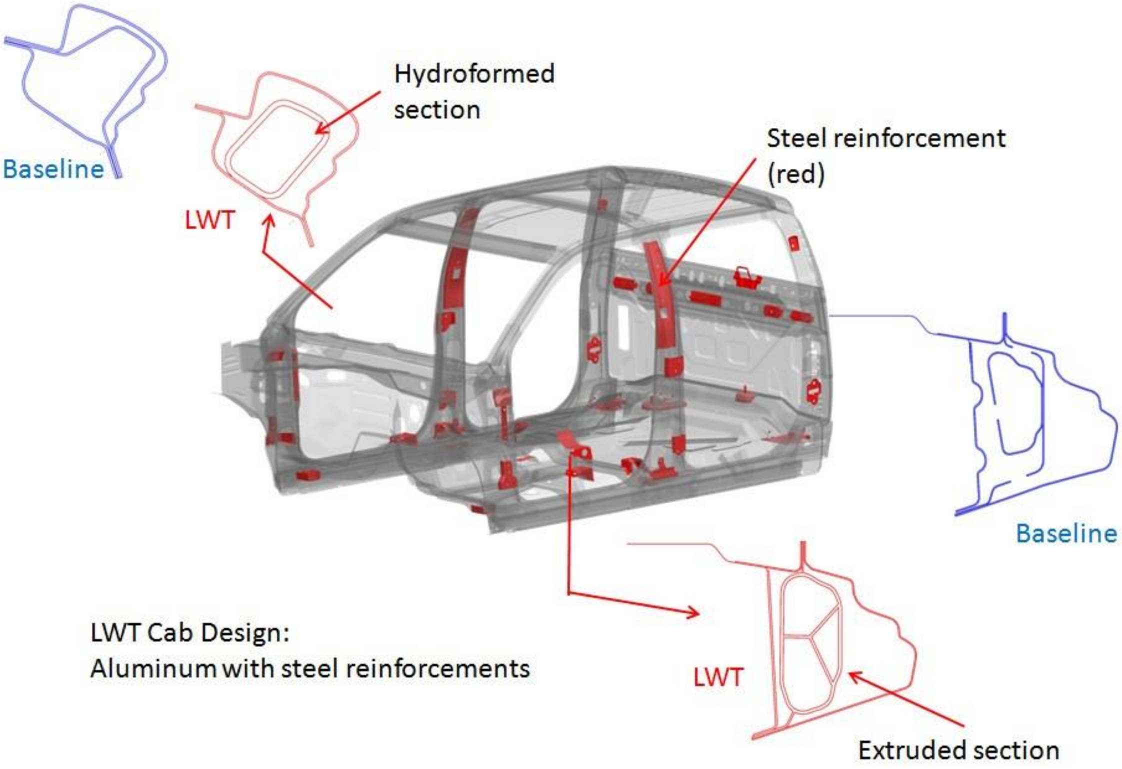

Figure 282: LWT Cab Design – Aluminum with Steel Reinforcements

8.6.2 Manufacturing Assessment

The manufacturability of all proposed body structure panels for the LWT was assessed using suitable simulation analysis tools. For example, the body structure parts that are produced using stamping process were analyzed using HYPER-FORM forming simulation programs. These analysis techniques are routinely applied in the automotive industry prior to the design being released for production tooling.

For the LWT, single-step simulation was done on most of the major parts of the cab, closures, and pickup box structure. Whether a stamped component design is safe or whether it will fail during the stamping process is determined through the forming limit diagram. This is an empirical curve showing the biaxial strain levels beyond which failure may occur in sheet metal forming. Stamping simulation results for the cab rear floor panel and rear panel are shown in Figure 283. The FLD diagrams predicted no failure for these panels. There are small areas where wrinkling and material failure can occur and these can be easily improved by implementing minor design changes to the CAD data.

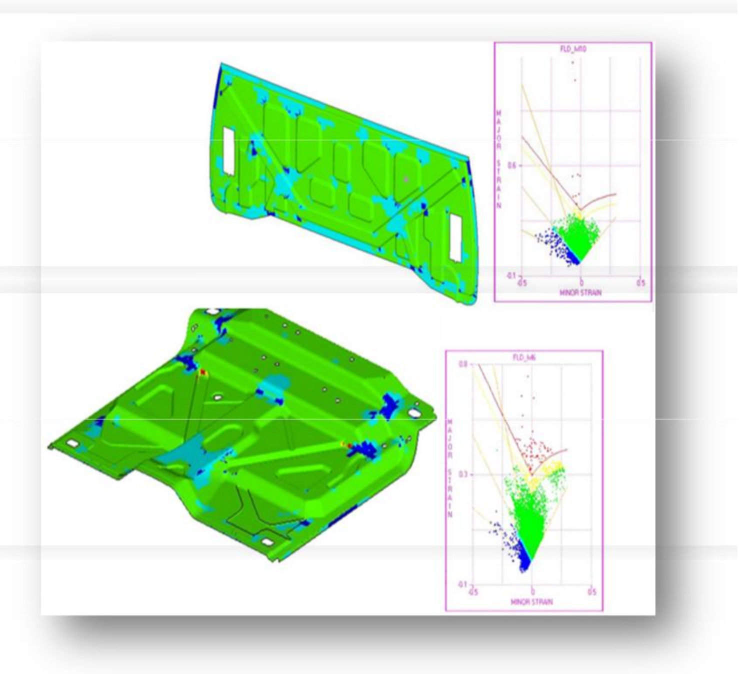

Figure 283: Cab Rear Floor and Rear Panel Single-Step Stamping Simulation

8.6.3 Structural Section 3G Optimization

In this step of the computer aided optimization process, the structural parts that form the major load paths identified through topology optimization are optimized. The material properties, gauges (thicknesses), and cross-sectional shapes are modeled independently as design variables. By considering these variables simultaneously for linear and non-linear crash requirements, the most structurally efficient design can be developed. This task uses the state-of-the-art analysis technique applied to a complete vehicle structure or individual vehicle systems. The following computer programs were setup to work in a continuous optimization loop to converge on to most optimal stable mass efficient solution.

- GENESIS (Vanderplaats Research & Development, Inc.) [138]
- HEEDS (Red Cedar Technologies, Inc.)[139]
- SFE CONCEPT software [140]
- LS-DYNA (LSTC, Inc.)

The optimization process simultaneously considers the requirements of all the specified loads cases, which included some or all of the following.

- Stiffness Bending and Torsion
- Frontal NCAP Full Barrier
- IIHS 40 Percent ODB Front Crash
- IIHS Side
- FMVSS No. 214 (Pole Impact)
- FMVSS No. 301 (Rear Crash)
- FMVSS No. 216 (Roof Crush)

The constraints and performance targets for each these loads are further explained in Section 6.3 for the bending and torsion stiffness loads cases and in Section 6.2 of this report for the crash load cases.

The result of this task is identification of optimized load paths. Computer-based 3G (geometry, gauge, and grade of material) optimization is an advanced state of the art CAE technique which yield optimized unconventional load-bearing geometry. This technique was applied to the chassis frame to determine the optimal section sizes and panel thickness for the central section of the frame design as shown in Figure 284. The results for this study show optimal sizes and panel thicknesses of the sections along the length of the frame rails as shown in Figure 285.

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[138] GENESIS is a finite element analysis and design optimization software package; see www.vrand.com/Genesis.html

[139] HEEDS interfaces with CAE applications to automate the design optimization process; see www.redcedartech.com/

[140] SFE applies numerical methods in order to solve complex problems in the field of engineering physics;see www.sfe-berlin.de/

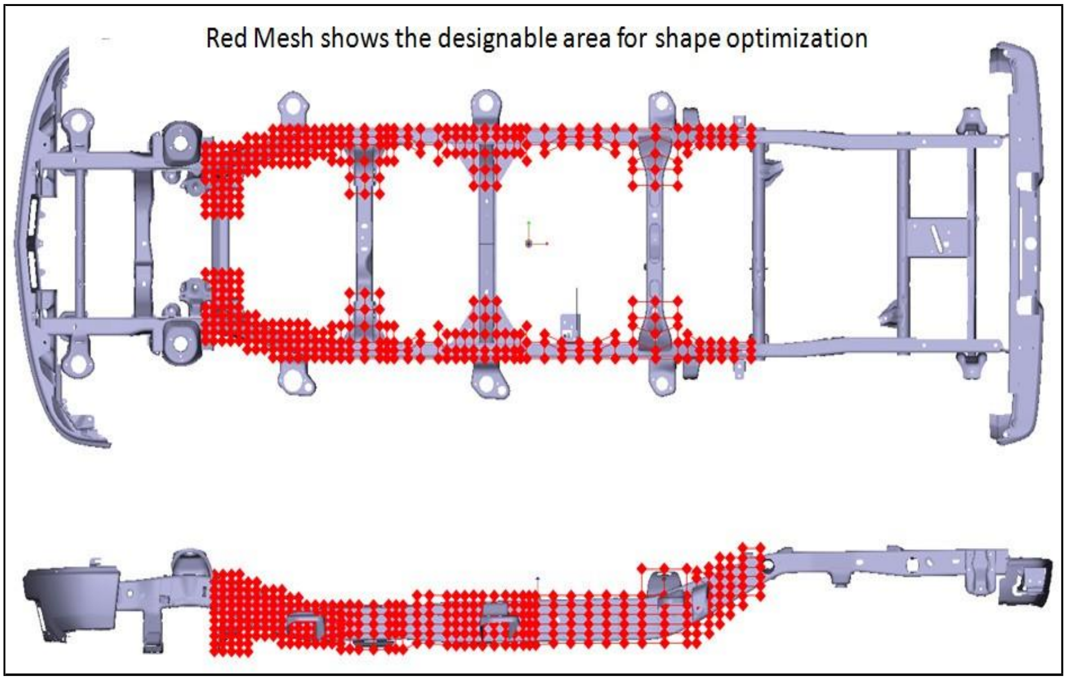


Figure 284: Frame Section Optimization Design Space

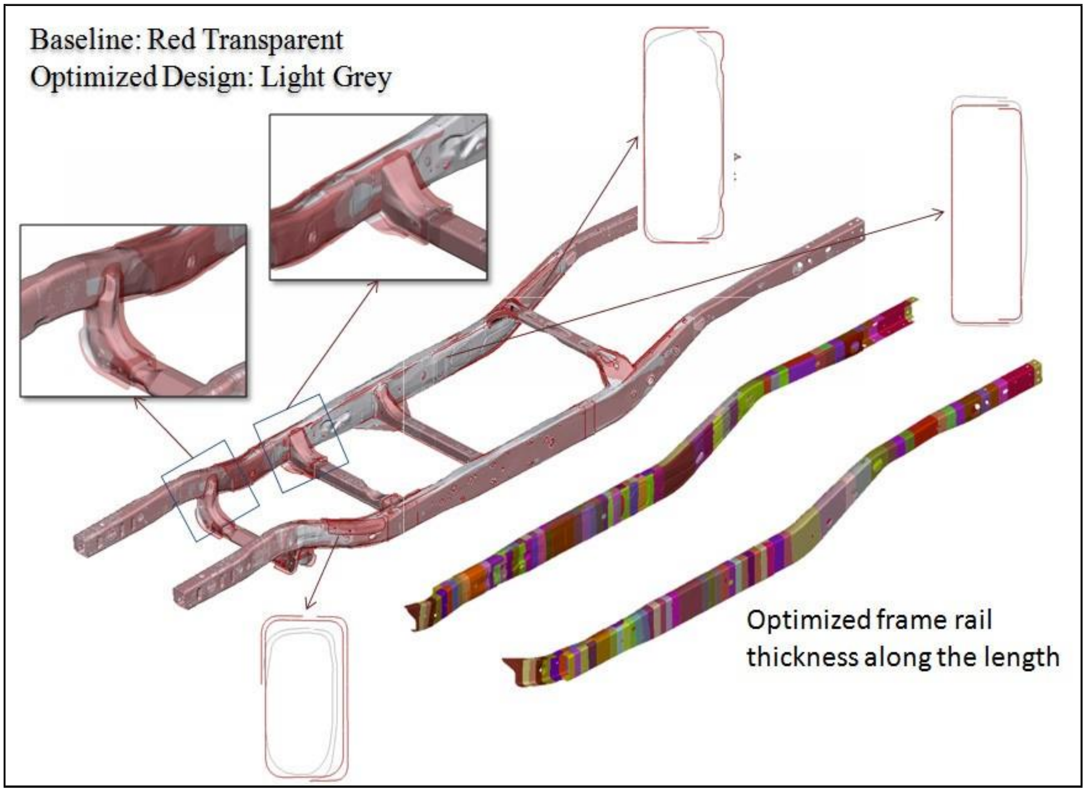


Figure 285: Frame Section 3G Optimization Results

Topology optimization and 3G optimization as described above are great engineering tools to generate mass efficient design ideas. The design of the LWT was developed using input from this type of analysis. This process was applied to the following LWT structural systems.

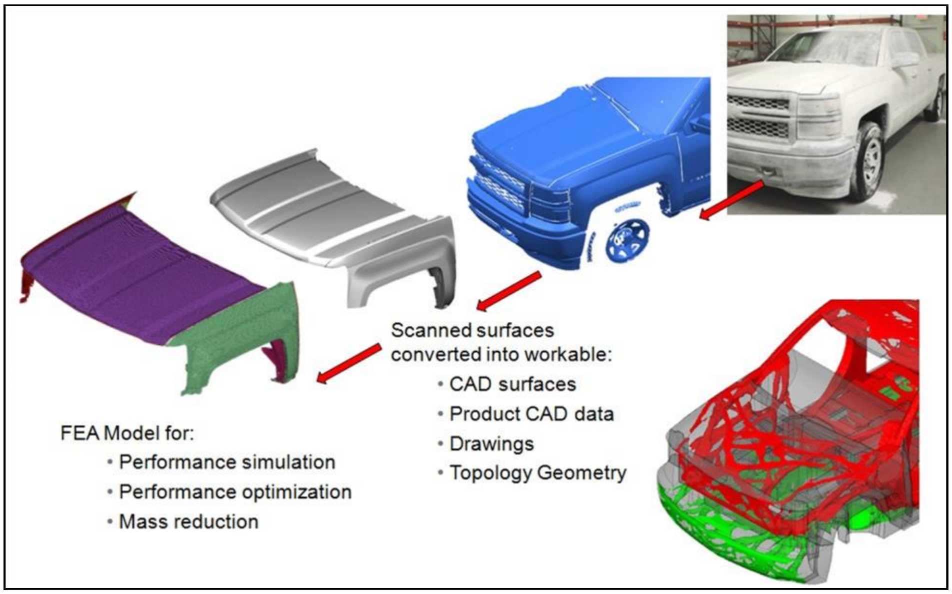
1. Cab including front end sheet metal and radiator support structure
2. Chassis frame, front and rear bumpers, towing hitch
3. Front and rear doors
4. Pickup box
5. Instrument panel structure
6. Lower control arm front suspension

9 LWT Crashworthiness Safety and Structural Performance

9.1 Baseline and LWT vehicle Finite Element Analysis Modeling Introduction

FEA models are used extensively in the automotive industry to support the design and engineering process to create safe and mass efficient vehicles. For this program, to demonstrate the functionalities of the LWT are maintained or improved compared with baseline vehicle, for noise, vibration, harshness, and crash safety, detailed FEA models for the baseline vehicle were constructed and correlated with the available test results. For crashworthiness, safety and vehicle stiffness and NVH similar FEA models were constructed of the proposed LWT vehicle and results compared with the baseline vehicle test results and baseline vehicle FEA predicted results. The CAE LSDYNA models are constructed to be compatible with available FEA models from George Washington University[141] and suitable for frontal vehicle-to-vehicle crash simulation.

FEA mesh for the baseline vehicle was created from the scanned geometry for the entire vehicle. An example of the steps in this process is shown in Figure 286. The part material data was obtained by conducting material tensile tests on the corresponding part samples. The gauge (thickness) and material data for each part were accordingly incorporated into the model. Parts that were not represented as geometry (interior trim, carpets, etc.) were added in the model as mass elements with weight and inertia characteristics.



Scanned surfaces converted into workable:

- CAD surfaces
- Product CAD data
- Drawings
- Topology Geometry

FEA Model for:

- Performance simulation
- Performance optimization
- Mass reduction

Figure 286: Body Structure Scanned Surfaces, CAD Data, and FEA Mesh

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[141] www.ncac.gwu.edu/vml/models.html

The FEA models were built and assembled for all of the vehicle subsystems. The subsystems consisted of the following assemblies.

- Cab
- Front and rear doors
- Hood
- Tailgate
- Cargo box
- Instrument panel structure
- Steering column
- Front seats
- Chassis frame
- Front and rear bumpers
- Tow bar
- Chassis components
- Engine and other powertrain components

The subsystem models were assembled into the NASTRAN models for linear stiffness and normal modes analysis as shown in Figure 287 and into full vehicle LSDYNA crash simulation models as shown in Figure 288. Similar detailed FEA LS-DYNA models were assembled for both the baseline vehicle and the LWT.

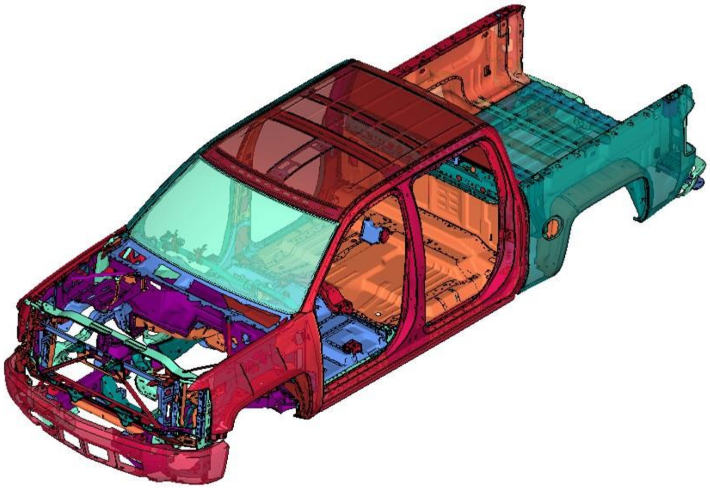
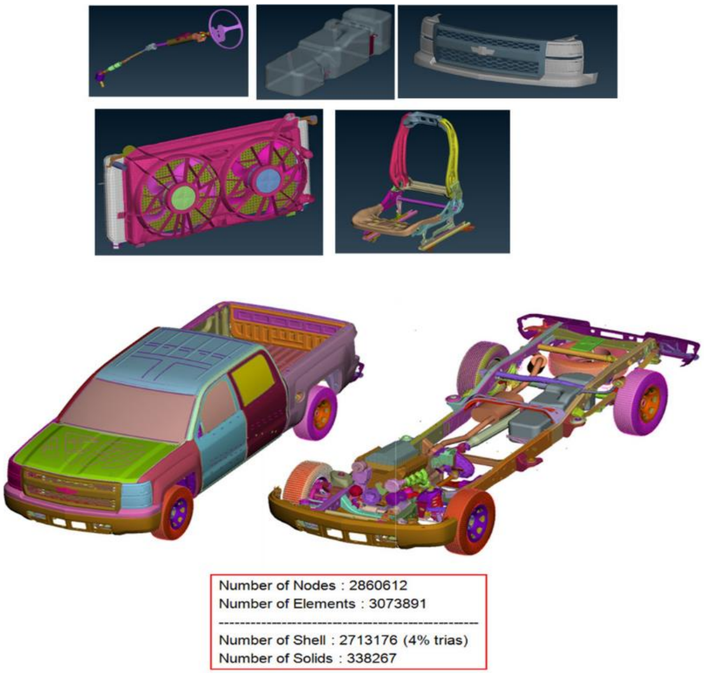


Figure 287: Baseline Vehicle NASTRAN FEA Model



```
Number of Nodes : 2860612
Number of Elements : 3073891
-----------------------------------------------
Number of Shell : 2713176 (4% trias)
Number of Solids : 338267
```

Figure 288: Baseline Vehicle LSDYNA FEA Model Details

9.1.1 Crash Simulation Software - LSDYNA

Finite element analysis methods are used extensively by automotive industry researchers and engineers to both simulate and analyze automotive crashes and also design and develop safety systems for passenger vehicles in high-speed impacts. LS-DYNA finite element software is the industry standard software for crash simulation and modeling. This software is based on non-linear explicit FE formulations, suited for large deformation applications, which is typical of the crashed structures seen in the automobile industry (single vehicles, vehicle-to-vehicle, vehicle-to-barrier, etc.). Other desirable features of LS-DYNA include an extensive library of material models, handling of large material deformation and material fracture, computational efficiency in explicit formulation, and domain decomposition by parallel processing for large simulations.

With the advent of high-speed, high-memory-capacity computers in the early 1990’s, computer technology reached the point where vehicle crashes could be accurately visualized (simulated) using the computer. Enhanced visualization from computer simulations also permits a better understanding of the crash event than using only high-speed videos of an actual crash. In addition, the simulation solvers like LS-DYNA calculate the accelerations, forces, deflections, stresses, and strains on every part of the vehicle and structure throughout the collision event. This vast amount of data collection is not possible for crash tests that rely on electronic sensors as the sole source of obtaining engineering data. Thus, impact simulations using nonlinear FE analysis and rigid body dynamics have become effective tools in optimizing and evaluating vehicle safety systems.

9.1.2 Crash Simulation LSDYNA FEA Models

The automotive companies use finite element models for crash simulation ranging in size of 2 to 10 million elements. For competitive reasons, these finite element models are not distributed outside the automotive companies. In terms of publically available, open-source finite element models of automobiles, the largest models are approaching about 2 million elements in size. For this study, the LS-DYNA models constructed for the baseline 2014 Silverado 1500 and for the LWT are approximately 3 million elements in size as shown in Figure 288 and These finite element models are quite extensive in details to accurately predict crashworthiness behavior of the vehicle in question.

	2014 Silverado 1500 LS-DYNA Model	LWT LS-DYNA Model
Number of Parts	1,473	1,518
Number of Nodes	2,844,357	2,813,994
Number of Shells	2,688,371	2,734,187
Number of Beams	22,403	22,395
Number of Solids	284,342	251,440
Total Number of Elements	2,995,230	3,008,098

Figure 289: Summary of Complete Vehicle LS-DYNA Crash Simulation Models

For this study LS-DYNA version 8.0 is used for simulation. Pre- and post-processing is done using a system that has Windows 7 64-bit as the operating system with 24.0 GB of RAM. The vehicle models are constructed to be compatible with available FEA models from George Washington University[142] and suitable for frontal vehicle-to-vehicle crash simulation. There are many aspects of FE modeling that affect the accuracy of the simulation. A partial list of the factors that were considered is listed below.

1. Element Type

   The element formulation in CAE model is used with LS-DYNA Type-16 fully integrated Bathe-Dvorkin shell element for major load path parts.

2. Element Formulation

   For the more accurate material stress strain behavior, option of the material formulation for strain rate effect, VP=1.0 is used.

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[142] www.ncac.gwu.edu/vml/models.html

3. Integration Points

   The integration point through the thickness of the sheet metal in the model is used with 5-point integration option for major load path parts.

4. Modeling of Spo-Welds, Self-Piercing Rivets, and Adhesive Bonding

   The spot-welds on the structure are modeled with mesh independent hexa solid weld element[143] of LSDYNA as shown in Figure 290 the mechanical properties of the spot-welds are dependent on the thickness and yield strength of the joining panels. Spot-weld failure based on tensile and shear force properties[144] is represented on MAT_100 (*MAT_SPOT-WELD-DAMAGE-FAILURE) LSDYNA material representation card. The data for the failure forces is taken from several technical publications[145] and scaled based on spot-weld nugget diameter, material yield strength and the thickness of the thinner of the two panels. The calculated failure forces are further scaled to account for the dynamic effects.[146] Self-piercing rivets are also represented using MAT_100 cards, with failure forces calculated based on test data.

   The adhesive bonding of panels is modeled using strips of hexa elements to represent the adhesive thickness layer as shown in Figure 291. LS-DYNA material MAT 240 cohesive material model is used. The adhesive material properties were provided by Dow Automotive and are based on test results that were correlated to failure prediction models. The data provided by Dow Automotive is confidential. In the LS-DYNA model, the adhesive material properties are encrypted.

5. Material Failure Criteria

   When considering the sheet material fracture/failure behavior, the failure option "major in plane strain at failure" (EPSMAJ) of LS-DYNA MAT_123 *MODIFIED_ PIECEWISE_LINEAR_PLASTICITY is used for the materials that are considered to have lower elongation and are prone to fail under extreme impact conditions. LS-DYNA computes the “major in plane strain” in all elements at each time step. When the plastic strain exceeds the failure criterion in an element, that element is eroded (i.e., removed from the finite element model).

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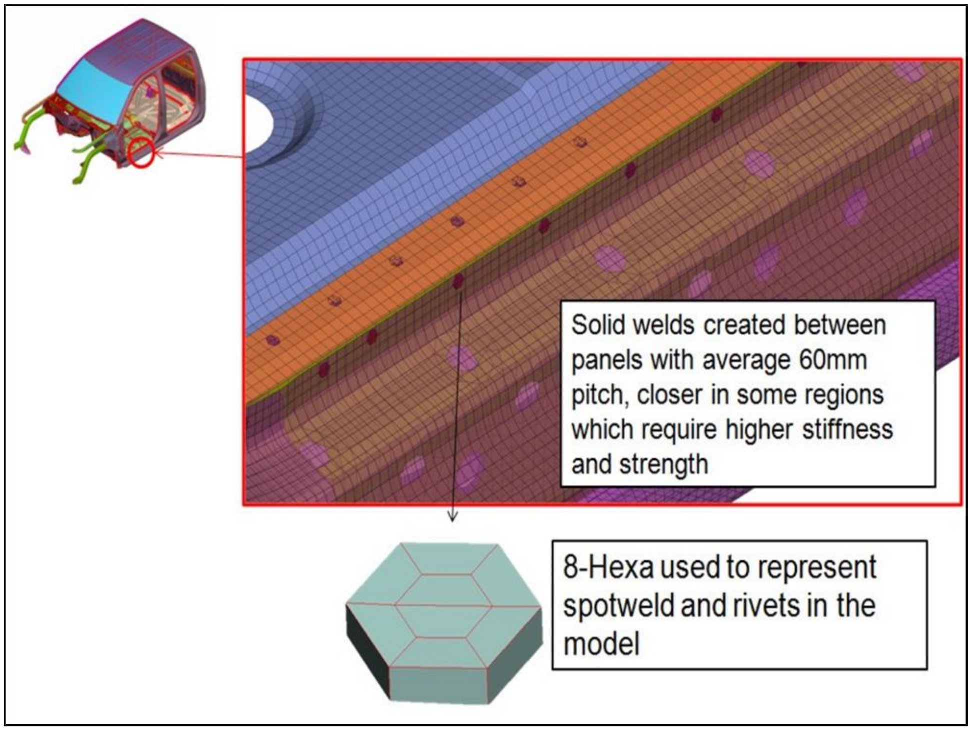
[143] Skye Malcolm and Emily Nutwell: Spotweld Failure Prediction using Solid Element Assemblies; 6th European LS-DYNA Users’ Conference

[144] Yuh J. Chao. Utimate Strength and Failure Mechanism of Resistance Spot Weld Subjected to Tensile, Shear, or Combine Tensile/Shear Loads, Journal of Engineering Materials and Technology APRIL 2003

[145] D. J. Radakovic and M. Tumuluru: Predicting Resistance Spot Weld Failure Modes in Shear Tension Tests of Advanced High-Strength Automotive Steels; Welding Journal, April 2008, VOL. 87

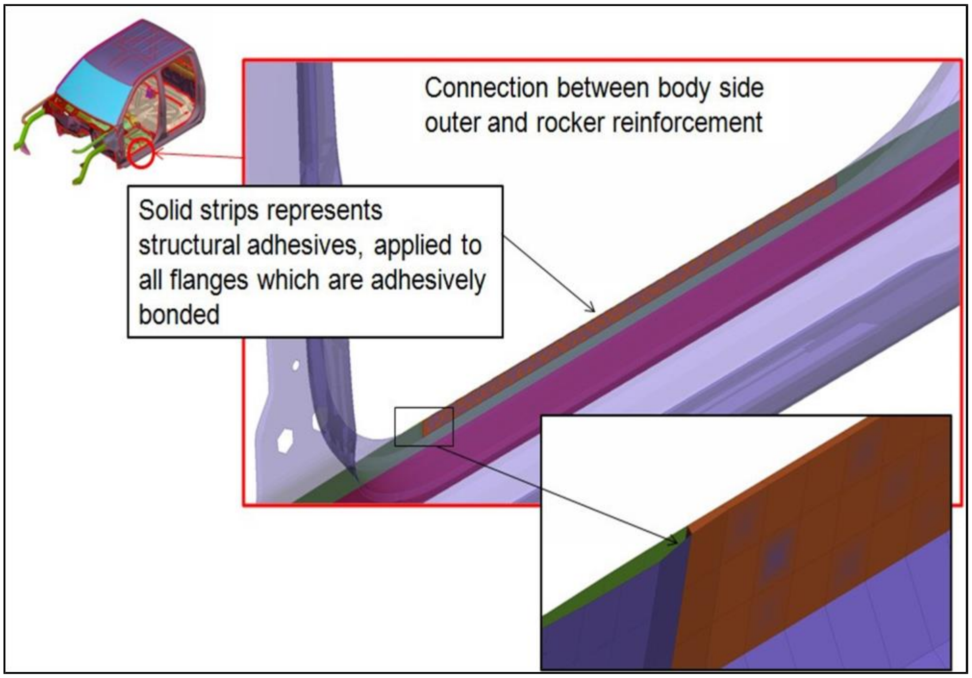
[146] K. Wang & Y.J. Chao & X. Zhu & K.W. Miller: Dynamic Separation of Resistance Spot-Welded Joints: Part II—Analysis of Test Results: Society for Experimental Mechanics 2009



Solid welds created between panels with average 60mm pitch, closer in some regions which require higher stiffness and strength

8-Hexa used to represent spotweld and rivets in the model

Figure 290: Modeling of Spot-Welds



Connection between body side outer and rocker reinforcement

Solid strips represents structural adhesives, applied to all flanges which are adhesively bonded

Figure 291: Modeling of Adhesive Bonding

9.1.3 Material Properties and Modeling

The following sections discuss how steel, aluminum, magnesium and GFRP are modeled in this study.

9.1.3.1 Steel

Figure 292 lists the common material properties of the steels used in the LS-DYNA model. Figure 293 and Figure 294 show data used to define the static and dynamic stress versus strain for the various types of steel used in the finite element baseline and LWT models. The steel properties for the various grades were provided by WorldAutoSteel,[147] the automotive group of the World Steel Association. The comprehensive data including strain rate dependent stress strain curves were developed through testing by WorldAutoSteel member companies.

For this project the part material data was obtained first by conducting material tensile tests on the corresponding part samples. From the tensile test data, the yield strength, ultimate tensile strength and elongation was compared with known grades of steel in the WorldAutoSteel database and the most suitable grade of steel was identified for each part.

Steel Grade	Density (kg/m^3)	Poisson’s ratio	Modulus of Elasticity (MPa)	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Failure Elongation (%)
Mild 140/270	7,850	0.3	21.0 x 10^4	140	270	No Failure
BH 210/340	7,850	0.3	21.0 x 10^4	210	340	No Failure
BH 260/370	7,850	0.3	21.0 x 10^4	260	370	No Failure
BH 280/400	7,850	0.3	21.0 x 10^4	280	400	No Failure
HSLA 350/450	7,850	0.3	21.0 x 10^4	350	450	No Failure
HSLA 420/500	7,850	0.3	21.0 x 10^4	420	500	No Failure
HSLA 550/650	7,850	0.3	21.0 x 10^4	550	675	No Failure
DP 700/1000	7,850	0.3	21.0 x 10^4	700	1000	29
HF 1050/1500	7,850	0.3	21.0 x 10^4	1050	1600	18
DP 1150/1270	7,850	0.3	21.0 x 10^4	1150	1270	24
MS 1250/1500	7,850	0.3	21.0 x 10^4	1250	1500	13.5

Figure 292: Table of common engineering properties of steels used in CAE models

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[147] WorldAutoSteel, the automotive group of the World Steel Association; http://worldautosteel.org/

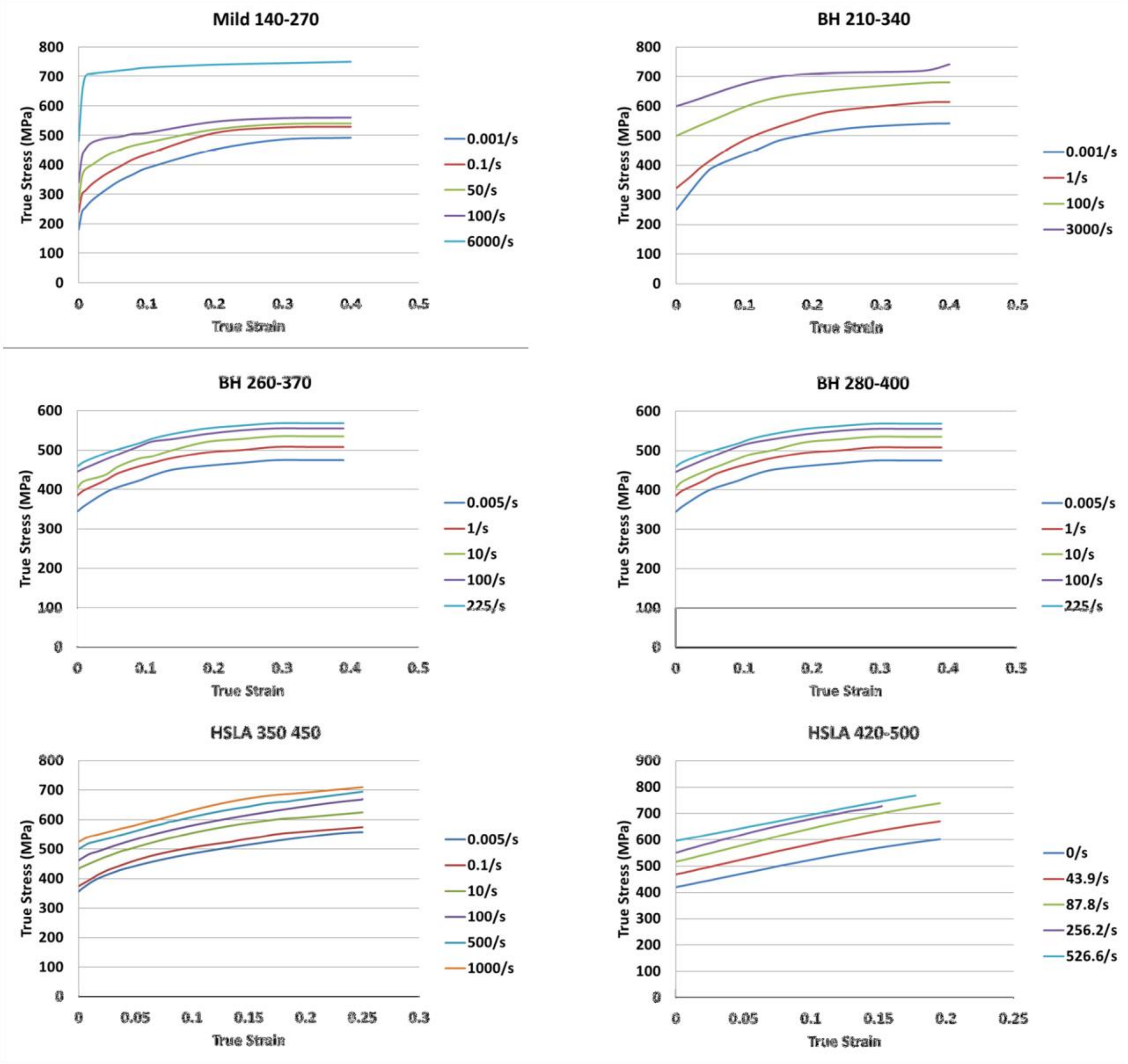

Figure 293: Material curves of stress versus stain used for steel in model – Part I[148]

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[148] WorldAutoSteel, the automotive group of the World Steel Association; http://worldautosteel.org/

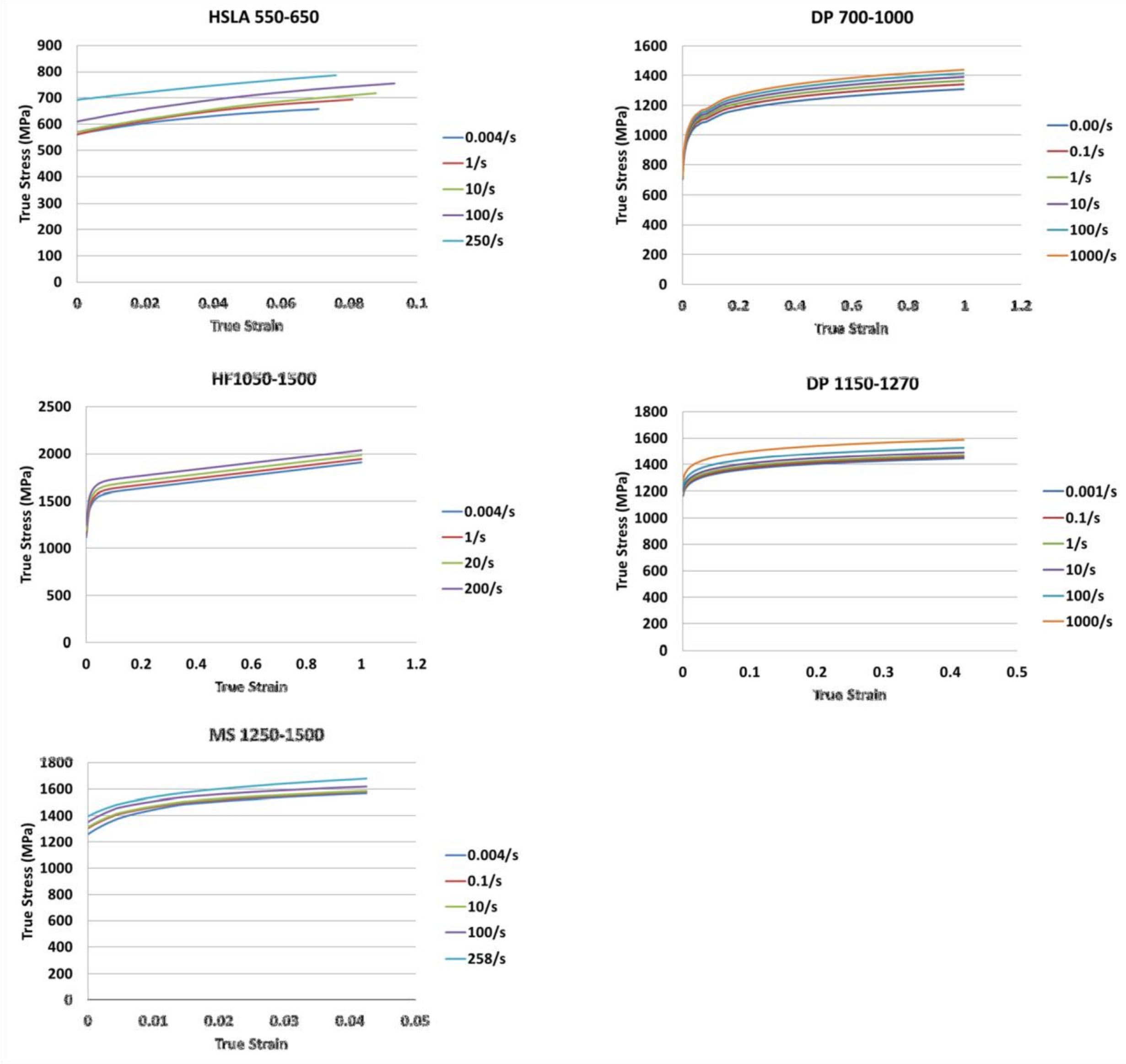

Figure 294: Material curves of stress versus stain used for steel in model – Part II[149]

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[149] WorldAutoSteel, the automotive group of the World Steel Association; http://worldautosteel.org/.

9.1.3.2 Aluminum

Aluminum is mainly used for the upper structure sheet metal of the LWT design. The modeling approach for aluminum is well understood as the automotive industry has been modeling this material satisfactorily for many years. The material properties of the aluminum grades used for this study are shown in Figure 295. The stress-strain curves for aluminum alloys used in the LS-DYNA model are presented in Figure 296. The material properties for aluminum grades were derived with input from aluminum Associations' Aluminum Transportation Group[150] and EDAG's in-house database.

Aluminum Alloy Grade	Density (kg/m3)	Poisson's ratio	Modulus of Elasticity (MPa)	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Failure Elongation (%)
AL 5754	2,700	0.33	7.1×10^4	120	250	16
AA 6014-T7	2,700	0.33	7.1×10^4	200	270	17
AA 6014-T6	2,700	0.33	7.1×10^4	225	294	18
AA 356-T6 CAST	2,700	0.33	7.1×10^4	232	302	10
AA 6111-T6	2,700	0.33	7.1×10^4	270	355	16

Figure 295: Table of common engineering properties of aluminum used in the CAE models

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[150] ATG (Aluminum Transportation Group); http://www.drivealuminum.org/

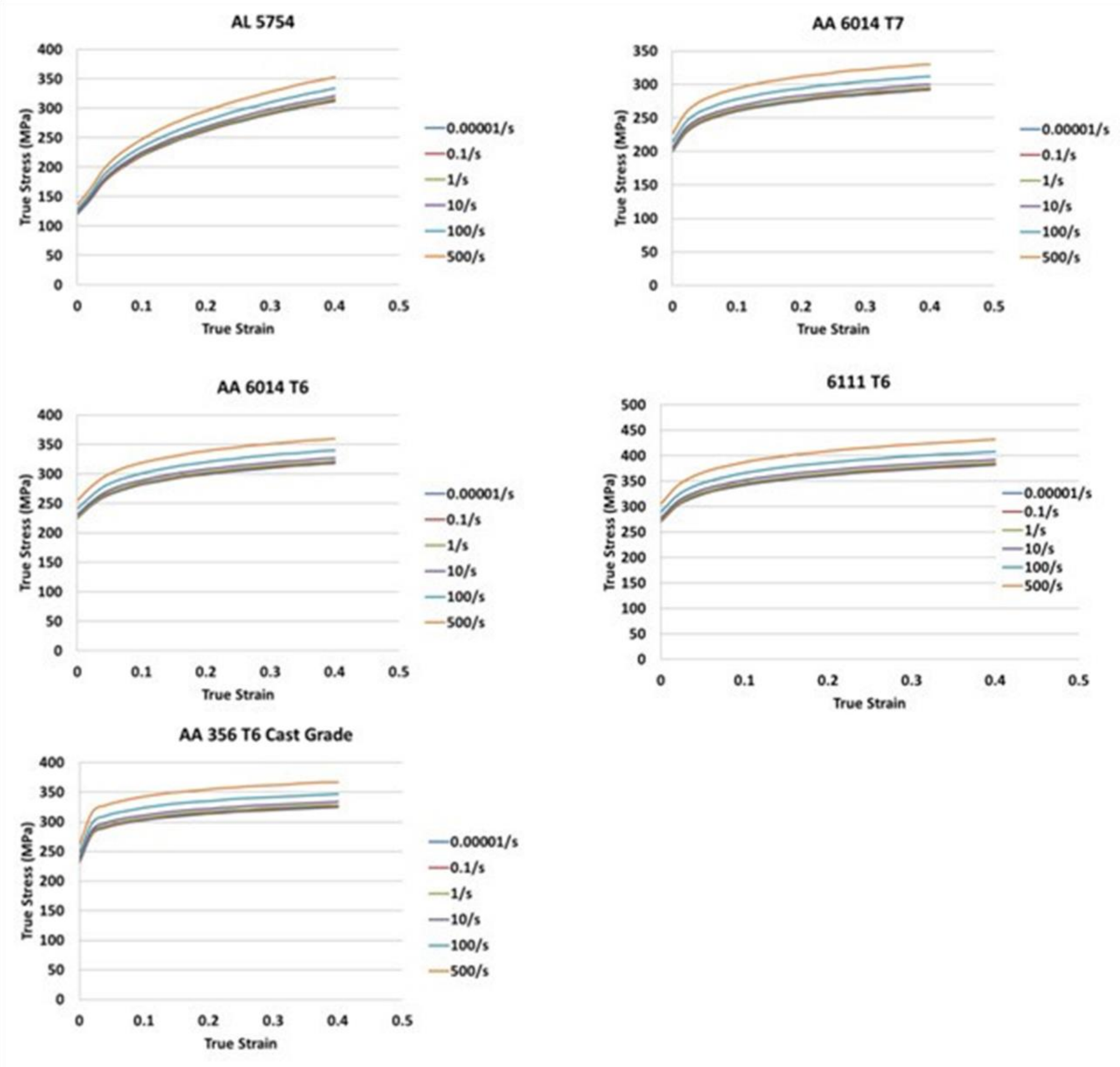

Figure 296: Material curves of stress versus strain used for aluminum in LS-DYNA model

9.1.3.3 Magnesium and GFRP

Magnesium die cast material grade AM60 is used in the LWT for structural components such as radiator support structure and instrument panel. The reason why this grade is chosen over other grade is because of its lower density than steel and aluminum and comparable strength. This alloy has 93.5 percent magnesium, 6 percent of aluminum 0.1 percent Zinc and 0.35 percent manganese. Magnesium alloys with aluminum content less than 6 percent are ductile in nature and can be used for various crashworthiness oriented components.

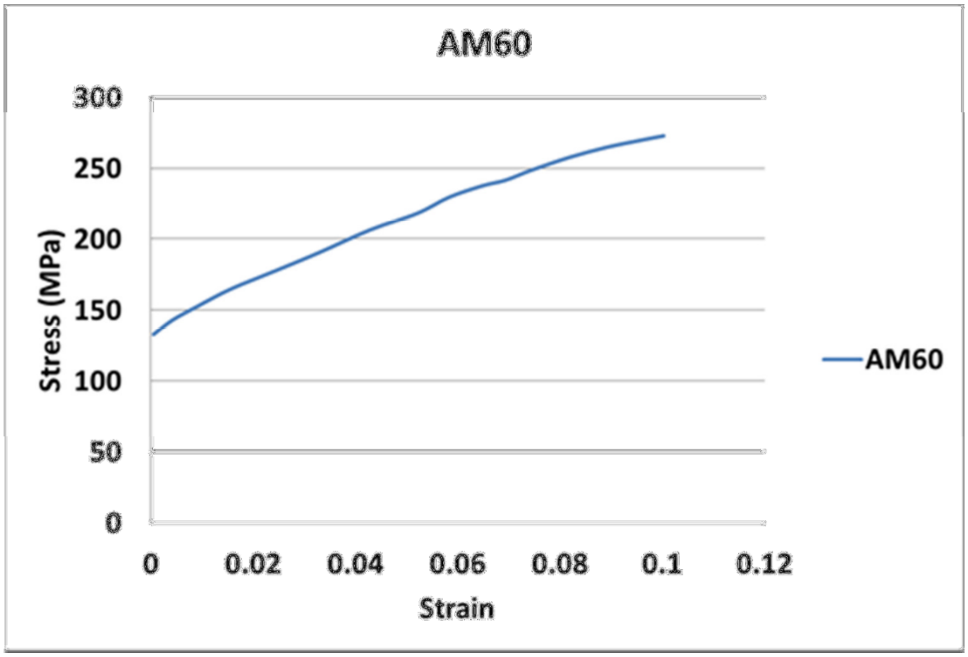

Figure 297: Magnesium Alloy AM60 Mechanical Properties

Rear Suspension in the LWT model is designed in GFRP material. Devendra and Kothari[151] designed and tested GFRP leaf springs using material data from Springer and Kollar[152] as shown in Figure 298.

Sr No.	Properties	Value
1	Tensile modulus along X-direction, MPa	34,000
2	Tensile modulus along Y-direction, MPa	6,530
3	Tensile modulus along Z-direction, MPa	6,530
4	Tensile strength of the material, MPa	900

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[151] Design and Analysis of Glass Fiber Reinforced Polymer Leaf Spring, Devendra K. Damor and K. D. Kothari

[152] Springer, George S., Kollar, Laszloa P., Mechanics of Composite Structures. Cambridge University Press, New York, 2003

5	Compressive strength of the material, MPa	450
6	Shear modulus along XY-direction, MPa	2,433
7	Shear modulus along YZ-direction, MPa	1,698
8	Shear modulus along ZX-direction, MPa	2,433
9	Poisson’s ratio along XY-direction	0.217
10	Poisson’s ratio along YZ-direction	0.366
11	Poisson’s ratio along ZX-direction	0.217
12	Mass Density of the material, kg/m^3	2,600
13	Flexural modulus of the material, MPa	40,000
14	Flexural strength of the material, MPa	1,200

Figure 298: GFRP Mechanical Properties

9.1.4 Material Strength Levels: Baseline Vehicle and LWT

The baseline vehicle 2014 Silverado 1500 make extensive use of AHSS throughout the design as shown in Figure 299 for the upper sheet metal including the cab and for the chassis frame shown in Figure 301. The LWT upper sheet metal structure including the cab and the pickup box takes advantage of lower density aluminum alloys and very high strength levels afforded by steel for the reinforcements for all the mounting areas and for B-pillar reinforcement as shown in Figure 300.

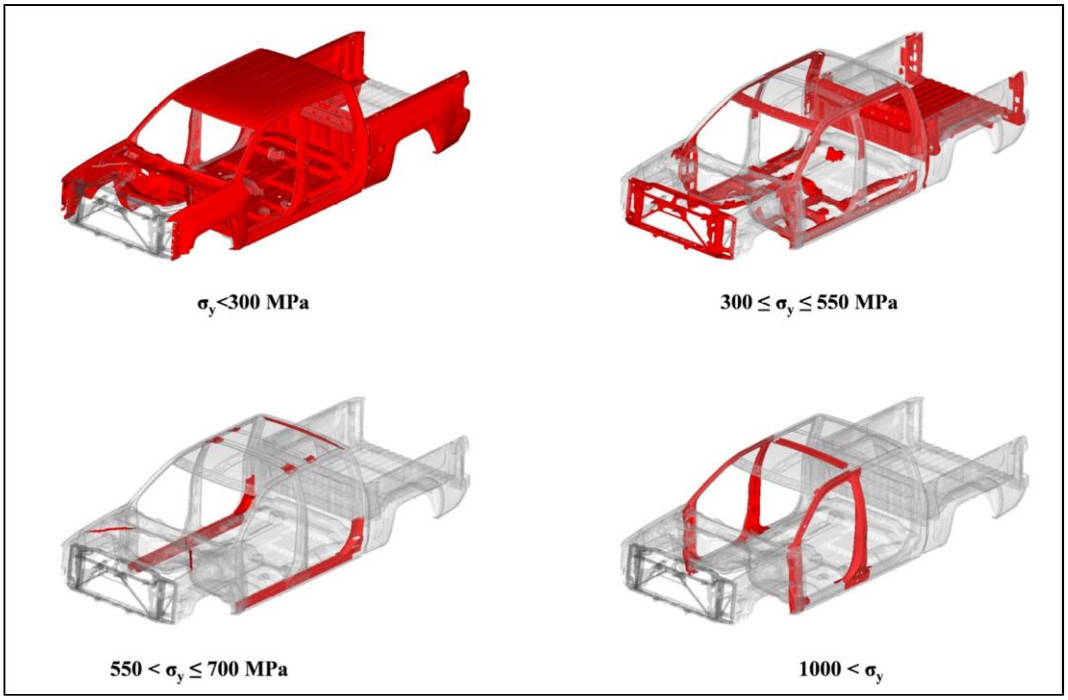


Figure 299: Baseline Vehicle, Steel Strength Levels Upper Sheet Metal

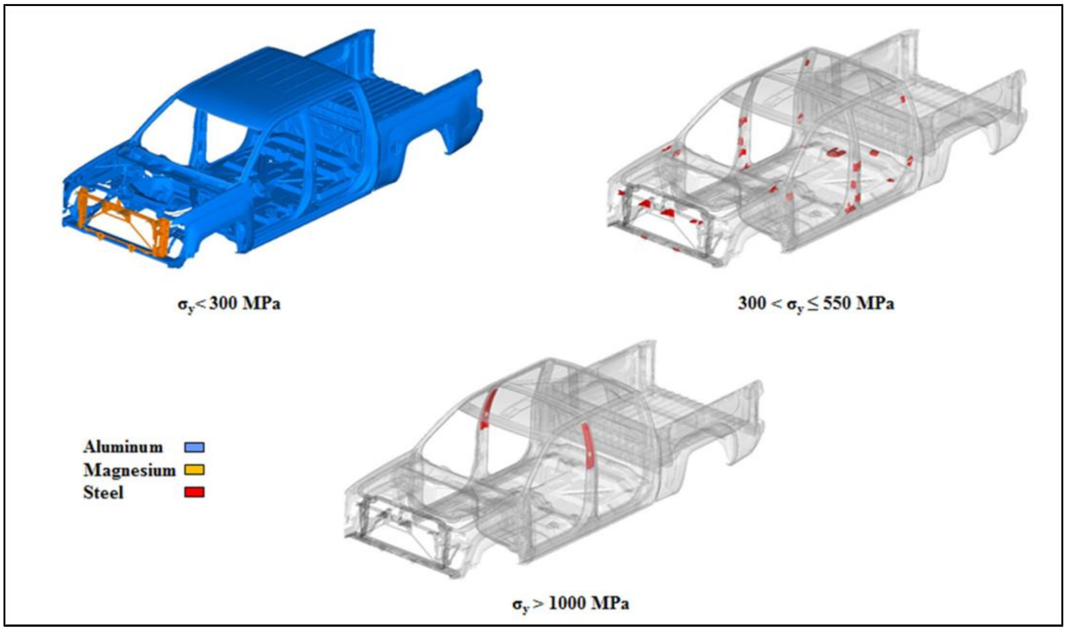


Figure 300: LWT, Steel & Aluminum Strength Levels Upper Sheet Metal

The LWT chassis frame is redesigned with higher content of AHSS compared with the baseline vehicle frame as shown in Figure 301 and Figure 302.

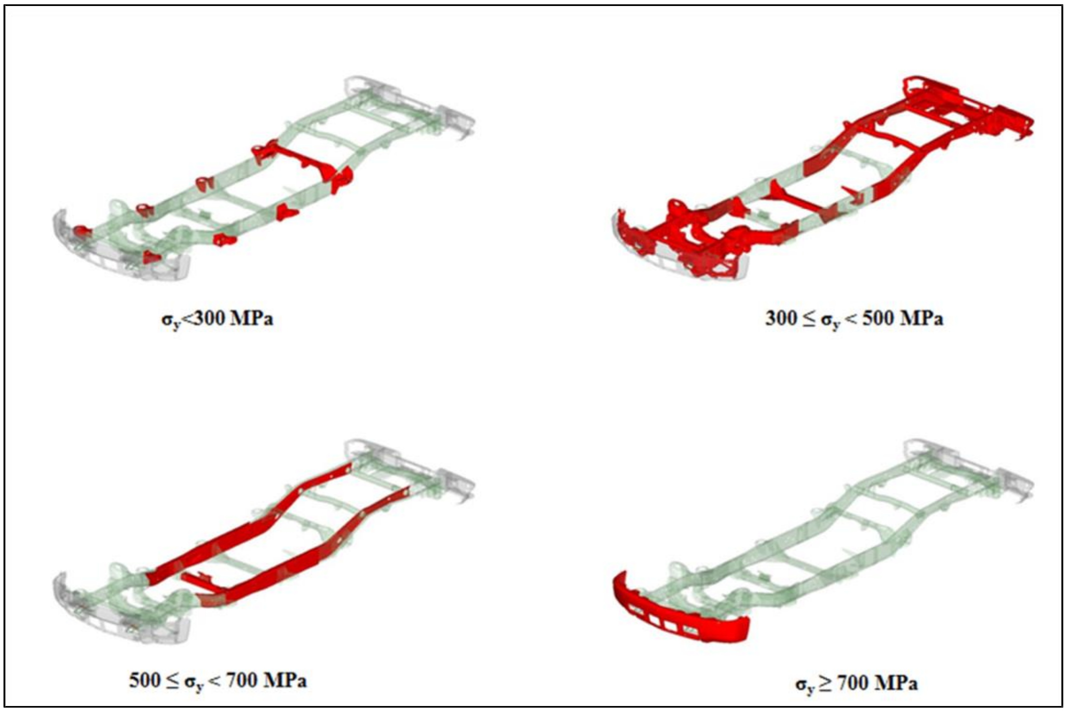


Figure 301: Baseline Vehicle, Steel Strength Levels Frame and Bumper

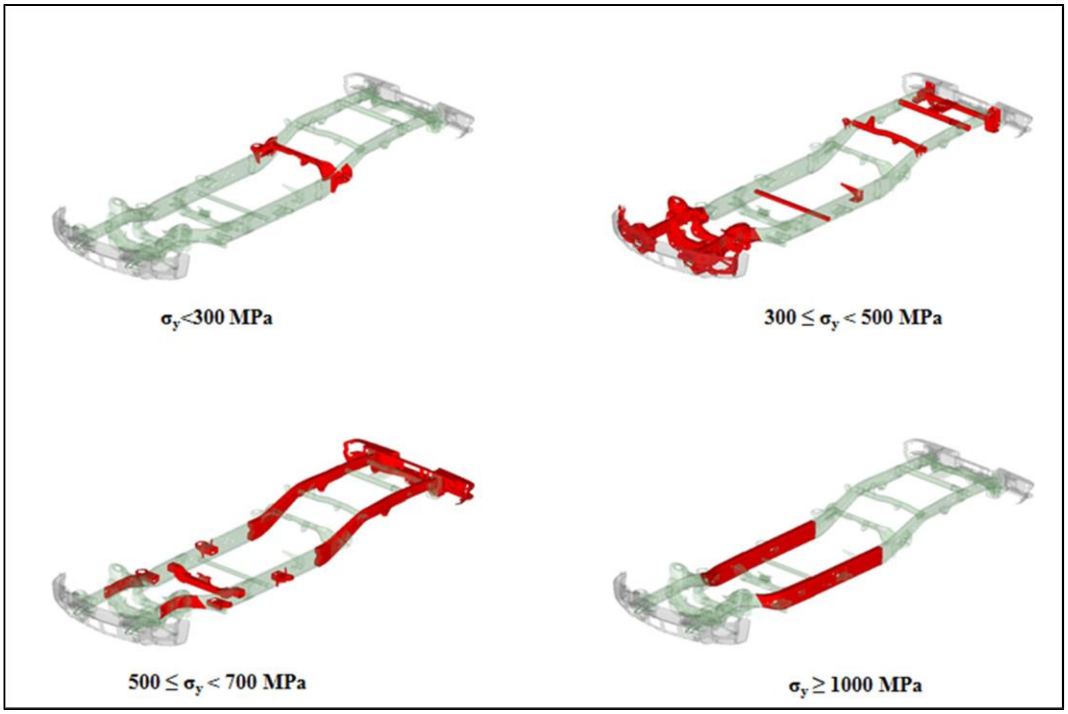


Figure 302: LWT, Steel Strength Levels Frame and Bumper

The LWT front and rear doors are redesigned using AHSS inner panels and side impact door crush beams with aluminum outer panels compared with the baseline vehicle doors being all steel design as shown in Figure 303 and Figure 304.

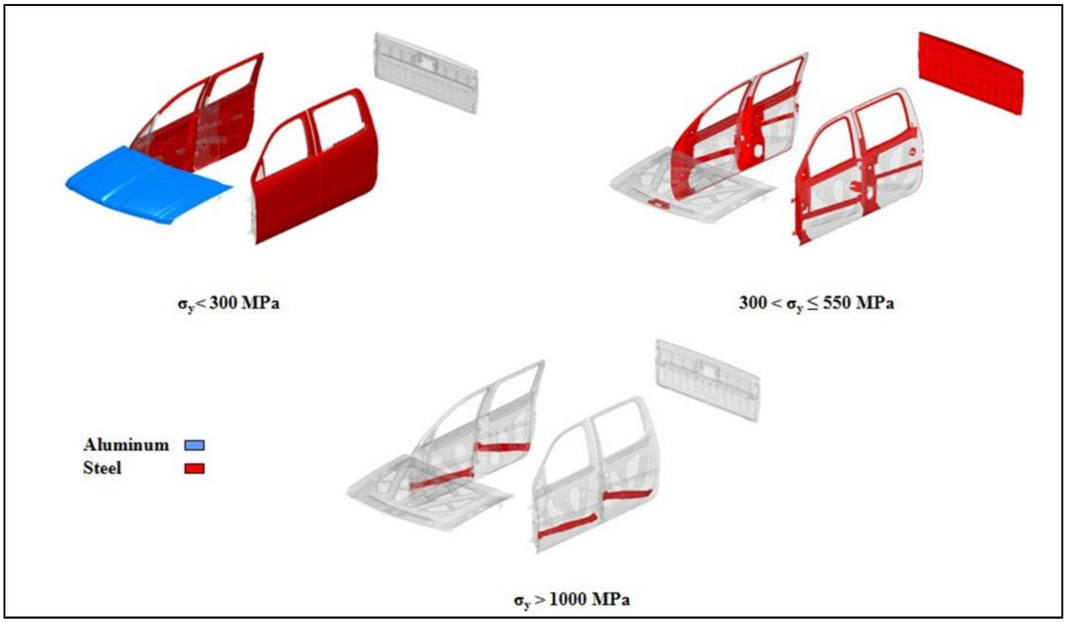


Figure 303: Baseline Vehicle, Steel Strength Levels for Closures

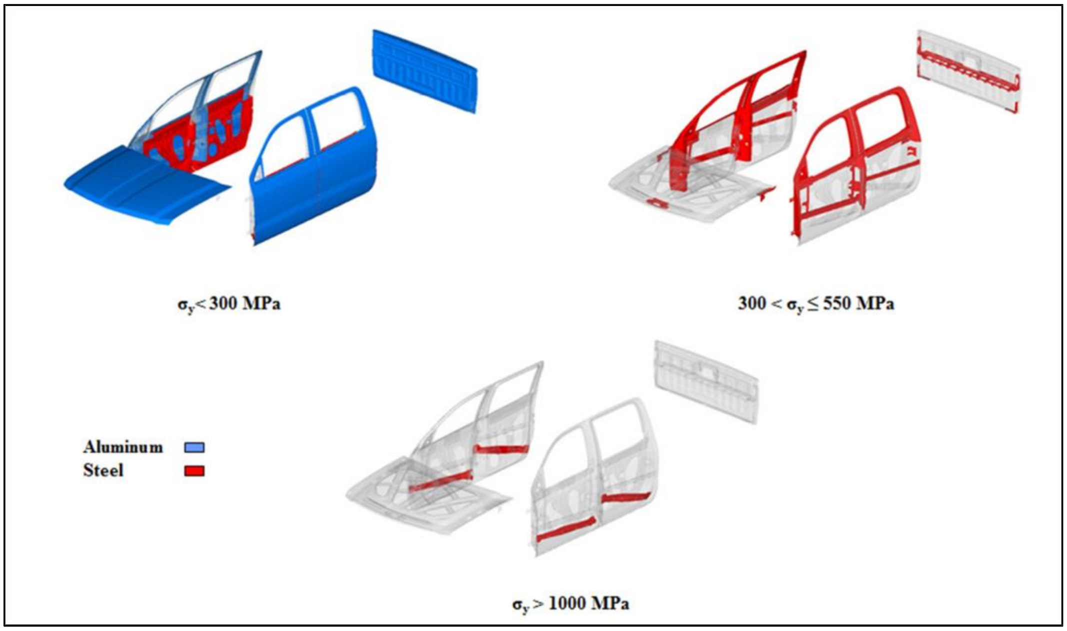


Figure 304: Closure Components of Baseline Vehicle and Their Types of Steel

9.2 Crash Simulation LSDYNA Correlation Load Cases

Baseline vehicle FEA LS-DYNA model was correlated to the baseline vehicle crash results, which include FMVSS, New Car Assessment Program NCAP and IIHS tests, as follows.

- NCAP frontal full barrier (NHTSA Test Numbers 8316 and 8456)
- NCAP side MDB (NHTSA Test Number 8315)
- NCAP side pole (NHTSA Test Numbers 8314 and 8454)
- IIHS Roof Strength Test
- FMVSS No. 301 Rear Impact
- IIHS offset 40 percent frontal
- IIHS side impact MDB
- IIHS small overlap 25 percent
- FMVSS 208 full barrier 25 mph (preliminary results)

For the load cases that did not have real vehicle test data to which to correlate to, the results are compared with other similar reference vehicles.

9.2.1 NCAP Frontal Full Barrier – 56 km/h (35 mph)

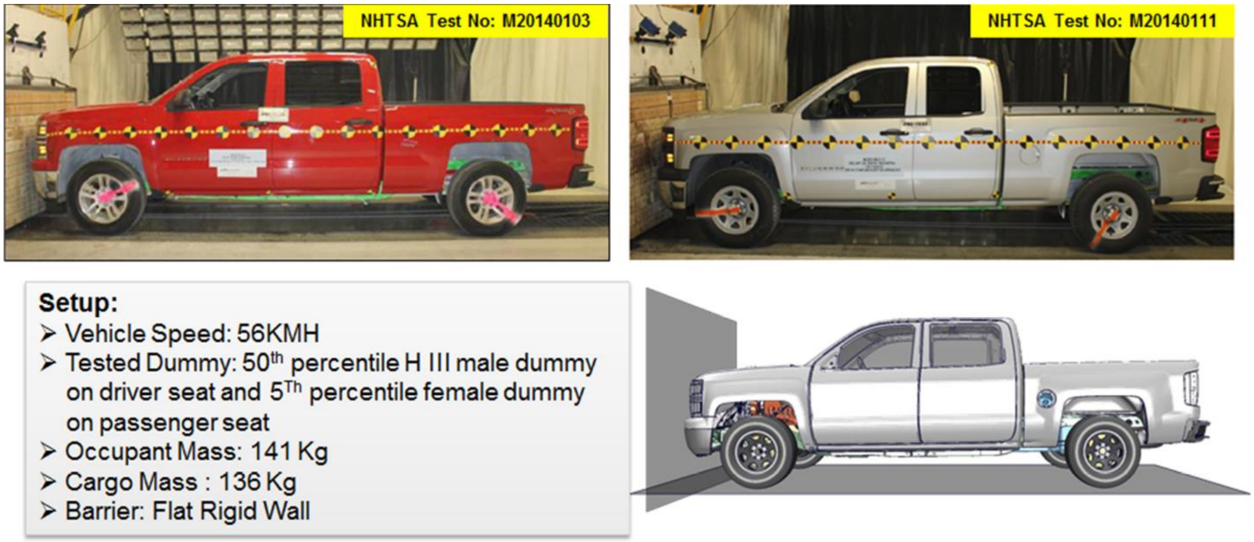
This test is used to determine the crashworthiness of the vehicle to protect occupants in frontal impact crash cases. The frontal impact test of the NCAP, undertaken by NHTSA, is a full frontal barrier test at a vehicle speed of 56 km/h (35 mph). The LS-DYNA models for the baseline 2014 Silverado and LWT were created to represent the test setup, such as vehicle velocity of 56 km/h against a flat, rigid wall barrier. The test vehicles are equipped with 50th percentile HIII male dummy on the driver seat and 5th percentile female dummy on passenger seat; with combined occupant mass of 141 kg and cargo mass of 136 kg. These masses were also accounted for in the CAE models. Comparisons of other vehicle test parameters are shown in Figure 305. Both test vehicles are different variants compared with the baseline vehicle.

The vehicle in test number 8316 is equipped with standard (6 ft 6 inch) size pickup box compared with the baseline vehicle that has short (5 ft 6 inch) pickup box, this leads to longer wheel base and longer overall length of the test vehicle. This test vehicle also has 18-inch rim wheels versus 17-inch for the baseline vehicle. The test vehicle is also 79 kg heavier. The other test vehicle (number 8456) comes with double cab and standard box versus crew cab with short box for the baseline vehicle. This test vehicle is 40 kg lighter than the baseline vehicle with same overall vehicle length and wheelbase. These differences will introduce some differences to the dynamic crush behavior, but it should not be significant to alter the safety crashworthiness ratings or conclusions.

	NCAP Test 8316 Crew Cab	**NCAP Test 8456 Double Cab**	**Baseline Vehicle FEA Model**	**LWT Vehicle FEA Model**
Curb Weight (kg)	2,518	2,392	2,432	2,018
Test Weight (kg)	2,788	2,669	2,709	2,295
Engine Type	5.3L V8	4.3L V6	5.3L V8	5.0L V8
Tire size	P265/65R18	P265/70R17	P265/70R17	P265/70R17
Final Drive	4-Wheel Drive	4-Wheel Drive	4-Wheel Drive	4-Wheel Drive
Wheelbase (mm)	3,900	3,660	3,649	3,649
CG (mm) Rear of Front Wheel C/L	1,707	1,602	1,695	1,686
CAB Style	Crew Cab	Extended Cab	Crew Cab	Crew Cab
Pickup Box Style	Standard	Standard	Short	Short

Figure 305: NCAP Frontal - Test Vehicles and CAE Models Parameters

The test vehicle and LS-DYNA set up for the frontal crash test of the baseline model into a rigid barrier is shown in Figure 306. The LWT LS-DYNA model was setup using exactly the same method.



Setup:

- Vehicle Speed: 56KMH
- Tested Dummy: 50th percentile H III male dummy on driver seat and 5Th percentile female dummy on passenger seat
- Occupant Mass: 141 Kg
- Cargo Mass : 136 Kg
- Barrier: Flat Rigid Wall

Figure 306: NCAP Frontal - Test and LS-DYNA Model set up

Images of the post-crash vehicles for the actual laboratory crash test and the simulation are in shown in Figure 307 and Figure 308. The overall predicted vehicle kinematics and the crushed shapes from the front side and from underneath the vehicle correlate very well with the test vehicles. The EDAG team visited the MGA Proving Ground to inspect and take additional measurements of the crash-tested vehicles. The additional collected information increased the team’s knowledge to improve the correlation between the test and the CAE models.

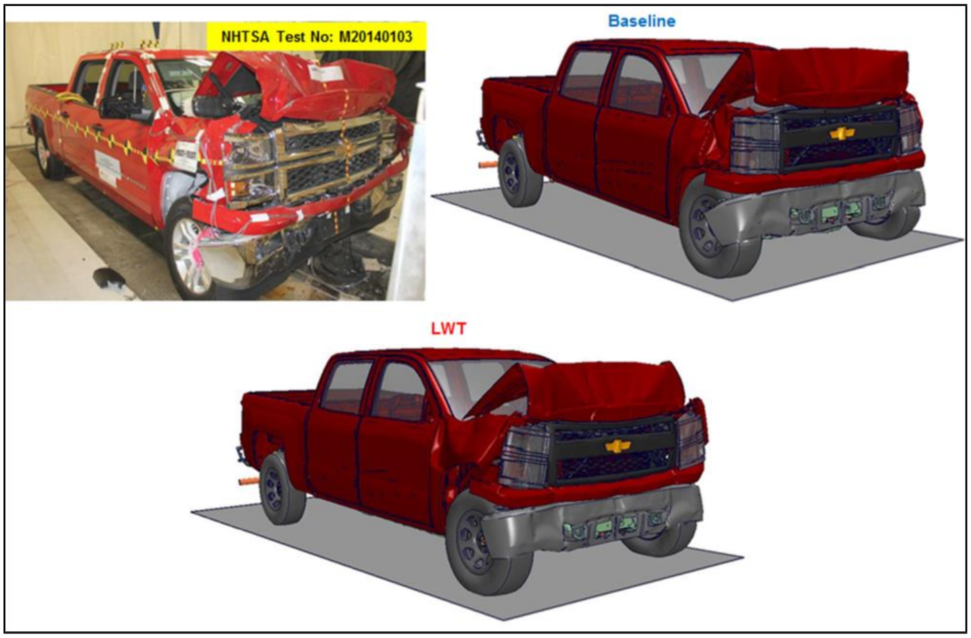


Figure 307: NCAP Frontal - Post-Crash Comparison Test Versus CAE Results, Baseline and LWT

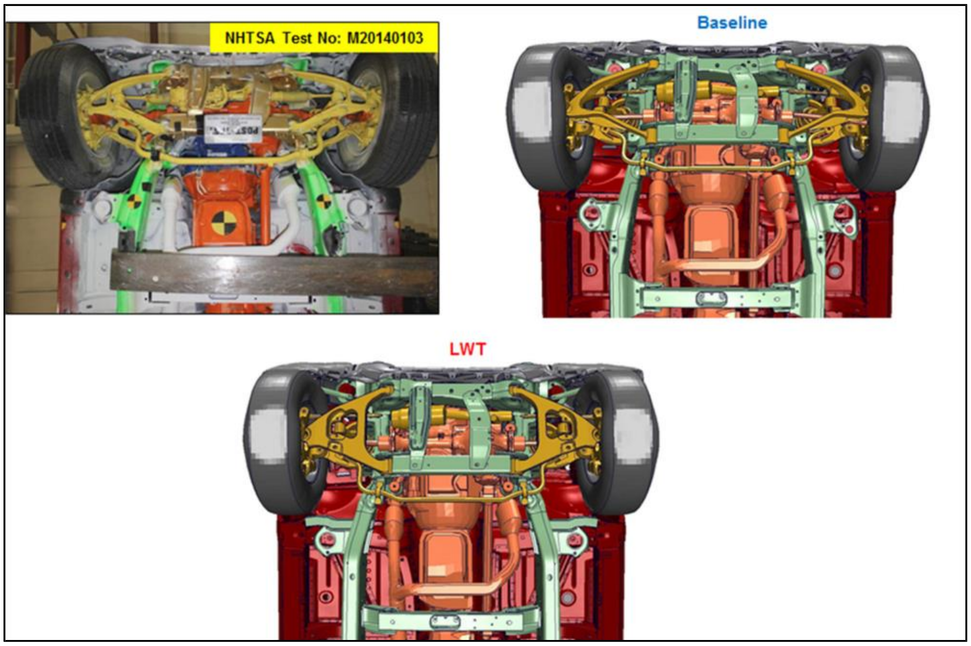
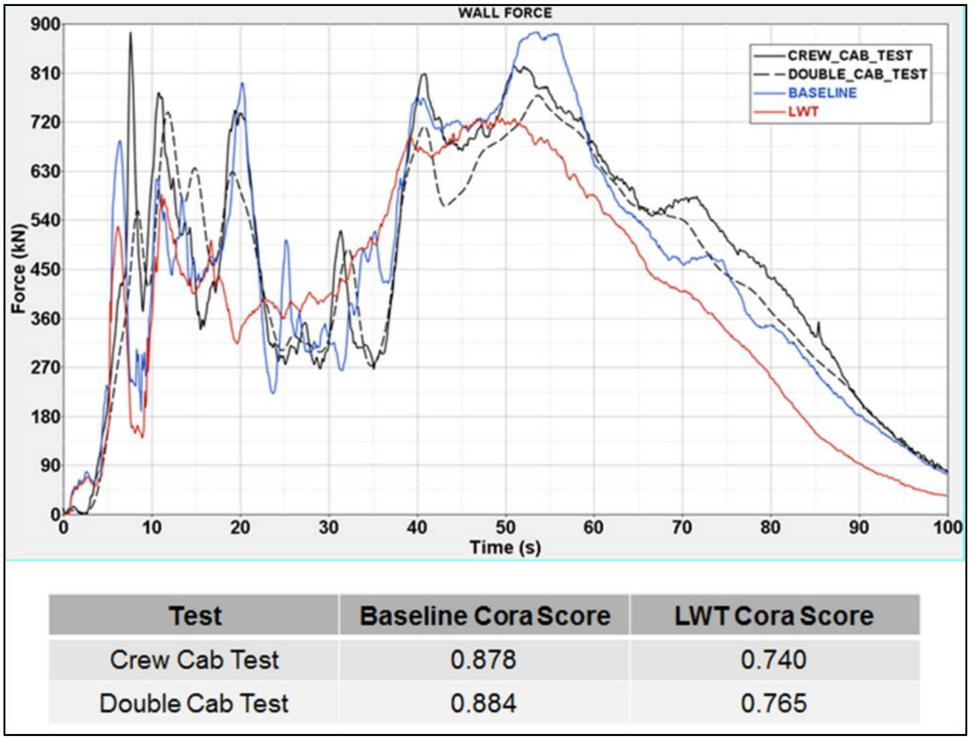


Figure 308: NCAP Frontal - Post-Crash Comparison Test Versus CAE Results, Baseline and LWT

Rigid wall force comparison for test vehicles, CAE baseline, and LWT are shown in Figure 309. Both baseline and LWT model have similar loading and unloading pattern as the test vehicles. The level of comparison was measured using a correlation tool named CORA, which uses corridor method and cross correlation method to calculate a unique correlation score between 0 to 1. Where 1 represents perfect correlation and 0 represents no correlation at all. Both of the CAE models, baseline and LWT, show good correlation with test vehicles with CORA score higher than 0.7 to 0.8.

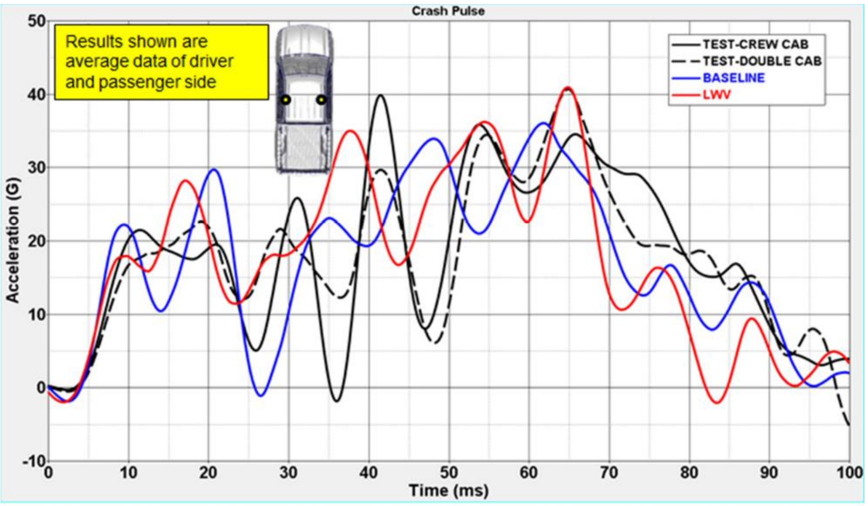


Test	Baseline Cora Score	LWT Cora Score
Crew Cab Test	0.878	0.740
Double Cab Test	0.884	0.765

Figure 309: NCAP Frontal – Wall Force Tests Versus Baseline and LWT

The crash pulse for the occupant compartment, shown in Figure 310 shows good overall agreement in terms of pulse shape, width and magnitude compared with the test pulse. For the overall length of the pulse approximately 100 msec, the prediction for the baseline and LWT CAE models is very close to the test values. The average pulse value for the two test vehicles and the baseline CAE is 20G and 22G for the LWT simulation. CORA score was calculated the same way as for the wall force and it came out to be higher than 0.65 for both CAE models.

Timely air bag deployment is critical in keeping the occupant injuries to the minimum and in meeting the 5-star safety ratings. The average value of acceleration generally is required to be of the order of 7G's or higher during 0.005 to 0.015 seconds for instruments to sense the crash event and deploy the air bags. As can be seen from Figure 310 the LWT pulse is higher than 7G's during this period, and similar magnitude as the test and baseline model. Indicating that the air bag deployment instruments can be correlated to identify the event in a timely manner similar to the baseline vehicle.



Results shown are average data of driver and passenger side

Test	Baseline Cora Score	LWT Cora Score
Crew Cab Test	0.646	0.699
Double Cab Test	0.685	0.748

Figure 310: NCAP Frontal - Acceleration pulse for Sill Seat Cross Member (LH/RH)

Figure 311 is the velocity plots for the baseline 2014 Silverado and LWT CAE models at the rear sill seat cross member. This figure shows that the structure of the LWT stops (i.e., goes from the initial velocity to zero) about 6 msec more quickly than the structure of the baseline Silverado. While it would be safer to stop the vehicle more slowly, 6 msec is a very short time difference, it is believed that the restraint system (air bags and seat belts) can be fine-tuned to accommodate a 6 msec difference in stopping time.

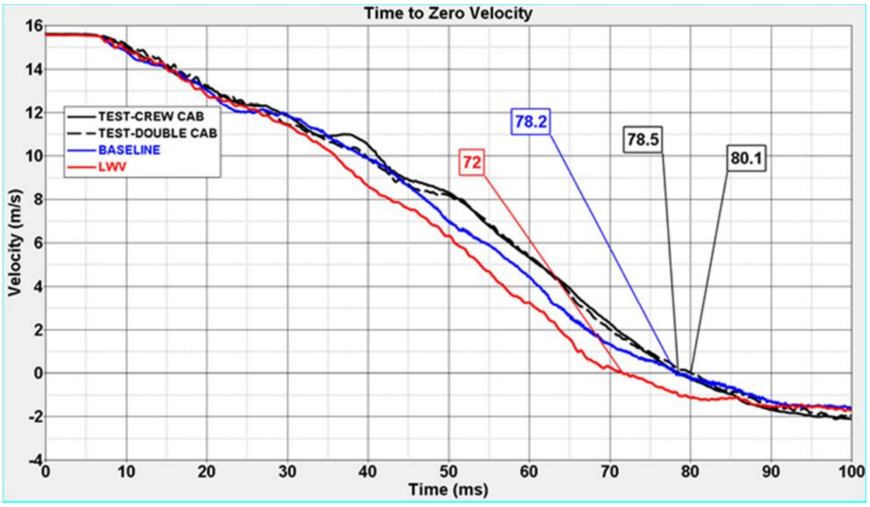


Figure 311: NCAP Frontal - Velocity of Baseline and LWT for Sill Seat Cross Member (LH/RH)

The dynamic crush distance, shown in Figure 312, the baseline CAE model correlate to within 36 and 30 mm compared with the two vehicle results. For the lighter weight, LWT design the crush distance is 46 mm lower than the baseline 2014 Silverado CAE model. This is to be expected as the LWT model is approximately 20 percent lighter.

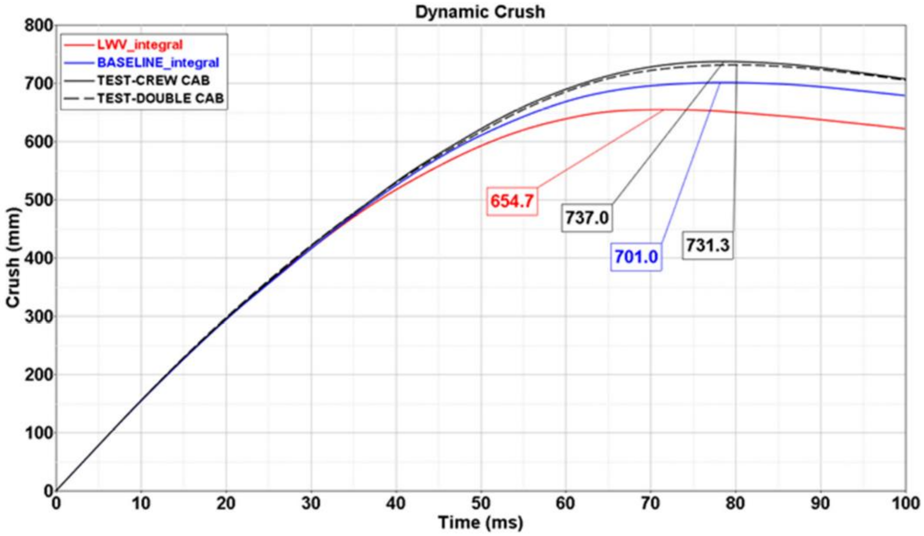
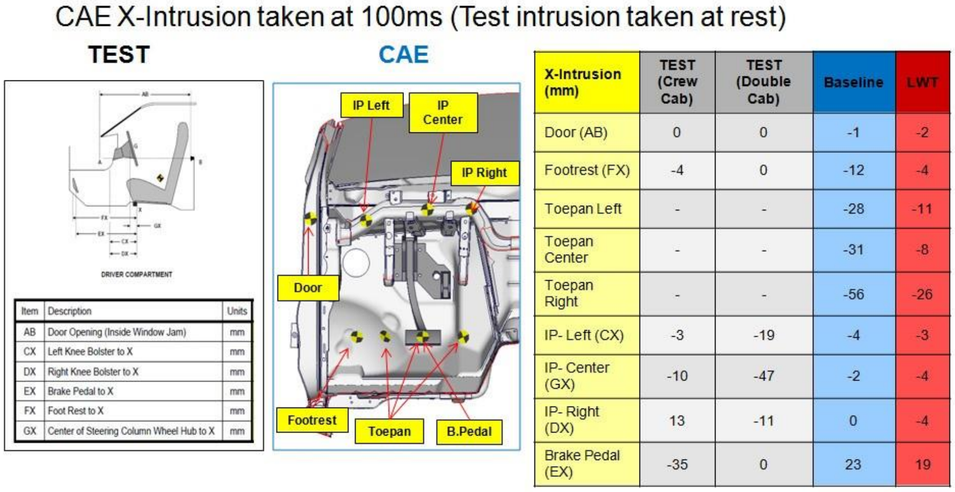


Figure 312: NCAP Frontal - Dynamic Crush Distance of Baseline and LWT CAE

Passenger compartment intrusion values at several locations, shown in Figure 313, are very small in magnitude with negligible differences between test and CAE predicted values.



Item	Description	Units
AB	Door Opening (Inside Window Jam)	mm
CX	Left Knee Bolster to X	mm
DX	Right Knee Bolster to X	mm
EX	Brake Pedal to X	mm
FX	Foot Rest to X	mm
GX	Center of Steering Column Wheel Hub to X	mm

X-Intrusion (mm)	TEST (Crew Cab)	TEST (Double Cab)	Baseline	LWT
Door (AB)	0	0	-1	-2
Footrest (FX)	-4	0	-12	-4
Toepan Left	-	-	-28	-11
Toepan Center	-	-	-31	-8
Toepan Right	-	-	-56	-26
IP- Left (CX)	-3	-19	-4	-3
IP- Center (GX)	-10	-47	-2	-4
IP- Right (DX)	13	-11	0	-4
Brake Pedal (EX)	-35	0	23	19

Figure 313: NCAP Frontal - Passenger Compartment Intrusions Test, Baseline and LWT CAE

In summary the results for the for 2014 Silverado 1500 CAE model correlate very well with the test results from the two vehicle tests. The LWT CAE also shows that its predicted performance is similar to the test and baseline CAE results.

9.2.2 NCAP Side MDB Test

In this crash test, a moveable deformable barrier with a mass of 1370 kg impacts the vehicle on the driver's side with a velocity of 61.9 kmh ± 0.8 kmh. The LS-DYNA models for the baseline 2014 Silverado and LWT were created to represent the test setup. Mass for for a 50th percentile male dummy on the driver seat and a 5th percentile female dummy on the passenger seat just behind the driver seat, combined occupant mass of 141 Kg and cargo mass of 136 kg in the rear was accounted for in the CAE models.

Comparisons of other vehicle test parameters are shown in Figure 314. The test vehicle is a rear wheel drive only and the baseline vehicle is 4-wheel drive. The test vehicle is 84 kg lighter than the baseline. Dimensionally the test vehicle is similar to the baseline vehicle. The differences will introduce some differences to the dynamic crush behavior, but it should not be significant to alter the safety crashworthiness ratings or conclusions. The lack of front wheel drive components on test vehicle should not have a significant effect on the side impact.

	NCAP Side MDB Test 8315	Baseline Vehicle FEA Model	LWT Vehicle FEA Model
Curb Weight (kg)	2,348	2,432	2,018
Test Weight (kg)	2,613	2,613	2,295
Engine Type	5.3L V8	5.3L V8	5.0L V8
Tire size	P255/70R17	P265/70R17	P265/70R17
Drive Type	Rear – Wheel Drive	4-Wheel Drive	4-Wheel Drive
Wheelbase (mm)	3,664	3,645	3,645
CG (mm) Rear of front wheel C/L	1,674	1,710	1,703
Body Style	Crew Cab	Crew Cab	Crew Cab
Pickup Box Style	Short	Short	Short

Figure 314: NCAP Side MDB - Test Vehicles and CAE Models Parameters

The LS-DYNA set up for the NCAP side impact MDB crash test of the 2014 Silverado model with a moving deformable barrier is show in Figure 315.


Setup:

- Barrier Speed: 62.4KMH
- Tested Dummy: 50th percentile ES-2re male dummy on driver seat and SID IIs female dummy on passenger seat
- Occupant Mass: 129.3 Kg
- Cargo Mass : 136 Kg
- Barrier: Moving Deformable Barrier

Figure 315: NCAP Side MDB - Test and LS-DYNA Model set up

Images of the post-crash vehicles for the crash test and the simulation results are shown in Figure 316 and Figure 317. The overall predicted vehicle kinematics and the crushed shapes from the side and from underneath the vehicle correlate very well with the test vehicles. The EDAG team visited MGA proving to inspect and take additional measurements of the crash tested vehicles.

The additional collected information increased the teams' knowledge to improve the correlation between the test and the CAE models.

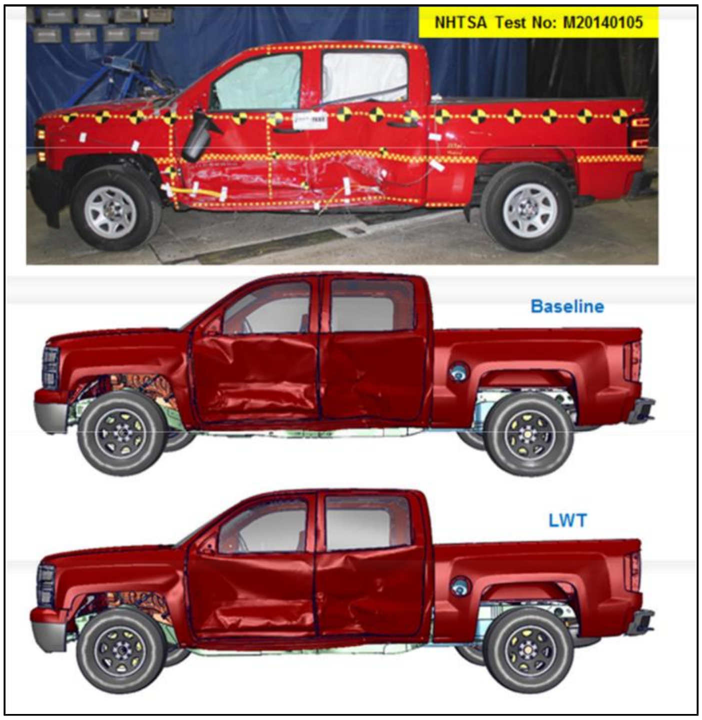


Figure 316: NCAP Side MDB - Post-Crash Comparison Test Versus CAE for Baseline and LWT

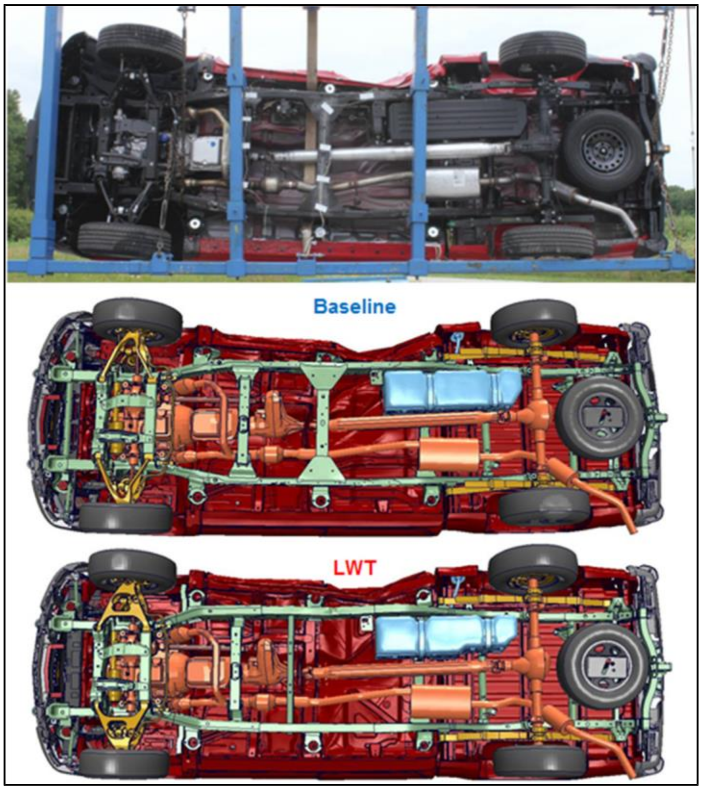


Figure 317: NCAP Side MDB - Post-Crash Comparison Test Versus CAE for Baseline and LWT

After the crash, the fuel tank should remain physically intact to prevent fuel leakage from the fuel tank after the crash. Figure 317 and Figure 318 below show that there is no damage to the fuel tank or the surrounding structure, and therefore there should be no leakage of gas from the tank.

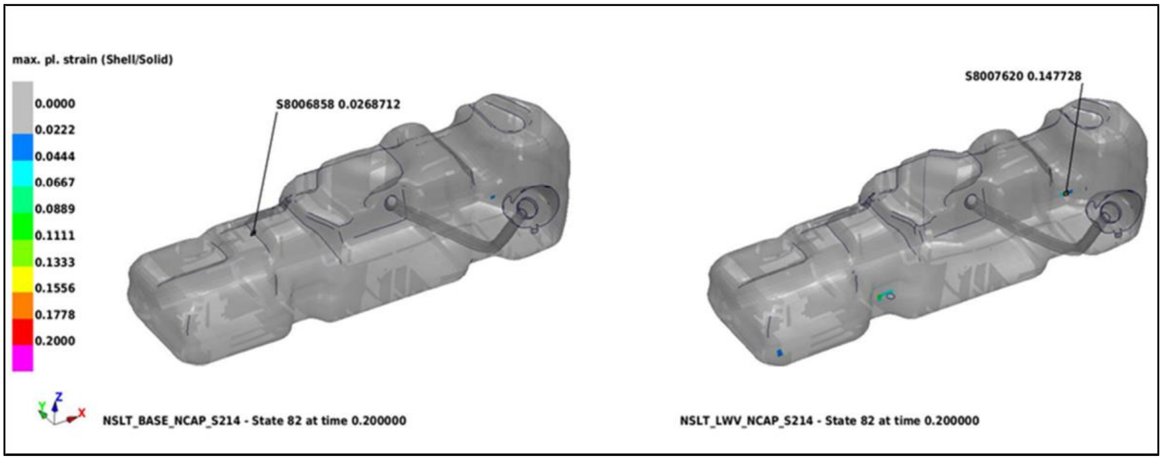
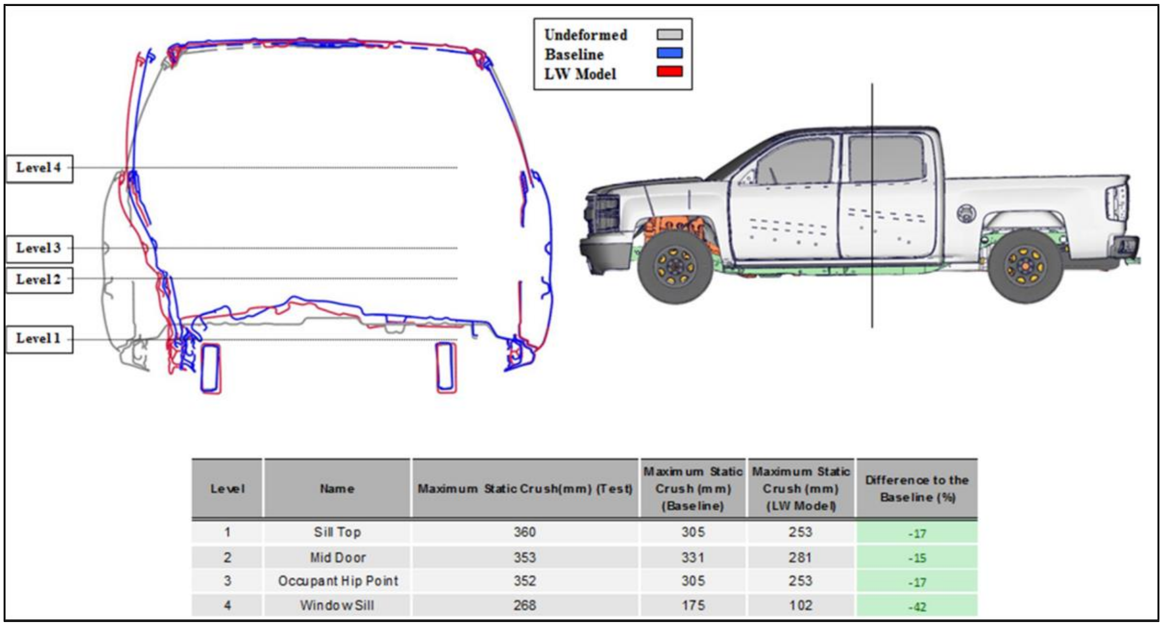


Figure 318: NCAP Side MDB – Post-Crash Fuel Tank Strain Comparison CAE for Baseline and LWT

Figure 319 and Figure 320 shows exterior crush profiles for levels 1 to 4; located at sill top, door midpoint, driver H-point and at the windowsill. As can be seen the exterior crush profiles at levels 1, 2 and 3 for the test vehicle are in good agreement with the baseline vehicle and LWT CAE results. At level 4 (rear door windowsill) the crush profiles compare well from -500 mm to 1,500 mm along the vehicle length, but the test values depart from the CAE values by approximately 80 mm. This type of localized intrusions are generally due to the door outer panel buckling or separation and is not regarded as a concern to the occupant safety, because the occupant come into contact with the interior surfaces of the vehicle. The LWT CAE also shows that its predicted performance is similar to the test and baseline vehicles.



Level	Name	Maximum Static Crush(mm) (Test)	Maximum Static Crush (mm) (Baseline)	Maximum Static Crush (mm) (LW Model)	Difference to the Baseline (%)
1	Sill Top	360	305	253	-17
2	Mid Door	353	331	281	-15
3	Occupant Hip Point	352	305	253	-17
4	Window Sill	268	175	102	-42

Figure 319: NCAP Side MDB – Post-Crash Comparison Test Versus CAE Baseline and LWT

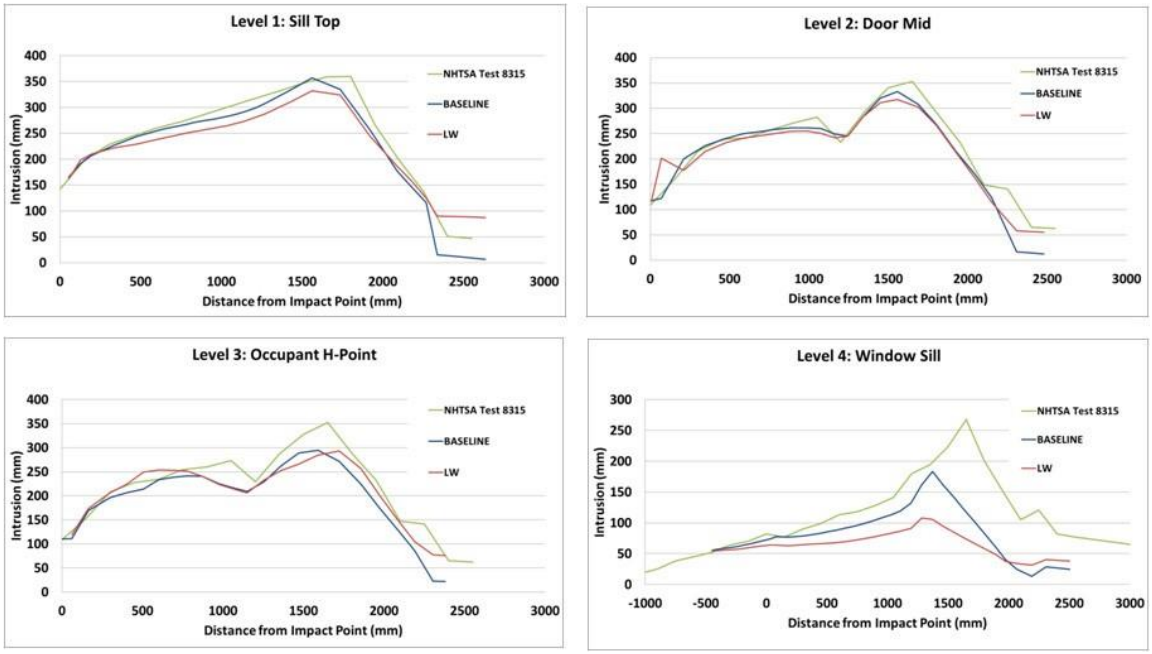


Figure 320: NCAP Side MDB - Post-Crash Comparison Test Versus CAE for Baseline and LWT

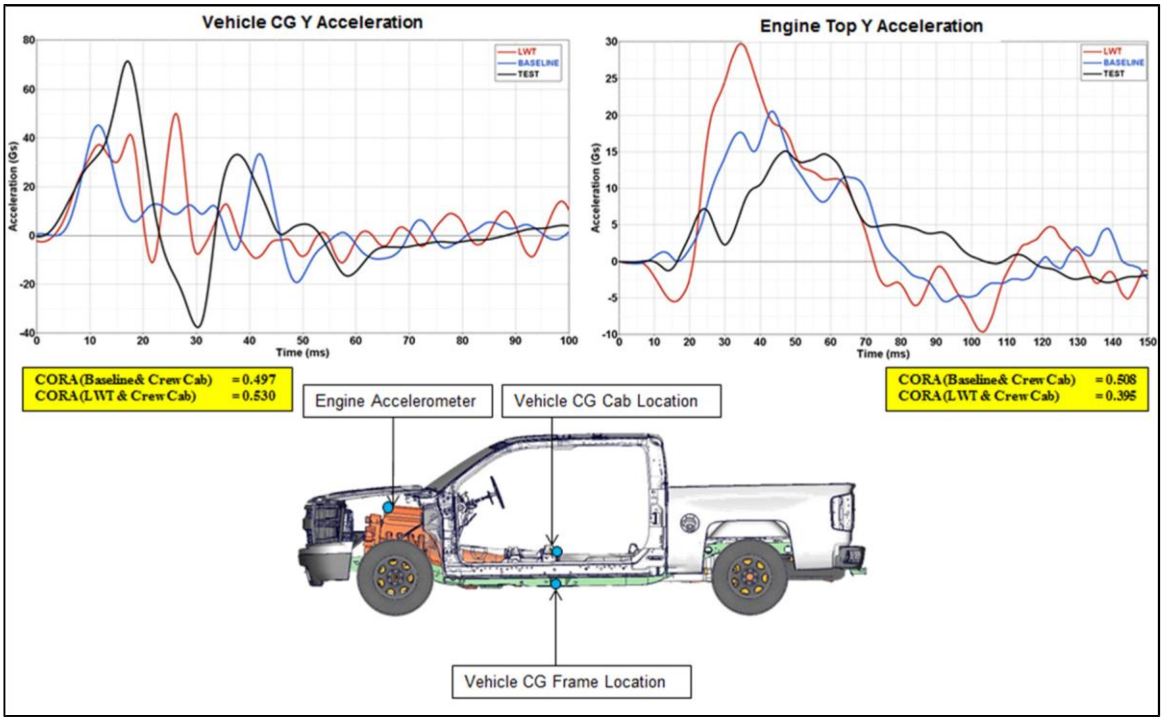


Figure 321: NCAP Side MDB – Vehicle CG Acceleration Test Versus CAE Baseline and VWT

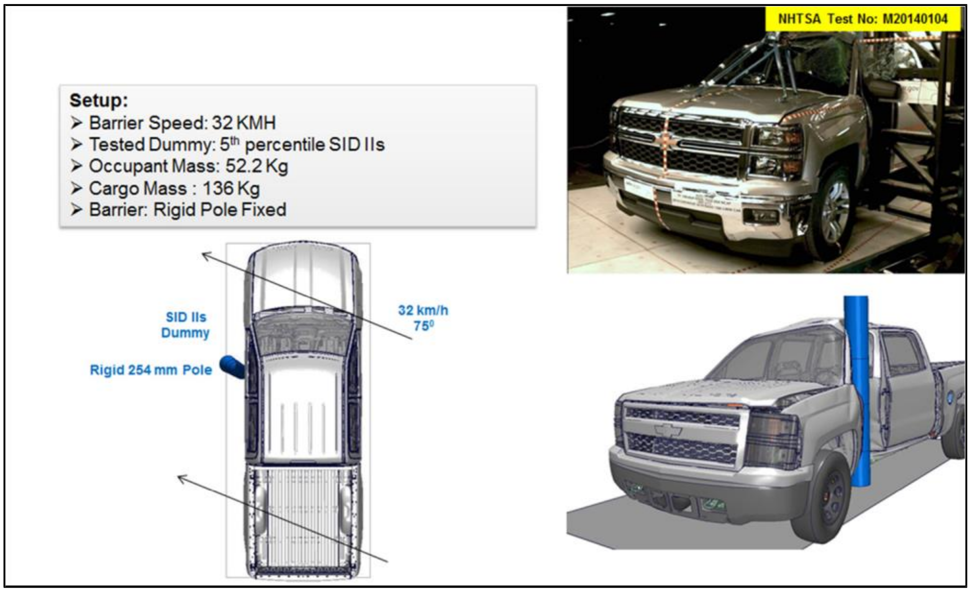
Vehicle lateral Center of gravity acceleration and engine top acceleration measured in Y direction and compared with the test vehicle as shown in Figure 321. CAE models correlate reasonably well with test results.

9.2.3 NCAP Side Rigid Pole Test

The NCAP side impact rigid pole test subjects the test vehicle to a side door impact with a fixed, rigid pole 254 mm (10 inches) in diameter, at a speed of 32.2 km/h (20 mph). The test vehicle is towed into the pole at a 75° angle. Figure 323 shows the baseline CAE model and test set-up. The only ATD used in this test is a fully instrumented 5th percentile female, positioned in the driver's seat. The CAE models fully account for the ATD and additional cargo mass required for this test. The two test vehicles are rear drive only versus the baseline vehicle that is 4 wheel drive, these differences should not have significant effect on the crash results. Figure 322 list the test and baseline vehicle parameters.

	NCAP Side Pole Test 8318	NCAP Side Pole Test 8454	Baseline Vehicle FEA Model	LWT Vehicle FEA Model
Curb Weight (kg)	2,384	2,272	2,432	2,018
Test Weight (kg)	2,572	2,460	2,620	2,206
Engine Type	5.3L V8	4.3L V6	5.3L V8	5.0L V8
Tire size	P265/65R18	P265/70R17	P265/70R17	P265/70R17
Final Drive	Rear	Rear	4-Wheel Drive	4-Wheel Drive
Wheelbase (mm)	3,664	3,660	3,645	3,645
CG (mm) Rear of Front Wheel C/L	1,667	1,605	1,703	1,697
Body Style	Crew Cab	Double Cab	Crew Cab	Crew Cab
Pickup Box Style	Short	Standard	Short	Short

Figure 322: NCAP Side Rigid Pole - Test Vehicles and CAE Models Parameters



Setup:

- Barrier Speed: 32 KMH
- Tested Dummy: 5th percentile SID IIs
- Occupant Mass: 52.2 Kg
- Cargo Mass : 136 Kg
- Barrier: Rigid Pole Fixed

Figure 323: NCAP Side Rigid Pole - Test and LS-DYNA Model Set Up

Side-structure deformation and vehicle crash behaviors were analyzed and compared to the test vehicle as shown in Figure 324, Figure 325 and Figure 326. By comparing the deformations, it can be observed the CAE baseline model and LWT model shows similar deformation modes as the tested vehicle.

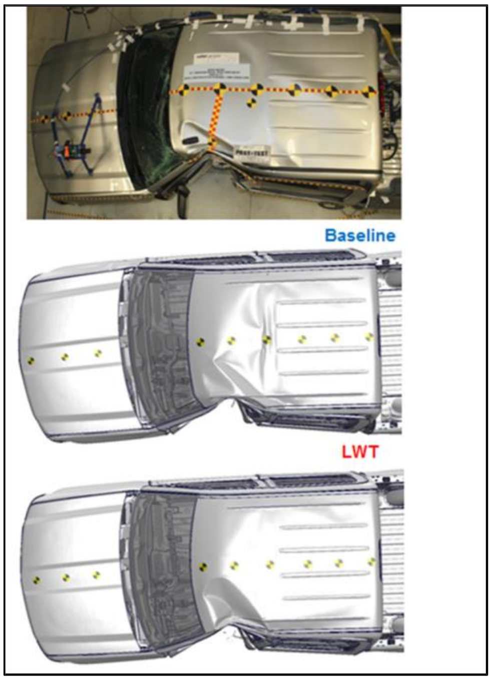


Figure 324: NCAP Side Rigid Pole - Comparison Test v CAE for Baseline & LWT

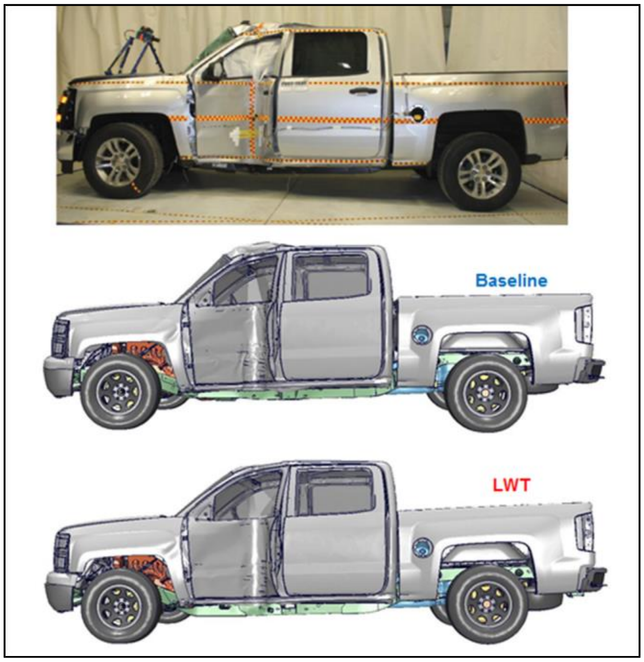


Figure 325: NCAP Side Rigid Pole – Comparison Test Versus CAE for Baseline and LWT

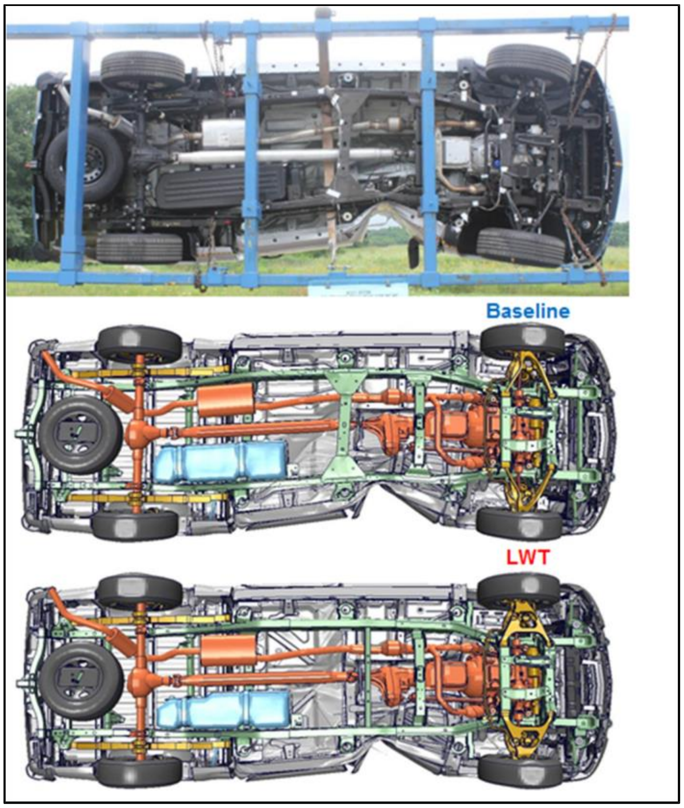


Figure 326: NCAP Side Rigid Pole - Comparison Test v CAE for Baseline & LWT

Vehicle center of gravity acceleration and engine top acceleration measured in lateral Y direction and compared with both test vehicles as shown in Figure 327. CAE models correlated partly with crew cab test vehicle and partly with double cab test vehicles. Vehicle center of gravity acceleration correlated good with double cab test vehicle giving CORA score more than 0.6. Whereas, output from the acceleration located on the top of engine block showed good correlation with crew cab test vehicle.

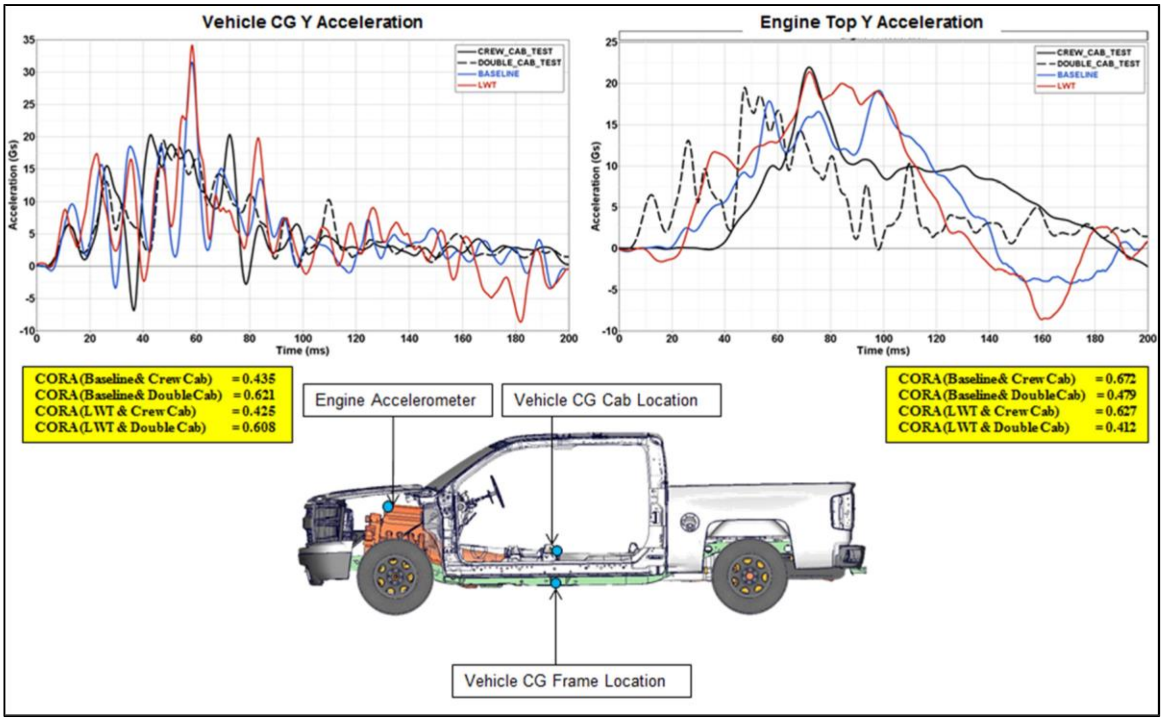
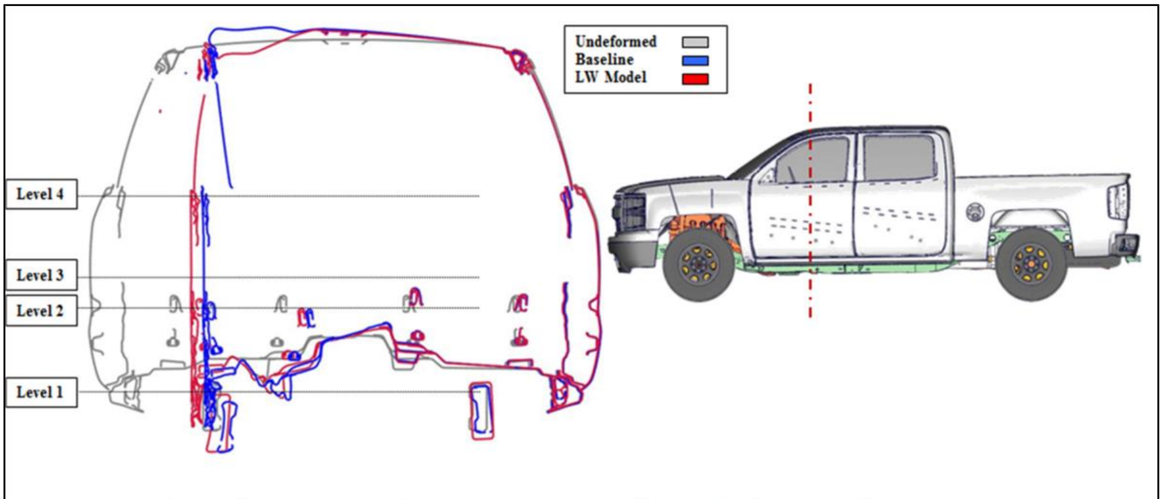


Figure 327: NCAP Rigid Side Pole – Vehicle CG and Engine Top Y acceleration Comparison Tests Versus Baseline and LWT

Figure 328 and Figure 329 shows cross-section view at the end of the simulation. The amount of intrusion is measured at all levels and it can be seen that LWT has 8 to 20 percent lower intrusion than baseline model. Other critical parameter to be compared for the pole-side impact case is the side structure intrusions on the struck side of the vehicle. The compartment structure intrusions are shown in Figure 329. The intrusion values are relative displacements with respect to an un- deformed outer structure. The intrusions along the length of the vehicle for levels 1 to 4; located at sill top, door midpoint, driver H-point and at the windowsill. As can be seen the exterior crush profiles at levels 1 through 4 for the test vehicle are in good agreement with the CAE baseline and LWT CAE model results.



Level	Name	Maximum Static Crush(mm) (Test)	Maximum Static Crush (mm) (Baseline)	Maximum Static Crush (mm) (LW Model)	Difference to the Baseline (%)
1	Sill Top	347	302	243	-20
2	Mid Door	424	404	368	-9
3	Occupant Hip Point	423	439	404	-8
4	Window Sill	382	354	318	-10

Figure 328: NCAP Side Rigid Pole – Post Crash Comparison Test Versus Baseline and LWT

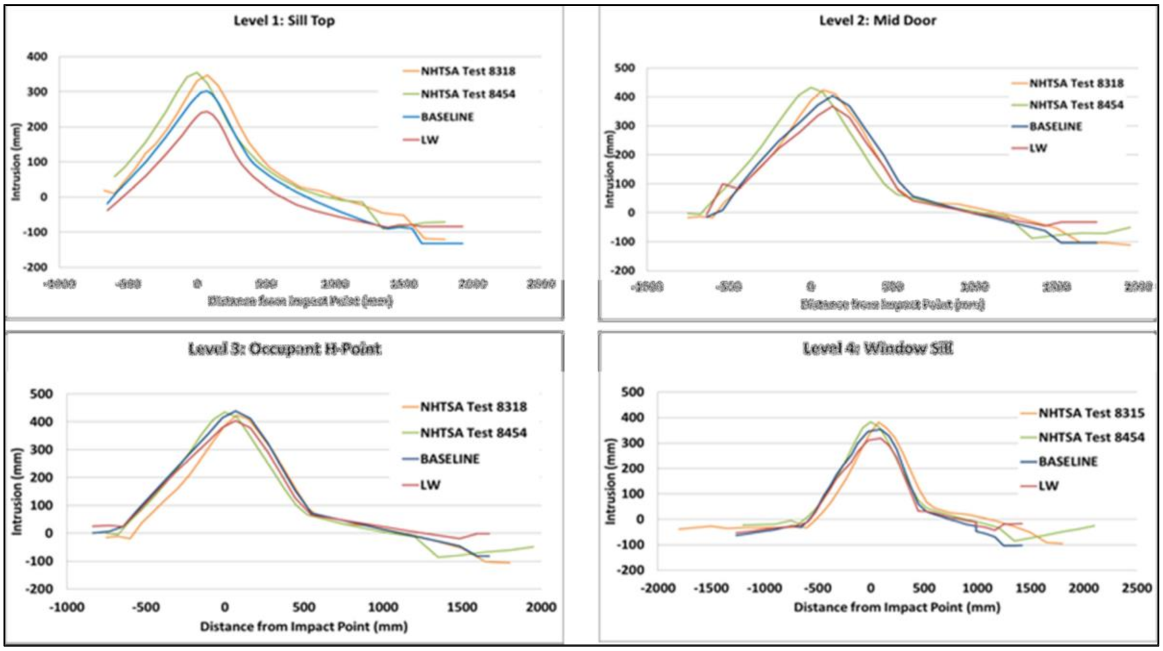


Figure 329: NCAP Side Rigid Pole - Post-Crash Comparison Test Versus CAE for Baseline and LWT

Post-crash strain levels observed on the fuel tank are shown in Figure 330. Strain at the end of 200 ms is found to be less than 6 percent in both CAE baseline and LWT model. Observed strain in caused by RB2 connections created in between straps and the fuel tank to hold the fuel tank. As in real life the fuel tank is tightly fitted with the straps. Being made up of multilayer HDPEmaterial the fuel tank can see about 70 percent strain without cracking.[153]

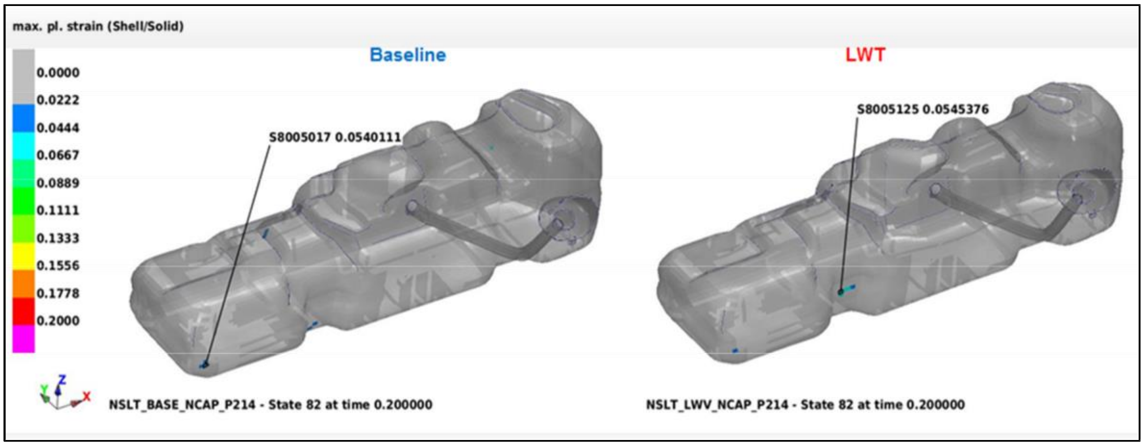


Figure 330: NCAP Side Rigid Pole – Post-Crash Comparison Test Versus CAE Baseline and LWT

9.2.4 IIHS Roof Strength Test

The IIHS roof crush test is used to evaluate the crashworthiness of the vehicle structure in rollover crashes. This test is conducted by crushing the roof structure of the vehicle against a rigid plate (platen) until 5 inches of crush is achieved. Then, the maximum force sustained by the roof before 5 inches of crush is compared to the vehicle's curb weight to find the strength-to-weight ratio (SWR). Both NHTSA and IIHS do roof crush tests. FMVSS No. 216 specifies that roof structure should sustain a load three times the vehicle curb weight. For vehicle with a GVWR between 6,001 and 10,000 lbs the SWR requirements are 1.5 time the CVW. The IIHS roof crush rating stipulates that the roof structure must sustain loading of four times the curb weight for a “good” rating. The NHTSA roof crush test is FMVSS No. 216, and is a regulation that does not rate the tested vehicle for safety. The IIHS roof crush test is a consumer information test, and rates the tested vehicle for safety. The NHTSA tests both sides of the roof of the vehicle. The IIHS tests just one side of the roof but requires a higher resistance to crush, which is a ratio of resistance force/curb weight must be 4 or greater for a “good” rating.

The LS-DYNA set up for the IIHS roof crush test of the baseline CAE model is shown in Figure 331. The CAE model is held rigidly with clamps about the rocker section.

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[153] Dynamic Material Characterization for Multilayer High Density Polyethylene Material; Ching-Shan Cheng and Kenneth A. Storm; GM R&D Center

Setup:
- Barrier Speed: Constant 0.2 in/s
- Total Displacement = 10 in.
- Tested Dummy: No Dummy

Figure 331: IIHS Roof Strength Test - LS-DYNA Model Setup

Figure 332 and Figure 333 show the results for the LS-DYNA simulation for the baseline CAE model and LWT CAE model. To date IIHS has not conducted the roof strength test on the 2014 Silverado. The results are compared instead with test results for the 2015 Ford F-150.[154] The strength to weight ratio, which is the force divided by vehicles' curb vehicle weight, versus platen displacement. The SWR for the baseline CAE model and the LWT model are 6.0 and 6.6 respectively and are rated as in the "good" zone. The SWR for the F150 is 5.9 very close to the predictions for the LWT vehicle.

In the IIHS roof crush test, parts that absorb much of the crash energy are (1) upper B-pillar, (2) roof side rail. The baseline vehicles' roof rail inner reinforcement and the B-pillar reinforcement are constructed of hot stamped AHSS with yield strength of greater than 1000 MPa. The construction of the F-150 uses an aluminum hydroformed section for the A-pillar and roof side rail reinforcement, leading to higher roof crush strength. The LWT design also takes advantage of hydroformed roof side rail and an optimized AHSS reinforcement in the B-pillar.

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[154] Insurance Institute for Highway Safety Crashworthiness Evaluation; Roof Strength Test Report 2015 Ford F-150 (SWR1505)

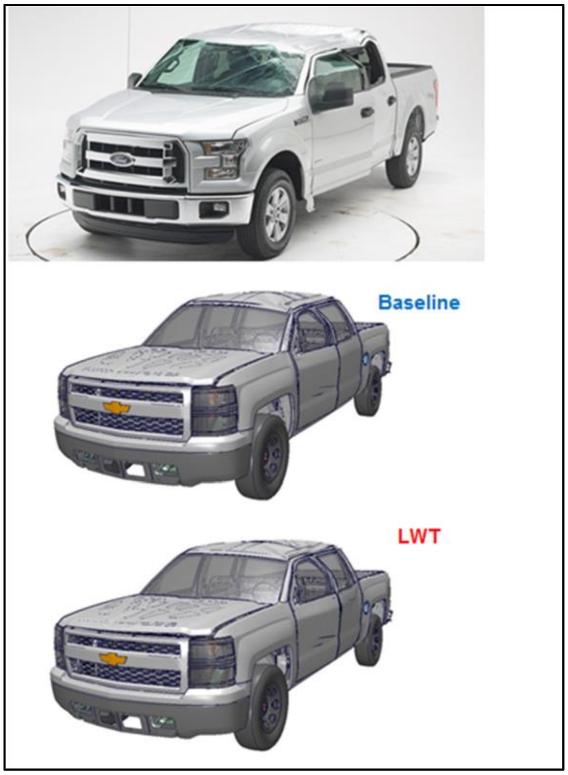
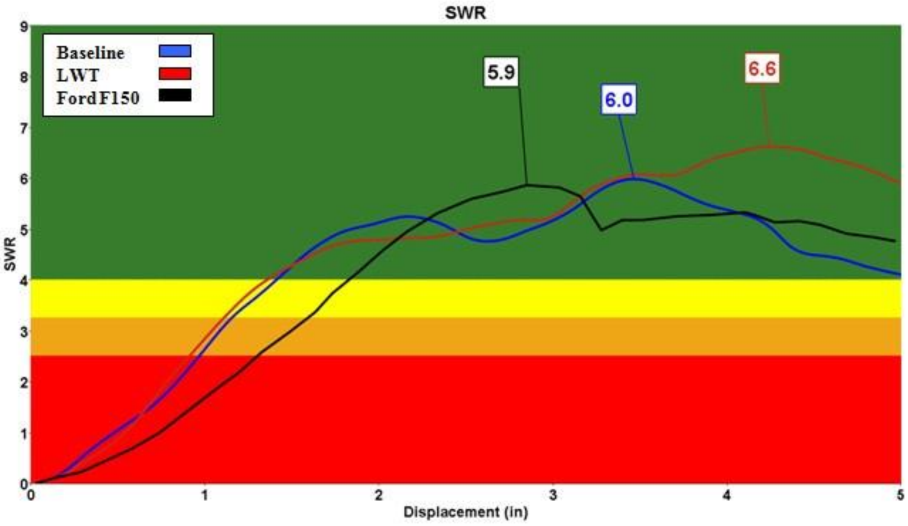
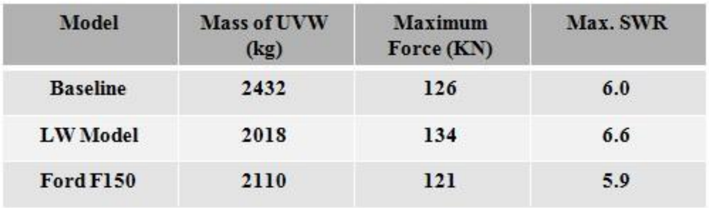


Figure 332: IIHS Roof Strength Test - Comparison Test Versus Baseline and LWT





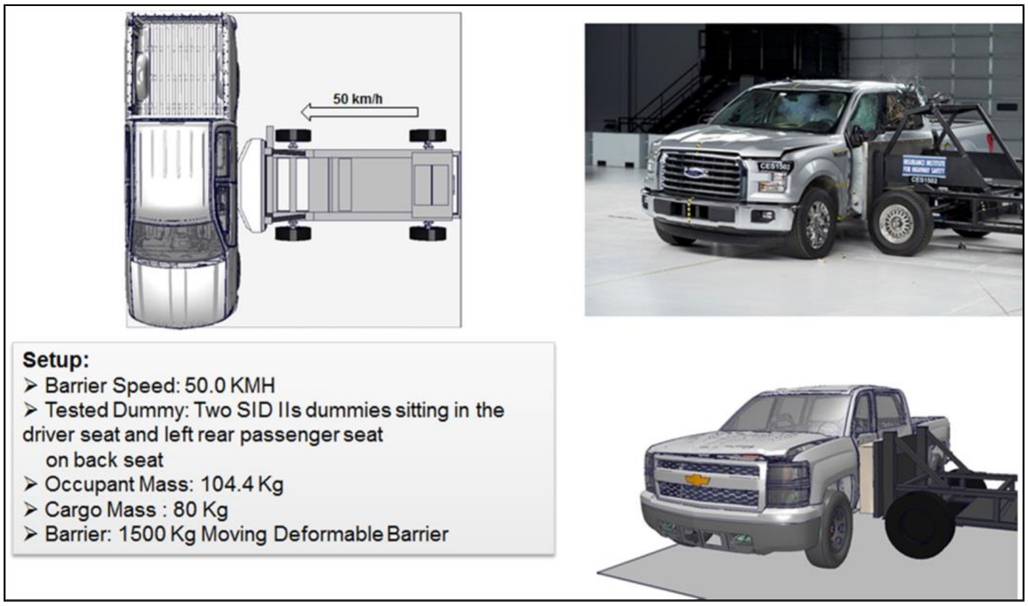
Model	Mass of UVW (kg)	Maximum Force (KN)	Max. SWR
Baseline	2432	126	6.0
LW Model	2018	134	6.6
Ford F150	2110	121	5.9

Figure 333: IIHS Roof Strength Test - Comparison F150 Test Versus CAE for Baseline and LWT

9.2.5 IIHS Side Impact Crash Test

The IIHS Side Impact Crash Test consists of a stationary test vehicle struck on the driver's side by a moving deformable barrier, a crash cart fitted with an IIHS deformable aluminum barrier element. The model was setup to include 1500kg MDV traveling at a speed 50km/h. The CAE model setup with the positioned MDB is shown in Figure 334. To date IIHS has not tested 2014 Silverado 1500 for side impact. Hence, the results are compared with the 2015 Ford F150[155] aluminum body that falls in the same segment as the Silverado.

According to the IIHS side impact test protocol, the test weight of the vehicle, which includes the vehicle instrumentation, three cameras, and two SID –IIs dummies, is 150 to 225 kg greater than the measured curb weight of the vehicle. If the vehicle test weight needs to be increased to fall within the range, ballast weight is distributed in a manner that comes closest to replicating the original front/rear and left/right weight distribution of the vehicle. Ford F150 test weight was 76 kg greater than the curb weight of the vehicle excluding dummies weight of 104.4 kg. Therefore, a ballast of 80 kg was added to the CAE model to make the test weight fall in the range specified by IIHS test protocol. Test and model setup are shown in Figure 334.



Setup:
- ➢ Barrier Speed: 50.0 KMH
- ➢ Tested Dummy: Two SID IIs dummies sitting in the driver seat and left rear passenger seat on back seat
- ➢ Occupant Mass: 104.4 Kg
- ➢ Cargo Mass : 80 Kg
- ➢ Barrier: 1500 Kg Moving Deformable Barrier

Figure 334: IIHS Side Impact Test - LS-DYNA Model Setup

Post-crash comparisons between Ford –F150, CAE baseline, and LWT are shown in Figure 335 & Figure 336. The predicted structural deformations for the LWT comparable to the 2015 Ford F-150 test results.

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[155] IIHSCrashworthiness Evaluation; 2015 Ford F-150 (CES1502) Side Impact Test

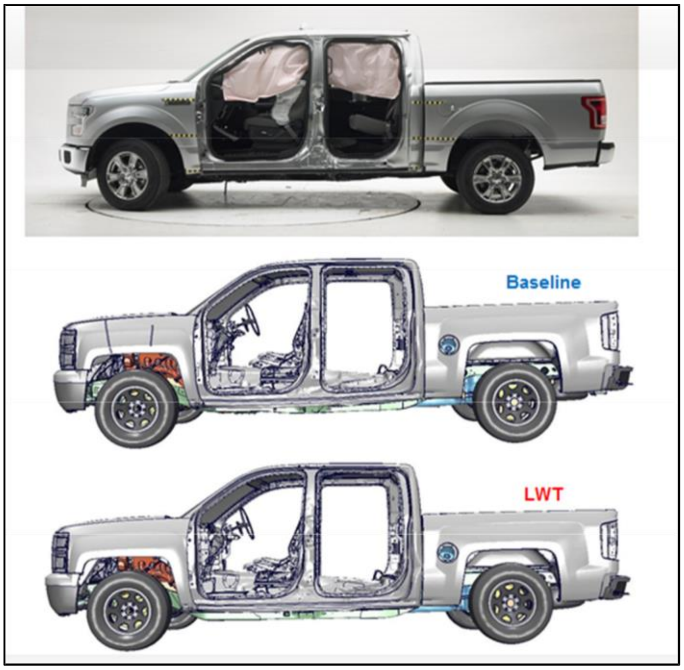

Figure 335: IIHS Side Impact - Comparison of F-150, Baseline, and LWT

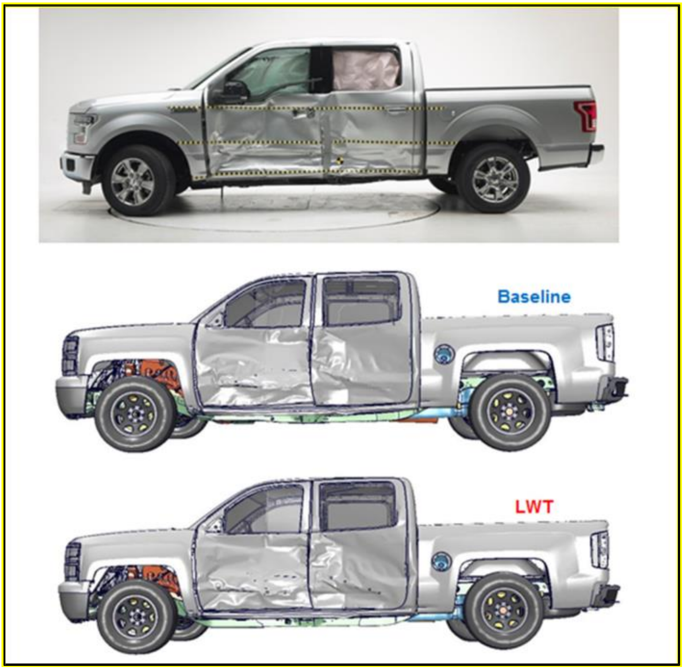

Figure 336: IIHS Side Impact – Comparison F-150 Test, Baseline, and LWT

Post-crash strain levels are observed on the fuel tank as shown in Figure 337. Strain at the end of 200 ms analysis simulation time is found to be less than 2 percent in the baseline and 8 percent in the LWT model. Observed strain is caused by RB2 connections created in between straps and the fuel tank to hold the fuel tank. As in real life the fuel tank is tightly fitted with the straps. Being made up of multilayer HDPE material, the fuel tank can see about 70 percent strain without cracking.[156]

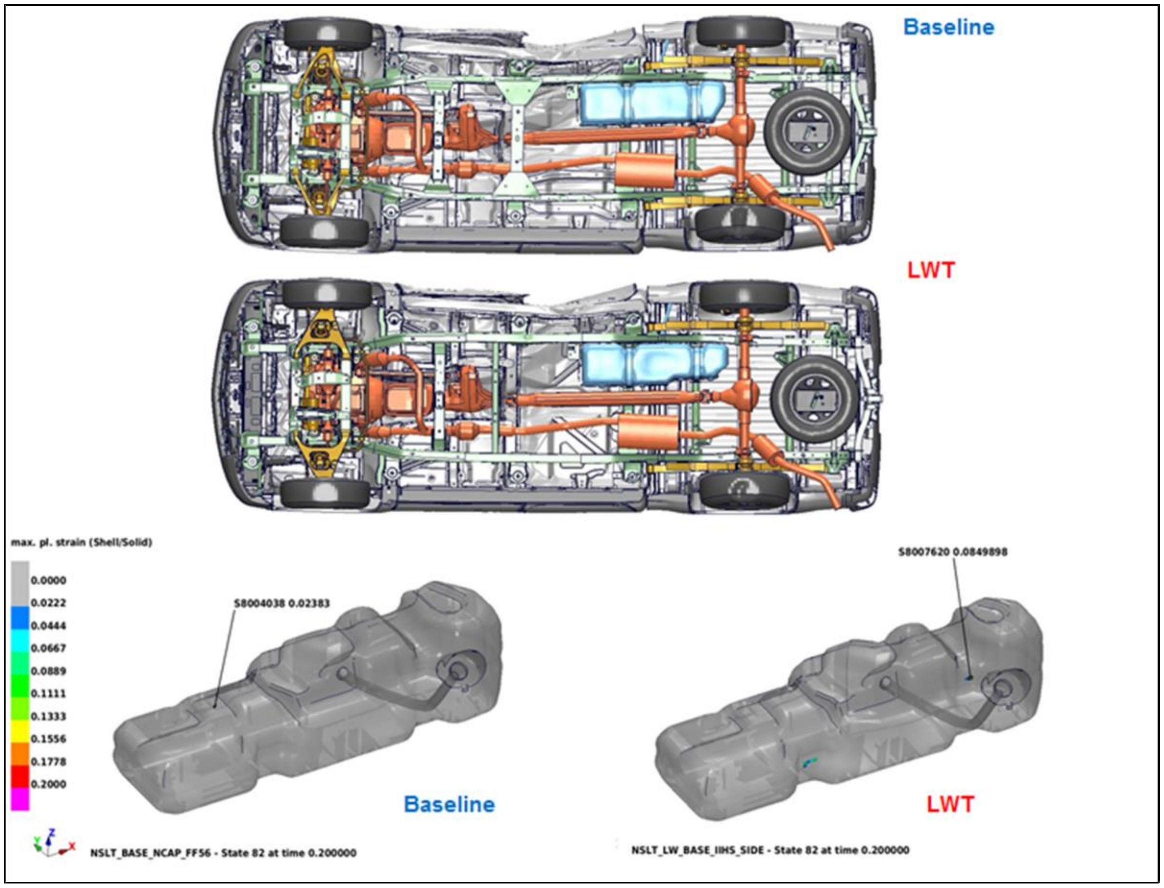

Figure 337: Fuel System Integrity

The IIHS side protocol defines the measurement of the intrusion relative to a plane at the seat centerline. Figure 338 shows comparison of the post-crash profile of B-pillar inner and B-pillar outer for Ford-F150, CAE baseline, and LWT. The LWT B-pillar crush profile matches well with the 2015 F-150 test values. Figure 339 is a similar comparison between CAE baseline and LWT. Though amount of intrusion is higher in LWT than baseline, it is still in the green zone and approximately 200 mm from the driver seat centerline.

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[156] Dynamic Material Characterization for Multilayer High Density Polyethylene Material; Ching-Shan Cheng and Kenneth A. Storm; GM R&D Center

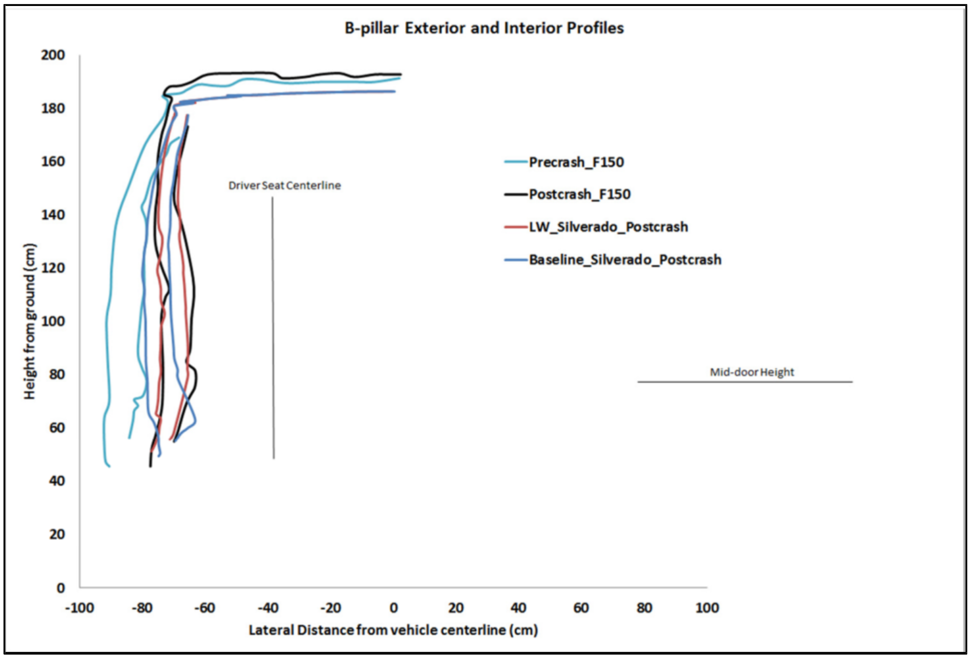


Figure 338: IIHS Side Impact Test - Comparison F150 Test Versus CAE for Baseline and LWT Side Intrusion Zones

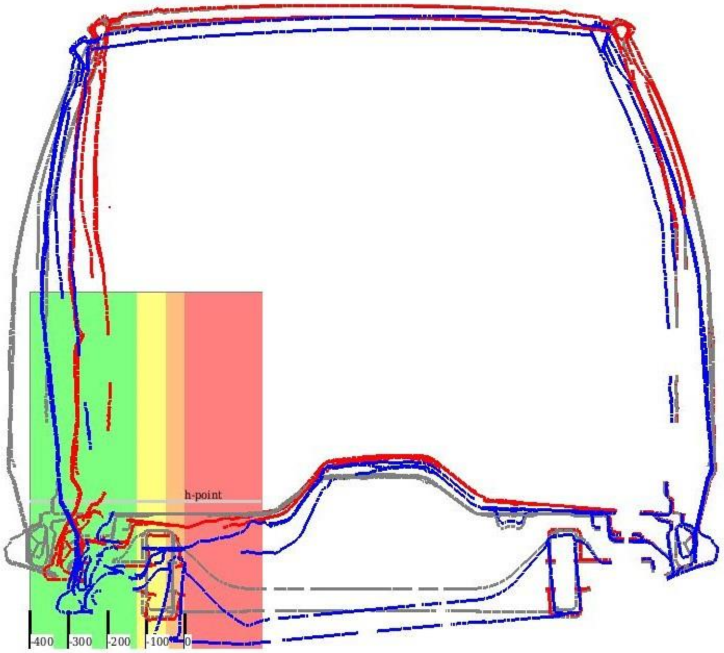


Figure 339: IIHS Side Impact Test – Comparison Baseline Versus LWT B Pillar Cross-section

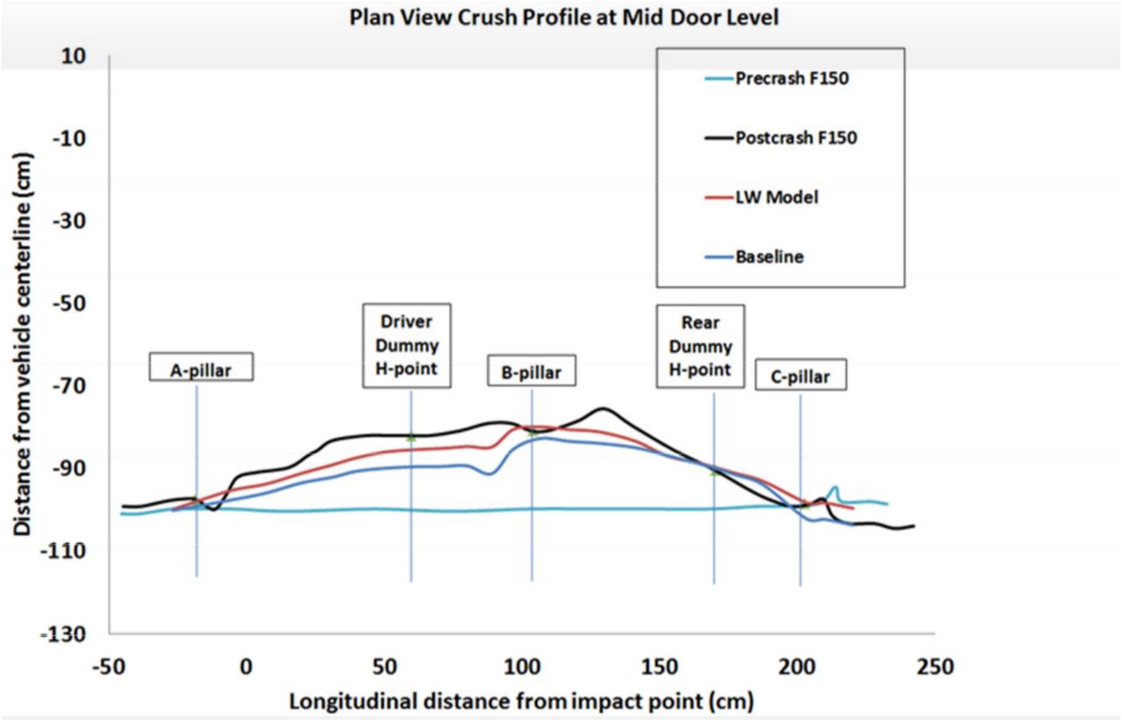


Figure 340: IIHS Side Impact Test - Comparison F150 Test Versus CAE for Baseline, and LWT: Side Structure Exterior Crush at Mid Door Level

Other critical parameter to be compared for the IIHS side impact case is the side structure intrusions on the struck side of the vehicle. The compartment exterior intrusions at mid-door level are shown in Figure 340. As can be seen the exterior surface crush profiles for the test vehicle 2015 F150 are in good agreement with the CAE baseline and LWT CAE model results.

9.2.6 IIHS Moderate Overlap Frontal Crash Test

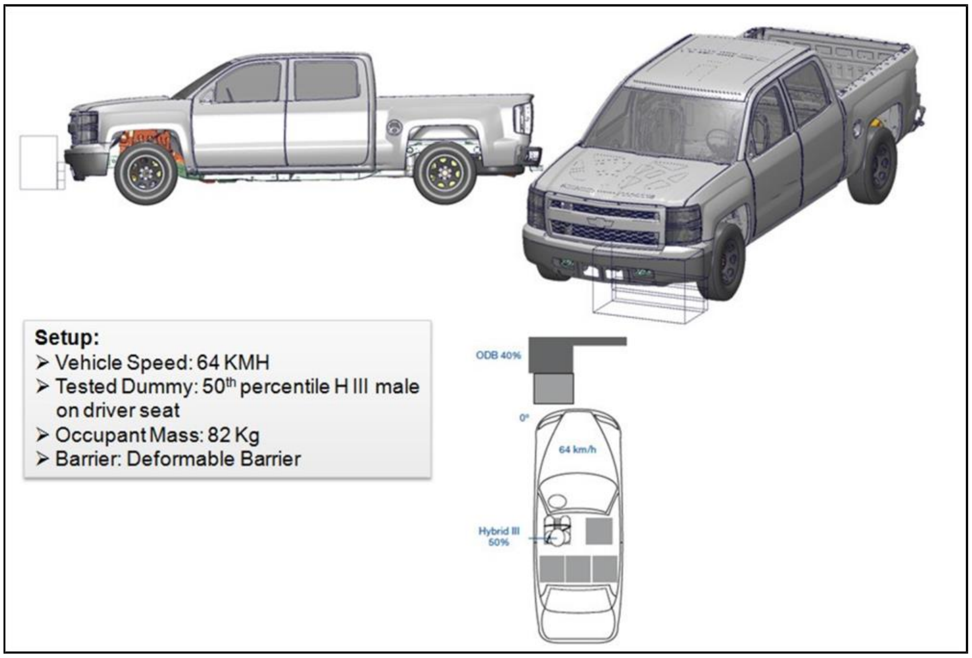
The IIHS Moderate Overlap Frontal Crash Test subjects the test vehicle to a partial frontal impact into a stationary deformable barrier. The test vehicle is aligned such that the right edge of the barrier is offset from the horizontal centerline of the vehicle by 10 percent ±1 percent of the vehicle width (defined in SAE J1100 – Motor Vehicle Dimensions); as shown in this way, 40 percent of the test vehicle's front face is impacted in the crash.

The LS-DYNA models for the baseline 2014 Silverado and LWT were created to represent the test setup, such as vehicle velocity of 64 km/h against a deformable barrier. The test vehicles are equipped with 50th percentile HIII male dummies in the driver seats. The mass of the test dummy was accounted for in the CAE models. Comparisons of vehicle parameters are shown in Figure 341. The test vehicle is 2-wheel drive compared with the baseline vehicle being 4-wheel drive. These differences will introduce some differences to the dynamic crush behavior and could affect the passenger compartment intrusion values, but it should not be significant to alter the safety crashworthiness ratings or conclusions.

	IIHS Test (GM)	Baseline Vehicle FEA Model	LWT Vehicle FEA Model
Curb Weight (kg)	2425	2432	2033
Test Weight (kg)	2507	2514	2115
Engine Type	5.3L V8	5.3L V8	5.0L V8
Tire Size	P265/65R18	P265/70R17	P265/70R17
Final Drive	2-Wheel Drive	4-Wheel Drive	4-Wheel Drive
Wheelbase (mm)	3644	3649	3649
CG (mm) Rear of Front Wheel C/L	1707	1673	1115
CAB Style	Crew Cab	Crew Cab	Crew Cab
Pickup Box Style	Standard	Short	Short

Figure 341: IIHS Frontal Moderate - Test Vehicles and CAE Models Parameters

The LS-DYNA model set up for the IIHS Frontal Moderate crash test of the baseline model is shown in Figure 342.



Setup:

- Vehicle Speed: 64 KMH
- Tested Dummy: 50th percentile H III male on driver seat
- Occupant Mass: 82 Kg
- Barrier: Deformable Barrier

Figure 342: IIHS Frontal Moderate - Test and LS-DYNA Model Set-Up

Post-crash images of the simulation results shown Figure 343 and Figure 344 compares the overall predicted vehicle crushed shapes from the front, side, and from underneath the vehicle. The baseline CAE model and the LWT CAE model show similar crash performance.

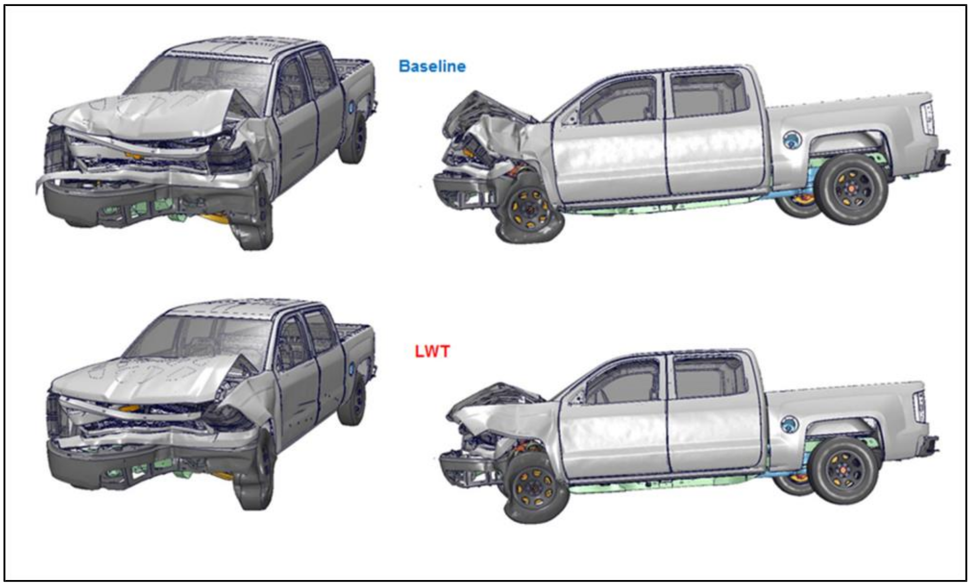


Figure 343: IIHS Frontal Moderate - Post-Crash Comparison CAE Results for Baseline and LWT

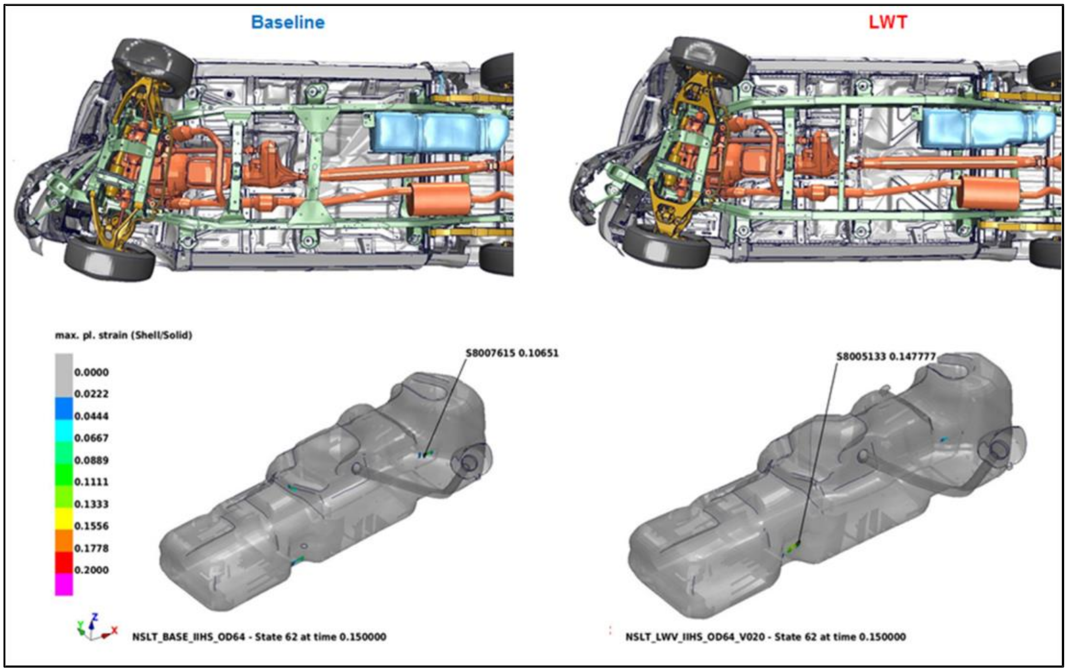


Figure 344: IIHS Frontal Moderate - Comparison CAE Results for Baseline and LWT

Post-crash strain levels are observed on the fuel tank as shown in Figure 344. Strains on the fuel tank are less than 11 percent in Baseline and 15 percent in LWT model. Observed strain in caused by RB2 connections created in between straps and the fuel tank to hold the fuel tank. As in real life the fuel tank is tightly fitted with the straps. Being made up of multilayer HDPE material the fuel tank can see about 70 percent strain without cracking.[157]

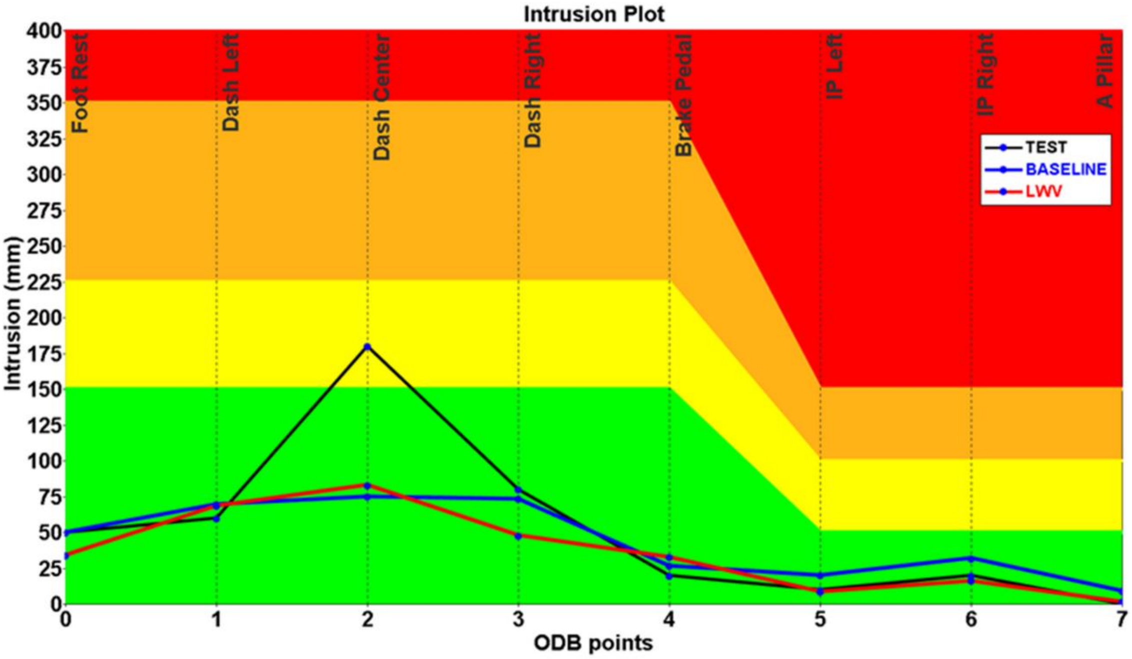


Figure 345: IIHS Frontal Moderate – Intrusion Values Comparison Test versus CAE Results for Baseline and LWT

The results for the for 2014 Silverado 1500 CAE model, Figure 345, correlate very well with the test results for the 2014 Silverado for all of the monitored points except for the driver toe pan central location. Full test report of this test is not available to study this further. It may however be related to the fact that the test vehicle is 2-wheel drive, without the front wheel drive components. The LWT CAE shows that its predicted performance is similar to the test and the baseline CAE model predicted values.

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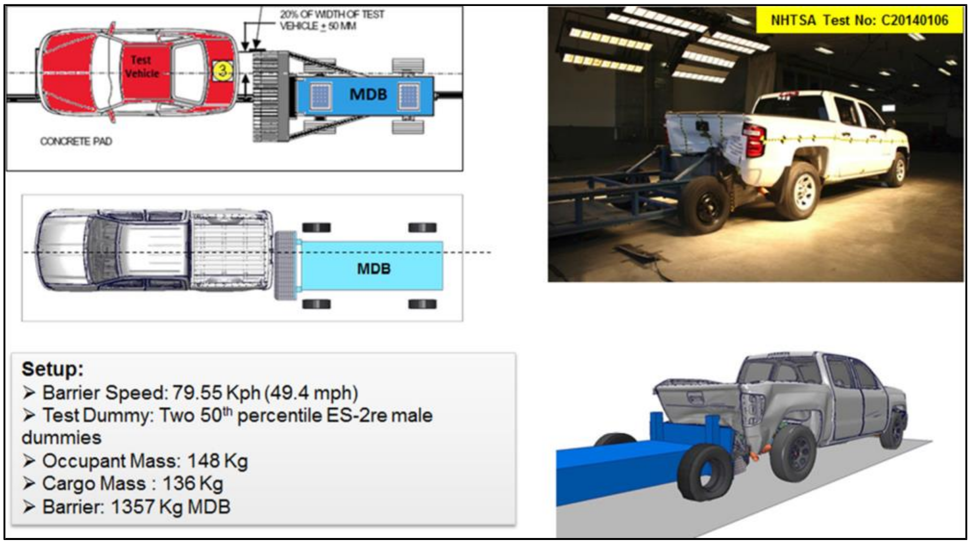
[157] Ibid

9.2.7 FMVSS No. 301 Rear Impact Test

FMVSS No. 301 specifies a rear-impact test. The rear-impact test is designed to promote crashworthiness of the body structure and protect the fuel tank from damage and hence avoid fuel leakage and possible fires. In this test a moveable deformable barrier impacts at 80 km/h (50 mph) into the rear of a stationary vehicle with an overlap of 70 percent as shown in Figure 346. The MDB used in the rear-impact test weighs 1,380 kg.



Setup:
- ➤ Barrier Speed: 79.55 Kph (49.4 mph)
- ➤ Test Dummy: Two 50th percentile ES-2re male dummies
- ➤ Occupant Mass: 148 Kg
- ➤ Cargo Mass : 136 Kg
- ➤ Barrier: 1357 Kg MDB

Figure 346: Test set up for FMVSS No. 301

Post-crash comparison between test, CAE baseline, and LWT are shown in Figure 347 & Figure 348. The CAE baseline model show very similar results compared to test. Rear end of the baseline including rear frame rail, pickup box, and spare wheel assembly deformed the same way as the test. The LWT model has improved performance as compared to the baseline and has very stable structure at the rear end with less deformation.

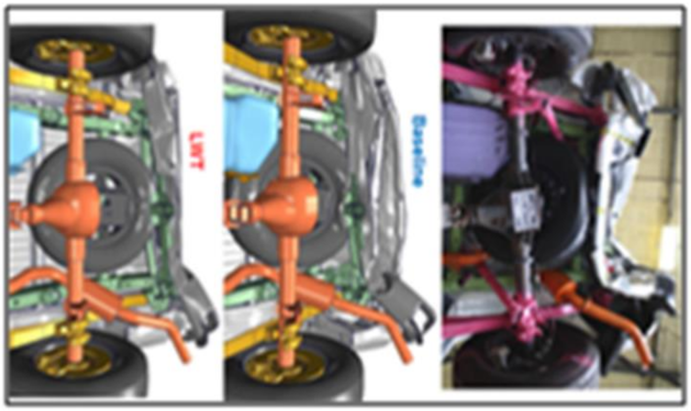


Figure 347: FMVSS 301R - Post-Crash Comparison Between Test and Baseline

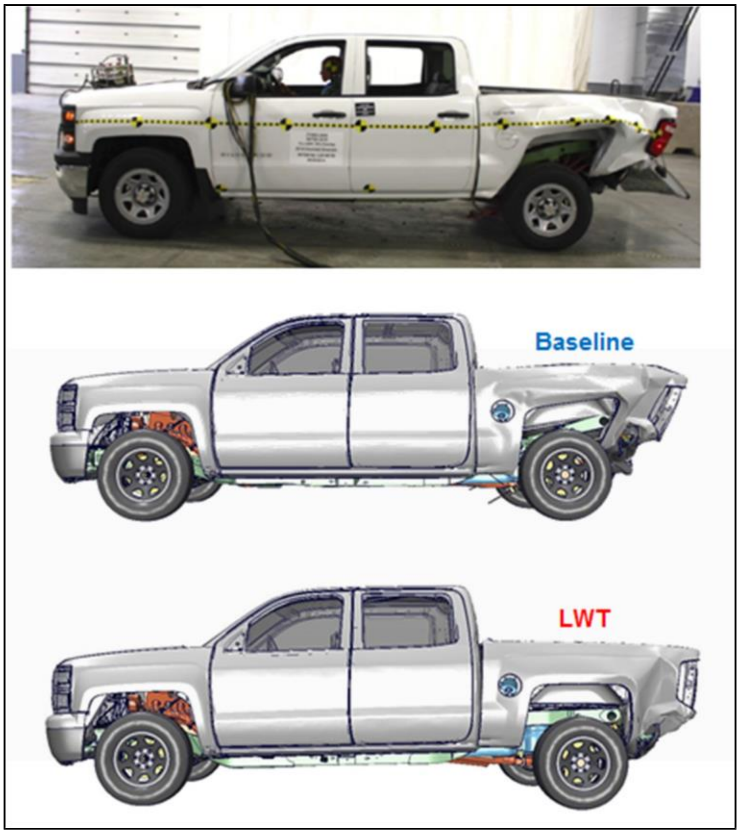
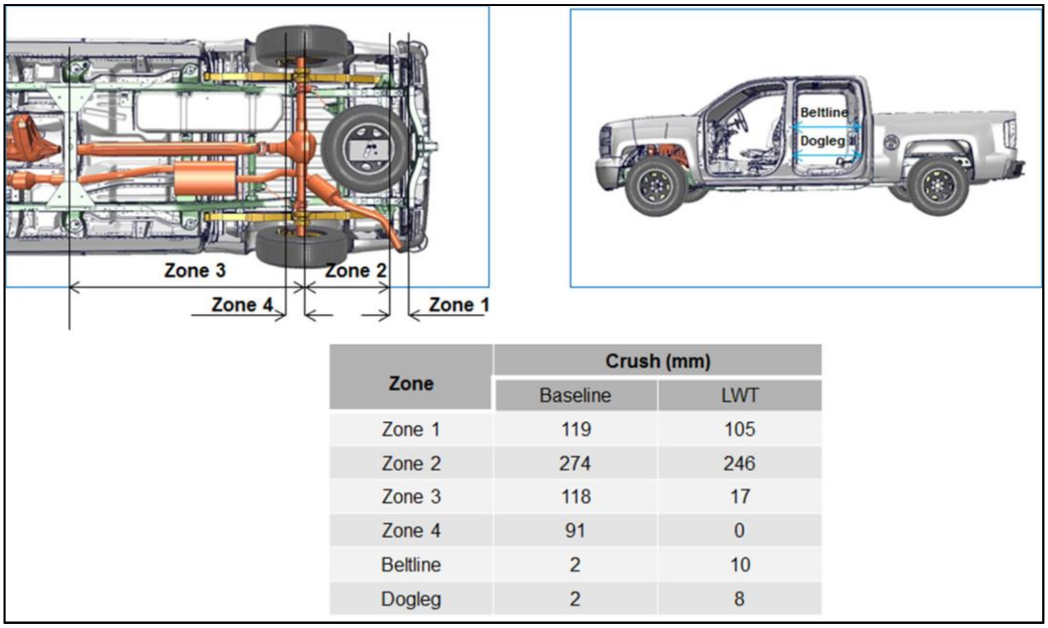


Figure 348: FMVSS 301R - Post-Crash Comparison Between Test and Baseline



Zone	Crush (mm)	
	Baseline	LWT
Zone 1	119	105
Zone 2	274	246
Zone 3	118	17
Zone 4	91	0
Beltline	2	10
Dogleg	2	8

Figure 349: FMVSS 301R - Rear End Intrusions

Four monitoring zones were created including rear door opening in CAE models to monitor amount of intrusion in rear impact and how can it affect the fuel tank. **Figure 349** shows the amount of intrusion measured and compared for baseline and LWT CAE models. It can be seen that intrusions are less in LWT than Baseline.

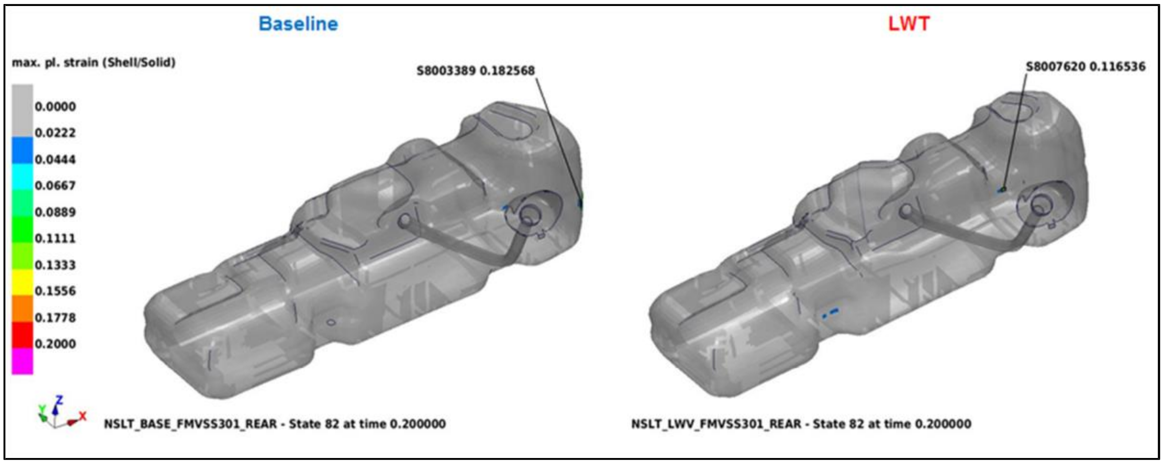


Figure 350: FMVSS 301R – Fuel Tank Integrity

Post-crash strain levels observed on the fuel tank are shown in Figure 350. In baseline, rear axle hits the back of the fuel tank that causes 18 percent strain. Similar behavior is observed in test vehicle as can be seen in Figure 347. Strain on the fuel tank is less than 11 percent in LWT model. Observed strain in caused by RB2 connections created in between straps and the fuel tank to hold the fuel tank. As in real life the fuel tank is tightly fitted with the straps. Being made up of multilayer HDPE material the fuel tank can see about 70 percent strain without cracking.[158]

9.2.8 IIHS Small Overlap Frontal Barrier Test

The IIHS small overlap frontal barrier test is designed to reproduce what happens when the front corner of a vehicle hits another vehicle or an object like a tree or utility pole. Because occupants move both forward and toward the side of the vehicle, the small overlap test is also a trial for some seat belt and air bag designs.

In this test a vehicle travels at 40 mph toward a 5-foot tall rigid steel barrier. An HIII dummy representing an average-size man is positioned in the driver seat. Twenty-five percent of the total width of the vehicle strikes the barrier on the driver side as shown in Figure 351. On most vehicles the barrier is outboard of the main longitudinal members of the vehicle structure. IIHS has not conducted this test on the baseline vehicle 2014 Silverado 1500. The CAE results for the baseline and the LWT models are compared with the IIHS test conducted on the 2015 Ford F-150.[159]

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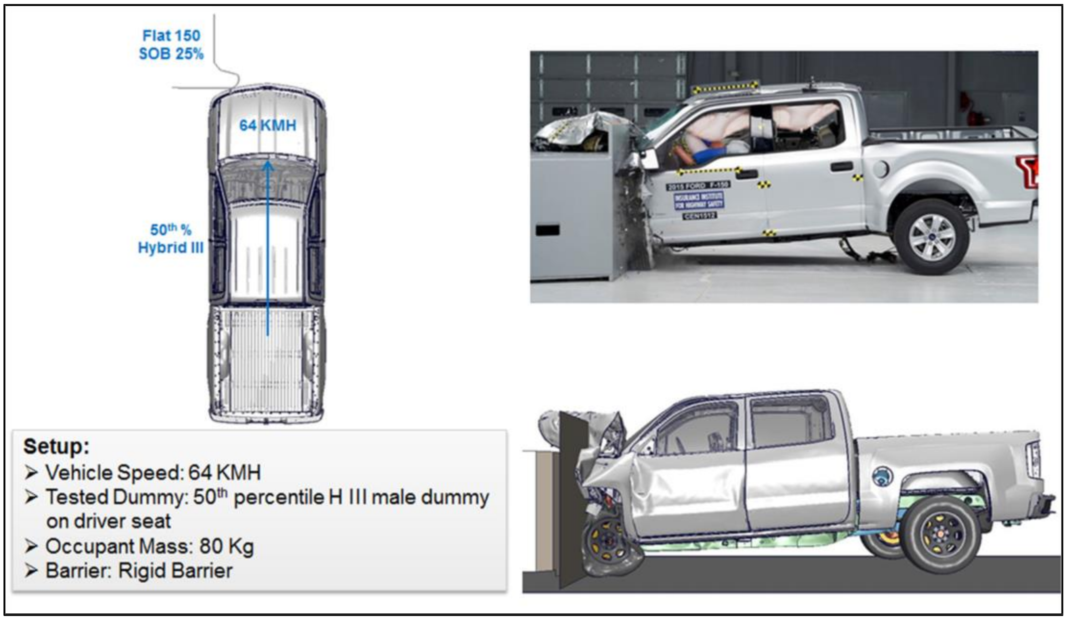
[158] Ibid

[159] Insurance Institute for Highway Safety Crashworthiness Evaluation; 2015 Ford F-150 (CEN1512) Small Overlap Front



Setup:

- Vehicle Speed: 64 KMH
- Tested Dummy: 50th percentile H III male dummy on driver seat
- Occupant Mass: 80 Kg
- Barrier: Rigid Barrier

Figure 351: IIHS Small Overlap Test – Test Setup

Post-crash images of the simulation results shown in Figure 352 and Figure 353 compares well the overall predicted vehicle crushed shapes from the front, side, and from underneath the vehicle. Compared with the baseline CAE model and the LWT, the CAE model showed improved crash performance.

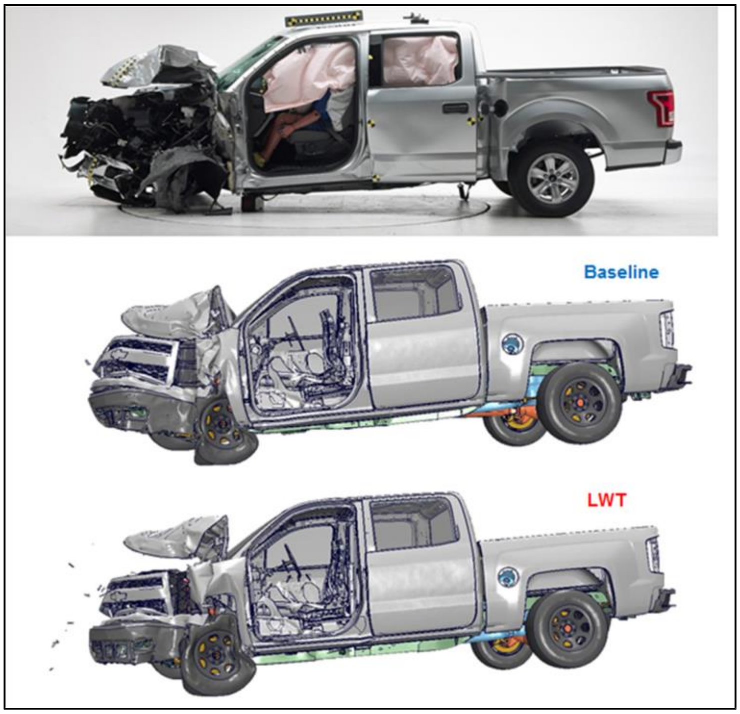


Figure 352: IIHS Small Overlap Test – Post Crash F-150[160] Versus CAE Baseline and LWT

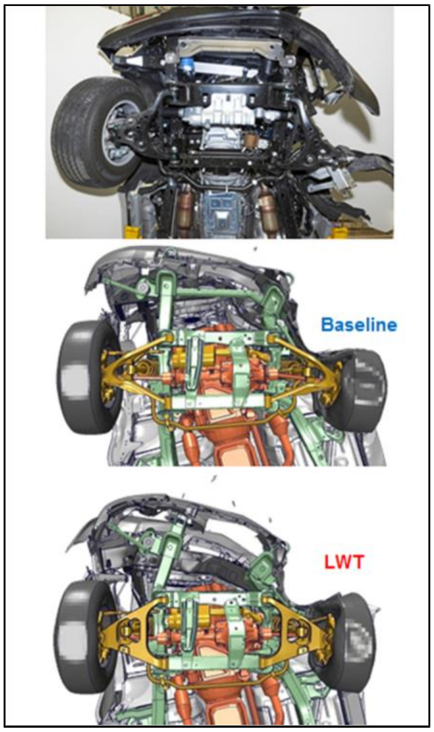


Figure 353: IIHS Small Overlap Test – Post Crash F150 Versus CAE Baseline and LWT

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[160] Insurance Institute for Highway Safety Crashworthiness Evaluation; 2015 Ford F-150 (CEN1512) Small Overlap Front

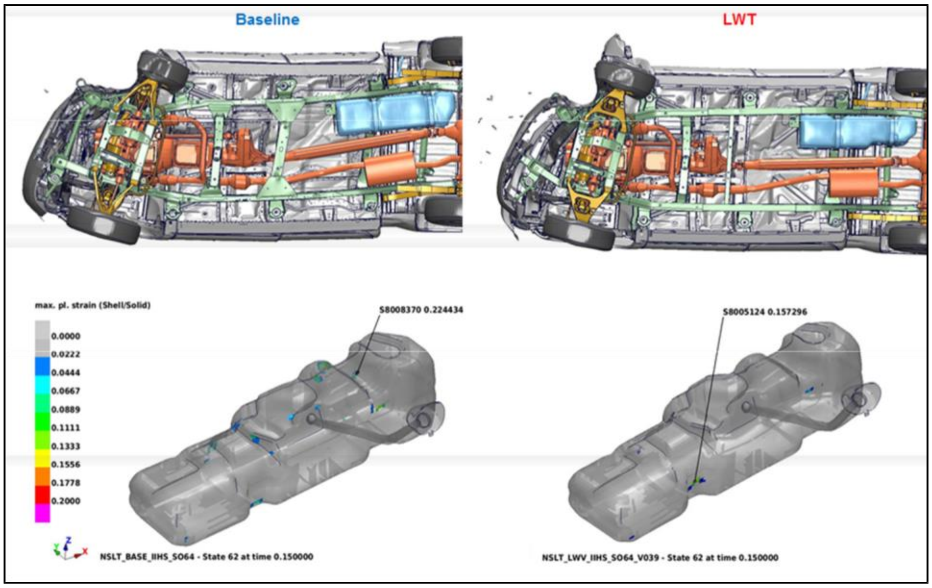

Figure 354: IIHS Small Overlap Test – Post Crash Fuel Tank Strain CAE Baseline v LWT

Post-crash strain levels are observed on the fuel tank as shown in Figure 354. Strain on the fuel tank less than 23 percent in Baseline and 16 percent in LWT model. Being made up of multilayer HDPEmaterial the fuel tank can withstand about 70 percent strain without cracking.[161]

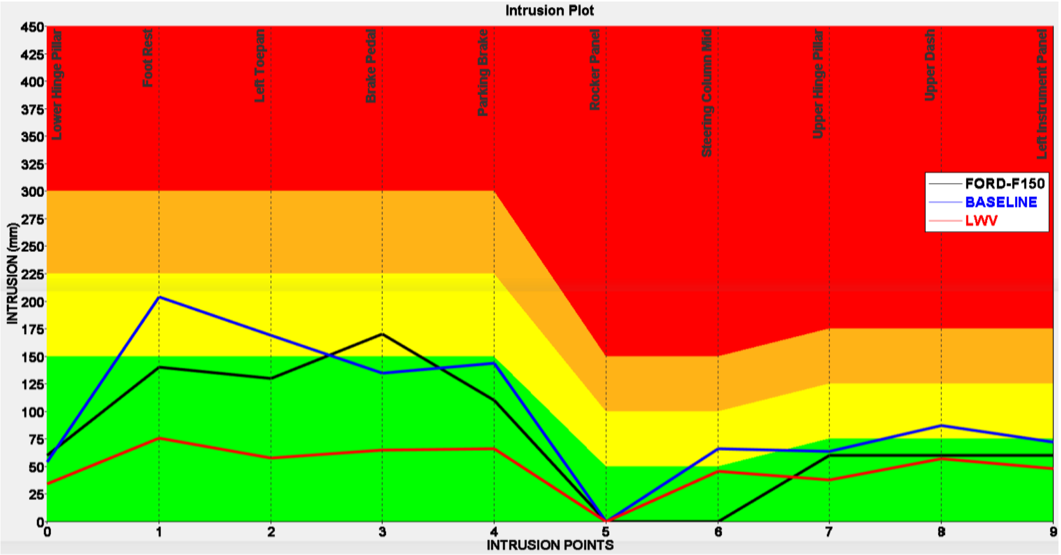

Figure 355: IIHS Small Overlap Test – Intrusions CAE Baseline Versus LWT Versus F150

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[161] Dynamic Material Characterization for Multilayer High Density Polyethylene Material; Ching-Shan Cheng and Kenneth A. Storm; GM R&D Center

The results for the 2014 Silverado 1500 CAE model, shown in Figure 355, show higher intrusion vales compared with the test results for the 2015 Ford F-150 for most of the monitored points. The LWT CAE shows that its predicted performance is significantly improved in comparison to the F-150 test and the baseline CAE model predicted values.

9.3 Vehicle NVH Assessment - Structural Stiffness and Normal Modes

In order to make sure that the light weighted vehicle design has similar performance in NVH and structural stiffness the activities were undertaken. For additional discussion see Section 7.1.3 of this report.

1. CAB Modal Frequencies (Baseline Test, Baseline CAE, and LWT CAE)
2. CAB Torsion and Bending Stiffness (Baseline CAE and LWT CAE)
3. Frame Torsion and Bending Stiffness (Baseline Test, Baseline CAE, and LWT CAE)
4. Frame Modal Frequencies (Baseline CAE and LWT CAE)
5. Frame and Box Torsion and Bending Stiffness (Baseline Test, Baseline CAE, and LWT CAE)
6. Frame and CAB Torsion and Bending Stiffness (Baseline Test, Baseline CAE, and LWT CAE)
7. Frame, CAB and Box Torsion and Bending Stiffness (Baseline Test, Baseline CAE, and LWT CAE)
8. Frame, CAB and Box Modal Frequencies (Baseline CAE and LWT CAE)

9.3.1 Vehicle CAB – Modal Frequencies Model Correlation

The cab FEA model in NASTRAN consists of the cab structure with front and rear glass, front-end sheet metal, radiator support structure, and the instrument panel steel structure. The meshed model of the Silverado baseline cabin model is made up of approximately one million elements. The model setup for normal modes analysis is shown Figure 356, and is similar to the test setup also shown in Figure 356. The MSC NASTRAN solver (Static Solution SOL 101) was used to analyze the NVH load cases. The results of the NVH simulations were studied with respect to the test results. The correlation of the CAE test results of the cab normal modes frequencies are shown in Figure 357. The FEA predicted resonance frequencies of the cab structure are within 5.0 percent of the test results. Similar FEA model of the LWT vehicle cab structure was used to make certain that the LWT cab has similar magnitude of resonance frequencies as the baseline vehicle. As can be seen in Figure 357 the LWT cab frequencies are higher than the test and baseline structure results.

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[162] MSC-NASTRAN User's Manual 2007

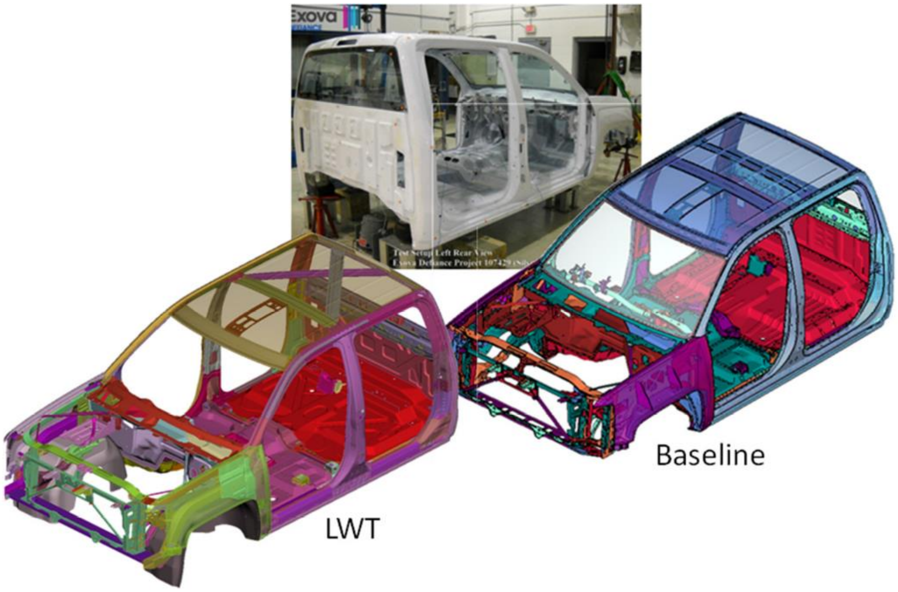


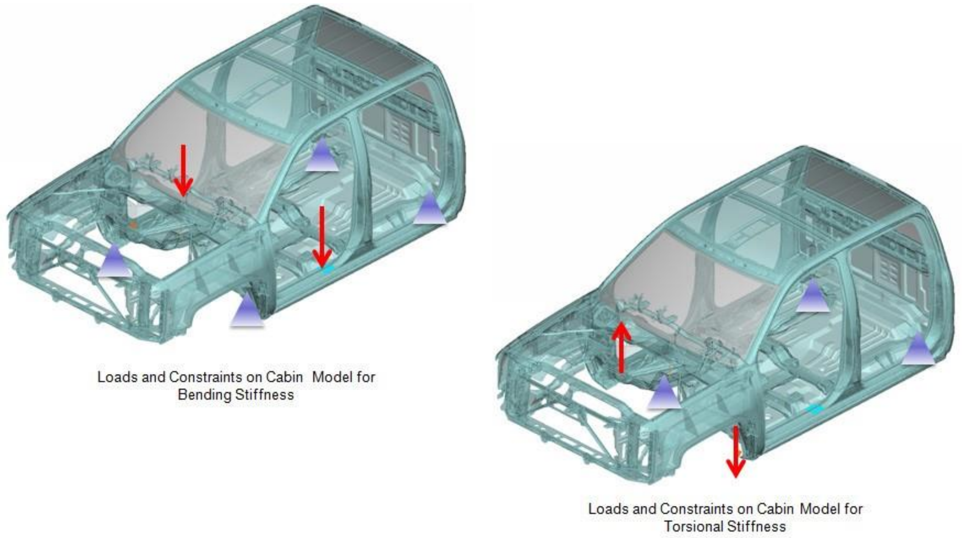
Figure 356: Vehicle CAB – Modal Frequencies Test Setup and FEA Model

Mode #	Baseline Test Freq (Hz)	EDAG Baseline CAE Model Frequency (Hz)		EDAG LWT CAE Model Frequency (Hz)		Mode Shape
1	22.5	23.4	3.7%	26.9	+19%	Global vertical bending
3	36.1	35.8	-0.9%	39.5	+9%	First Global Lateral Bending (more front)
6	46.5	44.1	-5.0%	50.5	+9%	Global Vertical Bending

Figure 357: Vehicle CAB – Modal Frequencies Test Versus CAE Results for Baseline and LWT

9.3.2 Vehicle CAB – Bending and Torsional Stiffness

The cab FEA NASTRAN models as described in Section 9.3.1 are also used for predicting the bending and torsional stiffness of the CAB structure. The FEA model constraints for bending and torsion are shown in Figure 358 and the predicted results using MSC NASTRAN Solution 101[163] are shown in Figure 359. The predicted bending and torsional stiffness of the LWT CAB is of similar order as the baseline vehicle CAB. During the design phase of the LWT cab, this type of analysis coupled with computer optimization, was routinely performed to support the ongoing LWT CAB design decisions.



Loads and Constraints on Cabin Model for Bending Stiffness

Loads and Constraints on Cabin Model for Torsional Stiffness

Figure 358: Vehicle CAB – Bending and Torsional Stiffness FEA Model

Study Description	Torsion Stiffness (Nm/Deg)	Bending Stiffness (N/mm)	Comments
Baseline CAB CAE Model	25,789	7,638	
LWT CAB CAE Model	24,390	7,953	
Difference	-5%	+4%	

Figure 359: Vehicle CAB – Bending and Torsional Stiffness FEA Results

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[163] MSC-NASTRAN User's Manual 2007

9.3.3 Vehicle Frame – Bending and Torsional Stiffness Correlation

The frame static stiffness NASTRAN FEA model consists of frame structure with front and rear bumpers and towing hitch structure. The model setup for stiffness analysis is shown in Figure 360, and is similar to the test setup also shown in Figure 360. The MSC NASTRAN solver (Static Solution SOL 101) was used to analyze the static stiffness load cases. The results of the simulations were studied with respect to the test results. The correlation of the CAE test results of the frame bending and torsion stiffness are shown in Figure 361. The FEA predicted results of the frame structure are within 5.0 percent of the test results. The predicted normal modes frequencies of the frame are shown in Figure 362. The LWV vehicle frame structure is designed with similar magnitude of bending and torsional stiffness and resonance frequencies as the baseline vehicle.

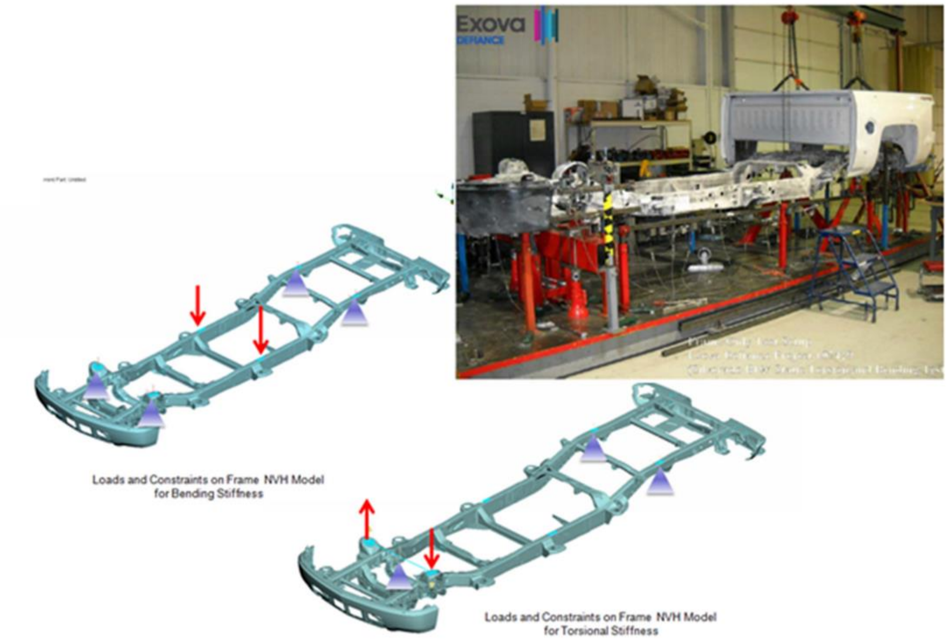

Figure 360: Vehicle FRAME – Bending andTorsional Stiffness Test Setup and FEA Model

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[164] MSC-NASTRAN User’s Manual 2007

Study Description	Torsion Stiffness (Nm/Deg)	Bending Stiffness Dr. Side(N/mm)	Bending Stiffness Pa. Side (N/mm)	Comments
Baseline Frame Test	3,270	2,860	2,953	Test Results
Baseline Frame CAE Model	3,100	2,940	2,940	CAE Model Correlated to Test Results
	-5%	+3%	0%	Comparison With Test
LWT Frame CAE Model	3,025	2,965	2,965	LWT Frame CAE Model
	-7%	+4%	0%	LWT Frame Comparison With Test
	-2%	+1%	+1%	LWT Frame Comparison With Baseline CAE Results

Figure 361: Vehicle FRAME – Bending and Torsional Stiffness Test and FEA Results

9.3.4 Baseline Vehicle Frame – Modal Frequencies

The frame FEA NASTRAN model as described in Section 9.3.3 is also used for predicting the normal modes frequencies of the frame structure. The predicted results using MSC NASTRAN are shown in Figure 362. As can be seen the LWT frame has improved torsion and bending frequencies.

Mode #	Frame Baseline CAE Model Frequency (Hz)	Frame LWT CAE Model Frequency (Hz)		Mode Shape
1	15.2	15.5	+2.0%	Global Torsion
2	19.0	19.7	+3.7%	Global Bending

Figure 362: Vehicle Frame – Modal Frequencies FEA Results

9.3.5 Vehicle Frame & Box – Bending and Torsional Stiffness Correlation

The pickup box assembly is rigidly bolted on to the frame. Due to the bolted connection, the frame and the pickup box act as a single assembly to react various loads that are imposed on the vehicle. Therefore, the stiffness performance of frame and pickup box assembly was determined for bending and torsional stiffness. Test and FEA model setup are shown in Figure 363. For bending and torsional stiffness the test results comparison with FEA results is shown in Figure 364. The baseline FEA model results are within 7 percent of the test results. The predicted torsion and bending stiffness of the frame designed for the LWV vehicle are of similar order.

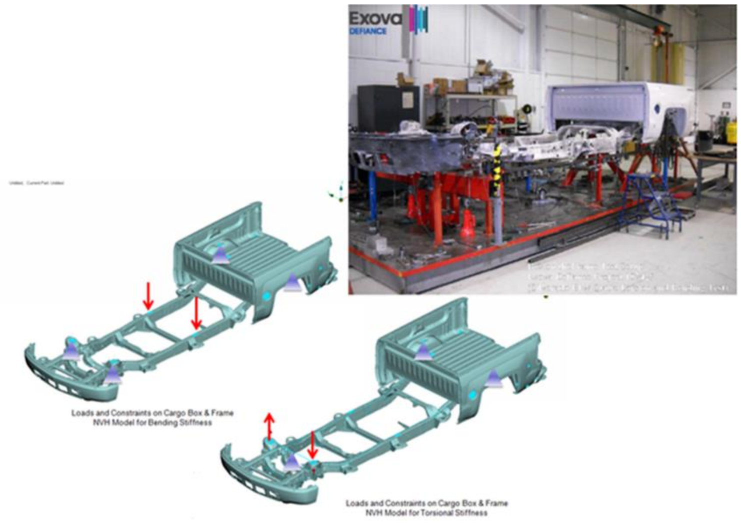


Figure 363: Vehicle Frame and Pickup Box – Bending and Torsional Stiffness Test Setup and FEA Model

Study Description	Torsion Stiffness (Nm/Deg)	Bending Stiffness Dr. Side(N/mm)	Bending Stiffness Pa. Side (N/mm)	Comments
Baseline Frame & Box Test	3,428	2,870	2,965	Test Results
Baseline Frame & Box CAE Model	3,205	2,940	2,940	CAE Model Versus Test Results
	-7%	2%	-1%	Comparison With Test
LWT Frame & Box CAE Model	3,101	2,967	2,967	LWT Frame CAE Model
	-10%	3%	0%	LWT Frame Comp With Test Results
	-3%	1%	1%	LWT Frame Comp With Baseline

Figure 364: Vehicle Frame and Box – Bending and Torsional Stiffness Test and FEA Results

For the LWT, the predicted resonance frequencies of the frame and box assembly shown in Figure 365, are over 30 percent higher compared with the baseline vehicle.

Mode #	Frame & Box Baseline CAE Model Frequency (Hz)	Frame & Box LWT CAE Model Frequency (Hz)		Mode Shape
1	11.8	15.4	+30.5%	Global Torsion
2	13.2	17.5	+32.6%	Global Bending

Figure 365: Vehicle Frame and Box – Resonance Frequencies FEA Results

9.3.6 Vehicle Frame, Box & Cab – Bending and Torsional Stiffness Correlation

The stiffness performance of the complete body on frame assembly was determined for bending and torsional stiffness. Test and FEA model setup are shown in Figure 366. For bending and torsional stiffness the test results comparison with FEA results is shown in Figure 367. The baseline vehicle FEA model results are within 6 percent of the test results. Normal modes analysis was also conducted on this model. The predicted results for global torsion and global bending modes are shown in Figure 368.

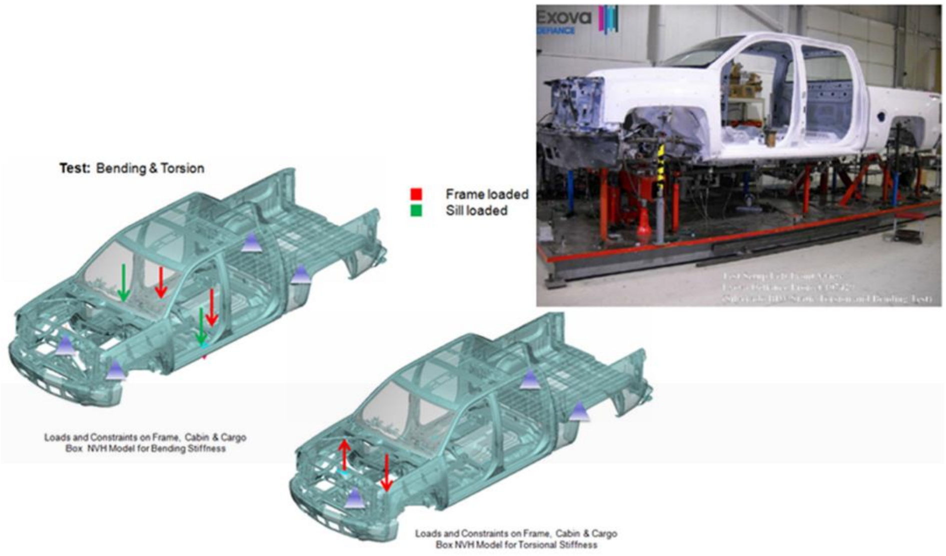


Figure 366: Vehicle Frame, Box, and Cab – Bending and Torsional Stiffness Test Setup and FEA Model

		Load Applied to CAB Sill (Rocker)	Load Applied to Frame		
Study Description	**Torsion Stiffness (Nm/Deg)**	**Bending Stiffness (N/mm)**	**Bending Stiffness Dr. Side(N/mm)**	**Bending Stiffness Pa. Side (N/mm)**	**Comments**
Baseline Frame, CAB & Box Test	5,509	1,947	3,185	3,257	Test Results
Baseline Frame, CAB & Box CAE Model	5,335	2,063	3,312	3,312	CAE Model correlated to test Results
	-3%	6%	4%	2%	Comparison With Test Results
LWT Frame, CAB & Box CAE Model	5,181	1,991	3,264	3,264	LWT CAE Model
	-6%	2%	2%	0%	LWT Comparison With Test Results
	-3%	-3%	-1%	-1%	LWT Comparison With Baseline

Figure 367: Vehicle Frame, Box, and Cab – Bending and Torsional Stiffness Test and FEA Results

Mode #	Baseline Frame, Box & CAB CAE Model Frequency (Hz)	LWT Frame, Box & CAB CAE Model Frequency (Hz)		Mode Shape
1	11.0	11.7	6.4%	Global Torsion
2	13.4	13.7	2.2%	Global Bending

Figure 368: Baseline Vehicle Frame, Box, and Cab – Modal frequencies FEA Results

9.3.7 Performance Evaluation of Pickup Box – Baseline versus LWT Design

The pickup box on light duty trucks is designed carry various type of payloads. Based on EDAG's experience for pickup boxes of a similar size and construction, along with the baseline values established in this analysis, pickup box targets where established. The target values are used in the mass reduction phase of the analysis to ensure pickup box mass reduction ideas do not result in performance degradation. The CAE models of the pickup box baseline and LWT design as shown in Figure 369 were subjected to the following industry standard load cases.

1. Distributed bed floor load – bed strength evaluation
2. Abusive drop load – bed strength evaluation, minimize denting
3. Header panel strength – to avoid or limit rear load penetration into CAB
4. Tie down hooks strength – sidewall strength
5. Pickup box assembly modal frequencies – vibration performance

The predicted performance results for the baseline vehicle and the LWT pickup box shown in Figure 370 indicate equivalent performance for both designs.

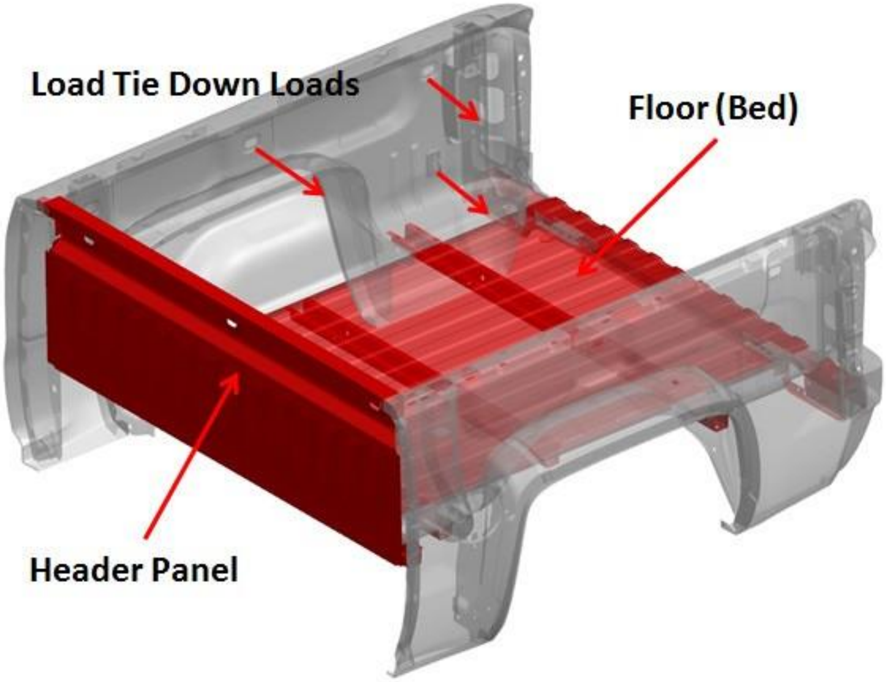


Figure 369: Pickup Box Performance Evaluation – CAE Model

Load Case	**Evaluation**	**Loading**	**Targets**	**Baseline Design Results**	**LWT Design Results**
Distributed Load Bed	Bed Floor Strength Evaluation	9 kN (2020 lbs) distributed on the bed floor	< 1mm Permanent Set	No Permanent Set	No Permanent Set
Abusive Drop Load Bed	Bed Floor Strength Evaluation	2.5 Kg Drop	< 7.5 mm Permanent Set	6 mm Permanent Set	5.2 mm Permanent set
Header Panel Strength	Header Strength on Impact	2,225 N Load applied to a 150mm x 150mm Area	< 25 mm deformation	26 mm deformation	24 mm deformation
Tie Down Load	Side Wall Strength	2,225N load to side hooks	< 1 mm Permanent Set	0.03mm Permanent Set	0.31 mm Permanent Set
Box Modal Frequencies	Torsion and Bending Modes	Normal Modes	Baseline or Higher	Torsion 32.6 Hz; Lateral Bending 26.6 Hz	Torsion 47.7Hz; Lateral Bending 36.2 Hz

Figure 370: Pickup Box Performance Evaluation – CAE Model Results

9.3.8 Evaluation of Frame and Towing Hitch – Baseline versus LWT Design

The frame and towing hitch of baseline light duty truck is designed for towing an 11,400 lbs trailer. The baseline values established using CAE analysis are used as targets for the LWT design. The target values are used in the mass reduction phase of the analysis to ensure mass reduction ideas do not result in performance degradation. The CAE models of the frame and hitch baseline and LWT design as shown in Figure 371 were subjected to the following load cases.

1. Hitch Loading Point stiffness assessment in the fore-aft direction
2. Hitch Loading Point stiffness assessment in the vertical direction
3. Frame and hitch structure strength

The predicted performance results for the baseline vehicle and the LWT pickup box shown in Figure 372 indicate equivalent performance for both designs.

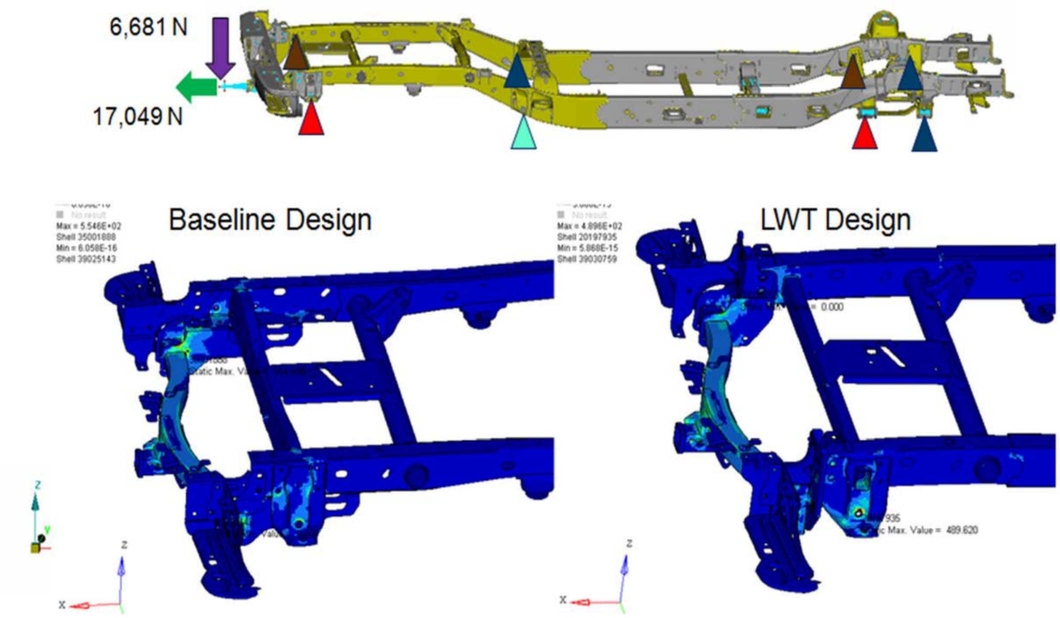


Figure 371: Frame Towing Load Performance Evaluation – CAE Model

Frame and Tow Hitch	Baseline Design	LWT Design
Fore-aft Stiffness kN/mm	11.1	15.9
Vertical Stiffness kN/mm	2.3	2.0
Max Mon-Mises Stress MPa	554	490

Figure 372: Frame Towing Load Performance Evaluation – CAE Model Results

9.3.9 Evaluation of Instrument Panel Structure – Baseline versus LWT Design

The instrument panel structure of the baseline light duty truck is steel welded assembly. The baseline values established using CAE analysis are used as targets for the LWT design constructed using magnesium casting. The target values are used in the mass reduction phase of the analysis to ensure mass reduction ideas do not result in performance degradation. The CAE models of the instrument panel structure baseline and LWT design as shown in Figure 373 were subjected to the following load cases.

1. Steering column mount stiffness
2. Modal analysis – resonance frequencies
3. Lateral crush strength in side crash event

The predicted performance results for the baseline vehicle and the LWT instrument panel structure shown in Figure 374 indicate equivalent or better performance compared with baseline design.

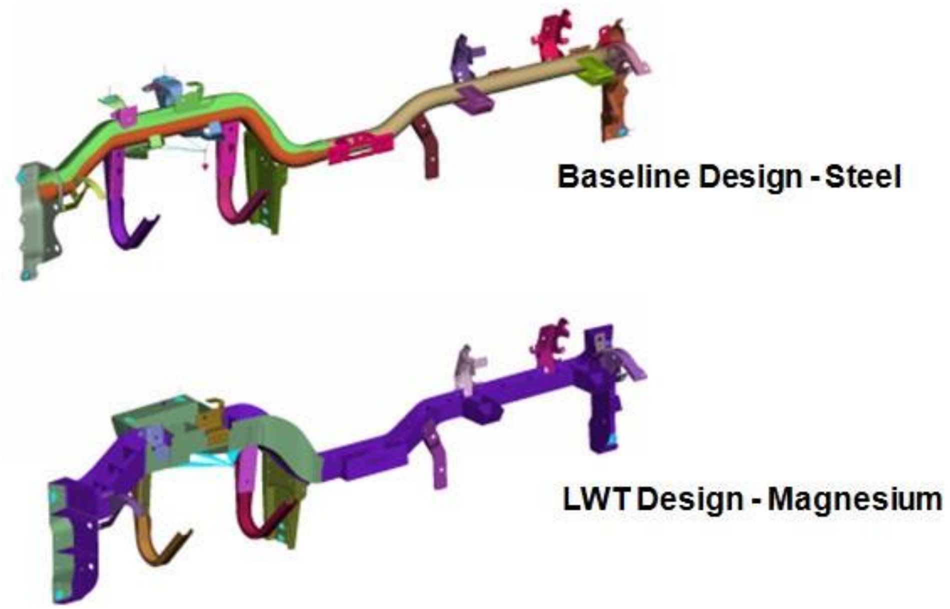


Figure 373: Instrument Panel Structure Performance Evaluation – CAE Model

Instrument Panel Beam Structure	Baseline Design	LWT Design	
Steering Column Stiffness N/mm	4,347	4,167	-4%
First Bending Freq Hz	168.0	252.0	+50%
First Torsional Freq Hz	252.0	323.0	+28%
Lateral Crush Force kN	25.0	28.5	+14%

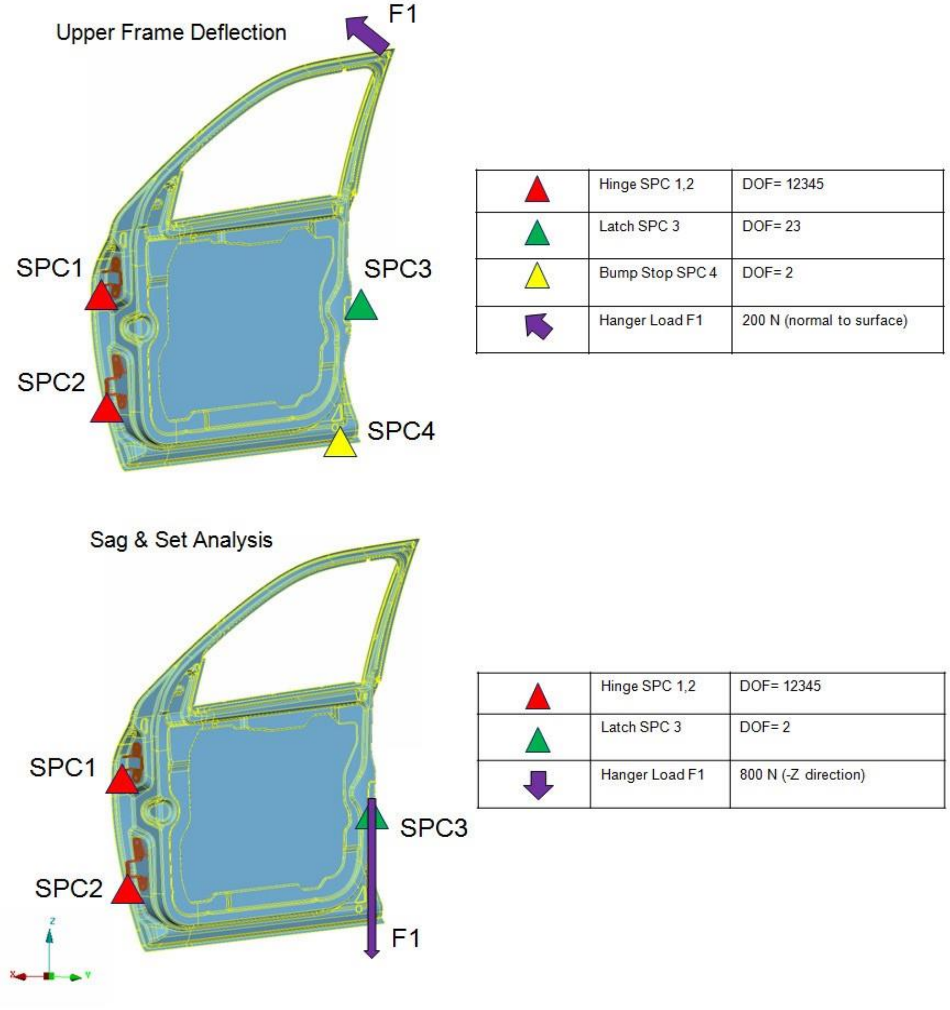
Figure 374: Instrument Panel Structure Performance Evaluation – CAE Model Results

9.3.10 Evaluation of Door Structure – Baseline versus LWT Design

The front and rear doors structure of the baseline light duty truck is steel welded assemblies. The baseline values established using CAE analysis are used as targets for the LWT design constructed using AHSS inner door structure and aluminum outer panel. The target values were used in the mass reduction phase of the analysis to ensure mass reduction ideas do not result in performance degradation. The CAE models of the door structure baseline and LWT design as shown in Figure 375 were subjected to the following load cases

1. Door frame stiffness
2. Door Sag when subjected to vertical overload

The predicted performance results for the baseline vehicle and the LWT door structure shown in Figure 376 for the front door and Figure 377 for the rear door indicate equivalent or better performance compared with baseline designs.



▲	Hinge SPC 1,2	DOF= 12345
▲	Latch SPC 3	DOF= 23
△	Bump Stop SPC 4	DOF= 2
⬉	Hanger Load F1	200 N (normal to surface)

▲	Hinge SPC 1,2	DOF= 12345
▲	Latch SPC 3	DOF= 2
⬇	Hanger Load F1	800 N (-Z direction)

Figure 375: Door Structure Performance Evaluation – CAE Model

Front Door	**Baseline Design**	**LWT Design**	
Door Frame Stiffness N/mm	36.7	37.1	1%
Door Sag Stiffness N/mm	353.5	354.3	0%
Door Sag Max von Mises Stress MPa	437.0	256.0	-41%

Figure 376: Front Door Structure Performance – CAE Model Results

Rear Door	Baseline Design	LWT Design	
Door Frame Stiffness N/mm	53.7	53.7	0%
Door Sag Stiffness N/mm	217.9	217.6	0%
Door Sag Max von Mises Stress MPa	359.0	398.0	11%

Figure 377: Rear Door Structure Performance – CAE Model Results

9.3.11 Evaluation of tailgate Structure – Baseline versus LWT Design

The tailgate structure of the baseline light duty truck is steel welded assembly. The baseline values established using CAE analysis are used as targets for the LWT design constructed using aluminum structure. The target values were used in the mass reduction phase of the analysis to ensure mass reduction ideas do not result in performance degradation. The CAE models of the tailgate structure baseline and LWT design as shown in Figure 378 were subjected to the following load cases.

1. Load front center edge 2,490 N (560 lbs) strength and stiffness
2. Load rear center edge 2,490 N (560 lbs) strength and stiffness

The predicted performance results for the baseline vehicle and the LWT tailgate structure shown in Figure 379 for the tailgate indicate equivalent or better performance compared with baseline design.

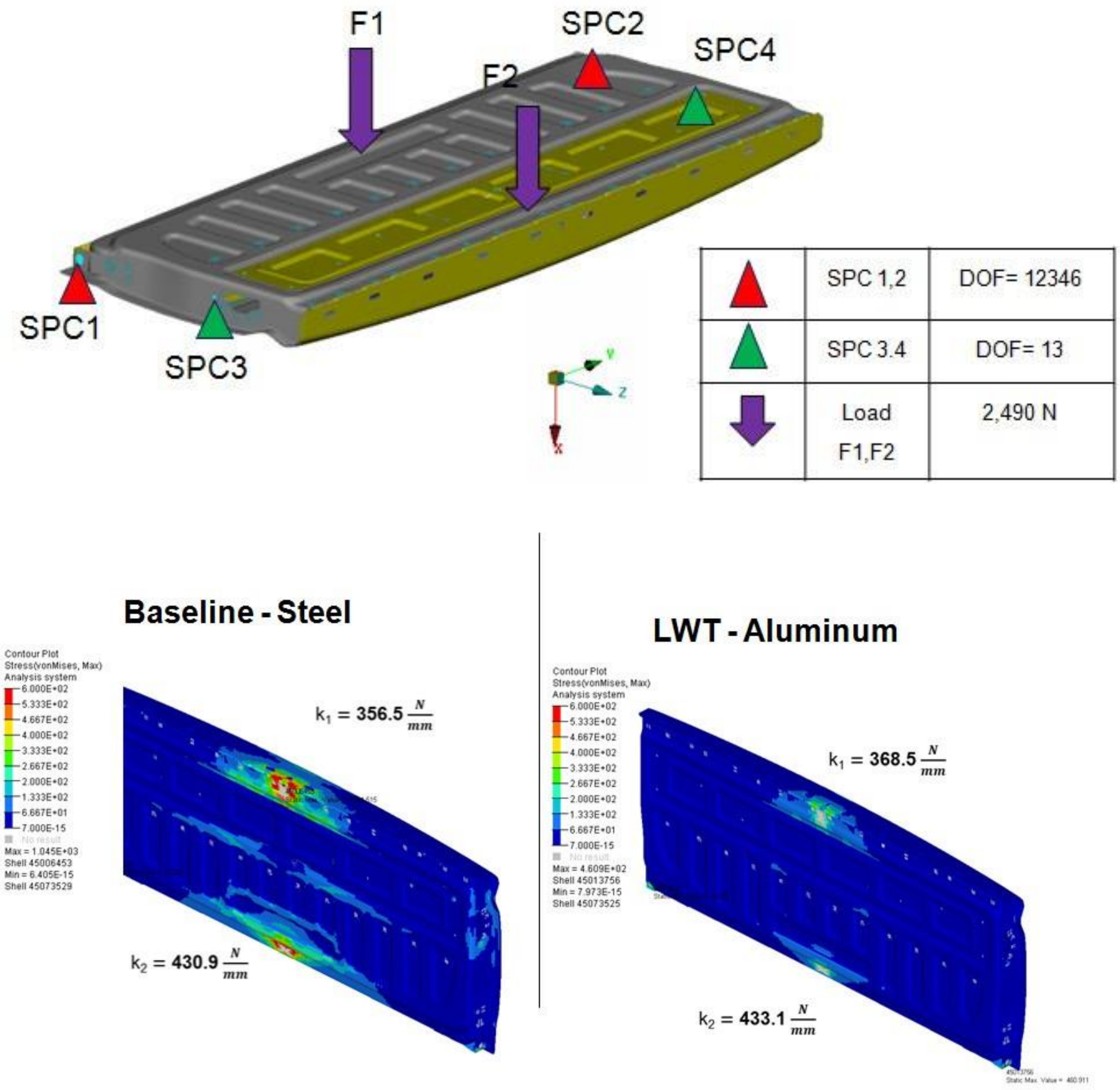


Figure 378: Tailgate Structure Performance Evaluation – CAE Model

Tailgate	Baseline Design	LWT Design	
Tailgate Stiffness (K1) N/mm	356.5	368.5	3%
Tailgate Stiffness (K2) N/mm	430.9	433.1	1%

Figure 379: Tailgate Structure Performance – CAE Model Results

9.4 Ride and Handling Performance

Ride and handling is the study of vehicle dynamic response to varying inputs including vehicle speed, change of speed, steering wheel angle, and road obstacles. Handling of the LWT was evaluated using MSC/ADAMS (Macneal-Schwendler Corporation/Automatic Dynamic Analysis of Mechanical Systems) software. The following five maneuvers were simulated.

1. Fish-hook Test
2. Double Lane Change Maneuver (ISO 38881)
3. Pothole Test
4. 0.7G Constant Radius Turn Test
5. 0.8G Forward Braking Test

9.4.1 ADAMS Vehicle Information

The LWT model includes the body, front double wishbone suspension, rear leaf spring suspension, front and rear tire model, front anti-roll bars, and powertrain, as shown in Figure 380.Vehicle specifications are listed in Figure 381.

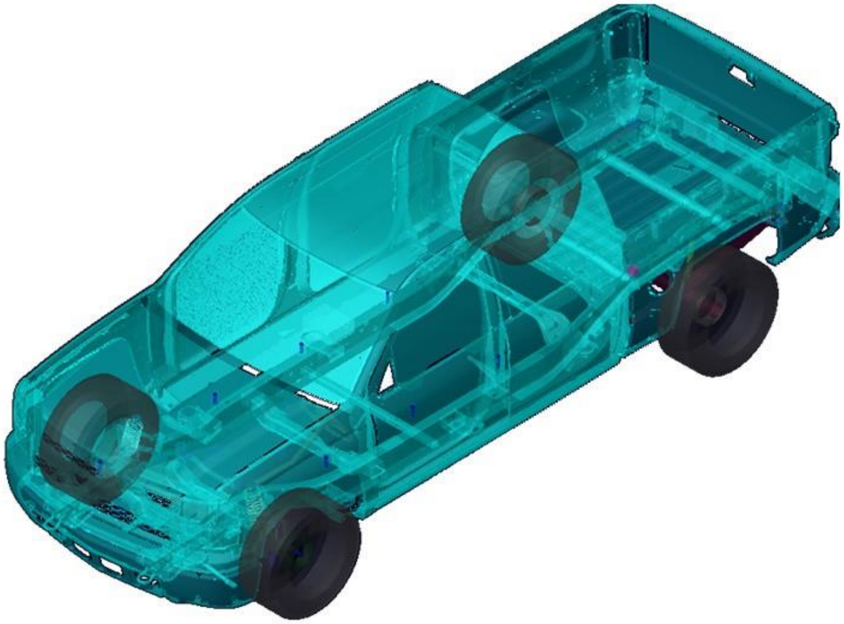


Figure 380: LWT ADAMS Model

ADAMS MODEL VEHICLE SPECIFICATION		
	BASELINE Model	LWT Model
Curb Weight	2432 Kg	2005 Kg
Center of Mass Height From Ground	721mm	698mm
Wheelbase	3645 mm	3645 mm
Tire Size	P255/70 R17	P255/70 R17
Track Width Front/Rear	1,745 mm / 1,716mm	1,745 mm/1,716mm
Front Suspension Type	Double wishbone suspension	Double wishbone suspension
Rear Suspension Type	Leaf Spring Suspension	Leaf Spring Suspension

Figure 381: ADAMS Models Vehicle Data for baseline and LWT

9.4.2 Fishhook Maneuver and Static Stability Factor

9.4.2.1 Test Summary

The fishhook test is used in conjunction with the static stability factor by NHTSA to rate the propensity for vehicle rollover.[165] The SSF in conjunction with whether or not the vehicle tips up during the fishhook maneuver determines the star rating. The SSF is the ratio of half a vehicle's track width to its center of gravity height. The SSF value for the LWT vehicle is calculated to be 1.26 and 1.20 for the baseline vehicle. This is a small improvement over the baseline vehicle; the risk of rollover is reduced from 17.4 percent to 16 percent for the LWT.

Figure 382 shows the curves that NHTSA uses to determine the vehicle rollover NCAP star ratings. Less than a 10 percent chance of rollover is a 5-star rating, 10 to 20 percent is a 4-star rating, 20 to 30 percent is a 3-star rating, 30 to 40 percent is a 2-star rating, and more than 40 percent is a 1-star rating.

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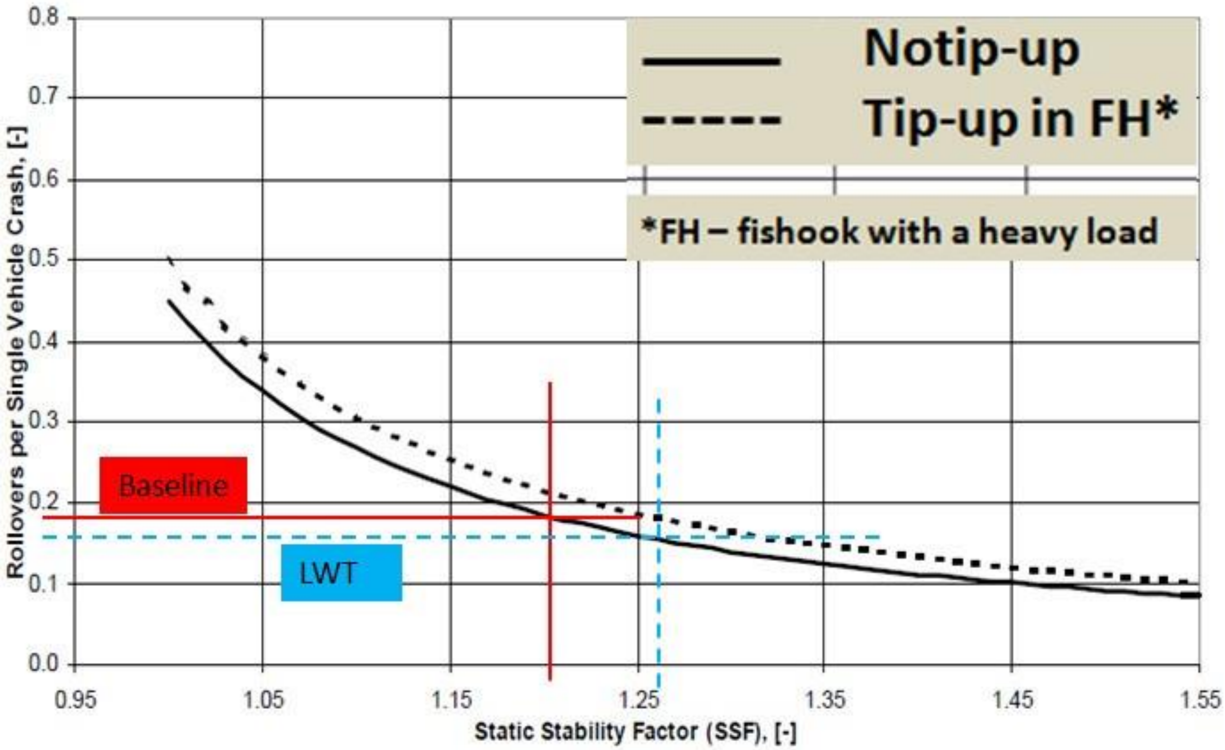
[165] NHTSA, 49CFR Part 575, Docket No. NHTSA-2001-9663; Notice 3



	SSF	Risk of Rollover	NCAP Star Rating
Baseline Vehicle	1.20	17.4%	4
LWT	1.26	16.0%	4

Figure 382: Static Stability Factor and Risk of Rollover

9.4.2.2 Test Procedure

The fishhook maneuver analysis was run in MSC/ADAMS with the driver, three rear passengers and instrumentation. The LWT test weight used was 2,380 kg. The procedure involves vehicle acceleration from zero to a certain test speed. Entrance speeds are 56.3, 64.3, 72.4, 76.4, and 80.5 kph. The throttle is then released and the vehicle steers to a determined hand wheel angle value (i.e., A in Figure 383) and counters to the same hand wheel angle value (i.e., –A in Figure 383) as shown in Figure 383. The hand wheel angle amplitude is determined by running the slowly increasing steer maneuver.

The slowly increasing steer maneuver requires the vehicle to be driven at a constant speed of 80.5 kph. Steering input is applied at a rate of 13.5 degrees per second from 0 to 270 degrees. The amplitude of the resulting steering angle that produces 0.3G is multiplied by 6.5 to determine the steering angle used for the test.

The test is run sequentially starting at an entrance speed of 56.3 kph making a left to right turn. If no two-wheel lift-off is observed, the maneuver is conducted at 64.3 kph, 72.4 kph, 76.4 kph, 80.5 kph. The test is stopped if there is two-wheel lift-off at speeds prior to 72.4 kph. If no wheel lift-off is observed during the aforementioned vehicle speeds, the same maneuver and speeds are conducted right to left. If lift-off is observed in the right to left sequence, the test is ended. The test also ends if there is rim to pavement contact or tire de-beading. The latter cannot be observed in ADAMS. Subsequent runs are made if there is lift-off left to right or right to left at speeds greater than 76.4 kph. Reference can be found at NHTSA's document 49CFR Part 575, Docket No. NHTSA-2001-9663; Notice 3. However, the runs require changing tires and re-running the event. Tire wear was not considered in this ADAMS model. Therefore analysis was made for the single series right-to-left and left-to-right turn.

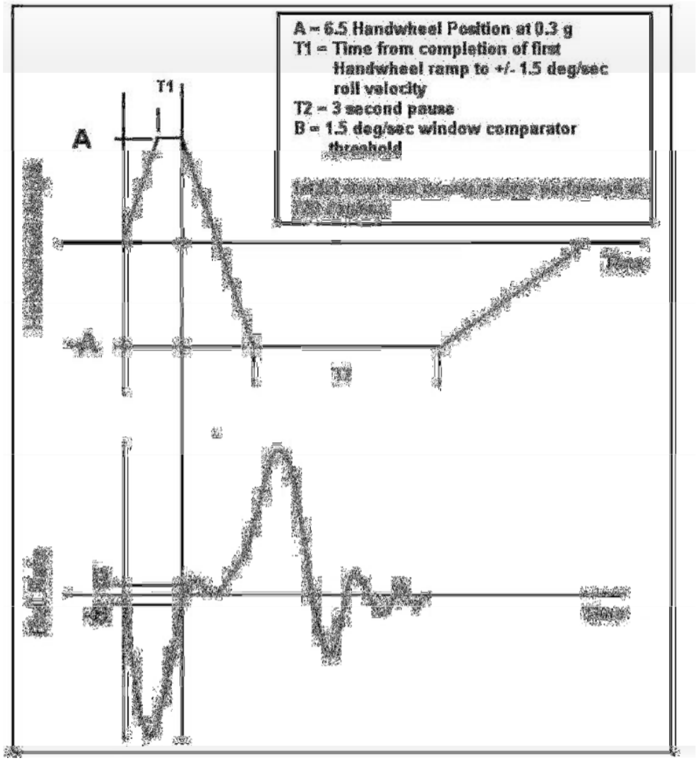


Figure 383: Steering Wheel Angle Fishhook Test

9.4.2.3 Performance Target

The chosen LWT target was to meet the 2014 Silverado 1500 Target, *i.e.*, Four-star 17.4 percent rollover risk with no wheel lift-off.

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[166] Department of Transportation NHTSA, 49CFR Part 575, Docket No. NHTSA-2001-9663; Notice 3

9.4.2.4 Performance Results

No vehicle tip-up was found during the simulated fishhook test. Given that the LWT has an SSF of 1.25, this is equivalent to a 4-star rating for rollover, the same as the baseline 2014 Silverado 1500. The risk of rollover is reduced from 17.4 percent for the baseline vehicle to 16 percent for the LWT.

9.4.3 Double Lane Change Maneuver

9.4.3.1 Test Summary

The double lane change maneuver[167] is an industry standard subjective test, ISO 38881-1. The vehicle is driven in a straight line in a driving lane, shifted into the adjacent lane and shifted back to the original driving lane. This helps to measure the stability of the vehicle to stay in the desired lane.

The ADAMS model setup is shown in Figure 384.

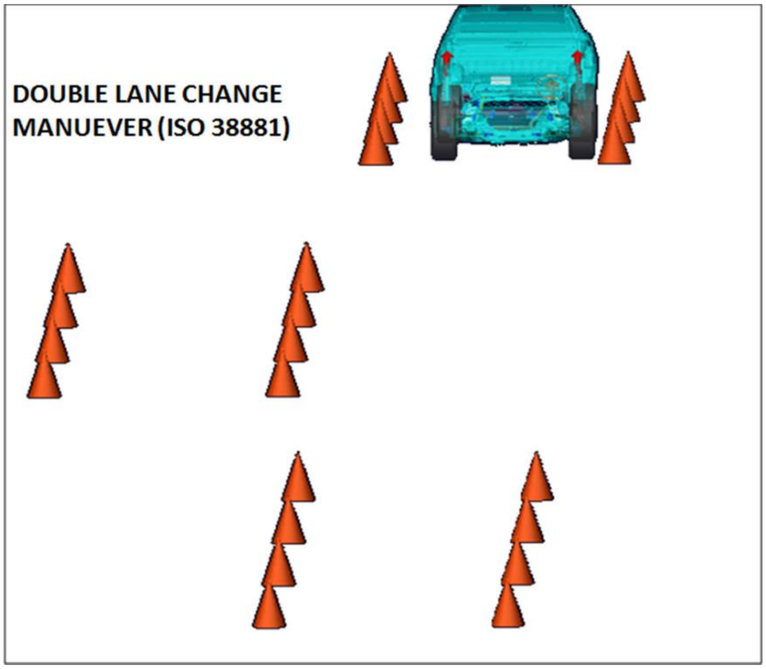

Figure 384: ADAMS Model Setup for Double Lane Change Maneuver

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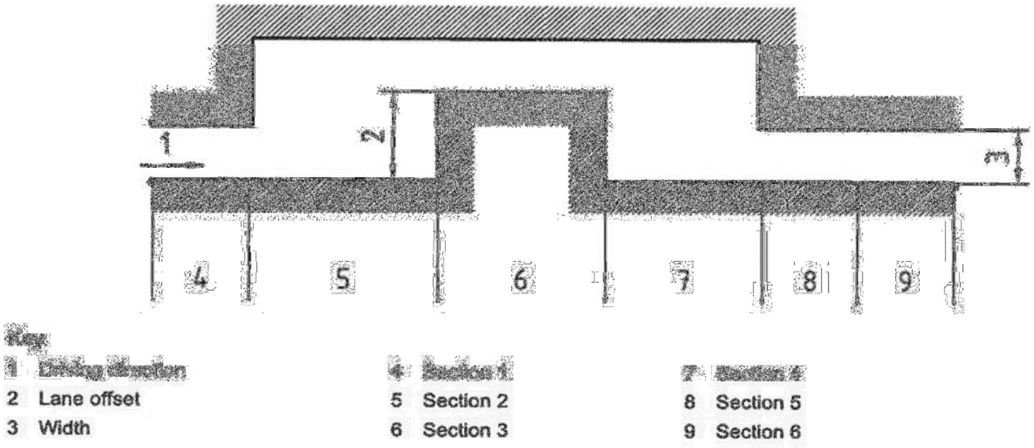
[167] Double Lane Change Maneuver, ISO 3888-1

9.4.3.2 Test Procedure

The double lane change maneuver was run in MSC/ADAMS with a driver and instrumentation. Test weight was 2,141 kg. Course parameters can be seen in Figure 385. The test was run at 80 +/- 3kph, and the throttle was varied to maintain test speed.



Section	Length (m)	Lane Offset (m)	Width (m)
1	15	-	1.1* vehicle width + 0.25
2	30	-	-
3	25	3.5	1.2* vehicle width + 0.25
4	25	-	-
5	15	-	1.3* vehicle width + 0.25
6	15	-	1.3* vehicle width + 0.25

Figure 385: ISO Lane Change Road Dimensions

9.4.3.3 Performance Target

The vehicle must be able to manipulate the track without exceeding the lane boundaries.

9.4.3.4 Performance Results

The LWT navigates the course without exceeding lane boundaries, which means that the chosen suspension geometry and other vehicle parameters such as mass distribution are within acceptable range for safe high-speed maneuvers.

9.5 Durability Loads

The ADAMS model of the LWT was used to predict loads at all of the chassis to frame structure-mounting points for the front and rear suspension. For each of the mounting points a time-based digital data file with force function is produced. This data is for input into the Design Life 6.0 fatigue life prediction program. Each OEM has its own testing schedules and durability requirements. The LWT frame was evaluated using frame mounting point loads extracted from the ADAMS model for the following load cases.

- Pothole Test 3G
- 0.7G Constant Radius Turn Test
- 0.8G Forward Braking Test

9.5.1 Pothole Test

9.5.1.1 Test Summary

The pothole test consists of driving a vehicle over a pothole at a speed of 48.2 kph. Suspension to frame bushing loads are recorded and used to evaluate vehicle fatigue performance.

9.5.1.2 Test Procedure

The pothole test was run in ADAMS with driver, three rear passengers, and instrumentation. The test weight was 2,380 kg. The vehicle was driven at 48.2 kph (30 mph) over a pothole that measured 0.1016 meters (4 inches) deep, as shown in Figure 386.

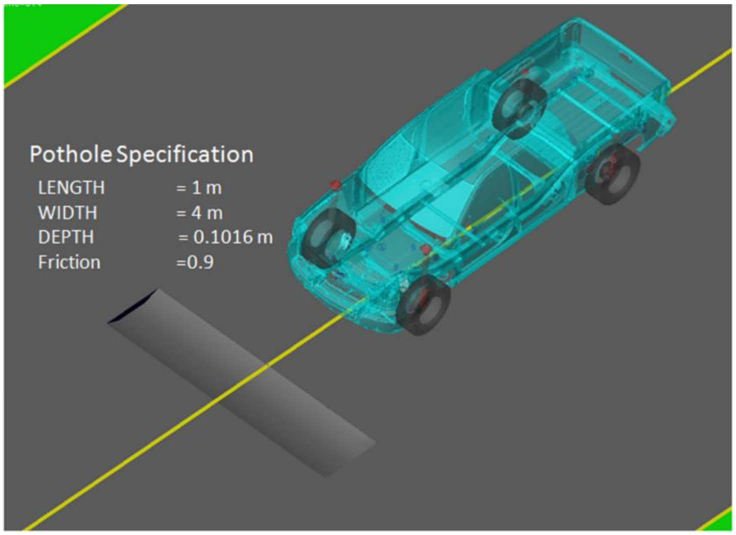


Figure 386: Pothole Test

9.5.2 0.7G Constant Radius Turn Test

9.5.2.1 Test Summary

The constant radius turn ADAMS pre-defined test maneuver was used. Suspension to frame bushing loads were recorded and used to evaluate vehicle fatigue performance.

9.5.2.2 Test Procedure

The test was run with a driver and instruments with vehicle test weight of 2,141 kg. The ADAMS constant radius maneuver was used with 0.7G lateral acceleration as final acceleration value on a 60.96 M (200 ft.) radius turn.

9.5.2.3 Performance Results

For the 0.7 G constant radius turn the reaction forces at mounting point to frame structure were predicted. The bushing load results as a function of time were converted to DAC files for input into the Design Life 6.0 fatigue life prediction program.

9.5.3 Forward Braking Test 0.8g Longitudinal Deceleration

9.5.3.1 Test Summary

The forward braking maneuver is driving a vehicle in a straight line and subsequently applying a 0.8G brake load. Suspension to frame bushing loads were recorded and used to evaluate vehicle fatigue performance.

9.5.3.2 Test Procedure

The 0.8G brake test was run with driver, three rear passengers, and instrumentation. The vehicle test weight was 2,380 kg. The ADAMS pre-defined braking straight-line event was applied. The initial velocity was 100 kph. The longitudinal applied deceleration was 0.8G.

9.5.3.3 Performance Results

For the 0.8 G brake loads, the reaction forces at mounting point to frame structure were predicted. The bushing load results as a function of time were converted to DAC files for input into the Design Life 6.0 fatigue life prediction program.

9.6 Durability Analysis

9.6.1 Introduction

Vehicle durability refers to the long-term performance of a vehicle under repetitive loading due to driving and other operating conditions. In normal operating conditions, tires and suspensions experience road loads and cascade throughout the vehicle body. The transfer and distribution of loads varies with the structural, inertia, and material attributes of the vehicle body and manifest as repetitive loads on the system and components. These repetitive loads cause fatigue damage, and the accumulation of damage ultimately results in the initiation of cracks, crack propagation, and system or part failure. A design for durability process is a method of managing the accumulation of fatigue damage to prevent cracks from initiating in advance of the complete design life of the vehicle.

There are two types of fatigue analyses in use for structural durability. The first is stress-based or S-N analysis, which is applicable for low stress and high cycle fatigue. In vehicle systems, this corresponds to loads from high speed rotating equipment such as the engine, transmissions, and auxiliaries. The second is strain-based or E-N analysis, which is applicable for high stress, low cycle fatigue as from road loads and other transient loads. The EDAG team evaluated the structural durability of the LWT through a strain-based analysis based on the following road load cases.

- Pot hole (same pot hole size as in Section 9.5.1 Pothole Test)
- 0.8G forward braking
- 0.7 G cornering

9.6.2 Process and tools used

By running the LWT – ADAMS model on different road profiles with proper suspensions and mounting bushing. The time dependent loads in x, y, and z directions at the following frame mounting locations were recorded in DAC files (see Section 5.5).

1. Front Upper Control Arm Mounting Points
2. Front Lower Control Arm Mounting Points
3. Front Shock Tower
4. Rear Shock
5. Rear Leaf Spring
6. Rear Spring Seat

The frame CAE model of the baseline vehicle showing the loading points is shown in Figure 387.

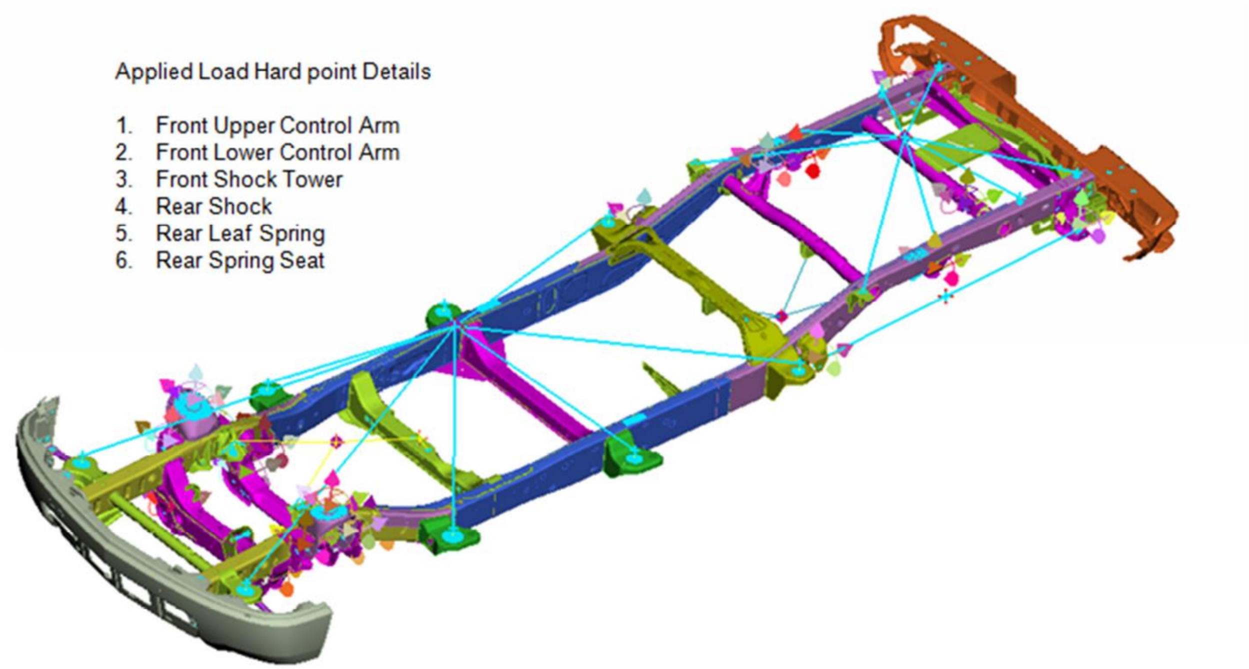


Figure 387: Frame Durability Model

The load histories from the ADAMS analysis are combined with stress output results from MSC/NASTRAN by the following two steps.

a) Extracting stress for unit Newton load at body mounting locations in NASTRAN with linear static solution (SOL 101) with inertia relief boundary condition.
b) For fatigue life calculation n-code Design Life program. Stresses from static solution are scaled with time-dependent loads and with the appropriate fatigue materials properties shown in Figure 388.

		Thickness		Gag	YS	YS	UTS	UTS	Tot EL	N-	Modulus	Fatigue	K
Item	**Steel**	**Min t**	**Max**	**Leng**	**Min**	**Typic**	**Min**	**Typic**	**Typic**	**Typic**	**Elasticity**	**Coeff**	**(MPa)**
1	Mild	0.35	4.60	A50	140	150	270	300	42-48	0.24	21.0 x	645	541
2	BH	0.45	3.40	A50	210	230	340	350	35-41	0.21	21.0 x	695	582
4	BH	0.45	2.80	A50	280	325	400	420	30-34	0.16	21.0 x	765	690
8	HSLA	0.50	5.00	A80	350	360	450	470	23-27	0.16	21.0 x	815	807
9	DP	0.50	2.50	A80	300	345	500	520	30-34	0.18	21.0 x	865	762
13	DP	0.60	5.00	A80	350	385	600	640	24-30	0.17	21.0 x	985	976
21	DP	0.60	4.00	A50	500	520	800	835	14-20	0.14	21.0 x	1180	1303
26	TWIP	0.80	2.00	A50	500	550	980	990	50-60	0.40	21.0 x	1335	1401
27	DP	0.60	2.30	A50	700	720	1000	1030	12-17	0.12	21.0 x	1375	1521
30	MS	0.50	3.20	A50	950	960	1200	1250	5-7	0.07	21.0 x	1595	1678
31	CP	0.80	2.30	A80	1000	1020	1200	1230	8-10	0.10	21.0 x	1575	1700
35	HF	0.60	4.50	A80	1050	1220	1500	1600	5-7	0.06	21.0 x	1945	2161

Figure 388: Material properties used for fatigue life calculations

9.6.3 Fatigue Analysis Results

Predicted life contour plots show areas where the fatigue cracks are likely to start. The number of cycles to failure is also predicted.

9.6.3.1 Pot Hole

For the pot hole load case, the predicted life of 413,476 cycles found at the engine cross-member to frame interface, is above the target value of 10,000 cycles as shown in Figure 389.

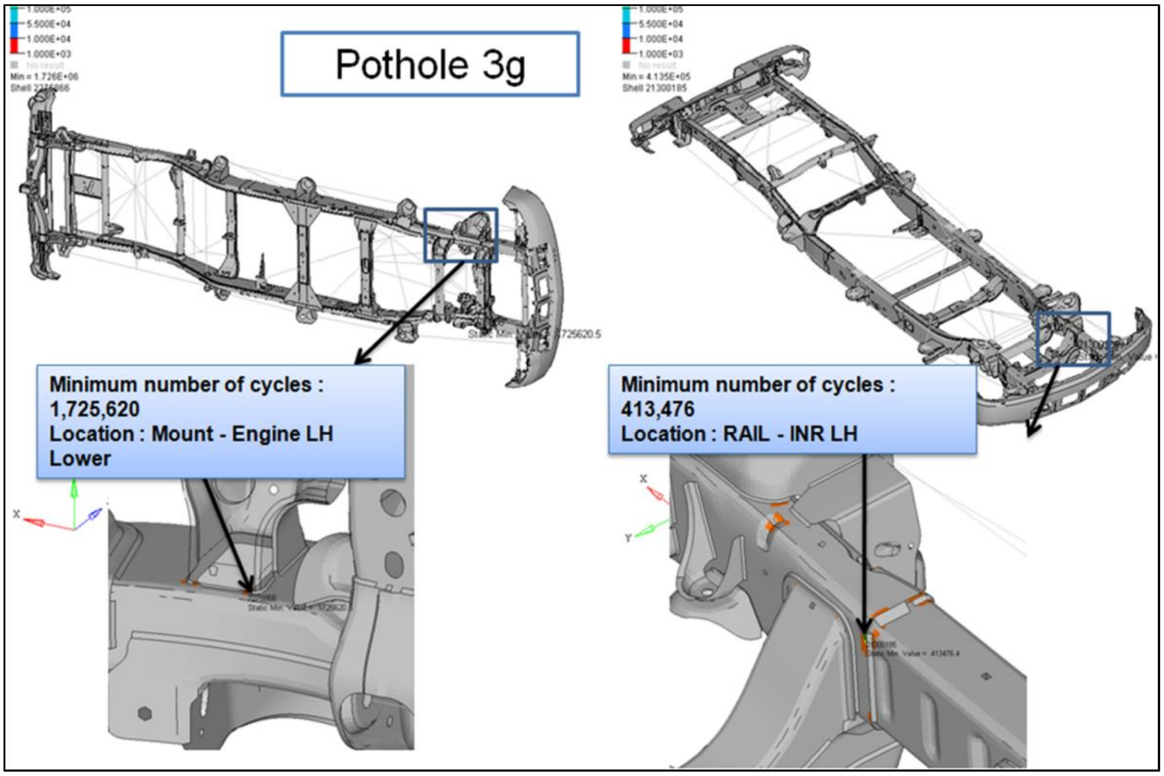


Figure 389: Pot hole contour plot

9.6.3.2 0.8G Forward Braking

For 0.8G forward braking is predicted to be significantly higher than the target value of 100,000 cycles as shown in Figure 391.

9.6.3.3 0.7 G Cornering

For 0.7G Cornering load, the results shown in Figure 390 and Figure 391 indicate significantly higher fatigue life than the target value of 100,000.

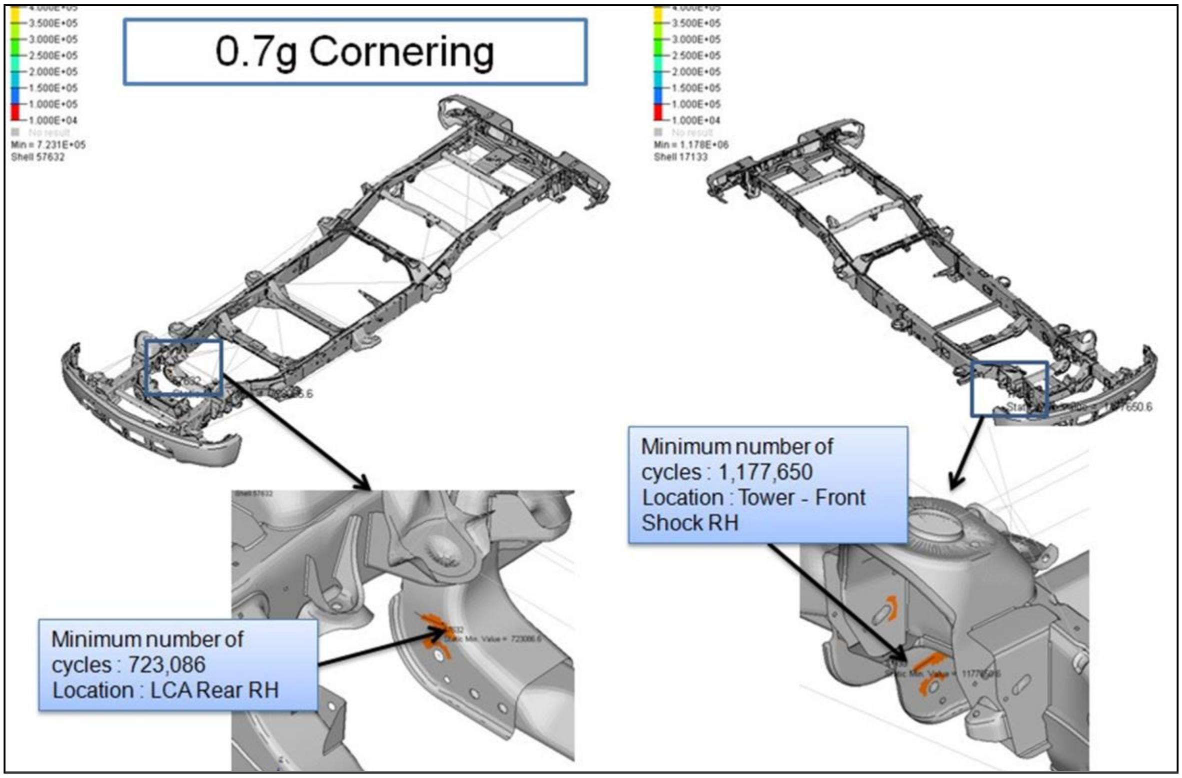


Figure 390: 0.7G Cornering contour plot

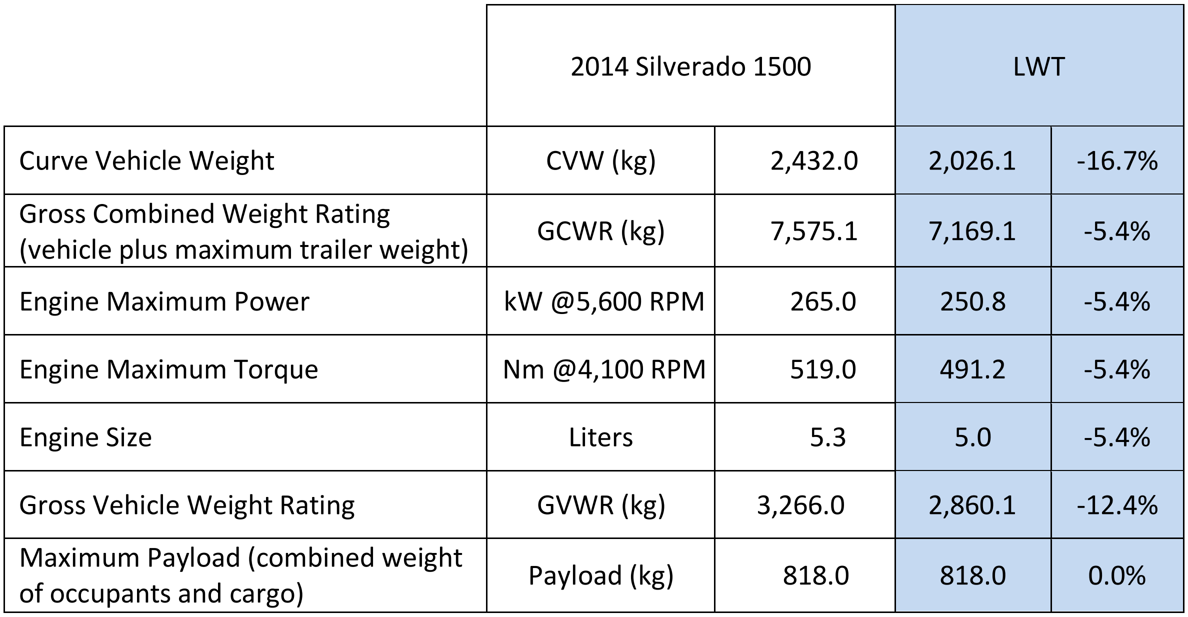
Load Case	**Number of Cycles (*n*)**		
	Baseline	**Light Weight**	**Target**
Pothole 3G	**1,725,620**	**413,476**	**10,000**
0.8g forward braking test	**> 100,000**	**> 100,000**	**100,000**
0.7g Constant radius turn test	**723,086**	**1,177,650**	**100,000**

Figure 391: Durability Test Simulation Results

The results presented in Figure 391 above indicate that, for all the durability load cases, the life of the LWV body structure exceeds the set targets and is comparable to the baseline frame.

9.7 Vehicle Performance and Engine Size

The baseline vehicle performance for acceleration, braking and maximum speed are shown in Figure 63. Such performance and vehicles' payload and towing capacity are directly related to the vehicle mass and maximum engine horsepower and torque. The baseline vehicle 2014 Silverado 1500 is equipped with EcoTec 5.3L V-8 engine with aluminum block and heads. The FlexFuel, direct injection engine with active fuel management is rated at 355 hp (265 kW) at 5,600 rpm and 383 lb-ft (519 Nm) torque at 4,100 rpm when operating with gasoline. To maintain baseline vehicle performance a lightweighted truck will require less horsepower and hence a smaller engine. The CVW of the proposed LWT is reduced by 16.7 percent compared with the baseline vehicle. To maintain same functionality (payload and maximum trailering capacity) the GCVW of the LWT is only reduced by 5.4 percent, resulting in engine power reduction from 265 kW to 251 kW. For same engine technology (EcoTec, direct injection, V-8) the size of the engine is reduced from 5.3L to 5.0L. The engine size calculation results are shown in Figure 392.



	2014 Silverado 1500		LWT	
Curve Vehicle Weight	CVW (kg)	2,432.0	2,026.1	-16.7%
Gross Combined Weight Rating (vehicle plus maximum trailer weight)	GCWR (kg)	7,575.1	7,169.1	-5.4%
Engine Maximum Power	kW @5,600 RPM	265.0	250.8	-5.4%
Engine Maximum Torque	Nm @4,100 RPM	519.0	491.2	-5.4%
Engine Size	Liters	5.3	5.0	-5.4%
Gross Vehicle Weight Rating	GVWR (kg)	3,266.0	2,860.1	-12.4%
Maximum Payload (combined weight of occupants and cargo)	Payload (kg)	818.0	818.0	0.0%

Figure 392: LWT Engine Size Calculations

The horsepower of the engine in combination with torque characteristics and chosen gear ratios determine the following five performance metrics of the vehicle.

1. 0-60 mph acceleration time
2. 0-30 mph acceleration time
3. Gradeability
4. Maximum speed
5. Quarter mile time and maximum speed at that time

These performance metrics are typically measured with limited payload (driver plus passenger or test equipment). With the chosen size of the engine for the LWT, being rated for maximum towing capabilities, the performance of all these metrics will be enhanced for the LWT compared with the baseline vehicle. For safety considerations, the maximum speed of the LWT will be limited to the same speed as the baseline vehicle by a governor-limiting device. The vehicle speed is monitored and compared to a maximum speed that the manufacturer has pre-defined. The engine speed is restricted if/when the pre-defined speed is attained. The governor-limited speed for the 2014 Silverado 1500 is 100 mph (Section 5.5.1).

9.8 Repairability

9.8.1 Repairability Steel Versus LWT Aluminum Version

With the increasing use of aluminum in the automotive industry, new techniques are required for the replacement and repair of aluminum body components. While the use of aluminum for vehicle hoods and deck lids adopted by the OEMs to save weight is becoming mainstream, the adoption of aluminum for body structure components presents different issues when it comes to repair and replacement of parts.

For the Chevrolet Silverado 1500 a lightweight version using aluminum for the cab, front-end structure, pickup box, and closures was developed while using a modified steel chassis frame with design changes that resulted in weight savings. As the baseline, the pickup truck has a steel frame repair or replacement of chassis components for the lightweight version that follows the same procedure. Any damage or misalignment is repaired using a typical push-pull straightening frame as shown Figure 393.

Figure 393: Typical Vehicle Repair Straightening Frame

A push-pull type of repair is when a distorted part, which is out of position due to collision damage, is either pulled or pushed to the correct position using a chain or a hydraulic ram mounted to the straightening frame. Figure 394 shows the straightening of a chassis front rail using a chain and hydraulic ram.

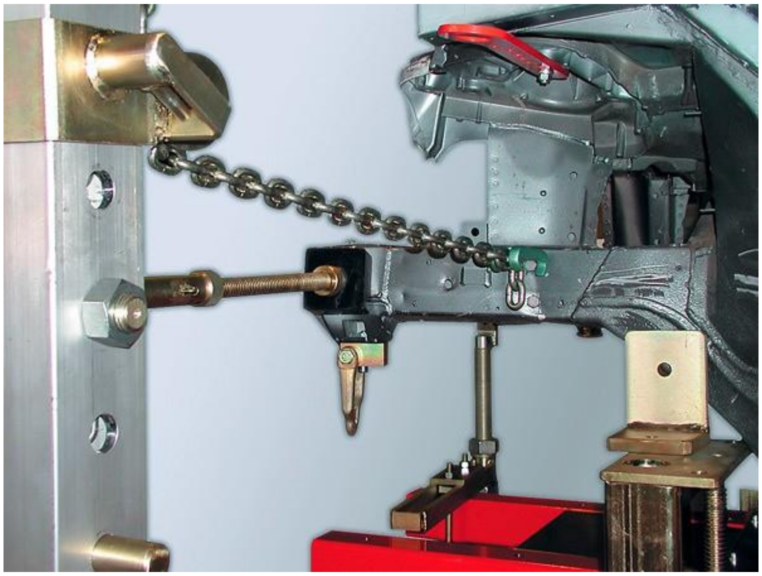


Figure 394: Straightening of a Chassis Front Rail

If a component on the chassis frame is damaged and needs an OEM replacement, a service part is used. First, the damaged part is removed using a plasma-cutting torch; the surface is then cleaned and ground flush and the service part MIG-welded in place. The frame is then locally repainted and an application of sealer material is applied. After repair, the frame is checked using a body dimensional checking rig as shown Figure 395.

Figure 395: Vehicle on a Typical Dimensional Checking Rig

9.8.2 Aluminum Structure Repair

With the advent of all aluminum automotive body structures a different repair and replace procedure has to be adopted compared with that used for an all steel structure. One of the most important features in a repair facility is a dedicated aluminum repair area to prevent cross-contamination (grinding dust) from a steel body repair area. This can be a screened area or a separate repair clean room as shown in Figure 396. An aluminum clean room is a quarantined area dedicated to aluminum work and is fully separated from all other types of work carried out on a steel vehicle. In this area repair technicians perform all welding, bonding, riveting, sanding, grinding, and structural procedures on aluminum structures and components.

Other vehicle metals such as steel contain elements that contaminate aluminum. Iron oxide partials are introduced in the air when technicians grind and sand steel components; this causes corrosion to aluminum parts that leads to adhesion and paint failures. In addition, a combination of contaminants, such as iron oxide with aluminum dust, can cause thermite reactions. A wet-mix air filtration system is required to eliminate these concerns.

Figure 396: Dedicated Screened Aluminum Clean Room Repair Area

Apart from a dedicated repair area additional equipment required by a repair facility to undertake aluminum vehicle repairs include

- A dedicated 200v aluminum MIG welding system equipped with pulse MIG technology;
- A dedicated aluminum dent extraction system with aluminum stud welder, heat gun, pyrometer, aluminum hammers, and dent full frame;
- A dedicated aluminum wet-mix air filtration system that can be a portable or a central installation;

- Dedicated self-piercing rivet and flow drill screw guns;
- Hand tool kits that contains all needed tools dedicated to aluminum repair;
- Aluminum-specific adhesive application guns; and
- Technician forced air safety systems required to prevent aluminum dust inhalation when sanding/grinding aluminum.

Many OEMs require repair facility certification and dictate the equipment used to be as close as possible to that used for the vehicle manufacture; this can be from the type of SPRs used to the manufacture of the MIG welding equipment. With this plus the specific equipment required for aluminum repair the cost to the repair facility can be from $50,000 to $70,000, independent of the normal equipment that is required, such as a paint shop.

9.8.3 Dent Repair

For a relative simple repair, dents on a front fender or pickup box side or closures outer panels a similar process to that used for steel panels can be used with some minor modifications to the process.

Unlike steel that has a memory when bent or deformed and has a tendency to return back to its original stamped shape during the repair process, aluminum does not have this memory feature and tends to remain deformed when damaged. In both cases localised heat can be applied during the repair process with aluminum the temperature of the applied heat is more critical. In the case of an aluminum panel an aluminum dent pull stud is welded to the panel and using heat and a dent puller frame the dent is removed.

Aluminum panel dents may also be removed by shrinking the metal with heat; the temperature applied is critical and must not exceed 425°F (218°C). If this temperature is exceeded the aluminum is annealed and loses strength. Any dent close to aluminum structural adhesive, which typically softens at 400°F (204°C), should be avoided and only a welded aluminum pull stud is used. This does not degrade the strength of the adhesive as there is only has a localized heat spot. The use of thermal paint or crayon, which melts and runs when the threshold temperature is reached, is also used to determine the correct temperature. The panel after dent and stud removal is sanded and painted, following OEM procedure, to complete the repair. Figure 397 shows a typical dent pull frame set-up.

Figure 397: Typical Dent Puller Frame

As an alternative to a welded dent stud, a paint-less dent removal process can be used when the dent is of a palm print type where there is no creased edge. A pull block is adhesively bonded to the panel and the dent is then removed using a pulling frame or a slide hammer. After removal of the adhesive block only a light polish to the paint surface is needed to complete the repair.

9.8.4 Body Structure Replace and Repair

The LWT design has an aluminum structure for the cab, front end, and pickup box plus all closures and the front fenders. This offers different challengers for the repair and replacement of parts than the baseline steel Silverado. The increased complexity of repair results from the aluminum material, the increased use of structural adhesive on all joint flanges, and the type of mechanical fasteners used, whether self-piercing rivets and flow drill screws, for the vehicle structure.

To simplify the repair process OEMs have adopted modular processes were the service parts are available in assemblies that speed the repair process and can guarantee the integrity of the parts in the assembly. See Figure 398.

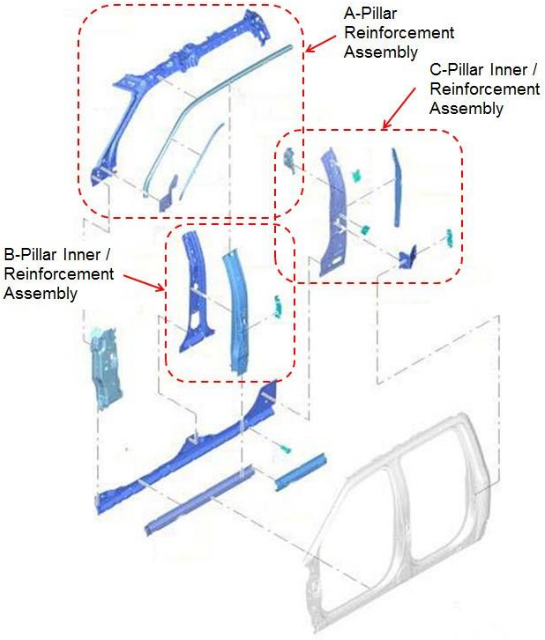


Figure 398: Typical Body Structure Service Parts Showing Body Side Reinforcement Assemblies

The most common joining methods used for an aluminum body structure is the use of mechanical fasteners self-piercing rivets followed by flow drill screws and in some cases clinching. When components need to be replaced, the OEM replacement and repair guidelines need to be followed without affecting vehicle strength and stiffness requirements and the vehicle OEM warranty.

For example, to replace a vehicle B-Pillar assembled using SPRs, a set process needs to be followed.

1. Review damaged part
2. Determined if additional surrounded parts are affected
3. Assemble all required parts and equipment
4. Remove all interior trim surrounding damaged pillar, door, and door hardware
5. Remove SPRs using handheld rivet gun
6. Locally apply heat up to 400°F (204°C) using a heat gun to soften the structural adhesive
7. Remove damaged part
8. Clean and prepare flange areas to ensure that they are free of adhesives
9. Reapply structural adhesives
10. Reassemble part using SPRs
11. Clean and prepare for paint
12. Check and confirm that part is in correct position using a dimensional checking rig
13. Paint
14. Reassemble interior trim and door hardware
15. Re-hang and align doors

9.8.4.1 Removal of self-piercing rivets and part replacement

The removal on SPRs is a relatively simple process using a handheld rivet gun fitted with a rivet removal punch, shown in Figure 399.

Figure 400 shows an SPR before and after removal.

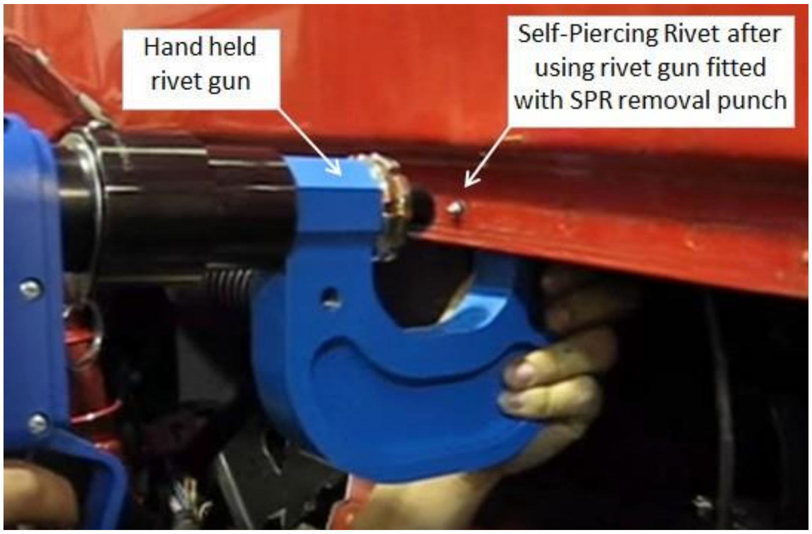


Figure 399: SPR Removal Using a Handheld Rivet Gun

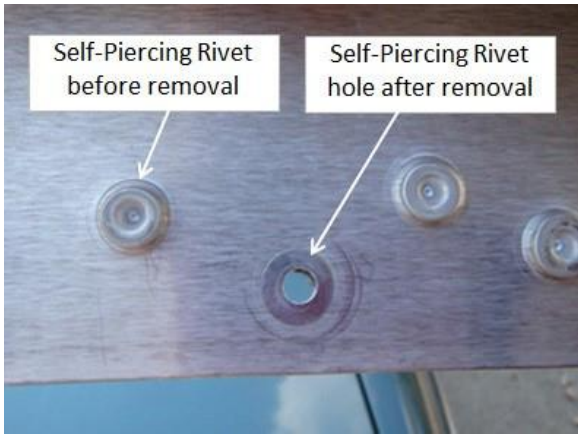


Figure 400: SPR Before and After Removal

After removal of SPRs and the damaged part, a new part is attached to the body structure using a handheld SPR rivet gun (Figure 401). As the replacement part from the OEM has no pre-drilled rivet holes, alignment holes using the drilled-out rivet holes is problematic. The new SPR is positioned in close proximity, within 10- to 15mm, to the stamped-out rivet.

Figure 401: Re-application of SPR's Using Hand Held Rivet Gun

9.8.4.2 Flow Drill Screws and Part Replacement

For parts that are assembled using flow drill screws, the repair follows a different process. The existing flow drill screws are removed. The damaged panel is then removed after locally heating of the part flange to soften the adhesive. The mating surface is cleaned of existing adhesive. A flow drill screw repair kit serves as a means of adding holes on new parts to match the position of the existing flow drill screws. Using the hole finder kit it is possible to transfer the flow drill screw hole positions to new aluminum part in the event of repair. Hole finder pins, Figure 402, are screwed into the existing flow drill screw holes. The new aluminum panel is fitted to the vehicle and secured with clamps in its correct position. Using a C-clamp or a soft mallet, the center of the holes from the existing panel are transferred to the replacement part. The replacement part now has the position of the holes and is removed. Holes are drilled at these locations to match the size of the screws. After removal of the hole finder pins and the application of structural adhesive the new part is attached to the body structure with new flow drill screws.

Figure 402: Hole Finder Pins

9.8.4.3 Body panel section replacement

When a section of the vehicle structure needs replacement, such as a damaged B-pillar, it may be necessary to also replace a portion of the cab side panel. This is achieved by cutting and removing of a section of the outer panel. Each OEM has predefined the position of all panel cut lines.

Figure 403 shows the possible cut tines for the B-pillar.

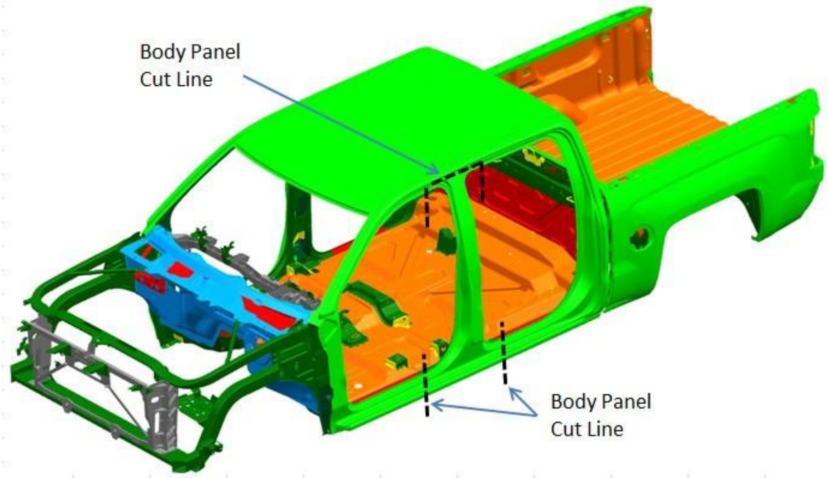


Figure 403: Example of Body Cut Lines (B-Pillar)

For the B-pillar, the deformed rocker reinforcement may be pulled to is original position using a push-pull frame. If this is not feasible due to excessive damage, a section of the reinforcement is removed and a replacement part, together with adhesive, is MIG-welded in position. The outer panel section is cut using a power saw and removed. The B-pillar section is replaced with the application of adhesive and self-piercing rivets. The joint between the new and existing panels is MIG-welded and finished to give a smooth transition between the two parts. The new B-pillar is painted to complete the repair. This process is followed for all other damaged areas that require the replacement of a section of the cab outer panel.

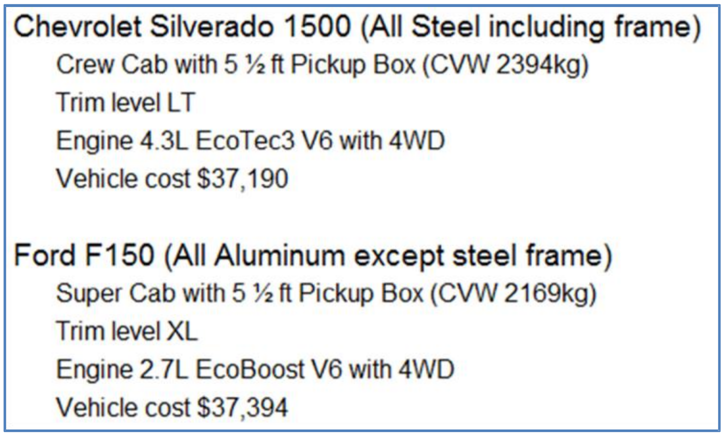
9.8.5 Repair time and cost

All repair tests up to this point, except the claims made by the OEMs themselves, seem to point to a higher cost to repair aluminum body vehicles. However, these tests are small sample sizes conducted during the first trial phases. Unfortunately, it is impossible to know if they are representative of the repair industry over the long term. It is reasonable to expect that until these repair facilities get to an expert level of capability for repairs on aluminum vehicles, the costs will be higher. Furthermore, many of these shops may be charging a premium at this point to recover the costs of the new tools, machinery, and training time required to repair these vehicles. Over the long term, these costs could settle into a rate that may be similar to steel. If the repair process is as easy as specified by Ford for the F150, the higher costs of materials will be averaged out with the shorter labor time required to make the repairs due to the adoption of supplying parts in a modular form. These costs just will not be truly known until there thousands of samples and not the number conducted during the repair trial phase.

The initial higher repair costs could result in higher insurance costs for aluminum vehicles. Currently each insurance company has different levels of coverage and uses different formulas to determine the insurance score that will determine the insurance premium. A smaller percentage in determining insurance premiums is the make and model of the car. This is related to the vehicle's safety rating and actual cash value of the car. A lesser impact to insurance premiums is the cost of repair. For this study four insurance online quotes were obtained. The vehicles used for the quote were the Chevrolet 2016 Silverado 1500 and 2016 Ford F150. Each vehicle had similar specifications. The criteria for each vehicle are shown below.

- Same cab style and pickup box size
- Similar trim level
- Similar engine output
- Vehicle MSRP cost to be as close as possible

Figure 404 shows the vehicle models selected for insurance quote.



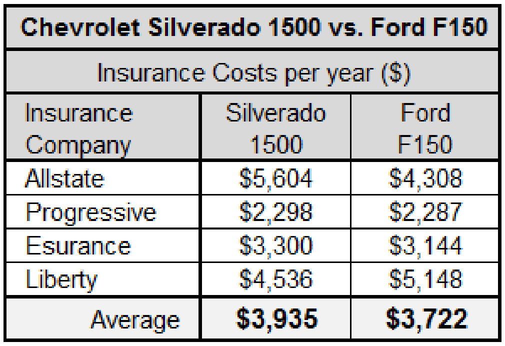
Chevrolet Silverado 1500 (All Steel including frame)
Crew Cab with 5 ½ ft Pickup Box (CVW 2394kg)
Trim level LT
Engine 4.3L EcoTec3 V6 with 4WD
Vehicle cost $37,190

Ford F150 (All Aluminum except steel frame)
Super Cab with 5 ½ ft Pickup Box (CVW 2169kg)
Trim level XL
Engine 2.7L EcoBoost V6 with 4WD
Vehicle cost $37,394

Figure 404: Silverado 1500 and Ford F150 used for insurance quote

Input to each insurance company was identical. Insurance companies used for on-line quote were:

- Allstate,
- Progressive,
- Esurance, and
- Liberty.



Chevrolet Silverado 1500 vs. Ford F150

Insurance Costs per year ($)

Insurance Company	Silverado 1500	Ford F150
Allstate	$5,604	$4,308
Progressive	$2,298	$2,287
Esurance	$3,300	$3,144
Liberty	$4,536	$5,148
Average	**$3,935**	**$3,722**

Figure 405: Results From On-Line Insurance Quotation

From the on-line insurance quotations, see Figure 405. There is no significant impact between the steel Chevrolet Silverado 1500 and the aluminum Ford F150. However, there may or may not be an increase for an aluminum vehicle when additional collision repair data is available.

10 Increment Cost Analysis on Full-Sized Pickup

10.1 Background

Incremental costs for a light weighted design of the 2014 Chevrolet Silverado 1500 referred to in this report as an LWT are calculated to make sure that the retail price of the LWT is within +10 percent of the original vehicle. All the estimated costs shown in this report represent costs of the baseline vehicle and LWT as of 2014. The study uses average material and labor costs for 2010 to 2014 scaled to 2014 economics. Accurately forecasting variables such as future material prices and labor rates, etc., are very challenging and, at times, can yield unpredictable results.

EDAG used two cost assessment methods to establish the baseline vehicle and LWT costs due to the different design levels of the LWT components, their corresponding manufacturing technologies, and component source (OEMs or suppliers). The two methods are:

- Technical Cost Modeling[168] - The team applied a TCM approach to the entire body structure, frame, closures, bumpers, fenders, front suspension, rear suspension, wheels, and their corresponding assembly process. Based on their initial assessment, the researchers identified that these vehicle systems had higher potentials for weight savings. These vehicle systems were then re-designed by EDAG to reduce weight and confirmed they meet the same performance and safety requirements through CAE analysis. The detailed design data provided all the inputs necessary to perform a technical cost assessment. The technical cost modeling methodology is explained in detail in Section 10.2

- Supplier Assessments – The team obtained the anticipated mass reduction technologies and the corresponding estimated cost to the OEM for 2020 from the leading suppliers of each respective system or component or select systems such as the seats, instrument panel, brakes, etc. This cost assessment method was used only for the sub- systems that were estimated for mass reduction based on future projections and conceptual technologies; the information required for conducting a technical cost assessment on these sub-systems were not readily available compared to the other sub- systems. However, all the assessments were validated using component cost information from Intellicosting[169] and through available internal expertise at EDAG (using previous benchmarking and sourcing data).

These two cost assessment methods allowed the team to calculate the OEM manufacturing cost including the purchased costs of all the supplier parts for the baseline 2014 Silverado 1500 and the LWT. The indirect costs were addressed by applying the retail price equivalent

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[168] Frank Field, Randolph Kirchain, & Richard Roth, Process cost modeling: Strategic engineering and economic evaluation of materials technologies, *JOM Journal of the Minerals, Metals and Materials Society, Volume 59,* Number 10, 21-32

[169] "Intellicosting provides clients with manufacturing experts combining detailed component teardown analysis with activity-based cost estimating, low cost country knowledge and purchasing/negotiation expertise." www.intellicosting.com Accessed February 9, 2012

multiplier to determine the retail price of the vehicle. The specific RPE multiplier varies from one automobile manufacturer to the next; however in 2000 researchers at the Argonne National Laboratory (Vyas, Santini, & Cuenca, 2000) calculated an average RPE multiplier across multiple OEMs of two (2.0).[170] RTI International used the same methodology to calculate the RPE multiplier for individual manufacturers and its specific RPE multiplier for GM in 2007 was 1.45.[171] NHTSA examined manufacturer financial statements from 1989 to 1997 and found an average RPE of 1.51.[172]

Even though the primary focus of the LWT design was mass savings, some of the adopted technologies and components also resulted in a projected cost savings. For example, adopting extrusion manufacturing methods for certain cab components results in a projected cost decrease compared to the equivalent stamped baseline designs. Some of the design changes adopted for the LWT that result in lower costs are specific to Silverado-based LWT and may not be applicable in another vehicle that does not share the same design features. Additionally, the LWT designs of certain systems reduced the overall number of components. For example, the optimized LWT frame design used AHSS lead elimination of some stamped parts. Such cost savings due to increased technology efficiencies and part consolidation could be applied to a 2025 baseline vehicle as well even if mass reduction is not the primary goal.

10.2 Approach

The costs of majority of the major components of the Silverado were estimated by EDAG using the TCM approach developed by the Massachusetts Institute of Technology's Materials Systems Laboratory's researchers.[173] In this method each of the elements that contribute to the total cost is individually estimated. For example, for a stamped sheet metal part, the cost model estimates the costs for each of the operations involved in the manufacturing process, starting from blanking the steel coil through the final stamping operation to produce the part. The final estimated total manufacturing cost and assembly cost are a sum total of all the respective cost elements including the costs for material, tooling, equipment, direct labor, energy, building, and maintenance. See Figure 406 showing cost model assumptions and inputs.

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[170] Vyas, A., D. Santini, & R. Cuenca. April 2000. "Comparison of Indirect Cost Multipliers for Manufacturing." Center for Transportation Research, Energy Systems Division, Argonne National Laboratory.

[171] Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers. EPA report EPA-420-R-09- 003, February 2009

[172] Advanced Air Bag Systems Cost, Weight, and Lead Time Analysis Summary Report, Contract NO DTNH22-96-0-12003, Task Orders - 001, 003, and 005.

[173] Frank Field, Randolph Kirchain, & Richard Roth, Process cost modeling: Strategic engineering and economic evaluation of materials technologies, *JOM Journal of the Minerals, Metals and Materials Society, Volume 59*, Number 10, 21-32

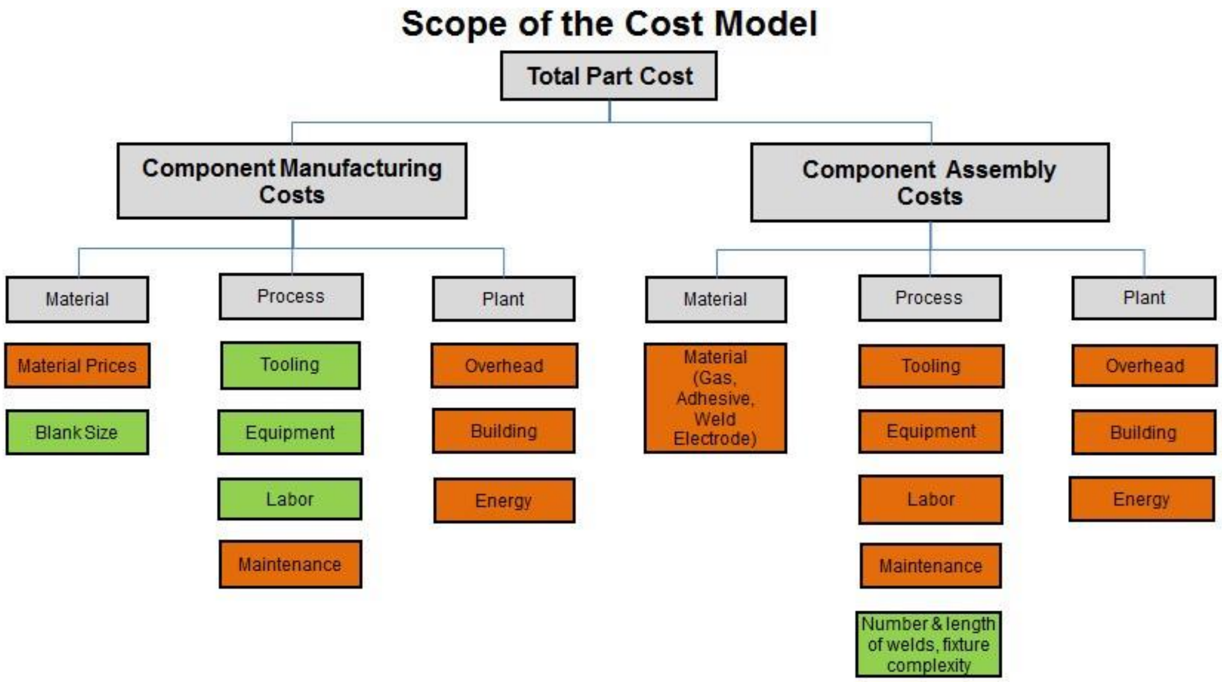

Figure 406: Cost Model Assumptions and Inputs

Within the costs model there are a number of different inputs.

- Program Assumptions
- Cost Model Assumptions
- User Defined Inputs

See Figure 407 showing cost model assumptions and user defined inputs.

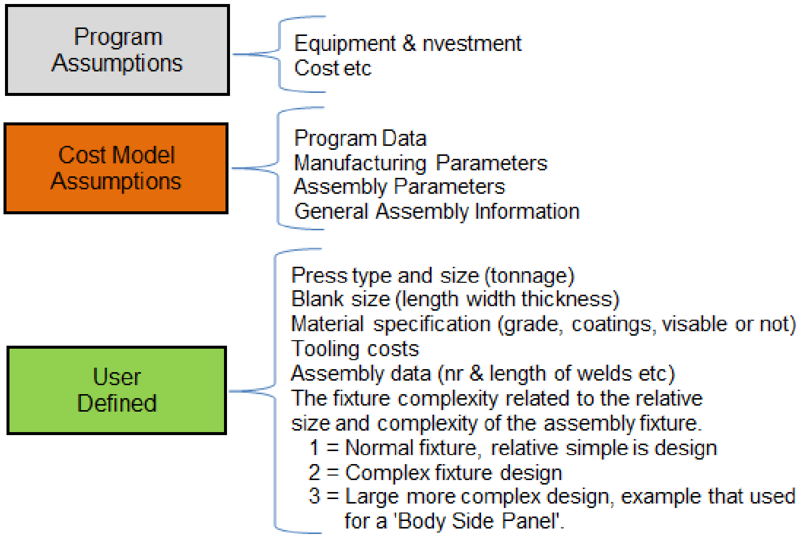

Figure 407: Cost Model Assumptions and User Defined Inputs

10.2.1 TCM Compared to Other Cost Models

Every vehicle system and component manufacturer has its own internal cost estimation procedures and tools to assess the cost impact of design changes. The cost estimation techniques range from simple rules-of-thumb or rough order magnitude cost estimations, to a more comprehensive cost estimation with a detailed cost breakdown of every cost driver.

The rough order magnitude cost estimation is usually used by a manufacturer for initial estimates and can be based upon extensive historical data. The historical costs are generally actual data from prior projects. The rule-of-thumb cost estimations often assume linear relationships between cost drivers and the final costs. However, this relationship may not hold if the design change includes a new technology. Further cost estimates are also sensitive to economic related costs such as raw material, labor etc. The impact of such volatile factors on the final cost cannot be easily analyzed using this technique because the input data for this technique relies on earlier projects data. Other cost estimating techniques involve allocating costs according to the activities involved in manufacturing and assembling a specific part, then estimating the cost per unit of output of the activity. This technique is called activity based costing, ABC.[174] These techniques have limited ability to conduct an in-depth cost analysis from design changes due to the lack of sufficient details of the incremental cost elements traceable to the design change. For purposes of this study to provide accurate and more detailed cost estimates, the team found both the “rough order magnitude” and ABC cost estimation approaches to lack the resolution and scope to conduct an in-depth analysis.

TCM is a comprehensive cost estimation technique accepted and used by multiple organizations in industry, government agencies and its national labs and academia. We attribute this acceptance to the methodology for TCM since in this model the cost of component or system is broken into costs associated to discrete manufacturing and assembly process steps and all the process assumptions are clearly defined upfront. TCM is specifically designed to assess the interaction between process input variables[175] and the final cost. The approach is based on applying basic engineering principles and clearly defined economic and accounting principles. For these reasons, the team believes TCM is an appropriate tool for studies focused on a comparative analysis between competing designs or technologies within a company where the remaining costs are assumed to be approximately identical, as is the case with this study. The focus of this study is to compare the cost impact of certain lightweight technologies to the baseline vehicle. TCM is a suitable tool for this study providing the incremental costs of the proposed LWT design along with the detailed costs elements.

10.2.2 TCM History and Usage

TCM was initially developed to support World Auto Steel’s Ultra-Light Steel Auto Body - Advanced Vehicle Concepts, ULSAB-AVC, a program intended “to demonstrate and communicate steel’s capability to help fulfill society’s demands for safe, affordable and

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[174] Stewart, Richard M. Wyskida, James D. Johannes: Cost Estimator’s Reference

[175] Inputs such as equipment type, cycle time, etc., specific to the process

environmentally responsible vehicles for the 21st Century."[176] Subsequently, EDAG expanded the cost model to support the Future Steel Vehicle Program that assessed body structure costs while also applying future manufacturing technologies.[177] EDAG's extensive and recognized modeling work yielded a portfolio of cost models for assessing body structures, closures, and other vehicle components or systems. For purposes of this study, the cost model was updated to align with the program and economic assumptions within the scope of this program.

10.2.3 Major Components of the Cost Model

For the LWT cost assessment, only the direct costs for manufacturing the parts and assembly of these parts were considered. The engineers assumed that paint shop costs are neutral. Similarly, they assumed the costs would be the same for the final trim assembly line. The major cost elements directly linked to manufacturing and assembly are summarized as follows.

- Fabrication costs of all the parts including tooling costs
- Assembly costs including tooling costs
- Material
- Direct labor
- Energy
- Equipment
- Building (facilities for manufacturing and assembly)
- Maintenance (for manufacturing and assembly)
- Overhead labor in manufacturing plant, (i.e., indirect labor directly connected to the manufacturing and assembly process)

The TCM estimated cost is sum total of all the cost elements directly linked to manufacturing and assembly mentioned above. All other costs not directly linked to manufacturing and assembly of the vehicle were excluded from the total manufacturing costs estimated using TCM as stated above. These excluded costs include the following.

- Logistics (pallets, shipping labor, etc.)
- Non-dedicated investment for plant not directly connected to the manufacturing or assembly process (IT, administration, etc.)
- Hourly and salaried labor not directly connected to the manufacturing process
- All planning and optimization activities of the manufacturing process
- Production overhead (warranty, R&D)
- Corporate overhead (retirement and health)
- Sales (distribution, marketing, dealer support)
- Profit

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[176] http://www.worldautosteel.org/Projects/ULSAB-AVC/Programme-Detail.aspx (last accessed February 9, 2012)

[177] http://www.worldautosteel.org/Projects/Future-Steel-Vehicle.aspx

10.3 Cost Model Assumptions

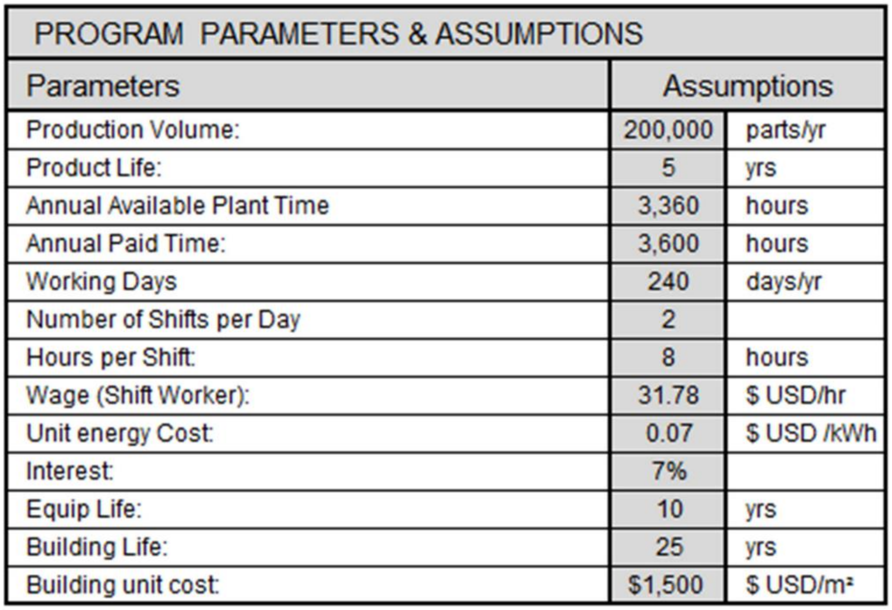
10.3.1 Cost Model General Assumptions

For this study, the cost model was created based on the assumption that the parts are manufactured in a ”Greenfield” facility, a new facility from the ground up, in the United States. A Greenfield site is a facility that has the metal stamping plant, body assembly line, paint facility and final assembly on one site. The growing trend is to also have an attached “supplier parts” adjacent to the vehicle assembly facility. See Figure 408 for a typical integrated vehicle assembly facility.

Figure 408: Integrated Vehicle Assembly Facility “Greenfield” Site

The cost assessment encompassed the raw material (steel, aluminum alloy, etc.) entering the plant to the complete vehicles leaving.

The life cycle for the Chevrolet Silverado is considered to be 5 years, with mid-life cycle face-lift changes. The mid-life cycle face-lift changes to the vehicle are typically changes such as interior upgrades that do not involve major design changes. For this cost assessment study, an annual production volume of 200,000 is used with a production life of 5 years in order to represent an average high sales volume vehicle. The other general cost model inputs, program parameters and assumptions that are typical of a high-volume manufacturing facility are summarized in Figure 409.

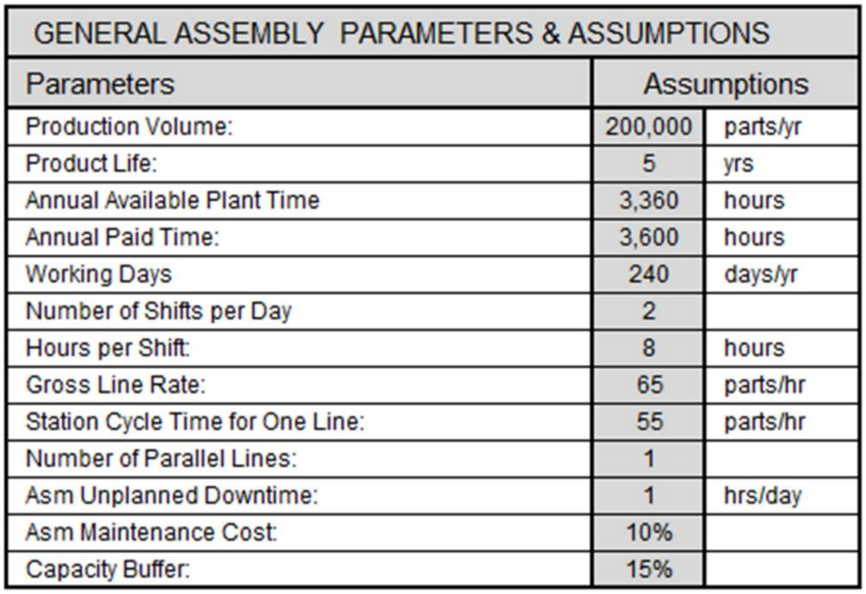


PROGRAM PARAMETERS & ASSUMPTIONS

Parameters	Assumptions	
Production Volume:	200,000	parts/yr
Product Life:	5	yrs
Annual Available Plant Time	3,360	hours
Annual Paid Time:	3,600	hours
Working Days	240	days/yr
Number of Shifts per Day	2	
Hours per Shift:	8	hours
Wage (Shift Worker):	31.78	$ USD/hr
Unit energy Cost:	0.07	$ USD /kWh
Interest:	7%	
Equip Life:	10	yrs
Building Life:	25	yrs
Building unit cost:	$1,500	$ USD/m²

Figure 409: Cost Model General Program Assumptions

Similar to the program parameters and assumptions general cost inputs for the assembly of individual parts that make up a major sub-system, this example is the front door assembly summarized in Figure 410.



GENERAL ASSEMBLY PARAMETERS & ASSUMPTIONS

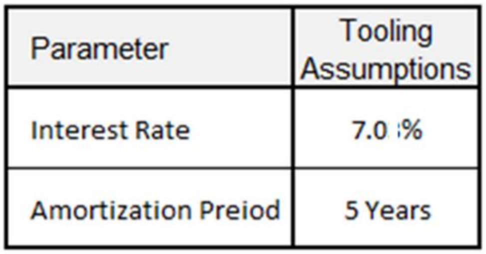
Parameters	Assumptions	
Production Volume:	200,000	parts/yr
Product Life:	5	yrs
Annual Available Plant Time	3,360	hours
Annual Paid Time:	3,600	hours
Working Days	240	days/yr
Number of Shifts per Day	2	
Hours per Shift:	8	hours
Gross Line Rate:	65	parts/hr
Station Cycle Time for One Line:	55	parts/hr
Number of Parallel Lines:	1	
Asm Unplanned Downtime:	1	hrs/day
Asm Maintenance Cost:	10%	
Capacity Buffer:	15%	

Figure 410: Cost Model General Assembly Assumptions

10.3.2 Cost Model Tooling, Equipment and Investment Assumptions

Tooling cost is defined as the cost to buy or build new tools, stamping dies, extrusion dies, holding fixtures, cutting tools, etc., to make a specific product. Moreover, the tooling costs are directly linked to the specific fabricated or assembled part as unique set of tools is required for every component or system. As mentioned earlier, the direct costs include the costs directly related to the total manufacturing costs of the vehicle; hence the team assumed that tooling costs are part of the direct costs.

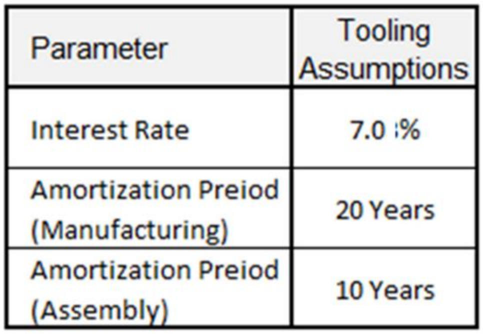
Further, since the tooling investment is unique for each part, the amortization period of the tooling investment is the 5-year life of the respective program. The tooling assumptions are summarized in Figure 411.



Parameter	Tooling Assumptions
Interest Rate	7.0 %
Amortization Preiod	5 Years

Figure 411: Tooling Investment Assumptions

For the equipment investments, it is important to point out that unlike tooling investments the equipment amortization period is the useful life of the particular equipment. For the majority of the equipment used in manufacturing (for example, sheet metal parts in the vehicle structure and closures) the team assumed the amortization period is 20 years. The useful life of most of the assembly equipment, (for example, welding and transfer robots, etc.) is the same as the program life according to the experience of assembly experts at EDAG and feedback from other suppliers. The equipment assumptions are summarized in Figure 412.



Parameter	Tooling Assumptions
Interest Rate	7.0 %
Amortization Preiod (Manufacturing)	20 Years
Amortization Preiod (Assembly)	10 Years

Figure 412: Equipment Investment Assumptions

10.4 Cost Modeling Process

10.4.1 Manufacturing Cost Modeling Process

As discussed above, the TCM uses an approach in which each of the elements that contribute to the manufacturing cost is estimated individually, the final manufacturing costs is a sum total of all the cost elements. The TCM methodology used for the manufacturing cost assessment mainly consists of the following steps.

1) Identify the component to be analyzed for costs and obtain the design data using teardown and reverse engineering for the baseline vehicle parts
2) Engineering review of the individual parts to determine the following.
   - Raw material
   - Appropriate manufacturing technology required
   - Key operations for manufacturing
   - Key applicable process inputs (equipment type, cycle time, material input, etc.)
3) Generate manufacturing process sheets containing the key information from the engineering review
4) Input the component specific parameters into the manufacturing cost model

The manufacturing cost assessment methodology is illustrated in Figure 413.

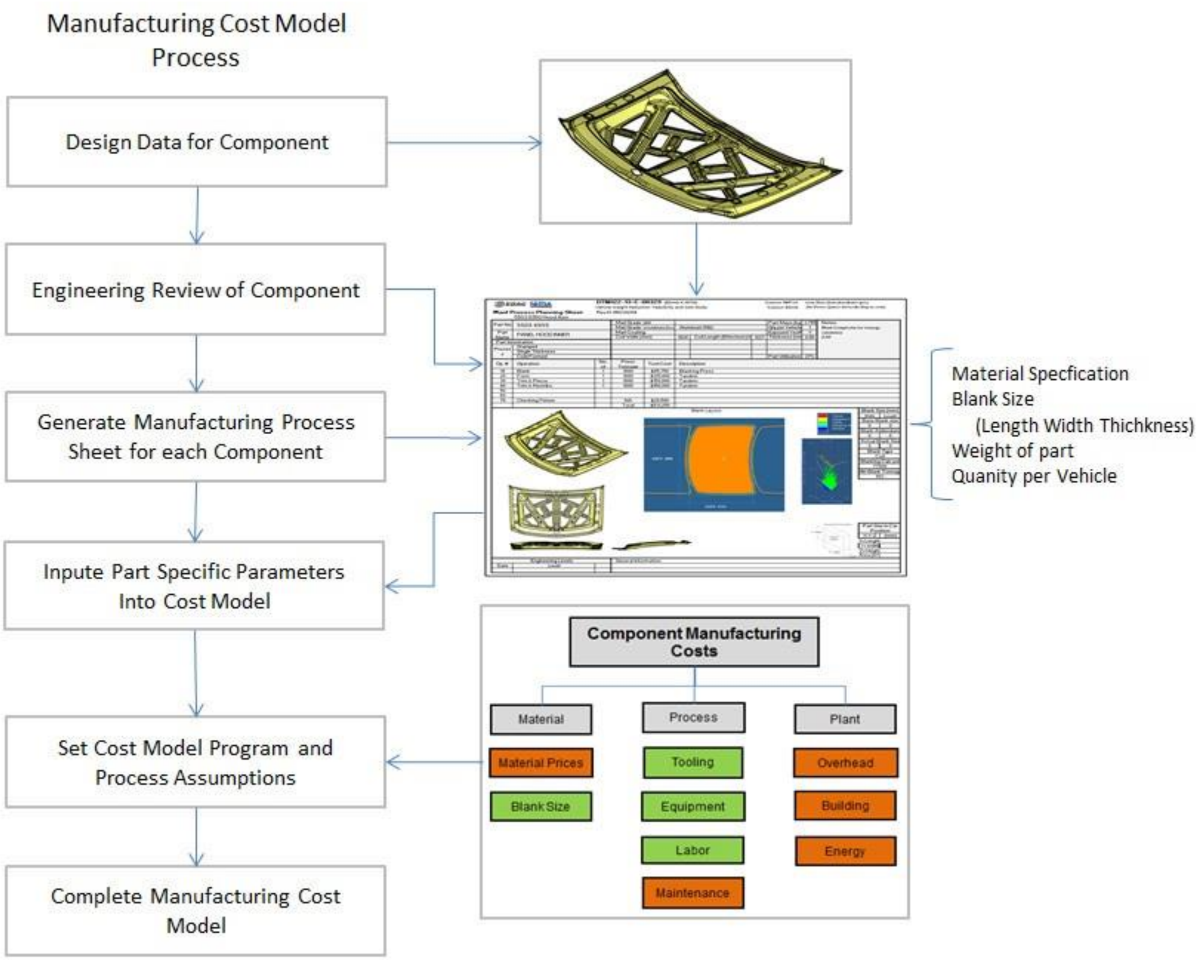
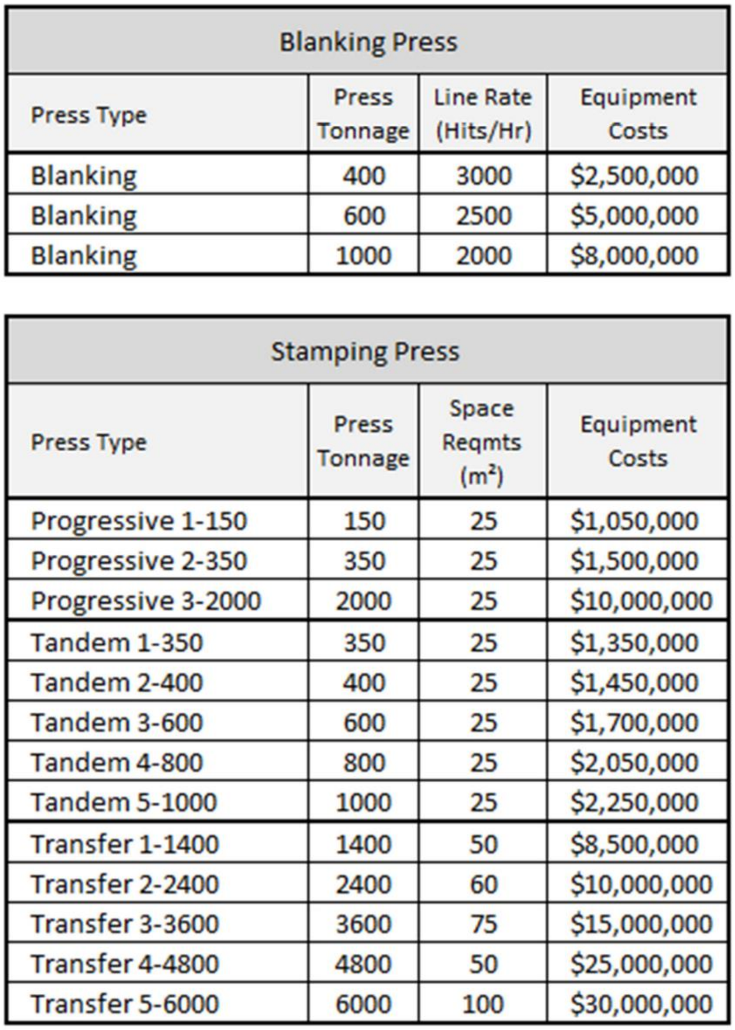


Figure 413: Fundamental Steps in Part Manufacturing Cost Assessment



Blanking Press			
Press Type	Press Tonnage	Line Rate (Hits/Hr)	Equipment Costs
Blanking	400	3000	$2,500,000
Blanking	600	2500	$5,000,000
Blanking	1000	2000	$8,000,000

Stamping Press			
Press Type	Press Tonnage	Space Reqmts (m^2)	Equipment Costs
Progressive 1-150	150	25	$1,050,000
Progressive 2-350	350	25	$1,500,000
Progressive 3-2000	2000	25	$10,000,000
Tandem 1-350	350	25	$1,350,000
Tandem 2-400	400	25	$1,450,000
Tandem 3-600	600	25	$1,700,000
Tandem 4-800	800	25	$2,050,000
Tandem 5-1000	1000	25	$2,250,000
Transfer 1-1400	1400	50	$8,500,000
Transfer 2-2400	2400	60	$10,000,000
Transfer 3-3600	3600	75	$15,000,000
Transfer 4-4800	4800	50	$25,000,000
Transfer 5-6000	6000	100	$30,000,000

Figure 414: Stamping Presses Selected for the Manufacturing Cost Assessment

10.4.2 Assembly Cost Modeling Process

The assembly costs of the vehicle structure and other sub-systems were estimated using a technical cost modeling approach similar to the manufacturing cost assessment methodology explained in Section 10.2. However, the key parameters for the assembly cost assessment were established based on a detailed engineering review of each individual assembly or sub-assembly.

The TCM methodology used for the assembly cost assessment mainly consists of the following steps.

1) Identify the sub-assemblies/assemblies to be analyzed for the costs and obtain the design data from the vehicle teardown analysis results and CAD data.

2) Engineering review of the sub-assemblies/assemblies to determine the following.
    - Sub-assembly/assembly structure
    - Joining process

- Assembly process parameters, for example:
    - Length of weld (laser welding, laser brazing)
    - Number of welds (resistance spot-welding)
    - Length of adhesives (adhesive bonding)
    - Length of hem flange (hemming)

3) Generate assembly sequence block diagrams sheets for each individual sub-assembly/assembly capturing all the key information from the engineering review

4) Input the sub-assembly/assembly specific parameters into the assembly cost model. The assembly cost assessment methodology is illustrated in **Figure 415**.

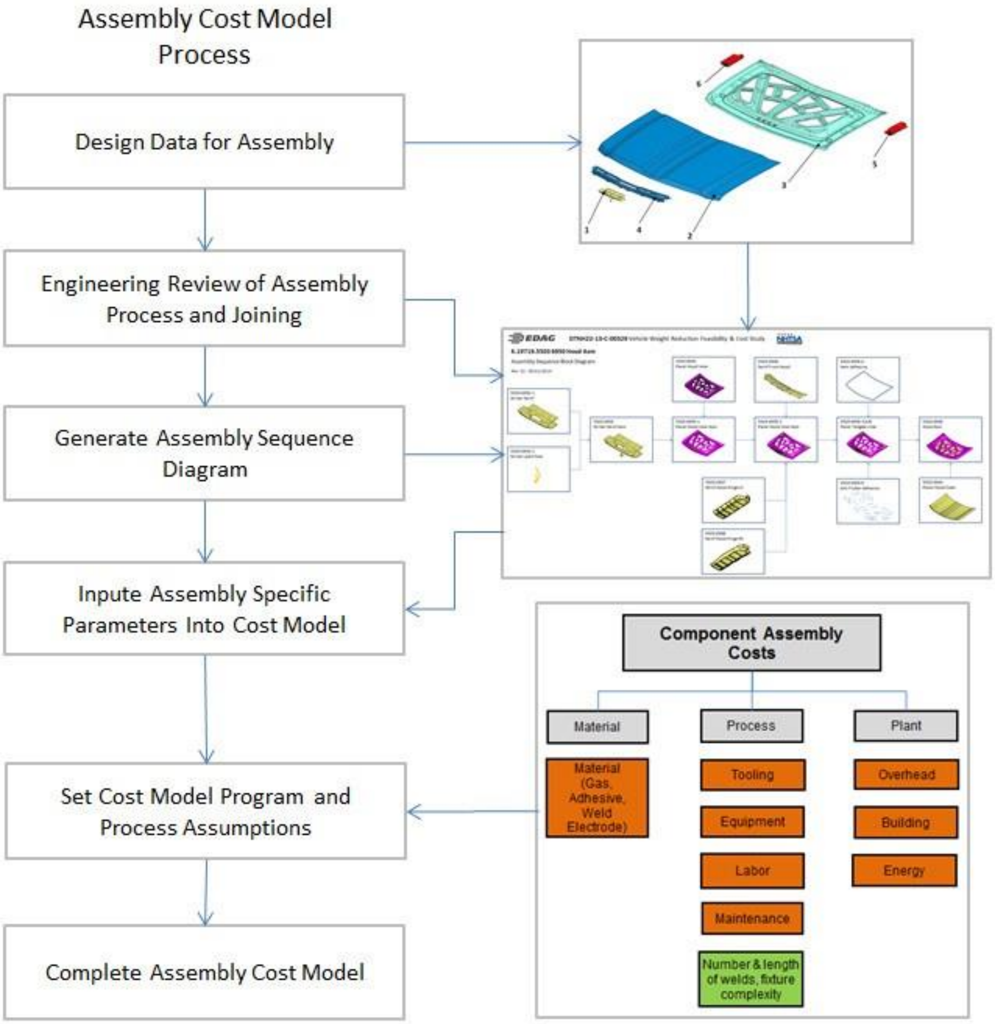
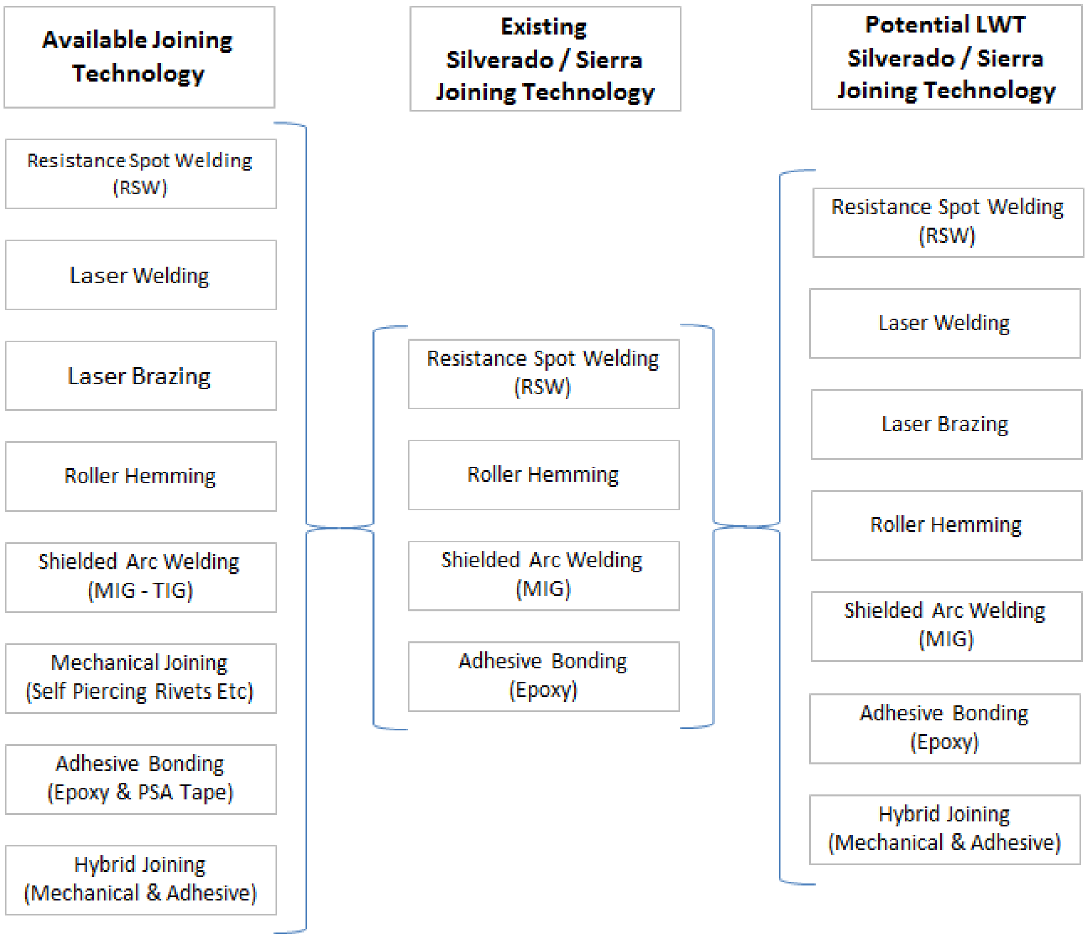


Figure 415: Fundamental Steps in Part Assembly Cost Assessment

For the assembly cost assessment, the joining methods used for the sub-system assembly are major contributions in the final assembly cost assembly. Typically, eight joining technologies are used. The Chevrolet Silverado sub-systems assemblies uses three of these technologies, resistance spot-welding, shielded arc welding (MIG), and roller hemming. The joining technologies for the baseline vehicle and the LWT project are shown in Figure 416. Hybrid joining technique using SPR and adhesive bonding is commonly used on aluminum structures similar to the aluminum Ford F-150 light-duty truck.



Available Joining Technology

Resistance Spot Welding (RSW)

Laser Welding

Laser Brazing

Roller Hemming

Shielded Arc Welding (MIG - TIG)

Mechanical Joining (Self Piercing Rivets Etc)

Adhesive Bonding (Epoxy & PSA Tape)

Hybrid Joining (Mechanical & Adhesive)

Existing Silverado / Sierra Joining Technology

Resistance Spot Welding (RSW)

Roller Hemming

Shielded Arc Welding (MIG)

Adhesive Bonding (Epoxy)

Potential LWT Silverado / Sierra Joining Technology

Resistance Spot Welding (RSW)

Laser Welding

Laser Brazing

Roller Hemming

Shielded Arc Welding (MIG)

Adhesive Bonding (Epoxy)

Hybrid Joining (Mechanical & Adhesive)

Figure 416: Joining Methods Used for the Part Assembly Cost Assessment

10.4.3 Special Consideration for Purchased Parts

Since this study only estimates the purchased parts costs to the OEM, the researchers applied an additional mark-up rate to account for the indirect costs incurred by the component supplier. For this study, the team considered selling, general, and administrative and profit to determine the final purchased price of the sub-system.

10.4.3.1 SG&A

SG&A mark-up rate is used by the supplier to account for the overhead or non-manufacturing related expenses, and some of the other elements such as:

- Supplier quality,
- Upper management,
- Divisional or corporate headquarters cost (e.g., non-manufacturing facilities, utilities, maintenance. etc.),
- Research and development,
- Sales, and
- Human resources.

The SG&A mark-up rate is applied as a percentage of the total estimated manufacturing costs. The default range for this cost analysis ranges from 4 to 6 percent depending on the complexity of the manufacturing technology and the respective sub-system design. For this study, since all the purchased item considered for cost estimation were manufactured using mature technologies, the mark-up rate applies was 4 percent. This mark-up rate was attained based on Intellicosting's prior consulting and sourcing projects data.

10.4.3.2 Profit

Similar to the SG&A mark-up rate, the profit mark-up rate is also proportional to the complexity of the part design and manufacturing method. It also depends on the availability of suppliers that possess a certain manufacturing technology. The profit mark-up rates tend to increase as the number of suppliers decreases for a certain manufacturing technologies. The profit mark-up ranges selected for this study were based on an assumption of 6 percent based on historical data available from suppliers and OEMs. In addition, all the purchased items analyzed in this study are mature with respect to the manufacturing feasibility and supplier availability.

10.4.4 Total Costs

The costs incurred by an automobile manufacturer during vehicle production can be broadly divided into two categories, direct and indirect costs. The manufacturing and assembly costs estimated using the TCM account for only the direct costs. The direct costs include those that can be directly related to the total manufacturing costs of making the vehicle, consisting of the following.

- Material, tooling and equipment
- Production labor costs
- Manufacturing overhead (building (facilities), maintenance, energy)
- Other direct costs related to manufacturing such as purchased parts

The TCM approach does not account for any indirect costs. The indirect costs include the costs that are not directly related to the manufacturing and assembly activities such as corporate overhead, marketing, shipping expenses, research and development. The final retail price of a vehicle is a sum of the direct costs and mark-up factors that relate the indirect costs to the changes in direct manufacturing costs. These mark-up factors are often referred to as retail price equivalent (RPE) multiplier. The indirect costs are addressed by applying the RPE multiplier (a specific RPE multiplier for GM, 1.45, was used for this study)[178] to determine the retail price of the baseline vehicle and the LWT.

10.5 Cost Model Inputs

10.5.1 Raw Material Cost

Raw material pricing is an important assumption for cost estimates. Accurately forecasting future material prices is very challenging. There are statistical methods available for predicting the future material prices such as regression analysis. However, these predictions are mainly based on the past price trends of the particular material; there are unpredictable global economic conditions such as the financial crisis of 2008-2009 that have an impact on the material prices (as shown in Figure 417). Adding to the challenges, material prices can undergo volatility both over time and across geographic locations. For example, the fluctuation of cold-rolled steel volatility is not exclusive to any particular material but the magnitude can vary, especially for materials such as precious metals.

For the cost assessment study, material price assumptions were based on the average of the available North American 2010-to-2014 material prices data adjusted to 2014 dollars by using a the gross domestic product[179] deflator. The prices of standard materials are often available through published sources and by consulting material suppliers or buyers. The prices for materials that are not available through published sources were established based on consultation with industry experts, including data from manufacturers of components using the specific material.

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[178] Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers," EPA report EPA-420-R-09- 003, February 2009

[179] See Table 1.1.9: Implicit Price Deflators for Gross Domestic Product, Bureau of Economic Analysis, U.S. Department of Commerce. Available at www.bea.gov/national/nipaweb/TableView.asp?SelectedTable=13&Freq=Qtr&FirstYear=2001&LastYear=2011.

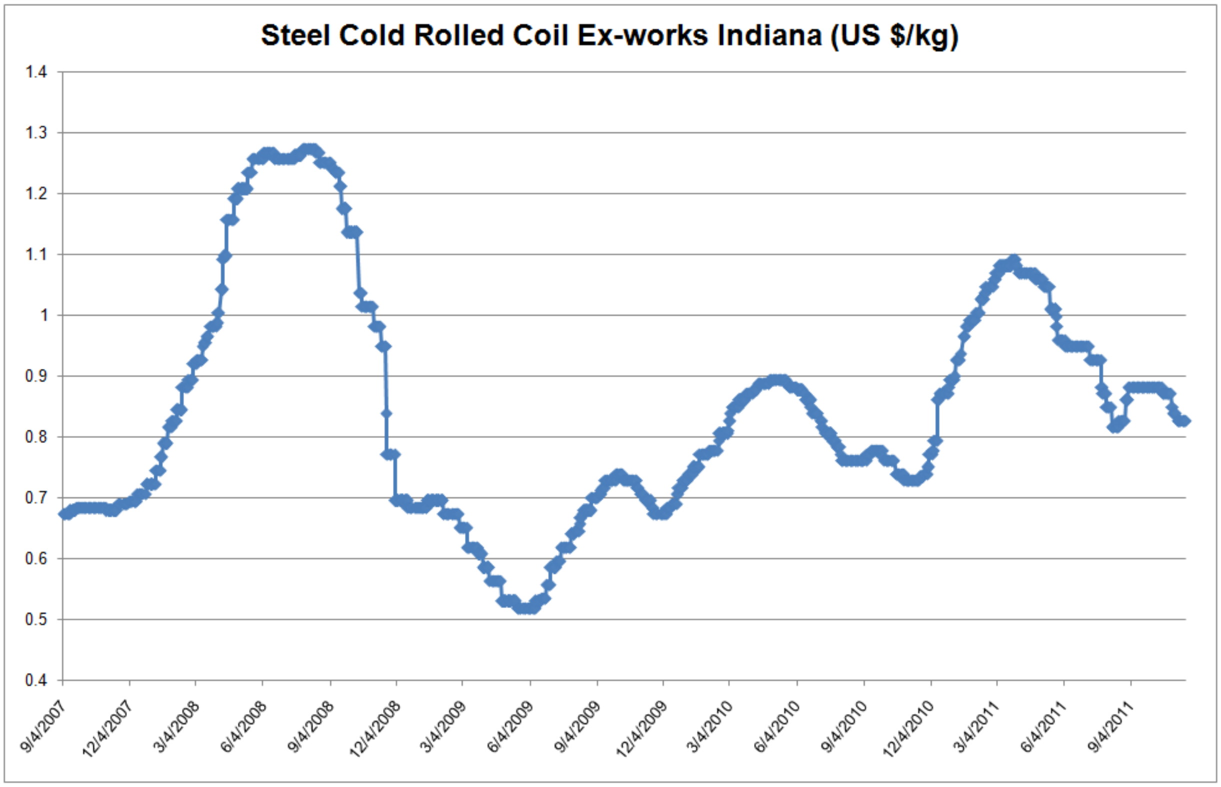

Figure 417: Steel (cold-rolled coil) ex-works Indiana prices[180]

10.5.2 Steel Prices

The fluctuation of the cold-rolled steel coil base prices from 2010 to 2014 are shown in Figure 418, including the nominal prices and the prices adjusted to 2014 dollars. The team used the 2010-to-2014 average steel price for the cost assessment, $0.82/kg adjusted to 2014 dollars.[181]

Using this figure as the base price for mild steel cold-rolled coils, the prices of the higher steel grades were established by applying the appropriate grade premiums to the base price. Similarly, the appropriate process premium was added to the base price to attain the prices of steel in other finished forms namely hot dip galvanized, tailor-rolled coils, and tubes.

The price of cast iron is not tracked as closely as the price of other materials, according to the feedback received from some of the metal raw material market data analysts.[182] Hence, a base price of $1.50/kg for cast iron was assumed for this study based on benchmarking data,[183]

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[180] Platts (Nominal Prices)

[181] Table 1.1.9, Implicit Price Deflators for GDP

[182] Platts, Metalprices

[183] EDAG/Inctelicosting design and sourcing consultation projects

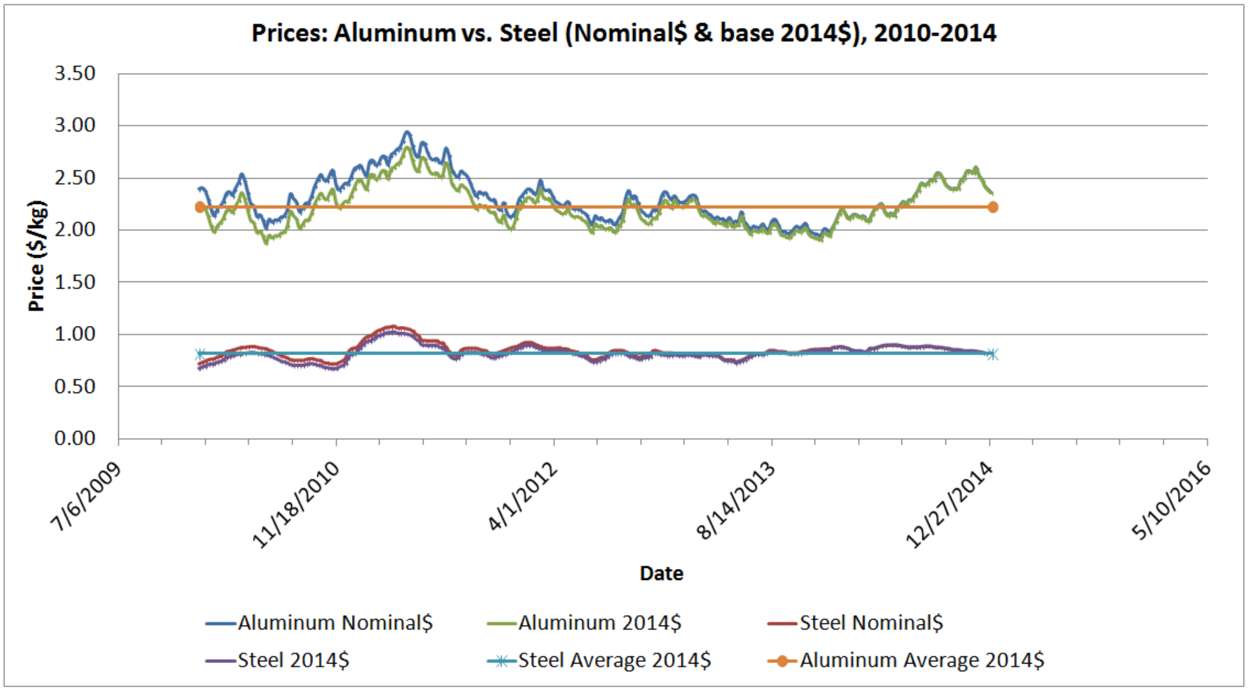

Figure 418: 2010 to 2014 Prices of, $/kg adjusted to 2014 dollars[184],[185]

The different grade and process premiums were estimated by EDAG based on inputs received from WorldAutoSteel. The different grades of steel and the respective premiums are shown in Figure 419. For example, if DP 700/1000 is the specified material for a part, a grade premium of $0.38 is added to $0.82 to get the material price of $1.20/ kg. If the material price is required for the DP 700/1000 grade steel in the form of tubes, an additional process premium of $0.55 is added to get the material price of $1.75/kg.

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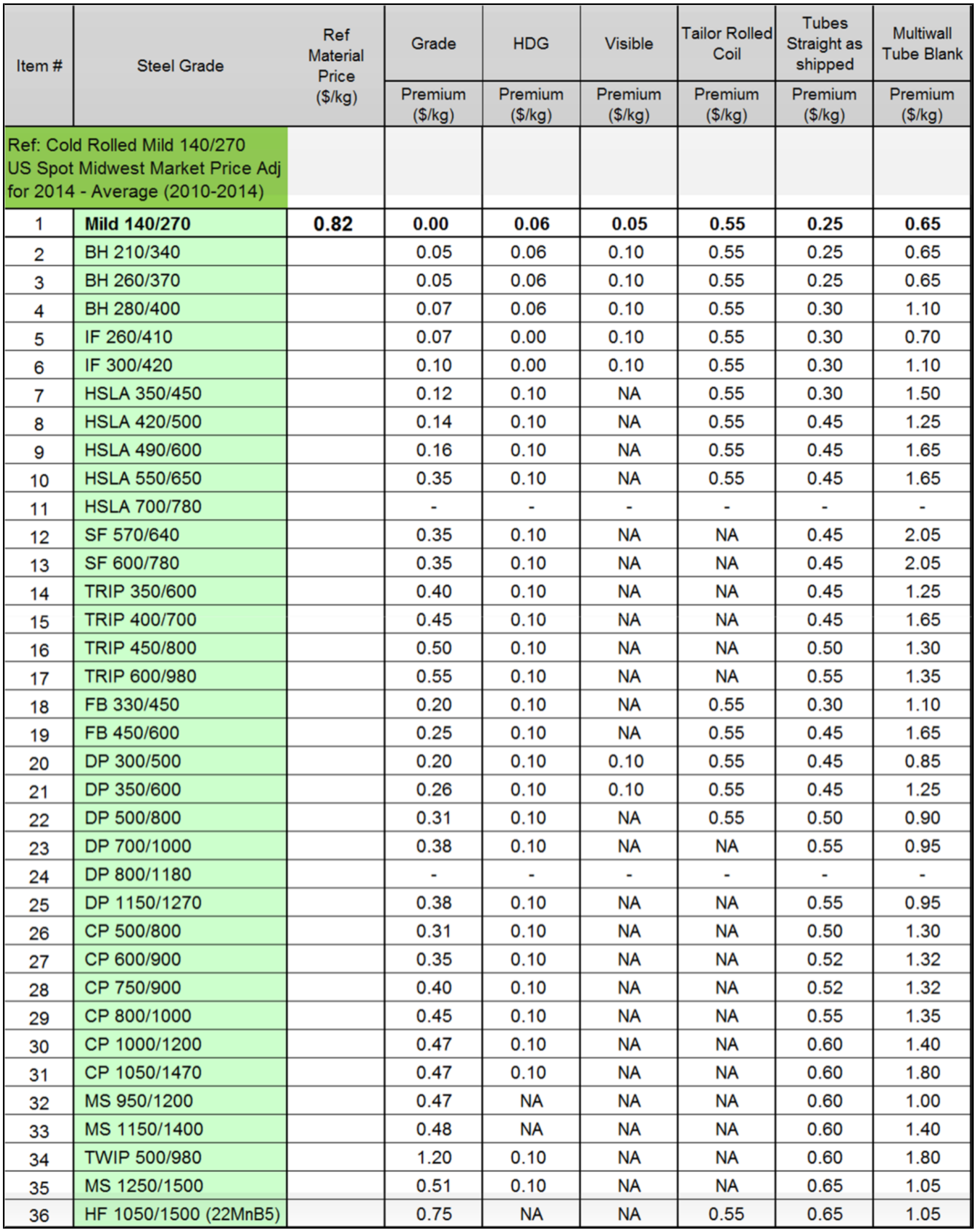
[184] Nominal Prices based on data received from Platts; Steel Cold-rolled Coil Ex-works Indiana Adjusted Prices take into account the GDP deflator in 2010, 2011, 2012, 2014

[185] Table 1.1.9, Implicit Price Deflators for GDP



Item #	Steel Grade	Ref Material Price ($/kg)	Grade	HDG	Visible	Tailor Rolled Coil	Tubes Straight as shipped	Multiwall Tube Blank
			Premium ($/kg)	Premium ($/kg)	Premium ($/kg)	Premium ($/kg)	Premium ($/kg)	Premium ($/kg)
Ref: Cold Rolled Mild 140/270 US Spot Midwest Market Price Adj for 2014 - Average (2010-2014)								
1	**Mild 140/270**	**0.82**	**0.00**	**0.06**	**0.05**	**0.55**	**0.25**	**0.65**
2	BH 210/340		0.05	0.06	0.10	0.55	0.25	0.65
3	BH 260/370		0.05	0.06	0.10	0.55	0.25	0.65
4	BH 280/400		0.07	0.06	0.10	0.55	0.30	1.10
5	IF 260/410		0.07	0.00	0.10	0.55	0.30	0.70
6	IF 300/420		0.10	0.00	0.10	0.55	0.30	1.10
7	HSLA 350/450		0.12	0.10	NA	0.55	0.30	1.50
8	HSLA 420/500		0.14	0.10	NA	0.55	0.45	1.25
9	HSLA 490/600		0.16	0.10	NA	0.55	0.45	1.65
10	HSLA 550/650		0.35	0.10	NA	0.55	0.45	1.65
11	HSLA 700/780		-	-	-	-	-	-
12	SF 570/640		0.35	0.10	NA	NA	0.45	2.05
13	SF 600/780		0.35	0.10	NA	NA	0.45	2.05
14	TRIP 350/600		0.40	0.10	NA	NA	0.45	1.25
15	TRIP 400/700		0.45	0.10	NA	NA	0.45	1.65
16	TRIP 450/800		0.50	0.10	NA	NA	0.50	1.30
17	TRIP 600/980		0.55	0.10	NA	NA	0.55	1.35
18	FB 330/450		0.20	0.10	NA	0.55	0.30	1.10
19	FB 450/600		0.25	0.10	NA	0.55	0.45	1.65
20	DP 300/500		0.20	0.10	0.10	0.55	0.45	0.85
21	DP 350/600		0.26	0.10	0.10	0.55	0.45	1.25
22	DP 500/800		0.31	0.10	NA	0.55	0.50	0.90
23	DP 700/1000		0.38	0.10	NA	NA	0.55	0.95
24	DP 800/1180		-	-	-	-	-	-
25	DP 1150/1270		0.38	0.10	NA	NA	0.55	0.95
26	CP 500/800		0.31	0.10	NA	NA	0.50	1.30
27	CP 600/900		0.35	0.10	NA	NA	0.52	1.32
28	CP 750/900		0.40	0.10	NA	NA	0.52	1.32
29	CP 800/1000		0.45	0.10	NA	NA	0.55	1.35
30	CP 1000/1200		0.47	0.10	NA	NA	0.60	1.40
31	CP 1050/1470		0.47	0.10	NA	NA	0.60	1.80
32	MS 950/1200		0.47	NA	NA	NA	0.60	1.00
33	MS 1150/1400		0.48	NA	NA	NA	0.60	1.40
34	TWIP 500/980		1.20	0.10	NA	NA	0.60	1.80
35	MS 1250/1500		0.51	0.10	NA	NA	0.65	1.05
36	HF 1050/1500 (22MnB5)		0.75	NA	NA	0.55	0.65	1.05

Figure 419: Price for different grades and finished forms of steel[186]

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[186] www.worldautosteel.org

10.5.3 Aluminum Prices

The base aluminum price used for the cost assessment was $2.23/kg. The 2010 to 2014 average prices was adjusted to 2014 dollars using the GDP deflator, as shown in Figure 418. Similar to the methodology used for steel prices, the researchers established the prices of the other aluminum grades by applying the appropriate grade premiums to the base price as summarized in Figure 420.

Item #	Aluminum Grade	Ref Price ($/kg)	Form	Grade Premium ($/kg)	Process Premium ($/kg)	Exposed Surface Premium ($/kg)	Total Cost ($/kg)
1	Aluminum Midwest USA (Platts)	$2.23					
2	A-380 (casting)		Ingot	$0.00	$0.00	n/a	$2.23
3	A-356 (casting)		Ingot	$0.19	$0.00	n/a	$2.42
4	5754 (sheet)		Sheet	$0.10	$1.80	n/a	$4.13
5	6014 (sheet)		Sheet	$0.10	$1.95	$0.07	$4.35
6	6111 (extrusion)		Billet	$0.10	$0.65	n/a	$2.98

Figure 420: Price for different grades and finished forms of aluminum

10.5.4 Labor Rates

The team applied an appropriate labor rate for the cost assessment based on the manufacturing or assembly technology used for a specific component. The labor rates used were divided into two categories: direct and indirect labor

The team applied the direct labor rate to all the work directly associated with the manufacturing of a part or assembly operations. For example, the direct labor rates were applied for the stamping, extruding, welding, cutting operators and general assemblers. All the other personnel not directly associated with the manufacturing or assembly was considered as indirect labor; examples include quality control, process engineers, material handling, etc.

The different types of labor classifications were identified based on the different manufacturing technologies identified in the baseline vehicle and LWT. The base labor rates for the required types of labors were acquired from the Bureau of Labor Statistics, North American Industry Classification System 336100 – Motor Vehicle Manufacturing. All labor rates are based on the data as available from BLS for 2010, 2012, and 2014.

For reference, all the production occupations have a base code of 51-000. Further, within the occupation groups the specific labor rates were acquired by matching the occupational description with the required type of labor based on the identified types of fabrication or assembly. The average base labor rates are shown in Figure 422.

The base wages were obtained from the BLS database. In addition, there are other expenses an employer pays for an employee to cover the employee benefits such as medical insurance, pension or retirement, vacation and holiday benefits etc. To account for these additional benefits above and beyond the base wage, the team applied an average markup of 41 percent from the BLS (Figure 421) to the wages. The total labor rates are illustrated in Figure 422.

Figure 421: Employer Costs for Employee Compensation[187]

The benefits as percentage of employee hourly rates for the years 2010, 2011, 2012, 2013 and 2014 are 41.2 percent, 41.8 percent, 40.6 percent, 42.7 percent and 39.6 percent respectively[188], with an average of 41.2 percent. Therefore the 41 percent for the year 2010 is still applicable.

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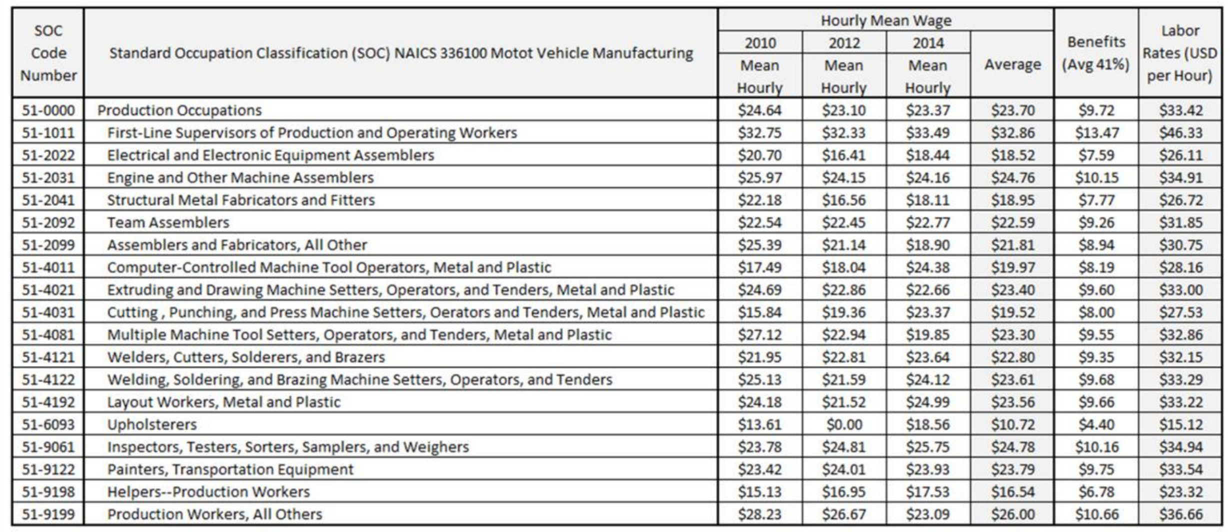
[187] Bureau of Labor Statistics, December 2010

[188] National Compensation Survey,Table 9. Private industry workers, by major occupational group: employer costs per hours worked for employee compensation and
costs as a percentage of total compensation, 2004-2016 – Page 141. www.bls.gov/ect



SOC Code Number	Standard Occupation Classification (SOC) NAICS 336100 Motot Vehicle Manufacturing	Hourly Mean Wage				Benefits (Avg 41%)	Labor Rates (USD per Hour)
		2010 Mean Hourly	2012 Mean Hourly	2014 Mean Hourly	Average		
51-0000	Production Occupations	$24.64	$23.10	$23.37	$23.70	$9.72	$33.42
51-1011	First-Line Supervisors of Production and Operating Workers	$32.75	$32.33	$33.49	$32.86	$13.47	$46.33
51-2022	Electrical and Electronic Equipment Assemblers	$20.70	$16.41	$18.44	$18.52	$7.59	$26.11
51-2031	Engine and Other Machine Assemblers	$25.97	$24.15	$24.16	$24.76	$10.15	$34.91
51-2041	Structural Metal Fabricators and Fitters	$22.18	$16.56	$18.11	$18.95	$7.77	$26.72
51-2092	Team Assemblers	$22.54	$22.45	$22.77	$22.59	$9.26	$31.85
51-2099	Assemblers and Fabricators, All Other	$25.39	$21.14	$18.90	$21.81	$8.94	$30.75
51-4011	Computer-Controlled Machine Tool Operators, Metal and Plastic	$17.49	$18.04	$24.38	$19.97	$8.19	$28.16
51-4021	Extruding and Drawing Machine Setters, Operators, and Tenders, Metal and Plastic	$24.69	$22.86	$22.66	$23.40	$9.60	$33.00
51-4031	Cutting , Punching, and Press Machine Setters, Oerators and Tenders, Metal and Plastic	$15.84	$19.36	$23.37	$19.52	$8.00	$27.53
51-4081	Multiple Machine Tool Setters, Operators, and Tenders, Metal and Plastic	$27.12	$22.94	$19.85	$23.30	$9.55	$32.86
51-4121	Welders, Cutters, Solderers, and Brazers	$21.95	$22.81	$23.64	$22.80	$9.35	$32.15
51-4122	Welding, Soldering, and Brazing Machine Setters, Operators, and Tenders	$25.13	$21.59	$24.12	$23.61	$9.68	$33.29
51-4192	Layout Workers, Metal and Plastic	$24.18	$21.52	$24.99	$23.56	$9.66	$33.22
51-6093	Upholsterers	$13.61	$0.00	$18.56	$10.72	$4.40	$15.12
51-9061	Inspectors, Testers, Sorters, Samplers, and Weighers	$23.78	$24.81	$25.75	$24.78	$10.16	$34.94
51-9122	Painters, Transportation Equipment	$23.42	$24.01	$23.93	$23.79	$9.75	$33.54
51-9198	Helpers--Production Workers	$15.13	$16.95	$17.53	$16.54	$6.78	$23.32
51-9199	Production Workers, All Others	$28.23	$26.67	$23.09	$26.00	$10.66	$36.66

Figure 422: Average Base Labor Rates plus including Benefits[189]

Finally, a markup of 25 percent was applied to account for the indirect labor from the same source.

10.5.5 Part Specific Inputs

One of the key steps in the part costs analysis is the determination of the material and the manufacturing technology suitable for producing each respective part. Most significantly, the manufacturing process should be able to produce the part at a high quality, and cost effectively in a high production volume scenario to represent the automotive manufacturing industry. Further, all the parts were also reviewed to establish the following key process input parameters that are unique for every component.

- Input material (blank size)
- Tooling investment and cycle time
- Equipment specification

10.5.6 Cost Model Generic Process Inputs

The unit manufacturing cost is derived from one of the following cost models based on the selected manufacturing processes.

- Stamping (Single Thickness)
- Stamping Tailor Rolled Blank
- Stamping Laser Welded Blank
- Hot Stamping
- Hot Stamping Tailor Rolled Blank
- Hot Stamping Laser Welded Blank

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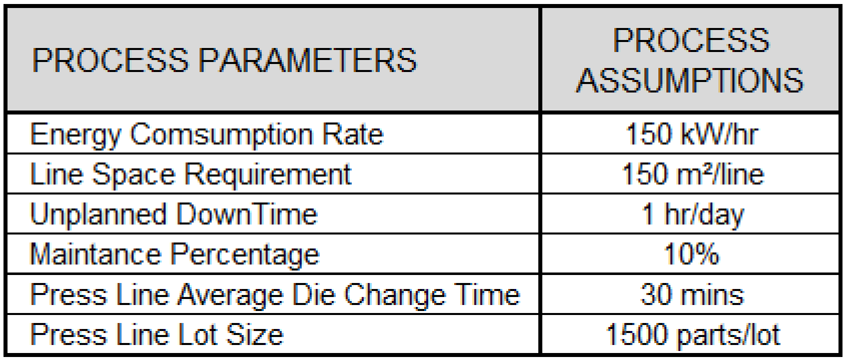
[189] www.bls.gov/oes/current/naics4_336300.htm

- Closed Profile Roll-forming
- Open Profile Roll-forming
- Hydroforming
- Hydroforming Laser Welded Tube
- Casting (Sand)
- High Pressure Die Casting
- Extrusion
- Resin Transfer Molding

The unit assembly cost employs one of the following joining technologies based on the selected assembly processes.

- Resistance Spot-Welding
- Shielded Arc Welding (MIG)/(TIG))
- Laser Welding
- Laser braze
- Mechanical Fasteners (Self Piercing Rivets)
- Adhesive bonding
- Roller Hemming
- Hybrid Joining

For each of the above mentioned processes, the generic process parameters that are independent of the part/assembly design are built-in as formulas within the cost model. For example, the general stamping press line process parameters are shown in Figure 423.



PROCESS PARAMETERS	PROCESS ASSUMPTIONS
Energy Comsumption Rate	150 kW/hr
Line Space Requirement	150 m²/line
Unplanned DownTime	1 hr/day
Maintance Percentage	10%
Press Line Average Die Change Time	30 mins
Press Line Lot Size	1500 parts/lot

Figure 423: Stamping Press Line General Process Parameters

Similar to the process parameters shown in Figure 423, there are generic parameters built into the cost model for each operation required to fabricate or assemble a part using a particular manufacturing or assembly technology. For each operation, the team adds each of these parameters into the model. They also must consider the sequence of the different operations, to estimate the overall manufacturing component cost for the various technologies as shown in Figure 424.

	MANUFACTURING TECHNOLOGY					
	Stamping	Stamping Tailor Rolled Blank	Stamping Laser Welded Blank	Hot Stamping	Hot Stamping Laser Welded Blank	High Pressure Die Casting
Operation #	Steel/Aluminum Matl Prices	Steel/Matl Prices with Process Premium	Steel Matl Prices	Steel Matl Prices	Steel Matl Prices	Aluminum Matl Prices
1	Blanking	Blanking	Laser Welding	Blanking	Laser Welding	Ingot Heating
2	Stamping	Stamping	Blanking	Blank Heating	Blanking	Die Casting
3	Trimming	Trimming	Stamping	Hot Forming	Blank Heating	Cooling & Ejection
4			Trimming	Laser Trimming	Hot Forming	Machining
5					Laser Trimming	

	MANUFACTURING TECHNOLOGY					
	Roll Forming Closed Profile	Roll Forming Open Profile	Hydroform	Hydroform Laser Welded Tubes	Extrusion	Inject Molding
Operation #	Steel Matl Prices	Steel Matl Prices	Steel Matl Prices	Steel Matl Prices	Aluminum Matl Prices	Plastic Matl Prices
1	Roll Forming	Roll Forming	Bending	Blanking	Billet Preperation	Inection
2	Welding	Trimming	Pre-Forming	Laser Welding	Extrusion	Molding
3	Trimming		Hydroforming	Tube	Straightening	Cooling
4			Trimming	Bending	Hydrosizing	Ejection
5				Pre-Forming	Machining	Trimming
6				Hydroforming		
7				Trimming		

Figure 424: Manufacturing Processes and Operations Sequence

Apart from the generic program assumptions and the generic process parameters, the cost model also uses certain key information for calculating the above mentioned cost components: the information for material prices ($/kg), labor rates ($/hr), equipment investment ($). Energy, building and maintenance are calculated based on each respective generic process parameters. The building costs estimated in the model were apportioned based on the actual space occupied and the specific requirements to manufacture a specific part. Similarly, the maintenance costs in the model is for maintaining the tools, equipment and building and is proportional to the actual use for manufacturing and assembly that is also directly linked to the manufacturing process. It is different from the building and maintenance calculated by RPE that accounts for the costs not directly linked to manufacturing or assembly, such as non-manufacturing offices, corporate headquarters etc.).

The EDAG cost model allows for updates to the key variables such as material prices, labor rates and equipment investments and then re-calculates the unit costs to reflect the changes.

10.6 Cost Modeling of Individual Components and Sub-Systems

This section of the report provides a detailed description of the approach used by the researchers to calculate the incremental costs of the completely re-designed cab structure assembly. A similar approach is used for all of the other re-designed components in the vehicle; therefore summarized results rather than a detailed description will be presented for those other systems. Detailed results and cost breakdowns of all components and sub-systems can be found in the cost models (Microsoft Excel files) published with this report.

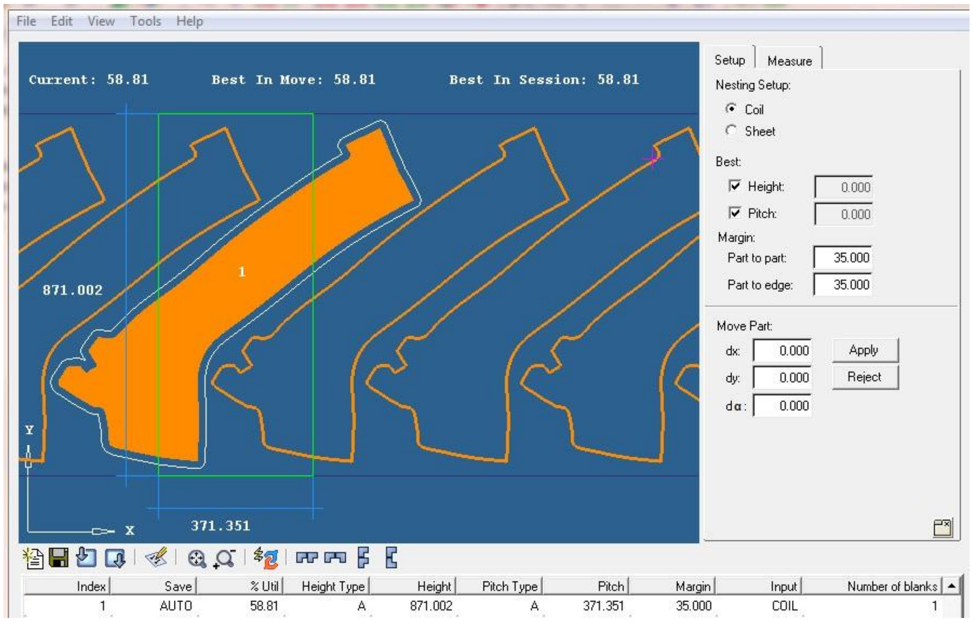
10.6.1 Manufacturing Cost Model Inputs

A detailed engineering review was conducted on every part making up the baseline 2014 Chevrolet Silverado 1500 to determine its material composition and the processes used to manufacture it. Engineering expertise and consultation with appropriate suppliers were used to evaluate the manufacturing processes likely used for each component. While sheet metal parts are predominantly manufactured using a stamping process, the team fully examined the geometry of each part in the baseline vehicle to confirm whether this or a different primary manufacturing process, such as roll forming or hydroforming, for example, had been used. Similarly, secondary manufacturing processes such as laser welded blanks, trimming, etc., were established. A similar procedure was used to confirm the LWT designs.

10.6.2 Blank Size

Each part was evaluated, using CAD data and manufacturing simulation tools, to determine the part optimal blank size, including the required addendum necessary for blank holder, draw beads for control of material flow, etc.

The team used part nesting, whenever possible, to reduce the amount of scrap and part costs. The part nesting process is more efficient in reducing the material scrap in the regular stamping process (single thickness blank). A blank size and part nesting for the A-pillar reinforcement is shown in Figure 425.



Current: 58.81 Best In Move: 58.81 Best In Session: 58.81

Nesting Setup:

● Coil

○ Sheet

Best:

☑ Height: 0.000

☑ Pitch: 0.000

Margin:

Part to part: 35.000

Part to edge: 35.000

Move Part:

dx: 0.000

dy: 0.000

dα: 0.000

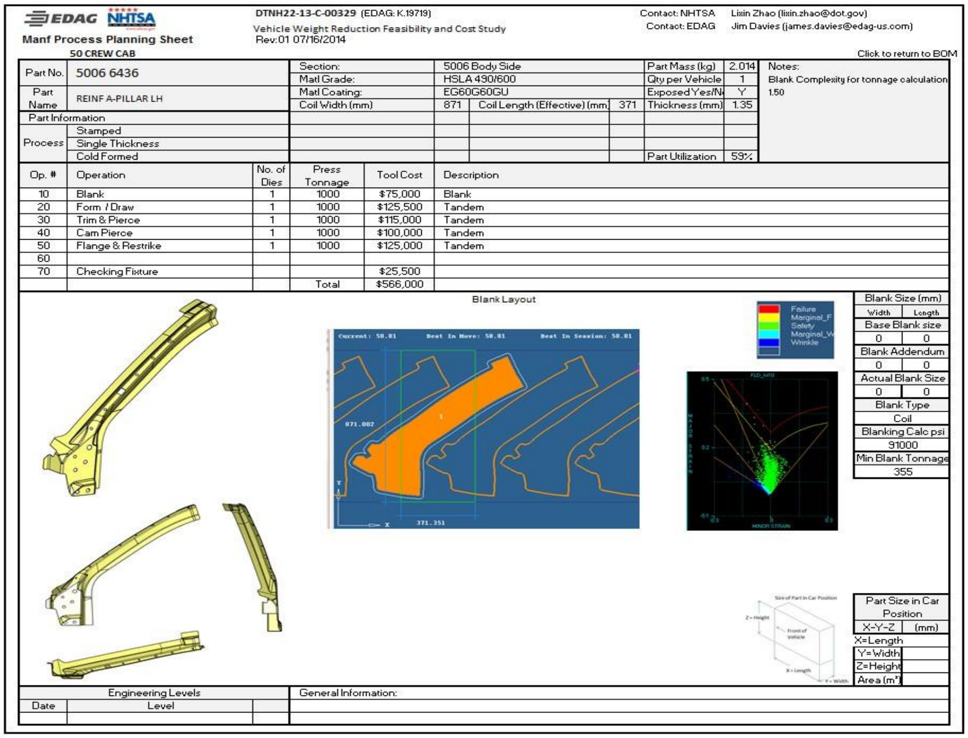
Apply

Reject

Index	Save	% Util	Height Type	Height	Pitch Type	Pitch	Margin	Input	Number of blanks
1	AUTO	58.81	A	871.002	A	371.351	35.000	COIL	1

Figure 425: A-Pillar Reinforcement Part Blank and Nesting

This information together with material specification part mass and material coating is added to a manufacturing process planning sheet as shown in Figure 427. Detailed explanation of additional data that goes onto this sheet is illustrated in Figure 427.



EDAG NHTSA

Manf Process Planning Sheet

50 CREW CAB

DTNH22-13-C-00329 (EDAG: K.19719)

Vehicle Weight Reduction Feasibility and Cost Study

Rev:01 07/16/2014

Contact: NHTSA Lixin Zhao (lixin.zhao@dot.gov)

Contact: EDAG Jim Davies (james.davies@edag-us.com)

Click to return to BOM

Part No.	5006 6436	Section:	5006 Body Side			Part Mass (kg)	2.014
		Matl Grade:	HSLA 490/600			Qty per Vehicle	1
Part Name	REINF A-PILLAR LH	Matl Coating:	EG60G60GU			Exposed Yes/N	Y
		Coil Width (mm)	871	Coil Length (Effective) (mm)	371	Thickness (mm)	1.35
Part Information							
Process	Stamped						
	Single Thickness						
	Cold Formed					Part Utilization	59%

Notes:

Blank Complexity for tonnage calculation 1.50

Op. #	Operation	No. of Dies	Press Tonnage	Tool Cost	Description
10	Blank	1	1000	$75,000	Blank
20	Form / Draw	1	1000	$125,500	Tandem
30	Trim & Pierce	1	1000	$115,000	Tandem
40	Cam Pierce	1	1000	$100,000	Tandem
50	Flange & Restrike	1	1000	$125,000	Tandem
60					
70	Checking Fixture			$25,500	
			Total	$566,000	

Blank Layout

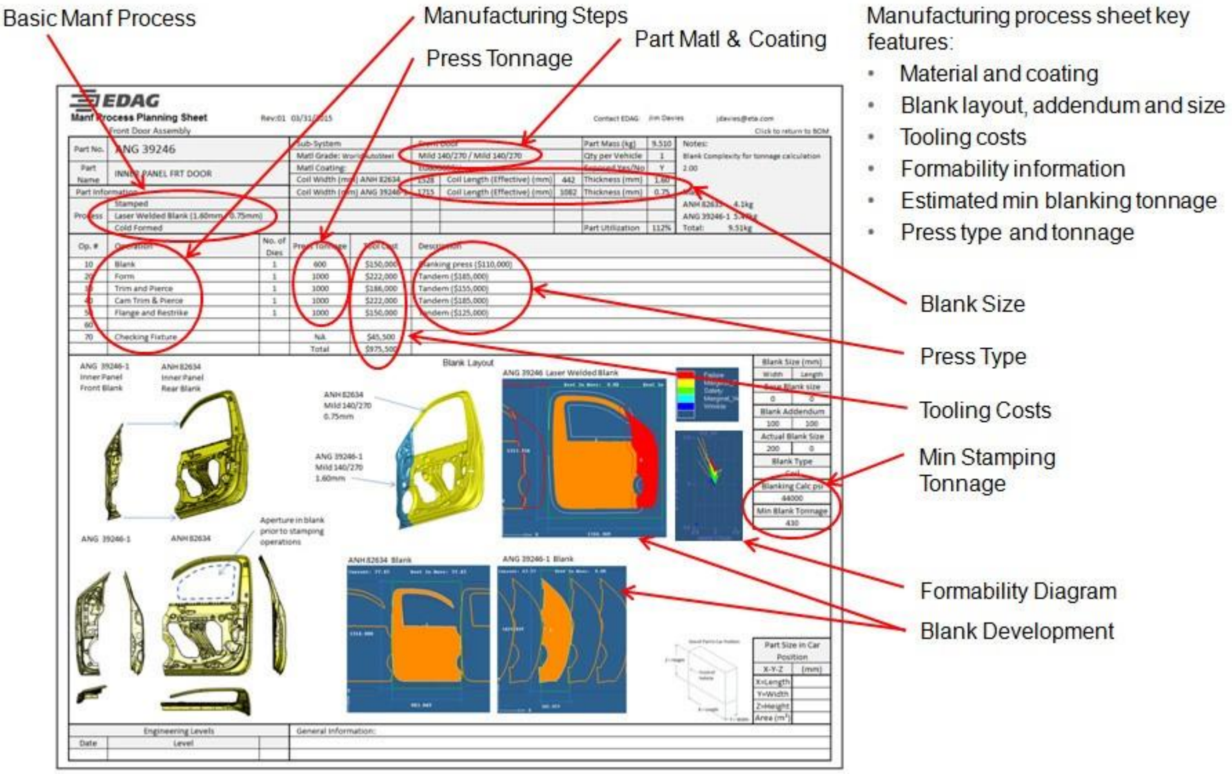
Blank Size (mm)	
Width	Length
Base Blank size	
0	0
Blank Addendum	
0	0
Actual Blank Size	
0	0
Blank Type	
Coil	
Blanking Calc psi	
91000	
Min Blank Tonnage	
355	

Part Size in Car Position	
X-Y-Z	(mm)
X=Length	
Y=Width	
Z=Height	
Area (m²)	

Engineering Levels		
Date	Level	

General Information:

Figure 426: Manufacturing Process Sheet for A-Pillar Reinforcement



Op. #	Operation	No. of Dies	Press Tonnage	Tool Cost	Description
10	Blank	1	600	$150,000	Blanking press ($110,000)
20	Form	1	1000	$222,000	Tandem ($185,000)
30	Trim and Pierce	1	1000	$186,000	Tandem ($155,000)
40	Cam Trim & Pierce	1	1000	$222,000	Tandem ($185,000)
50	Flange and Restrike	1	1000	$150,000	Tandem ($125,000)
60					
70	Checking Fixture		NA	$45,500	
			Total	$975,500	

Figure 427: Manufacturing Process Sheet for Detailed Explanation

In addition to the above mentioned information and using the same simulation software that was used to develop the part blank size a formability check is made. Figure 428 shows formability check for an A-pillar reinforcement.

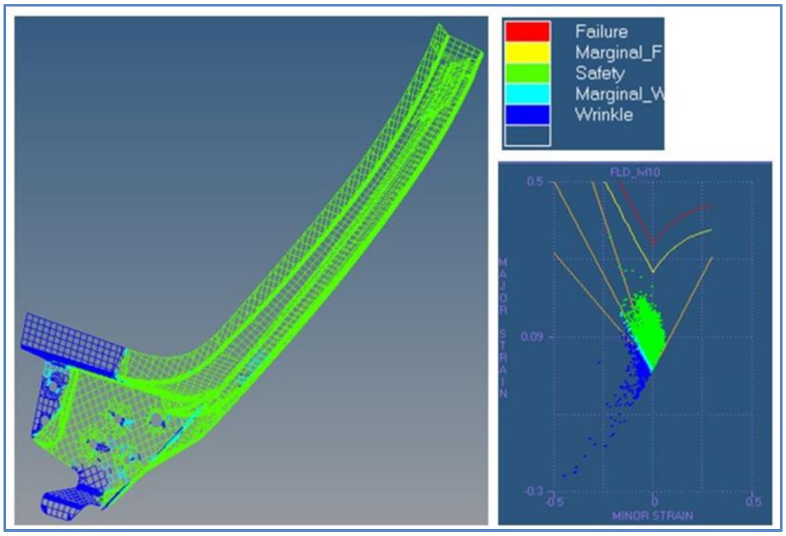


Figure 428: Formability checks for A-Pillar Reinforcement

10.6.3 Tooling Investment and Cycle Time

Once the process for manufacturing a part was established, each operation for fabricating the part was reviewed to determine its tooling investment and cycle time. The part design and complexity were reviewed to determine the tooling costs that include the following: tool design, manufacturing machining, checking fixtures, and tryouts.

10.6.4 Equipment Specification

The part design and complexity were also reviewed to determine the suitable equipment to produce an acceptable quality part cost effectively in a high production volume scenario. The cost model assumed that the fabrication lines are not fully dedicated to the manufacturing of one specific part. This means that in the remaining time other parts can be fabricated with the associated costs distributed across all of the parts being fabricated.

10.6.5 Assembly Cost Model Inputs

In an assembly line sequence, individual components are assembled together to form separate sub-assemblies, which are then combined on an assembly line to form the complete assembly. The researchers performed an engineering review of all the parts in each sub-assembly to ensure they are presented in a proper sequence to allow the workers sufficient access to the parts at their work stations. As part of the review, the team also determined other process inputs such as type of welds, number of welds, etc. The team performed a similar review on the combining of the sub-assemblies into a full assembly. A unique assembly sequence diagram was prepared for each individual sub-assembly and assembly. As an example, the LWT pickup box assembly sequence is illustrated in Figure 429.

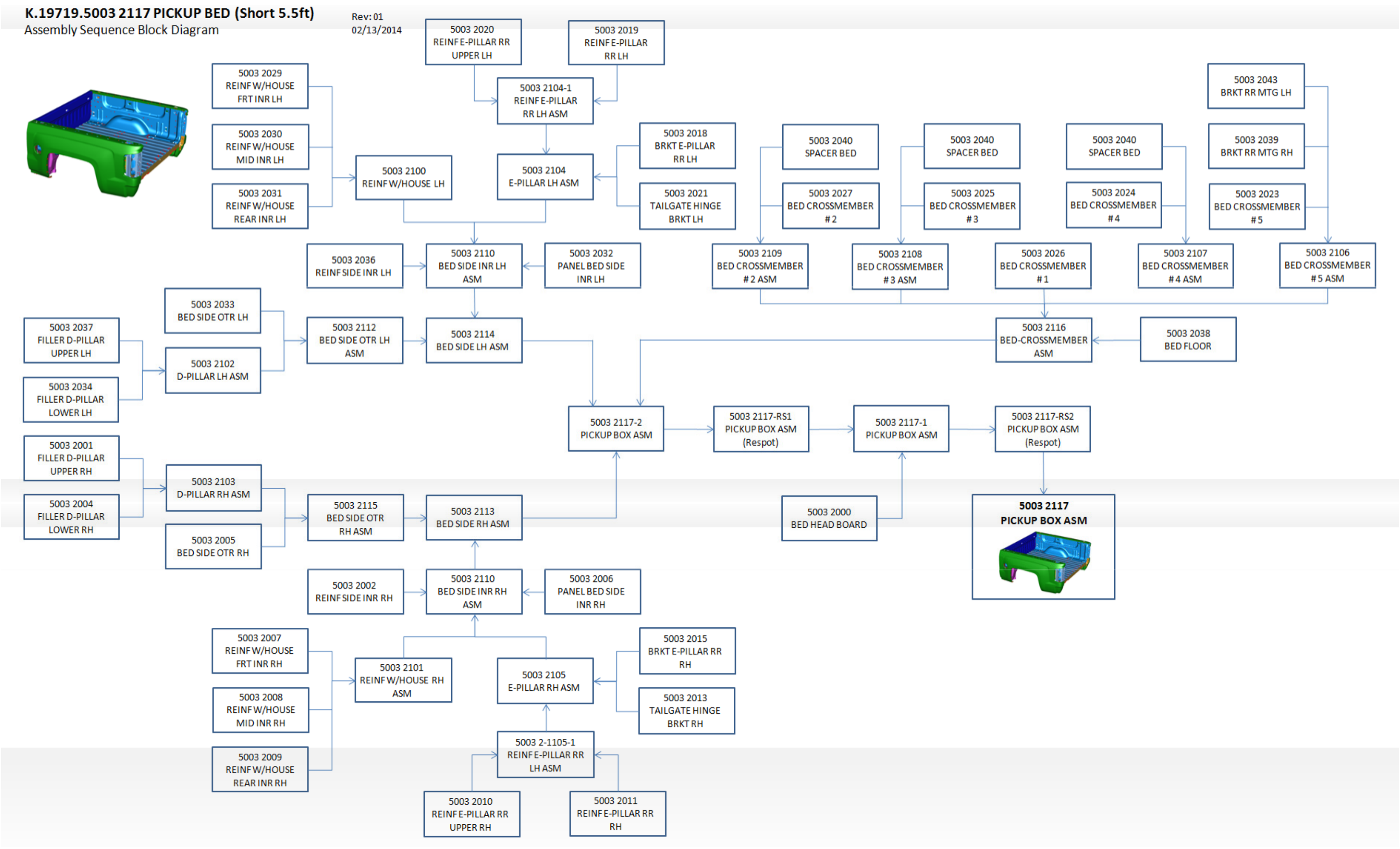


Figure 429: Pickup Box Assembly Sequence Block Diagram (for illustration only)

The assembly parameters for the baseline vehicle were based upon the process information available in the benchmark CAD data and upon an engineering evaluation of the assembly sequence. However, the latter may not represent the actual sequence followed by the manufacturer of the baseline vehicle. Also, the manufacturer may have purchased certain components as sub-assemblies. Without specific information, the team was not able to differentiate between the manufactured and purchased parts or sub-assemblies. Therefore, they considered all of them to be individually assembled parts. These same assumptions were made for the LWT assembly parameters. Because the cost assessments for both the baseline and the LWT assemblies were made based upon a consistent set of assumptions, the team believes that the estimated incremental costs should be accurate.

10.7 LWT Incremental Cost Compared With Baseline Vehicle

10.7.1 Cab Structure Assembly

The final LWT optimized cab assembly incorporated the cab, fender assemblies (LH and RH) and radiator support structures. The structure supporting the fenders and radiator support were integrated into the cab structure, as shown in Figure 430. This reduced the complexity of the supporting structure and allowed the fender design to be a simple 3-piece bolt-on construction. The baseline radiator support structure was redesigned to magnesium casting shown in red in Figure 430. Some of the baseline fender structure and radiator support structure elements are incorporated into the LWT cab structure. While the cost of the fenders and radiator support were reduced in the LWT that of the cab structure was increased.

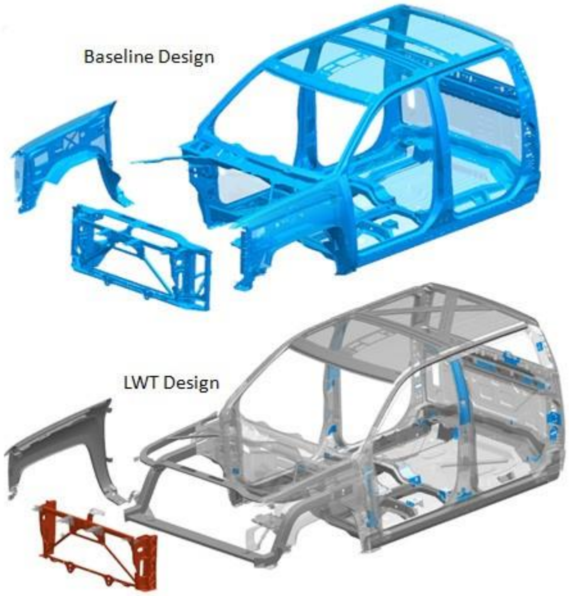


Figure 430: Baseline and LWT Cab Assembly Structure Design

10.7.1.1 Baseline Cab Structure Costs

The baseline 2014 Chevrolet Silverado 1500 cab structure is a modern unibody monocoque structure constructed primarily from HSS. Nearly all of the parts in the baseline cab structure are fabricated using conventional stamping operations and roll forming. The manufacturing and assembly costs of the baseline vehicle cab structure are summarized in Figure 431. The manufacturing cost breakdown of the baseline cab structure is summarized in Figure 432.

MANUFACTURING TECHNOLOGY	PARTS WEIGHT (kg)	PARTS COST ($ USD)
Stamping Single Thickness (Steel)	220.96	502.52
Roll-Formed (Steel)	19.13	20.86
Cab Structure - Manufacturing	240.09	523.37
Cab Structure - Assembly	0.00	202.53
Cab Structure - Total	240.09	725.90

Figure 431: Baseline Vehicle Cab Structure Manufacturing and Assembly Costs

CAB STRUCTURE COST BREAKDOWN	MANUFACTURING COSTS ($ USD)	ASSEMBLY COSTS ($ USD)	BASELINE COSTS ($ USD)
Material Price	330.65	0.59	331.24
Labor	21.74	56.99	78.73
Energy	13.64	21.62	35.25
Equipment	70.57	53.17	123.74
Tooling	52.58	16.85	69.43
Building	2.20	17.81	20.01
Maintenance	12.74	8.78	21.52
Overhead	19.26	26.73	45.99
TOTAL	523.37	202.53	725.90

Figure 432: Baseline Vehicle Cab Structure Costs Breakdown

10.7.1.2 LWT Cab Structure Costs

The LWT cab replaces the baseline steel with aluminum. The manufacturing processes are similar to those used on the baseline vehicle. The predominant manufacturing technology used in the LWT is, like the baseline, conventional stamping (approximately 86% of the total LWT cab structure weight compared with 92% in the baseline). Hydroforming accounts for 8 percent of the total cab structure weight while roll forming accounts for 6 percent. Based upon the geometry of each specific LWT part, the team chose the most cost effective process to manufacture a high quality part in a high production volume scenario. The LWT cab structure manufacturing and assembly costs are summarized in Figure 433 and the cost breakdown is summarized in Figure 434. The assembly costs shown in Figure 433 and Figure 434 are based upon the LWT assembly weld details.

MANUFACTURING TECHNOLOGY	PARTS WEIGHT (kg)	PARTS COST ($ USD)
Stamping Single Thickness (Aluminum)	114.35	989.43
Stamping Single Thickness (Steel)	5.63	31.24
Hydroformed Single Thickness (Aluminum)	7.06	99.46
Extrusion (Aluminum)	14.47	64.26
Roll Formed (Aluminum)	7.57	35.72
Cab Structure - Manufacturing	149.08	1,220.11
Cab Structure - Assembly	0.00	335.81
Cab Structure - Total	**149.08**	**1,555.92**

Figure 433: LWT Cab Structure Manufacturing and Assembly Costs

CAB STRUCTURE COST BREAKDOWN	MANUFACTURING COSTS ($ USD)	ASSEMBLY COSTS ($ USD)	LWT COSTS ($ USD)
Material Price	946.42	125.69	1,072.11
Labor	37.08	102.51	139.59
Energy	29.68	5.00	34.68
Equipment	78.41	24.67	103.08
Tooling	63.96	15.57	79.53
Building	6.70	16.58	23.28
Maintenance	13.24	5.68	18.93
Overhead	44.62	40.10	84.72
TOTAL	**1,220.11**	**335.81**	**1,555.92**

Figure 434: LWT Cab Structure Costs Breakdown

The LWT cab structure incremental costs compared with those of the baseline vehicle are summarized in Figure 435.

CAB STRUCTURE COST BREAKDOWN	BASELINE COSTS ($ USD)	LWT COSTS ($ USD)		INCREMENTAL COSTS ($ USD)
Material Price	331.24	1,072.11		740.87
Labor	78.73	139.59		60.86
Energy	35.25	34.68		-0.58
Equipment	123.74	103.08		-20.66
Tooling	69.43	79.53		10.11
Building	20.01	23.28		3.27
Maintenance	21.52	18.93		-2.60
Overhead	45.99	84.72		38.73
TOTAL	725.90	1,555.92		830.02

Figure 435: LWT Cab Structure Incremental Costs Summary

10.7.1.3 Fenders: Front End Sheet Metal

The front fenders on the baseline 2014 Chevrolet Silverado are built primarily from cold-rolled sheet steel. They are each composed of a stamped inner and outer panel, reinforcements, brackets, supports, fasteners, and wheel liner, as shown in Figure 436. The left hand fender also includes a battery tray. With the exception of the liners, all these components are constructed of steel. The inner panel is spot-welded to the outer panel while other components are mechanically fastened.

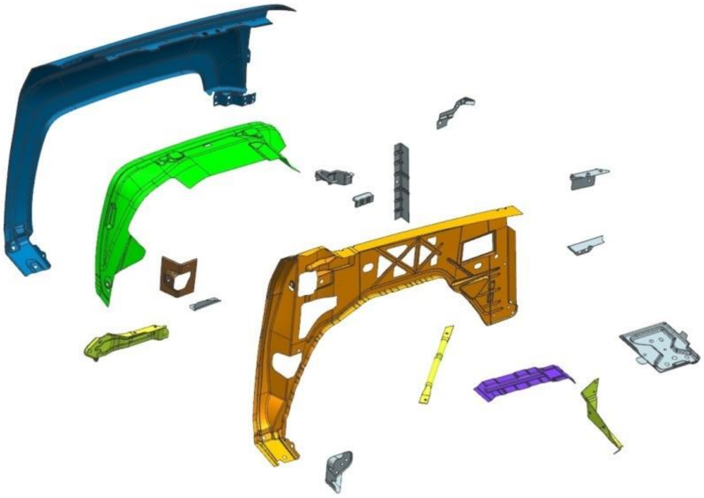


Figure 436: Baseline Silverado Front Fender (LH)

The LWT fender design consists of aluminum stampings for the entire structure including brackets and reinforcements. Manufacturing and assembly processes are similar to those on the baseline fenders. The LWT left hand fender incremental costs are summarized in Figure 437, Figure 438, and Figure 439.

MANUFACTURING TECHNOLOGY BASELINE	PARTS WEIGHT (kg)	PARTS COST ($ USD)
Stamping Single Thickness	13.74	41.85
Fender (LH) Structure - Manufacturing	13.74	41.85
Fender (LH) Structure - Assembly	0.00	14.21
Fender (LH) Structure - Total	13.74	56.06

Figure 437: Baseline Fender Structure Manufacturing and Assembly Costs

MANUFACTURING TECHNOLOGY	PARTS WEIGHT (kg)	PARTS COST ($ USD)
Stamping Single Thickness	2.57	15.54
Fender (LH) Structure - Manufacturing	2.57	15.54
Fender (LH) Structure - Assembly	0.00	3.32
Fender (LH) Structure - Total	2.57	18.85

Figure 438: LWT Fender Structure Manufacturing and Assembly Costs

FENDER (LH) STRUCTURE COST BREAKDOWN	BASELINE COSTS ($ USD)	LWT COSTS ($ USD)	INCREMENTAL COSTS ($ USD)
Material Price	22.62	12.01	-10.61
Labor	6.98	2.14	-4.85
Energy	2.95	0.52	-2.43
Equipment	10.07	1.94	-8.14
Tooling	5.46	0.38	-5.09
Building	1.62	0.38	-1.24
Maintenance	1.74	0.28	-1.46
Overhead	4.62	1.21	-3.41
TOTAL	56.06	18.85	-37.20

Figure 439: LWT Left Hand Fender Incremental Costs Summary

Some of the baseline fender structure elements are incorporated into the LWT cab structure (see Figure 430). The mass and cost of the LWT fenders is significantly lower compared with the baseline because the support structure is integrated into the LWT Cab.

10.7.1.4 Radiator Support

The baseline radiator support on the 2014 Chevrolet Silverado, shown in Figure 440, is primarily constructed of stamped steel elements spot-welded together. The LWT design replaces the steel with aluminum stampings and extrusions, using similar manufacturing and assembly processes as were used on the baseline. A comparison of the baseline and LWT radiator support is shown in Figure 441. The incremental cost of the LWT radiator support is a savings of $26.31, as shown in **Figure 444**.

Figure 440: Baseline Chevrolet Silverado Radiator Support Assembly

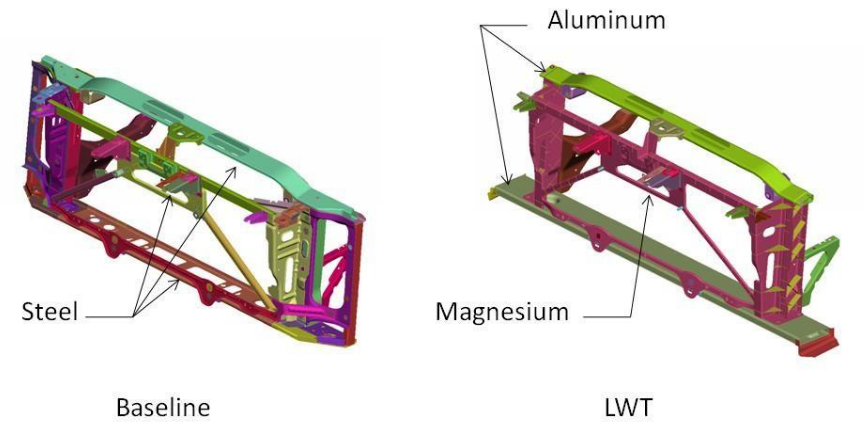


Figure 441: Radiator Support Structure – Baseline Versus LWT

MANUFACTURING TECHNOLOGY BASELINE	PARTS WEIGHT (kg)	PARTS COST ($ USD)
Stamping Single Thickness (Steel)	9.75	58.24
Roll Forming Closed (Steel)	10.23	13.99
Rad Support Structure - Manufacturing	19.98	72.23
Rad Support Structure - Assembly	0.00	28.74
Rad Support Structure - Total	19.98	100.96

Figure 442: Baseline Rad Support Structure Manufacturing and Assembly Costs

MANUFACTURING TECHNOLOGY LWT	PARTS WEIGHT (kg)	PARTS COST ($ USD)
Stamping Single Thickness (Aluminum)	0.61	11.26
High Pressure Die cast (Magnesium)	3.80	25.48
Roll Form (Closed Profile)	3.25	15.09
Rad Support Structure - Manufacturing	7.66	51.83
Rad Support Structure - Assembly	0.00	19.53
Rad Support Structure - Total	7.66	71.37

Figure 443: LWT Rad Support Structure Manufacturing and Assembly Costs

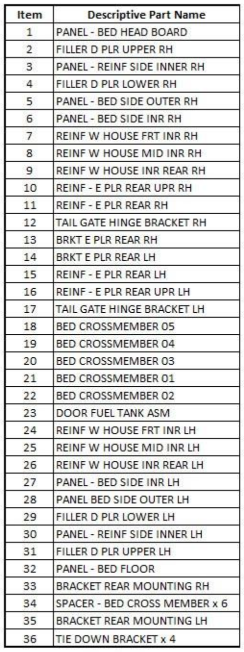
RAD SUPPORT STRUCTURE COST BREAKDOWN	BASELINE COSTS ($ USD)	LWT COSTS ($ USD)	INCREMENTAL COSTS ($ USD)
Material Price	42.57	44.59	2.03
Labor	13.39	8.94	-4.45
Energy	9.49	2.90	-6.59
Equipment	11.00	3.94	-7.06
Tooling	9.16	1.98	-7.18
Building	3.36	2.43	-0.94
Maintenance	2.28	0.69	-1.59
Overhead	9.72	5.89	-3.83
TOTAL	100.96	71.37	-29.60

Figure 444: LWT Radiator Support Incremental Costs

Some of the radiator structure elements are incorporated into the LWT cab structure (see Figure 430). The mass and cost of the LWT radiator is lower compared with the baseline because some of the support structure is integrated into the LWT Cab.

10.7.2 Pickup Box

The baseline 2014 Chevrolet Silverado pickup box is composed of four major sub-assemblies: bed headboard, right hand bedside, left hand bedside and floor. The bed headboard and sides are made of stamped steel inner panels spot-welded to stamped steel outer panels. The floor structure is made of a roll formed panel spot-welded to roll formed and stamped cross members. The four sub-assemblies are spot-welded together to make up the pickup box assembly. An exploded view of the pickup box assembly is shown in Figure 445.



Item	Descriptive Part Name
1	PANEL - BED HEAD BOARD
2	FILLER D PLR UPPER RH
3	PANEL - REINF SIDE INNER RH
4	FILLER D PLR LOWER RH
5	PANEL - BED SIDE OUTER RH
6	PANEL - BED SIDE INR RH
7	REINF W HOUSE FRT INR RH
8	REINF W HOUSE MID INR RH
9	REINF W HOUSE INR REAR RH
10	REINF - E PLR REAR UPR RH
11	REINF - E PLR REAR RH
12	TAIL GATE HINGE BRACKET RH
13	BRKT E PLR REAR RH
14	BRKT E PLR REAR LH
15	REINF - E PLR REAR LH
16	REINF - E PLR REAR UPR LH
17	TAIL GATE HINGE BRACKET LH
18	BED CROSSMEMBER 05
19	BED CROSSMEMBER 04
20	BED CROSSMEMBER 03
21	BED CROSSMEMBER 01
22	BED CROSSMEMBER 02
23	DOOR FUEL TANK ASM
24	REINF W HOUSE FRT INR LH
25	REINF W HOUSE MID INR LH
26	REINF W HOUSE INR REAR LH
27	PANEL - BED SIDE INR LH
28	PANEL BED SIDE OUTER LH
29	FILLER D PLR LOWER LH
30	PANEL - REINF SIDE INNER LH
31	FILLER D PLR UPPER LH
32	PANEL - BED FLOOR
33	BRACKET REAR MOUNTING RH
34	SPACER - BED CROSS MEMBER x 6
35	BRACKET REAR MOUNTING LH
36	TIE DOWN BRACKET x 4

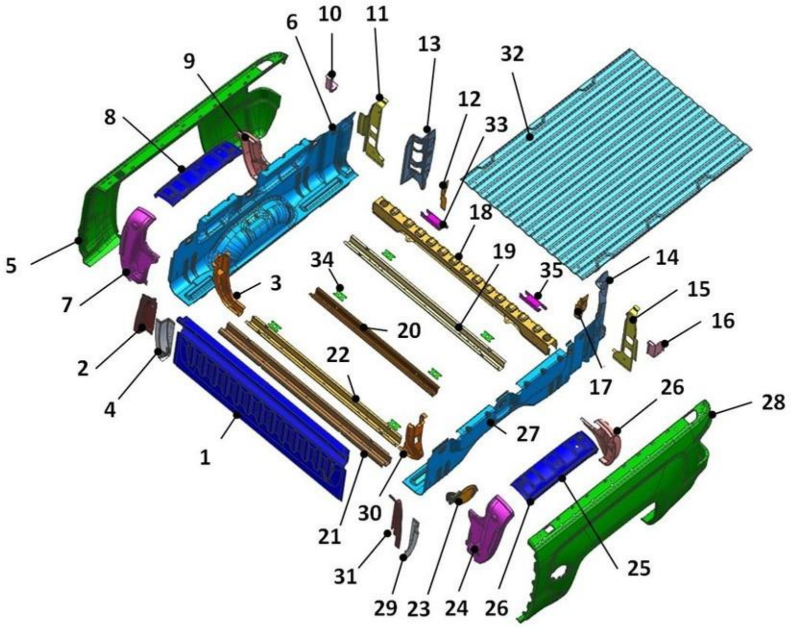


Figure 445: Baseline Pickup Box Exploded View

The LWT pickup box design replaces the baseline’s steel stampings with aluminum, using similar fabrication methods. Stamping accounts for 74 percent of the pickup box structural weight in the baseline and 68 percent in the LWT. Roll forming accounts for 26 percent and 33 percent, respectively. The baseline vehicle and the LWT pickup box manufacturing technology is summarized in Figure 446 and Figure 447 respectively. The LWT pickup box structure incremental costs compared with those of the baseline vehicle are summarized in Figure 448.

MANUFACTURING TECHNOLOGY BASELINE	PARTS WEIGHT (kg)	PARTS COST ($ USD)
Stamping Single Thickness	80.42	166.41
Roll Forming Open	28.69	32.92
Pickup Box Structure - Manufacturing	109.11	199.33
Pickup Box Structure - Assembly	0.00	53.11
Pickup Box Structure - Total	109.11	252.44

Figure 446: Baseline Vehicle Pickup Box Structure Manufacturing and Assembly Costs

MANUFACTURING TECHNOLOGY LWT	PARTS WEIGHT (kg)	PARTS COST ($ USD)
Stamping Single Thickness (Aluminum)	43.23	355.11
Roll Forming Open (Aluminum)	20.95	93.49
Stamping Single Thickness (Steel)	1.13	4.94
Pickup Box Structure - Manufacturing	65.31	453.53
Pickup Box Structure - Assembly	0.00	96.02
Pickup Box Structure - Total	65.31	549.55

Figure 447: LWT Pickup Box Structure Manufacturing and Assembly Costs

PICKUP BOX STRUCTURE COST BREAKDOWN	BASELINE COSTS ($ USD)	LWT COSTS ($ USD)	INCREMENTAL COSTS ($ USD)
Material Price	148.61	424.50	275.89
Labor	22.41	39.18	16.78
Energy	9.77	7.33	-2.43
Equipment	30.19	29.65	-0.53
Tooling	16.74	17.57	0.84
Building	4.99	5.82	0.83
Maintenance	5.26	5.38	0.12
Overhead	14.49	20.10	5.61
TOTAL	252.45	549.55	297.10

Figure 448: Baseline Versus LWT Pickup Box Structure Incremental Costs Summary

10.7.3 Closures

10.7.3.1 Front Doors

The front doors of the baseline 2014 Chevrolet Silverado are constructed of cold-rolled sheet steel of various bake-hardenable grades. The major components of the complete door assembly include the inner and outer panels, intrusion beam, regulator guides, glass, mirror, lock, latch, handles, hinges, electrical components (switches, speakers, wiring, etc.), trim panels, seals, sound insulation, waterproofing, brackets, reinforcements and fasteners. The laser welded inner panel is roller hemmed to the stamped outer panel, while most of the internal components are mechanically fastened or adhesively bonded.

The LWT front door design uses a combination of AHSS and aluminum. The intrusion beam is an AHSS extrusion while the outer door panel is an aluminum stamping. The inner door panel and other various metal parts (reinforcement plates, brackets, etc.) are AHSS stampings. Other components such as the hinges, door lock striker and windows are carried over from the baseline vehicle. A comparison of the baseline and LWT front doors can be seen in Figure 449. Assembly techniques are similar to the baseline doors. The incremental costs of the baseline and LWT left hand front door are summarized in Figure 450, Figure 451 and Figure 452.

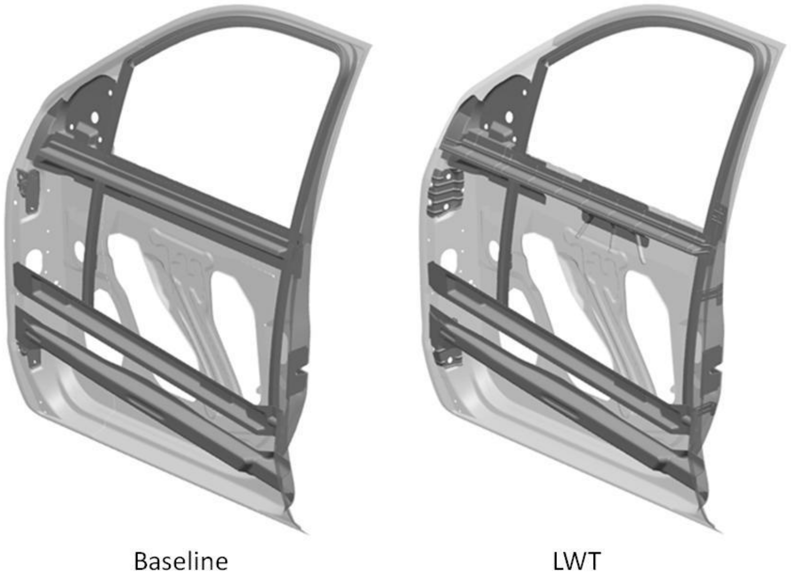


Figure 449: Front Door Frames – Baseline Versus LWT

MANUFACTURING TECHNOLOGY BASELINE	PARTS WEIGHT (kg)	PARTS COST ($ USD)
Stamping Single Thickness	12.95	33.68
Stamping Laser Welded Blanks	9.11	16.00
Roll Formed Open Profile	0.64	0.92
Front Door (LH) Structure - Manufacturing	22.70	50.60
Front Door (LH) Structure - Assembly	0.00	37.98
Front Door (LH) Structure - Total	22.70	88.58

Figure 450: Baseline Front Door Frame Structure Manufacturing and Assembly Costs

MANUFACTURING TECHNOLOGY LWT	PARTS WEIGHT (kg)	PARTS COST ($ USD)
Stamping Single Thickness (Steel)	2.61	14.98
Stamping Laser Welded Blanks	5.93	16.36
Roll Formed Open Profile	0.94	1.35
Stamping Single Thickness (Aluminum)	2.55	19.13
Hot Stamping Single Thickness	3.40	6.57
Front Door (LH) Structure - Manufacturing	15.43	58.39
Front Door (LH) Structure - Assembly	0.00	37.98
Front Door (LH) Structure - Total	15.43	96.37

Figure 451: LWT Front Door Frame Structure Manufacturing and Assembly Costs

FRONT DOOR (LH) STRUCTURE COST BREAKDOWN	BASELINE COSTS ($ USD)	LWT COSTS ($ USD)	INCREMENTAL COSTS ($ USD)
Material Price	31.54	37.63	6.10
Labor	16.62	17.33	0.71
Energy	3.85	4.05	0.20
Equipment	14.35	14.46	0.11
Tooling	6.67	6.35	-0.31
Building	3.86	4.16	0.30
Maintenance	2.51	2.53	0.02
Overhead	9.19	9.85	0.66
TOTAL	88.58	96.37	7.79

Figure 452: LWT Left Hand Front Door Incremental Costs (Mfg. and Assembly) Summary

10.7.3.2 Rear Doors

The rear doors of the baseline 2014 Chevrolet Silverado are, like the front doors, constructed of bake-hardenable, cold-rolled sheet steel. The major components of the complete rear door assembly are the inner and outer panels, intrusion beam, regulator guides, glass, lock, latch, handles, hinges, electrical components (switches, speakers, wiring, etc.), trim panel, seals, sound insulation, waterproofing, brackets, reinforcements and fasteners. As with the front doors, the laser welded inner panel is roller hemmed to the stamped outer panel, while most of the internal components are mechanically fastened or adhesively bonded.

The rear door design approach is similar to the front doors, with aluminum stampings used for the door outer panels and AHSS extrusions and stampings used for the intrusion beam, door inner panel, brackets and reinforcements. The windows, hinges and door lock striker are carried over from the baseline rear doors. Figure 453 shows a comparison of the baseline and LWT rear doorframes. The baseline and LWT left hand rear door incremental costs are summarized in Figure 454, Figure 455 Figure 456

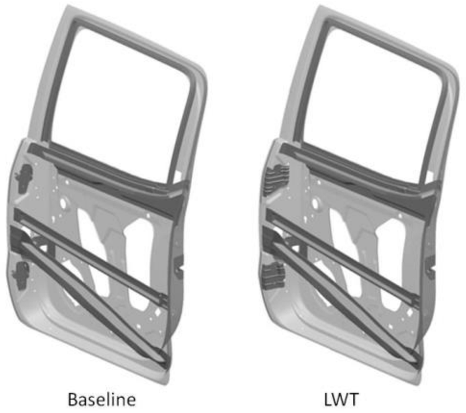


Figure 453: Rear Door Frames – Baseline Versus LWT

MANUFACTURING TECHNOLOGY BASELINE	PARTS WEIGHT (kg)	PARTS COST ($ USD)
Stamping Single Thickness	9.95	28.28
Stamping Laser Welded Blanks	8.62	15.99
Roll Formed Open Profile	1.21	1.79
Rear Door (LH) Structure - Manufacturing	19.78	46.05
Rear Door (LH) Structure - Assembly	0.00	39.91
Rear Door Structure - Total	19.78	85.96

Figure 454: Baseline Rear Door Frame Structure Manufacturing and Assembly Costs

MANUFACTURING TECHNOLOGY	PARTS WEIGHT (kg)	PARTS COST ($ USD)
Stamping Single Thickness (Steel)	2.78	12.16
Stamping Laser Welded Blanks	6.25	14.85
Roll Formed Open Profile	0.90	1.32
Stamping Single Thickness (Aluminum)	2.39	18.81
Hot Stamping Single Thickness	1.40	5.43
Rear Door (LH) Structure - Manufacturing	13.72	52.57
Rear Door (LH) Structure - Assembly	0.00	39.91
Rear Door (LH) Structure - Total	13.72	92.48

Figure 455: LWT Rear Door Frame Structure Manufacturing and Assembly Costs

REAR DOOR (LH) STRUCTURE COST BREAKDOWN	BASELINE COSTS ($ USD)	LWT COSTS ($ USD)	INCREMENTAL COSTS ($ USD)
Material Price	29.00	35.22	6.22
Labor	16.93	17.44	0.52
Energy	3.38	3.39	0.01
Equipment	14.09	13.79	-0.30
Tooling	6.72	6.14	-0.58
Building	4.09	4.34	0.25
Maintenance	2.50	2.46	-0.03
Overhead	9.25	9.69	0.44
TOTAL	85.96	92.48	6.52

Figure 456: LWT Left Hand Rear Door Incremental Costs (Mfg and Assembly) Summary

10.7.3.3 Hood

The inner and outer panels of the baseline 2014 Chevrolet Silverado hood are constructed of aluminum stampings, as are the reinforcements. The inner panel is joined to the outer panel by roller hemming. The hinges, latch and associated hardware are made of mild steel. The pressed fiber hood insulator is attached with fir tree fasteners. The structural components of the baseline hood are shown in Figure 457.

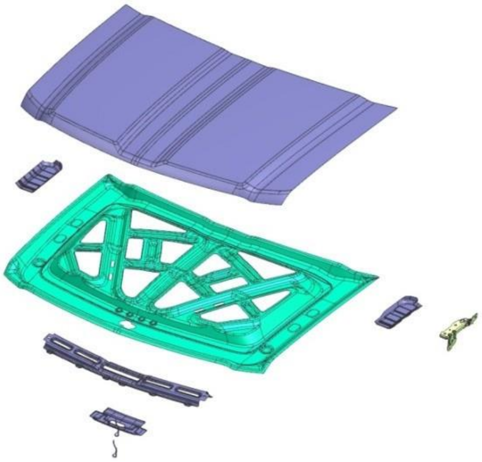


Figure 457: Baseline Silverado Hood Structure

The baseline hood is already a lightweight design and is carried over to the LWT.

10.7.3.4 Tailgate

Like the doors, the tailgate of the 2014 Chevrolet Silverado is composed of a laser-welded inner panel roller hemmed to the stamped outer panel. A removable access panel is bolted to the inner panel. The panels and reinforcements are constructed of mild steel, as are the hinges, latch, and associated hardware. Refer to **Figure 458** for the baseline tailgate structure.

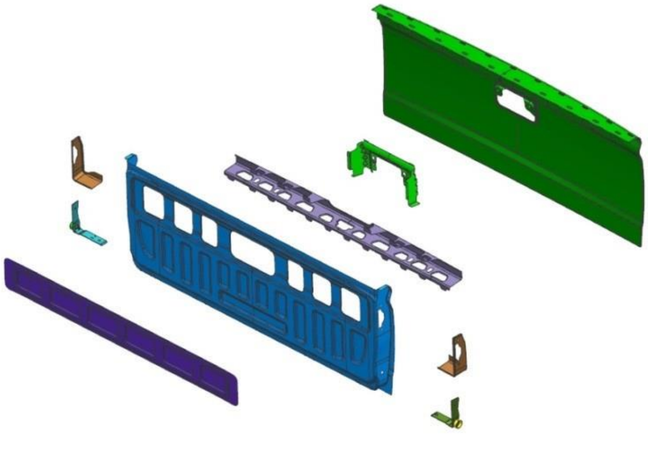


Figure 458: Baseline Silverado Tailgate Structure

The LWT design replaces the baseline steel stampings with aluminum, while keeping the geometry relatively unchanged. The hinges, latch/lock and striker are carried over from the baseline. The LWT tailgate incremental costs are summarized in Figure 459, Figure 460 and Figure 461.

MANUFACTURING TECHNOLOGY	PARTS WEIGHT (kg)	PARTS COST ($ USD)
Stamping Single Thickness Steel	19.99	36.43
Tailgate Structure - Manufacturing	19.99	36.43
Tailgate Structure - Assembly	0.00	25.40
Tailgate Structure - Total	19.99	61.83

Figure 459: Baseline Tailgate Structure Manufacturing and Assembly Costs

MANUFACTURING TECHNOLOGY	PARTS WEIGHT (kg)	PARTS COST ($ USD)
Stamping Single Thickness Steel	5.19	9.07
Stamping Single Thickness Aluminum	7.64	49.10
Tailgate Structure - Manufacturing	12.83	58.16
Tailgate Structure - Assembly	0.00	25.40
Tailgate Structure - Total	12.83	83.56

Figure 460: LWT Tailgate Structure Manufacturing and Assembly Costs

TAILGATE STRUCTURE COST BREAKDOWN	BASELINE COSTS ($ USD)	LWT COSTS ($ USD)	INCREMENTAL COSTS ($ USD)
Material Price	26.29	51.66	25.37
Labor	10.52	10.53	0.01
Energy	1.86	1.77	-0.10
Equipment	8.58	7.16	-1.42
Tooling	4.70	3.02	-1.68
Building	2.46	2.45	-0.01
Maintenance	1.60	4.95	3.35
Overhead	5.83	2.04	-3.79
TOTAL	61.83	83.57	21.74

Figure 461: LWT Tailgate Incremental Costs (Manufacturing and Assembly) Summary

10.7.4 Chassis

The Chevrolet Silverado chassis is composed of the frame, bumpers, towing hitch, front and rear suspension, wheels and tires, brakes and steering system, as shown in **Figure 462**.

Figure 462: 2014 Chevrolet Silverado Chassis System

10.7.4.1 Frame

The baseline Chevrolet Silverado frame assembly, shown in Figure 463, is constructed primarily of steel frame rails, cross members, reinforcements, brackets and shock tower panels. The frame rails are roll formed steel while the cross members, brackets, reinforcements and shock tower panels are stamped steel. The cab isolators (mounts) are made from a combination of steel and elastomers.

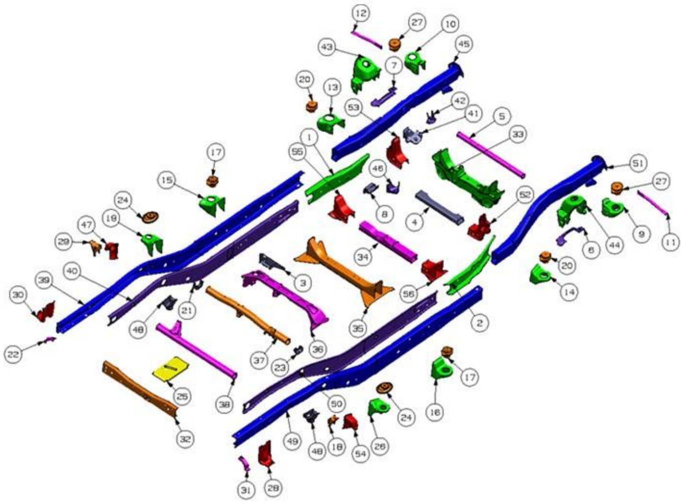


Figure 463: Baseline Silverado Frame Exploded View

The LWT frame assembly replaces the HSS components with AHSS, allowing the metal gages to be reduced. The manufacturing and assembly processes are unchanged. The LWT frame incremental costs are summarized in Figure 464, Figure 465, and Figure 466.

MANUFACTURING TECHNOLOGY	PARTS WEIGHT (kg)	PARTS COST ($ USD)
Stamping Single Thickness	180.76	387.19
Hydroformed Single Thickness	45.80	58.16
Frame Structure - Manufacturing	226.56	445.35
Frame Structure - Assembly	0.00	99.68
Frame Structure - Total	226.56	545.03

Figure 464: Baseline Frame Structure Manufacturing and Assembly Costs

MANUFACTURING TECHNOLOGY	PARTS WEIGHT (kg)	PARTS COST ($ USD)
Stamping Single Thickness Steel	109.82	308.76
Hydroformed Single Thickness	25.68	43.49
Closed Roll Formed	40.19	84.71
Stamping Single Thickness Aluminum	3.19	23.41
Stamping Single Thickness Steel (TRB)	33.84	60.73
Manufacturing	212.71	521.10
Assembly		99.68
Total Frame	212.71	620.78

Figure 465: LWT Frame Structure Manufacturing and Assembly Costs

FRAME STRUCTURE COST BREAKDOWN	BASELINE COSTS ($ USD)	LWT COSTS ($ USD)	INCREMENTAL COSTS ($ USD)
Material Price	329.58	421.40	91.82
Labor	26.92	17.88	-9.04
Energy	20.20	22.24	2.04
Equipment	65.55	66.72	1.17
Tooling	48.24	38.84	-9.40
Building	12.18	12.58	0.40
Maintenance	12.61	11.69	-0.92
Overhead	29.78	29.44	-0.34
TOTAL	545.06	620.78	75.72

Figure 466: LWT Frame Incremental Costs Summary

10.7.4.2 Bumpers

The bumper system on the baseline 2014 Chevrolet Silverado is composed of stamped steel bumper panels mechanically fastened to the frame with stamped steel brackets. Exploded views of the front and rear bumpers are shown in **Figure 467**.

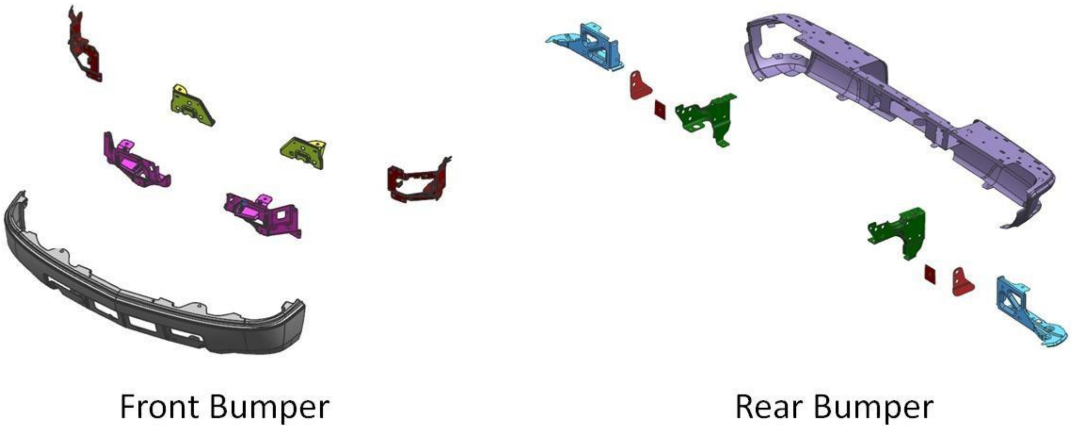


Figure 467: Baseline Silverado Front and Rear Bumpers

The LWT front and rear bumpers are modified designs of the original baseline designs, with substitute AHSS for the baseline steel, allowing the metal gauges to be reduced. The incremental cost impact to produce the front bumper is cost saving of $10.76, while that for the rear bumper it is increase of $3.15 as summarized in Figure 468 and Figure 469 respectively.

FRONT BUMPER STRUCTURE COST BREAKDOWN	BASELINE COSTS ($ USD)	LWT COSTS ($ USD)	INCREMENTAL COSTS ($ USD)
Material Price	62.87	52.10	-10.76
Labor	5.26	5.32	0.06
Energy	1.68	1.74	0.06
Equipment	6.03	6.22	0.19
Tooling	5.26	5.43	0.17
Building	0.76	0.76	0.01
Maintenance	1.23	1.26	0.04
Overhead	2.85	2.90	0.05
TOTAL	85.94	75.74	-10.20

Figure 468: LWT Front Bumper Incremental Costs

REAR BUMPER STRUCTURE COST BREAKDOWN	BASELINE COSTS ($ USD)	LWT COSTS ($ USD)	INCREMENTAL COSTS ($ USD)
Material Price	26.61	29.18	2.56
Labor	3.72	3.78	0.06
Energy	1.09	1.14	0.05
Equipment	4.91	5.11	0.20
Tooling	4.18	4.36	0.18
Building	0.56	0.57	0.00
Maintenance	0.98	1.02	0.04
Overhead	2.04	2.08	0.05
TOTAL	44.08	47.23	3.15

Figure 469: LWT Rear Bumper Incremental Costs

10.7.4.3 Tow Hitch

The Chevrolet Silverado towing hitch assembly is composed of the main hitch tube, hitch receiver and various reinforcements and brackets. All these parts are constructed of roll formed or stamped steel and are MIG-welded together.

The hitch receiver on the LWT has been carried over from the baseline vehicle. AHSS replaced the baseline steel on all the other LWT tow hitch components, and the side bracket attachments to the frame have been redesigned, as shown in Figure 470. The tow hitch incremental costs are summarized in Figure 471.

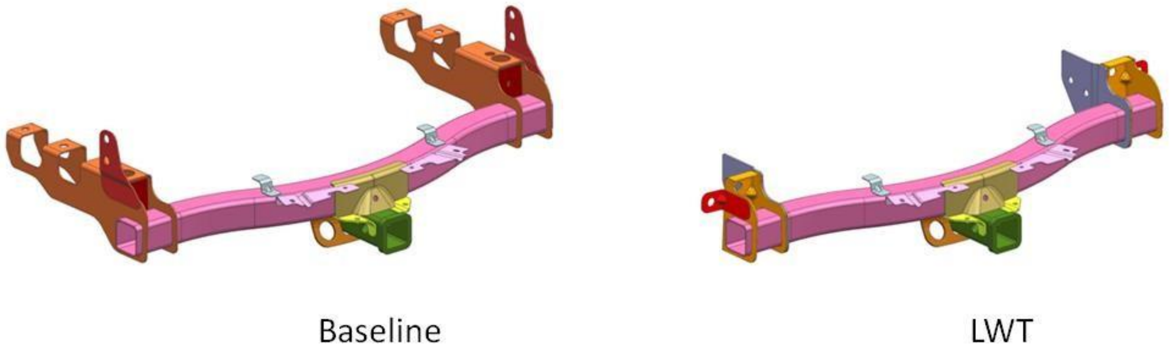


Figure 470: Tow Hitch Assembly – Baseline Versus LWT

TOW HITCH STRUCTURE COST BREAKDOWN	BASELINE COSTS ($ USD)	LWT COSTS ($ USD)	INCREMENTAL COSTS ($ USD)
Material Price	26.61	29.18	2.56
Labor	3.72	3.78	0.06
Energy	1.09	1.14	0.05
Equipment	4.91	5.11	0.20
Tooling	4.18	4.36	0.18
Building	0.56	0.57	0.00
Maintenance	0.98	1.02	0.04
Overhead	2.04	2.08	0.05
TOTAL	44.08	47.23	3.15

Figure 471: LWT Tow Hitch Incremental Costs

10.7.4.4 Front Suspension

The front suspension of the baseline 2014 Chevrolet Silverado is a standard coil-over-shock, double wishbone design consisting of the shock absorbers, coil springs, upper and lower control arms, steering knuckles, hub/bearing assemblies, stabilizer bar, and other miscellaneous parts, as shown in **Figure 472**. The material distribution by mass is approximately 45 percent steel, 37 percent aluminu and 18 percent plastics, elastomers and other materials. The principle steel components are the coil springs, stabilizer bar, and hub/bearings, while the principle aluminum components are the upper control arms, lower control arms, and steering knuckles.

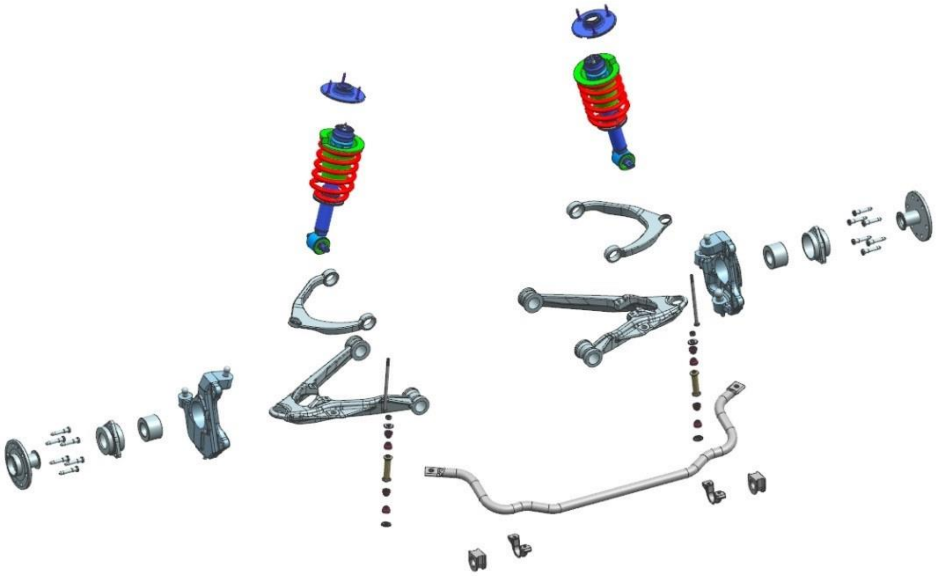


Figure 472: Baseline Chevrolet Silverado Front Suspension Components

The most significant change in the LWT front suspension is a complete redesign of the lower control arm from cast aluminum to stamped AHSS, as shown in Figure 473. The rest of the front suspension design maintains the baseline material selections, but takes advantage of the lower overall vehicle mass to scale down all of the components. The redesigned lower control arm results in a cost savings of $11.29, as shown in Figure 474, while the cost savings from the entire LWT front suspension is $29.25, as summarized in Figure 475.

Figure 473: Lower Control Arm – Baseline Versus LWT

FRAME STRUCTURE COST BREAKDOWN	BASELINE COSTS ($ USD)	LWT COSTS ($ USD)	INCREMENTAL COSTS ($ USD)
Material Price	19.21	17.60	-1.61
Labor	6.44	1.27	-5.17
Energy	1.78	0.44	-1.34
Equipment	3.53	2.83	-0.70
Tooling	1.93	2.34	0.41
Building	0.38	0.74	0.36
Maintenance	0.29	0.58	0.29
Overhead	4.94	1.41	-3.53
TOTAL	38.50	27.21	-11.29

Figure 474: LWT Lower Control Arm Incremental Costs

Component	Front Suspension (per vehicle)	
	Mass Reduction	Cost Increase
	Mass Saving (kg)	Incremental ($)
AHSS LCA and Downsize	7.21	-29.25
Upper Control Arm (Alum)	0.40	-1.17
Lower Control Arm (Alum to Steel)	-0.60	-11.29
Coil Spring (Steel)	1.55	-3.34
Shock Absorber Assembly	1.66	-3.58
Stabilizer Bar Assembly (Steel)	0.97	-2.10
Steering Knuckle (Alum)	1.07	-3.13
Hub, Bearing, and Misc.	2.16	-4.65

Figure 475: LWT Front Suspension Incremental Cost

10.7.4.5 Rear Suspension

The baseline 2014 Chevrolet Silverado uses a semi-elliptical, 2-stage multi-leaf spring rear suspension. The major components of the rear suspension are the leaf spring blades, supports, mounts, and shock absorbers, as shown in Figure 476. Steel is the primary material used in the rear suspension module (87% by mass) with the exceptions being the leaf spring top plate (aluminum), shock absorber assemblies, and a small amount of elastomeric material.

Figure 476: Baseline Chevrolet Silverado Rear Suspension Components

The LWT rear suspension design replaces the steel leaf spring blades with GFRP and scales down the other components by taking advantage of the overall lower vehicle mass. The incremental cost increase for the LWT rear suspension is $56.59 per vehicle, as shown in Figure 477.

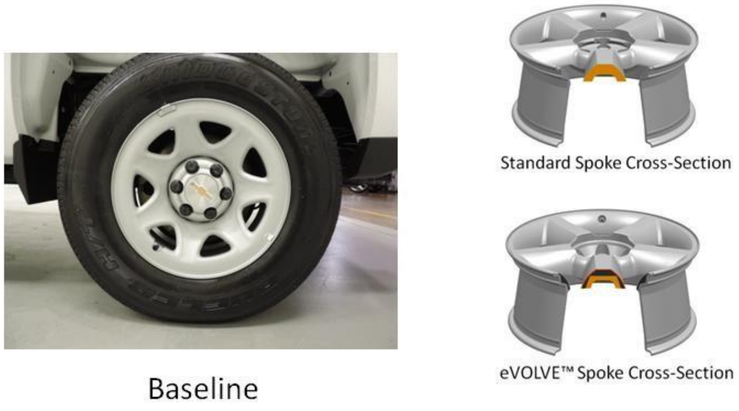
Component	Rear Suspension (per vehicle)	
	Mass Reduction	Cost Increase
	Mass Saving (kg)	Incremental ($)
Leaf Springs: 1 Steel + 2 Fiberglass	19.25	56.59
Leaf Spring Blades (Steel and GFRP)	17.88	54.76
Leaf Spring Support (Steel)	0.43	-0.57
Leaf Spring Top Plate (Alum)	0.11	-0.73
Leaf Spring Body Mounts	0.21	-0.28
Rear Axle Assembly (Steel)	0.09	-0.12
Shock Absorber Assembly	0.52	-0.69

Figure 477: LWT Rear Suspension Incremental Costs

10.7.4.6 Wheels and Tires

The baseline wheel and tire system consists of four road wheels/tires, a spare wheel/tire, jack, tools and spare tire mounting hardware. The road tires are standard tubeless tires while the road wheel rims, jack, tools and mounting hardware are steel. The spare tire is the same as the road tire, but the spare rim is aluminum rather than steel.

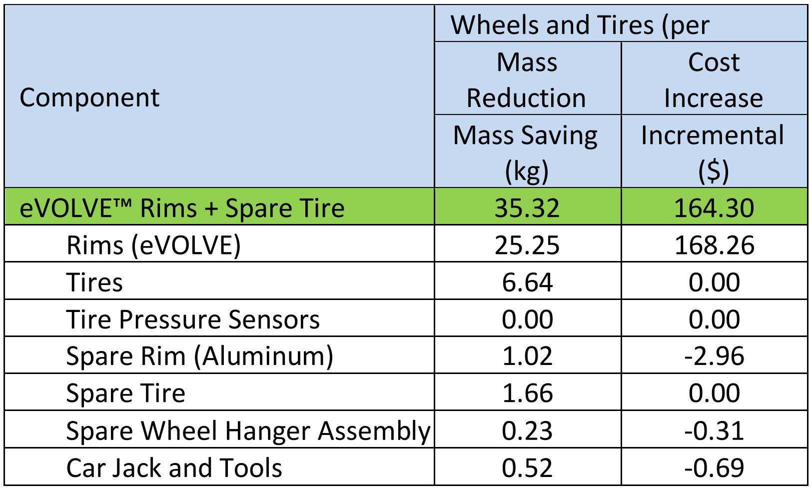
The LWT replaces the baseline steel rims with eVOLVE hybrid wheels from Lacks Wheel Trim Systems, LLC, as shown in Figure 478. In addition, other components are downsized, taking advantage of the overall reduced vehicle mass. This change results in an incremental cost increase of $164.30 per vehicle, as illustrated in Figure 479**.**


Baseline

Standard Spoke Cross-Section

eVOLVE™ Spoke Cross-Section

Figure 478: Baseline Wheels Versus LWT Wheels



Component	Wheels and Tires (per	
	Mass Reduction	Cost Increase
	Mass Saving (kg)	Incremental ($)
eVOLVE™ Rims + Spare Tire	35.32	164.30
Rims (eVOLVE)	25.25	168.26
Tires	6.64	0.00
Tire Pressure Sensors	0.00	0.00
Spare Rim (Aluminum)	1.02	-2.96
Spare Tire	1.66	0.00
Spare Wheel Hanger Assembly	0.23	-0.31
Car Jack and Tools	0.52	-0.69

Figure 479: LWT Wheels and Tires Incremental Costs

10.7.4.7 Brakes

The baseline Chevrolet Silverado features a conventional 4-wheel antilock disc brake system. This system includes the master cylinder, hydraulic lines, discs, calipers, brake pads, parking brakes, ABS and various shields, brackets, and sensors. The front discs, front calipers, and rear discs are cast iron while the rear calipers are cast aluminum.

The reduced weight of the LWT allows the brake system (master cylinder, calipers, pads, and discs) to be scaled down without degrading vehicle performance. In addition, the cast iron front calipers are replaced by cast aluminum. Replacing the baseline mechanical parking brake with an electric parking brake offers potential for cost savings, however for this study the costs are assumed to be neutral. The ABS system and brake lines are carried over from the baseline. The overall cost effect of these changes is a savings of $12.01 per vehicle, as shown in Figure 480.

Component	Brake System	
	Mass Reduction	Cost Increase
	Mass Saving (kg)	Incremental ($)
Brake System - Iron Discs	8.97	-12.01
Master Cylinder Assembly	0.00	
Front Discs (Iron)	2.36	-4.77
Front Calipers (Iron --> Alum)	3.56	-1.32
Front Pads	0.12	0.00
Rear Discs (Iron)	1.93	-3.89
Rear Calipers (Aluminum)	0.38	-1.10
Rear Pads	0.07	0.00
Park Brake to EPB	0.10	0.00
ABS System	0.00	0.00
Brakelines	0.00	0.00
Caliper Supports	0.46	-0.93

Figure 480: LWT Brake System Incremental Costs

10.7.4.8 Steering

The baseline Chevrolet Silverado uses an electric power steering system consisting of the steering column assembly, steering wheel, rack, and electric motor. These components are primarily constructed of steel except for the steering wheel (magnesium casting covered with a nylon overwrap), air bag assembly, electrical parts, and a small amount of plastic trim.

The LWT design replaces the steel steering column with cast magnesium and, taking advantage of the lower overall vehicle mass, scales down the steering rack assembly and motor. The changes to the steering motor are expected to be cost neutral. The steering wheel assembly is carried over from the baseline Silverado. The overall effect is an incremental cost increase of $11.89, as shown in Figure 481.

Vehicle Sub-System	Steering System	
	Mass Reduction	Cost Increase
	Mass Saving (kg)	Incremental ($)
Steering System	4.38	11.89
Steering Column Assembly	3.22	15.33
Steering Wheel Assembly	0.00	0.00
Steering Rack Assembly	0.93	-3.45
Steering Motor	0.23	0.00

Figure 481: LWT Steering System Incremental Costs

10.7.5 Powertrain

The baseline Chevrolet Silverado powertrain system is composed of the engine, transmission (including front differential, transfer case and rear axle/differential), drive shafts, fuel system, exhaust system, and engine cooling system, as shown in Figure 482.

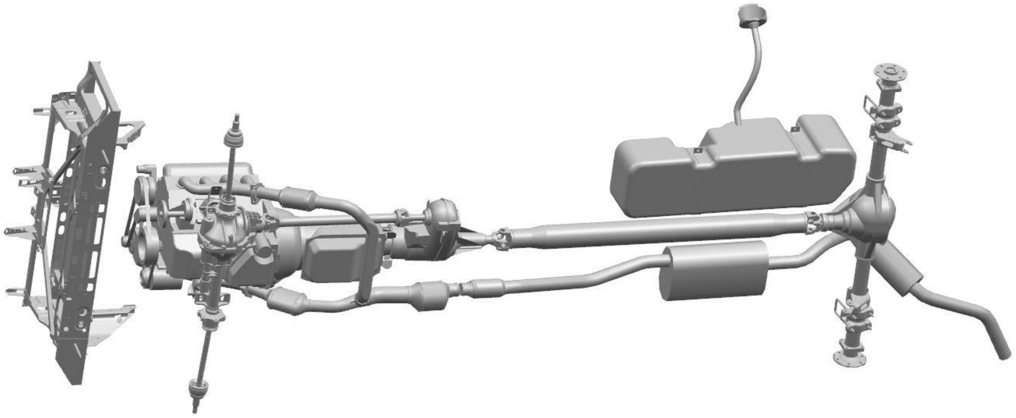


Figure 482: Baseline Chevrolet Silverado Powertrain System

10.7.5.1 Engine

The engine used in the baseline 2014 Chevrolet Silverado is an aluminum block 5.3 liter Ecotec3 V8. This engine is composed of approximately 46 percent steel, 43 percent aluminum and 11 percent various other materials. An exploded view of the complete engine can be seen in **Figure 483**. It is a very lightweight design and does not offer many mass reduction opportunities.

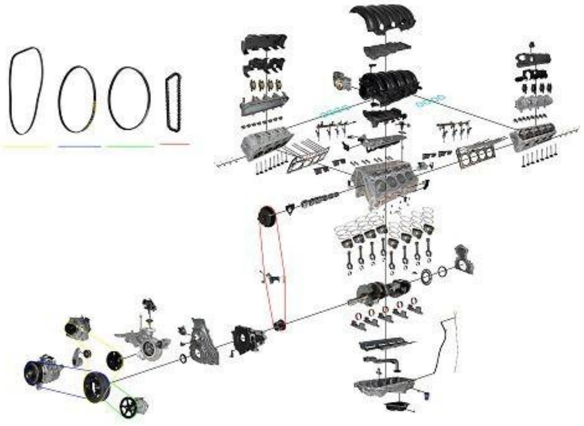


Figure 483: Baseline Chevrolet Silverado 5.3L Engine, Exploded View (A2Mac1)

The LWT engine design is able to take advantage of the overall lower vehicle mass to scale down the size of the engine without sacrificing performance. While a detailed engine incremental costs study is not within the scope of this study, the LWT incremental cost effect based upon the material cost estimates represent a savings of $19.77 per vehicle, as shown in Figure 484.

Vehicle Sub-System	Engine	
	Mass Reduction	Cost Increase
	Mass Saving (kg)	Incremental ($)
Engine	7.43	-19.79
Fuel Injection System	0.33	-1.70
Engine Block	1.48	-5.23
Engine Mounts	0.39	-0.61
Cylinder Head	1.48	-3.70
Crankshaft System	2.85	-5.38
Front Engine System	0.03	-0.04
Lubrication System	0.60	-2.06
Cooling System	0.22	-0.70
Style Cover	0.06	-0.35

Figure 484: LWT Engine Incremental Costs[190]

10.7.5.2 Engine Cooling

The 2014 Chevrolet Silverado uses a conventional water cooled engine with a radiator, water pump, fan, thermostat, hoses, and fittings. The aluminum radiator makes up 50 percent of the engine cooling system mass while plastics and rubber account for the rest. The engine cooling system in the LWT is downsized based upon the lower overall vehicle mass. The resulting cost saving is $4.18, as shown in Figure 485. All manufacturing and assembly processes are carried over from the baseline. The water pump is not shown here as it is included with the engine.

Vehicle Sub-System	HVAC	
	Mass Reduction	Cost Increase
	Mass Saving (kg)	Incremental ($)
Water Cooling	0.93	-4.18
Radiator	0.50	-1.46
Radiator Support Inner Shroud and	0.00	0.00
Hoses	0.08	-0.52
Fan System	0.28	-1.75
Expansion Bottle and Purge Pipe	0.07	-0.44

Figure 485: LWT Engine Cooling Incremental Costs

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[190] All engine specifications and weights obtained from A2Mac1; incremental costs based on material savings

10.7.5.3 Transmission

The baseline 2014 Chevrolet Silverado comes equipped with a 6-speed automatic transmission with overdrive and manually switched 4WD. The transmission, transfer case assembly, and front differential are each constructed of an aluminum housing surrounding hardened steel internal components. The rear axle/differential assembly is constructed of a cast steel housing with hardened steel used for the differential and other internal components. Based upon mass, these components are composed of approximately 75 percent steel, 18 percent aluminum and 7 percent various other materials.

The most significant change incorporated into the LWT transmission design is replacing the cast steel rear axle/differential housing with cast aluminum. In addition to this, the LWT design takes advantage of the lower overall vehicle mass to scale down all of the transmission components. The manufacturing and assembly processes are the same as those used for the baseline. These changes result in a cost savings of $13.01 based on material costs only, as illustrated in Figure 486.

Components	Transmission	
	Mass Reduction	Cost Increase
	Mass Saving (kg)	Incremental ($)
Downsize; Rear Diff. Housing to Alum	23.17	13.01
Automatic Gearbox	4.03	-8.36
Shift Lever Mechanism	0.00	0.00
Front Drive Shaft//Differential	2.37	-4.16
Intermediate Transmission	0.00	0.00
Rear Drive Shaft/Differential	14.65	29.40
Transfer Case	2.10	-3.88
4x4 Activation System	0.00	0.00

Figure 486: LWT Transmission Incremental Costs[191]

10.7.5.4 Drive Shafts

The baseline Chevrolet Silverado is a -4wheel drive vehicle with a manual transfer case. This system includes six drive shafts, as shown in Figure 487. The rear intermediate drive shaft is constructed of tubular aluminum while the front intermediate shaft is tubular steel. The remaining four drive shafts are conventional steel bar construction.

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[191] All transmission specifications and weights obtained from A2Mac1; incremental costs based on material savings

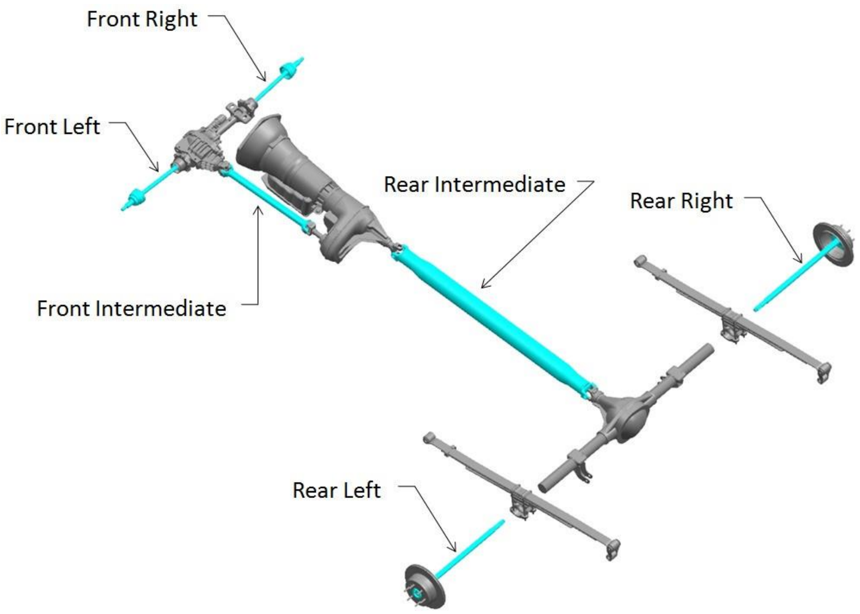


Figure 487: Baseline Chevrolet Silverado Drive Shafts

The LWT takes advantage of the lower overall vehicle mass to scale down the drive shafts while using the same manufacturing processes as the baseline, resulting in a cost savings of $7.74 (refer to Figure 488).

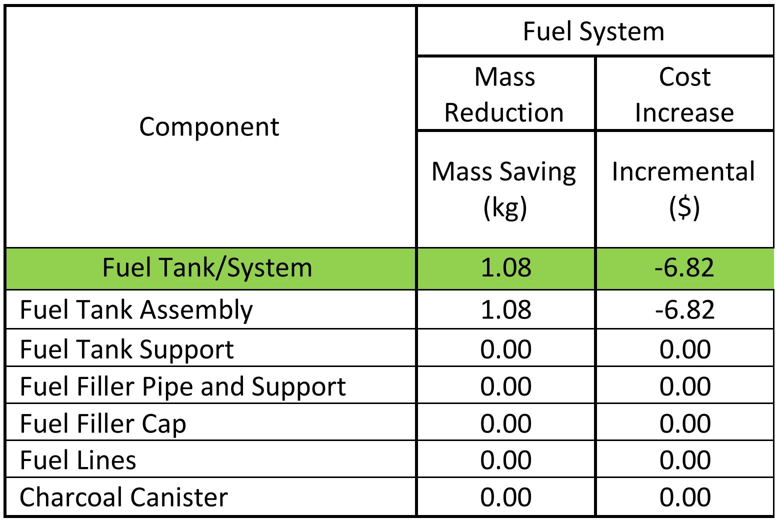
Component	Drive Shafts	
	Mass Reduction	Cost Increase
	Mass Saving (kg)	Incremental ($)
Downsize	2.69	-7.74
Front Drive Shafts (Steel)	0.86	-1.85
Interm. Drive Shaft, Frt (Steel)	0.33	-0.71
Interm. Drive Shaft, RR (Alum)	0.43	-2.88
Rear Drive Shafts (Steel)	1.07	-2.30

Figure 488: LWT Drive Shaft Incremental Costs

10.7.5.5 Fuel System

The baseline Chevrolet Silverado fuel system is composed of a 26-gallon (98.4 liter) plastic fuel tank, tank protection and supports, filler pipe, filler cap, charcoal canister, and fuel lines. Steel accounts for 19 percent of the fuel system mass (filler pipe, fuel lines, and supports) while plastics and other materials make up the remaining 81 percent. Fuel mass, which is covered in the Fluid section of this report, is not reflected in these percentages.

The lower overall vehicle mass makes it possible to reduce the capacity and size of the fuel tank while maintaining the same driving range as the baseline vehicle. This results in a manufacturing cost reduction of $6.82. As can be seen in Figure 489, the remaining fuel system components are carried over from the baseline.



Component	Fuel System	
	Mass Reduction	Cost Increase
	Mass Saving (kg)	Incremental ($)
Fuel Tank/System	1.08	-6.82
Fuel Tank Assembly	1.08	-6.82
Fuel Tank Support	0.00	0.00
Fuel Filler Pipe and Support	0.00	0.00
Fuel Filler Cap	0.00	0.00
Fuel Lines	0.00	0.00
Charcoal Canister	0.00	0.00

Figure 489: Fuel System Incremental Costs

10.7.5.6 Exhaust System

The baseline Chevrolet Silverado uses a conventional exhaust system composed of manifolds, exhaust pipes, catalytic converter, muffler, heat shields, seals, and hangers, as shown in Figure 490. Most of the components are steel with the exception of the hangers (a combination of rubber and steel) and the inner components of the catalytic converter.

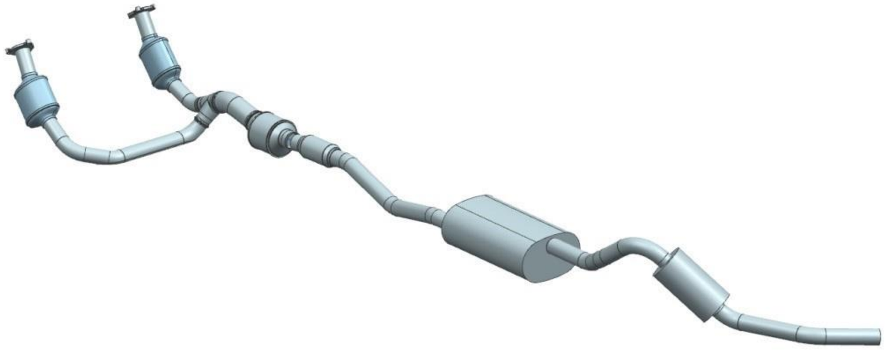
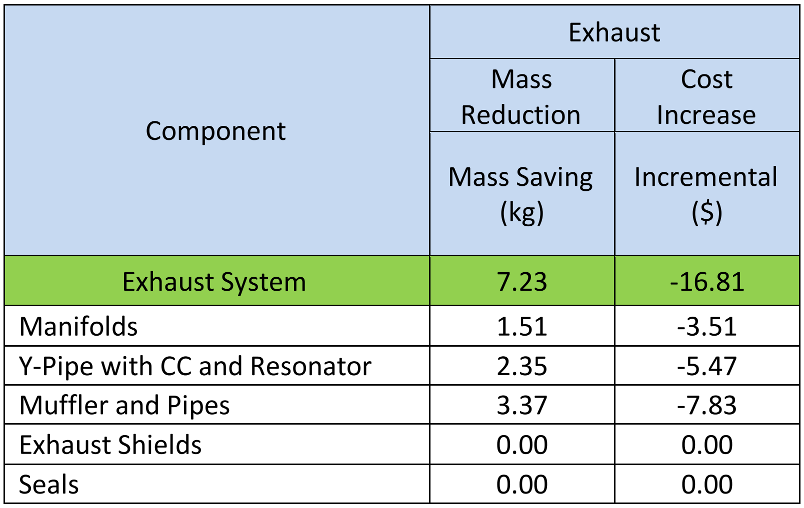


Figure 490: Baseline Chevrolet Silverado Exhaust System

The LWT exhaust design is scaled down from the baseline due to the reduction in overall vehicle mass, resulting in a cost reduction of $16.81 per vehicle, as shown in Figure 491. Due to thermal requirements, the shields and seals are carried over from the baseline Silverado. Manufacturing and assembly processes are unchanged from the baseline.



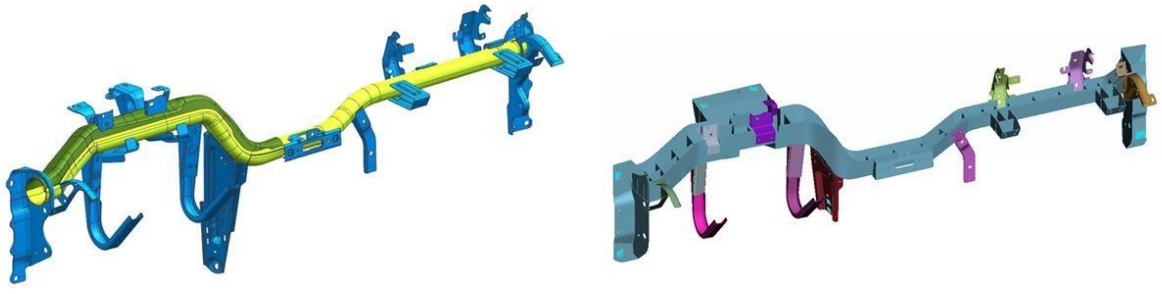
Component	Exhaust	
	Mass Reduction	Cost Increase
	Mass Saving (kg)	Incremental ($)
Exhaust System	7.23	-16.81
Manifolds	1.51	-3.51
Y-Pipe with CC and Resonator	2.35	-5.47
Muffler and Pipes	3.37	-7.83
Exhaust Shields	0.00	0.00
Seals	0.00	0.00

Figure 491: LWT Exhaust System Incremental Costs

10.7.6 Instrument Panel

The baseline 2014 Chevrolet Silverado instrument panel assembly is constructed of a cross-car beam, carrier, upper and lower covers, HVAC ducts/vents, glove box and door, electronics (instrument cluster, radio, GPS, HVAC controls, center display and various control modules), inflatable restraint system, bezels, brackets, and mounts. The mounting brackets allow for the attachment of the cross-car beam to the body structure and instrument panel assembly, in addition to providing attachment points for the steering column and passenger air bag module.

As can be seen in Figure 492, the cross-car beam is tubular steel while the brackets and mounts welded to it are stamped steel. This assembly accounts for 38 percent of the instrument panel mass. Most of the other components, aside from electronics and inflatable restraint system, are various types of plastics.



Baseline

LWT

Figure 492: I/P Cross-Car Beam Assembly – Baseline Versus LWT

The LWT design replaces the steel cross-car beam with cast magnesium. The incremental costs of the magnesium cross-car beam were estimated based upon the assumption that all the design parameters required to facilitate the magnesium casting process are incorporated into the cross-car beam. The tooling and equipment costs were estimated through consultation with suppliers and industry experts. The additional assembly costs of welding the brackets and mounts to the cross-car beam in the baseline vehicle are eliminated in the LWT by incorporating them into the basic casting. The incremental costs are summarized in Figure 493, Figure 494 and Figure 495.

MANUFACTURING TECHNOLOGY	PARTS WEIGHT (kg)	PARTS COST ($ USD)
Stamping Single Thickness	10.22	36.49
Roll Forming Closed Profile	1.97	2.01
IP Beam Structure - Manufacturing	12.19	38.50
IP Beam Structure - Assembly	0.00	12.48
IP Beam Structure - Total	12.19	50.98

Figure 493: Baseline IP Beam Structure Manufacturing and Assembly Costs

MANUFACTURING TECHNOLOGY	PARTS WEIGHT (kg)	PARTS COST ($ USD)
Stamping Single Thickness (Aluminum)	2.91	14.89
High Pressure Diecast (Magnesium)	3.90	26.77
IP Beam Structure - Manufacturing	6.81	41.66
IP Beam Structure - Assembly	0.00	13.12
IP Beam Structure - Total	6.81	54.78

Figure 494: LWT IP Beam Structure Manufacturing and Assembly Costs

IP BEAM STRUCTURE COST BREAKDOWN	BASELINE COSTS ($ USD)	LWT COSTS ($ USD)	INCREMENTAL COSTS ($ USD)
Material Price	15.88	28.03	12.15
Labor	5.09	5.67	0.58
Energy	4.47	2.64	-1.83
Equipment	9.19	6.14	-3.05
Tooling	7.35	4.63	-2.72
Building	1.93	1.82	-0.11
Maintenance	1.84	1.11	-0.73
Overhead	5.23	4.74	-0.49
TOTAL	50.98	54.78	3.80

Figure 495: Instrument Panel Beam Incremental Costs

The I/P carrier, HVAC ducting, electronics housings and plastic storage/trim parts incorporate Trexel's MuCell microcellular polymer technology. Wittmann Battenfeld's Cellmould foaming core sandwich structure technology is used on the upper and lower covers.
Incorporating MuCell and Cellmould technologies are expected to be cost neutral as the design process and tooling resources are the same as those in the baseline.

10.7.7 Seats and Center Console

The baseline 2014 Chevrolet Silverado 40/20/40 split bench front seat is of a conventional design with respect to materials and construction. It consists of a frame, base, tracks, riser, recline and lumbar adjustment mechanisms, safety restraints, seat belt attachment anchors, foam cushioning, fabric cover and plastic garnishments. Fore and aft, recline and lumbar support adjustments for the front seats (driver and passenger) are manually operated. A teardown analysis was conducted to assess the individual parts and the structure of the front and rear seat assemblies and the center console. The teardown analysis results were compared to the available technical cost analysis data of similar seats used in full-size pickup trucks. The historical data of similar detailed cost study results were used as the basis for developing the incremental costs summarized in Figure 496 and Figure 497.

Component	Front Seat and Center Console	
	Mass Reduction	Cost Increase
	Mass Saving (kg)	Incremental ($)
Multi-Material Solution (Gen 3)	16.98	89.40
Frame and Base (AHSS, Alum,	13.96	81.22
Foam	1.23	0.00
Fabric (Microfiber)	0.47	0.00
Others	1.32	8.18

Figure 496: LWT Front Seats (Passenger and Driver Side) Incremental Costs

Component	Rear Seat	
	Mass Reduction	Cost Increase
	Mass Saving (kg)	Incremental ($)
Multi-Material Solution (Gen 3)	11.97	48.30
Frame and Base (AHSS, Alum,	10.26	45.88
Foam	0.84	0.00
Fabric (Microfiber)	0.48	0.00
Others	0.39	2.42

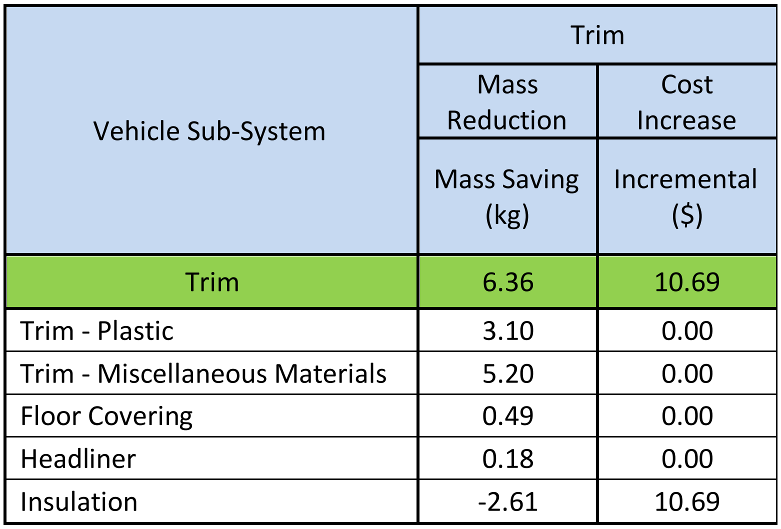
Figure 497: LWT Rear Seats Incremental Costs

The incremental costs of the future lightweight seat technologies were calculated using the seating technologies matrix developed through discussion with a leading seat supplier. Due to the unavailability of detailed design, the TCM methodology could not be applied for cost estimation of the LWT seats. The future lightweighting technologies cost increment estimated by the supplier ranges from 10 percent to 30 percent, depending up on the technologies involved.

10.7.8 Trim and Insulation

The Chevrolet Silverado exterior trim consists of air dams/spoilers, moldings, weather-stripping, bumper trim, splash shields, exterior mirrors, and badging, etc. The interior trim consists of garnish moldings, door trim, floor coverings, and headliners, etc. Most of the baseline exterior and interior trim is constructed of injection molded plastics with fabrics, pressed fiber, foam, and rubber used where needed. The majority of the insulation in the baseline Chevrolet Silverado, consisting of conventional cotton fiber batting, is located in the front of dash, cab rear, floor, doors, and overhead.

The LWT incorporates lightweight plastics technology, such as MuCell and Cellmould, where feasible on trim applications. Some parts, in particular those with Class A surfaces, do not lend themselves to these new technologies and are being carried over from the baseline. The baseline insulation is replaced with 3M's Thinsulate. A summary of the incremental costs can be seen in Figure 498.



Vehicle Sub-System	Trim	
	Mass Reduction	Cost Increase
	Mass Saving (kg)	Incremental ($)
Trim	6.36	10.69
Trim - Plastic	3.10	0.00
Trim - Miscellaneous Materials	5.20	0.00
Floor Covering	0.49	0.00
Headliner	0.18	0.00
Insulation	-2.61	10.69

Figure 498: LWT Trim Incremental Costs

10.7.9 Entertainment

The baseline Chevrolet Silverado is equipped with the optional MyLink 4.2" Diagonal Color Radio system that includes a conventional AM/FM/CD radio, six speakers, and GPS. The baseline entertainment system uses the latest lightweight components; therefore, the baseline entertainment system is carried over to the LWT.

10.7.10 Control Systems

The Chevrolet Silverado control systems include the accelerator pedal, brake pedal, parking brake lever, gear selector handle and housing assembly, transfer case handle and housing assembly, linkages, brackets, and switches. The total mass of these components is 5.44 kg of which steel accounts for 2.07 kg and plastics 1.66 kg. The remaining 1.71 kg are fasteners and various materials.

The minimal mass saving potential offered by redesigning new control systems do not justify the costs and resources needed. Therefore, these baseline components are carried over to the LWT.

10.7.11 Locks, Latches and Hinges

As was mentioned in the closure section of this report, LWT locks, latches, and hinges are carried over from the baseline.

10.7.12 HVAC System

The HVAC system in the baseline Chevrolet Silverado consists of the HVAC unit, compressor, ducting, tubing, hoses, connectors and fasteners. The LWT design replaces steel housings with low density plastics as well as incorporating MuCell technology into ducts (as was previously mentioned). The tubing, hoses, connectors, and fasteners are carried over from the baseline Silverado. The incremental costs of the HVAC system can be seen in Figure 499.

Vehicle Sub-System	HVAC	
	Mass Reduction	Cost Increase
	Mass Saving (kg)	Incremental ($)
HVAC	2.16	-2.87
Air Filter	0.02	-0.15
Housing Assembly	0.21	-1.31
Air Intake Resonator Assembly	0.22	-1.41
HVAC Unit	0.51	0.00
Compressor	0.29	0.00
Ducting	0.91	0.00

Figure 499: LWT HVAC System Incremental Costs

10.7.13 Electrical System

The baseline Chevrolet Silverado electrical system consists of the battery, lighting, wiring, modules/relays, computers, connectors and fasteners. Wiring accounts for 49 percent of the mass of this system with the battery (34%) and lighting, modules, relays and sensors (17%) making up the rest. The LWT will use a standard lead-acid battery, but will take advantage of the lower overall vehicle mass to downsize it. Where possible, the copper wiring will be replaced by copper clad aluminum. This replacement cannot be made in under hood applications or where the larger gage CCA wiring violates space constraints. Taking those restrictions into account, approximately 24 percent of the vehicle wiring can be replaced by CCA, while the rest will be carried over from the baseline. The headlight and taillight housings will incorporate MuCell microcellular polymer technology. The downsized battery and MuCell applications are considered cost neutral for this study. Figure 500 shows the incremental costs of the LWT electrical system.

Component	Electrical	
	Mass Reduction	Cost Increase
	Mass Saving (kg)	Incremental ($)
Electrical - Lead Acid Battery	4.87	-28.07
Wiring (Copper Clad Aluminum)	1.38	-28.07
Wiring (Copper)	0.00	0.00
Battery	1.55	0.00
Head Lamps (MuCell Housings)	1.54	0.00
Tail Lamps (MuCell Housings)	0.40	0.00

Figure 500: LWT Electrical System Incremental Cost

10.7.14 Glazings

The glazings on the baseline Chevrolet Silverado include the windshield, front door glass, rear door glass and rear window (backlite). The 5 mm thick windshield is constructed of inner and outer layers of conventional soda lime float glass laminated around a center layer of polyvinyl butyral. The front door glazing is a single layer of tempered glass with a thickness of 5 mm. The rear door and backlite glazings are 4 mm thick, single layer tempered glass.

Advanced glazing technologies that will be available for high-volume production in the 2020-2030 time frame do not provide adequate mass savings to justify the costs associated with implementing them. Therefore, the LWT carries over the baseline glazings.

10.7.15 Washers/Wipers

The windshield washing/wiping system is composed of the wiper arms/blades, motor, pump, reservoir, tubes and fluid.

The most likely candidate for mass savings in the windshield washer/wiper system is reducing the volume of the washer fluid reservoir. However, that requires the consumer to fill the reservoir more frequently and increases the risk of it running dry. This would be seen by the consumer as a degradation of the system’s performance and, therefore, will not be implemented on the LWT. The baseline system has been carried over.

10.7.16 Safety Systems

The Chevrolet Silverado safety system consists of seat belts, air bags, sensors and mechanical fasteners. The majority of materials used in seat belts and air bags are lightweight polyester and nylon. These materials are mounted to control surfaces and pyrotechnic devices, such as air bag inflators, that are typically constructed of steel to withstand the forces and heat generated during deployment.

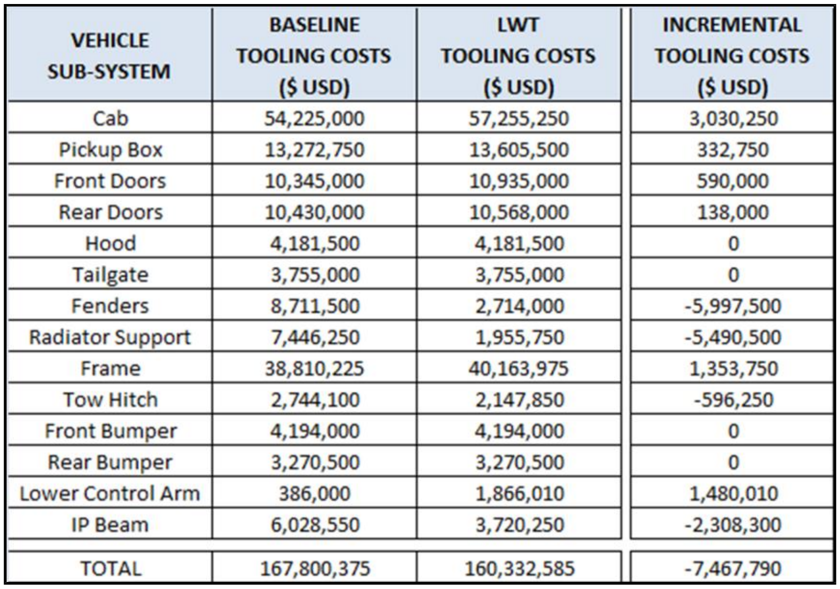
The potential mass savings from a redesign of the safety systems do not justify the development, validation and manufacturing costs that would be required. Therefore the LWT has carried over the baseline system.

10.7.17 Fluids

Fluids used in the Chevrolet Silverado include fuel, engine oil, transmission oil, engine coolant, brake fluid, power steering fluid, air conditioning gas, windshield washer fluid, front differential oil, rear differential oil and transfer case oil. As was repeatedly discussed in this report, the overall vehicle mass reduction of the LWT allows many systems to be downsized. This is true of the fluid volumes also.

10.8 Capital Expenditure

Significant costs are involved in building new tools for the different LWT sub-systems. Costs for stamping dies, extrusion dies, holding fixtures, and cutting tools, etc., were amortized to calculate a cost per system and are summarized in **Figure 501**. In cases where the number of parts in an assembly is the same for the LWT as it was for the baseline, it is assumed that the tooling costs are unchanged. Tooling is typically owned by the OEM and considered as capital expenditure. Mass savings in other vehicle systems (such as engine, transmission, drive shafts, front suspension, fuel system, and exhaust) resulted from direct material substitution or downsizing for the lighter vehicle. In these cases the tooling costs were predominantly cost neutral.



VEHICLE SUB-SYSTEM	BASELINE TOOLING COSTS ($ USD)	LWT TOOLING COSTS ($ USD)	INCREMENTAL TOOLING COSTS ($ USD)
Cab	54,225,000	57,255,250	3,030,250
Pickup Box	13,272,750	13,605,500	332,750
Front Doors	10,345,000	10,935,000	590,000
Rear Doors	10,430,000	10,568,000	138,000
Hood	4,181,500	4,181,500	0
Tailgate	3,755,000	3,755,000	0
Fenders	8,711,500	2,714,000	-5,997,500
Radiator Support	7,446,250	1,955,750	-5,490,500
Frame	38,810,225	40,163,975	1,353,750
Tow Hitch	2,744,100	2,147,850	-596,250
Front Bumper	4,194,000	4,194,000	0
Rear Bumper	3,270,500	3,270,500	0
Lower Control Arm	386,000	1,866,010	1,480,010
IP Beam	6,028,550	3,720,250	-2,308,300
TOTAL	167,800,375	160,332,585	-7,467,790

Figure 501: LWT Incremental Tooling Costs Summary

Assumptions made for the manufacturing equipment (stamping presses, extrusion presses etc.) and the assembly equipment (welding robots, roller-hem, etc.) are the same for both the baseline and LWT cost estimations. The only exception is the laser welding assembly equipment, because it is not used as a joining method on the baseline vehicle. The estimated cost of laser welding equipment used for the cost assessment is already included in the incremental cost estimates shown in Figure 502. This would be considered a capital expenditure by an OEM converting its process from spot to laser welding. However, one laser welder can replace several spot-welders on the baseline vehicle, and could serve to reduce the actual expenditure.

10.9 Total Vehicle Cost Increment

The cost increment for the chosen LWT vehicle sub-systems (Section 7.10), including the incremental tooling costs shown in Figure 501, are summarized in Figure 502. The total direct cost increase is $1,448 per vehicle when the cost reduction for the downsized powertrain (engine, transmission, exhaust, fuel system, fuel, oil, and coolant) is included in the incremental cost calculation. This increases to $1,498 per vehicle if the powertrain cost reductions are not included.

Most vehicle systems can be broadly categorized as structural or non-structural. The structural systems, those that provide primary load bearing and crash energy management elements, include chassis frame, cab structure, suspension and powertrain systems. Non-structural systems are those such as seats, lighting, safety systems, interior trim and instrument panel; that are not dependant on the vehicle mass or performance. Many of the LWT design options summarized in Figure 502 identified as non-structural could be implemented during the vehicle’s mid-cycle face-lift without major structural changes to the load bearing members and/or changes to the powertrain. More significant changes that can be implemented in a vehicle without affecting the remaining vehicle systems are the re-design of the closures (doors and tailgate) and pickup box using aluminum as the primary material. Combining the non-structural changes previously mentioned with the implementation of aluminum closures and pickup box results in a total mass savings of approximately 5.5 percent and a total incremental manufacturing cost of $500 per vehicle.

		Light Weight Truck (LWT)				
	Vehicle System	2014 Silverado System Mass (kg)	Mass Reduction (kg)	Delta Cost ($)	Premium ($/kg)	Lightweighting Implemented Technology
	Cab Structure	242.52	91.01	830.02	9.12	Aluminum
	FESM (per vehicle)	32.77	22.33	-74.42	-3.33	Aluminum
	Radiator Support Structure	19.98	12.32	-29.59	-2.40	Magnesium + Alum
ns	Front Door Frames	45.46	14.03	17.62	1.26	Aluminum + AHSS
ns	Rear Door Frames	42.44	11.61	15.09	1.30	Aluminum + AHSS
ns	Hood Frame	11.42	0.00	0.00	0.00	Aluminum
ns	Tailgate Frame	22.43	7.16	21.73	3.03	Aluminum
ns	Pickup Box	109.90	43.80	297.11	6.78	Aluminum
	Front Bumper	30.09	6.39	-10.20	-1.60	AHSS
	Rear Bumper	15.04	1.93	3.15	1.63	AHSS
	Chassis Frame	242.10	19.40	75.76	3.90	AHSS
	Towing Hitch	15.81	1.98	-0.85	-0.43	AHSS
	Front Suspension	67.95	7.21	-29.25	-4.06	AHSS LCA and Downsize
	Rear Suspension	66.87	19.25	56.59	2.94	Leaf Springs: 1 Steel + 2 GFRP
	Wheels and Tires	158.96	35.32	164.30	4.65	eVOLVE™ Rims + Spare Tire
ns	Front Seat and Centre Console	57.02	16.98	89.40	5.26	Multi-Material Solution (Gen 3)
ns	Rear Seat	40.43	11.97	48.30	4.04	Multi-Material Solution (Gen 3)
ns	Instrument Panel	32.71	8.29	19.23	2.32	Magnesium Casting
	Engine	200.73	7.43	-19.79	-2.66	Engine Re-Size
	Transmission	230.08	23.17	13.01	0.56	Rear Diff. Housing to Alum
	Drive Shafts	53.71	2.69	-7.74	-2.88	Downsize
	Fuel System	22.19	1.08	-6.82	-6.32	Fuel Tank/System
ns	Trim	86.13	6.36	10.69	1.68	Trim
	Exhaust	51.91	7.23	-16.81	-2.33	Exhaust System
	Brake System	84.35	8.97	-12.01	-1.34	Brake System - Iron Discs
ns	HVAC	30.66	2.16	-2.87	-1.33	HVAC
	Water Cooling	18.00	0.93	-4.18	-4.49	HVAC
ns	Electrical	38.17	3.32	-28.07	-8.46	Copper clad alum
	Battery	19.55	1.55	0.00	0.00	Lead Acid
ns	Fluids	38.31	1.71	0.00	0.00	Fluids
	Fuel	65.77	6.71	-7.66	-1.14	Fuel
ns	Glazings	39.59	0.00	0.00	0.00	Carryover Baseline
ns	Air Bags and Seat Belts	18.47	0.00	0.00	0.00	Air Bags and Seat Belts
ns	Steering System	34.72	4.38	11.89	2.71	Steering System
ns	Wiper System	5.19	0.00	0.00	0.00	Wiper System
ns	Misc. latches/fasteners/mirrors	140.6	0.00	0.00	0.00	
	Total - With Powertrain	2432.0	408.7	1,424	3.48	
	Total - Without Powertrain	1789.6	359.4	1,474	4.10	Powertrain includes Engine, Transmission, Fuel System, Exhaust System, Fuel and Coolant

Figure 502: LWT Incremental Costs (Direct) Summary

10.10 LWT Vehicle Mass Savings Cost Curves

From the various technologies that were reviewed for future mass saving potential, four different vehicle built scenarios with low to high mass saving potential are shown in Figure 264 Section 7.10. The four light weighting vehicle build options range from a vehicle mass saving of 10.5 percent to 22.9 percent with cost increase range from $ 212 to $8,661 as shown in Figure 503.

1. For an all AHSS intensive LWT design, including cab, pickup box, closures, chassis frame, seat frames and instrument panel beam structures. This option leads to total vehicle mass saving of 10.5 percent with vehicle manufacturing cost increase of $212 equivalent to mass saving premium of $0.83 per kg.
2. Design with AHSS chassis frame structure and aluminum cab, pickup box, closures, and multi-material seats, achieves a mass saving of 16.8 percent with vehicle manufacturing cost increase of $1,424 equivalent to mass saving premium of $3.48 per kg.
3. An aluminum intensive solution, using aluminum for body structure, closures, chassis frames and magnesium for seats leads to a mass saving of 17.8 percent with vehicle manufacturing cost increase of $2,784 equivalent to mass saving premium of $6.45 per kg.
4. An advanced carbon fiber and multi-material Solution, using carbon fiber reinforced composite body structure, CFRP/magnesium/aluminum closures, aluminum chassis frames, and magnesium/composite seat structures, achieves a total vehicle mass saving of 22.9 percent with vehicle manufacturing cost increase of $8,661 equivalent to mass saving premium of $15.55 per kg.

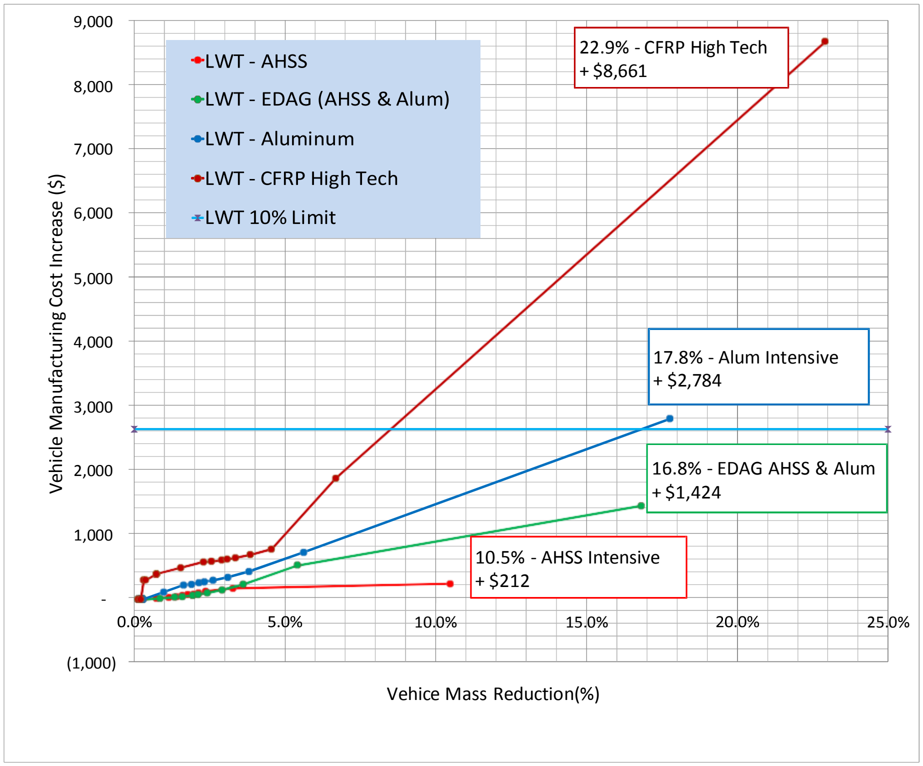


Figure 503: LWT Mass Reduction Versus Vehicle Manufacturing Cost Increase

From the four options above, which one of these light-weighting approaches combined with other fuel saving technologies is going to be implemented by each OEM is a long-term strategic business decision. All production vehicles in this category during 2014 were predominantly steel intensive designs. The Option 1 described above represent an evolutionary path for the 2014 steel intensive designs for the next two model releases for year 2020 and 2025. This AHSS intensive approach limits the total vehicle mass saving to 10.5 percent for a vehicle, which meets the same functionality and performance as the 2014 Baseline vehicle. Option 2 is design with AHSS chassis frame structure and aluminum cab, pickup box, and multi-material closures and seats, achieves a maximum mass saving of 16.8 percent is an evolutionary path similar to the 2015 Ford F-150 for future model years. The 2015 Ford F-150 achieved a mass saving of approximately 13 percent when compared with a similarly equipped 2014 Ford F-150 as shown in Figure 504. From the four options above the EDAG team working on this project believes that this approach using AHSS chassis frame structure and aluminum cab, pickup box, and multi-material seats and closures, is most likely to be implemented for production years 2025 to 2030.

Figure 504: 2014 Ford F-150 versus 2015 Ford F-150 Weight in Pounds[192]

Option 3 an aluminum intensive design with the chassis frame also constructed from aluminum only leads to less than 1 percent additional mass saving but at $1,360 increase in manufacturing cost over the recommended LWT design, Option 2. Option 4 using all advanced technologies CFRP for the structure, Li-Ion battery etc., sets the maximum mass saving limit at 22.9 percent of the vehicle mass at a manufacturing cost increase over the baseline vehicle of $8,661. This is significantly above the cost increase target set for this project of $2,537.

The LWT vehicle mass reduction cost curve, Figure 505, is derived using mass cost data from the recommended Option 2 (points 1, 2, and 3) and maximum mass saving limit points for Option 3 and 4, points 4 and 5 respectively. Points 1 to 2 on the curves are for the implementation of the

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[192] 2015 Ford F-150 weight loss secrets revealed, Published July 23, 2014, FoxNews.com

non-structural items up to 5.4 percent mass saving requires no changes to the powertrain. Mass saving higher than the 5.4 percent requires redesign-using AHSS chassis frame structure and aluminum cab, pickup box, and multi-material seats and closures, with resizing of the powertrain.

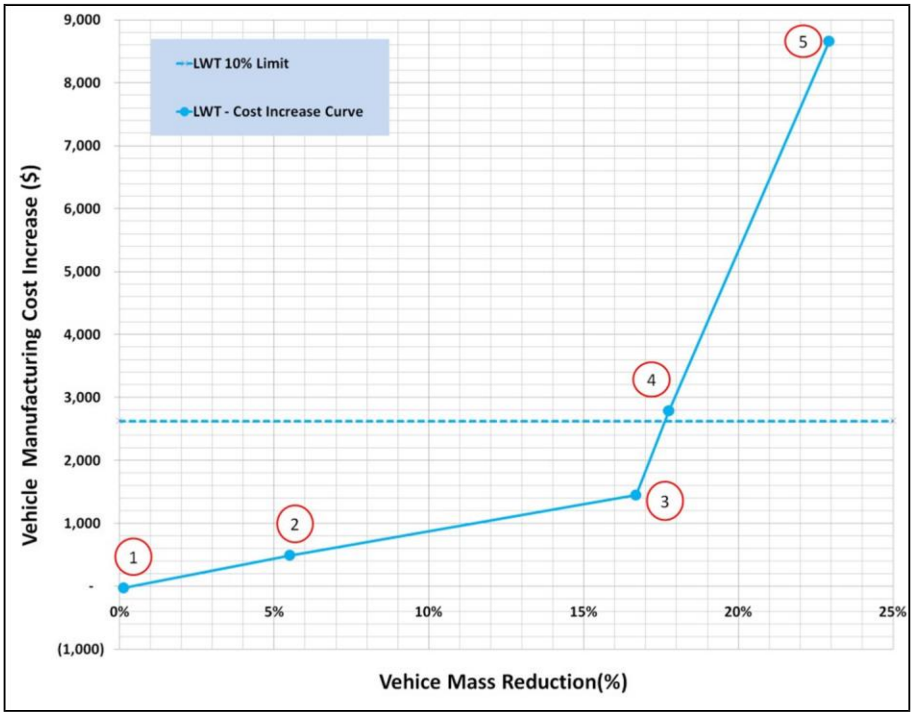

Figure 505: LWT Vehicle Mass Reduction Cost Curve

10.11 LWT and LWV Glider Mass Savings Cost Curves

The mass saving cost curves for the “glider” (vehicle structure and systems without the powertrain) are shown in Figure 506 and Figure 507. The data from the previous NHTSA studies[193] [194] [195] for mid-size sedan passenger car, which used Honda Accord as baseline vehicle, is also plotted on these graphs. The costs for the LWV passenger car study were updated to include; 1. Honda Motor Companies Comments, 2. Additional cost to meet IIHS Small Off-Set Barrier Test, 3. Updated material costs as per this report.

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[193] Singh, H. (2012, August). *Mass reduction for light-duty vehicles for model years 2017-2025* (Report No. DOT HS 811 666). Washington, DC: National Highway Traffic Safety Administration.

[194] SAE International 2015 - Structural Design Considerations for a Lightweighted Vehicle to achieve “Good” Rating in IIHS Small Overlap Test, EDAG, Inc.

[195] .Singh, H., Kan, C-D., Marzougui, D., & Quong, S. (2016, February). *Update to future midsize lightweight vehicle findings in response to manufacturer review and IIHS small-overlap testing* (Report No. DOT HS 812 237). Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/812237_LightWeightVehicleReport.pdf

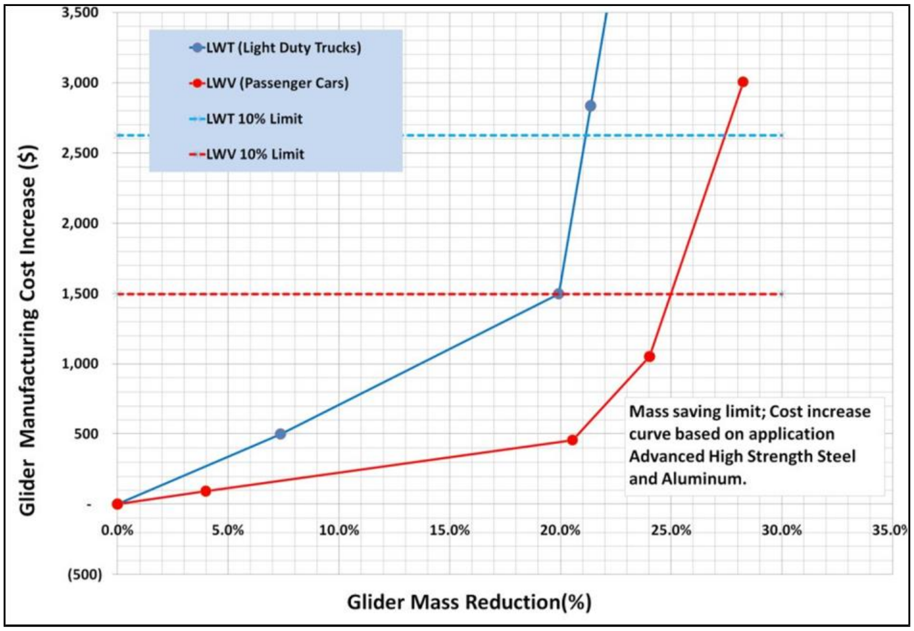

Figure 506: Glider Mass Savings Versus Incremental Costs (without Powertrain) Curve

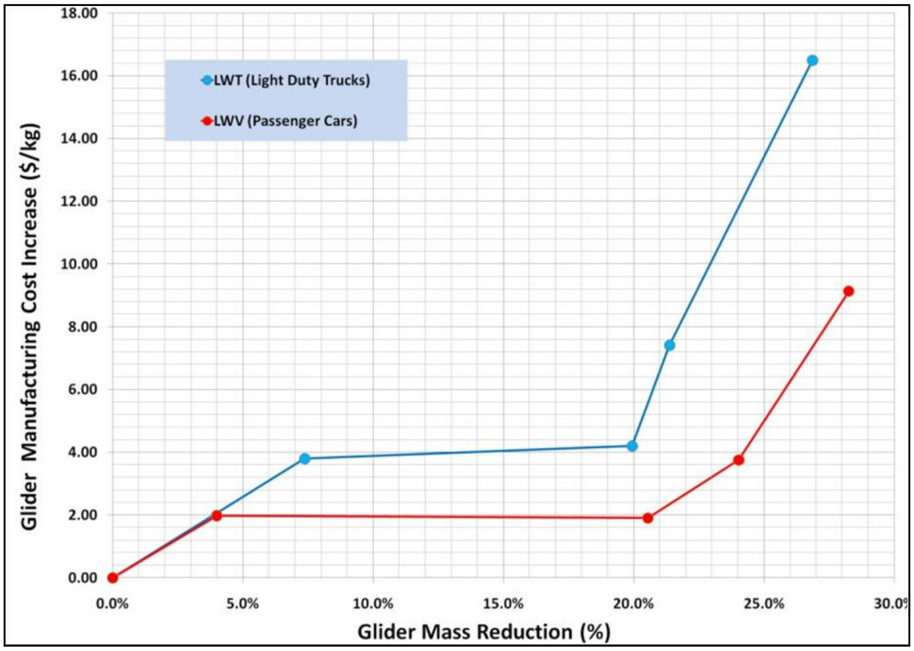

Figure 507: Glider Mass Savings vs Costs Premium (without Powertrain) Curve

11 Mass Reduction for Other Light-Duty Vehicles (Optional Task 1)

11.1 Introduction

The technologies for mass reduction were assessed for various automotive systems and were implemented on the lightweight truck. The technologies for mass reduction were then judiciously applied to other light-duty passenger vehicle segments to estimate the mass savings while maintaining the vehicle size, performance and functionality. Lessons learned from previous NHTSA funded mass reduction study on a mid-size passenger car based on an MY 2011 Honda Accord[196] and subsequent feedback from Honda Motor Company and others was also taken into consideration. The mass saving percentages achieved for the LWT systems were not directly extrapolated to the other vehicle segments. Each sub-system was reviewed by the team and a suitable mass reduction for each component was determined and applied. This assessment was conducted for the following light-duty vehicle classes.

- Subcompact passenger cars
- Compact passenger cars
- Midsize passenger cars
- Large passenger cars
- Minivans
- Small CUV/SUV/light-duty trucks
- Midsize CUV/SUV/light-duty trucks
- Large CUV/SUV/light-duty trucks

Use of aluminum or multi material solution for the body structures was limited to the large passenger cars, Minivans and Large CUV/SUV/light-duty truck segments, as these segments are at higher price point. For all vehicle segments aluminum and other premium cost materials were considered for all other systems such as closers, chassis, seats and instrument panel. The chosen mass reduction technologies are feasible within the time frame of model years 2020 to 2030 and would be available across the passenger car and light-truck vehicle fleet. In addition to the introduction of weight saving technologies, consideration was also given to the capability of suppliers to deliver these mass saving measures in sufficient volumes to support this initiative.

The general approach in performing this analysis can be categorized in the following steps:

1. Identify representative vehicles in each vehicle subclasses;
2. Select representative vehicle for each vehicle subclass using the North American A2Mac1 database;
3. Calculate average vehicle metrics[197] for each vehicle subclasses;

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[196] Singh, 2012.

[197] Average vehicle metrics - curb weight, average track width, wheelbase, footprint, and sales

4. Apply appropriate lightweighting technologies researched/used in the light-duty pickup truck study as discussed in Chapter 7 to each representative vehicle and calculate vehicle mass reduction amount; and
5. The calculated mass reduction percentage is then applied to the "2014 Class Average"[198,199]to estimate the "2025 Class Average."

11.2 Analytical Approach

The options for lightweighting technologies and the solutions applied to the LWT are fully discussed in Section 7 of this report. Suitable choices of materials and manufacturing technologies based upon the lessons learned from the LWT program were applied to each class of vehicles. It must be noted that the amount of percentage mass reductions determined for the LWT are not directly applied to other sub-classes of vehicles. The percentage mass reduction applied to each vehicle system also took into account the current manufacturing technology of the system. For example, if an iron/steel part on the LWT is replaced with an aluminum part, the percentage mass reduction is likely to be significantly high, but this high value cannot be applied to another vehicle's system if it is already made from aluminum. The mass saving percentages achieved for the LWT systems were not directly extrapolated to the other vehicle segments. Each sub-system was reviewed by the team and a suitable mass reduction for each component was determined and applied. Lessons learned from previous NHTSA-funded mass reduction study on a mid-size passenger car based on a MY 2011 Honda Accord and subsequent feedback from Honda Motor Company and others was also taken into consideration.

To maintain the performance of the selected vehicles, engine, powertrain, and fuel system were resized using mass compounding. For passenger cars for every 1.0 kg saving in gross vehicle weight the powertrain mass was reduced by 0.22 kg (see Section 9.8.1 of Singh, 2012 [200]). However, for the light-duty trucks or vehicles designed to tow trailers significantly higher than the vehicles own weight the required horse power (HP) is governed by the vehicle manufactures rating GCWR, the total mass of a vehicle including all trailers. For baseline vehicle 2014 Silverado 1500, the manufactures specified GCWR is 7,575 kg (16,700 lbs). The curb vehicle weight -- weight of the vehicle with full tank at curb side ready for loading and driving -- of the baseline vehicle 2,432 kg (5,362 lbs) is approximately one third of the GCWR. For the larger SUV's and light trucks, from the LWT program it was determined that for every 1.1 kg of vehicle weight saving the powertrain weight could be reduced by 0.12kg. Resizing of the powertrain, engine and transmission was considered when calculating the weight reduction

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[198] NHTSA's market data file contains information about major vehicle characteristic, such as engine, transmission, weight, size, as well as vehicle production volume. For detailed information about this file, a brief description can be found in NHTSA and EPA's MY 2017-2025 TSD for NPRM at the following link: www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/2017-25_CAFE_Joint_TSD_Compiled_Signature_Version_11162011b.pdf

[199] "2010 Class Average" is the average for vehicles listed in NHTSA's 2010 market data file for MY2017-2020 NPRM analysis.

[200] Singh, 2012.

for the vehicles in each subclass. The fuel system was also resized to maintain the same driving range as the baseline vehicle. This was done by applying the assumption that 10 percent mass saving generally leads to 6.5 percent improvement in fuel economy when the powertrain is resized to match the lower mass of the vehicle. Typically if the powertrain is not resized, 10 percent mass saving generally leads to 3.5 percent improvement in fuel economy.

The sub-system content and weights, for each selected vehicle within a vehicle sub-class was obtained from A2Mac1 North American benchmark database.
Vehicle sub-systems that were considered for weight reduction below.

1. Body Structure (minus paint, sealer and NVH)
2. Door Front Lh/Rh (Complete)
    a. Frame
    b. Trim
3. Door Rear Lh/Rh (Complete)
    a. Frame
    b. Trim
4. Hood (Complete)
    a. Frame
    b. Trim
5. Decklid /Tailgate (Complete)
    a. Frame
    b. Trim
6. Fenders LH/RH
7. Bumpers Front (Complete)
    a. Front Bumper Beam
    b. Front Fascia (Minus bumper beam)
8. Bumpers Rear (Complete)
    a. Rear Bumper Beam
    b. Rear Fascia (Minus bumper beam)
9. Front Suspension (Complete with-out damper)
    a. Frame
    b. Suspension Arms Lh/Rh
    c. Knuckle Lh/Rh
10. Spring Damper Front Lh/Rh
11. Rear Suspension (Complete with-out damper)
    a. Frame
    b. Suspension Arms Lh/Rh
12. Spring Damper Rear Lh/Rh
13. Engine/Transmission
    a. Engine
    b. Engine Oil
    c. Transmission
    d. Transmission Fluid
14. Drive Shafts Lh/Rh
15. Exhaust System
16. Fuel System

17. Fuel
18. Wheels
    a. Rim
    b. Tire
19. Spare Wheel
20. Brakes Front (Complete)
    a. Front Rotors
    b. Front Calipers
21. Brakes Rear (Complete)
    a. Rear Rotors
    b. Rear Calipers
22. Seats Front Driver/Passenger
23. Seat Rear (Plus 3rd Row where applicable)
24. Instrument Panel
    a. IP Beam
    b. Plastic trim
    c. Instrumentation
25. Center Console
26. Trim Interior
27. Wiring
28. Battery
29. Lighting
30. HVAC and Cooling
31. Cooling System (Water)
32. Safety Systems
33. Steering System
34. Wiper System (Minus washer fluid)
35. Washer Fluid
36. Noise Insulation
37. Glass (Windshield, back and side glass)
38. Accessories
39. Brackets/Fasteners/Misc. Items

11.3 Vehicle Classification System

For regulatory purposes, NHTSA and EPA have differing criteria when determining vehicle classification. NHTSA classification criteria for vehicle technology analysis are based on vehicles footprint (wheel base x wheel track), while taking into consideration vehicle power-to-weight ratio. Vehicles are split into 12 separate categories that distinguish performance and non-performance passenger cars. In this study, 8 separate categories are considered as shown in the Volpe model. NHTSA uses this Volpe model set of vehicle classification in its technology analysis modeling. Under passenger cars there are 4 categories; subcompact, compact, mid-size, and large. For other vehicles, the 4 classes are small suv/lt (light truck), mid-sized suv/lt and large suv/lt and minivans (unibody structure).

Vehicle Class	**Size (square feet)**	**Example Vehicles Models**
Subcompact Car	Footprint <=43	• Chevrolet Aveo • Honda Fit • Toyota Yaris • Ford Fiesta
Compact Car	43<=Footprint<46	• Hyundai Elantra • Chevrolet Cruze • Honda Civic.
Mid-Size Car	46<=Footprint<53	• Chevrolet Malibu • Ford Fusion • Honda Accord • Toyota Camry
Large Car	56<=Footprint	• Ford Taurus • Audi A8 • Buick Lacrosse • Chrysler 300 • Chevrolet Impala
Minivans	Unibody Vans	• Honda Odyssey • Chrysler Town& Country • Toyota Sienna
Small SUV/Light Truck	SUV: 43<=Footprint<46 LT: Footprint<50	• Ford Ranger (pickup) • Toyota Rav4 • Ford Escape • Honda CR-V
Mid-Sized SUV/LT	--	• Ford Explorer • Chevrolet Equinox • Honda Pilot • GMC Canyon (pickup). • Audi Q5
Large SUV/LT	SUV: 46<=Footprint LT: 50<=Footprint	• Chevrolet Silverado • Dodge Ram • Ford F150

Figure 508: Vehicle classification criteria[201]

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[201] Classification used in NHTSA Honda Accord LWV study Program

11.4 Technology Availability

All the technologies used in the weight saving assessment for the LWT and other vehicle segments are considered to be mature and are available either at present or will be mature in model years 2020 to 2030. The materials used for the body structure and the changing of specific components to advanced high strength steels have been introduced by a number of OEMs and would not be an issue for the component quantities covered by this study. Changing the materials of the doors, hood, deck-lid/ tailgate and fenders to aluminum could put some strain on the aluminum sheet suppliers if introduced at once across all vehicle classes. Changes of this order are generally gradual and it gives the supplier industry time to keep up with increased demand.

Currently, there is limited magnesium high-pressure die cast manufacturing capacity in North America to support high-volume production for the instrument panel cross car beam. If the demand is generated from the OEMs, researchers of this study believes that the magnesium casting industry should be able to keep up with the demand after discussion with major magnesium suppliers.

11.5 Baseline Vehicle Selection

11.5.1 Primary Vehicle and Vehicle Subclass Selection

For the mass reduction of other light-duty vehicle subclasses, vehicles listed in NHTSA's 2014 market input file were used. This file lists 2,160 vehicles with various levels of trim from a number of vehicle manufacturers. Information on each vehicle contained the following.

- Type of vehicle body structure
- Vehicle style
- Vehicle model year
- Vehicle length and width
- Vehicle wheelbase
- Avg. vehicle track width
- Vehicle footprint (wheelbase x track width)
- Vehicle curb weight
- Vehicle sales for 2014

This information was supplemented from the vehicle manufactures and number of other web sites listed at the end of this section. Information obtained from these sites includes vehicle curb weight ranges for different trim models and sales volumes. The A2Mac1 benchmark database is contains detailed information for the sub-systems for the selected representative vehicles subclass. After the representative vehicle for each vehicle subclasses was identified, lightweighting technologies determined during the LWT study were applied to these representative vehicles to determine the amount of mass reduction feasible for each vehicle subclass. Mass savings for the vehicle subclasses shown in Figure 508 were identified. The average values for the vehicle length, width, wheel-base, track (front, rear), foot print and curb weight are shown in Figure 510 (and similar figures for other subclasses) represent the ‘2014 Class Averages’ calculated for the total number of vehicles in each class (NHTSA 2014 File[202,]).

11.5.2 Subcompact passenger cars

The NHTSA 2014 vehicle market file contains 179 subcompact passenger cars. Some of the vehicles in this class are two seat sports cars; these were removed from the list for the class average calculations, see Section 11.2 Analytical Approach. Figure 509 shows the four vehicles that were selected as representative vehicles for the subcompact class.

- Chevrolet Sonic
- Hyundai Accent
- Ford Fiesta
- Nissan Juke

Figure 509: Subcompact vehicles selected for the light-duty vehicle study

Figure 510 shows data for the representative subcompact vehicles used for the light-duty vehicle study. Nissan Juke was not selected as representative model for having the lowest sales and having significant 9 percent higher CVW difference from the subcompact fleet average. The Hyundai Accent was not selected as representative vehicle for having significantly lower CVW by 12 percent. This weight decrease is attributed to manual transmission that reduces the weight of the powertrain and overall vehicle curb weight. The 2012 Chevrolet Sonic is consistent in footprint, closely matches the class average CVW, and had the most significant sales of the class. For these reasons, the Chevrolet Sonic is selected as class representative.

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[202] NHTSA’s market data file contains information about major vehicle characteristic, such as engine, transmission, weight, size, as well as vehicle production volume. For detailed information about this file, a brief description can be found in NHTSA and EPA’s MY 2017-2025 TSD for NPRM at the following link: www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/2017-25_CAFE_Joint_TSD_Compiled_Signature_Version_11162011b.pdf

The Chevrolet Sonic is of a front-wheel drive configuration with a front suspension of MacPherson strut and torsion beam for the rear suspension; this is standard for this class of vehicles. The front engine cradle and rear torsion beam assembly are of steel construction.

Subcompacts	Model Year	Length mm	Width mm	Wheelbase mm	Avg. Track mm	Foot Print ft^2	Curb Weight kg	Sales 2014
Chevrolet Sonic	2012	4,397	1,735	2,525	1,509	41.0	1,287	93,518
Hyundai Accent	2013	4,369	1,699	2,570	1,509	41.7	1,087	63,309
Ford Fiesta	2011	4,067	1,722	2,489	1,466	39.3	1,151	63,192
Nissan Juke	2011	4,125	1,765	2,530	1,515	41.3	1,342	38,184
2014 Subcompact Fleet Averages		4,237	1,724	2,552	1,495	41.1	1,230	1,035,412

Figure 510: Subcompact vehicle list

11.5.3 Compact passenger cars

The compact vehicle class consists of 185 vehicles in the NHTSA 2014 market file. Out of these, the following 4 as shown in Figure 511 were chosen for detailed comparison.

- Honda Civic
- Toyota Corolla
- Chevrolet Cruz
- Hyundai Elantra

Figure 511: Compact vehicles selected for the light-duty vehicle study

Figure 512 shows the detailed information for these four selected vehicles and fleet averages for compact passenger car. Data shows that Toyota Corolla weight range resembles the compact car subclass average weight well within 6 percent of the fleet average; the footprint is also significant, within 1 percent of the compact fleet average. Information for the Toyota Corolla is for 2014; the most recent in A2Mac1 compared to the other representative vehicle models for this subclass. For these reasons, Toyota Corolla was selected as representative vehicle for this segment.

The Toyota Corolla has a front-wheel drive configuration; the front suspension is MacPherson strut with an engine cradle of steel construction, and the rear suspension is torsion beam assembly that is constructed from steel.

Compact Cars	Model Year	Length mm	Width mm	Wheelbase mm	Avg. Track mm	Foot Print ft^2	Curb Weight kg	Sales 2014
Honda Civic	2007	4,488	1,753	2,700	1,514	44.0	1,218	325,981
Toyota Corolla	2014	4,638	1,775	2,700	1,520	44.2	1,309	316,728
Chevrolet Cruz	2011	4,597	1,852	2,685	1,549	44.8	1,293	273,060
Hyundai Elantra	2013	4,529	1,775	2,700	1,558	45.3	1,225	222,023
2014 Compact Fleet Averages		4,531	1,796	2,670	1,547	44.5	1,397	3,025,404

Figure 512: Compact Car vehicles list

11.5.4 Mid-Sized passenger cars

The mid-size passenger car class has 185 vehicles listed in the NHTSA 2014 market file. From these 280 vehicles, four chosen for evaluation are shown Figure 513.

- Toyota Camry
- Honda Accord
- Nissan Altima
- Ford Fusion

Figure 513: Mid-sized vehicles selected for the light-duty vehicle study

Of the vehicle selection, Toyota Camry had most significant sales as representative of the subclass; the model year was not the most current, the CVW varied 6 percent from the vehicle fleet average, and for these reasons was not subject to further evaluation. The Honda Accord was featured in the previous lightweight study conducted by EDAG, and therefore not selected for further evaluation for lightweighting. The Nissan Altima was also considered as representative for the mid-sized fleet, having a consistent footprint and current model year; however the CVW was 8 percent lower than the fleet average and was not selected. Ford Fusion was selected as the representative class model; it CVW was within 1 percent of the fleet average.

Midsize Cars	Model Year	Length mm	Width mm	Wheelbase mm	Avg. Track mm	Foot Print ft^2	Curb Weight kg	Sales 2014
Toyota Camry	2011	4,806	1,821	2,776	1,570	46.9	1,480	428,606
Honda Accord	2013	4,862	1,849	2,776	1,584	47.3	1,614	388,374
Nissan Altima	2013	4,864	1,829	2,776	1,585	47.4	1,446	335,644
Ford Fusion	2013	4,869	1,852	2,850	1,589	48.7	1,581	276,360
2014 Midsize Fleet Averages		4,832	1,846	2,784	1,588	47.6	1,568	3,467,244

Figure 514: Mid-Sized vehicle list

The Ford Fusion has a front-wheel drive configuration and has Macpherson strut front suspension with a steel engine cradle and a multi-link independent rear suspension with a rear k- frame of steel construction.

11.5.5 Large passenger cars

The large passenger car subclass consists of 399 vehicles in the NHTSA 2014 market file. Out of these 167 vehicles, 4 were selected for comparison, as shown in
Figure 515.

- Chevrolet Impala
- Dodge Charger
- Toyota Avalon
- Ford Taurus

Chevrolet Impala
Dodge Charger
Toyota Avalon
Ford Taurus

Figure 515: Large passenger vehicles selected for the light-duty vehicle study

Chevrolet Impala has the highest sales volume among the 4 vehicles considered and its footprint being most comparable to the fleet average. Another contributing factor is the model year for production is most current; therefore, it was chosen as the representative vehicle for large passenger subclass. Figure 516 lists large passenger vehicles used for this study.

Large Cars	**Model Year**	**Length mm**	**Width mm**	**Wheelbase mm**	**Avg. Track mm**	**Foot Print ft^2**	**Curb Weight kg**	**Sales 2014**
Chevrolet Impala	2014	5,113	1,854	2,837	1,577	48.2	1,774	140,280
Dodge Charger	2013	5,156	1,885	3,053	1,615	53.1	1,797	94,099
Toyota Avalon	2011	5,019	1,849	2,819	1,572	47.7	1,620	67,183
Ford Taurus	2010	5,154	2,177	2,868	1,661	51.3	1,821	62,629
2014 Large Cars Fleet Averages		4,969	1,862	2,868	1,594	49.2	1,710	1,089,877

Figure 516: Large passenger vehicle list

The Chevrolet Impala has a front-wheel drive configuration with MacPherson strut front suspension with a steel engine cradle and an independent multi-link rear suspension with a k-frame of steel construction.

11.5.6 Minivans

Out of the two subclasses for vans, minivans, and large vans, minivan body structures are all of a unibody construction, which distinguishes minivans from large vans that are of body-on-frame construction. Minivan subclass includes a small listing of only 13 vans, of which the 3 shown in Figure 517 were selected as representatives of the subclass.

- Chrysler Town & Country
- Toyota Sienna
- Honda Odyssey

Figure 517: Minivan vehicles selected for the light-duty vehicle studys

For this analysis, the Chrysler Town & Country was selected as the representative vehicle for the minivan subclass. The curb weight, footprint and sales volume for Chrysler Town & Country fulfills our selection criteria, and the benchmark data is available in A2Mac1. For the Honda Odyssey, the CVW was below the average and was not a recent vehicle model, therefore was not considered a viable option as representative vehicle for this subclass. The Chrysler Town & Country is of a front-wheel drive configuration; the front suspension is of MacPherson strut type with a steel engine cradle. The rear suspension is a torsion beam of steel construction. Figure 518 lists the minivan vehicles used for the study.

Minivan	**Model Year**	**Length mm**	**Width mm**	**Wheelbase mm**	**Avg. Track mm**	**Foot Print ft^2**	**Curb Weight kg**	**Sales 2014**
Chrysler Town & Country	2012	5,144	1,953	3,078	1,656	54.9	2,159	138,040
Toyota Sienna	2011	5,085	1986	3,030	1,720	56.1	2062	124,502
Honda Odyssey	2011	5,154	2,,012	2,890	1,731	53.9	1,,967	122,738
2014 Minivan Fleet Averages		5,126	1,994	3,042	1,686	55.2	2,005	599,643

Figure 518: Minivan vehicle list

11.5.7 Small CUV/SUV/Trucks

The small SUVs/pickups subclass from the NHTSA 2014 market file consists of 39 vehicles, of which 4 shown in Figure 519 were selected for the study.

- Honda CR-V
- Ford Escape
- Toyota RAV4
- Jeep Cherokee

Honda CR-V Ford Escape

Toyota RAV4 Jeep Cherokee

Figure 519: Small SUV/truck vehicles

Of these 4 vehicles, the Honda CR-V has the greatest sales but is the least current model year; the Honda CR-V is not selected as representative vehicle. Ford Escape has the second greatest sales for this subclass, curb weight within 6 percent of the fleet average, and recent vehicle model year. For these reasons, the Ford Escape is selected as primary vehicle for Small SUV subclass. See Figure 520 for the small SUV/trucks vehicle list.

Small SUV PT	**Model Year**	**Length mm**	**Width mm**	**Wheelbase mm**	**Avg. Track mm**	**Foot Print ft^2**	**Curb Weight kg**	**Sales 2014**
Honda CR-V	2010	4,554	1,819	2,619	1,565	44.1	1,556	335,019
Ford Escape	2013	4,524	1,839	2,690	1,563	45.3	1,692	306,212
Toyota RAV4	2013	4,569	1,844	2,659	1,560	44.6	1,558	267,698
Jeep Cherokee	2014	4,623	1,859	2,700	1,574	45.7	1,669	178,508
2014 Small SUV/PT Fleet Averages		4,559	1,817	2,659	1,554	44.5	1,590	1,152,849

Figure 520: Small SUV/Truck vehicle list

The Ford Escape has all-wheel drive availability. The front suspension is MacPherson strut and multi-link for the rear suspension. The front engine cradle and rear k-frame are of steel construction.

11.5.8 Midsize CUV/SUV/trucks

This subclass has 65 vehicles listed in NHTSA 2014 market input file. From those 65 vehicles, 4 are selected for consideration for the mid-size subclass.

- Chevrolet Equinox
- Jeep Wrangler
- Nissan Rogue
- Toyota Highlander

See **Figure 521** for vehicles selected for the mid-sized SUV/truck vehicle class

Chevrolet Equinox

Nissan Rogue

Jeep Wrangler

Toyota Highlander

Figure 521: Mid-sized SUV/truck vehicles selected for the light-duty vehicle study

For this class, the Jeep Wrangler is considered as representative vehicle having second largest sales and current model year of 2013. The vehicle curb weight is above the average by 5 percent and footprint is the largest, with a 4 percent difference from the fleet average. For these reasons, the Jeep Wrangler is not selected as representative for the mid-size SUV class.

The Nissan Rogue and Toyota Highlander are also considered for the mid-size SUV class. The footprint of the Rogue is 3 percent less than the fleet average and the curb weight is significantly lower than the average by 14 percent. Based on the criteria, the Nissan Rogue is not representative of the mid-sized SUV class. The Toyota Highlander footprint is within 2 percent of the fleet average and the CVW is within 4 percent; the sales are the lowest and the model year is least current. For these reasons, Toyota Highlander is not selected as representative vehicle.

The Chevrolet Equinox has the greatest sales of this class and data indicates the footprint is within 2 percent of the fleet average, wheelbase is within 3 percent of the fleet average, and CVW is within 1 percent of the fleet average. For these reasons, the Chevrolet Equinox is selected as representative mid-sized SUV vehicle.

Midsize SUV PT	Model Year	Length mm	Width mm	Wheelbase mm	Avg. Track mm	Foot Print ft^2	Curb Weight kg	Sales 2014
Chevrolet Equinox	2012	4,770	1,842	2,858	1,588	48.8	1,873	242,242
Jeep Wrangler	2013	4,404	1,872	2,946	1,572	49.9	1,936	159,328
Nissan Rogue	2014	4,630	1,839	2,705	1,595	46.5	1,608	155,411
Toyota Highlander	2011	4,785	1,910	2,789	1,628	48.9	1,790	146,127
2014 Mid SUV/PT Fleet Averages		4,742	1,876	2,781	1,601	48	1,867	675,972

Figure 522: Mid-Sized SUV/Truck Vehicle List

11.5.9 Large CUV/SUV/Light-Duty Trucks

The large SUV/truck subclass has the highest vehicle sales volume as listed in the NHTSA 2014 market file with the number of vehicles at 292. Out of these 292 SUV/pickups, 4 vehicles were considered for this class as shown in Figure 523

- Ford F150
- Dodge Ram
- GMC Sierra
- Toyota Tundra


Ford F150
GMC Sierra
Dodge Ram
Toyota Tundra

Figure 523: Large SUV/truck vehicles selected for the light-duty vehicle study

Details of the 4 vehicles in this class are shown in Figure 524. The GMC Sierra model year is least current for the fleet average. Its CVW is significantly larger (15%) than large SUV/truck fleet average and the third highest sales for the class. Based on the criterion, GMC Sierra is not selected for representative vehicle. The Dodge Ram has second greatest sales and fairly represented of vehicle dimension averages. The Dodge Ram did not have the most current year model listed, for this reason the Dodge Ram was not selected to represent the Large SUV/light-duty truck segment.

Comparatively, the Ford F150 has the most current model year (2015), CVW within 5 percent of the fleet average, and has a footprint of 8 percent above average. Based on the A2Mac1 availability, another consideration is the lightweighting of the 2015 Ford F150 done by Ford. The lightweighting options considered for this study are similar to weight reduction technologies implemented on the 2015 Ford F150. Toyota Tundra is also evaluated for representative vehicle; model year is second current at 2014 and CVW is 12 percent within fleet average. For the purposes of this study, both the Ford F150 and Toyota Tundra will be evaluated to represent the large SUV/light-duty truck segment. The Toyota Tundra will represent the lightweighting technologies of steel model; the Ford F150 will represent the lightweighting technologies for aluminum model.

Large SUV PT	A2Mac1 Model Year	Length mm	Width mm	Wheelbase mm	Avg. Track mm	Foot Print ft^2	Curb Weight kg	Sales 2014
Ford F150	2015	5,890	2,029	3,683	1,717	73.6	2,470	
Dodge Ram	2013	5,817	2,017	3,569	1,723	77.5	2,511	439,789
Gmc Sierra	2011	5,847	2,032	3,645	1,716	67.3	2,694	211,833
Toyota Tundra	2014	5,814	2,029	3,701	1,725	68.7	2,634	118,493
2014 Large SUV/PT Fleet Averages		5,595	2,007	3,426	1,704	63	2,344	2,566,989

Figure 524: Large SUV/Truck vehicle list

The vehicles in other vehicle subclasses are of unibody construction while most vehicles in large SUV/Truck subclass, such as the Ford F-150 and Toyota Tundra, are of the body-on-chassis construction. The Ford F-150 is built with a rear pickup box and has a light-duty truck tailgate with step feature. The F-150 has a non-permanent all-wheel drive configuration with a double wishbone front suspension and a solid axle rear suspension with leaf springs. The Toyota Tundra is built with a rear pickup box and light-duty truck tailgate. The Tundra has a non-permanent all-wheel drive configuration with a double wishbone front suspension and a solid axle rear suspension with leaf springs.

Figure 525 shows the selected aluminum vehicle, 2015 Ford F150, and Figure 526 shows the selected steel vehicle, Toyota Tundra, for the large SUV/truck class.

Figure 525: Ford F150[203] selected for the representative large SUV/truck.

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[203] Image provided by the Car connection, www.thecarconnection.com/photos/ford_f-150_2015

Figure 526: Toyota Tundra[204] selected for the representative steel large SUV/truck

11.5.10 Summary of chosen baseline vehicles for 2014

For each vehicle class the chosen vehicle and its mass comparison with the 2014 class average is shown in Figure 527. The mass of the chosen vehicle is within +/- 10 percent of the class average, except for the 2014 Toyota Tundra.

Vehicle Class	MY	Selected Baseline Vehicle	Baseline Vehicle CVW (kg)	2014 Class Average CVW (kg)	Difference in Mass (%)
Sub-Compact	2012	Chevrolet Sonic	1,287	1,230	-4.7%
Compact	2014	Toyota Corolla	1,309	1,397	6.3%
Mid-Sized	2013	Ford Fusion	1,581	1,568	-0.8%
Large	2014	Chevrolet Impala	1,773	1,710	-3.7%
Minivans	2012	Chrysler Town & Country	2,159	2,005	-7.7%
Small SUV/LT	2013	Ford Escape	1,692	1,590	-6.4%
Mid-Sized SUV/LT	2013	Chevrolet Equinox	1,873	1,867	-0.3%
Large SUV/LT	2014	Toyota Tundra	2,666	2,344	-13.7%
Large SUV/LT	2015	Ford F-150 (alum body)	2,470		

Figure 527: Comparison of Selected Baseline Vehicle Versus Class Average

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[204] Image provided by A2Mac1

11.5.11 Comparison of 2014 Versus 2010 Class Average CVW

For each vehicle class, comparison of 2010 averages are to 2014 class average is shown in Figure 528. Only two classes show mass increase; other vehicle classes show reductions from 2010 to 2014. Least significant savings are shown in Compact Car subclass.

Vehicle Class	2010 Class Average CVW (kg)	2014 Class Average CVW (kg)	Mass Reduction (%)
Sub-Compact Car	1,261	1,230	-2.5%
Compact Car	1,345	1,397	3.9%
Mid-Sized Car	1,561	1,568	0.4%
Large Car	1,752	1,710	-2.4%
Minivans	2,035	2,005	-1.5%
Small SUV/LT	1,592	1,590	-0.1%
Mid-Sized SUV/LT	1,916	1,867	-2.6%
Large SUV/LT	2,391	2,344	-2.0%

Figure 528: Comparison of 2010 and 2014 Class Average

11.6 Results: Mass Reduction of Other Light-Duty Vehicles

11.6.1 Subcompact passenger cars

The selected vehicle for the subcompact segment is 2012 1.8 LTZ Chevrolet Sonic rated at 138hp, manufactured in Lake Orion for the American market with a front-wheel drive automatic transmission. The Sonic has a curb vehicle weight of 1287.3kg.

The Sonic vehicle system mass break down and lightweighting options results are shown in Figure 531. The Sonic body structure is of unibody construction and was reduced 20 percent with the material selection of AHSS. For the Sonic body structure the 20 percent mass saving is equivalent to 53.9kg Due to limited packaging space on a subcompact compared with a mid-size vehicle or large SUV/ light-duty pickup truck, the amount of optimization will not be comparable for the subcompact structure. For all the closures, which include hood, fenders, front and rear doors, and the tailgate, aluminum/AHSS application leads to mass saving of 19.0 kg. The percentage mass reduction applied to the closures is 20 percent to 25 percent. The Sonic door frames are of light weight steel construction.

The front suspension shown in Figure 529 is comprised of a steel K-frame (engine cradle) and steel for other suspension components. For lightweighting the K-frame and other selected components with aluminum, produces a mass reduction of 9.7kg and a mass saving of 5.0kg for the rear suspension. Figure 530 shows the rear suspension.

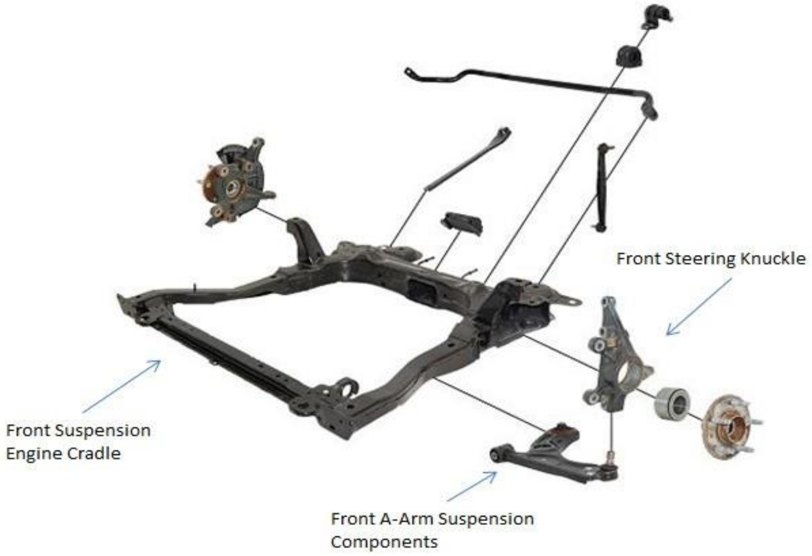

Figure 529: Chevrolet Sonic front suspension[205]

The rear suspension is comprised of a torsion beam assembly; this is the primary suspension component and is selected to alter from steel to aluminum design.

Figure 530: Chevrolet Sonic rear suspension[206]

The total weight savings of the Sonic as result of all the proposed lightweighting options is 197.3 kg (15.3 %). This is shown in Figure 531. The reduction includes 40.3 kg attributable to downsizing of powertrain and 5.0 kg for resizing the fuel system; this is while maintaining vehicle size and vehicle performance.

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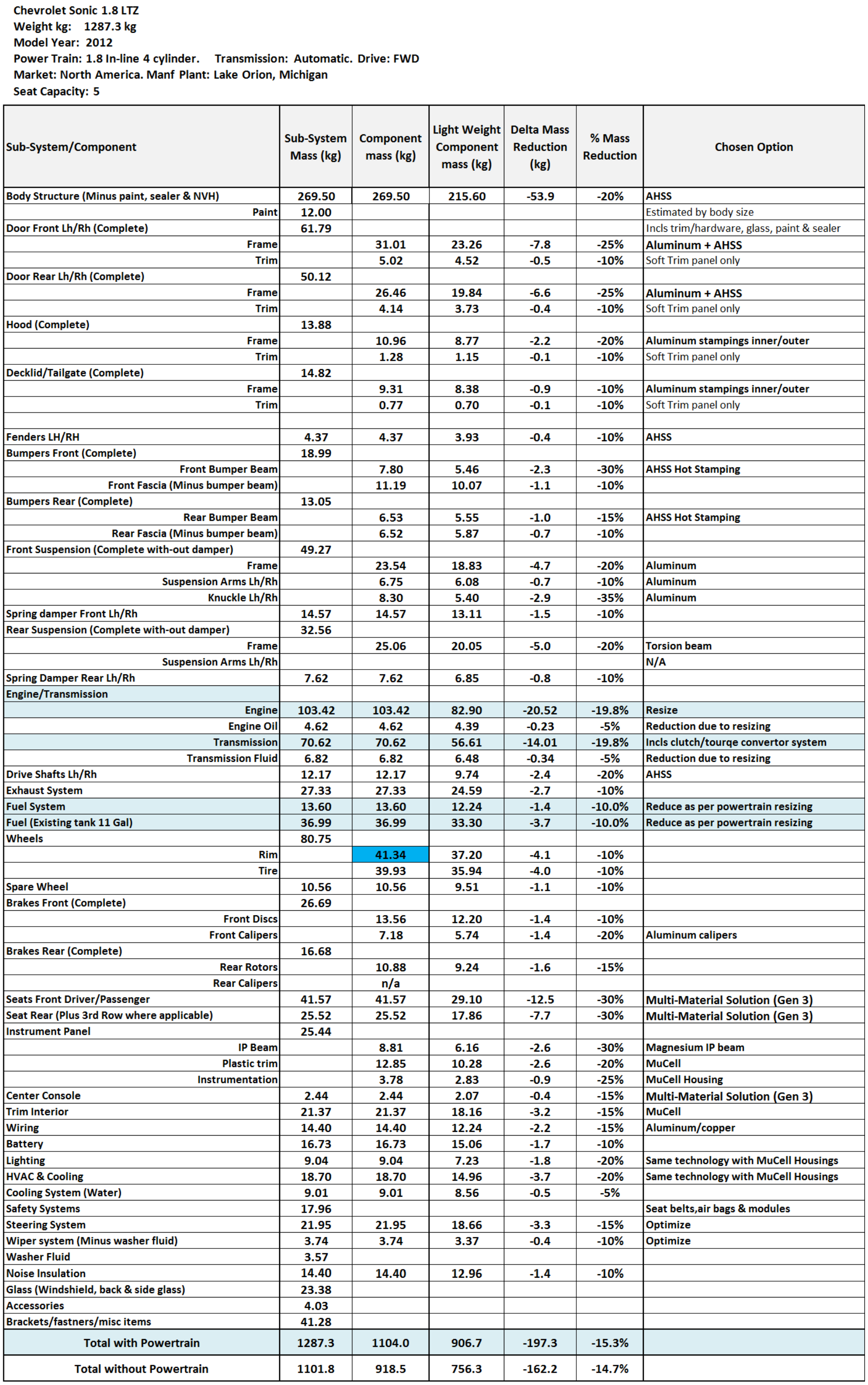
[205] A2Mac1
[206] A2Mac1



Chevrolet Sonic 1.8 LTZ
Weight kg: 1287.3 kg
Model Year: 2012
Power Train: 1.8 In-line 4 cylinder. Transmission: Automatic. Drive: FWD
Market: North America. Manf Plant: Lake Orion, Michigan
Seat Capacity: 5

Sub-System/Component	Sub-System Mass (kg)	Component mass (kg)	Light Weight Component mass (kg)	Delta Mass Reduction (kg)	% Mass Reduction	Chosen Option
Body Structure (Minus paint, sealer & NVH)	269.50	269.50	215.60	-53.9	-20%	AHSS
Paint	12.00					Estimated by body size
Door Front Lh/Rh (Complete)	61.79					Incls trim/hardware, glass, paint & sealer
Frame		31.01	23.26	-7.8	-25%	Aluminum + AHSS
Trim		5.02	4.52	-0.5	-10%	Soft Trim panel only
Door Rear Lh/Rh (Complete)	50.12					
Frame		26.46	19.84	-6.6	-25%	Aluminum + AHSS
Trim		4.14	3.73	-0.4	-10%	Soft Trim panel only
Hood (Complete)	13.88					
Frame		10.96	8.77	-2.2	-20%	Aluminum stampings inner/outer
Trim		1.28	1.15	-0.1	-10%	Soft Trim panel only
Decklid/Tailgate (Complete)	14.82					
Frame		9.31	8.38	-0.9	-10%	Aluminum stampings inner/outer
Trim		0.77	0.70	-0.1	-10%	Soft Trim panel only
Fenders LH/RH	4.37	4.37	3.93	-0.4	-10%	AHSS
Bumpers Front (Complete)	18.99					
Front Bumper Beam		7.80	5.46	-2.3	-30%	AHSS Hot Stamping
Front Fascia (Minus bumper beam)		11.19	10.07	-1.1	-10%	
Bumpers Rear (Complete)	13.05					
Rear Bumper Beam		6.53	5.55	-1.0	-15%	AHSS Hot Stamping
Rear Fascia (Minus bumper beam)		6.52	5.87	-0.7	-10%	
Front Suspension (Complete with-out damper)	49.27					
Frame		23.54	18.83	-4.7	-20%	Aluminum
Suspension Arms Lh/Rh		6.75	6.08	-0.7	-10%	Aluminum
Knuckle Lh/Rh		8.30	5.40	-2.9	-35%	Aluminum
Spring damper Front Lh/Rh	14.57	14.57	13.11	-1.5	-10%	
Rear Suspension (Complete with-out damper)	32.56					
Frame		25.06	20.05	-5.0	-20%	Torsion beam
Suspension Arms Lh/Rh						N/A
Spring Damper Rear Lh/Rh	7.62	7.62	6.85	-0.8	-10%	
Engine/Transmission						
Engine	103.42	103.42	82.90	-20.52	-19.8%	Resize
Engine Oil	4.62	4.62	4.39	-0.23	-5%	Reduction due to resizing
Transmission	70.62	70.62	56.61	-14.01	-19.8%	Incls clutch/tourqe convertor system
Transmission Fluid	6.82	6.82	6.48	-0.34	-5%	Reduction due to resizing
Drive Shafts Lh/Rh	12.17	12.17	9.74	-2.4	-20%	AHSS
Exhaust System	27.33	27.33	24.59	-2.7	-10%	
Fuel System	13.60	13.60	12.24	-1.4	-10.0%	Reduce as per powertrain resizing
Fuel (Existing tank 11 Gal)	36.99	36.99	33.30	-3.7	-10.0%	Reduce as per powertrain resizing
Wheels	80.75					
Rim		41.34	37.20	-4.1	-10%	
Tire		39.93	35.94	-4.0	-10%	
Spare Wheel	10.56	10.56	9.51	-1.1	-10%	
Brakes Front (Complete)	26.69					
Front Discs		13.56	12.20	-1.4	-10%	
Front Calipers		7.18	5.74	-1.4	-20%	Aluminum calipers
Brakes Rear (Complete)	16.68					
Rear Rotors		10.88	9.24	-1.6	-15%	
Rear Calipers		n/a				
Seats Front Driver/Passenger	41.57	41.57	29.10	-12.5	-30%	Multi-Material Solution (Gen 3)
Seat Rear (Plus 3rd Row where applicable)	25.52	25.52	17.86	-7.7	-30%	Multi-Material Solution (Gen 3)
Instrument Panel	25.44					
IP Beam		8.81	6.16	-2.6	-30%	Magnesium IP beam
Plastic trim		12.85	10.28	-2.6	-20%	MuCell
Instrumentation		3.78	2.83	-0.9	-25%	MuCell Housing
Center Console	2.44	2.44	2.07	-0.4	-15%	Multi-Material Solution (Gen 3)
Trim Interior	21.37	21.37	18.16	-3.2	-15%	MuCell
Wiring	14.40	14.40	12.24	-2.2	-15%	Aluminum/copper
Battery	16.73	16.73	15.06	-1.7	-10%	
Lighting	9.04	9.04	7.23	-1.8	-20%	Same technology with MuCell Housings
HVAC & Cooling	18.70	18.70	14.96	-3.7	-20%	Same technology with MuCell Housings
Cooling System (Water)	9.01	9.01	8.56	-0.5	-5%	
Safety Systems	17.96					Seat belts,air bags & modules
Steering System	21.95	21.95	18.66	-3.3	-15%	Optimize
Wiper system (Minus washer fluid)	3.74	3.74	3.37	-0.4	-10%	Optimize
Washer Fluid	3.57					
Noise Insulation	14.40	14.40	12.96	-1.4	-10%	
Glass (Windshield, back & side glass)	23.38					
Accessories	4.03					
Brackets/fastners/misc items	41.28					
Total with Powertrain	1287.3	1104.0	906.7	-197.3	-15.3%	
Total without Powertrain	1101.8	918.5	756.3	-162.2	-14.7%	

Figure 531: Chevrolet Sonic sub-system/component weight savings

11.6.2 Compact passenger cars

The compact segment option is a 1.8L Toyota Corolla LE, production year 2014 and manufactured in the United States for the U.S. market with a vehicle weight of 1309.1kg. The results for the Toyota Corolla are shown in below Figure 534. For the body structure a 20 percent mass reduction with the adoption of AHSS is assumed. For the body structure, the mass saving is equivalent to 57.3kg. For closures, which include hood, fenders, and the deck lid, in aluminum/AHSS leads to mass saving of 8.0kg. For the front and rear doors, aluminum and AHSS technologies were applied for a mass reduction of 21.3 kg. The percentage mass reduction applied to all other systems are shown in Figure 531.

The front suspension of the Toyota Corolla shown in Figure 532 employs steel K-frame (engine cradle) and steel for other suspension components. For lightweighting the K-frame and other selected suspension components in aluminum, provides an accumulated mass reduction of 7.8kg and for the rear suspension a mass reduction of 5.3kg.

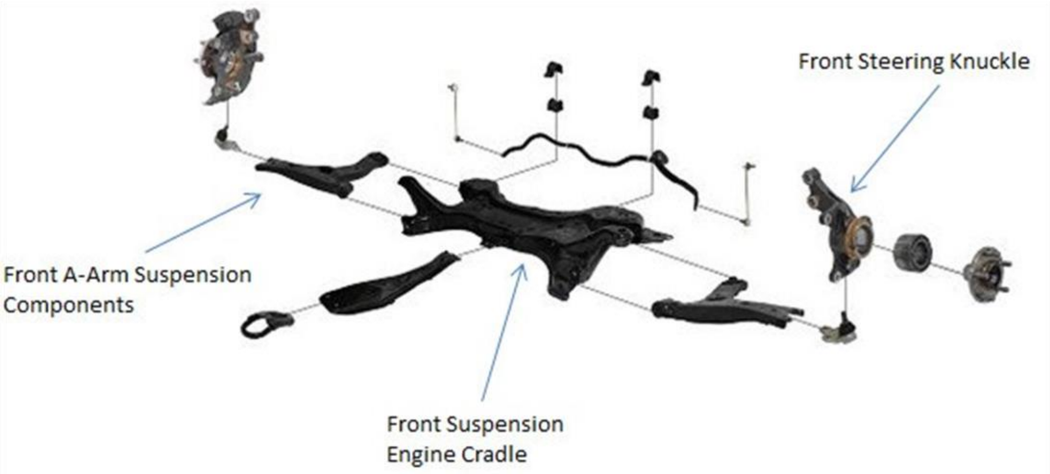


Figure 532: Toyota Corolla front suspension[207]

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[207] A2Mac1

The Toyota Corolla rear suspension shown in Figure 533 uses a torsion beam as the main suspension component for supporting the rear axle.

Figure 533: Toyota Corolla rear suspension[208]

The total weight reduction of the proposed lightweighting options implemented as shown in Figure 534 leads to a savings of 202.1kg (15.4%). This reduction includes 42.1kg from resizing the powertrain and 5.6 kg for resizing the fuel system vehicle size and vehicle performance were maintained functionalities.

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[208] A2Mac1

Toyota Corolla LE 1.8 DOHC dual VVT-i
Weight kg: 1309.152
Model Year: 2014
Power Train: 1.8 (Gasoline) 132hp. Transmission: Automatic. Drive: FWD
Market: North America. Manf Plant: Tupelo, Mississippi
Seat Capacity: 5

Sub-System/Component	Sub-System Mass (kg)	Component mass (kg)	Light Weight Component mass (kg)	Delta Mass Reduction (kg)	% Mass Reduction	Chosen Option
Body Structure (Minus paint, sealer & NVH)	286.50	286.50	229.20	-57.3	-20%	AHSS
Paint	13.00					Estimated by body size
Door Front Lh/Rh (Complete)	67.92					Incls trim/hardware, glass, paint & sealer
Frame		39.63	27.74	-11.9	-30%	Aluminum + AHSS
Trim		6.24	5.61	-0.6	-10%	Soft trim panel only
Door Rear Lh/Rh (Complete)	50.87					Incls trim/hardware, glass, paint & sealer
Frame		27.90	19.53	-8.4	-30%	Aluminum + AHSS
Trim		4.08	3.67	-0.4	-10%	Soft trim panel only
Hood (Complete)	13.91					Incls trim/hardware, glass, paint & sealer
Frame		12.18	7.92	-4.3	-35%	Aluminum stampings inner/outer
Trim		0.14				Soft trim panel only
Decklid/Tailgate (Complete)	12.63					Incls trim/hardware, glass, paint & sealer
Frame		8.87	6.21	-2.7	-30%	Aluminum stampings inner/outer
Trim		0.98				Soft trim panel only
Fenders Front/Rear	5.32	5.32	4.25	-1.1	-20%	Aluminium stamping
Bumpers Front (Complete)	13.68					
Front Bumper Beam		6.62	5.96	-0.7	-10%	AHSS Hot Stamping
Front Fascia (Minus bumper beam)		7.06	6.35	-0.7	-10%	
Bumpers Rear (Complete)	11.95					
Rear Bumper Beam		6.23	5.60	-0.6	-10%	AHSS Hot Stamping
Rear Fascia (Minus bumper beam)		5.72	5.15	-0.6	-10%	
Front Suspension (Complete with-out damper)	45.86					
Frame		13.59	10.87	-2.7	-20%	Aluminum
Suspension Arms Lh/Rh		8.04	6.44	-1.6	-20%	Aluminum
Knuckle Lh/Rh		7.78	4.28	-3.5	-45%	Aluminum
Spring damper Front Lh/Rh	17.32	17.32	15.59	-1.7	-10%	
Rear Suspension (Complete with-out damper)	37.57	11.95	10.16	-1.8	-0.2	AHSS
Frame		25.61	23.05	-2.6	-10%	
Suspension Arms Lh/Rh			0.00	0.0	0.0	
Spring Damper Rear Lh/Rh	9.31	9.31	8.38	-0.9	-10%	
Engine/Transmission						
Engine	102.45	102.45	81.63	-20.82	-20.3%	Resize
Engine Oil	3.74	3.74	3.55	-0.19	-5%	Reduction due to resizing
Transmission	71.78	71.78	57.19	-14.59	-20.3%	Incls clutch/tourqe convertor system
Transmission Fluid	5.81	5.81	5.52	-0.29	-5%	Reduction due to resizing
Drive Shafts Lh/Rh	13.56	13.56	10.84	-2.7	-20%	AHSS
Exhaust System	23.71	23.71	20.15	-3.6	-15%	
Fuel System	17.72	17.72	15.94	-1.8	-10.0%	Incls fuel lines & tank
Fuel (Existing tank 11 Gal)	37.61	37.61	33.83	-3.8	-10.0%	Reduce as per powertrain resizing
Wheels	78.17					
Rim		39.92	37.92	-2.0	-5%	Aluminum
Tire		37.70	33.93	-3.8	-10%	
Spare Wheel		12.63	11.36	-1.3	-10%	
Brakes Front (Complete)	24.56					
Front Rotors		12.35	10.50	-1.9	-15%	
Front Calipers		6.36	5.09	-1.3	-20%	Aluminum calipers
Brakes Rear (Complete)	18.41					
Rear Rotors		11.59	9.85	-1.7	-15%	Drum brakes
Rear Calipers		n/a				
Seats Front Driver/Passenger	42.17	42.17	29.52	-12.6	-30%	Multi-Material Solution (Gen 3)
Seat Rear (Plus 3rd Row where applicable)	21.09	21.09	17.93	-3.2	-15%	Multi-Material Solution (Gen 3)
Instrument Panel	22.80					
IP Beam		8.36	5.44	-2.9	-35%	Magnesium IP beam
Plastic trim		9.88	8.39	-1.5	-15%	MuCell
Instrumentation		4.56	3.24	-1.3	-29%	MuCell Housing
Center Console	5.47	5.47	4.92	-0.5	-10%	Multi-Material Solution (Gen 3)
Trim Interior	23.06	23.06	19.60	-3.5	-15%	
Wiring	17.08	17.08	14.52	-2.6	-15%	Aluminum/copper
Battery	17.03	17.03	15.33	-1.7	-10%	
Lighting	8.56	8.56	6.85	-1.7	-20%	
HVAC & Cooling	19.01	19.01	15.21	-3.8	-20%	
Cooling System (Water)	6.87	6.87	6.18	-0.7	-10%	
Safety Systems	15.01					Seat belts,air bags & modules
Steering System	20.49	20.49	18.44	-2.0	-10%	
Wiper system (Minus washer fluid)	4.17	4.17	3.96	-0.2	-5%	
Washer Fluid	4.85					
Noise Insulation	4.29	4.29	4.07	-0.2	-5%	
Glass (Windshield, back & side glass)	19.80					
Accessories	5.22					
Brackets/fastners/misc items	68.84					
Total with Powertrain	1309.1	1120.0	916.8	-202.1	-15.4%	
Total without Powertrain	1125.3	936.2	768.9	-166.2	-14.8%	

Figure 534: Toyota Corolla sub-system/component weight savings

11.6.3 Mid-Sized Passenger Cars

The mid-sized segment selection is a Ford Fusion SE with a production year 2013 and manufactured in Mexico for North American market; the weight of the Ford Fusion is 1,580 kg. The Ford Fusion is equipped with a 1.6L EcoBoost gasoline engine with a 6-speed automatic transmission and rated at 178hp. The drivetrain is front-wheel drive configuration.

The Fusion has a MacPherson strut front suspension, available in Figure 535, with a steel K-frame, suspension components and steering knuckle. Mass reduction of the front steering knuckle will involve downsizing since it is already manufactured in aluminum for the Ford Fusion. The lightweighting for the engine cradle and other selected suspension components in aluminum leads to a mass reduction of 7.5kg and for the rear suspension a mass saving of 10.3kg as shown in Figure 536.

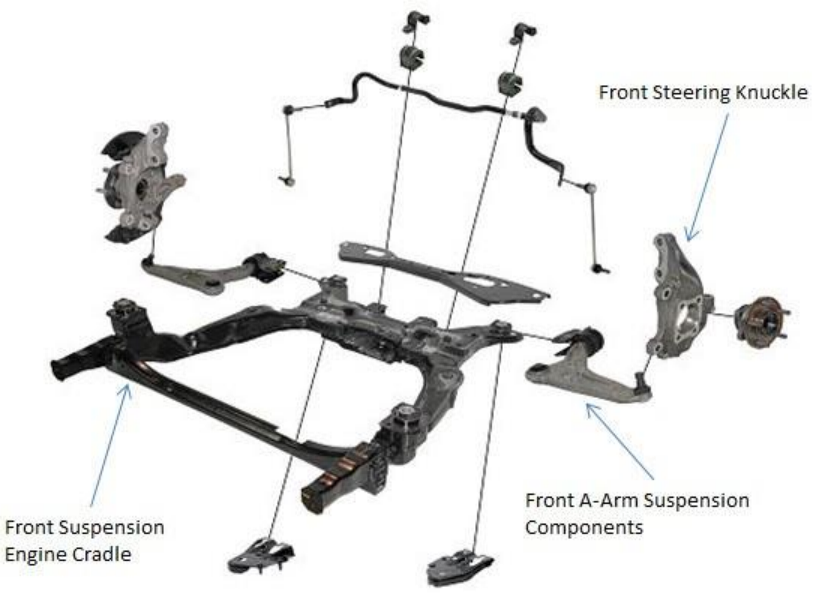

Figure 535: Ford Fusion front suspension[209]

The rear suspension of the Fusion, as shown in Figure 536, is of a rear K-frame support with a multi-link independent assembly of steel construction with cast steel arm components. The lightweighting method applied here is using AHSS for accumulating mass reduction and resizing of arm components.

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[209] A2Mac1

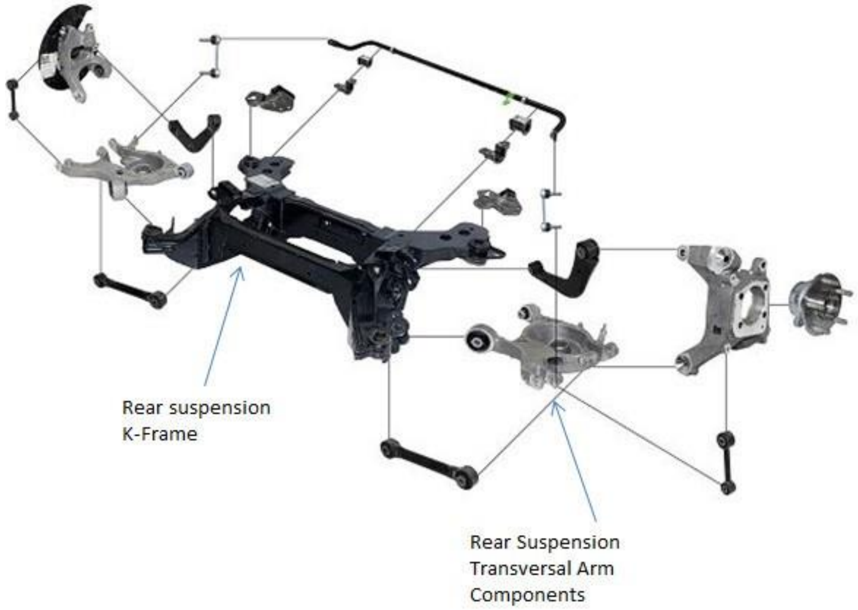

Figure 536: Ford Fusion rear suspension[210]

The results for the Ford Fusion are shown in Figure 537. The body structure assumes a 20 percent mass reduction with the option of AHSS for materials. For the body structure, the mass saving is equivalent to 63.2kg. For all doors, the selection of AHSS in combination with aluminum panels will lead to mass saving of 14.5kg. The closures, which are fenders and deck lid, in aluminum leads to 5.9kg weight reduction. The Ford Fusion hood is already manufactured in aluminum. As a result, all lightweighting options implemented as shown in Figure 537, a total weight savings of 250.4kg (15.8%) is achieved. This reduction includes 53.9kg due to powertrain downsizing and 6.2 kg for resizing the fuel system, while maintaining vehicle size and vehicle performance functionalities.

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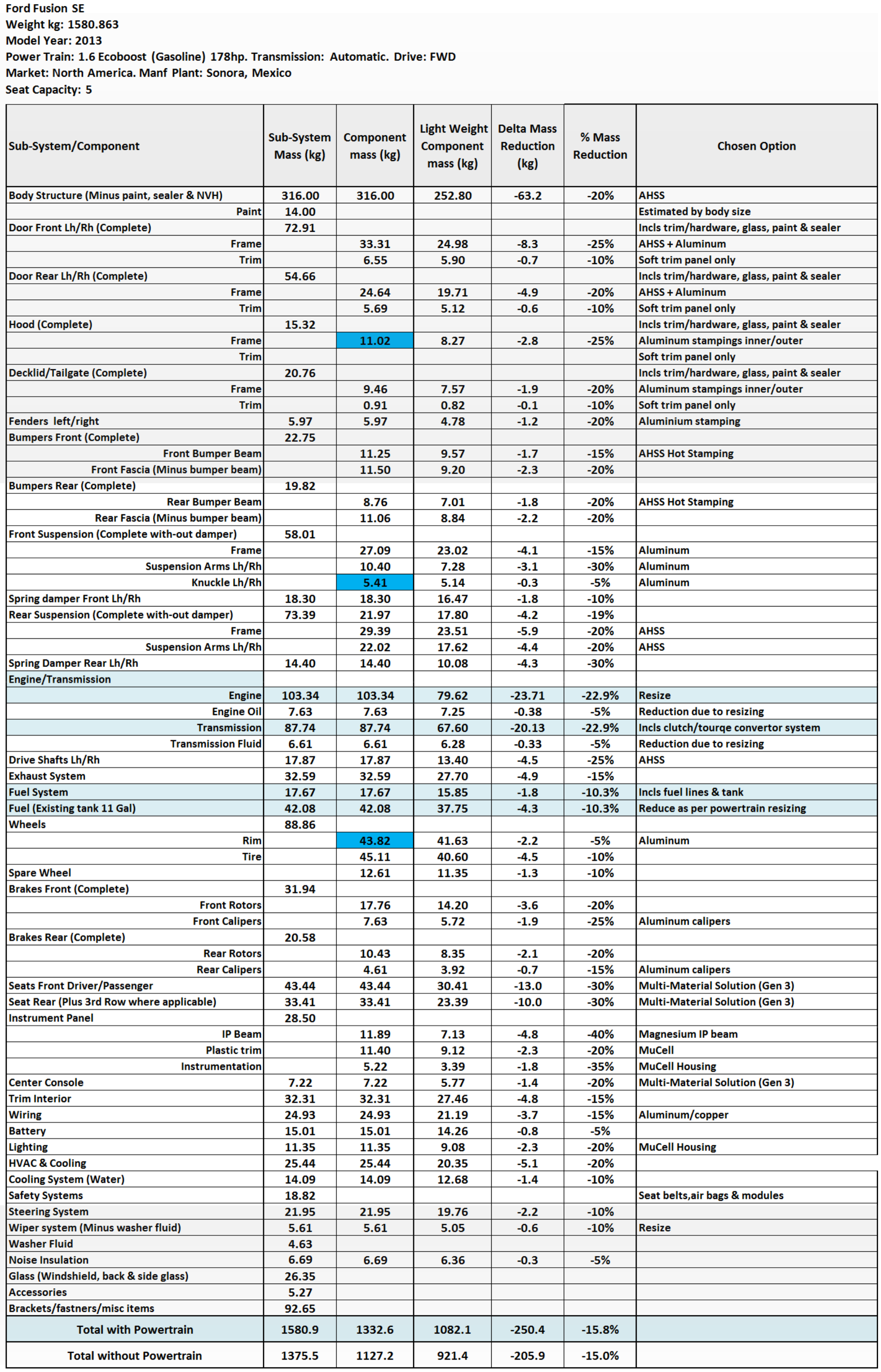
[210] A2Mac1



Ford Fusion SE
Weight kg: 1580.863
Model Year: 2013
Power Train: 1.6 Ecoboost (Gasoline) 178hp. Transmission: Automatic. Drive: FWD
Market: North America. Manf Plant: Sonora, Mexico
Seat Capacity: 5

Sub-System/Component	Sub-System Mass (kg)	Component mass (kg)	Light Weight Component mass (kg)	Delta Mass Reduction (kg)	% Mass Reduction	Chosen Option
Body Structure (Minus paint, sealer & NVH)	316.00	316.00	252.80	-63.2	-20%	AHSS
Paint	14.00					Estimated by body size
Door Front Lh/Rh (Complete)	72.91					Incls trim/hardware, glass, paint & sealer
Frame		33.31	24.98	-8.3	-25%	AHSS + Aluminum
Trim		6.55	5.90	-0.7	-10%	Soft trim panel only
Door Rear Lh/Rh (Complete)	54.66					Incls trim/hardware, glass, paint & sealer
Frame		24.64	19.71	-4.9	-20%	AHSS + Aluminum
Trim		5.69	5.12	-0.6	-10%	Soft trim panel only
Hood (Complete)	15.32					Incls trim/hardware, glass, paint & sealer
Frame		11.02	8.27	-2.8	-25%	Aluminum stampings inner/outer
Trim						Soft trim panel only
Decklid/Tailgate (Complete)	20.76					Incls trim/hardware, glass, paint & sealer
Frame		9.46	7.57	-1.9	-20%	Aluminum stampings inner/outer
Trim		0.91	0.82	-0.1	-10%	Soft trim panel only
Fenders left/right	5.97	5.97	4.78	-1.2	-20%	Aluminium stamping
Bumpers Front (Complete)	22.75					
Front Bumper Beam		11.25	9.57	-1.7	-15%	AHSS Hot Stamping
Front Fascia (Minus bumper beam)		11.50	9.20	-2.3	-20%	
Bumpers Rear (Complete)	19.82					
Rear Bumper Beam		8.76	7.01	-1.8	-20%	AHSS Hot Stamping
Rear Fascia (Minus bumper beam)		11.06	8.84	-2.2	-20%	
Front Suspension (Complete with-out damper)	58.01					
Frame		27.09	23.02	-4.1	-15%	Aluminum
Suspension Arms Lh/Rh		10.40	7.28	-3.1	-30%	Aluminum
Knuckle Lh/Rh		5.41	5.14	-0.3	-5%	Aluminum
Spring damper Front Lh/Rh	18.30	18.30	16.47	-1.8	-10%	
Rear Suspension (Complete with-out damper)	73.39	21.97	17.80	-4.2	-19%	
Frame		29.39	23.51	-5.9	-20%	AHSS
Suspension Arms Lh/Rh		22.02	17.62	-4.4	-20%	AHSS
Spring Damper Rear Lh/Rh	14.40	14.40	10.08	-4.3	-30%	
Engine/Transmission						
Engine	103.34	103.34	79.62	-23.71	-22.9%	Resize
Engine Oil	7.63	7.63	7.25	-0.38	-5%	Reduction due to resizing
Transmission	87.74	87.74	67.60	-20.13	-22.9%	Incls clutch/tourqe convertor system
Transmission Fluid	6.61	6.61	6.28	-0.33	-5%	Reduction due to resizing
Drive Shafts Lh/Rh	17.87	17.87	13.40	-4.5	-25%	AHSS
Exhaust System	32.59	32.59	27.70	-4.9	-15%	
Fuel System	17.67	17.67	15.85	-1.8	-10.3%	Incls fuel lines & tank
Fuel (Existing tank 11 Gal)	42.08	42.08	37.75	-4.3	-10.3%	Reduce as per powertrain resizing
Wheels	88.86					
Rim		43.82	41.63	-2.2	-5%	Aluminum
Tire		45.11	40.60	-4.5	-10%	
Spare Wheel		12.61	11.35	-1.3	-10%	
Brakes Front (Complete)	31.94					
Front Rotors		17.76	14.20	-3.6	-20%	
Front Calipers		7.63	5.72	-1.9	-25%	Aluminum calipers
Brakes Rear (Complete)	20.58					
Rear Rotors		10.43	8.35	-2.1	-20%	
Rear Calipers		4.61	3.92	-0.7	-15%	Aluminum calipers
Seats Front Driver/Passenger	43.44	43.44	30.41	-13.0	-30%	Multi-Material Solution (Gen 3)
Seat Rear (Plus 3rd Row where applicable)	33.41	33.41	23.39	-10.0	-30%	Multi-Material Solution (Gen 3)
Instrument Panel	28.50					
IP Beam		11.89	7.13	-4.8	-40%	Magnesium IP beam
Plastic trim		11.40	9.12	-2.3	-20%	MuCell
Instrumentation		5.22	3.39	-1.8	-35%	MuCell Housing
Center Console	7.22	7.22	5.77	-1.4	-20%	Multi-Material Solution (Gen 3)
Trim Interior	32.31	32.31	27.46	-4.8	-15%	
Wiring	24.93	24.93	21.19	-3.7	-15%	Aluminum/copper
Battery	15.01	15.01	14.26	-0.8	-5%	
Lighting	11.35	11.35	9.08	-2.3	-20%	MuCell Housing
HVAC & Cooling	25.44	25.44	20.35	-5.1	-20%	
Cooling System (Water)	14.09	14.09	12.68	-1.4	-10%	
Safety Systems	18.82					Seat belts,air bags & modules
Steering System	21.95	21.95	19.76	-2.2	-10%	
Wiper system (Minus washer fluid)	5.61	5.61	5.05	-0.6	-10%	Resize
Washer Fluid	4.63					
Noise Insulation	6.69	6.69	6.36	-0.3	-5%	
Glass (Windshield, back & side glass)	26.35					
Accessories	5.27					
Brackets/fastners/misc items	92.65					
Total with Powertrain	1580.9	1332.6	1082.1	-250.4	-15.8%	
Total without Powertrain	1375.5	1127.2	921.4	-205.9	-15.0%	

Figure 537: Ford Fusion 2013 sub-system/component weight saving

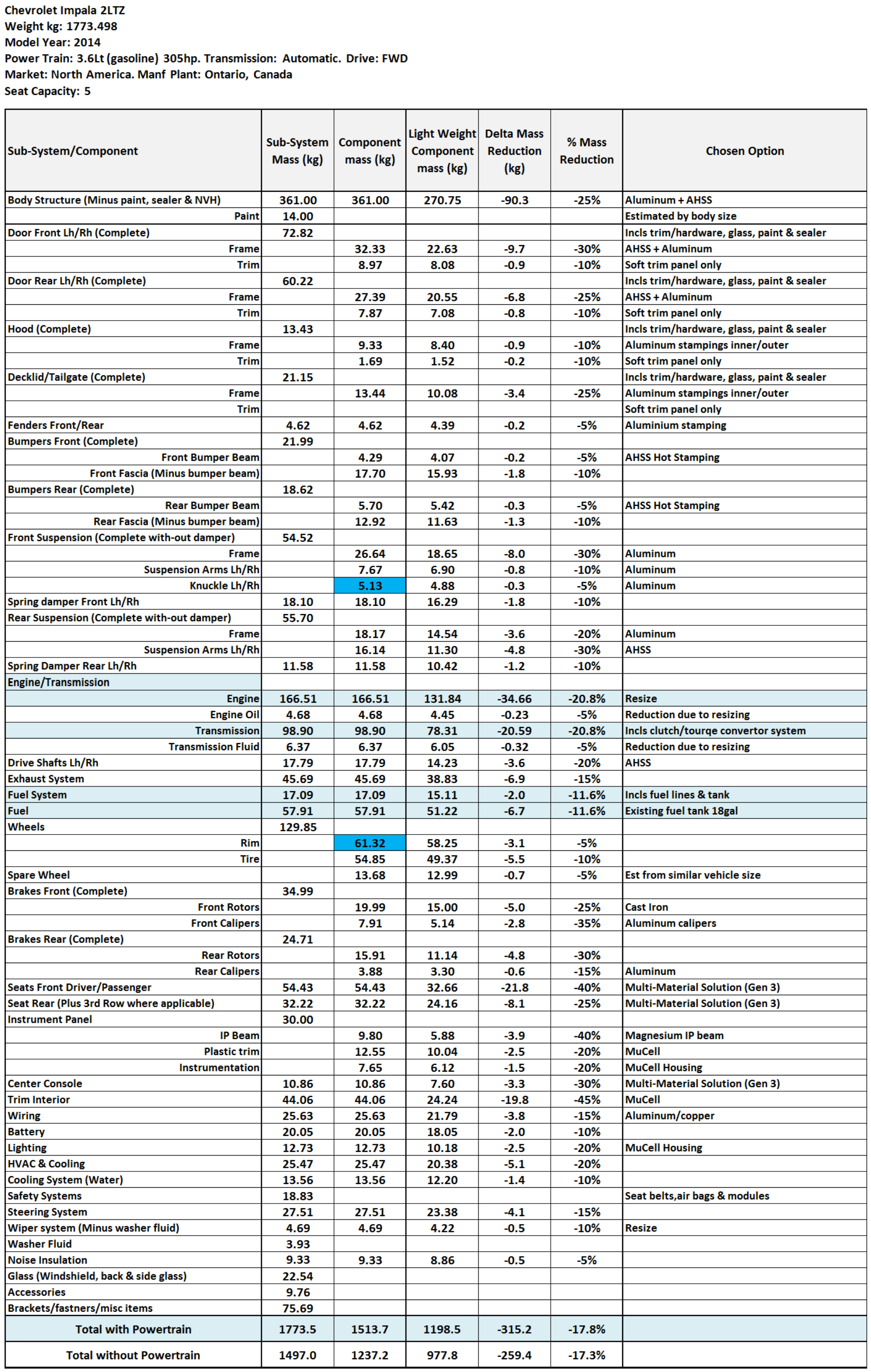
11.6.4 Large passenger cars

The vehicle selected for the large car segment is 2014 Chevrolet Impala 2LTZ. The vehicle weight is 1773.5kg and is manufactured in Canada for the North American market. The Chevrolet Impala has a 3.6L engine with automatic transmission and front-wheel drive train.

The results for the Chevrolet Impala are shown in Figure 538. The body structure has a 25 percent mass reduction with the use of multi-material aluminum/AHSS is assumed, this is similar to the structure used on the 2016 Cadillac CT6. Applying this lightweighting technology to the body structure, the mass savings is 90.3kg. For all doors, the combination of AHSS and aluminum results in equivalent mass savings of 18.2kg. For all remaining closures, which include hood, fenders, and the tailgate in aluminum, produces a mass savings of 4.7kg.

The Chevrolet Impala front suspension, uses steel K-frame (engine cradle) and steel for other suspension components, less the steering knuckle that is comprised of aluminum. For lightweighting the K-frame and other selected suspension components in aluminum, the mass reduction of the front suspension is 10.8kg. For the rear suspension frame, aluminum materials led to a reduction in mass 9.6kg.

As a result of all the proposed lightweighting options implemented as shown in Figure 538, a total weight savings of 315.2 (17.8%) is achieved. This reduction includes 66.2kg due to powertrain downsizing and 8.7 kg for resizing the fuel system, while maintaining vehicle size and vehicle performance functionalities.



Chevrolet Impala 2LTZ
Weight kg: 1773.498
Model Year: 2014
Power Train: 3.6Lt (gasoline) 305hp. Transmission: Automatic. Drive: FWD
Market: North America. Manf Plant: Ontario, Canada
Seat Capacity: 5

Sub-System/Component	Sub-System Mass (kg)	Component mass (kg)	Light Weight Component mass (kg)	Delta Mass Reduction (kg)	% Mass Reduction	Chosen Option
Body Structure (Minus paint, sealer & NVH)	361.00	361.00	270.75	-90.3	-25%	Aluminum + AHSS
Paint	14.00					Estimated by body size
Door Front Lh/Rh (Complete)	72.82					Incls trim/hardware, glass, paint & sealer
Frame		32.33	22.63	-9.7	-30%	AHSS + Aluminum
Trim		8.97	8.08	-0.9	-10%	Soft trim panel only
Door Rear Lh/Rh (Complete)	60.22					Incls trim/hardware, glass, paint & sealer
Frame		27.39	20.55	-6.8	-25%	AHSS + Aluminum
Trim		7.87	7.08	-0.8	-10%	Soft trim panel only
Hood (Complete)	13.43					Incls trim/hardware, glass, paint & sealer
Frame		9.33	8.40	-0.9	-10%	Aluminum stampings inner/outer
Trim		1.69	1.52	-0.2	-10%	Soft trim panel only
Decklid/Tailgate (Complete)	21.15					Incls trim/hardware, glass, paint & sealer
Frame		13.44	10.08	-3.4	-25%	Aluminum stampings inner/outer
Trim						Soft trim panel only
Fenders Front/Rear	4.62	4.62	4.39	-0.2	-5%	Aluminium stamping
Bumpers Front (Complete)	21.99					
Front Bumper Beam		4.29	4.07	-0.2	-5%	AHSS Hot Stamping
Front Fascia (Minus bumper beam)		17.70	15.93	-1.8	-10%	
Bumpers Rear (Complete)	18.62					
Rear Bumper Beam		5.70	5.42	-0.3	-5%	AHSS Hot Stamping
Rear Fascia (Minus bumper beam)		12.92	11.63	-1.3	-10%	
Front Suspension (Complete with-out damper)	54.52					
Frame		26.64	18.65	-8.0	-30%	Aluminum
Suspension Arms Lh/Rh		7.67	6.90	-0.8	-10%	Aluminum
Knuckle Lh/Rh		5.13	4.88	-0.3	-5%	Aluminum
Spring damper Front Lh/Rh	18.10	18.10	16.29	-1.8	-10%	
Rear Suspension (Complete with-out damper)	55.70					
Frame		18.17	14.54	-3.6	-20%	Aluminum
Suspension Arms Lh/Rh		16.14	11.30	-4.8	-30%	AHSS
Spring Damper Rear Lh/Rh	11.58	11.58	10.42	-1.2	-10%	
Engine/Transmission						
Engine	166.51	166.51	131.84	-34.66	-20.8%	Resize
Engine Oil	4.68	4.68	4.45	-0.23	-5%	Reduction due to resizing
Transmission	98.90	98.90	78.31	-20.59	-20.8%	Incls clutch/tourqe convertor system
Transmission Fluid	6.37	6.37	6.05	-0.32	-5%	Reduction due to resizing
Drive Shafts Lh/Rh	17.79	17.79	14.23	-3.6	-20%	AHSS
Exhaust System	45.69	45.69	38.83	-6.9	-15%	
Fuel System	17.09	17.09	15.11	-2.0	-11.6%	Incls fuel lines & tank
Fuel	57.91	57.91	51.22	-6.7	-11.6%	Existing fuel tank 18gal
Wheels	129.85					
Rim		61.32	58.25	-3.1	-5%	
Tire		54.85	49.37	-5.5	-10%	
Spare Wheel		13.68	12.99	-0.7	-5%	Est from similar vehicle size
Brakes Front (Complete)	34.99					
Front Rotors		19.99	15.00	-5.0	-25%	Cast Iron
Front Calipers		7.91	5.14	-2.8	-35%	Aluminum calipers
Brakes Rear (Complete)	24.71					
Rear Rotors		15.91	11.14	-4.8	-30%	
Rear Calipers		3.88	3.30	-0.6	-15%	Aluminum
Seats Front Driver/Passenger	54.43	54.43	32.66	-21.8	-40%	Multi-Material Solution (Gen 3)
Seat Rear (Plus 3rd Row where applicable)	32.22	32.22	24.16	-8.1	-25%	Multi-Material Solution (Gen 3)
Instrument Panel	30.00					
IP Beam		9.80	5.88	-3.9	-40%	Magnesium IP beam
Plastic trim		12.55	10.04	-2.5	-20%	MuCell
Instrumentation		7.65	6.12	-1.5	-20%	MuCell Housing
Center Console	10.86	10.86	7.60	-3.3	-30%	Multi-Material Solution (Gen 3)
Trim Interior	44.06	44.06	24.24	-19.8	-45%	MuCell
Wiring	25.63	25.63	21.79	-3.8	-15%	Aluminum/copper
Battery	20.05	20.05	18.05	-2.0	-10%	
Lighting	12.73	12.73	10.18	-2.5	-20%	MuCell Housing
HVAC & Cooling	25.47	25.47	20.38	-5.1	-20%	
Cooling System (Water)	13.56	13.56	12.20	-1.4	-10%	
Safety Systems	18.83					Seat belts,air bags & modules
Steering System	27.51	27.51	23.38	-4.1	-15%	
Wiper system (Minus washer fluid)	4.69	4.69	4.22	-0.5	-10%	Resize
Washer Fluid	3.93					
Noise Insulation	9.33	9.33	8.86	-0.5	-5%	
Glass (Windshield, back & side glass)	22.54					
Accessories	9.76					
Brackets/fastners/misc items	75.69					
Total with Powertrain	1773.5	1513.7	1198.5	-315.2	-17.8%	
Total without Powertrain	1497.0	1237.2	977.8	-259.4	-17.3%	

Figure 538: Chevrolet Impala sub-system/component weight savings

11.6.5 Minivans

The baseline vehicle selected for the minivan segment is the Chrysler Town & Country Limited with a production year of 2012 and manufactured in Canada for the North American market; this vehicle has a weight of 2159 kg. The Chrysler Town & Country has a drive train of front-wheel drive, automatic transmission, and maximumhorsepower of 283.

The results for the Chrysler Town & Country are shown in Figure 542. For the body structure, applying a 25 percent mass reduction with the use of multi-material AHSS/aluminum is assumed. The approximate mass savings for the body structure is 127.6kg. For the closures, which include hood, fenders, and the tailgate, in AHSS/aluminum leads to mass saving of 8.1 kg. For the front and rear doors, the combination of aluminum and AHSS leads to a mass savings of 20.7kg.

The Chrysler Town & Country front suspension MacPherson strut design is shown in Figure 539. It is comprised of steel K-frame (engine cradle) and steel for other suspension components. Lightweighting the K-frame and other selected suspension components using aluminum offer a mass reduction of 11.8kg.

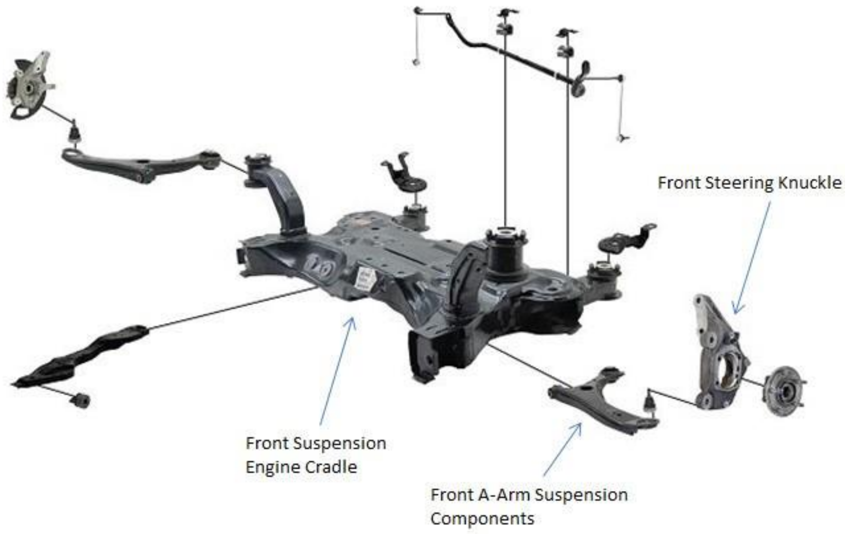


Figure 539: Chrysler Town & Country front suspension[211]

The Chrysler Town & Country rear suspension uses a steel torsion bar/axle as shown in Figure 540. The estimated mass saving for the rear suspension components is 9.8 kg.

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[211] A2Mac1

Figure 540: Chrysler Town & Country rear suspension showing torsion bar/axle[212]

Town & Country seats weigh 185.7 kg (59kg driver and front passenger and 126.7kg second and third row).

Figure 541 shows the Chrysler Town & Country 3rd row rear seat arrangement. Estimated mass saving for all the seats is 55.7kg, using multi-material solution (Generation 3) for seating technology specified for the LWT, discussed in Section 5 of this report.

Figure 541: Chrysler Town & Country 3rd row rear seat[213]

As result of all the proposed lightweighting options implemented as shown in Figure 542, a total weight savings of 401.2kg (18.6%) is achieved. This reduction includes 83.5kg due to powertrain downsizing and 8.5kg for resizing the fuel system, while maintaining vehicle size and vehicle performance functionalities.

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[212] A2Mac1

[213] A2Mac1

Chrysler Town & Country LTD
Weight kg: 2159.105
Model Year: 2012
Power Train: Lt (Gasoline) 283hp. Transmission: Automatic. Drive: FWD
Market: North America. Manf Plant: Ontario, Canada.
Seat Capacity: 7

Sub-System/Component	Sub-System Mass (A2Mac1) (kg)	Component mass (A2Mac1) (kg)	New Light Weight Component mass (kg)	Delta Mass Reduction (kg)	% Mass Reduction	Chosen Option
Body Structure (Minus paint, sealer & NVH)	510.50	510.50	382.88	-127.6	-25%	Aluminum + AHSS
Paint	16.00					Estimated by body size
Door Front Lh/Rh (Complete)	86.01					Incls trim/hardware, glass, paint & sealer
Frame		37.27	27.95	-9.3	-25%	AHSS + Aluminum
Trim		9.14	8.23	-0.9	-10%	Soft trim panel only
Door Rear Lh/Rh (Complete)	100.18					Incls trim/hardware, glass, paint & sealer
Frame		38.51	28.88	-9.6	-25%	AHSS + Aluminum
Trim		8.41	7.57	-0.8	-10%	Soft trim panel only
Hood (Complete)	11.30					Incls trim/hardware, glass, paint & sealer
Frame		8.39	7.55	-0.8	-10%	Aluminum stampings inner/outer
Trim		0.62	0.56	-0.1	-10%	Soft trim panel only
Decklid/Tailgate (Complete)	45.37					Incls trim/hardware, glass, paint & sealer
Frame		19.17	14.38	-4.8	-25%	Aluminum stampings inner/outer
Trim		3.69	3.32	-0.4	-10%	Soft trim panel only
Fenders Front/Rear	6.66	6.66	4.66	-2.0	-30%	Aluminium stamping
Bumpers Front (Complete)	17.09					
Front Bumper Beam		9.54	7.63	-1.9	-20%	AHSS Hot Stamping
Front Fascia (Minus bumper beam)		7.55	6.79	-0.8	-10%	
Bumpers Rear (Complete)	19.48					
Rear Bumper Beam		8.05	6.44	-1.6	-20%	AHSS Hot Stamping
Rear Fascia (Minus bumper beam)		11.43	10.29	-1.1	-10%	
Front Suspension (Complete with-out damper)	67.58					Assembly - various materials
Frame		23.30	17.47	-5.8	-25%	Aluminum
Suspension Arms Lh/Rh		10.79	7.56	-3.2	-30%	Aluminum
Knuckle Lh/Rh		5.62	4.77	-0.8	-15%	Aluminum
Spring damper Front Lh/Rh	18.88	18.88	16.99	-1.9	-10%	
Rear Suspension (Complete with-out damper)	44.09					Assembly - various materials
Frame		28.33	19.83	-8.5	-30%	AHSS
Suspension Arms Lh/Rh						
Spring Damper Rear Lh/Rh	12.53	12.53	11.28	-1.3	-10%	
Engine/Transmission						
Engine	158.55	158.55	115.66	-42.88	-27.0%	Resize
Engine Oil	5.10	5.10	4.85	-0.26	-5%	Reduction due to resizing
Transmission	101.55	101.55	74.08	-27.47	-27%	Incls clutch/tourqe convertor system
Transmission Fluid	6.97	6.97	6.62	-0.35	-5%	Reduction due to resizing
Drive Shafts Lh/Rh	21.13	21.13	14.79	-6.3	-30%	AHSS
Exhaust System	41.44	41.44	35.23	-6.2	-15%	
Fuel System	19.75	19.75	17.36	-2.4	-12%	Incls fuel lines & tank
Fuel	50.82	50.82	44.68	-6.1	-12%	Existing tank 20.8 gal
Wheels	115.56					
Rim		46.76	44.43	-2.3	-5%	Reduction
Tire		47.35	42.62	-4.7	-10%	
Spare Wheel	15.50	15.50	14.73	-0.8	-5%	Est from similar vehicle size
Brakes Front (Complete)	37.05					
Front Rotors		19.23	13.46	-5.8	-30%	
Front Calipers		9.40	6.58	-2.8	-30%	Aluminum calipers
Brakes Rear (Complete)	25.98					
Rear Rotors		12.66	9.49	-3.2	-25%	
Rear Calipers		6.68	4.67	-2.0	-30%	Aluminum calipers
Seats Front Driver/Passenger	59.05	59.05	41.34	-17.7	-30%	Multi-Material Solution (Gen 3)
Seat Rear (Plus 3rd Row where applicable)	126.68	126.68	88.68	-38.0	-30%	Multi-Material Solution (Gen 3)
Instrument Panel	37.57					
IP Beam		16.47	9.06	-7.4	-45%	Magnesium IP beam
Plastic trim		15.08	12.06	-3.0	-20%	MuCell
Instrumentation		6.02	4.82	-1.2	-20%	MuCell Housing
Center Console	13.85	13.85	11.77	-2.1	-15%	Multi-Material Solution (Gen 3)
Trim Interior	63.21	63.21	50.57	-12.6	-20%	MuCell
Wiring	28.44	28.44	24.17	-4.3	-15%	Aluminum/copper
Battery	20.82	20.82	18.74	-2.1	-10%	
Lighting	9.85	9.85	8.37	-1.5	-15%	MuCell Housing
HVAC & Cooling	38.72	38.72	30.98	-7.7	-20%	
Cooling System (Water)	10.79	10.79	9.17	-1.6	-15%	
Safety Systems	23.62					Seat belts,air bags & modules
Steering System	22.65	22.65	19.25	-3.4	-15%	
Wiper system (Minus washer fluid)	6.54	6.54	5.89	-0.7	-10%	Resize
Washer Fluid	4.11					
Noise Insulation	5.74	5.74	4.88	-0.9	-15%	
Glass (Windshield, back & side glass)	28.38					
Accessories	22.79					
Brackets/fastners/misc items	81.20					
Total with Powertrain	2159.1	1785.2	1384.0	-401.2	-18.6%	
Total without Powertrain	1886.9	1513.0	1182.8	-330.2	-17.5%	

Figure 542: Chrysler Town & Country sub-system/component weight savings

11.6.6 Small CUV/SUV/trucks

The baseline vehicle selected for the small SUV segment is a Ford Escape that was produced in 2013, in the United States for the North American market, vehicle weight1692.3kg. The Ford Escape has a 2.0L GTDI EcoBoost engine with automatic transmission and all wheel drive drivetrain.

The results for the Ford Escape are shown in Figure 544. For the body structure, a 20 percent mass reduction with the use of AHSS is assumed. Mass savings for the body structure is estimated 63.8kg using AHSS body panels. For the front and rear doors a combination of AHSS and aluminum were applied, leading to 16.9kg mass savings. For remaining closures, which include hood, fenders, and tailgate, in aluminum lead to a mass reduction of 11.3kg.

The Ford Escape front suspension is a MacPherson strut design is shown in Figure 543. It is comprised of steel K-frame (engine support) and suspension components. For lightweighting the K-frame and other selected suspension components in aluminum, leads to a mass reduction of 9.0kg and for the rear suspension a mass saving of 9.6kg.

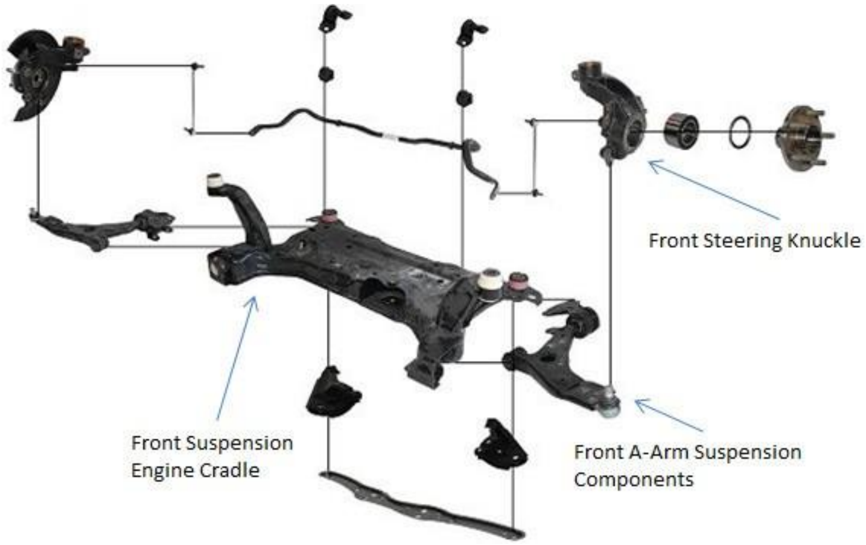

Figure 543: Ford Escape front suspension[214]

As result of all the proposed lightweighting options implemented as shown in Figure 544, a total weight savings of 254.8kg (15.1%) is achieved. This reduction includes 62.5kg due to powertrain downsizing and 3.4kg for resizing the fuel system, while maintaining vehicle size and vehicle performance functionalities.

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[214] A2Mac1

Ford Escape 2.0 GTDI Ecoboost
Weight kg: 1692.298
Model Year: 2013
Power Train: 2.0 GTDI Ecoboost (Gasoline) 240hp. Transmission: Automatic. Drive: AWD
Market: North America. Manf Plant: Kentucky, USA.
Seat Capacity: 5

Sub-System/Component	Sub-System Mass (kg)	Component mass (kg)	Light Weight Component mass (kg)	Delta Mass Reduction (kg)	% Mass Reduction	Chosen Option
Body Structure (Minus paint, sealer & NVH)	319.00	319.00	255.20	-63.8	-20%	AHSS
Paint	14.00					Estimated by body size
Door Front Lh/Rh (Complete)	73.72					Incls trim/hardware, glass, paint & sealer
Frame		33.31	24.98	-8.3	-25%	AHSS + Aluminum
Trim		6.42	5.46	-1.0	-15%	Soft trim panel only
Door Rear Lh/Rh (Complete)	56.91					Incls trim/hardware, glass, paint & sealer
Frame		27.47	20.60	-6.9	-25%	AHSS + Aluminum
Trim		4.84	4.11	-0.7	-15%	Soft trim panel only
Hood (Complete)	17.24					Incls trim/hardware, glass, paint & sealer
Frame		13.46	9.42	-4.0	-30%	Aluminum stampings inner/outer
Trim		0.63	0.63	0.0		Soft trim panel only
Decklid/Tailgate (Complete)	37.68					Incls trim/hardware, glass, paint & sealer
Frame		18.89	13.22	-5.7	-30%	Aluminum stampings inner/outer
Trim					-10%	Soft trim panel only
Fenders Front/Rear	7.78	7.78	6.22	-1.6	-20%	Aluminium stamping
Bumpers Front (Complete)	27.03					
Front Bumper Beam		10.42	9.38	-1.0	-10%	AHSS Hot Stamping
Front Fascia (Minus bumper beam)		16.61	14.95	-1.7	-10%	
Bumpers Rear (Complete)	15.27					
Rear Bumper Beam		6.43	5.79	-0.6	-10%	AHSS Hot Stamping
Rear Fascia (Minus bumper beam)		8.83	7.95	-0.9	-10%	
Front Suspension (Complete with-out damper)	55.56					
Frame		17.85	14.28	-3.6	-20%	Aluminum
Suspension Arms Lh/Rh		10.25	8.72	-1.5	-15%	Aluminum
Knuckle Lh/Rh		12.51	10.01	-2.5	-20%	Aluminum
Spring damper Front Lh/Rh	14.29	14.29	12.86	-1.4	-10%	
Rear Suspension (Complete with-out damper)	60.17					
Frame		19.78	14.83	-4.9	-25%	Aluminum
Suspension Arms Lh/Rh		13.53	10.15	-3.4	-25%	Aluminum
Spring Damper Rear Lh/Rh	12.88	12.88	11.59	-1.3	-10%	
Engine/Transmission						70.076
Engine	132.74	132.74	107.31	-25.43	-19%	Resize
Engine Oil	5.665	5.665	5.38	-0.28	-5%	Reduction due to resizing
Transmission	100.19	100.19	81.00	-19.19	-19%	Incls clutch/tourqe convertor system
Transmission Fluid	6.934	6.934	6.59	-0.35	-5%	Reduction due to resizing
Drive Shafts Lh/Rh	71.07	71.07	56.85	-14.2	-20%	AHSS
Exhaust System	30.34	30.34	27.30	-3.0	-10%	
Fuel System	17.45	17.45	15.74	-1.7	-10%	Incls fuel lines & tank
Fuel	17.45	17.45	15.74	-1.7	-10%	Reduce as per powertrain resizing
Wheels	110.00					
Rim		45.70	43.41	-2.3	-5%	Downsize
Tire		48.05	43.24	-4.8	-10%	
Spare Wheel	16.06	16.06	15.26	-0.8	-5%	Est from similar vehicle size
Brakes Front (Complete)	32.66					
Front Rotors		17.40	15.66	-1.7	-10%	
Front Calipers		8.58	5.58	-3.0	-35%	Aluminum calipers
Brakes Rear (Complete)	16.42					
Rear Rotors		9.39	8.45	-0.9	-10%	
Rear Calipers		3.54	3.01	-0.5	-15%	Aluminum calipers
Seats Front Driver/Passenger	39.11	39.11	27.38	-11.7	-30%	Multi-Material Solution (Gen 3)
Seat Rear (Plus 3rd Row where applicable)	47.38	47.38	33.17	-14.2	-30%	Multi-Material Solution (Gen 3)
Instrument Panel	31.25					
IP Beam		8.38	6.29	-2.1	-25%	Magnesium IP beam
Plastic trim		16.47	14.00	-2.5	-15%	MuCell
Instrumentation		6.40	4.48	-1.9	-30%	MuCell Housing
Center Console	7.32	7.32	6.96	-0.4	-5%	Multi-Material Solution (Gen 3)
Trim Interior	40.57	40.57	28.40	-12.2	-30%	MuCell
Wiring	21.86	21.86	18.58	-3.3	-15%	Aluminum/copper
Battery	17.05	17.05	15.35	-1.7	-10%	
Lighting	10.28	10.28	8.22	-2.1	-20%	MuCell Housing
HVAC & Cooling	24.16	24.16	21.74	-2.4	-10%	
Cooling System (Water)	16.06	16.06	14.46	-1.6	-10%	
Safety Systems	17.68					Seat belts,air bags & modules
Steering System	21.53	21.53	19.38	-2.2	-10%	
Wiper system (Minus washer fluid)	6.74	6.74	6.07	-0.7	-10%	Optimize
Washer Fluid	3.529					
Noise Insulation	10.48	10.48	9.43	-1.0	-10%	
Glass (Windshield, back & side glass)	20.38					
Accessories	5.34					
Brackets/fastners/misc items	99.21					
Total with Powertrain	1692.3	1386.9	1144.8	-254.8	-15.1%	
Total without Powertrain	1459.4	1154.0	944.5	-209.5	-14.4%	

Figure 544: Ford Escape sub-system/component weight savings

11.6.7 Midsize CUV/SUV/trucks

The vehicle chosen for the mid-sized SUV segment is the Chevrolet Equinox with production year 2012 and manufactured in Canada for North American Market. Vehicle weight is 1872.5 kg and has 3.0L gasoline engine that yields 264hp, automatic transmission, and all-wheel drive.

The lightweighting results for the Chevrolet Equinox are shown in Figure 547. Mass reduction for the body structure yielded 23 percent savings using AHSS stampings. The mass saving is approximately 81.7kg. The front and rear doors are assumed to change from steel construction to a combination of AHSS and aluminum for mass savings of 18.7kg. For all remaining closures, using aluminum leads to mass saving of 11.2kg.

The Chevrolet Equinox front suspension is a MacPherson strut design is shown in Figure 545. It is comprised of steel K-frame (engine support) and suspension components. For lightweighting, the K-frame and other selected suspension components in aluminum leads to a mass reduction of 10.6kg.

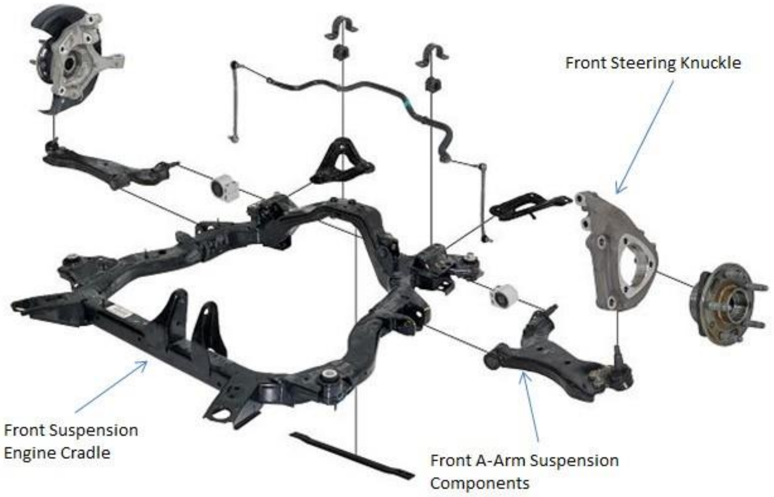

Figure 545: Chevrolet Equinox front suspension[215]

The Chevrolet Equinox rear suspension, shown in Figure 546, is comprised of steel K-frame and multi-link suspension components. The mass reduction of rear suspension is estimated to be 6.4kg with application of aluminum components.

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[215] A2Mac1

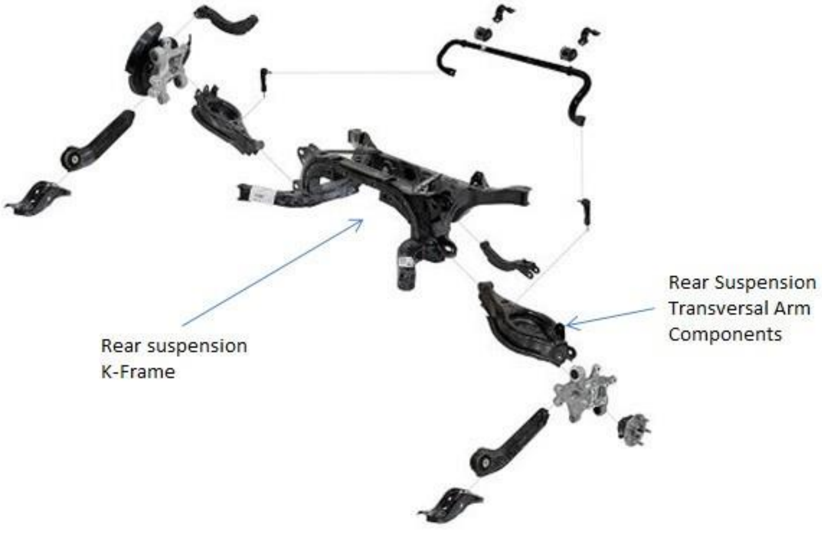

Figure 546: Chevrolet Equinox rear suspension[216]

As result of all the proposed lightweighting options implemented as shown in Figure 547, a total weight savings of 302.6kg (16.2%) is achieved. This reduction includes 76.3kg due to powertrain downsizing and 8.0kg for resizing the fuel system, while maintaining vehicle size and vehicle performance functionalities.

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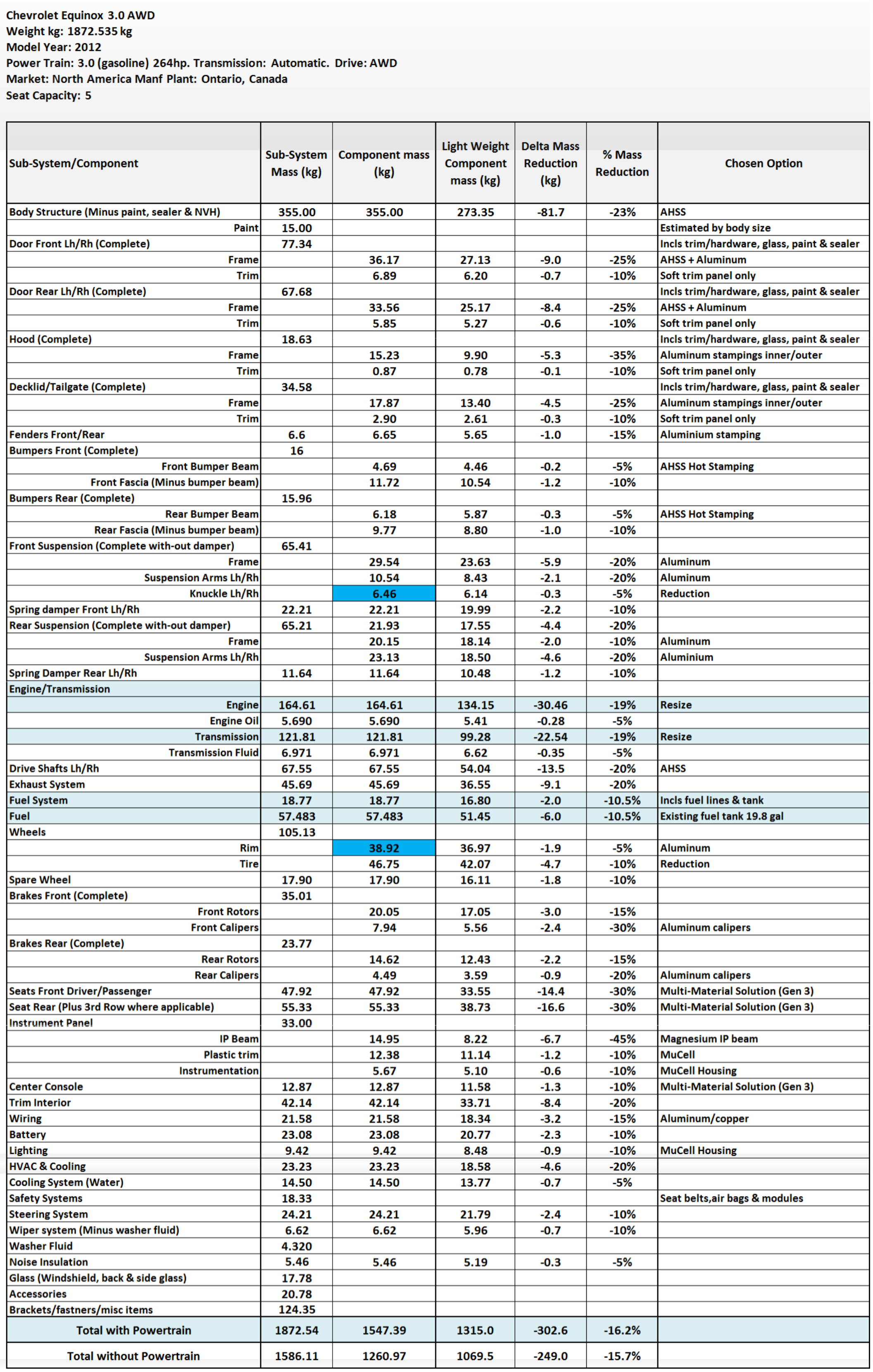
[216] A2Mac1



Chevrolet Equinox 3.0 AWD
Weight kg: 1872.535 kg
Model Year: 2012
Power Train: 3.0 (gasoline) 264hp. Transmission: Automatic. Drive: AWD
Market: North America Manf Plant: Ontario, Canada
Seat Capacity: 5

Sub-System/Component	Sub-System Mass (kg)	Component mass (kg)	Light Weight Component mass (kg)	Delta Mass Reduction (kg)	% Mass Reduction	Chosen Option
Body Structure (Minus paint, sealer & NVH)	355.00	355.00	273.35	-81.7	-23%	AHSS
Paint	15.00					Estimated by body size
Door Front Lh/Rh (Complete)	77.34					Incls trim/hardware, glass, paint & sealer
Frame		36.17	27.13	-9.0	-25%	AHSS + Aluminum
Trim		6.89	6.20	-0.7	-10%	Soft trim panel only
Door Rear Lh/Rh (Complete)	67.68					Incls trim/hardware, glass, paint & sealer
Frame		33.56	25.17	-8.4	-25%	AHSS + Aluminum
Trim		5.85	5.27	-0.6	-10%	Soft trim panel only
Hood (Complete)	18.63					Incls trim/hardware, glass, paint & sealer
Frame		15.23	9.90	-5.3	-35%	Aluminum stampings inner/outer
Trim		0.87	0.78	-0.1	-10%	Soft trim panel only
Decklid/Tailgate (Complete)	34.58					Incls trim/hardware, glass, paint & sealer
Frame		17.87	13.40	-4.5	-25%	Aluminum stampings inner/outer
Trim		2.90	2.61	-0.3	-10%	Soft trim panel only
Fenders Front/Rear	6.6	6.65	5.65	-1.0	-15%	Aluminium stamping
Bumpers Front (Complete)	16					
Front Bumper Beam		4.69	4.46	-0.2	-5%	AHSS Hot Stamping
Front Fascia (Minus bumper beam)		11.72	10.54	-1.2	-10%	
Bumpers Rear (Complete)	15.96					
Rear Bumper Beam		6.18	5.87	-0.3	-5%	AHSS Hot Stamping
Rear Fascia (Minus bumper beam)		9.77	8.80	-1.0	-10%	
Front Suspension (Complete with-out damper)	65.41					
Frame		29.54	23.63	-5.9	-20%	Aluminum
Suspension Arms Lh/Rh		10.54	8.43	-2.1	-20%	Aluminum
Knuckle Lh/Rh		6.46	6.14	-0.3	-5%	Reduction
Spring damper Front Lh/Rh	22.21	22.21	19.99	-2.2	-10%	
Rear Suspension (Complete with-out damper)	65.21	21.93	17.55	-4.4	-20%	
Frame		20.15	18.14	-2.0	-10%	Aluminum
Suspension Arms Lh/Rh		23.13	18.50	-4.6	-20%	Aluminium
Spring Damper Rear Lh/Rh	11.64	11.64	10.48	-1.2	-10%	
Engine/Transmission						
Engine	164.61	164.61	134.15	-30.46	-19%	Resize
Engine Oil	5.690	5.690	5.41	-0.28	-5%	
Transmission	121.81	121.81	99.28	-22.54	-19%	Resize
Transmission Fluid	6.971	6.971	6.62	-0.35	-5%	
Drive Shafts Lh/Rh	67.55	67.55	54.04	-13.5	-20%	AHSS
Exhaust System	45.69	45.69	36.55	-9.1	-20%	
Fuel System	18.77	18.77	16.80	-2.0	-10.5%	Incls fuel lines & tank
Fuel	57.483	57.483	51.45	-6.0	-10.5%	Existing fuel tank 19.8 gal
Wheels	105.13					
Rim		38.92	36.97	-1.9	-5%	Aluminum
Tire		46.75	42.07	-4.7	-10%	Reduction
Spare Wheel	17.90	17.90	16.11	-1.8	-10%	
Brakes Front (Complete)	35.01					
Front Rotors		20.05	17.05	-3.0	-15%	
Front Calipers		7.94	5.56	-2.4	-30%	Aluminum calipers
Brakes Rear (Complete)	23.77					
Rear Rotors		14.62	12.43	-2.2	-15%	
Rear Calipers		4.49	3.59	-0.9	-20%	Aluminum calipers
Seats Front Driver/Passenger	47.92	47.92	33.55	-14.4	-30%	Multi-Material Solution (Gen 3)
Seat Rear (Plus 3rd Row where applicable)	55.33	55.33	38.73	-16.6	-30%	Multi-Material Solution (Gen 3)
Instrument Panel	33.00					
IP Beam		14.95	8.22	-6.7	-45%	Magnesium IP beam
Plastic trim		12.38	11.14	-1.2	-10%	MuCell
Instrumentation		5.67	5.10	-0.6	-10%	MuCell Housing
Center Console	12.87	12.87	11.58	-1.3	-10%	Multi-Material Solution (Gen 3)
Trim Interior	42.14	42.14	33.71	-8.4	-20%	
Wiring	21.58	21.58	18.34	-3.2	-15%	Aluminum/copper
Battery	23.08	23.08	20.77	-2.3	-10%	
Lighting	9.42	9.42	8.48	-0.9	-10%	MuCell Housing
HVAC & Cooling	23.23	23.23	18.58	-4.6	-20%	
Cooling System (Water)	14.50	14.50	13.77	-0.7	-5%	
Safety Systems	18.33					Seat belts,air bags & modules
Steering System	24.21	24.21	21.79	-2.4	-10%	
Wiper system (Minus washer fluid)	6.62	6.62	5.96	-0.7	-10%	
Washer Fluid	4.320					
Noise Insulation	5.46	5.46	5.19	-0.3	-5%	
Glass (Windshield, back & side glass)	17.78					
Accessories	20.78					
Brackets/fastners/misc items	124.35					
Total with Powertrain	1872.54	1547.39	1315.0	-302.6	-16.2%	
Total without Powertrain	1586.11	1260.97	1069.5	-249.0	-15.7%	

Figure 547: Chevrolet Equinox sub-system/component weight savings.

11.6.8 Large CUV/SUV/light-duty trucks

11.6.8.1 Toyota Tundra- Steel Intensive Upper Body Structure

The baseline vehicle selected for the large SUV/light-duty truck steel segment is Toyota Tundra Platinum Crewmax with production year 2014, manufactured in the United States for the North American market, and has a CVW of 2,666.2 kg. The Toyota Tundra is of a body-on-frame construction and the engine capacity is 5.7L and has automatic transmission.

The front suspension for Toyota Tundra is a double wishbone strut design that connects directly to the chassis frame. It is comprised of steel upper and lower control arms and suspension components. For lightweighting, the control arms and other selected suspension components in aluminum leads to a mass reduction of 18.8 kg. See Figure 548 for Toyota Tundra front suspension.

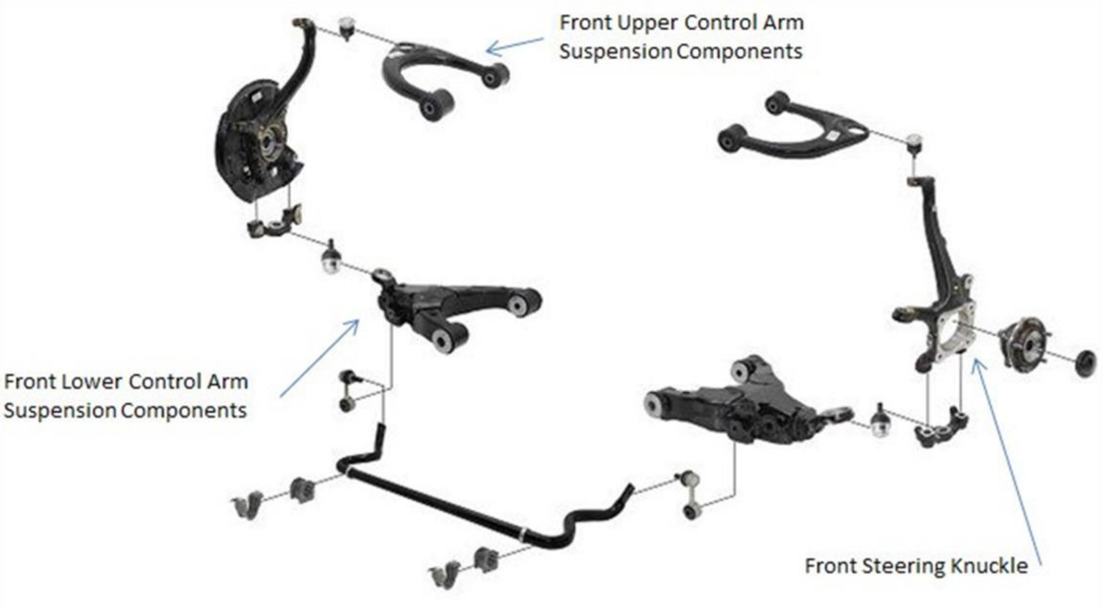


Figure 548: Toyota Tundra Front Suspension[217]

The chassis frame uses a 15 percent mass reduction with use of AHSS. Mass reduction of frame is estimated to be 35 kg. Additional mass savings includes the conversion of the leaf springs to fiberglass GFRP blades from steel. Using GFRP provide a mass savings of 26.2 kg for the rear suspension. Schematic of the rear suspension is shown in Figure 549.

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[217] A2Mac1

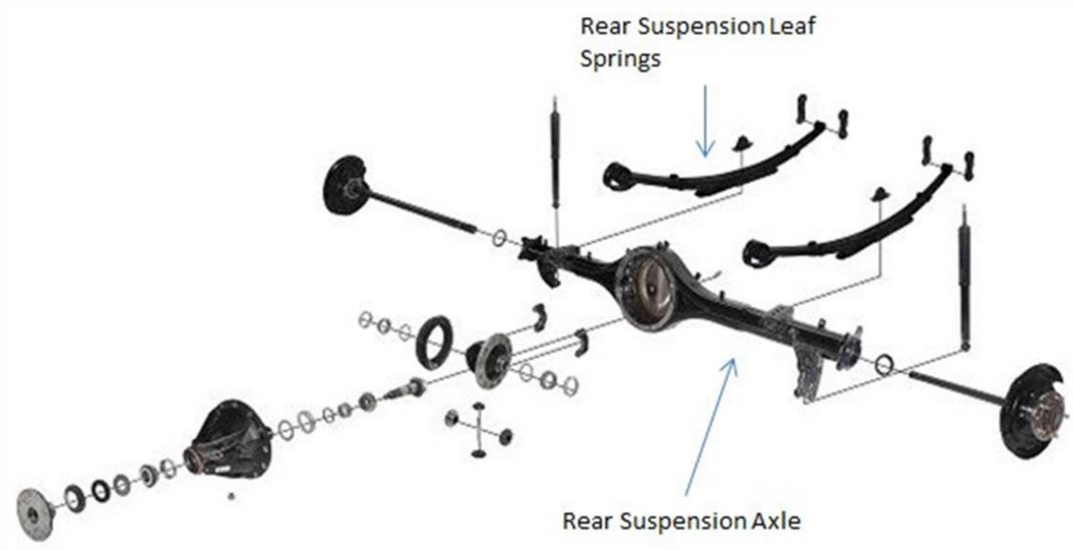

Figure 549: Toyota Tundra Rear Suspension[218]

Apart from the vehicle roll over roof-crush-strength requirement, the cab structure performance is mainly stiffness dependent. The LWT study achieved over 40 percent mass saving for the cab structure constructed out of aluminum stampings and extrusions. This is also the method used on the 2015 Ford F-150. The cab assembly mass is reduced by approximately 106.6 kg. The Toyota Tundra's cab structure is shown in Figure 550 below.

Figure 550: Toyota Tundra Cab Structure[219]

The mass reduction on pickup box with the selection of aluminum as construction materials is also of the order of 40 percent equivalent to 41.8 kg. See Figure 551 for images of the pickup box for the Toyota Tundra.

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[218] A2Mac1

[219] A2Mac1

Figure 551: Toyota Tundra Pickup Box Underside[220]

For the front and rear doors, the Toyota Tundra uses full steel construction. Based on the LWT design, the front and rear doors mass reductions of 23.5 kg can be achieved using aluminum stampings for outer panels with AHSS for the inner door frame structure. The remaining closures that include hood, fenders, and tailgate are designed in aluminum, this leads to a mass saving of 19.3 kg.

All proposed lightweighting options implemented are shown in Figure 552, a total weight savings of 438.1 kg (16.4%) is achieved. This reduction includes 68.2 kg due to powertrain downsizing and 10.0 kg for resizing the fuel system, while maintaining vehicle size and vehicle performance functionalities

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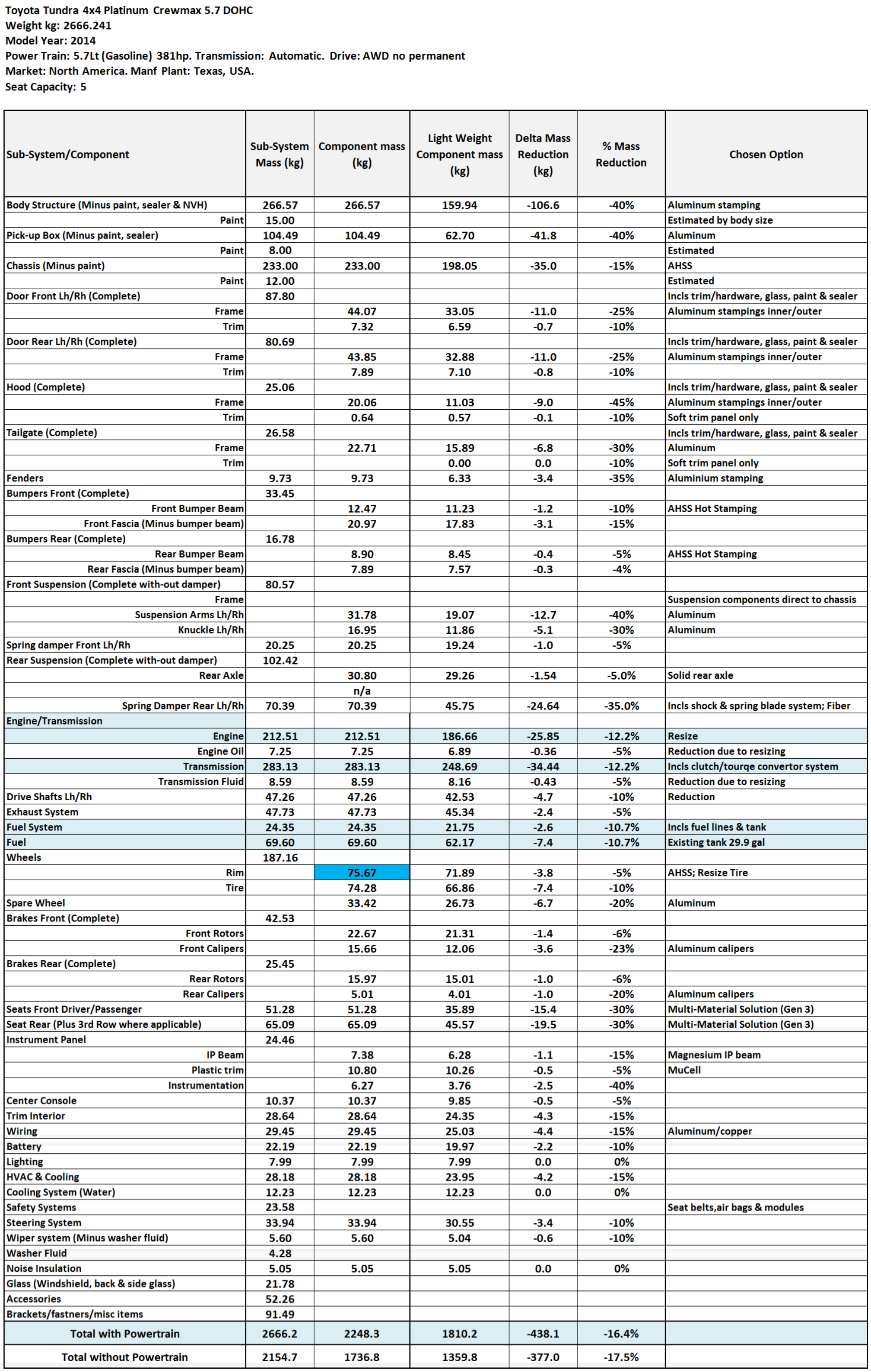
[220] A2Mac1



Toyota Tundra 4x4 Platinum Crewmax 5.7 DOHC
Weight kg: 2666.241
Model Year: 2014
Power Train: 5.7Lt (Gasoline) 381hp. Transmission: Automatic. Drive: AWD no permanent
Market: North America. Manf Plant: Texas, USA.
Seat Capacity: 5

Sub-System/Component	Sub-System Mass (kg)	Component mass (kg)	Light Weight Component mass (kg)	Delta Mass Reduction (kg)	% Mass Reduction	Chosen Option
Body Structure (Minus paint, sealer & NVH)	266.57	266.57	159.94	-106.6	-40%	Aluminum stamping
Paint	15.00					Estimated by body size
Pick-up Box (Minus paint, sealer)	104.49	104.49	62.70	-41.8	-40%	Aluminum
Paint	8.00					Estimated
Chassis (Minus paint)	233.00	233.00	198.05	-35.0	-15%	AHSS
Paint	12.00					Estimated
Door Front Lh/Rh (Complete)	87.80					Incls trim/hardware, glass, paint & sealer
Frame		44.07	33.05	-11.0	-25%	Aluminum stampings inner/outer
Trim		7.32	6.59	-0.7	-10%	
Door Rear Lh/Rh (Complete)	80.69					Incls trim/hardware, glass, paint & sealer
Frame		43.85	32.88	-11.0	-25%	Aluminum stampings inner/outer
Trim		7.89	7.10	-0.8	-10%	
Hood (Complete)	25.06					Incls trim/hardware, glass, paint & sealer
Frame		20.06	11.03	-9.0	-45%	Aluminum stampings inner/outer
Trim		0.64	0.57	-0.1	-10%	Soft trim panel only
Tailgate (Complete)	26.58					Incls trim/hardware, glass, paint & sealer
Frame		22.71	15.89	-6.8	-30%	Aluminum
Trim			0.00	0.0	-10%	Soft trim panel only
Fenders	9.73	9.73	6.33	-3.4	-35%	Aluminium stamping
Bumpers Front (Complete)	33.45					
Front Bumper Beam		12.47	11.23	-1.2	-10%	AHSS Hot Stamping
Front Fascia (Minus bumper beam)		20.97	17.83	-3.1	-15%	
Bumpers Rear (Complete)	16.78					
Rear Bumper Beam		8.90	8.45	-0.4	-5%	AHSS Hot Stamping
Rear Fascia (Minus bumper beam)		7.89	7.57	-0.3	-4%	
Front Suspension (Complete with-out damper)	80.57					
Frame						Suspension components direct to chassis
Suspension Arms Lh/Rh		31.78	19.07	-12.7	-40%	Aluminum
Knuckle Lh/Rh		16.95	11.86	-5.1	-30%	Aluminum
Spring damper Front Lh/Rh	20.25	20.25	19.24	-1.0	-5%	
Rear Suspension (Complete with-out damper)	102.42					
Rear Axle		30.80	29.26	-1.54	-5.0%	Solid rear axle
		n/a				
Spring Damper Rear Lh/Rh	70.39	70.39	45.75	-24.64	-35.0%	Incls shock & spring blade system; Fiber
Engine/Transmission						
Engine	212.51	212.51	186.66	-25.85	-12.2%	Resize
Engine Oil	7.25	7.25	6.89	-0.36	-5%	Reduction due to resizing
Transmission	283.13	283.13	248.69	-34.44	-12.2%	Incls clutch/tourqe convertor system
Transmission Fluid	8.59	8.59	8.16	-0.43	-5%	Reduction due to resizing
Drive Shafts Lh/Rh	47.26	47.26	42.53	-4.7	-10%	Reduction
Exhaust System	47.73	47.73	45.34	-2.4	-5%	
Fuel System	24.35	24.35	21.75	-2.6	-10.7%	Incls fuel lines & tank
Fuel	69.60	69.60	62.17	-7.4	-10.7%	Existing tank 29.9 gal
Wheels	187.16					
Rim		75.67	71.89	-3.8	-5%	AHSS; Resize Tire
Tire		74.28	66.86	-7.4	-10%	
Spare Wheel		33.42	26.73	-6.7	-20%	Aluminum
Brakes Front (Complete)	42.53					
Front Rotors		22.67	21.31	-1.4	-6%	
Front Calipers		15.66	12.06	-3.6	-23%	Aluminum calipers
Brakes Rear (Complete)	25.45					
Rear Rotors		15.97	15.01	-1.0	-6%	
Rear Calipers		5.01	4.01	-1.0	-20%	Aluminum calipers
Seats Front Driver/Passenger	51.28	51.28	35.89	-15.4	-30%	Multi-Material Solution (Gen 3)
Seat Rear (Plus 3rd Row where applicable)	65.09	65.09	45.57	-19.5	-30%	Multi-Material Solution (Gen 3)
Instrument Panel	24.46					
IP Beam		7.38	6.28	-1.1	-15%	Magnesium IP beam
Plastic trim		10.80	10.26	-0.5	-5%	MuCell
Instrumentation		6.27	3.76	-2.5	-40%	
Center Console	10.37	10.37	9.85	-0.5	-5%	
Trim Interior	28.64	28.64	24.35	-4.3	-15%	
Wiring	29.45	29.45	25.03	-4.4	-15%	Aluminum/copper
Battery	22.19	22.19	19.97	-2.2	-10%	
Lighting	7.99	7.99	7.99	0.0	0%	
HVAC & Cooling	28.18	28.18	23.95	-4.2	-15%	
Cooling System (Water)	12.23	12.23	12.23	0.0	0%	
Safety Systems	23.58					Seat belts,air bags & modules
Steering System	33.94	33.94	30.55	-3.4	-10%	
Wiper system (Minus washer fluid)	5.60	5.60	5.04	-0.6	-10%	
Washer Fluid	4.28					
Noise Insulation	5.05	5.05	5.05	0.0	0%	
Glass (Windshield, back & side glass)	21.78					
Accessories	52.26					
Brackets/fastners/misc items	91.49					
Total with Powertrain	2666.2	2248.3	1810.2	-438.1	-16.4%	
Total without Powertrain	2154.7	1736.8	1359.8	-377.0	-17.5%	

Figure 552: Toyota Tundra sub-system//component weight reduction

11.6.8.2 2015 Ford F-150 with Aluminum Intensive Upper Body Structure

The Ford F-150 Supercrew Platinum production year 2015, manufactured in the United States for the North American market, has a CVW of 2,469.9 kg. The 2015 Ford F-150 is the latest design of light-duty truck that uses extensive amount of aluminum for the upper body structure, including the cab, pickup box, and all the closures. The 2015 Ford F-150 achieved a mass saving of approximately 13 percent when compared with a similarly equipped 2014 Ford F-150 as shown in **Figure 504**.

The aluminum cab body structure is mounted onto AHSS frame through flexible rubber bushing to isolate the cab/occupants from vibration and structure born noise. As the 2015 F-150 already uses aluminum for the cab structure only 10 percent additional mass saving (17 kg) is assumed over the next two generations of the F-150 for year 2025. This will be achieved through further design optimization and application of advanced grades of aluminum alloys. Similarly, the rear pickup box is manufactured in aluminum for the Ford F150; no additional mass reduction is assumed for this system for year 2025. The Ford F150's under-body chassis frame plays a very significant role in crash performance and as a load bearing structure for the suspension systems and powertrain that are directly mounted to the chassis frame structure. Ford F150 uses AHSS construction for the chassis frame, a 15 percent mass reduction 23.6 kg is estimated by optimization and by use of advanced grades of steel that will be available by year 2025.

The Ford F150 front suspension is a double wishbone strut design that connects directly to the chassis frame. The schematic of the front suspension is shown in Figure 553. It is comprised of steel upper and lower control arms and suspension components. For lightweighting the control arms and other selected suspension components in AHSS/aluminum will leads to a mass reduction of 9.6 kg.

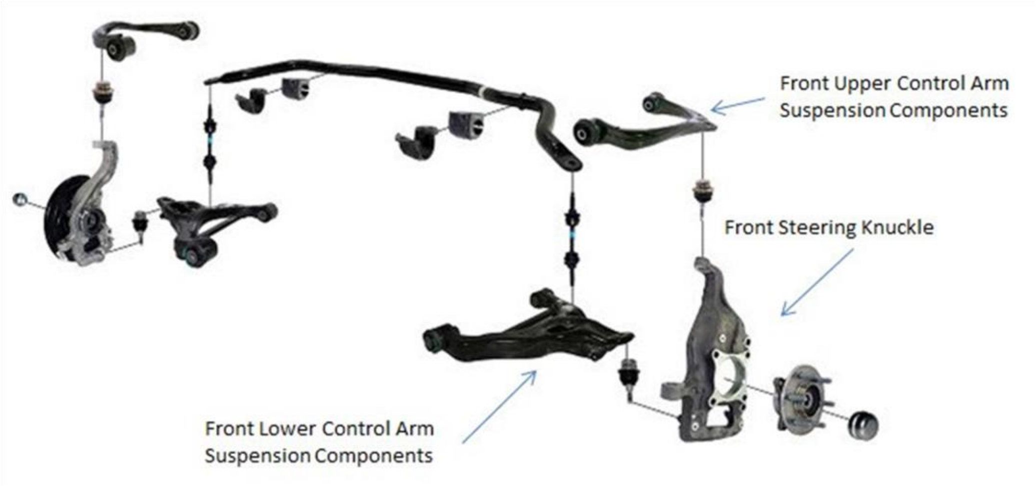


Figure 553: Ford F150 Front Suspension[221]

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[221] A2Mac1

Additional possible mass savings includes the conversion of the leaf springs to fiberglass GFRP blades from steel. Using GFRP could provide a mass savings of 30 percent or 20 kg. The rear suspension is shown in Figure 554.

Figure 554: Ford F150 Rear Axle / Suspension[222]

For the tailgate, the structure is comprised of a combination of aluminum and steel; the aluminum forms the outer surfaces with some aluminum reinforcements, while the steel is the structure and support of the pull out ladder assembly. Figure 555 shows the components of the tailgate assembly. The fold out step is integrated in the rear tailgate with a lift assist handle. This is optional on all trim packages for the 2015 Ford F150.[223]

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[222] A2Mac1

[223] www.ford.com/trucks/f150/compare-models/?models=platinum|xl|xlt|lariat#categoryExterior_Features

Figure 555: Ford F150 tailgate fold-out step and lift assist[224]

For the front and rear doors, Ford F150 designs are of aluminum and AHSS construction; for these closures, 5 percent additional mass savings should be possible over next two design iterations.

All proposed lightweighting options implemented are shown in Figure 556, a total weight savings of 237.8 kg (9.6%). This reduction includes 42.6 kg due to powertrain downsizing and 7.5 kg for resizing the fuel system, while maintaining vehicle size and vehicle performance functionalities. The EDAG team working on this project believes that this approach using AHSS chassis frame structure and aluminum cab, pickup box and multi-material seats and closures, is most likely to be implemented for production years 2025 to 2030.

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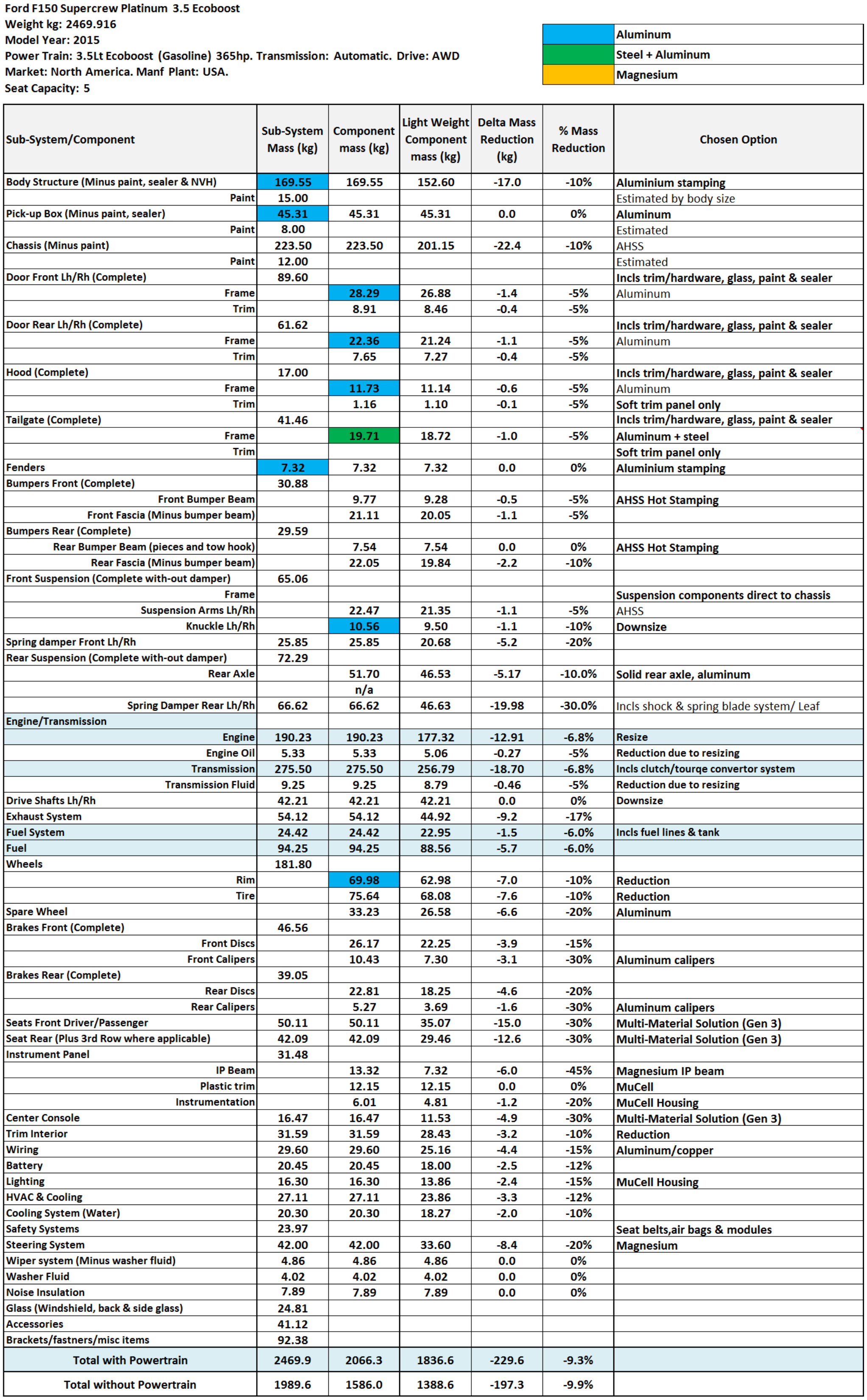
[224] A2Mac1



Ford F150 Supercrew Platinum 3.5 Ecoboost
Weight kg: 2469.916
Model Year: 2015
Power Train: 3.5Lt Ecoboost (Gasoline) 365hp. Transmission: Automatic. Drive: AWD
Market: North America. Manf Plant: USA.
Seat Capacity: 5

🟦 Aluminum
🟩 Steel + Aluminum
🟨 Magnesium

Sub-System/Component	Sub-System Mass (kg)	Component mass (kg)	Light Weight Component mass (kg)	Delta Mass Reduction (kg)	% Mass Reduction	Chosen Option
Body Structure (Minus paint, sealer & NVH)	169.55	169.55	152.60	-17.0	-10%	Aluminium stamping
Paint	15.00					Estimated by body size
Pick-up Box (Minus paint, sealer)	45.31	45.31	45.31	0.0	0%	Aluminum
Paint	8.00					Estimated
Chassis (Minus paint)	223.50	223.50	201.15	-22.4	-10%	AHSS
Paint	12.00					Estimated
Door Front Lh/Rh (Complete)	89.60					Incls trim/hardware, glass, paint & sealer
Frame		28.29	26.88	-1.4	-5%	Aluminum
Trim		8.91	8.46	-0.4	-5%	
Door Rear Lh/Rh (Complete)	61.62					Incls trim/hardware, glass, paint & sealer
Frame		22.36	21.24	-1.1	-5%	Aluminum
Trim		7.65	7.27	-0.4	-5%	
Hood (Complete)	17.00					Incls trim/hardware, glass, paint & sealer
Frame		11.73	11.14	-0.6	-5%	Aluminum
Trim		1.16	1.10	-0.1	-5%	Soft trim panel only
Tailgate (Complete)	41.46					Incls trim/hardware, glass, paint & sealer
Frame		19.71	18.72	-1.0	-5%	Aluminum + steel
Trim						Soft trim panel only
Fenders	7.32	7.32	7.32	0.0	0%	Aluminium stamping
Bumpers Front (Complete)	30.88					
Front Bumper Beam		9.77	9.28	-0.5	-5%	AHSS Hot Stamping
Front Fascia (Minus bumper beam)		21.11	20.05	-1.1	-5%	
Bumpers Rear (Complete)	29.59					
Rear Bumper Beam (pieces and tow hook)		7.54	7.54	0.0	0%	AHSS Hot Stamping
Rear Fascia (Minus bumper beam)		22.05	19.84	-2.2	-10%	
Front Suspension (Complete with-out damper)	65.06					
Frame						Suspension components direct to chassis
Suspension Arms Lh/Rh		22.47	21.35	-1.1	-5%	AHSS
Knuckle Lh/Rh		10.56	9.50	-1.1	-10%	Downsize
Spring damper Front Lh/Rh	25.85	25.85	20.68	-5.2	-20%	
Rear Suspension (Complete with-out damper)	72.29					
Rear Axle		51.70	46.53	-5.17	-10.0%	Solid rear axle, aluminum
		n/a				
Spring Damper Rear Lh/Rh	66.62	66.62	46.63	-19.98	-30.0%	Incls shock & spring blade system/ Leaf
Engine/Transmission						
Engine	190.23	190.23	177.32	-12.91	-6.8%	Resize
Engine Oil	5.33	5.33	5.06	-0.27	-5%	Reduction due to resizing
Transmission	275.50	275.50	256.79	-18.70	-6.8%	Incls clutch/tourqe convertor system
Transmission Fluid	9.25	9.25	8.79	-0.46	-5%	Reduction due to resizing
Drive Shafts Lh/Rh	42.21	42.21	42.21	0.0	0%	Downsize
Exhaust System	54.12	54.12	44.92	-9.2	-17%	
Fuel System	24.42	24.42	22.95	-1.5	-6.0%	Incls fuel lines & tank
Fuel	94.25	94.25	88.56	-5.7	-6.0%	
Wheels	181.80					
Rim		69.98	62.98	-7.0	-10%	Reduction
Tire		75.64	68.08	-7.6	-10%	Reduction
Spare Wheel		33.23	26.58	-6.6	-20%	Aluminum
Brakes Front (Complete)	46.56					
Front Discs		26.17	22.25	-3.9	-15%	
Front Calipers		10.43	7.30	-3.1	-30%	Aluminum calipers
Brakes Rear (Complete)	39.05					
Rear Discs		22.81	18.25	-4.6	-20%	
Rear Calipers		5.27	3.69	-1.6	-30%	Aluminum calipers
Seats Front Driver/Passenger	50.11	50.11	35.07	-15.0	-30%	Multi-Material Solution (Gen 3)
Seat Rear (Plus 3rd Row where applicable)	42.09	42.09	29.46	-12.6	-30%	Multi-Material Solution (Gen 3)
Instrument Panel	31.48					
IP Beam		13.32	7.32	-6.0	-45%	Magnesium IP beam
Plastic trim		12.15	12.15	0.0	0%	MuCell
Instrumentation		6.01	4.81	-1.2	-20%	MuCell Housing
Center Console	16.47	16.47	11.53	-4.9	-30%	Multi-Material Solution (Gen 3)
Trim Interior	31.59	31.59	28.43	-3.2	-10%	Reduction
Wiring	29.60	29.60	25.16	-4.4	-15%	Aluminum/copper
Battery	20.45	20.45	18.00	-2.5	-12%	
Lighting	16.30	16.30	13.86	-2.4	-15%	MuCell Housing
HVAC & Cooling	27.11	27.11	23.86	-3.3	-12%	
Cooling System (Water)	20.30	20.30	18.27	-2.0	-10%	
Safety Systems	23.97					Seat belts,air bags & modules
Steering System	42.00	42.00	33.60	-8.4	-20%	Magnesium
Wiper system (Minus washer fluid)	4.86	4.86	4.86	0.0	0%	
Washer Fluid	4.02	4.02	4.02	0.0	0%	
Noise Insulation	7.89	7.89	7.89	0.0	0%	
Glass (Windshield, back & side glass)	24.81					
Accessories	41.12					
Brackets/fastners/misc items	92.38					
Total with Powertrain	2469.9	2066.3	1836.6	-229.6	-9.3%	
Total without Powertrain	1989.6	1586.0	1388.6	-197.3	-9.9%	

Figure 556: Ford F150 sub-system//component weight reduction

11.7 Conclusions: Mass Reduction of Other Light-duty Vehicles

The estimated mass reduction for the baseline vehicle in each class is shown in Figure 557. The mass saving potential for all the classes is in a range from 15.1 percent to 18.6 percent for 2014 model year vehicles. For 2015 Ford F-150 the estimated mass saving for year 2025 is 9.6 percent. This range of results is consistent with the results obtained for the LWT mass reduction of 17.6 percent.

The baseline vehicles for the large SUV/light-duty Truck aluminum and steel models, the Ford F150 and Toyota Tundra, have construction that differs from vehicles in the other subclasses as they are body-on-frame construction with a rear pickup box and a truck tailgate; this is consistent with our LWT design. The Toyota Tundra had the highest weight at 2,666 kg among all the vehicles selected. Due to the additional parts and the type of construction, the amount of weight savings potential is greater than passenger cars.

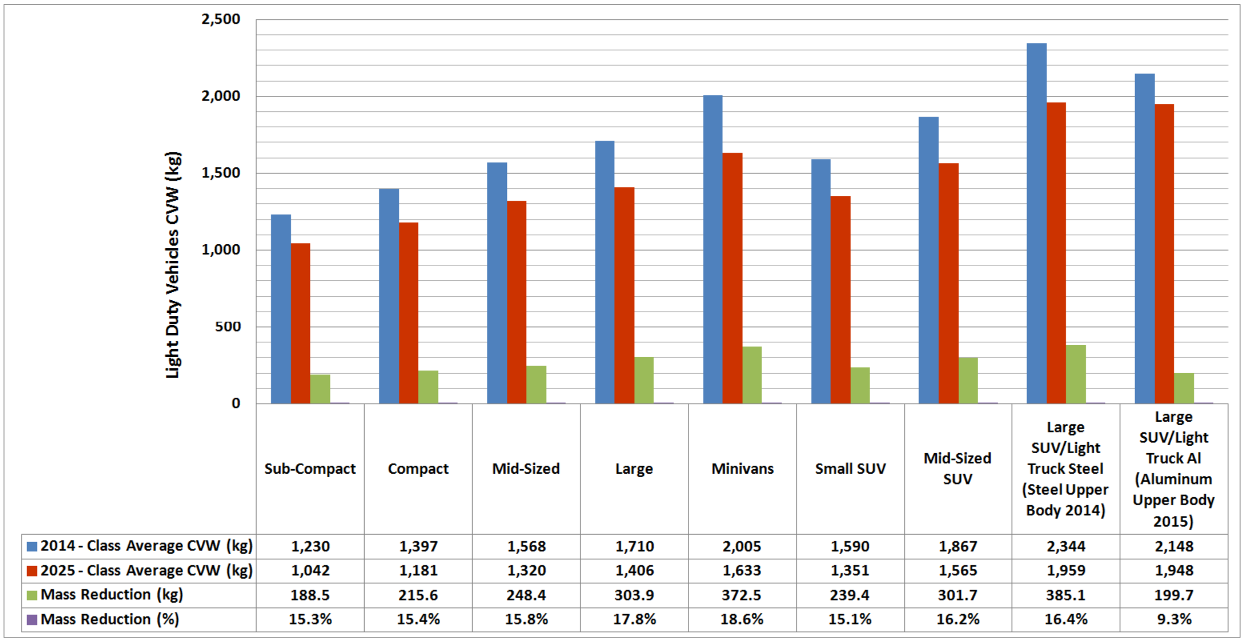
Vehicle Class	Selected Baseline Vehicle	Baseline Vehicle CVW (kg)	2025 LWV CVW (kg)	Mass Reduction (kg)	Mass Reduction (%)
Sub-Compact Car	Chevrolet Sonic 1.8L (2012)	1,287	1,090	197	15.3%
Compact Car	Toyota Corolla LE 1.8 (2014	1,309	1,107	202	15.4%
Mid-Sized Car	Ford Fusion SE 1.6 (2013)	1,581	1,330	250	15.8%
Large Car	Chevrolet Impala 2LTZ 3.6 (2014)	1,773	1,458	315	17.8%
Minivans	Chrysler Town & Country Limited (2012)	2,159	1,758	401	18.6%
Small SUV/LT	Ford Escape 2.0 SE (2013)	1,692	1,438	255	15.1%
Mid-Sized SUV/LT	Chevrolet Equinox 3.0 (2012)	1,873	1,570	303	16.2%
Large SUV/LT	Ford F150 3.5L (2015)	2,470	2,240	230	9.3%
Large SUV/LT	Toyota Tundra 5.7L (2014)	2,666	2,228	438	16.4%

Figure 557: Summary of vehicle subclass weight saving results

In addition to the weight savings estimated for the selected vehicles within each subclass, the percentage reduction determined from of the subclasses results was applied to the average vehicle weight for each subclass. Figure 558 and Figure 559 show the estimated 2025 Class average mass compared with the 2014 vehicle class averages.

Vehicle Class	2014 - Class Average CVW (kg)	2025 - Class Average CVW (kg)	Mass Reduction (kg)	Mass Reduction (%)
Sub-Compact Car	1,230	1,042	188.5	15.3%
Compact Car	1,397	1,181	215.6	15.4%
Mid-Sized Car	1,568	1,320	248.4	15.8%
Small SUV/LT	1,590	1,351	239.4	15.1%
Large Car	1,710	1,406	303.9	17.8%
Mid-Sized SUV/LT	1,867	1,565	301.7	16.2%
Minivans	2,005	1,633	372.5	18.6%
Large SUV/Light Truck (Steel Upper Body 2014)	2,344	1,959	385.1	16.4%
Large SUV/Light Truck (Aluminum Upper Body 2015)	2,148	1,948	199.7	9.3%
Light-Duty Vehicle Average	1,714	1,432	281.9	16.4%

Figure 558: Comparison between 2014 and 2025 Class Average weights



	Sub-Compact	Compact	Mid-Sized	Large	Minivans	Small SUV	Mid-Sized SUV	Large SUV/Light Truck Steel (Steel Upper Body 2014)	Large SUV/Light Truck Al (Aluminum Upper Body 2015)
🟦 2014 - Class Average CVW (kg)	1,230	1,397	1,568	1,710	2,005	1,590	1,867	2,344	2,148
🟥 2025 - Class Average CVW (kg)	1,042	1,181	1,320	1,406	1,633	1,351	1,565	1,959	1,948
🟩 Mass Reduction (kg)	188.5	215.6	248.4	303.9	372.5	239.4	301.7	385.1	199.7
🟪 Mass Reduction (%)	15.3%	15.4%	15.8%	17.8%	18.6%	15.1%	16.2%	16.4%	9.3%

Figure 559: Comparison between 2014 and 2025 Class Average weights

In conclusion, all the weight reduction technologies developed for the LWT program using the 2014 Chevrolet Silverado 1500 as the baseline vehicle can readily be introduced to all of the selected vehicles within each of the vehicle subclasses, subcompact to large SUV/light truck, to achieve weight savings from 15.1 percent to 18.6 percent over the next two design cycles for model years 2025 to 2030.

Further, it can be seen when comparing the results for each of the vehicle segments there is a significant weight improvement when downsizing the powertrain, this shows the importance of matching the powertrain to the vehicle weight when undergoing a weight reduction program as this impacts other sub-systems within the vehicle.

As demonstrated through detailed design and computer simulation of LWT, these estimated weight reductions can be achieved. It is important to use the latest weight saving optimization tools such body structure CAE optimization for material gage-grade-geometry selection. Taking full advantage of mass compounding and resizing all sub-systems is also critical to achieve the most mass efficient design.

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