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16. Abstract

The Department of Transportation National Highway Traffic Safety Administration (NHTSA) awarded contract to an engineering team consisting of Electricore, Inc. (prime contractor), EDAG, and George Washington University (GWU) to design a future midsize lightweight vehicle (LWV). This vehicle will use manufacturing processes available in model year 2017-2025 and capable of high volume production (200,000 units per year). 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 LWV must be within +10% of the original vehicle1. Based upon its production volume, market share, and five-star crash rating, the team selected the model year 2011 Honda Accord 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. The major boundary conditions for this project include the followings.

1. Maintain or improve vehicle size compared to the baseline vehicle.
2. Maintain retail price parity (±10% variation) with the baseline vehicle2.
3. Maintain or improve vehicle functionalities compared to the baseline vehicle, including maintaining comparable performance in NHTSA's New Car Assessment Program (NCAP) frontal, side, side pole and IIHS test programs through appropriate crash simulations.
4. Powertrain may be downsized, however alternate powertrain configurations (i.e. hybrid electric, battery electric, and diesel) will not be considered.
5. All advanced design, material, technologies and manufacturing processes must be realistically projected to be available for fleet wide production in time frame of model years 2017-2025 and capable of high volume production (200,000 units per year).
6. Achieve the maximum feasible amount of mass reduction within the constraints.

Overall the complete LWV achieved a total weight savings of 22 percent (332 kg) from the baseline vehicle (1480 kg) at an incremental cost increase of $319 or $0.96 per kg. To achieve same vehicle performance as the baseline vehicle, the size of the engine for LWV was proportionally reduced from 2.4L-177 HP to 1.8L-140HP. Without the mass and cost reduction allowance for the powertrain (engine and transmission) the mass saving for the 'glider' is 24 percent (264kg) at mass saving cost premium of $1.63 per kg mass saving.

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1 Executive Summary

The Department of Transportation National Highway Traffic Safety Administration (NHTSA) awarded contract to an engineering team consisting of Electricore, Inc. (prime contractor), EDAG, and George Washington University (GWU) to design a future midsize lightweight vehicle (LWV). This vehicle will use manufacturing processes available in model year 2017-2025 and capable of high volume production (200,000 units per year). 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 LWV must be within +10% of the original vehicle[1]. Based upon its production volume, market share, and five-star crash rating, the team selected the model year 2011 Honda Accord 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. The major boundary conditions for this project include the followings.

1. Maintain or improve vehicle size compared to the baseline vehicle.
2. Maintain retail price parity (±10% variation) with the baseline vehicle[2].
3. Maintain or improve vehicle functionalities compared to the baseline vehicle, including maintaining comparable performance in NHTSA's New Car Assessment Program (NCAP) frontal, side, side pole and IIHS test programs through appropriate crash simulations.
4. Powertrain may be downsized, however alternate powertrain configurations (i.e. hybrid electric, battery electric, and diesel) will not be considered.
5. All advanced design, material, technologies and manufacturing processes must be realistically projected to be available for fleet wide production in time frame of model years 2017-2025 and capable of high volume production (200,000 units per year).
6. Achieve the maximum feasible amount of mass reduction within the constraints.

When executing this project, the Electricore team adopted a collaborative design, engineering and CAE process with built-in feedback loops to incorporate results and outcomes from each of the design steps into the overall vehicle design and analysis. In a simple linear sense, the approach is to benchmark the baseline 2011 Honda Accord and then undertake a series of baseline design selections, new material selections, new technology selections and finally overall vehicle design optimization. Vehicle performance, safety (crashworthiness) simulations and cost analyses are run in parallel to the design and engineering effort to help ensure that design decisions are made in line with the established boundary conditions. This is further constrained by developing a high volume production vehicle specifically targeted for model years 2017-2025, which means the team use technologies and materials which will be available for large scale production and available within two to three design generations (e.g. model years 2015, 2020 and 2025). This high level approach helps the final design meet the project objectives within the boundary conditions, and ideally provides the government and industry a truly production feasible vehicle design to use for future studies and analysis. The project team strives to make sure that the project's objectives, approach and conclusions meet the highest levels of automotive engineering standards and be justifiable and supportable under rigorous peer review and analysis. The results of this work will provide a basis for helping to estimate some of the impacts of future CAFE standards for model years 2017-2025.

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[1] 10% of the baseline MSRP equals to $2198; based on Honda Accord 4DR-LX Window Sticker shown in Figure 3

[2] 10% of the baseline MSRP equals to $2198; based on Honda Accord 4DR-LX Window Sticker shown in Figure 3

Due to reliability, manufacturability and cost concerns many manufacturers may opt to only use technologies, materials and manufacturing processes that are currently in use or planned to be in use on existing vehicle platforms. Automotive manufacturers often introduce new materials, technologies and processes on low-volume, high price vehicles first and then migrate those technologies to high-production vehicle lines over time. This significantly reduces the risk to the Original Equipment Manufacturer (OEM) from new designs and materials being introduced into mass production vehicles. Therefore, the Electricore team utilized, to the extent possible, only those materials, technologies and designs which are currently in-use or planned to be introduced in the near term (model years 2012-2015) on low and high production vehicles. The recommended materials (advanced high strength steels, aluminum, magnesium and plastics), manufacturing processes, (stamping, hot stamping, die casting, extrusions, and roll forming) and assembly methods (spot welding, laser welding 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. The process parameters for manufacturing with advanced high strength steels can be supported by computer simulation. This approach eliminated those material and technology options which would likely be unrealistic or overly aggressive to implement in mass production by model years 2017-2025.

The researchers began the investigation by measuring, evaluating, and modeling the baseline vehicle. 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 body-in-white, closures, bumpers, and suspensions, EDAG created a design to fully optimize the mass savings, using the latest computer aided engineering (CAE) optimization techniques. For those components which 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 which were re-designed by EDAG, they used a Technical Cost Modeling approach which 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 2020 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 Accord and the LWV. The indirect manufacturing costs were addressed by applying the Retail Price Equivalent (RPE) multiplier of 1.47[4], to determine the manufacturer suggested retail price of the vehicle.

In the baseline vehicle, the body structure accounts for 22 percent of the vehicle weight (328 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 LWV body structure out of advanced high strength steel. The newly designed body structure weighed 22 percent less (255kg) than the baseline vehicle at overall incremental cost increase of $147. Although other materials, such as aluminum and composite offer greater weight savings, their cost premium and large scale manufacturing limitations prevented the team from choosing them for the body structure.

Other components in the vehicle did use some of these advanced materials and others including aluminum, magnesium, and plastic. Overall the complete LWV achieved a total weight savings of 22

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[3] www.intellicosting.com

[4] Source: Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers" EPA report EPA-420-R-09-003, February 2009

percent (332 kg) from the baseline vehicle (1480 kg) at an incremental cost increase of $319 or $0.96 per kg.

To achieve same vehicle performance as the baseline vehicle, the size of the engine for LWV was proportionally reduced from 2.4L-177 HP to 1.8L-140HP. Without the mass and cost reduction allowance for the powertrain (engine and transmission) the mass saving for the 'glider' is 24 percent (264kg) at mass saving cost premium of $1.63 per kg mass saving.

Once the LWV was assembled, GWU verified, through CAE modeling, that it meets all relevant crash tests. The LS-DYNA finite element software used by the GWU National Crash Analysis Center (NCAC) is an industry standard for crash simulation and modeling. The researchers modeled the crashworthiness of the LWV 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 tests. All of the modeled tests were comparable to the actual crash tests performed on the Honda Accord. Furthermore, the team also modeled the FMVSS No. 301 rear impact test and it showed no damage to the fuel system.

Electricore Inc., EDAG, and GWU believe that their approach balanced various factors and produced a LWV which had the greatest weight savings while meeting the baseline vehicle functionalities, cost, and manufacturing targets for year 2017-2025; however additional research can provide more insight to the future of vehicle weight reduction. This can include creating a detailed design for another platform (e.g., large truck) using similar rigorous engineering approach or creating another LWV design with a longer time horizon (2030 and beyond).

2 Definitions and Acronyms

3D
Three dimensional, consisting of three dimensions e.g. width, length, and depth.

4WD (or 4x4)
This represents a vehicle, with a drivetrain, that allows all four wheels to receive torque from the engine simultaneously. It differs from all wheel drive (AWD) in that it is a system that powers all four wheels of a vehicle at all times by locking all of the wheels to rotate at the same velocity. AWD is much less capable in 'off-road' settings and inferior to 4WD.

5th Percentile Female
This population represents a small framed woman that averages 152 cm. 95% of women are larger than a 5th percentile female.

99th Percentile Male
This population represents a large framed man that averages 183 cm. A man of this size would be larger than 98% of the male population.

A-Arm
Automotive suspension systems contain control arms (it is 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.

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

ABS (Braking System)
This anti-lock braking system (ABS) is a safety system which prevents the wheels on a motor vehicle 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 (ABS) is a common synthetic thermoplastic used to make light, rigid, injection molded and extruded products making it useful in a manufacturing environment.

A/C (or AC)
Air Conditioning - See HVAC

Al (or Alum.)
Aluminum

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

B-Pillar
See ‘A’ Pillar above.

BH (or Bake Hardenable) Steel
Bake Hardenable Steel is an advanced processing technique to produce low carbon steels that are used for car bodies. The process provides high strength through an optimized batch annealing treatment that is necessary in order to have enough carbon in solution required for bake hardening. This makes automotive bodies, and panels, strengthened after paint baking treatment.

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

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.

BIW
Body-In-White refers to the stage in automotive manufacturing in which the vehicle’s body sheet metal components have been welded together. It is before the components such as doors, the hood, deck-lid, fenders, and etcetera have been added prior to paint.

BMSB
Blow Molded Seat Back is also known as ‘blow forming’. This manufacturing process creates hollow, plastic components, from thermoplastic. In general, there are three primary processes are extrusion molding, injection molding, and stretch blow molding.

BOM
Bill of Materials (BOM) is a list of the raw materials, sub-assemblies, intermediate assemblies, subcomponents, components, parts, and the quantities of each needed to successfully manufacture a final product or end item. It may be used for communication between manufacturing partners, or confined to a single manufacturing plant.

BSFC
Brake Specific Fuel Consumption is a 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.

BUS
A BUS in a computer or on a network is a transmission path on which signals are dropped off or picked up at every device attached to the line. Each device has a unique identity and can recognize those signals intended for it.

C-Pillar
See ‘A’ Pillar above.

C Segment
Refers to a vehicle classification used in Europe. It is the equivalent to an American Compact.

CAD
Computer-Aided Design (CAD) is the use of computer technology for the process of design and design-documentation.

CAE
Computer-Aided Engineering (CAE) is a broad usage of computer software to aid in engineering tasks. It provides technology to support engineers in tasks such as analysis, simulation, design, manufacture, planning, diagnosis, and repair.

CAN-BUS
Controller–Area Network (CAN or CAN-bus) is a vehicle bus standard designed to allow microcontrollers and devices to communicate with each other within a vehicle without a host computer. It is a serial bus protocol to connect individual systems and sensors as an alternative to conventional multi-wire looms. It allows automotive components to communicate on a single or dual-wire networked data bus up to 1Mbps.

CCA (or CCAW)
Copper Clad Aluminum (wire) is widely used in applications requiring the conductivity of copper while retaining much of the weight advantages of aluminum. The primary application of this conductor is for high-quality coils such as the voice coils in headphones, portable loudspeakers or mobile coils in other applications.

Center Stack
Serving as the center portion of the instrument panel, this area is typically capable of receiving a number of service modules. It contains the sound system, HVAC controls, and the navigation system screen.

CG
Center of Gravity The center of gravity of a material body is a point that may be used for a summary description of gravitational interactions.

Class ‘A’ Surface
This term is used in automotive design to describe the surface area that is most easily seen by the customer. These areas have a higher standard for appearance and quality in the automotive industry.

CFM
Cubic Feet per Minute (CFPM or CFM) is a non-SI unit of measurement of gas-flow (most often airflow) that indicates how many cubic feet of gas (most often air) pass by a stationary point in one minute.

CO
Carbon Monoxide is a colorless, odorless gas formed when a compound containing carbon burns incompletely because there is not enough oxygen. It is present in the exhaust gases of automobile engines and is very poisonous.

CO2
Carbon dioxide is a colorless, odorless, incombustible gas present in the atmosphere. Its chemical compound is composed of two oxygen atoms covalently bonded to a single carbon atom.

Composite
Composites are a complex material, such as wood or fiberglass, 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.

CSA
Cross Sectional Area. In geometry, a cross-section is the intersection of a body in 2-dimensional space with a line, or of a body in 3-dimensional space with a plane. Simply stated, when cutting an object into slices one gets many parallel cross-sections.

Cut and Sew
A 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 is a vehicle that is built on a car platform and combines features of a sport utility vehicle (SUV) with features from a passenger vehicle.

CVT
A Continuously Variable Transmission shifts steplessly 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 revolutions per minute (RPM) for a range of vehicle speeds.

D-Pillar
See 'A' Pillar.

DLO
Daylight Opening. Automotive industry term for glassed-in areas of a vehicle's cabin

Dm
Deutsche Mark (1948-2002), former official currency of Germany

DP (or Dual Phase Steel)
Dual-phase steel (DPA) is a 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 is the executive branch of the European Union. This Commission operates as a ‘cabinet government’ body is responsible for proposing legislation, implementing decisions, upholding the Union's treaties and the general day-to-day running of the Union.

EGR
Exhaust Gas Recirculation is 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.

EPA
United States Environmental Protection Agency.

EPDM
EPDM rubber (Ethylene Propylene Diene Monomer) is a type of synthetic rubber containing a saturated chain of the polyethylene and is used in a wide range of applications.

EPP
Expanded Polypropylene is a foam form of polypropylene. It is used in a wide 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
Current European Union 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 is the copolymer of ethylene and vinyl acetate. This polymer 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.

FEA
Finite Element Analysis is a computational method of stress calculation in which the component under load is considered as a large number of small pieces (‘elements’). The FEA software is then able to calculate the stress level in each element, allowing a prediction of deflection or failure.

FEM
Front End Module. An assembly, or complex structure, that has been stream-lined to include the contents of what, were previously, multiple separate parts.

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 the United States Department of Transportation's National Highway Traffic Safety Administration.

FR Plastic
Fiber Reinforced. Fiber-reinforced plastic (FRP, also fiber-reinforced polymer) is a composite material made of a polymer matrix reinforced with fibers.

Frt
Front

FWD
Front-Wheel Drive is a form of engine and transmission layout used in motor vehicles, where the engine drives the front wheels only. This is more common on traditional passenger vehicles. Vehicles classified in the sport car category still utilize rear wheel drive.

GAWR
Gross Axle Weight Rating is 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.

GPS
The Global Positioning System (GPS) is a space-based global navigation satellite system that provides location and time information anywhere on earth. It is commonly used to refer to any device or function that uses the GPS satellites.

GVW (or GVWR)
A gross vehicle weight rating is 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
Another type of suspension control arm which attaches to the frame or body at two points and to the wheel carrier or knuckle at two points.

HAN
Human Area Networking is a process by which external devices can transmit signal information through manipulation of the small magnetic field that exists surrounding the human body.
Haptic Sensory feedback that interfaces to the user via the sense of touch by applying forces, vibrations, and/or motions to the user. This mechanical stimulation may be used to assist in the creation of virtual objects (objects existing only in a computer simulation), for control of such virtual objects, and to enhance the remote control of machines and devices (tele-operators).

HC
Hydrocarbon. Any of numerous organic compounds, such as benzene and methane that contain only carbon and hydrogen.

HDPE
High Density Polyethylene or Polyethylene High-Density (PEHD) is a strong, relatively opaque form of polyethylene having a dense structure with few side branches off the main carbon backbone.

HIC
The Head Injury Criterion (HIC) is a measure of the likelihood of head injury arising from an impact. The HIC can be used to assess safety related to vehicles.

HMI
Human Machine Interface is the interaction between humans, computers and machines.

HP
Horsepower is the name of several units of power. The unit was widely adopted to measure the output of piston engines, turbines, electric motors, and other machinery. One mechanical horsepower of 550 foot-pounds per second is equivalent to 745.7 watts.

HPA
Hydraulic Power Assistance specifies that pressurized hydraulic fluid is used to increase the manual force being applied in a mechanical system.

HSS
High Strength Steel is low carbon steel with minute amounts of molybdenum, niobium, titanium, and/or vanadium. Is sometimes used to refer to high strength low alloy steel (HSLA) or to the entire group of engineered alloys of steels developed for high strength.

HVAC
Acronym for the closely related functions of "Heating, Ventilating, and Air Conditioning"- the technology of indoor environmental comfort.

IC
Internal Combustion. The internal combustion engine is an engine in which the combustion of a fuel occurs with an oxidizer, usually air, in a combustion chamber.

ICE
In-Car Entertainment that is sometimes referred to as ICE, is a collection of hardware devices installed into automobiles and other modes of transportation, to provide audio and/or audio/visual entertainment, as well as automotive navigation systems. This acronym can also be used to describe an Internal Combustion Engine, an engine type that burns fuel in a sealed chamber using either spark ignition (SI - Gasoline) or compression ignition (CI – Diesel).

IEM
Integrated Exhaust Manifold as used in the report refers to the integration of the exhaust manifold with the cylinder head as used in the Lotus SABRE project.

IIHS
The Insurance Institute for Highway Safety (IIHS) is a U.S. non-profit organization funded by auto insurers. It works to reduce the number of motor vehicle crashes, and the rate of injuries and amount of property damage in the crashes that still occur. It carries out research and produces ratings for popular passenger vehicles as well as for certain consumer products such as child car booster seats.

IMA
Integrated Motor Assist is Honda's hybrid car technology. It is a specific implementation of a parallel hybrid. It uses an electric motor mounted between the engine and transmission to act as a starter motor, engine balancer, and assist traction motor.

ISOFIX
ISOFIX is 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") within the U.S. and as LUAS ("Lower Universal Anchorage System") or Canfix in Canada. It has also been called the "Universal Child Safety Seat System" or UCSSS.

IP
Instrument Panel is a control panel located under the windshield of an automobile. It contains the instrumentation and controls pertaining to the operation of the vehicle. During the design phase of an automobile, the dashboard or instrument panel may be abbreviated as "IP".

IVT
Infinitely Variable Transmission, a type of continuously variable transmission system for motor vehicles and other applications.

kg
Kilogram, unit of weight, 1 kg = 2.205 pounds.

km
Kilometer, unit of length, 1 km = 0.6214 statute miles.

kW
The kilowatt equal to one thousand watts. It is typically used to state the power output of engines and the power consumption of tools and machines. A kilowatt is approximately equivalent to 1.34 horsepower.

kWh
The watt hour, or watt-hour, is a unit of energy equal to 3.6 kilojoules. Energy in watt hours is the multiplication of power in watts and time in hours.

LATCH
Lower Anchors and Tethers for Children. See ISOFIX.

LCA
Lower Control Arm. See ‘A-Arm’.

LCD
Liquid Crystal Display is a low-power, flat-panel, display used in many digital devices to display numbers or images. It is made of liquid containing crystals that are affected by electric current, sandwiched between filtering layers of glass or plastic. LCDs do not produce light of their own; instead, when electric current is passed through the material, the molecules of the "liquid crystal" twist so that they either reflect or transmit light from an external source.

LED
Light-Emitting Diode is considered an electronic light source.

LF
Left Front

LH
Left Hand

m^3 or m3 or m3
Meters cubed or cubic meters, measure of volume.

mJ
Millijoules. The joule (symbol J), named for James Prescott Joule, is the derived unit of energy in the International System of Units. It is the energy exerted by a force of one newton acting to move an object through a distance of one meter. 1 mJ = 2.77x10-7 Watt hours

mm
Millimeters, unit of length, 1 mm = 0.03937 inches.

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.

LWR
Lower

Mg
Magnesium

MG, MG1 or MG2
A Motor-Generator (an M-G set or a dynamotor for dynamo-motor) is a device for converting electrical power to another form.

MPa
Mega Pascals, unit of pressure or stress, 1 MPa = 145 Pounds per square inch.

MPG
Miles per gallon is a unit of measurement that measures how many miles a vehicle can travel on one gallon of fuel.

MPV
Multi-Purpose Vehicle is a type of automobile similar in shape to a van that is designed for personal use. Minivans are taller than a sedan, hatch-back or a station wagon, and are designed for maximum interior room.

MS
Mild steel or Carbon steel, also called plain carbon steel, is steel where the main alloying constituent is carbon.

MSRP
Manufacturer's Suggested Retail Price of a product is the price the manufacturer recommends that the retailer sell it for.

MY
Model Year. The model year of a product is a number used worldwide. It is used to describe the approximation of when a product was produced. It also indicates the coinciding base specification of that product.

NCAP
The European New Car Assessment Program (Euro NCAP) is a European car safety performance assessment program founded in 1997 by the Transport Research Laboratory for the UK Department for Transport and now the standard throughout Europe.

NHTSA
The National Highway Traffic Safety Administration is an agency of the Executive Branch of the U.S. Government and a part of the Department of Transportation.

NOx
NOx is a generic term for mono-nitrogen oxides (NO and NO2).

NPI
New Product Introduction.

NVH
Noise, vibration, and harshness (NVH) is 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.

OD
Outside Diameter of a circular object.

OEM
Original Equipment Manufacturer definition in the automobile industry constitutes a federally licensed entity required to warrant and/or guarantee their products. "Aftermarket" products, however, are not legally bound to a government-dictated level of liability.

OLED
An Organic Light Emitting Diode (OLED), also light emitting polymer (LEP) and organic electroLuminescence (OEL), is a light-emitting diode (LED) whose emissive electroluminescent layer is composed of a film of organic compounds.

OTR
Outer

PRNDL
Refers to the automatic transmission gear selector based on the letters appearing on most selectors. It stands for Park, Reverse, Neutral, Drive, and Low.

PA
Polyamide is a polymer containing monomers of amides joined by peptide bonds. They can occur both naturally and also artificially through step-growth polymerization.

PC
Polycarbonates refer to a group of thermoplastic polymers.

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.

PHEV
Plug-In Hybrid Electric Vehicle (PHEV) is 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 is sometimes referred to as particulates or fine particles, are tiny particles of solid or liquid suspended in a gas or liquid.

PP
Polypropylene or Polypropene is a thermoplastic polymer. It is made by the chemical industry and used in a wide variety of applications.

PPO
Poly (p-phenylene oxide) is 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.

PU (or PUR)
Polyurethane is used in various resins, widely varying in flexibility, used in tough chemical-resistant coatings, adhesives, and foams.

PVC
Polyvinyl Chloride is commonly abbreviated PVC. It is the third most widely used thermoplastic polymer after polyethylene and polypropylene.

QTR
Quarter

R-Value
The R-Value is a measure of thermal resistance.

Rad
Radiator

Reinf
Reinforcement

RF
Right Front

RH
Right hand

ROM
Rough Order of Magnitude is a general term that is often used in analysis equating to 'Estimate'

RR
Rear

RWD
Rear-wheel drive is 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.

SLA
A Short Long Arms suspension is also known as an unequal length double wishbone suspension.

Stepper Motor
A Stepper Motor, sometimes referred to as a ‘step motor’ is a brushless, synchronous electric motor that can divide a full rotation into a large number of discrete steps.

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.

Sub-System
A smaller assembly living within a larger assembly. A seat assembly is considered a sub-system to the interior system.

SUV
A Sport Utility Vehicle is a generic marketing term for a vehicle similar to a station wagon, but built on a light-truck chassis. It is usually equipped with four-wheel drive for on-road or off-road ability, and with some pretension or ability to be used as an off-road vehicle. Some SUVs include the towing capacity of a pickup truck with the passenger-carrying space of a minivan or large sedan.

TRIP Steel
TRIP stands for 'Transformation Induced Plasticity'. TRIP steel is an example of 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 is defined as a technology that 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.

US (or U.S.)
United States of America.

UTS
Ultimate Tensile Strength.

UV
Ultraviolet light is the spectrum of electromagnetic radiation with frequencies higher than those that humans identify as the color violet.

V
The volt is the SI derived unit of electromotive force, commonly called 'voltage'.

VR
Virtual Reality is a computer technology which allows a user to simulate physical presence in the real world or in the imaginary world.

Whse
The Wheelhouse is the inner area behind the fender described by the inner and outer fender panels.

YS
Yield strength (or yield point) is 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 redesign an original baseline model year 2008 or later Honda Accord (in this case we chose 2011 Honda Accord) to reduce its mass (through a variety of techniques), while maintaining the functionalities (defined in a variety of ways, discussed below and in Section 5.1) of the original vehicle and also controlling for direct and indirect costs to maintain retail price parity within 10 percent. The Electricore team used advanced design, material, and manufacturing processes that it believes to be available in the time frame of model years 2017-2025 and developed a detailed and holistic engineering design. Using that design, the Electricore team developed a comprehensive direct manufacturing cost estimates for the light weighting technologies for the concept vehicle, including both detailed direct and indirect cost estimates. Finally, the concept lightweight vehicle was then computer modeled and simulated to demonstrate equivalent crashworthiness of the vehicle to the baseline Honda Accord.

The National Highway Traffic Safety Administration (NHTSA) initiated this project to gain more information about the maximum feasible amount of mass reduction and the cost of future mass reduction that could be used to support Corporate Average Fuel Economy (CAFE) rulemaking. NHTSA anticipates that one of the tools that industry will use in the future to raise their vehicles' fuel economy levels is vehicle mass reduction. This report also analyzes the safety effects of the vehicle mass reduction approaches considered, and shows that under the right circumstances, mass reduction can occur in a safety neutral, or perhaps even a safety beneficial manner while maintaining baseline vehicle performance and cost constraints. NHTSA also sought, through this study, to gain more information using the Finite Element Analysis (FEA) model from this study in a vehicle fleet simulation analysis regarding the potential future safety effects of wider-spread future light-weighting as manufacturers transition to a higher fuel-economy fleet.

3.2 Background

As part of its mission, NHTSA has been issuing CAFE standards under the Energy Policy and Conservation Act (EPCA) for the last thirty years. EPCA requires DOT (and by delegation, NHTSA) 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 standards, NHTSA must "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 (EISA), enacted on December 19, 2007, amended EPCA by mandating, in addition to passenger car and light truck standards being set at the maximum feasible level in each model year, that the model year (MY) 2011-2020 CAFE standards be set sufficiently high to ensure that the industry-wide average of all new passenger cars and light trucks, combined, is not less than 35 miles per gallon (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 and emissions standards, NHTSA published a joint final rule with the Environmental Protection Agency (EPA) in Spring 2010 to set CAFE standards under EPCA/EISA and greenhouse gas (GHG) standards under the

Clean Air Act (CAA) for passenger cars and light trucks manufactured in model years 2012-2016.[5] The CAFE standards will increase annually, and for MY 2016, are estimated to require a combined industry-wide fleet fuel economy of 34.1 mpg. Building on the success of the National Program for the MYs 2012-2016 standards, on May 21, 2010, President Obama directed NHTSA and EPA to take the next steps to improve fuel economy and reduce GHG emissions from mobile sources for model years 2017-2025.[6] NHTSA and EPA released a joint Notice of Proposed Rulemaking (NPRM) in November 2011,[7] and are working toward finalizing that proposal in mid-2012.

Based on NHTSA's discussions with manufacturers about how they plan to comply with CAFE standards in those model years, 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. For example, in the analysis for MYs 2017-2025 NPRM, 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 sub-classes. 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.[8]

As part of the research leading up to the NPRM, NHTSA became aware of several studies published that appear to show significantly greater amounts of mass reduction than NHTSA had previously analyzed.[9,10] The agency is reviewing its implementation of the mass reduction technology options in its compliance modeling and sought assistance in assessing the maximum feasible amount of mass reduction that could still be cost-effective in the time frame of model years 2017 to 2025. Assuming the light weighted design from this study will be representative of some of the future vehicles on road as a result of meeting the future CAFE and GHG standards, the agency can then use the FEA model developed in this study as one representative for the future vehicles on-road to evaluate the safety impact of future light weighting strategies over the fleet.

3.3 Approach

The Electricore team, including EDAG, Inc., (EDAG) and the George Washington University National Crash Analysis Center (GWU), used design and engineering practices and methodologies commonly accepted within the automotive industry for this project. EDAG is one of the world's largest independent engineering companies and has developed ready-for-production vehicles, assemblies, and modules for original equipment manufacturers (OEMs) and suppliers world-wide. Additionally, GWU has conducted independent simulations and crashworthiness analysis on vehicles of all classes for the

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[5] The final rule was issued on April 1, 2010, and was published in the Federal Register on May 7, 2010, at 75 Fed. Reg. 25324. A copy is also available on NHTSA's website at http://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/CAFE-GHG_MY_2012-2016_Final_Rule_FR.pdf (last accessed July 12, 2010).

[6] The full version of President Obama's announcement can be found at http://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/2017-Memorandum_05212010.pdf

[7] 76 Fed. Reg. 74854 (Dec. 1, 2011).

[8] 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* http://www.nhtsa.gov/fuel-economy.

[9] ICCT, 2010. An Assessment of Mass Reduction Opportunities for a 2017-2020 Model Year Vehicle Program. Final Report. March 2010. http://www.theicct.org/documents/0000/1430/Mass_reduction_final_2010.pdf

[10] EDAG, 2009. Future Steel Vehicle: Phase I. For WorldAutoSteel. http://www.worldautosteel.org/uploaded/FSV_Executive_Summary.pdf

FHWA, NHTSA and industry since its inception in 1992. Prior to presenting the specifics of our activities and results, it is important to review the overall objectives and approach for conducting a vehicle lightweighting project, such as this one, to better understand the methodology and thought process presented in the report.

The major boundary conditions set for this project included:

1. Maintain or increase vehicle size compared to the baseline vehicle.
2. Maintain retail price parity (±10% variation) with the baseline vehicle[11].
3. Maintain or improve vehicle functionalities compared to the baseline vehicle, including maintaining comparable performance in NHTSA's New Car Assessment Program (NCAP) frontal, side, side pole and IIHS test programs through appropriate crash simulations.
4. Powertrain may be downsized, however alternate powertrain configurations (i.e. hybrid electric, battery electric, and diesel) will not be considered.
5. All advanced design, material, technologies and manufacturing processes must be realistically projected to be available for fleet wide production in time frame of model years 2017-2025.
6. Achieve the maximum feasible amount of mass reduction within the constraints.

The Electricore team's approach for executing this project was to take a collaborative design, engineering and CAE process with built in feedback loops to incorporate results and outcomes from each of the design steps into the overall vehicle design and analysis. In a simple linear sense, the approach is to benchmark the baseline 2011 Honda Accord and then undertake a series of baseline design selections, new material selections, new technology selections and finally overall vehicle design optimization. Vehicle functionalities, safety (crashworthiness) simulations and cost analyses are run in parallel to the design and engineering effort to help ensure that design decisions are made in line with the established boundary conditions. The project team aimed that the results of this work would provide a basis for potentially helping to estimate some of the impacts of future CAFE standards for model years 2017-2025, so the project's objectives, approach and conclusions have to meet the highest levels of automotive engineering standards and be justifiable and supportable under rigorous peer review and analysis.

This high level approach helps the final design meet the project objectives within the boundary conditions, and ideally provides the government and industry with a truly feasible production-possible vehicle to use for future studies and analysis. This is, however, further constrained by developing a high volume (200,000 vehicles per year) production vehicle specifically targeted for model years 2017-2025. This means the team must use technologies and materials which will be available for large scale production and available within two to three design generations (*e.g.* model years 2015, 2020 and 2025).

Due to reliability, manufacturability and cost concerns many manufacturers may opt to only use technologies, materials and manufacturing processes that are currently in use or planned to be in use on existing vehicle platforms. Automotive manufacturers often introduce new materials, technologies and processes on low-volume, high price vehicles first and then migrate those technologies to high-production vehicle lines over time. This significantly reduces the risk to the OEM from new designs and materials being introduced into mass-production vehicles. Therefore, the Electricore team utilized, to the extent possible, only those materials, technologies and designs which are currently in-use or planned to be introduced in the near term (model years 2012-2015) on low-production vehicles. This approach

[11] 10% of the baseline MSRP - $2198; based on Honda Accord 4DR-LX Window Sticker shown in Figure 3

eliminated those material and technology options which would likely be unrealistic or overly aggressive to implement in mass production by model years 2017-2025.

This study is not a study to determine the maximum weight reduction in a vehicle without cost or other constraints. The first step in such a project, thus, was to establish the requirements and specification for the project – essentially establishing the ground rules for moving forward during the project. By fixing these boundary conditions early the project team was able to make consistent and mutually supportive decisions throughout the engineering and design process.

Some of the other similar studies have focused more on the stretching the limits of vehicle lightweighting with more lead time to develop these advanced technologies, reduce their cost, and establish high volume manufacturing practices. While these are instructive on helping to establish longer-term goals for the industry, often they are too aggressive to use as a baseline for near-term policy and regulatory analysis. The approach for this study is an evolutionary implementation of advanced materials and manufacturing technologies currently used in the automotive industry. The recommended materials (Advanced High Strength Steels, Aluminum, Magnesium and Plastics) manufacturing processes (Stamping, Hot Stamping, Die Casting, Extrusions, Roll Forming) and assembly methods (Spot welding, Laser welding 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. The process parameters for manufacturing with Advanced High Strength Steels can be supported by computer simulation.

Additionally and possibly most importantly, some of the other studies may not have analyzed and validated the designs against NCAP and IIHS safety standards. By considering safety foremost and throughout the design and engineering process, we are again taking a more realistic design approach. This may lead to less weight reduction or higher costs, but it also helps to ensure that the design is consistent with actual industry design, engineering and production methods and that it fully accounts for all elements in the vehicle's cost.

The approach taken in this study thus aims to address each of the issues found with other related efforts and helps to provide NHTSA with a thorough and realistic baseline for ongoing analysis. It is important to clarify that this study did not seek to represent the "only solution" for vehicle light-weighting, but instead sets an achievable baseline for vehicle mass reduction to help the DOT determine the "maximum feasible" average fuel economy level that manufacturers can achieve in that model year.

3.4 Technical Scope of Work

The following technical activities were undertaken as part of this project:

3.4.1 Computer Modeling Design

The Electricore Team used state-of-art computer modeling to design, develop and validate a light weight vehicle design computer model of a mid-size passenger car based on a model year 2011 Honda Accord mid-size passenger car. In doing so, the Electricore Team factored in advanced design, material and manufacturing processes projected by the team to be available in the MYs 2017-2025 time frame. A target model year of 2020 was specified by NHTSA to be the basis for the project in order to provide a single snapshot in time versus an average vehicle over the 2017-2025 period. Available advanced design, material and manufacturing processes selected for the model were based upon literature review and consultation with the automotive industry OEMs and suppliers as well as industry experts with regard to what appeared likely to be feasible for vehicle manufacturers to adopt in that time frame.

3.4.2 Cost and Functional Analysis of Vehicle

The target vehicle was designed to maintain cost parity with the baseline 2011 Honda Accord, defined as the maximum feasible amount of mass reduction that could be accomplished with only ±10 percent variation in production cost while maintaining or improving vehicle size and performance functionalities[12]compared to the baseline vehicle.

3.4.3 Engineering Analysis

The Electricore Team included as part of the preliminary design, draft report, and final report detailed engineering analysis and documentation to prove that the functionality is maintained or improved within the acceptable cost parameter defined in 3.4.2. The team has concluded that the proposed design would be commercially feasible for high volume production (around 200,000 units per year) in MY 2020.

3.4.4 Powertrain Design

The powertrain of the LWV was downsized to maintain vehicle acceleration and/or towing compared to the baseline 2011 Honda Accord. The Electricore Team provided an incremental mass and cost difference between the powertrain chosen and the baseline powertrain without a full scaled powertrain study. However, in order to verify and validate the LWV for fuel economy and powertrain performance, a simulation model for the baseline MY 2011 Honda Accord was first built in Powertrain System Analysis Toolkit (PSAT). The correlated baseline PSAT model was used to conduct further studies to establish vehicle performance for lower weight vehicle conditions.

3.4.5 Future Technologies Impacts

As part of designing the LWV, the Electricore Team considered certain vehicle mass reduction technologies that the team did not consider mature or that are currently limited to small volume production. When it did so, given the requirement that the LWV be able to be produced at high volume by the rulemaking time frame, the Electricore Team identified and discusses any risks associated with including these developmental technologies as part of the LWV design (that is, the probability that these technologies will be available for fleet wide production in the time frame studied.) For each technology chosen for this inclusion in the LWV design, this report lists the technology readiness and the associated risks if the technology is still in the development stage. In particular, the report identifies when the team anticipates that these developing technologies will be mature and applicable to mass production. In choosing technologies, the Electricore Team considered 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.

3.4.6 Preliminary Vehicle and Proof of Concept Design

The Electricore Team used Computer Aided Design (CAD) tools and identify, define, conduct, build, simulate and validate a Computer Aided Engineering (CAE) model developed in LS-DYNA for this vehicle as a deliverable of this contract. The Electricore Team performed virtual vehicle design, rather

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

than simply reviewing literature and providing a compilation of available technologies. Vehicle design constraints and feasibility were considered when selecting light weight approaches for components and sub-systems, as required by the contract. In order to help ensure that the LWV is feasible and meets all performance functionalities of the baseline 2011 Honda Accord, consideration was also given to the joining technologies. The output CAD model will be used for vehicle crashworthiness simulation by NHTSA.

3.4.7 Crashworthiness Analysis

Using the output CAD vehicle model described above, the Electricore team considered the LWV's structural performance in NHTSA's New Car Assessment Program (NCAP) frontal, side, and side pole test programs. For each of these rating tests, the Electricore Team conducted a crash simulation and compared the crash acceleration and occupant compartment intrusion against test results of the baseline 2011 Honda Accord.[13] The occupant compartment acceleration was evaluated in terms of peak acceleration and relevant intrusion measurements for the crash mode. The vehicle model also demonstrated compliance with the requirements of FMVSS No. 216 "Roof crush resistance." The Electricore Team also conducted crash simulations to evaluate the structural performance requirements of the Insurance Institute for Highway Safety (IIHS)[14] offset and side impact test programs. Based on those simulations, the LWV design obtained ratings in each of the structural or intrusion ratings performed by IIHS that were at least equivalent to the baseline vehicle.

3.4.8 LS-DYNA Model and Final Report

The Electricore Team provided NHTSA with the LS-DYNA model of the LWV (validated as explained above and in Section 6 for verification and a compatibility check to help ensure that the model is compatible with FEA models that George Washington University developed for NHTSA as specified.

3.4.9 Optional Requirements

At the option of the government, the Electricore Team was required to provide the following additional support and services. The government exercised all options under this project.

3.4.9.1 Optional Requirement 1 "Mass Reduction for Other Light-Duty Vehicles"

In addition to the vehicle design developed, the Electricore Team considered how the mass reduction evaluated for the vehicle could be applied to other types of light-duty passenger vehicles besides the midsize passenger car evaluated. Those other types of light-duty vehicles include:

- Subcompact passenger cars;
- Compact passenger cars;
- Large passenger cars;
- Minivans;
- Small CUV/SUV/trucks;
- Midsize CUV/SUV/trucks; and,
- Large CUV/SUV/light duty trucks.

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[13] NHTSA crash test data available at: http://www.nhtsa.gov/Research/Databases+and+Software

[14] 40 mph offset deformable barrier frontal and 31 mph moving deformable barrier side impact test, http://www.iihs.org/ratings/default.aspx

As documented in the MYs 2012-2016 final rule[15] and the preceding Notice of Proposed Rulemaking (NPRM)[16], for purposes of applying fuel-saving technologies, NHTSA's modeling analysis considered twelve technology "subclasses" of passenger cars and light trucks (*i.e.*, 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 to comply with FMVSS and consumer information programs: *i.e.*, more mass can likely be taken out of large vehicles than small vehicles. The Electricore Team provided feasible mass reduction estimates for each vehicle subclass used in the CAFE model, along with supporting documentation.

The Electricore Team provided details about the amount of mass reduction that is feasible for each of the vehicle subclasses stated above used in the CAFE model and phase-in caps for amount of mass reduction for each subclass for model year 2017-2025. The conclusions are supported with detailed analysis and are provided as Section 8 of this report.

3.4.9.2 Optional Requirement 2 "Conduct Incremental Cost Analysis on Mid-size Vehicle Designed and Developed"

Cost is frequently a constraint when vehicle manufacturers decide which fuel-saving technology to apply to a vehicle. The Electricore Team performed an incremental cost analysis for all the new technologies applied to reduce mass of the vehicle designed. The cost estimates are comprehensive and include variable cost as well as non-variable cost, such as manufacturer's investment cost for tooling, product development, etc. The amount of feasible mass reduction was determined with reference to maintaining overall vehicle retail price parity with the baseline vehicle with ±10% variation. Furthermore, costs were considered and accounted for on any new or novel manufacturing processes considered for a design that requires not only tooling but investment in capital equipment.

The Electricore Team provided a detailed account describing the methodologies used in the cost estimates, the factors included in the cost estimates, and the database structure for the cost breakdown. This is provided as Section 9 of this report.

3.4.9.3 Optional Requirement 3 "Effect of 'Learning' on Technology Costs"

As documented in the MY 2012-2016 final rule, NHTSA's modeling analysis uses "learning" for the purpose of reducing technology costs, *i.e.*, the agency anticipates that efficiency improvements occur and costs come down as production volumes increases ("volume-based learning"), or with incremental process and design revisions that occur over a period of years("time-based learning"). The Electricore Team made suggestions on the appropriateness of applying cost reductions through learning and how the cost will be reduced in the future, using time-based learning, volume-based learning, or other methods that are appropriate. This was in particular applied to the vehicle body structure assembly process. The advantages of the application of laser welding versus the conventional spot welding process was studied in detail and is provided as Chapter 10 of this report.

3.5 Project Team Members

This project was completed by the Electricore Consortium; inclusive of Electricore Inc., EDAG Inc., and the George Washington University (GWU) National Crash Analysis Center (NCAC). This team has

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

extensive experience in the areas of government contracting, research and development, automotive engineering, and vehicle crash test modeling and analysis. Electricore Inc. is a 501(c)(3) non-profit company with over 15 years' experience in managing federal programs, including several with DOT. Electricore was the program manager and prime contractor. EDAG, Inc. was the technical lead on optimizing the light weight vehicle design, performing the cost modeling, and examining advanced manufacturing techniques. GWU NCAC was the technical lead for crash modeling to examine the crashworthiness of the lightweight vehicle designs.

3.5.1 Electricore, Inc.

Since its inception, Electricore has had a successful history of collaboration with the departments of Defense, Energy and Transportation in the development, demonstration and deployment of advanced technologies. Electricore has managed over 80 multi-partnered research programs ultimately involving several hundred industry, university and government entities with over $170 million in federal projects. Electricore has established a network of world-renowned scientists available as part of its technical resource base. This base provides members and sponsors with services that include technical consulting, technology assessment, competitive analysis and design review. Electricore partners with public and private organizations, fleets, and government to develop and employ clean, cost-effective transportation solutions. Electricore's research includes the following areas: Electric and Hybrid Vehicles (Ground, Air and Sea), Electric and Hybrid Infrastructure, Energy Storage and Energy Management, Fuel Cell Vehicles and APUs, Lightweight Materials, and Aerodynamics.

3.5.2 EDAG, Inc.

EDAG, the world's largest independent engineering concern, develops production ready solutions to sustain mobility in the future. Thanks to its holistic understanding of vehicles and their production plants, EDAG is the leading partner that can offer the fusion of product and production, from development through to implementation in plant construction. EDAG is an all-round development partner for the international automotive industry, offering engineering services to the implementation of complete production systems for body-in-white construction and vehicles assembly through to the low volume production of modules and special vehicles series.

3.5.3 George Washington University, National Crash Analysis Center

Chartered in 1992, the NCAC at The George Washington University's Virginia Campus is one of the nation's leading authorities in automotive and highway safety research. A cooperative effort of the Federal Highway Administration (FHWA), the National Highway Traffic Safety Administration (NHTSA), The George Washington University and several industry and academic experts, NCAC's comprehensive approach addresses the total safety problem related to surface transportation. The NCAC at GWU has developed unique capabilities in crash analysis, crash data statistics, causation studies, countermeasure benefit analysis, simulation and modeling, vehicle and barrier design, and dissemination of models and results. These capabilities, expertise, and resources are not duplicated elsewhere in the world at their present comprehensive and sophisticated level. Today, the NCAC finite element models are utilized by researchers worldwide to address various safety issues. The methods developed and disseminated by the NCAC scientists and engineers have been used by many researchers worldwide. GWU scientists have successfully assisted and provided technical advice, recommendations, support, and solutions to FHWA, NHTSA, FAA, DOS, State DOTs, automotive companies, and other federal and state agencies in some of the Nation's most critical transportation safety and security issues, resulting in improved safety, enhanced security, and enormous cost savings.

3.6 Peer Review

This study is peer reviewed by technical experts. After peer review, the study is updated based on the recommendations from the reviewers. The responses to peer review comments are shown in Appendix G of this report. The peer review report which contains the curriculum vitae and the peer review comments (verbatim) for each peer reviewer is published in a separate document titled "Peer Review for Mass Reduction for Light-Duty Vehicles for Model years 2017-2025".

4 Baseline Honda Accord—Benchmarking

4.1 Baseline Vehicle

The chosen baseline vehicle for this project is the 2011 Honda Accord, a four door midsize sedan. The midsize sedans are the single largest sales volume segment in the U.S. in MY 2010, with nearly 20 percent of the market. In this segment the Honda Accord was second overall in vehicle sales for 2010 and is regarded as a benchmark vehicle with good performance in all areas, roominess, comfort, fuel economy, safety, luxury features, with a competitive price. Figure 1 below lists the top five vehicle models in terms of U.S. vehicle sales in the midsize car category for MY 2010. In the SOW of the contract, NHTSA specified the use of a MY2008 or later Honda Accord as the baseline. The Electricore team selected the 2011 Honda Accord because this vehicle has the same body structure as the 2008 Accord and it also achieved a five-star rating in NHTSA's New Car Assessment Program (NCAP).

Ranking	Vehicle	Veh. Sold
1	Toyota Camry	327,804
2	**Honda Accord**	**311,381**
3	Toyota Corolla	266,082
4	Honda Civic	260,218
5	Nissan Altima	229,263

Figure 1: US Vehicle Sales in the midsized car category for MY2010[17]

To identify the utility, performance, and other baseline engineering targets for the LWV program a base trim level 2011 2.4L Honda Accord 4DR-LX with a 5-speed automatic transmission was purchased and completely torn down to its individual sub-system or component level. The Accord LX in this model year is available with a limited range of additional options, but many of these options would likely not significantly impact the vehicle's mass. Options that may impact the vehicle's mass, such as power seats or a sunroof option, are not available on the base level Accord LX model. Figure 2 is a picture of the baseline Honda Accord LX.

Figure 2: Baseline Honda Accord LX

The window sticker for the vehicle is shown in Figure 3 so that the reader can get an idea of some of the features of the 2011 Honda Accord. For the Honda Accord LX vehicle specifications, see Appendix B.

[17] NHTSA Vehicle market sales MY2010

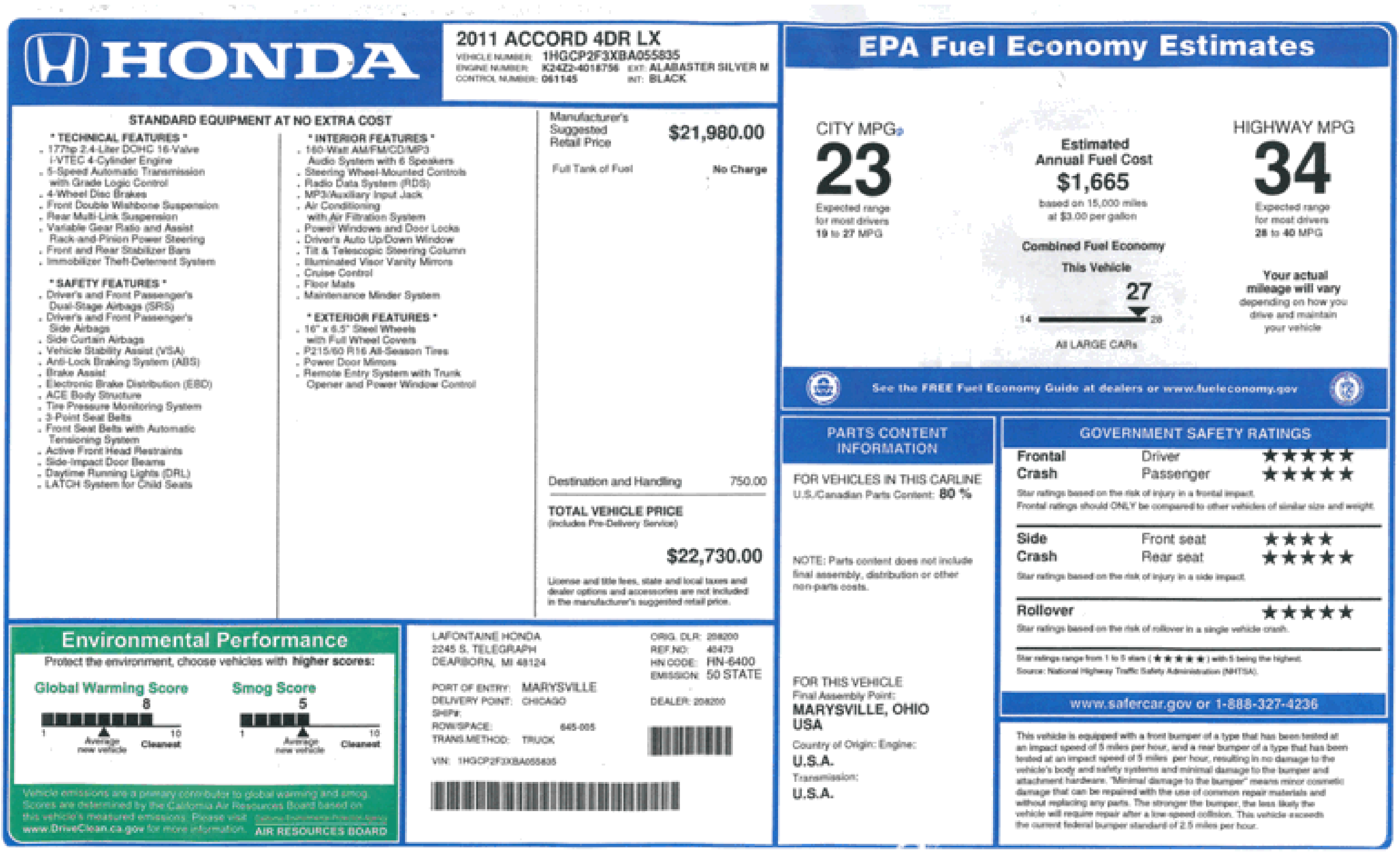

Figure 3: Purchased Honda Accord 4DR-LX Window Sticker[18]

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18 EDAG & Honda US

The 2011 Accord achieved five-star ratings in NHTSA's New Car Assessment Program (NCAP) for frontal crash (driver and passenger), side crash (rear seat), and rollover resistance.

Year/Make/Model	Overall	Frontal Crash	Side Crash	Rollover
2011 Honda Accord Sedan FWD	★★★★★	★★★★★	★★★★★	★★★★★

Figure 4: Honda Accord NHTSA 5 Star Rating[19]

The newly introduced 'Overall Vehicle Score' is part of the federal government's more stringent NCAP test that is first being applied to 2011 models. As a convenience to new car shoppers, the 'Overall Vehicle Score' represents the combined results of the overall ratings from the frontal crash tests, the side crash tests and the rollover-resistance into a single summary score between one and five stars[20].The 2011 Honda Accord currently is one of only six vehicles to achieve the NHTSA five-star 'Overall Vehicle Score', and is the first to achieve five stars in each of the three ratings categories, overall frontal crash safety rating, overall side crash safety rating and rollover rating, as shown in Figure 5.

2011 Honda Accord Sedan NCAP 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**
Over all Side-Barriesr Crash Safety Rating	5
Front Seat Position (Male)	4
Front Seat Position (Female)	5
Side-Pole Crash Safety Rating	5
Front Seat Side Impact Rating	4
Rear Seat Side Impact Rating	5
Rollover Rating	**5**

Figure 5: Honda Accord NCAP 5 Star Rating[21]

4.2 Honda Accord Overview

The baseline vehicle for this project, the Accord LX sedan with a base level trim package, is the entry level model in the Accord range of vehicles. The base level trim package is standard for the LX model and is the highest selling option. The LX is powered by a 177-horsepower 2.4-liter four-cylinder engine and comes with cloth upholstery, air conditioning, power mirrors, window and door locks, a tilt-telescoping steering column, folding rear seats and a 160-watt sound system with single CD and an auxiliary jack. The Accord LX is also fitted with a 5-speed automatic transmission. Within the Accord LX model, because it is the entry-level Accord, only

[19] http://www.safercar.gov
[20] http://www.safercar.gov/Safety+Ratings
[21] http://www.safercar.gov

a few additional options are available – power seats, for example, are only available on the Accord LX-P model.

4.2.1 Additional Features

In addition to the ACE structure, Honda Accord standard safety equipment includes Vehicle Stability Assist (VSA) with traction control, and Anti-lock Braking System (ABS). Airbags include side curtain airbags, dual-stage multiple-threshold front airbags, driver's and passenger's side airbags with an Occupant Position Detection System (OPDS). The OPDS is designed to deactivate the passenger's side airbag if a child or a small-stature adult is leaning into the deployment zone of the airbag.

The Accord uses a double-wishbone system for the front suspension. The front lower control arms are forged steel, a steel upper control arm with a forged steel knuckle and nitrogen filled dampers are used. The front suspension system is attached to a steel flexible mounted engine cradle.

The Accord uses a multi-link rear suspension with nitrogen gas filled dampers, and a steel upper A-arm, plus two tubular steel lower links. A-Control links are mounted to an aluminum cast knuckle. These suspension components are mounted to a floating rear K-frame.

The Honda Accord includes all wheel disc brakes with Electronic Brake-force Distribution (EBD) system and brake assist. EBD is a technology that enables the braking force of the vehicle to be increased or applied automatically, when the brake pedal is applied depending on road conditions, speed and weight of the vehicle. The parking brake uses a variable link system that permits full application of the parking brake with a shorter handle stroke.

Active safety features on the Accord include Anti-lock Braking System (ABS), Vehicle Stability Assist (VSA). VSA is an electronic stability control system that measures lateral acceleration, steering wheel angle, wheel speeds and vehicle yaw rate and then modifies individual brakes and engine power to improve directional control of the vehicle. VSA brakes individual wheels and/or reduces engine power in the event of over-steer or under-steer to help regain the driver's intended path. The system also features a traction control function that helps prevent wheel spin during acceleration.

The Accord has power assisted Variable Gear Ratio (VGR) steering, which is a variable mechanical ratio rack and pinion steering system. The VGR power steering provides higher precision at highway speeds, and quick manoeuvrability at low speeds, as in parking. The VGR steering system also gives a small turning circle, 11.5m curb to curb, with a number of steering wheel turns of 2.56 'lock-to-lock'. The steering rack assembly with an aluminum steering rack & engine mount carrier is mounted to the engine cradle.

Every Honda Accord from model year 2008 onwards includes a Tire Pressure Monitoring System (TPMS). This is a direct TPMS system which employs internal pressure sensors, attached to the tire valve stem, which measures the tire pressure in each tire and relays this information to the vehicle's instrument cluster.

The baseline Accord LX is fitted with steel 16-inch wheels with plastic wheel trim. The tires fitted are P215/60R16 94H Dunlop XP Sport 2000 all season. The spare tire is a space saving T135/80D16 101M temporary unit, mounted in the luggage compartment under the rear carpet.

4.2.2 Vehicle Teardown and Surface Scan

The Honda Accord, prior to scanning and teardown, was weighed using a four point weigh scale. The mass of the baseline Honda Accord with a full gas tank was weighed at 1480.5 kg. The mass split between front and rear axle was measured to be 60.7% and 39.3% respectively. This mass distribution is typical of front wheel drive vehicle with a gasoline engine, the higher mass at the front is due to the weight of the engine and drivetrain, compared to the rear were there are no drivetrain components. See Figure 6 for Accord weight distribution and Figure 7 for Accord weights and dimensions. [22]

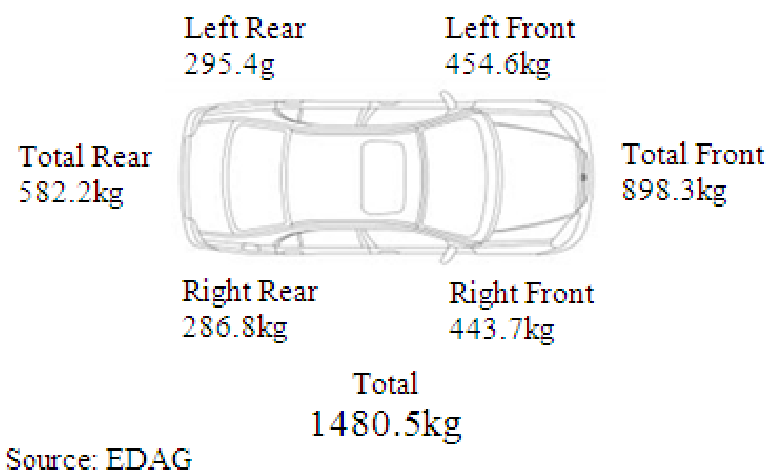

Figure 6: Honda Accord Vehicle Weight and Weight Distribution

[22] http://automobiles.honda.com/accord-sedan/specifications.aspx?group=dimensions

Dimensions & Weights	
Curb weight, OEM claim (kgs.)	1487.4
Curb weight, as tested (kgs.)*	1480.5
Weight distribution, as tested, f / r (kg)*	898.3 / 582.2
Length (mm.)	4938
Width (mm.)	1831
Height (mm.)	1476
Wheelbase (mm.)	2799
Track, front (imm.)	1590
Turning circle (m)	11.5

Figure 7: Honda Accord Weights and Base Dimensions[23]

See Figure 8 for Honda Accord prior to exterior vehicle scanning.

Figure 8: Honda Accord Exterior Prior to Scanning and Teardown

See Figure 9 for Honda Accord prior to interior scanning.

[23] http://www.automobiles.honda.com

Figure 9: Honda Accord Interior Prior to Scanning and Teardown

A complete vehicle exterior and interior white-light scan was then completed. A scanning head fringe pattern is projected onto the vehicle or component surfaces with a white light projector. These are then recorded by two cameras mounted on the scanning head. The system self-checks its calibration related 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 (STL) for further processing to CAD data.

Due to the camera optics the body is sprayed using a removable talc spray to eliminate reflections from the painted surface. The Honda Accord prepared with talc spray for the white light scanning process is shown in Figure 10. The black interior is also sprayed with talc, as shown inFigure 11, as black color absorbs white light and does not give a satisfactory scan image.

Figure 10: Honda Accord Prepared for External Scan

Figure 11: Honda Accord Prepared for Internal Scan

Reference point decals are added to allow multiple scan patches to be made, manipulated and aligned to a three dimensional (3D) XYZ axis to create 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 a STL data file that comprised of a series of small triangulated surfaces. The STL data is then converted to CAD data file format such as Unigraphics (UG) or Catia. The Honda Accord converted STL file from the 3D scan and workable exterior surface are shown in Figure 12.

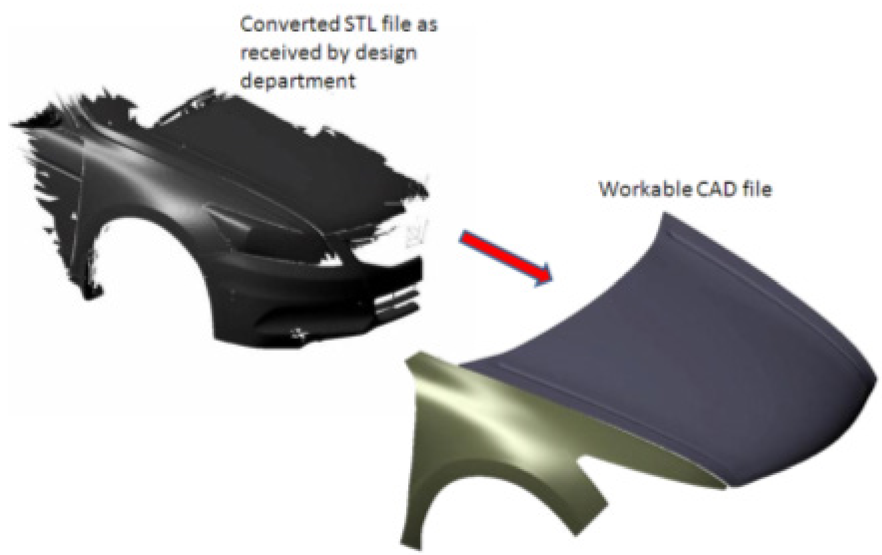

Figure 12: Converted STL File and Workable CAD Exterior Surface

Areas scanned on the complete vehicle prior to teardown included:

- Vehicle exterior to 200mm past vehicle center.
- Engine bay with hood open.
- Rear luggage compartment with decklid open.
- Complete under body with under body front splash panel removed to give access to engine cradle.
- Complete interior.

The Honda Accord underwent a complete vehicle tear down to the individual component or sub-assembly level. All closures, front/rear doors, hood, decklid and front fenders were removed from the body structure. Teardown of the left hand front and rear doors plus hood and decklid was then completed. Figure 13 provides a flowchart of the basic teardown process.

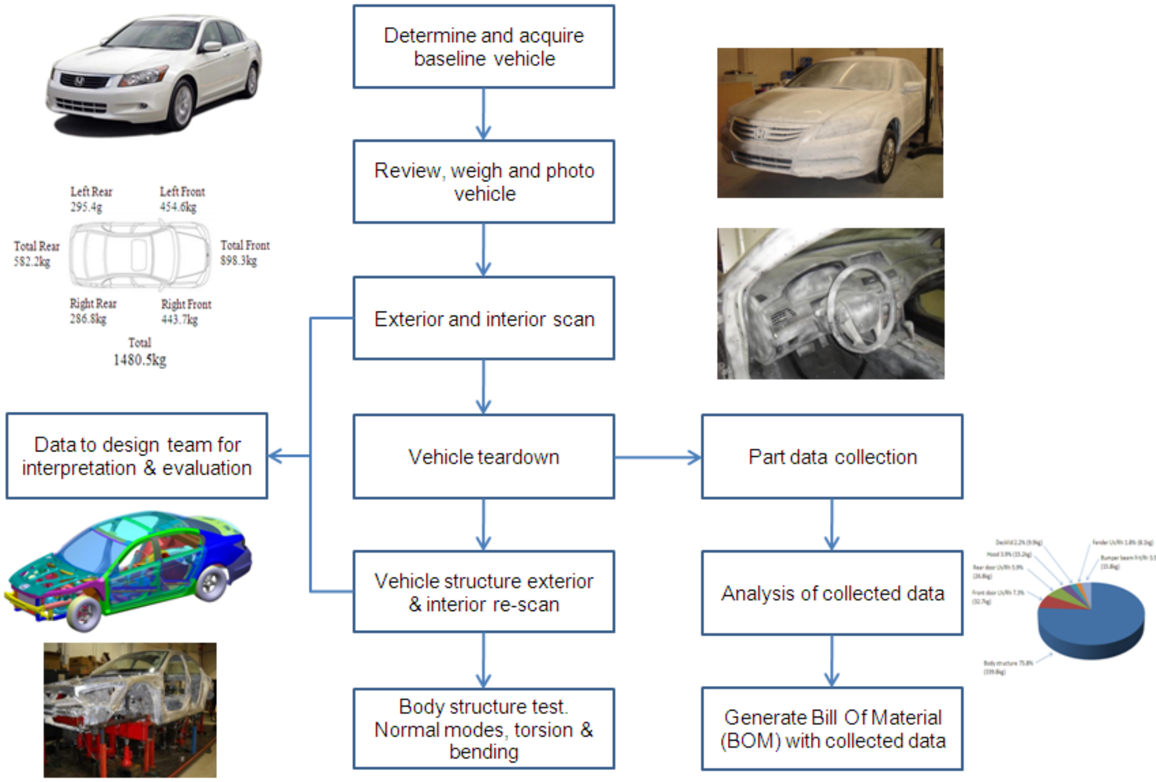

Figure 13: Basic Vehicle Teardown Process

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.

- Complete body structure, exterior and interior, underbody, engine bay and luggage compartment, with all components, interior/exterior, and powertrain etc. removed.
- Front and rear doors inner surfaces.
- Hood and decklid inner surfaces.
- Front suspension module including engine cradle and steering rack.
- Rear suspension module which included the rear K-frame.
- Fuel tank.
- Front driver seat frame.

After teardown of the body structure and additional scanning were completed, the body structure underwent static torsion and bending, plus modal testing to determine the baseline stiffness criteria for the LWV, an external source, Defiance Testing &Engineering[24], was engaged to complete these tests.

The front windshield and rear glass was not removed from the body and the instrument panel cross car beam was re-assembled to the body structure for these tests as these components contribute to the overall vehicle stiffness. See Appendix C for test results.

[24] www.defiancetest.com

Each individual component or sub-assembly was weighed and photographed. The part weight information was collected and this information was added to a parts database, reported in Appendix A.

4.3 Honda Accord Body Structure

Several steps were performed to ensure that the components of the Honda Accord body structure were completely accounted for. An analysis of the Honda Accord 4DR-LX body structure assembly was made to determine the assembly sequence of the major sub-assemblies. In addition, a body structure Bill-Of-Materials (BOM) was generated, and a spot weld count was made. From the assembly analysis, it was determined that there are 596 parts that make up the Honda Accord LX Body-In-White (BIW) prior to the paint process. This includes the body structure, closures and all add-on parts. See Figure 14 and Figure 15 for Honda Accord LX part count per sub-system.

Sub-System	Part Count
Front Structure	135
Rear Floor	111
Body Side Lh	65
Body Side Rh	65
Front Floor	37
Front Bumper	22
Front Door Lh	20
Front Door Rh	20
Rear Door Lh	19
Rear Door Rh	19
Rear Bumper	17
Package Tray	13
Back Panel	12
Roof Structure	10
Decklid	7
Hood	6
Front Fender Lh	5
Front Fender Rh	5
Tank Flap	4
Battery Tray	4
Total # Parts	596

Figure 14: Vehicle Part Count by Sub-system

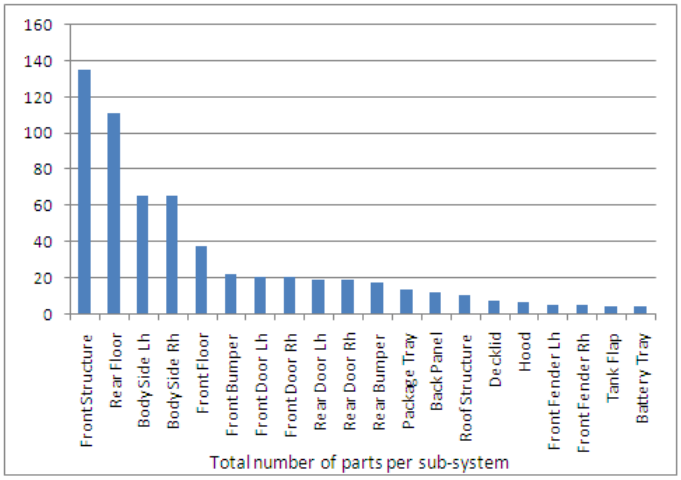

Figure 15: Vehicle Parts Distribution by Body Structure Sub-system

After analysis of the Honda Accord assembly it was determined that the Accord follows a conventional assembly process where the body-in-white, which includes the body structure, closures and hand-on parts, are divided into a number of sub-assemblies. The body structure is generally spot-welded, with the exception of the shotgun outer which is metal inert gas (MIG) welded to the body side. The front and rear bumper beams also have a MIG welding content. It was determined that there are a total of 4487 spot welds and approximately 1200 mm of MIG welding per bumper beam plus 60 mm MIG welding per shotgun outer.

Sub-Assembly	# Spot Welds
Front Structure	1112
Rear Floor	772
Framer	543
Bodyside Rh	462
Bodyside Lh	462
Mid-Floor	350
Rear Door Lh	125
Rear Door Rh	125
Front Door Lh	115
Front Door Rh	115
Lower Back Panel	64
Rear Bumper Beam	64
Parcel Shelf	59
Front Bumper Beam	44
Hood	28
Decklid	25
Battery Tray	14
Front Fenders Lh/Rh	4
Fuel Fill Door	4

Total spots welds: **4487**

Figure 16: Number of Spot Welds per Body Structure Sub-system

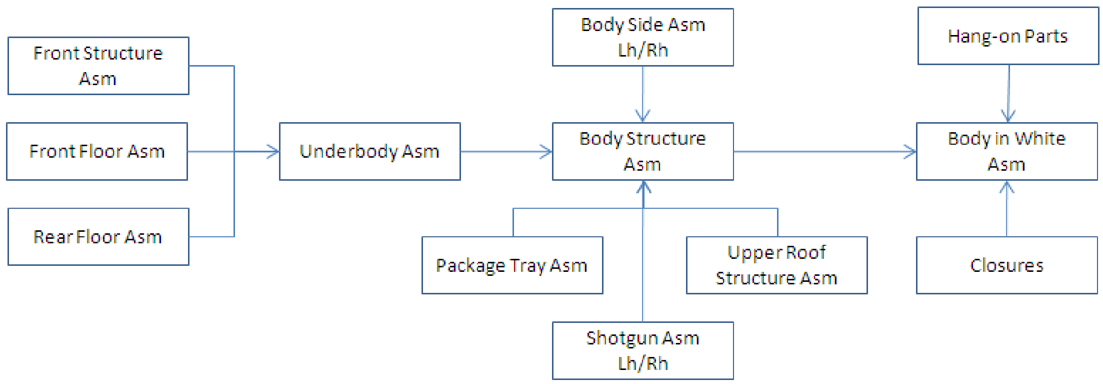

Figure 17: Honda Accord Assembly Block Diagram

For the body structure assembly sequence block diagrams, see Appendix E.

4.4 Vehicle, Subsystem and Component Weights

4.4.1 Mass & Material Distribution

The body structure, which includes all closures plus front fenders and other add-on parts, accounts for 38 percent of the vehicle's mass, which makes it the largest individual portion. The vehicle's power train, including engine and transmission, accounts for approximately 17 percent, of the overall vehicle weight while the front and rear suspension accounts for approximately 15.3 percent. See Figure 18 and Figure 19 for mass distribution. Appendix A provides a complete vehicle parts list showing sub-system mass.

Sub-system	Mass (kg)	Mass (%)
Body Closures & Hang-on	564.3	38.1
Suspension Front/Rear	226.2	15.3
Engine	169.9	11.5
Transmission	96.7	6.5
Fluids	69.2	4.7
Seats Systems Front/Rear	64.9	4.4
Brake Systems Front/Rear	57.1	3.9
Interior Systems	56.6	3.8
Electrics Complete	36.4	2.5
Exhaust	20.7	1.4
Steering System	19.7	1.3
Safety	17.4	1.2
Fuel System	14.9	1.0
Cooling System	14.8	1.0
Heating System	13.7	0.9
Misc Items	13.0	0.9
Air Conditioning System	12.2	0.8
Air System	9.6	0.7
Pedels	3.0	0.2
Totals:	1480.5	100.0

Figure 18: Vehicle Mass Distribution (kg & %)

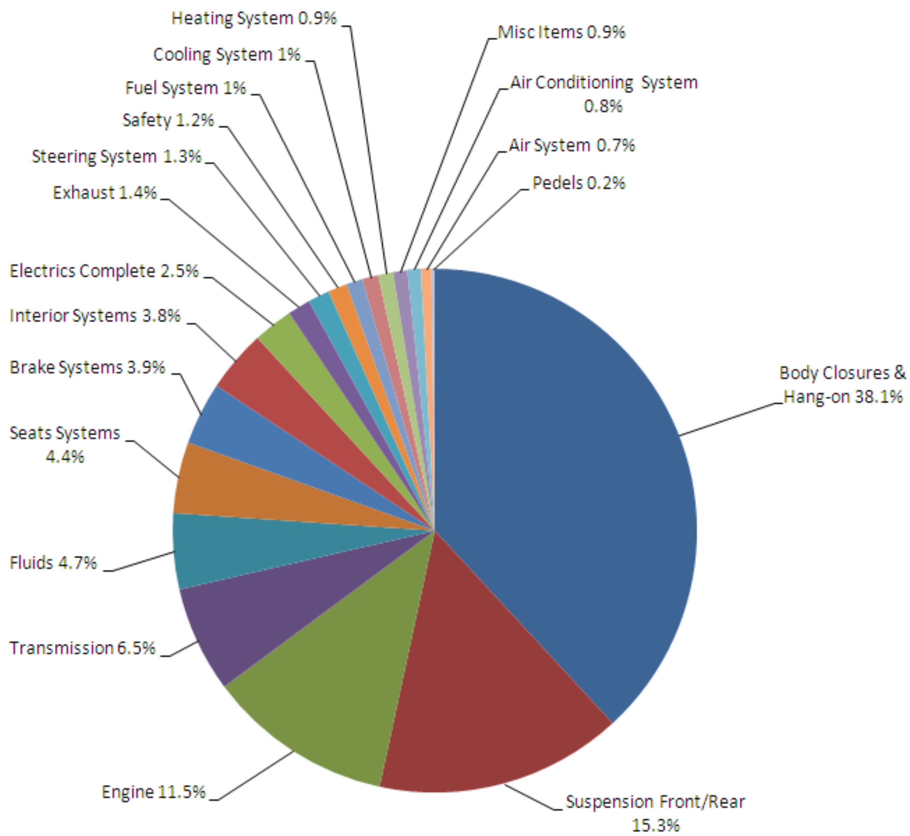

Figure 19: Vehicle Mass Distribution (%)

The breakdown of vehicle system masses obtained during the benchmarking process completed at EDAG is shown in Figure 20.

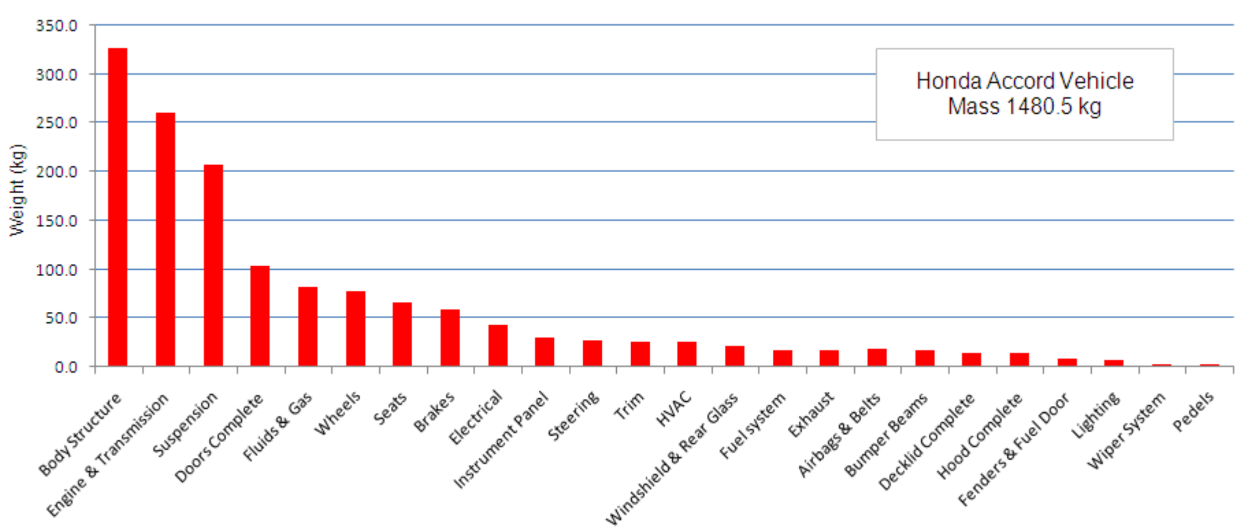

Figure 20: Honda Accord mass distribution by major sub-systems (kg)

In addition to the vehicle mass distribution, a material distribution analysis was also performed.

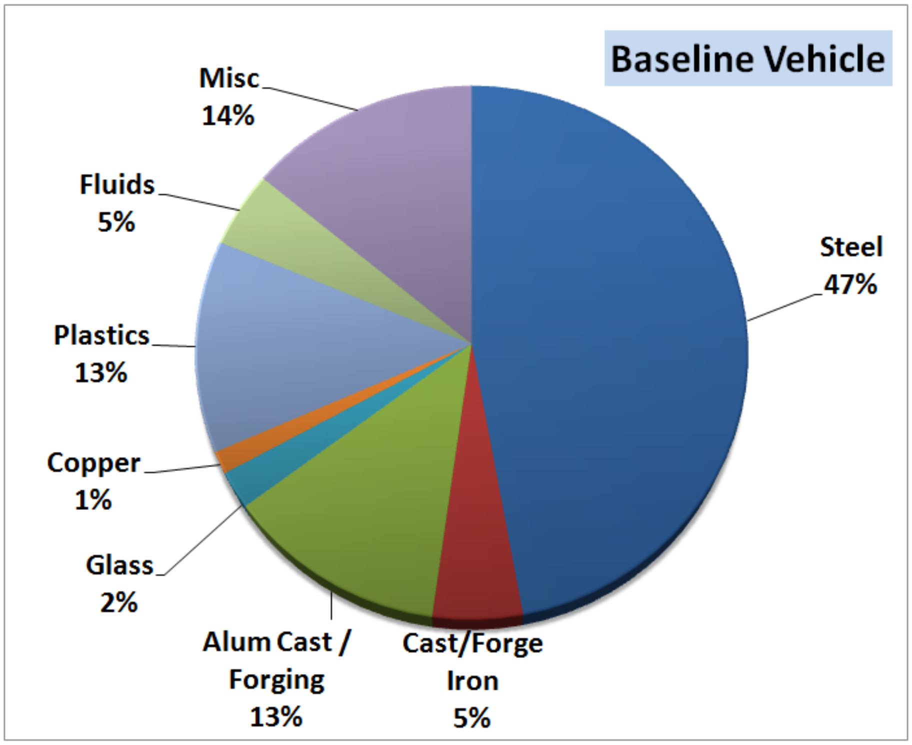

Figure 21: Material distribution for the Honda Accord

4.4.2 Material Usage Analysis for major vehicle systems

For the Honda Accord sub-system weights see Appendix A.

In addition to the Body-in-White (BIW) other sub-systems in the baseline vehicle were reviewed to determine the material distribution, including the following:

- Front seat assembly
- Instrument panel
- Steering system
- Front suspension module
- Rear suspension module

Each one of these systems is described in detail below.

4.4.2.1 Body in White (BIW)

The complete Body-in-White (BIW), which includes closures, front/rear doors, hood, deck lid, front fenders and front and rear bumper beams, was benchmarked for the weight and material composition of each component. The weight of individual BIW components reflects the condition of the BIW assembly as received by the final assembly shop after leaving the paint shop. The BIW of the 2011 Honda Accord BIW includes paint, sealer, anti-flutter adhesive and some NVH measures added prior to the paint process. With the exception of paint and sealer the BIW is of steel construction. Figure 22shows the part weight distribution for the BIW structure. The closures, front and rear doors, hood and decklid also include hem and anti-flutter adhesive.

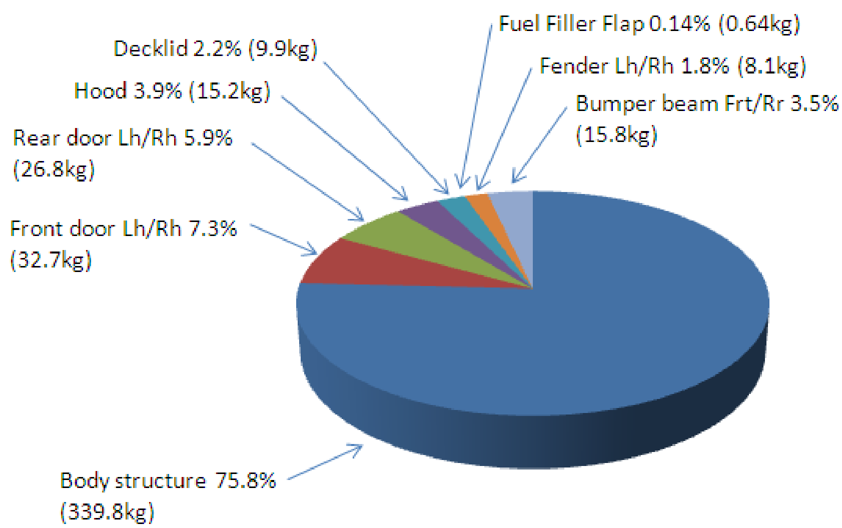

Figure 22: Part Weight Distribution for the Honda Accord 'Body in White' Structure

Previously published data by Honda[17] shows the High Strength Steel (HSS) usage on the body structure to be 48% of the mass. This is equivalent to an average tensile strength of 412 MPa.

4.4.2.2 Front Seat Assembly

Based on the analysis of the front seat it was determined that the highest proportion (70 percent) of the Honda Accord seat weight is made up of the seat frame, with a weight of 16.03 kg. For the components that make up the front seat assembly see Figure 23 below.

Figure 23: Front Seat Assembly Components[25]

[25] A2Mac1.com Automotive Benchmarking

The material and weight distribution for the front seat is shown in Figure 24.

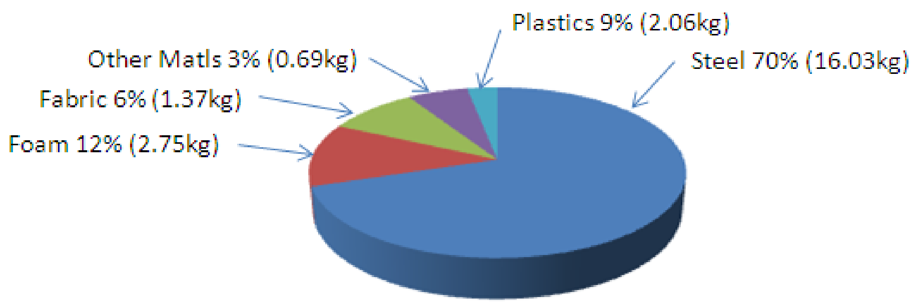

Figure 24: Material and Weight Distribution for the Honda Accord Front Seat Assembly[26]

4.4.2.3 Instrument Panel

The instrument panel contains three main material groups: (1) various types of plastics, (2) steel, which is mainly concentrated in the instrument panel cross car beam, and (3) electronic components. The instrument panel cross-car beam accounts for 35 percent (11.88kg) of the 2010 Honda Accord's total instrument panel weight. The electronics include the instrument cluster, radio, and heater controls, plus the center display and all instrument panel-mounted control modules. The grades of the steel used for the IP were considered to be industry norms, which are typically, to be mild steel with a Yield Strength of 140MPa and an Ultimate Tensile Strength of 270MPa. For the components that make up the instrument panel assembly see Figure 25.

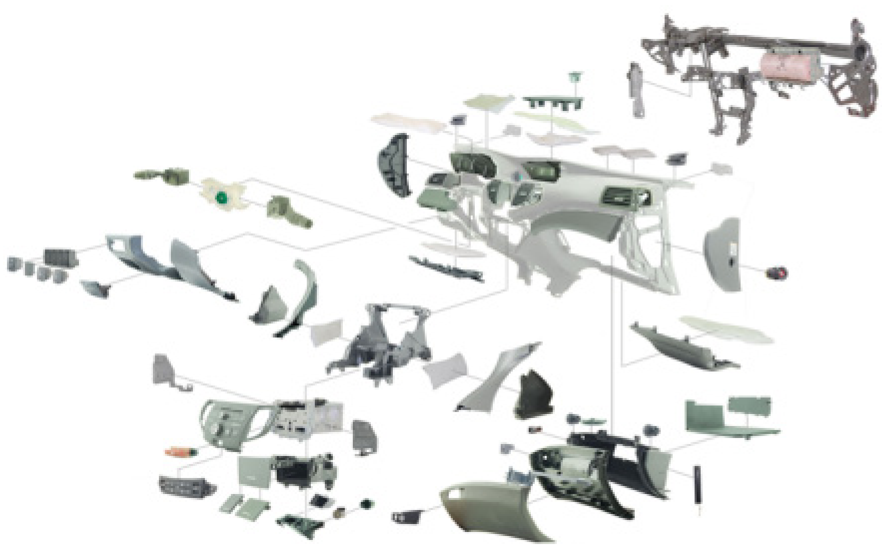

Figure 25: Components That Make Up the Instrument Panel Assembly[27]

The instrument panel material and weight distribution is shown in Figure 26.

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[26]A2Mac1.com Automotive Benchmarking
[27]A2Mac1.com Automotive Benchmarking

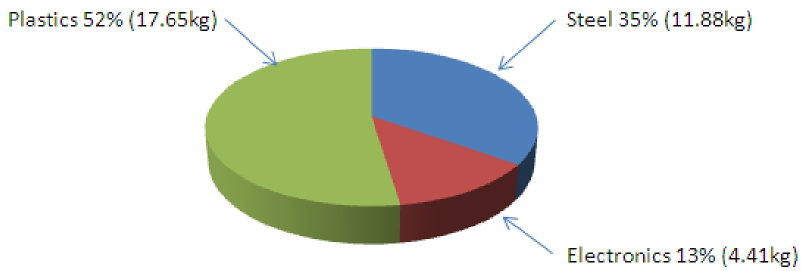

Figure 26: Instrument Panel Material and Weight Distribution[28]

4.4.2.4 Steering Subsystem

The steering sub-system comprises the steering rack, column and steering wheel, plus all related trim parts that attach to the steering column. For the components that make up the steering subsystem, see Figure 27.

Figure 27: Components That Make Up the Steering Subsystem[29]

See Figure 28 for the steering sub-system material and weight distribution.

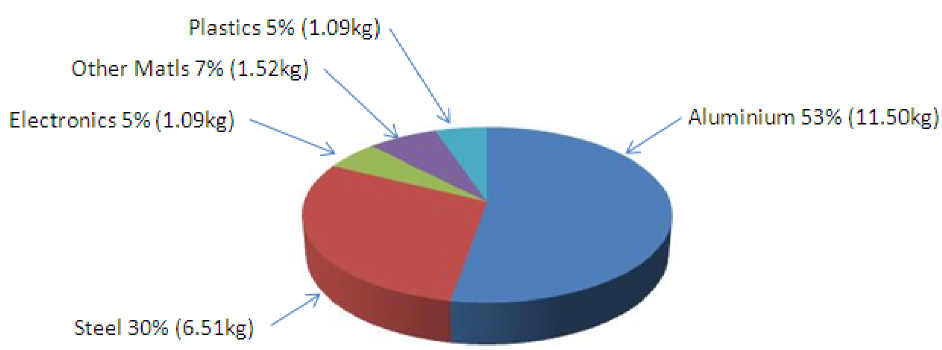

Figure 28: Steering Subsystem Material and Weight Distribution[30]

[28] A2Mac1.com Automotive Benchmarking
[29] A2Mac1.com Automotive Benchmarking

4.4.2.5 Front Suspension Module

The front suspension module on the Honda Accord is of a double wishbone type, which is an independent suspension design using two wishbone shaped arms to locate the front wheel and maintains the wheel, through the suspension geometry, perpendicular to the road surface irrespective of the wheel/suspension movement. This gives a better quality ride than the more common and less complex MacPherson strut suspension but is more costly to manufacture. The module is comprised of the K-Frame, commonly known as the engine cradle, the upper and lower wishbone A-arms, steering knuckle, stabilizer bar, and other miscellaneous parts, as shown in Figure 29. For materials, the suspension module is of approximately 98.7 percent steel construction, the remaining 1.3 percent consists of a steel/elastomeric mix.

Figure 29: Components That Make Up the Front Suspension Module[31]

The part weight distribution of the major components for the front suspension module is shown in Figure 30.

[30]A2Mac1.com Automotive Benchmarking and EDAG

[31]A2Mac1.com Automotive Benchmarking

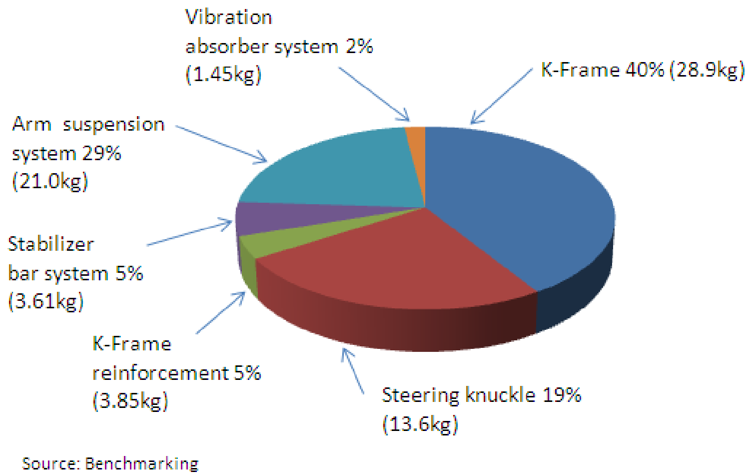

Figure 30: Part Weight Distribution of the Front Suspension Module[32]

The material distribution of the front suspension module is shown in Figure 31. Forty percent (28.9kg) of the front suspension module's mass is the K-frame, which is of 100 percent steel construction. The material distribution for the front suspension is shown in Figure 31.

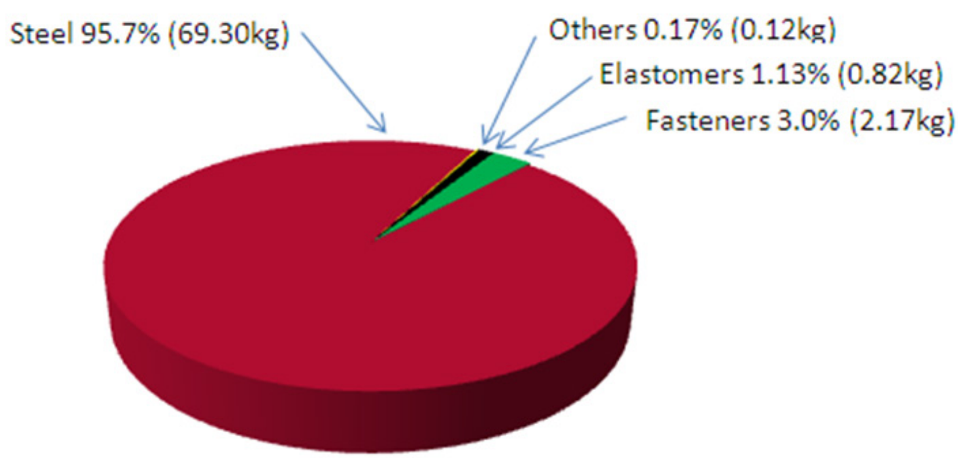

Figure 31: Front Suspension Module Material and Weight Distribution[33]

4.4.2.6 Rear Suspension Module

The Honda Accord rear suspension is a multi-link independent suspension that uses control arms to guide the wheel maintaining wheel contact perpendicular to the road surface. A sub-frame promotes ride comfort and permits the suspension to be pre-assembled while the vehicle is being assembled. Multi-link suspension, while giving a good quality ride and handling, is more complex and has higher manufacturing costs than other more simple suspension arrangements.

[32] A2Mac1.com Automotive Benchmarking

[33] A2Mac1.com Automotive Benchmarking

The Honda Accord rear suspension is comprised of a rear K-frame, multi-link suspension arms, rear hub and the rear casting, plus other miscellaneous parts, as shown in Figure 32. Similar to the front suspension module, the highest contributor to the rear suspension module weight is the K-frame at 41 percent (21.78kg), which is all steel construction.

Figure 32: Components That Make Up the Rear Suspension Module[34]

See Figure 33 for the rear suspension module part weight distribution.

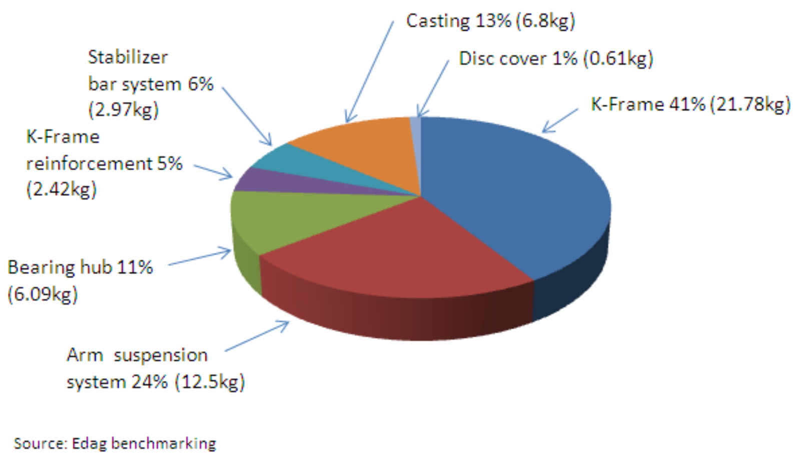

Figure 33: Rear Suspension Module Part Material and Weight Distribution[35]

See Figure 34 for the rear suspension module material and weight distribution.

[34] A2Mac1.com Automotive Benchmarking

[35] A2Mac1.com

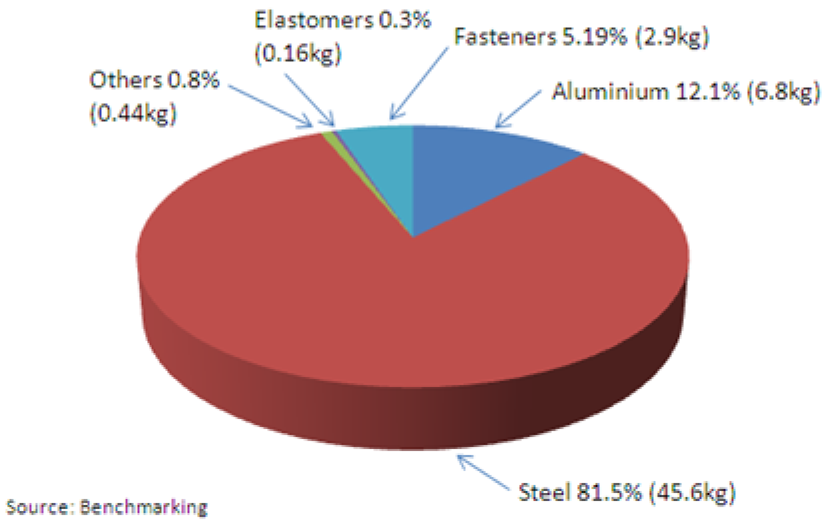

Figure 34: Rear Suspension Module Material and Weight Distribution[36]

4.5 Performance

The LWV is to have similar functionality and performance as the baseline Honda Accord. This section establishes the performance data for the baseline vehicle to which the LWV will be compared.

4.5.1 Fuel Economy

The Honda Accord currently is rated by the EPA to have a fuel economy label rating of 23 mpg City, 34 mpg Highway, with a combined mpg of 27. See Honda Accord window sticker in Figure 3.This rating is generally indicative of the real-world fuel economy that drivers will experience on-road.

4.5.2 Powertrain

The Honda Accord is available in two engine configurations, a V-6, 3471cc, 271hp, 24-valve SOHC i-VTEC engine and an in-line 4 cylinder, 2454cc, 177hp, 16-valve DOHC i-VTEC engine. The baseline vehicle, 2010 Accord LX, comes with the 4 cylinder engine[37]. See Figure 35 showing details of the engine used in the baseline vehicle.

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[36] A2Mac1.com
[37] http://automobiles.honda.com/accord-sedan/specifications.aspx

Item	Details
Configuration	Transverse mounted, front-engine, front-wheel drive
Engine type	Naturally aspirated, port-injected, inline-4, gasoline
Displacement (cc/cu-in)	2,354cc (144 cu-in)
Block/head material	Aluminum/aluminum
Valvetrain	DOHC, four valves per cylinder, variable intake + exhaust-valve timing and lift
Compression ratio (x:1)	10.5
Redline, indicated (rpm)	6,750
Fuel cutoff/rev limiter (rpm)	6,800
Horsepower (hp @ rpm)	177 @ 6,500
Torque (lb-ft @ rpm)	161 @ 4,300
Fuel type	87-octane recommended

Figure 35: 2010 Honda Accord LX Engine Details[38]

Similar to the different types of engines available for the Honda Accord, there are three different transmission configurations available, including a 5-speed manual, a 5-speed automatic with a final drive of 4.44, and a 5-speed automatic with a final drive of 4.31 which is matched to the V-6 engine.

While the 5-speed manual transmission is available on the Accord LX model the 5-speed automatic transmission with a 4.44 final drive was selected for the baseline option as the automatic transmission is the most common option selected for the LX model. Figure 36 shows details of the baseline automatic transmission gear and final drive ratios.

Gear Ratio	
1st	2.652
2nd	1.517
3rd	1.037
4th	0.738
5th	0.537
Reverse	2.000
Final Drive Ratio	4.44

Source: Honda

Figure 36: Honda Accord LX Transmission Ratios[39]

4.5.3 Performance/Drivability

Honda Accord's performance data required for this study is not available from Honda. The following data is from Edmunds, a privately held company providing automotive information via its web site. Edmunds conducted independent performance testing on the Honda Accord at the California speed way in September 2010. The results of this performance testing are presented below.

[38] http://automobiles.honda.com/accord-sedan/specifications.aspx & Edmunds.com
[39] http://automobiles.honda.com/accord-sedan/specifications.aspx

4.5.3.1 Acceleration

The following information concerning the acceleration of the Honda Accord was obtained during performance testing completed by Edmunds. Figure 37 details the performance results obtained from Edmunds.[40]

The Accord tested by Edmunds for performance was the SE version with in the LX model range; this is fitted with the same 2.4L 177hp engine and 5-speed automatic transmission as the baseline LX model.

The base LX model has a vehicle weight of 1480kg while the SE version weight is 1496kg[41]. It was considered that this weight difference would have no significant effect on the test results.

Test	Results
Acceleration, 0-30 mph (sec.)	3
0-45 mph (sec.)	5.2
0-60 mph (sec.)	8
0-60 with 1 foot of rollout (sec.)	7.7
0-75 mph (sec.)	12.1
1/4-mile (sec. @ mph)	16.0 @ 86.8
Braking, 30-0 mph (ft.)	34
60-0 mph (ft.)	133
Slalom, 6 x 100 ft. (mph)	62.3
Slalom, 6 x 100 ft. (mph) ESC ON	59.9
Skid pad, 200-ft. diameter (lateral g)	0.81
Skid pad, 200-ft. diameter (lateral g) ESC ON	0.79
Sound level @ idle (dB)	41.9
@ Full throttle (dB)	76.5
@ 70 mph cruise (dB)	67.4
Engine speed @ 70 mph (rpm)	2,600

Figure 37: Honda Accord Performance Test Results[42]

4.5.3.2 Towing

The Honda Accord LX used as the LWV baseline vehicle was not fitted with a receiver hitch. The 2011 Accord when fitted with a class-1 receiver hitch is capable of a 454 kg (1,000 lbs.) towing capacity. The receiver hitch is bolted to existing attachment points on the body structure and does not require any modification to either the body structure or rear suspension. The LWV structure will be able to perform similar towing function as the baseline vehicle.

[40] http://www.edmunds.com/honda/accord/2011/road-test-specs.html
[41] http://automobiles.honda.com/accord-sedan/specifications.aspx
[42] http://www.edmunds.com/honda/accord/2011/road-test-specs.html

4.5.3.3 Total Driving Range

The Accord is fitted with an 18.5 gallon fuel tank. Using the combined mileage of 27 mpg, stated by the EPA, yields a driving range of 500 miles. The range for city driving is 426 miles and for highway driving is 629 miles. The recommended fuel for this vehicle is 87-octane regular gasoline. The LWV will also be designed to have 500 mile driving range to maintain same functionality as the baseline vehicle, using the combined predicted miles per gallon for the LWV.

4.5.3.4 Maximum Speed

On the base Honda Accord with the 177 hp, 2.4 L engine and 5-speed automatic transmission, the maximum speed is governor-limited to 127 MPH. Without the governor limiter, this vehicle can attain a maximum speed of 137.3 MPH as simulated using PSAT by EDAG (see Section 5.3 for further details on PSAT analysis). Limiting the maximum speed to a particular limit is an OEM decision based on marketing/safety and other considerations. Maximum speed of 112 MPH is common on some of the other mid-size sedan vehicles that compete with the Honda Accord. Examples of mid-size sedans with a 112 MPH limit include Chevrolet Malibu, Ford Fusion SEL, and Nissan Altima 2.5S.

4.5.3.5 Minimum turning radius

The Accord has a turning radius of 5.75 m (18.85 ft.), which gives a curb-to-curb turning circle of 11.5 m (37.7 ft.)[43]. As this is an important feature when manoeuvring the vehicle in tight spaces, this will be maintained on the LWV.

4.5.4 Utility

4.5.4.1 Sun Roof

The roof structure of the baseline Honda Accord LX is not configured to accept a sunroof module as this is not available on the LX model range. A sunroof module can be fitted to the roof structure by the elimination of the front bond beam and center roof bow. These parts would then be replaced by the sunroof reinforcement panel. This would allow the roof panel with the sunroof opening plus reinforcement panel to be assembled in the body structure assembly line. Even that the Accord LX has no sunroof, the LWV is package protected to include a sunroof module.

4.5.4.2 Rear Folding Seat for stowing larger items

The Accord is fitted with a full width folding rear seat that folds in one piece for additional cargo space this gives access to the rear luggage compartment. Also included in the rear seat back is a small pass-through feature for longer items like skis. Access to this feature is achieved by first lowering the centre armrest and opening the pass-through[44] as shown in Figure 38. This is an important feature which is package protected in the LWV design.

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[43] http://automobiles.honda.com/accord-sedan/specifications.aspx
[44] http://automobiles.honda.com/accord-sedan/interior-photos.aspx

Figure 38: Rear Seat with Pass-Through Feature[45]

4.5.4.3 Larger Alloy Wheels

The baseline Accord LX is fitted with steel 16-inch wheels with plastic wheel trim. The tires fitted are P215/60R16 94H Dunlop XP Sport 2000 all season tire, with a spare wheel and of a space-saving type, T135/80D16 101M temporary unit, mounted in the luggage compartment under the rear carpet.

The Accord's body structure is capable of accepting a 16 or 17 inch alloy wheel. The spare tire remains unchanged no matter whether the Accord is fitted with a 16 or the larger 17 inch alloy wheel. The larger alloy wheels are a styling feature that enhances the car's appearance for sales appeal. Even though the 16 inch wheel is used in the LWV as for the baseline vehicle, the LWV

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[45] www.automobiles.honda.com

front and rear suspension and body structure is package protected to accommodate both wheel sizes and the spare tire.

4.6 Packaging

4.6.1 Ergonomics

The Honda Accord is a mid-sized vehicle with a seating capacity of five (5), driver plus four passengers. Figure 39 shows seating configuration for Honda Accord and Figure 40 shows the interior dimensions for Honda Accord. Similar interior dimensions were maintained for the LWV.

Figure 39: Honda Accord Seating Configuration[46]

Dimensions Interior	
Legroom, front (mm)	1080
Legroom, rear (mm)	945
Headroom, front (mm)	1052
Headroom, rear (mm)	978
Shoulder room, front (mm)	1478
Shoulder room, rear (mm)	1433
Cargo volume (L)	416
Passenger Volume (Lt)	3002
Seating capacity	5

Figure 40: Accord Interior Dimensions[47]

[46] http://automobiles.honda.com/accord-sedan/interior-photos.aspx

[47] http://automobiles.honda.com/accord-sedan/specifications.aspx.

4.7 Vehicle Stiffness

The Honda Accord body structure torsion and bending stiffness are signatures of the vehicle structural performance. Vehicles with higher stiffness are generally associated with a refined ride and handling qualities. A rigid vehicle structure helps to minimize noise, vibration and harshness (NVH) in the passenger compartment which improves the vehicle's ride quality, comfort and interior quietness. The torsion stiffness number is also used to calculate the Lightweight Design Index, which represents the comparative efficiency of the body structure with other vehicles. The Lightweight Design Index has no particular value that is regarded as acceptable. It is an index which engineers like to use for comparison purposes. Lower value means increased structural efficiency. After the Honda Accord was completely disassembled at EDAG, it underwent testing for the normal modes of vibration, torsion and bending stiffness, as discussed in the sections below. The body structure, with windshield, back glass and instrument panel cross car beam assembled in place, was made available to a test facility to complete the tests.

See Figure 41 for an overview of test results, and the Appendix C and D for full test results. The calculated LWV Light Weight Index is shown in Figure 42.

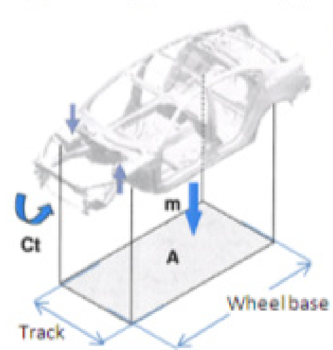
Front End Lateral Mode (Hz)	35.1
First Bending Mode (Hz)	44.2
First Torsion Mode (Hz)	50.1
Torsional Stiffness (kN/Deg)	12,330
Bending Stiffnes (N/mm)	8,690

Figure 41: Base Line Honda Accord Torsion and Bending Results

Light Weight Index (L)

$$L = \frac{M}{A \times Ct}$$

m: Body structure mass (kg)
A: Wheel base x Track (m²)
Ct: Static rigidity (KNm/deg)



BIW Mass (kg)	327
Torsional Stiffness (kNm/deg)	12,330
Area (m^2)	4.45
Light Weight Index	5.96

Source: EDAG

Figure 42: Honda Accord 'Light Weight Index'

4.7.1 Normal Modes Frequency Testing

A normal mode of a body structure is a pattern of motion in which all parts of the system move with the same frequency and in phase. The normal mode frequencies of a body system are known as its natural frequencies or resonant frequencies. A vehicle body has a set of normal modes that depend on its structure, materials and boundary conditions. The objective of this modal test was to find the modal properties of a 2011 Honda Accord BIW (with front and rear glass and instrument panel beam), from 0 to 100 Hz frequency range. The major resonance frequencies of body structure that 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 sure these are separated from the engine and wheel forcing frequencies.

For the test set-up, the Accord BIW was supported with four rubber airbags 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 airbags 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. The test set-up for the normal modes test is shown in Figure 43.

Figure 43: Vehicle Set-Up for Normal Modes Test

The results from the modal test for the baseline Honda Accord are used as targets for the LWV body structure, as shown in Figure 44. See Appendix C for the full modal test report.

	Honda Accord	LWV Target
Front End Lateral Mode (Hz)	35.1	35.1
First Bending Mode (Hz)	44.2	44.2
First Torsion Mode (Hz)	50.1	50.1

Figure 44: Modal Test Results

4.7.2 Torsional Stiffness

Torsional stiffness is determined when a static moment is applied to the body-in-white at the front shock towers when the rear shock towers are constrained, as shown in Figure 45.

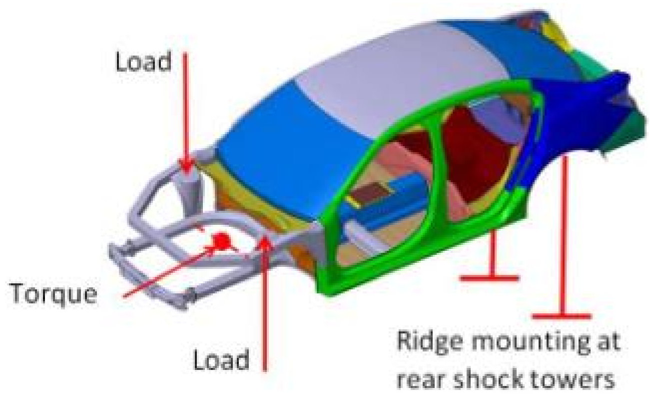


Figure 45: Vehicle Load and Mounting for Torsional Stiffness Test

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. Higher torsional stiffness value means a stiffer vehicle, which would result in better ride characteristics. The Honda body structure with the windshield, the rear glass and the instrument panel cross car beam was loaded to a torsion and stiffness rig as shown in Figure 46. The test results are shown in Figure 47. The detailed torsion test report is shown in Appendix D.

Figure 46: Body Structure on Test Rig for Torsion and Bending Stiffness Test

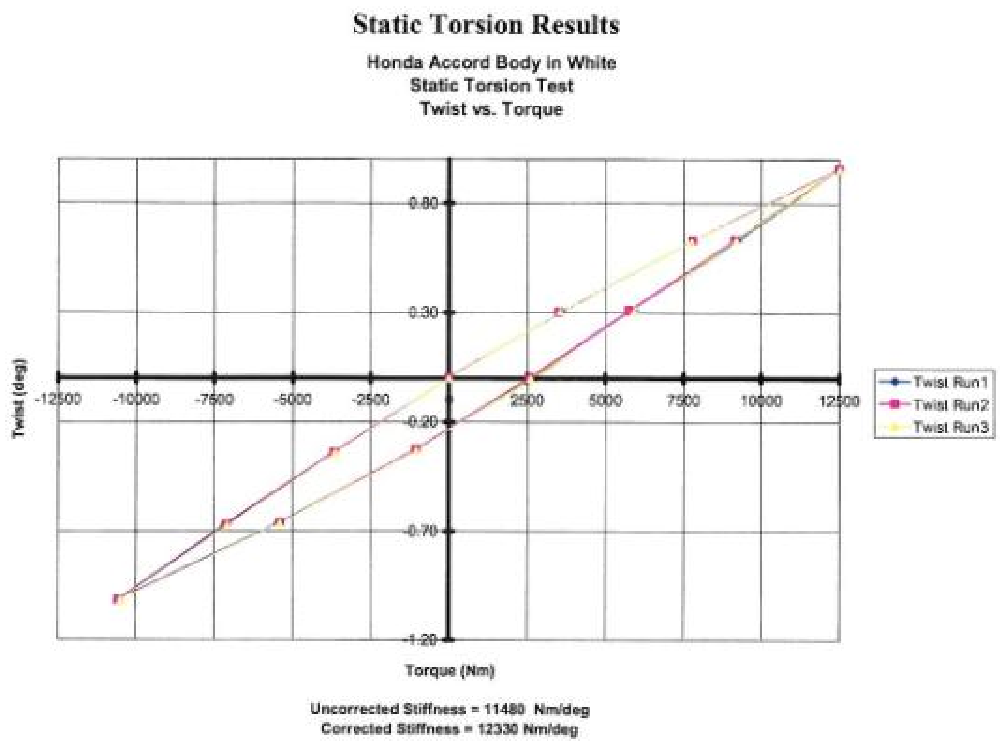


Figure 47: Torsional Stiffness Results

4.7.3 Bending Stiffness

The vehicle bending stiffness is measured on the same test rig that is used for torsion testing. Different load cases are available. During a global bending test, forces are applied at the front seat locations, but with the body constrained at front and rear shock towers, as shown in Figure 48.

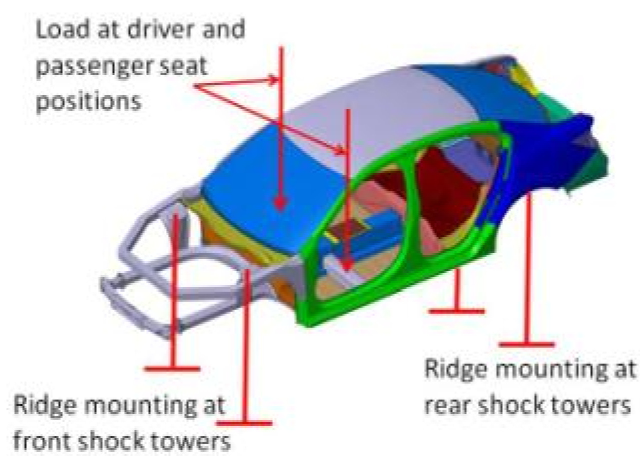


Figure 48: Representative Global Bending Test

During the bending test, loads are applied at the front seat positions. The bending stiffness results from the ratio of the applied load to the maximum deflection along the rocker panel and tunnel. Excessive amount of deflections under bending loads could lead to unacceptable relative movements between components, a possible cause of squeaks and rattles. It could also lead to premature structural failures. See Figure 49 for bending stiffness test results. The detailed static bending test report is shown in Appendix D.

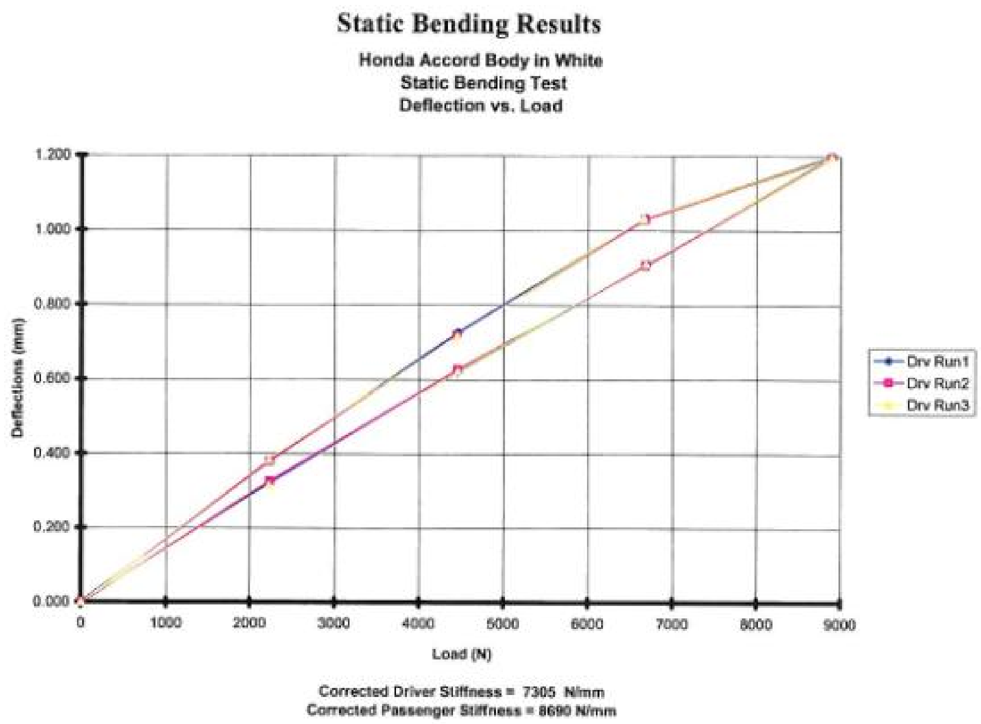


Figure 49: Bending Stiffness Test Results

The results from the torsion and bending stiffness tests for baseline Honda Accord are used as targets for the LWV body structures as shown in Figure 50.

	Honda Accord	LWV Target
Torsional Stiffnes (kN/Deg)	12,330	12,500
Bending Stiffness N/mm	8,690	9,000

Figure 50: Torsion and Bending Stiffness Targets for LWV

4.8 Crash Safety

Crashworthiness is the ability of a vehicle to protect its occupants during an impact. Toward this end, the vehicle needs good restraint systems to limit the crash forces exerted on the occupant and on its structure to manage and absorb the crash energy as well as provide an environment in which the restraint systems can perform their function. This structural performance includes maintaining the occupant compartment's integrity to the highest degree possible, as well as controlling for the forces exerted on the occupant either directly by contact with the vehicle interior or indirectly through interactions with the restraint systems.

Establishing the crashworthiness of a passenger vehicle typically requires several cycles of dynamic testing, both mathematically and physically in the laboratory, with restraint systems and anthropomorphic test devices (ATD) exposed to different crash severities and impact directions. The scope of this particular project includes (but is not limited to) reducing the overall mass of a passenger vehicle while retaining a current, equivalent level of safety. This task is complicated, however, by the fact that safety is based on the combination of the structure plus the restraint system (air bags, force-limited safety belts, pretension safety belts, and so on). The team understand that: it requires good safety structural performance, good restraint system and good interaction between these two factors for a vehicle to achieve good safety performance. The scope and allocated resources of this study focus on making the structure of the LWV strong enough to protect the occupant, but do not include the development of occupant restraints.

In the past, engineers have established heuristic guidelines for assessing the potential of a structure for superior crashworthiness.[48,49 ,50]These structural rules are (1) a longer crash pulse in frontal impact is better than a shorter crash pulse, (2) a crash pulse of lower magnitude in frontal impact is better than a crash pulse with higher magnitude, and (3) little or no intrusion into the occupant compartment is better than a larger intrusion, (4) timely deployment of airbags based on early (0 to 20 millisecond) structural response is very critical.

4.8.1 Baseline Honda Accord

From 2001 to 2008, Honda vehicles showed (1) an increase in consumer-information safety ratings and (2) a decrease in fatality rate.[51]In particular, the 2011 Honda Accord received "5 stars" on the NCAP frontal and side tests and a "good" rating in the IIHS front and side test. Kamiji observed that downsizing is a major consumer response to high fuel prices, resulting in

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[48]Hong, S-W., Park, C-K., Morgan, R.M., Kan, C-D., Park, S., and Bae, H., "A Study of the Rear Seat Occupant Safety using a 10-Year-Old Child Dummy in the New Car Assessment Program," SAE Paper 2008-01-0511, April 2008.
[49]Insurance Institute for Highway Safety, *Frontal Offset Crashworthiness Evaluation Guidelines for Rating Structural Performance,* 1005 N. Glebe Road, Arlington, VA 22201, April 2002.
[50]Park, B.T., Hackney, J.R., Morgan, R.M., Chan, H., Lowrie, J.C., and Devlin, H.E., "The New Car Assessment Program: Has It Led to Stiffer Light Trucks and Vans over the Years?, SAE International Congress and Exposition, Detroit, Michigan, SAE Paper No. 1999-01-0064, March 1 – 4, 1999.
[51]Kamiji, K., "Honda's Thinking About Size, Weight, and Safety," NHTSA Workshop on Vehicle Mass-Size-Safety, Washington, DC, February 25, 2011. http://www.nhtsa.gov/Laws+&+Regulations/CAFE+-+Fuel+Economy/NHTSA+Workshop+on+Vehicle+Mass-Size-Safety

reduced vehicle mass.[52] He noted that rather than reducing mass; however, the mass of the BIW of the Honda Accord increased approximately 39 percent from model year 1994 to model year 2008. The vehicle got heavier due to many reasons, including structure improvement to meet stricter safety test requirement, enhancement to increase body rigidity for better NVH, increasing vehicle size (from EPA class MID to LARGE) and moving up-market compared with original 1994 model. To counter this trend of increasing vehicle weight, Honda began using lighter high strength steel and optimized body structure. For the 2003 model year Accord, about 40 percent of the steel in the BIW was high strength steel, and roughly 50 percent of the steel in the BIW of the model year 2008 Accord is high strength steel. In designing the Honda Accord in the near term, Kamiji noted that Honda plans to use a greater percentage of high strength steel to bring down the weight of the BIW structure.

The model year 2008 and later Accord also has Honda's Advanced Compatibility Engineering (ACE) body structure. According to Honda, the ACE is designed to lessen injury to car occupants due to mismatch in weight or height in vehicle-to-vehicle crashes[53]. Figure 51shows the ACE design meant to help spread out the forces in a frontal collision, circumventing concentrated forces that cause occupant trauma. Figure 52 represents a single-load-path design that distributes the forces of a collision primarily through the two longitudinal rails. Figure 53 shows the distribution of forces onto a wall due to a 100 percent overlap of the frontal of the vehicle. The conventional structure has two regions of high impact force lined up with the longitudinal rails. In contrast, the ACE structure trims down the high spikes and spreads the force out over the impacted area.

Figure 51: ACE improved body structure[54]

[52]Kamiji, K., "Honda's Thinking About Size, Weight, and Safety," NHTSA Workshop on Vehicle Mass-Size-Safety, Washington, DC, February 25, 2011. http://www.nhtsa.gov/Laws+&+Regulations/CAFE+-+Fuel+Economy/NHTSA+Workshop+on+Vehicle+Mass-Size-Safety

[53]American Honda Motor, Co., "Leadership in Collision Compatibility," http://corporate.honda.com/safety/details.aspx?id=collision (accessed February 1, 2012)

[54]American Honda Motor, Co., "Leadership in Collision Compatibility," http://corporate.honda.com/safety/details.aspx?id=collision (accessed February 1, 2012)

Figure 52: Former design of body structure[55]

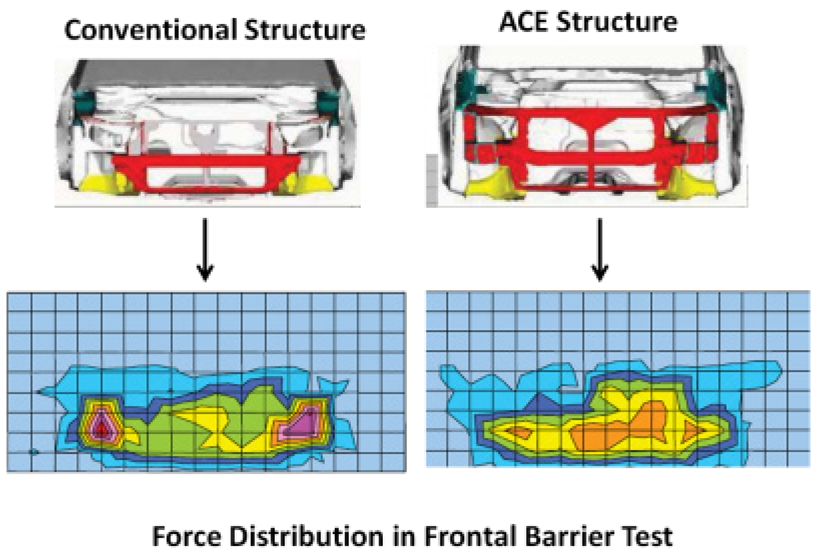

Figure 53: Dispersal of force in full-width impact of the conventional design and of the ACE design[56]

4.8.2 Frontal NCAP Test

The NCAP frontal test is a full-width impact to the front of the vehicle. Crash test dummies are seated in the location of the driver and the right front passenger. The vehicle crashes head-on into a rigid concrete barrier at nominally 56 kph (35 mph). During the collision, instruments in the dummies measure the severity of the impact to the body of the occupant. As compared to the Insurance Institute for Highway Safety (IIHS) frontal test, the NCAP frontal test has shorter

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[55]American Honda Motor, Co., "Leadership in Collision Compatibility," http://corporate.honda.com/safety/details.aspx?id=collision (accessed February 1, 2012)

[56]Kamiji, K., "Honda's Thinking About Size, Weight, and Safety," NHTSA Workshop on Vehicle Mass-Size-Safety, Washington, DC, February 25, 2011. http://www.nhtsa.gov/Laws+&+Regulations/CAFE+-+Fuel+Economy/NHTSA+Workshop+on+Vehicle+Mass-Size-Safety

pulse time width and lower occupant compartment intrusion. Figure 54 shows the test set up and the post-crash vehicle for the NCAP frontal test.

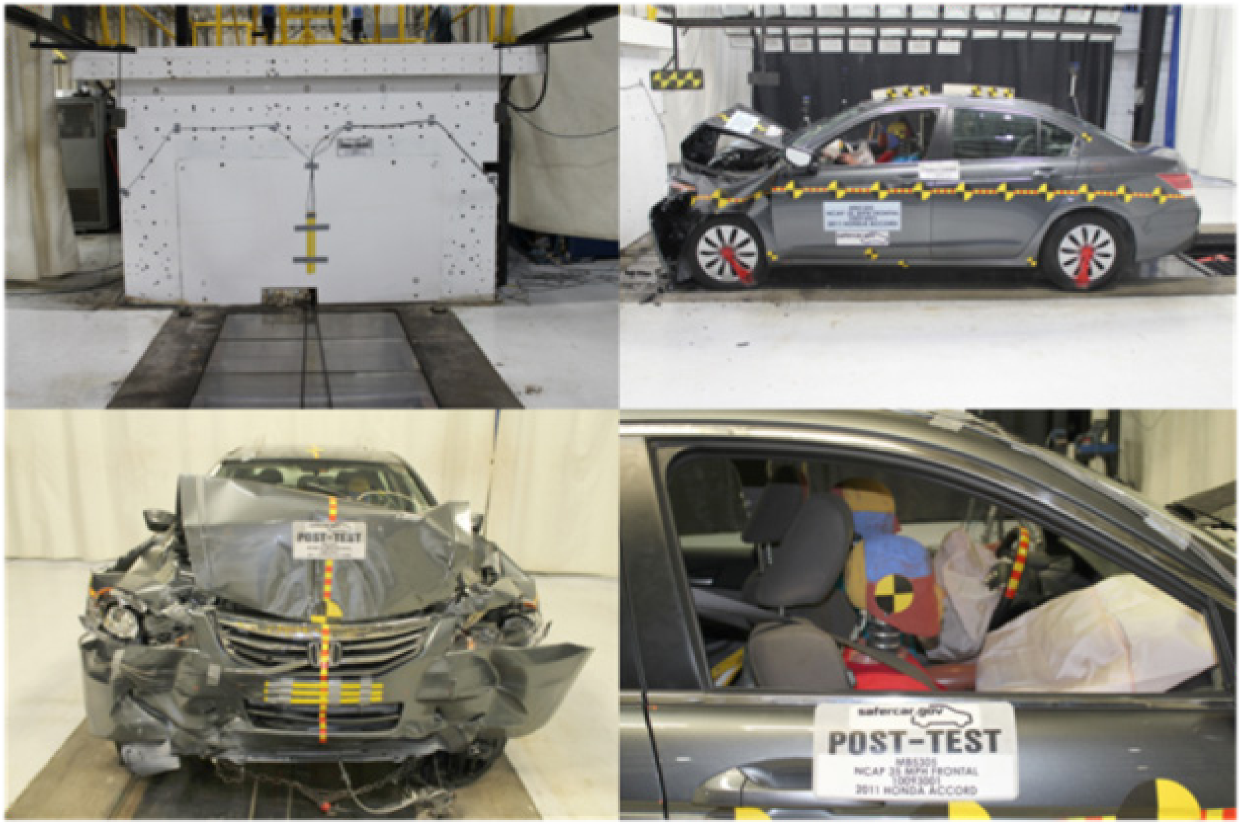

Figure 54: Test set up and the post-crash vehicle of the NCAP frontal crash[57]

The 2011 Honda Accord sedan underwent a frontal barrier impact test on September 30, 2010.[58] The crash was conducted by MGA Research at an initial speed of 56.5 kph. A 50th percentile male ATD was positioned in the left front seat and a 5th percentile female ATD was positioned in the right front seat. In subsequent analysis, the Honda Accord was awarded a 5 “star” safety rating (*i.e.*, the highest safety rating) for the frontal NCAP test.[59]

As explained in the previous section, 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 project concentrates on the dynamic and static response of the structure of the basic Honda Accord and the LWV. Based on the measured acceleration from the accelerometer mounted at the left rear cross member in the longitudinal direction, the crash pulse of the 2011 Honda Accord is shown in Figure 55. The sudden drop in acceleration (45 to 50 msec) appears to be associated with the

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[57]MGA Research Corporation, *New Car Assessment Program (NCAP) Frontal Barrier Impact Test 2011 Honda Accord LX Sedan*, Report No. NCAP-MGA-2011-027, 5000 Warren Road, Burlington, WI 53105, October 28, 2010.
[58]MGA Research Corporation, *New Car Assessment Program (NCAP) Frontal Barrier Impact Test 2011 Honda Accord LX Sedan*, Report No. NCAP-MGA-2011-027, 5000 Warren Road, Burlington, WI 53105, October 28, 2010.
[59]National Highway Traffic Safety Administration Web Site, “5-Star Safety Rating,” http://www.safercar.gov/.

rear engine cradle mount failure (by design) during the crash, which could actually be observed during the test in an undercarriage camera.[60]

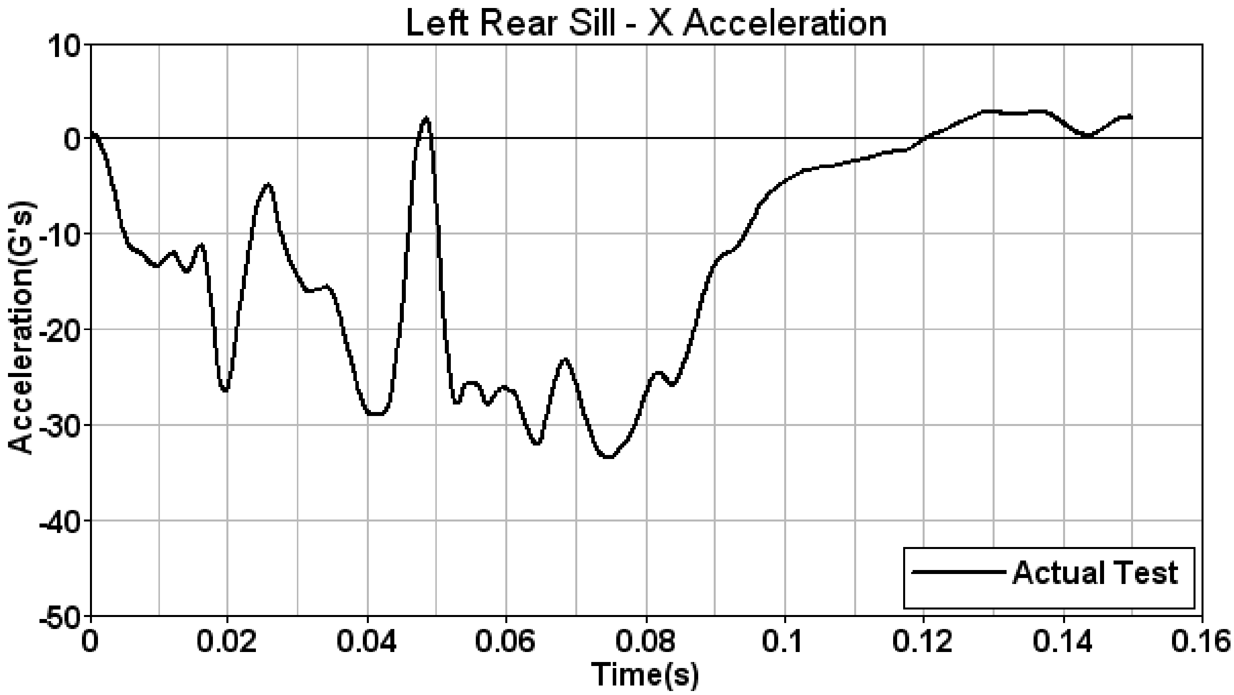

Figure 55: Crash pulse from frontal NCAP test of Honda Accord 2011

Passenger compartment intrusion measurements taken post-crash showed low values. Eight measurement points on the floor pan are illustrated in Figure 56. For all eight sites, the differences in pre-crash location and post-crash location were zero, i.e. there was no deformation of the floor pan. Vehicle intrusion measurements are depicted in Figure 57. The post-crash driver-compartment intrusion measurements are listed in Figure 58. For purposes of safety, these intrusions are minuscule.

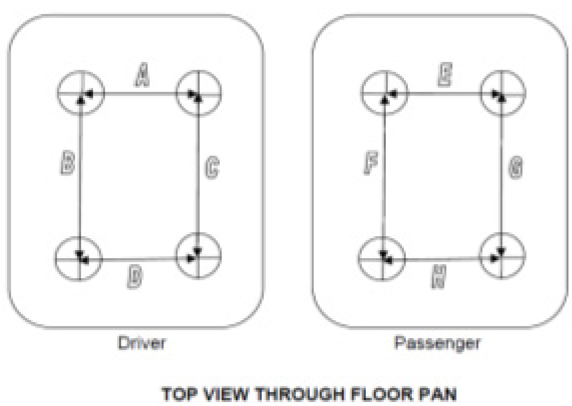

Figure 56: Scheme used to measure under-body floorboard deformation[61]

[60]MGA Research Corporation, *New Car Assessment Program (NCAP) Frontal Barrier Impact Test 2011 Honda Accord LX Sedan*, Report No. NCAP-MGA-2011-027, 5000 Warren Road, Burlington, WI 53105, October 28, 2010.

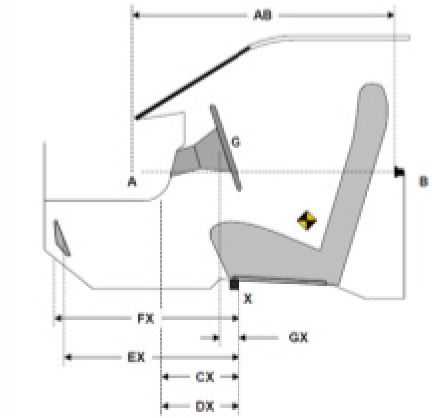

Figure 57: Scheme for driver compartment intrusion measurement[62]

Symbol	Description	Units	Difference in pre-test and post-test measurement
CX	Left knee bolster	mm	-1
DX	Right knee bolster	mm	-1
EX	Brake pedal	mm	-3
FX	Foot rest	mm	8
GX	Center of steering column wheel hub	mm	5

Figure 58: Driver compartment intrusion in x direction[63]

4.8.3 Lateral NCAP Moving Deformable Barrier Test

For the NCAP side impact test with a moving deformable barrier, a 1,368 kg (3,015 pounds) trolley impacts the side of the struck vehicle. This trolley (with wheels crabbed at 27 degrees to its forward line of motion) strikes a stationary vehicle (positioned at an angle of 63 degrees to the line of forward motion). See Figure 59 for trolley to vehicle orientation.[64] The trolley, with a deformable barrier on the front, moves at 62 km/h (38.6 mph). Crash test dummies are positioned on the struck side at the location of the front seat and the rear seat occupant. During the collision, instruments in the dummies measure the severity of the impact to the body of the occupant. Figure 60 shows the test set up and the post-crash vehicle.

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[61]MGA Research Corporation, *New Car Assessment Program (NCAP) Frontal Barrier Impact Test 2011 Honda Accord LX Sedan*, Report No. NCAP-MGA-2011-027, 5000 Warren Road, Burlington, WI 53105, October 28, 2010.
[62]MGA Research Corporation, *New Car Assessment Program (NCAP) Frontal Barrier Impact Test 2011 Honda Accord LX Sedan*, Report No. NCAP-MGA-2011-027, 5000 Warren Road, Burlington, WI 53105, October 28, 2010.
[63]MGA Research Corporation, *New Car Assessment Program (NCAP) Frontal Barrier Impact Test 2011 Honda Accord LX Sedan*, Report No. NCAP-MGA-2011-027, 5000 Warren Road, Burlington, WI 53105, October 28, 2010.
[64]MGA Research Corporation, *New Car Assessment Program (NCAP) Moving Deformable Barrier Side Impact Test 2011 Honda Accord LX Sedan*, Report No. SINCAP-MGA-2011-028, 5000 Warren Road, Burlington, WI 53105, October 28, 2010.

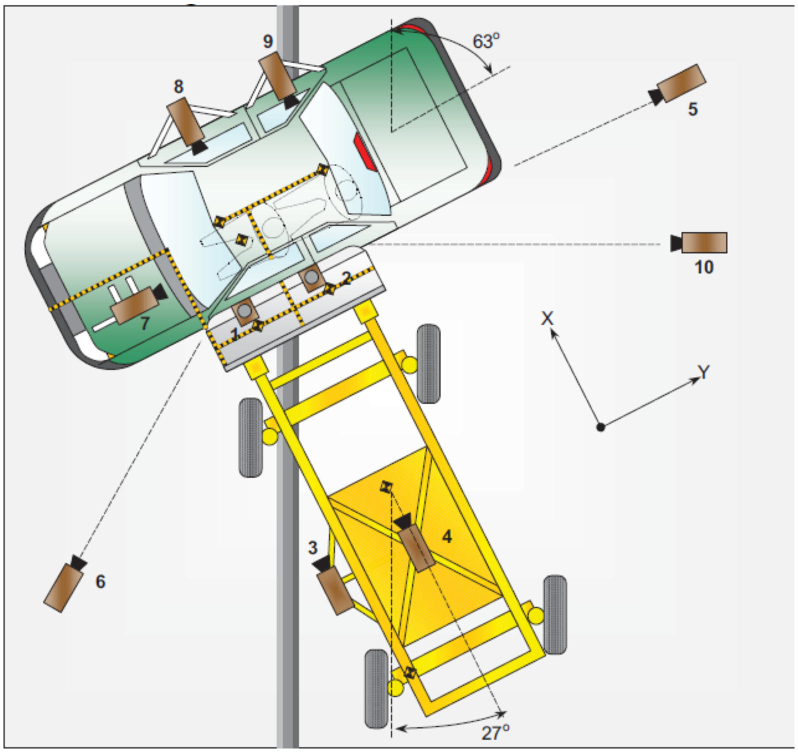

Figure 59: Orientation of trolley to struck vehicle in NCAP side test with moving deformable barrier[65]

Figure 60: Test set up and the post-crash vehicle of the NCAP side impact test with moving deformable barrier[66]

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[65]MGA Research Corporation, *New Car Assessment Program (NCAP) Moving Deformable Barrier Side Impact Test 2011 Honda Accord LX Sedan*, Report No. SINCAP-MGA-2011-028, 5000 Warren Road, Burlington, WI 53105, October 28, 2010

The 2011 Honda Accord sedan was impacted by a moving deformable barrier on October 1, 2010.[67] (The analysis herein is for the Accord sedan and should not be extended to the crash performance of the Accord coupe.) The crash was conducted by MGA Research for Honda with the barrier moving at an initial speed of 61.8 kph. A 50th percentile male ATD was positioned in the left front seat and a 5th percentile female ATD was positioned in the left rear seat. In subsequent analysis, the Honda Accord was awarded a 5 "star" safety rating for the side NCAP test.[68]

Vehicle crush measurements were recorded following the diagram in Figure 61. Following the diagram, the crush sustained by the baseline Honda Accord is given in Figure 62. The levels are (1) sill top, (2) occupant H-point, (3) mid-door, (4) window sill, and (5) window top.

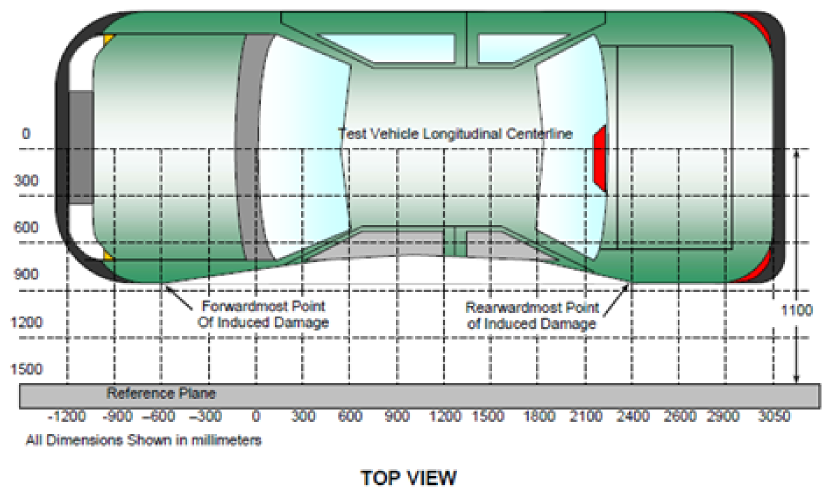

Figure 61: Diagram used for recording crush in side impact with moving barrier[69]

[66]MGA Research Corporation, *New Car Assessment Program (NCAP) Moving Deformable Barrier Side Impact Test 2011 Honda Accord LX Sedan*, Report No. SINCAP-MGA-2011-028, 5000 Warren Road, Burlington, WI 53105, October 28, 2010
[67]MGA Research Corporation, *New Car Assessment Program (NCAP) Moving Deformable Barrier Side Impact Test 2011 Honda Accord LX Sedan*, Report No. SINCAP-MGA-2011-028, 5000 Warren Road, Burlington, WI 53105, October 28, 2010
[68]National Highway Traffic Safety Administration Web Site, "5-Star Safety Rating," http://www.safercar.gov/.
[69]MGA Research Corporation, *New Car Assessment Program (NCAP) Moving Deformable Barrier Side Impact Test 2011 Honda Accord LX Sedan*, Report No. SINCAP-MGA-2011-028, 5000 Warren Road, Burlington, WI 53105, October 28, 2010

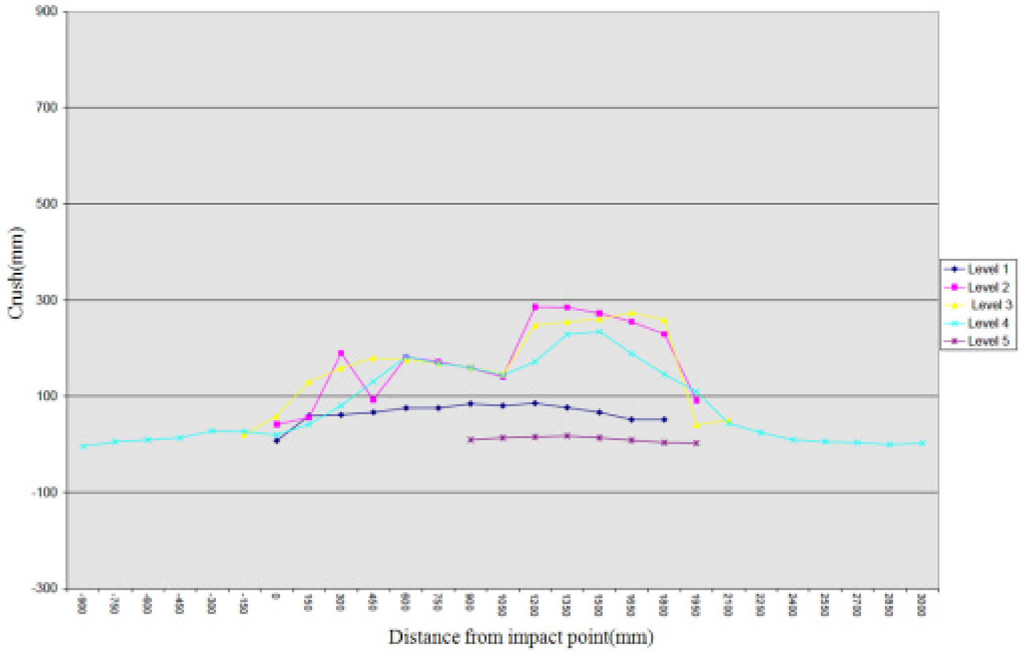

Figure 62: Measurements of crush of Honda Accord 2011 in NCAP moving barrier side test[70]

4.8.4 Lateral NCAP Pole Test

A vehicle in the NCAP side pole test is impacted into a fixed, rigid pole 254 mm (10 inches) in diameter, at a speed of 32 km/h (20 mph). Figure 63 shows the pole. A 5th percentile female dummy is positioned in the front seating position. The complete test set up is illustrated in Figure 64.[71]

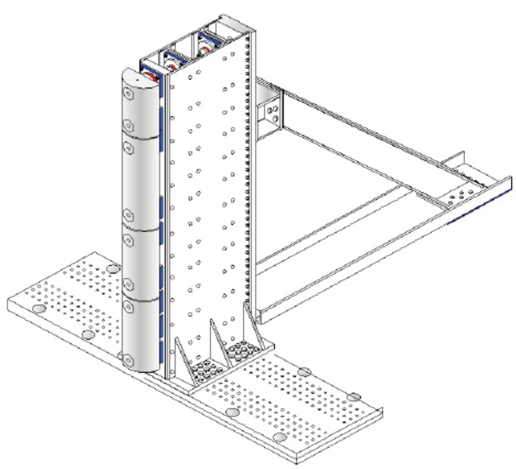

Figure 63: Fixed, rigid pole 254 mm (10 inches) in diameter, used for NCAP side pole test[72]

[70]MGA Research Corporation, *New Car Assessment Program (NCAP) Moving Deformable Barrier Side Impact Test 2011 Honda Accord LX Sedan*, Report No. SINCAP-MGA-2011-028, 5000 Warren Road, Burlington, WI 53105, October 28, 2010

[71]MGA Research Corporation, *New Car Assessment Program (NCAP) Side Impact Pole Test 2011 Honda Accord LX Sedan*, Report No. SPNCAP-MGA-2011-026, 5000 Warren Road, Burlington, WI 53105, October 28, 2010.

[72] U.S. Department of Transportation, National Highway Traffic Safety Administration, "Laboratory Test Procedure for FMVSS 214 Rigid Pole Side Impact Test," Report No. TP-214P-00, August 2007.

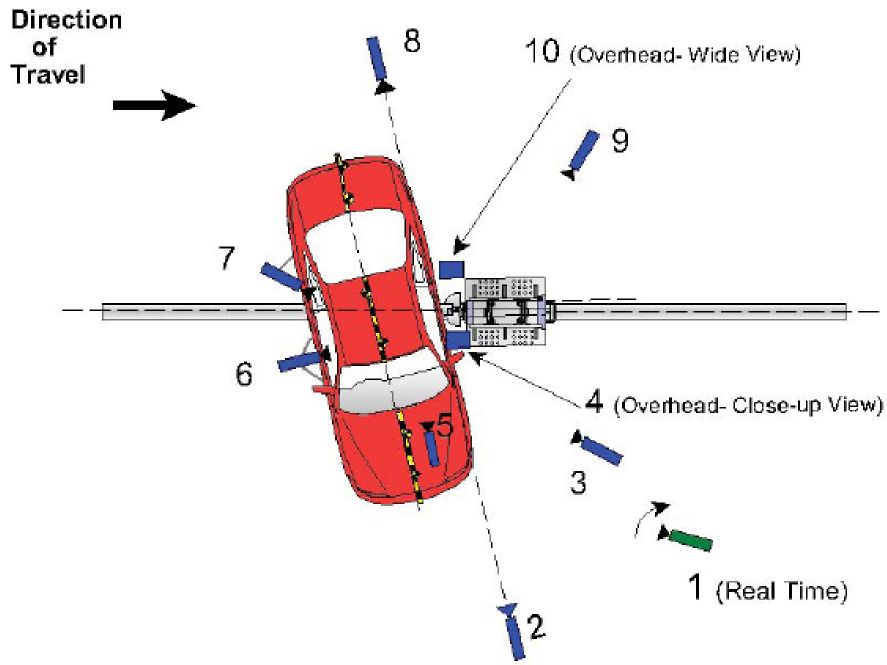

Figure 64: Complete test set up for NCAP side pole test[73]

The 2011 Honda Accord sedan was impacted in the side by a rigid pole on September 29, 2010.[74] The crash was conducted by MGA Research for Honda with the Honda Accord moving at an initial speed of 32.2 kph into the pole. A 5th percentile female ATD was positioned in the left front seat. In subsequent analysis, the Honda Accord was awarded a 5 "star" safety rating for this side NCAP test into a rigid pole.[75]

For the pole test, Figure 65 shows the velocity versus time of the middle B-pillar on the struck side. Vehicle crush measurements were recorded following the diagram in Figure 66. Following the diagram, the crush sustained by the baseline Honda Accord is given in Figure 67. Just as in the moving barrier NCAP test, the levels are (1) sill top, (2) occupant H-point, (3) mid-door, (4) window sill, and (5) window top.

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[73]MGA Research Corporation, *New Car Assessment Program (NCAP) Side Impact Pole Test 2011 Honda Accord LX Sedan*, Report No. SPNCAP-MGA-2011-026, 5000 Warren Road, Burlington, WI 53105, October 28, 2010.
[74]MGA Research Corporation, *New Car Assessment Program (NCAP) Side Impact Pole Test 2011 Honda Accord LX Sedan*, Report No. SPNCAP-MGA-2011-026, 5000 Warren Road, Burlington, WI 53105, October 28, 2010.
[75]National Highway Traffic Safety Administration Web Site, "5-Star Safety Rating," http://www.safercar.gov/.

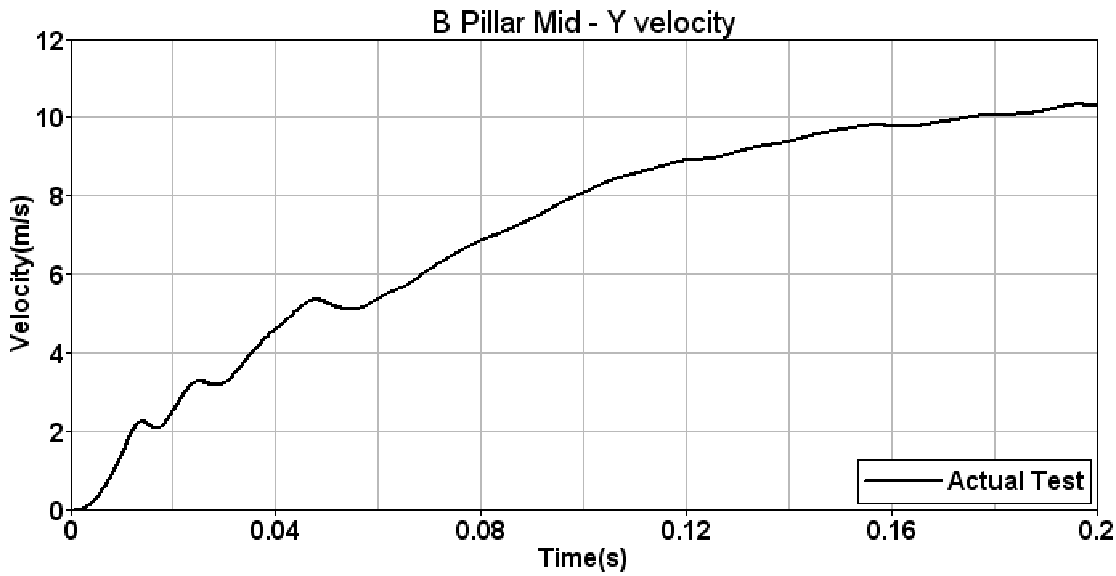

Figure 65: Velocity versus time for the left middle B-pillar for the side NCAP test with the rigid pole[76]

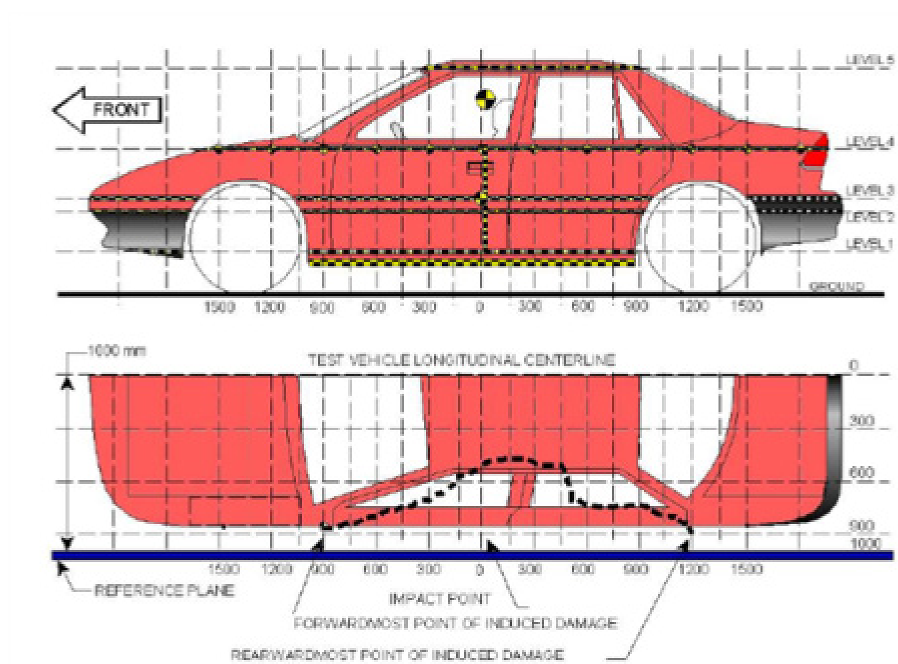

Figure 66: Diagram used for recording crush in side impact with rigid pole[77]

[76]MGA Research Corporation, *New Car Assessment Program (NCAP) Side Impact Pole Test 2011 Honda Accord LX Sedan*, Report No. SPNCAP-MGA-2011-026, 5000 Warren Road, Burlington, WI 53105, October 28, 2010.
[77]MGA Research Corporation, *New Car Assessment Program (NCAP) Side Impact Pole Test 2011 Honda Accord LX Sedan*, Report No. SPNCAP-MGA-2011-026, 5000 Warren Road, Burlington, WI 53105, October 28, 2010.

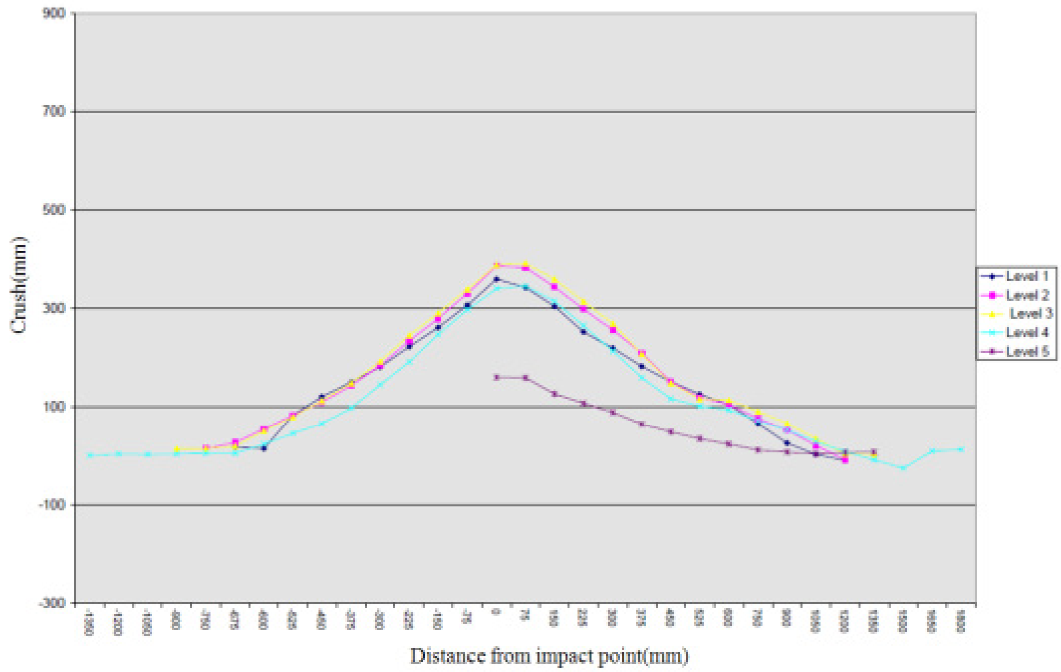

Figure 67: Measurements of crush of Honda Accord 2011 in NCAP rigid pole side test[78]

4.8.5 IIHS Roof Crush Test

The IIHS pushes a metal plate against one side of a roof at a constant speed. (IIHS, 2011) The test set up is shown in Figure 68. To receive a “good” IIHS rating, the roof must withstand a force of 4 times the vehicle's weight before reaching 5 inches of crush. This is called a strength-to-weight ratio (SWR). As shown in the IIHS data comparison in Figure 69, the minimum required strength-to-weight ratio for “acceptable” is 3.25. A “marginal” rating value is 2.5.[79]

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[78]MGA Research Corporation, *New Car Assessment Program (NCAP) Side Impact Pole Test 2011 Honda Accord LX Sedan*, Report No. SPNCAP-MGA-2011-026, 5000 Warren Road, Burlington, WI 53105, October 28, 2010.
[79]Insurance Institute for Highway Safety, *Procedures for Rating Roof Crush*, 1005 N. Glebe Road, Arlington, VA 22201, 2011.

Figure 68: Test set up for IIHS roof crush test[80]

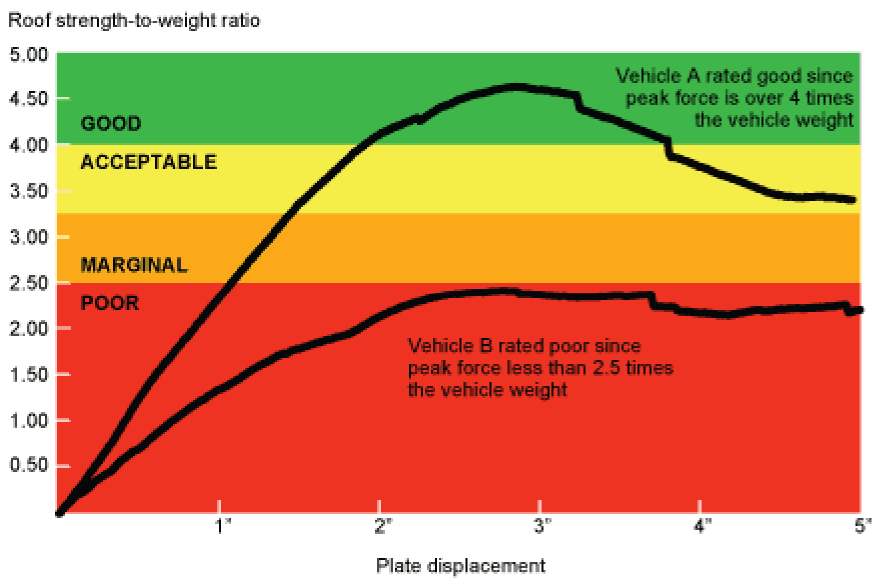

Figure 69: IIHS Sample data comparing test results for vehicles rated "good" and "poor"[81]

For the IIHS roof crush test on October 21, 2009, IIHS researchers struck a 2009 Honda Accord with a curb weight of 3,273 lbs. quasi-statically with a platen. The peak force measured within 5 in. of crush was 12,656-lb (IIHS, 2009). The strength-to-weight ratio was 3.87. The metric for the LWV in this project is to reach a SWR equal to or higher than the SWR of 3.75 reached by the Honda Accord in the IIHS roof crush test. The plot of force versus crush of the platen is

[80]Insurance Institute for Highway Safety, *Procedures for Rating Roof Crush*, 1005 N. Glebe Road, Arlington, VA 22201, 2011.
[81]Insurance Institute for Highway Safety, *Procedures for Rating Roof Crush*, 1005 N. Glebe Road, Arlington, VA 22201, 2011.

presented in Figure 70. The Honda Accord was rated "acceptable" in the roof crush test. The IIHS rating diagram is shown in Figure 71.[82]

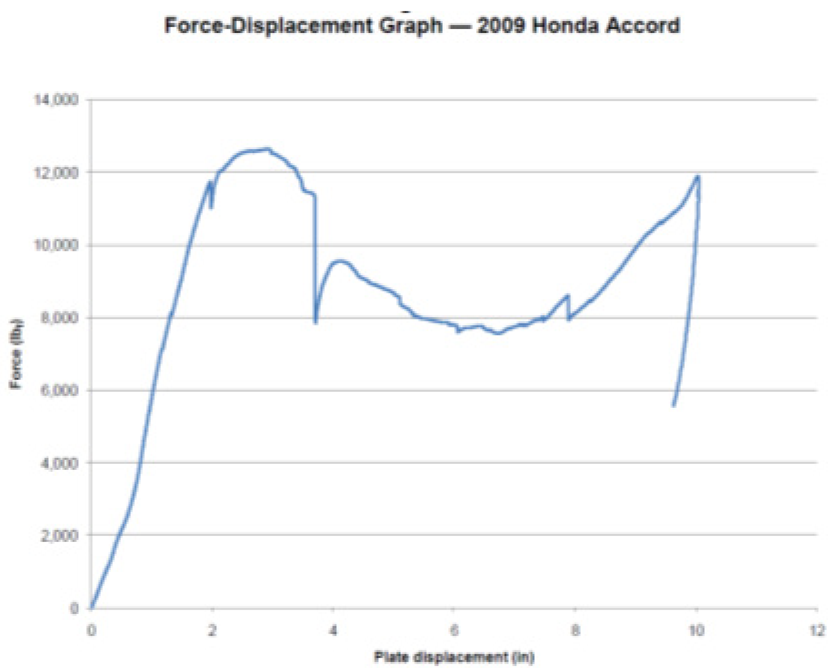

Figure 70: Force versus crush of the platen for Honda Accord 2009[83]

Figure 71: Honda Accord was rated "acceptable" in the IIHS roof crush test[84]

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[82]Insurance Institute for Highway Safety, *Roof Strength Report 2009 Honda Accord*, Report No. SWR0936, 1005 N. Glebe Road, Arlington, VA 22201, date of crash test October 21, 2009.

[83]Insurance Institute for Highway Safety, *Roof Strength Report 2009 Honda Accord*, Report No. SWR0936, 1005 N. Glebe Road, Arlington, VA 22201, date of crash test October 21, 2009.

[84]Insurance Institute for Highway Safety, *Roof Strength Report 2009 Honda Accord*, Report No. SWR0936, 1005 N. Glebe Road, Arlington, VA 22201, date of crash test October 21, 2009.

4.8.6 IIHS Lateral Moving Deformable Barrier Test

The IIHS side impact crash tests consist of a stationary test vehicle struck on the driver's side by a trolley fitted with an IIHS deformable barrier element. (IIHS, 2008) The 1,500 kg moving deformable barrier (MDB) has an impact velocity of 50 km/h (31.1 mi/h) and strikes the 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 dependent 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 closest edge of the deformable barrier when it first contacts the vehicle (Figure 72). The moving deformable barrier is found in Figure 73.[85]

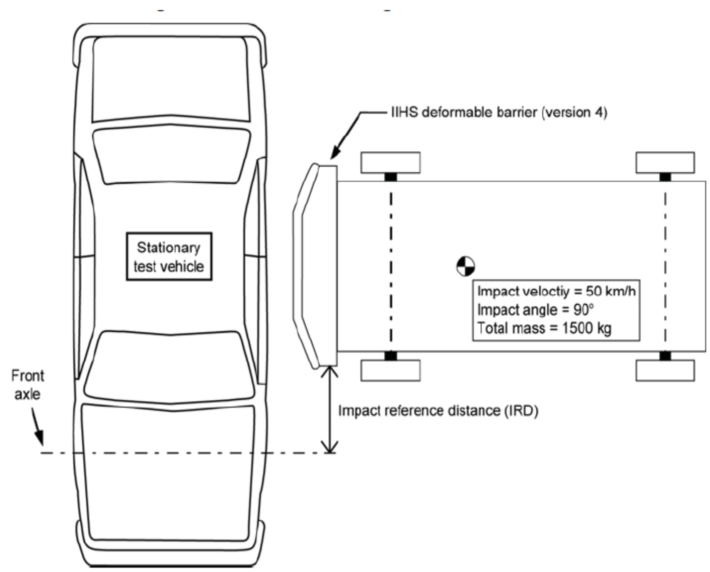

Figure 72: IIHS moving deformable barrier aligned with vehicle to be tested[86]

[85]Insurance Institute for Highway Safety, *Side Impact Crashworthiness Evaluation: Crash Test Protocol (Version V)*, 1005 N. Glebe Road, Arlington, VA 22201, May 2008.
[86]Insurance Institute for Highway Safety, *Side Impact Crashworthiness Evaluation: Crash Test Protocol (Version V)*, 1005 N. Glebe Road, Arlington, VA 22201, May 2008.

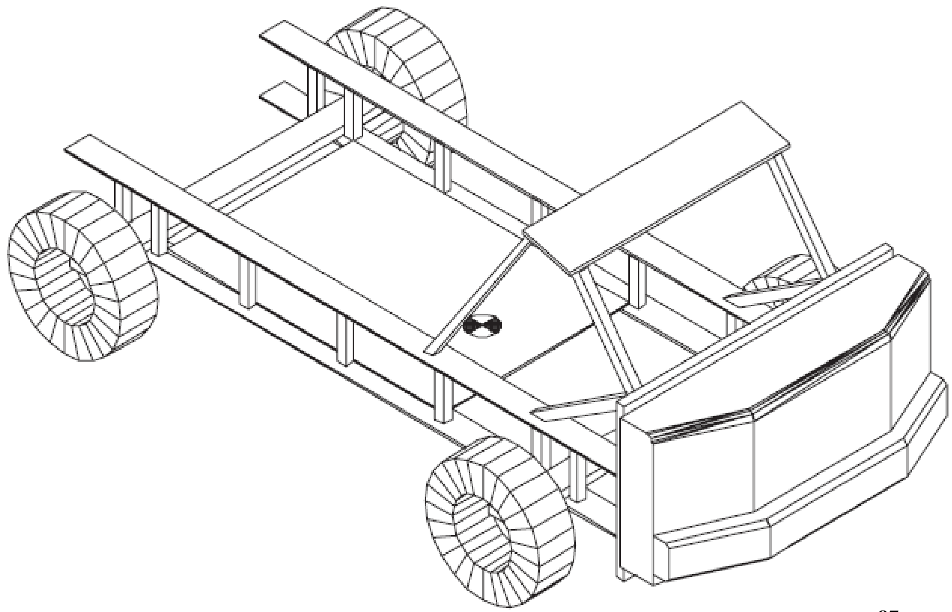

Figure 73: IIHS deformable barrier used in side impact test[87]

A lateral IIHS moving deformable barrier test was performed into the side of a 2008 Honda Accord by IIHS on September 27, 2007.[88]The metrics to be met or exceeded by the LWV are (1) equivalent or less severe B-pillar intrusion at mid-door level and (2) equivalent or less severe crush at the mid-door level at the transverse lines for the driver H-point, B-pillar, and rear-dummy H-point. These metrics are the intrusion attributes used by IIHS for rating their crash test.[89] The B-pillar intrusion profile is documented in Figure 74. A crush profile at the mid-door level is documented in Figure 75**.** The Honda Accord was rated "good" in the IIHS side impact test safety rating. The IIHS side impact rating diagram is shown in Figure 76 for the Honda Accord 2008.

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[87]Insurance Institute for Highway Safety, *Side Impact Crashworthiness Evaluation: Crash Test Protocol (Version V)*, 1005 N. Glebe Road, Arlington, VA 22201, May 2008.
[88]Insurance Institute for Highway Safety, *Side Impact Crashworthiness Evaluation Crash Test Report 2008 Honda Accord*, Report No. CES0735, 1005 N. Glebe Road, Arlington, VA 22201, crash test date September 27, 2007.
[89]Insurance Institute for Highway Safety, *Side Impact Crashworthiness Evaluation Crash Test Report 2008 Honda Accord*, Report No. CES0735, 1005 N. Glebe Road, Arlington, VA 22201, crash test date September 27, 2007.

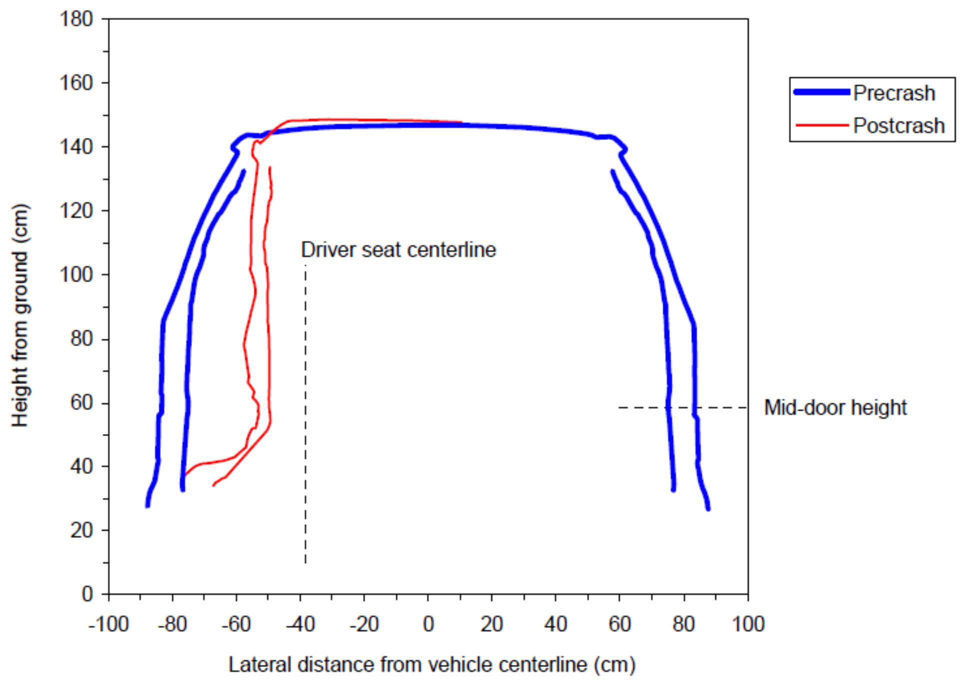

Figure 74: B-pillar exterior and interior profile for 2008 Honda Accord[90]

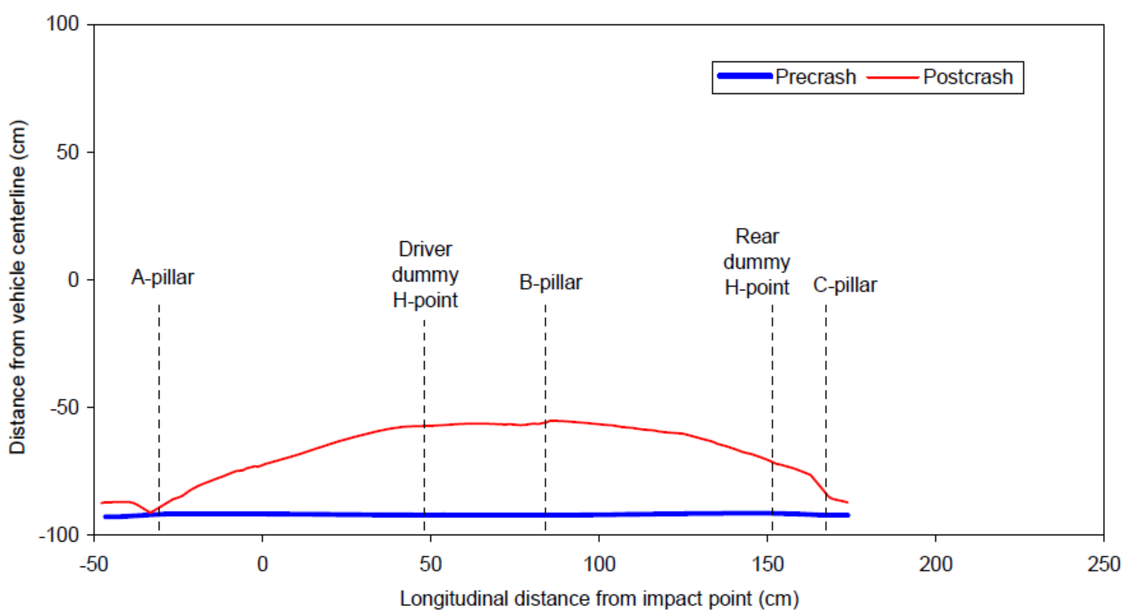

Figure 75: Crush profile at mid-door level for 2008 Honda Accord[91]

[90]Insurance Institute for Highway Safety, *Side Impact Crashworthiness Evaluation Crash Test Report 2008 Honda Accord*, Report No. CES0735, 1005 N. Glebe Road, Arlington, VA 22201, crash test date September 27, 2007.
[91]Insurance Institute for Highway Safety, *Side Impact Crashworthiness Evaluation Crash Test Report 2008 Honda Accord*, Report No. CES0735, 1005 N. Glebe Road, Arlington, VA 22201, crash test date September 27, 2007.

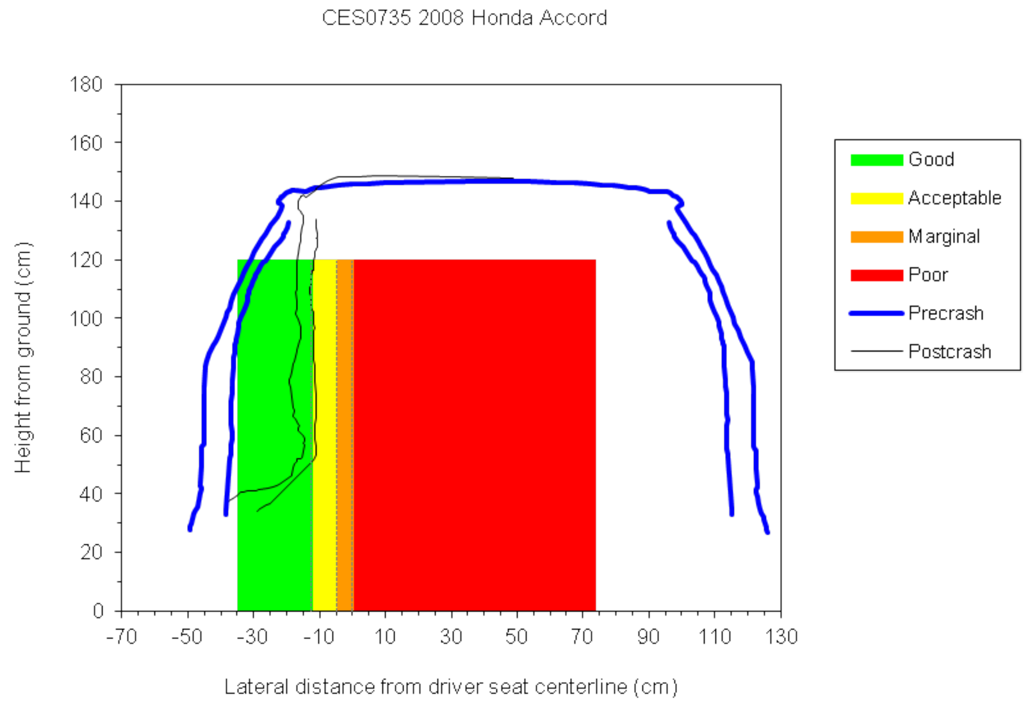

Figure 76: Honda Accord was rated "good" in the IIHS side impact test[92]

4.8.7 IIHS Frontal Offset Test

The IIHS frontal 40% offset test is conducted at 64.4 ± 1 km/h (40 ± 0.6 mi/h) and 40 ± 1 percent overlap. (IIHS, 2008) A 50th percentile male dummy with instrumented lower legs is positioned in the driver seat. IIHS measures a total of 14 locations on the driver side interior and exterior of the vehicle, and their longitudinal, lateral, and vertical coordinates are recorded. These same marks are measured after the crash using the same reference coordinate system.[93] The test set up is shown in Figure 77. The barrier into which the vehicle is crashed is shown in Figure 78.

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[92]Insurance Institute for Highway Safety, *Side Impact Crashworthiness Evaluation Crash Test Report 2008 Honda Accord*, Report No. CES0735, 1005 N. Glebe Road, Arlington, VA 22201, crash test date September 27, 2007.
[93]Insurance Institute for Highway Safety, *Frontal Offset Crashworthiness Evaluation: Offset Barrier Crash Test Protocol (Version XIII)*, 1005 N. Glebe Road, Arlington, VA 22201, May 2008.

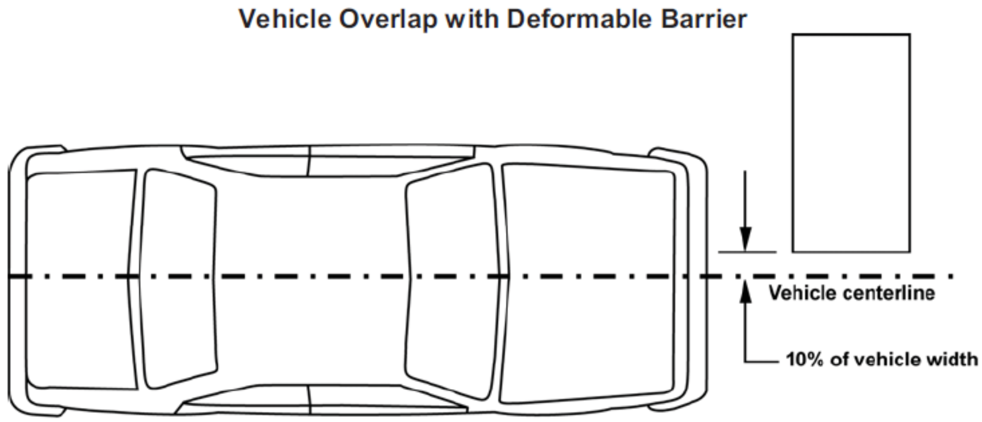

Figure 77: Set up of the IIHS frontal 40% offset barrier test[94]

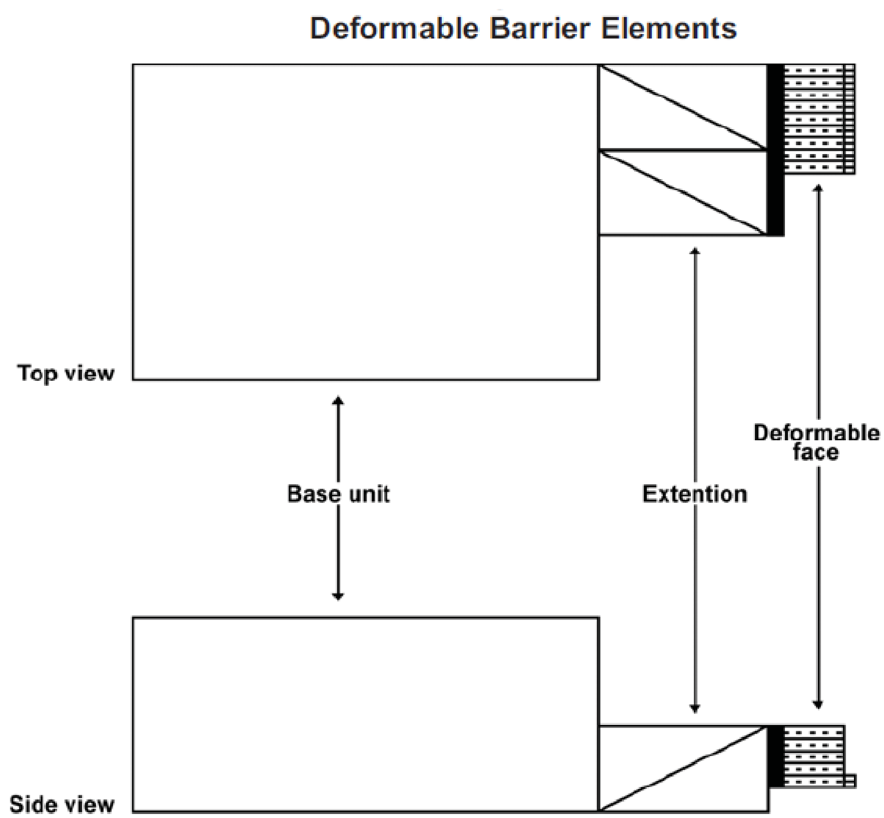

Figure 78: Deformable barrier used in IIHS frontal 40% offset barrier test[95]

[94]Insurance Institute for Highway Safety, *Frontal Offset Crashworthiness Evaluation: Offset Barrier Crash Test Protocol (Version XIII)*, 1005 N. Glebe Road, Arlington, VA 22201, May 2008.
[95]Insurance Institute for Highway Safety, *Frontal Offset Crashworthiness Evaluation: Offset Barrier Crash Test Protocol (Version XIII)*, 1005 N. Glebe Road, Arlington, VA 22201, May 2008.

For the IIHS frontal test, the LWV is required to have (1) a crash pulse equivalent to or less severe (lower peak deceleration) than the Honda Accord tested by IIHS in time width and peak magnitude, and (2) occupant compartment intrusion equivalent to or less than the Honda Accord tested. The most recent Honda Accord tested by IIHS was the year 2003 model. The model year 2003 model was the design before the model year 2011 Honda Accord. For crash comparison, the 2003 Honda Accord cannot be matched up to the 2011 Honda Accord because the safety design is different.

For purposes of this project, given that the prior version of the Honda Accord tested by IIHS had characteristics that made it not particularly comparable], the Electricore Team searched the IIHS database and identified that IIHS tested the 2010 Honda Crosstour. The front structure of the 2010 Honda Crosstour and the 2011 Honda Accord are the same design and build. Therefore, the crash behaviour of the 2010 Honda Crosstour and the 2011 Honda Accord should be the same in a frontal crash. The Honda Crosstour was tested on April 14, 2010.[96] The crash pulse of the 2010 Honda Crosstour is shown in Figure 79. As shown in Figure 80 for occupant compartment intrusion, the Honda Crosstour was rated "good" in the IIHS frontal offset test safety rating.

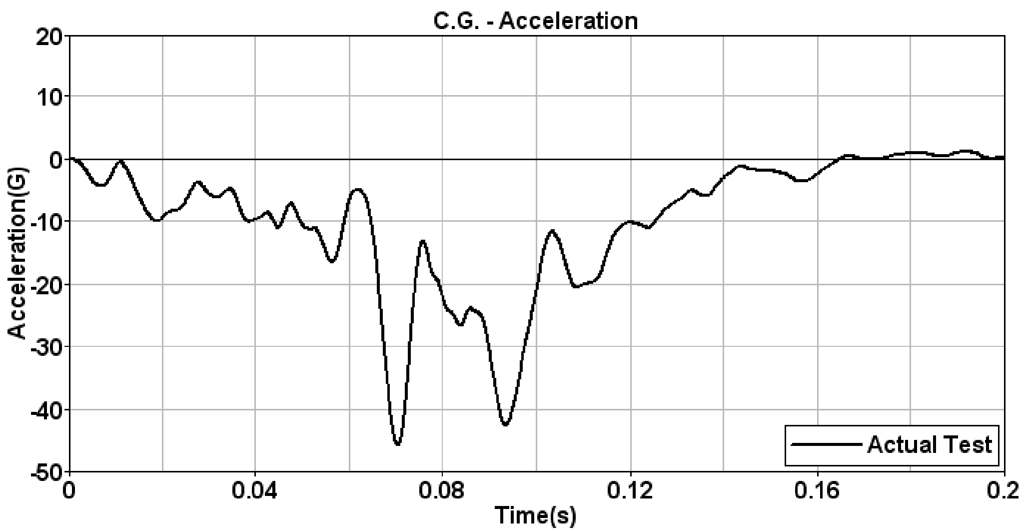

Figure 79: 2010 Honda Crosstour crash pulse in IIHS frontal offset test[97]

[96]Insurance Institute for Highway Safety, *Frontal Crashworthiness Evaluation Crash Test Report 2010 Honda Crosstour*, Report No. CEF1003, 1005 N. Glebe Road, Arlington, VA 22201, crash test date April 14, 2010.
[97]Insurance Institute for Highway Safety, *Frontal Crashworthiness Evaluation Crash Test Report 2010 Honda Crosstour*, Report No. CEF1003, 1005 N. Glebe Road, Arlington, VA 22201, crash test date April 14, 2010.

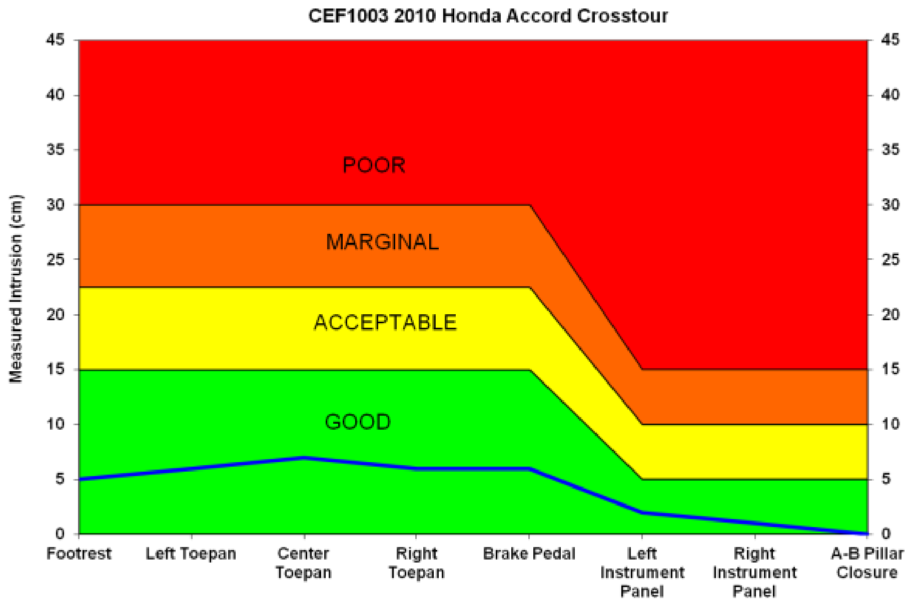

Figure 80: Honda Crosstour was rated "good" in the IIHS frontal offset test[98]

4.8.8 Summary of Baseline Honda Accord Crash Test

Figure 81 summarizes the dynamic and static (crush and intrusion) crash test results of the MY 2011 Honda Accord. In assessing the relative safety performance of the LWV with the baseline Honda Accord, the safety elements in the table will be employed.

Structural Response of the Honda Accord 2011		
Test	**Dynamic**	**Static**
NCAP frontal	Peak acceleration and the pulse time width in Figure 55	Driver compartment intrusion in Figure 57
NCAP side with moving deformable barrier	Meaningful comparison not possible as instruments on B-pillar were damaged or rotated excessively in actual laboratory test	Vehicle crush in Figure 62
NCAP pole	Velocity versus time for B-pillar in Figure 65	Vehicle crush in Figure 67
IIHS roof crush	Strictly a static test and not a dynamic examination	Roof crush in Figure 71
IIHS side with moving deformable barrier	No dynamic instrumentation on A- or B-pillar	Occupant compartment intrusion in Figure 76
IIHS 40% offset frontal	Acceleration and the pulse time width in Figure 79	Occupant compartment intrusion in Figure 80

Figure 81: Structural Response of the Honda Accord 2011

[98]Insurance Institute for Highway Safety, *Frontal Crashworthiness Evaluation Crash Test Report 2010 Honda Crosstour*, Report No. CEF1003, 1005 N. Glebe Road, Arlington, VA 22201, crash test date April 14, 2010.

Not all crashes fall into the specific laboratory tests performed by NCAP and IIHS. An NCAP document notes that a 5 "star" vehicle has an injury risk much less than average. However, the goal of NCAP is to continuously improve the crashworthiness of vehicles.[99] The IIHS and others have identified crash types other than those done by NCAP and IIHS as having a high risk of injury.[100,101,102] Herein, the evaluation of equivalent safety rating was based on the NCAP and IIHS tests and not on all dangerous situations.

4.9 Other Considerations

4.9.1 Serviceability and Repair-ability

All OEMs have documented guidelines for serviceability design in one form or another. The guidelines address the issue of corrective and preventive maintenance, and problem diagnostic capabilities. Design for Serviceability (DFS) takes into account part accessibility and repair costs; which include assessment of labour, parts and repair times. This type of detailed analysis is outside the scope of this program, given that it requires extensive amount of detailed design. The impact of such studies on the mass of the vehicle would be very limited. For the LWV the serviceability and reparability was given due care engineering consideration during the design stage of all proposed solutions. Repair-ability is further discussed in Section 5.6.6

4.9.2 Durability

Vehicle durability refers to the long-term performance of a vehicle under repetitive loading due to driving and other operating conditions. There are many aspects of durability. The two major aspects include stress and fatigue related durability and durability for vehicle to resist corrosion due to weather, salt spray, etc. To address corrosion, OEMs generally conducts series of environmental testing with identified durations. It is very important to consider the location of the components and the environment where the components operate when selecting material usage for various components. The choice of materials and their protective coatings, for the LWV takes into account similar corrosion protection considerations as the baseline vehicle. For example the LWV body structure is designed to go through similar corrosion protection and paint operation as the baseline vehicle. Typical process steps are shown in Figure 82.

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[99]U.S. Department of Transportation, National Highway Traffic Safety Administration, "Frequently Asked Questions 5-Star Safety Rating," http://www.safercar.gov/staticfiles/toolkit/pdfs/faq.pdf.
[100]Insurance Institute for Highway Safety, *Status Report*, Vol. 44, No. 2, March 7, 2009.
[101]Rudd, R., Scarboro, M., Saunders, J., "Injury Analysis of Real-World Small Overlap and Oblique Frontal Crashes," Paper No. 11-0384, Enhanced Safety Vehicle Conference, Washington, DC, June 2011.
[102] Scullion, P., Morgan, R.M., Digges, K., and Kan, C-D, "Frontal Crashes Between the Longitudinal Rails," Paper No. 11-0372, Enhanced Safety Vehicle Conference, Washington, DC, June 2011.

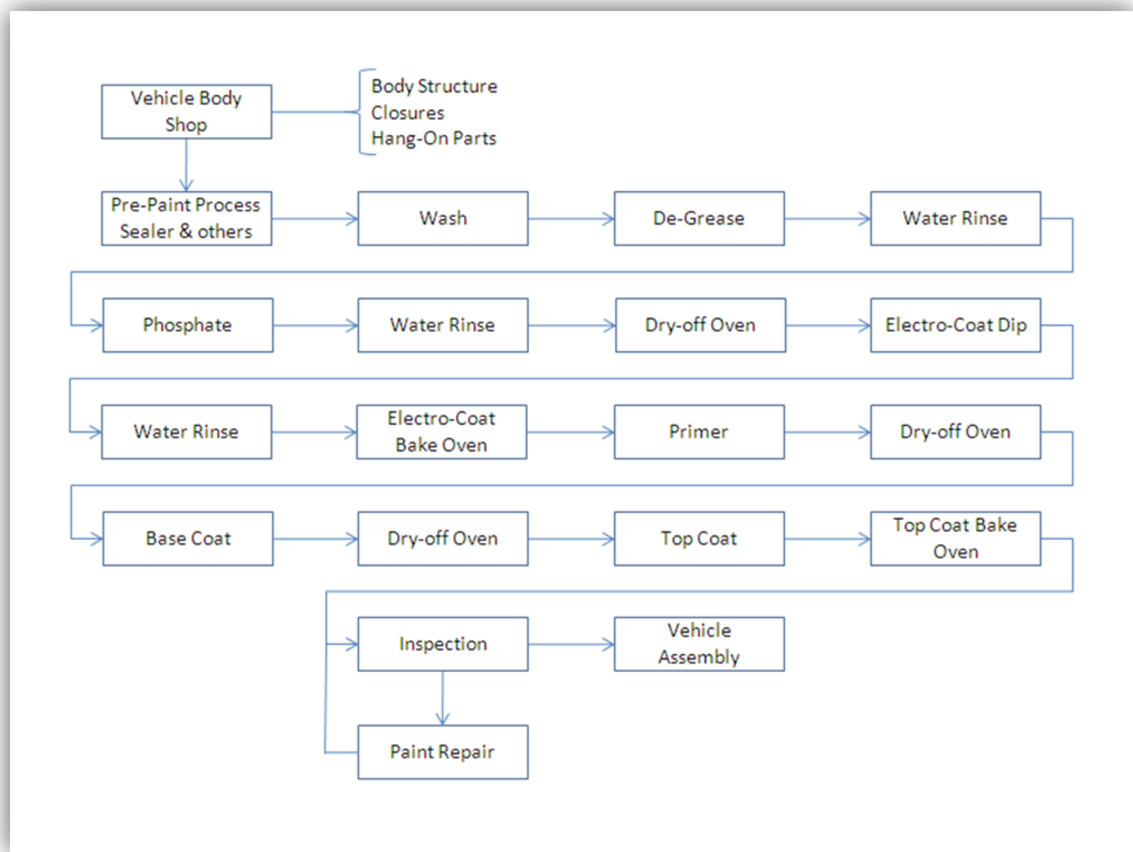

Figure 82: Corrosion protection and paint process steps

As for the stress aspect of durability, in normal operating conditions, tires and suspensions experience road loads that cascade throughout the vehicle body. The transfer and distribution of loads varies with the structural, inertial, 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. The 2011 Honda Accord body structure has been in production since 2008. To the knowledge of the Electricore Team there has been no issues reported relating to the Accord structure. Full assessment of the durability of the LWV is outside the scope of this program as this normally requires 'Road Load' test data derived from instrumented prototype vehicles. The proposed LWV was assessed for basic durability load cases generated from an Automatic Dynamic Analysis of Mechanical Systems (ADAMS) [103] ride and handling mathematical model. ADAMS multi-body dynamics software is an analysis tool engineers use 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.

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[103] http://www.mscsoftware.com/Products/CAE-Tools/Adams.aspx

The LWV durability was analyzed for the following road load cases:

1. Pot hole (Vertical loads transmitted from the suspension)
2. 0.7 G Cornering (Lateral loads transmitted from the suspension)
3. 0.8G forward braking cases (Fore and aft loading during braking)

For these load cases the LWV durability life cycle targets are based on 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) pot-hole every 20 miles, one very hard cornering event every two miles and one emergency braking event every two miles.

1. Pot hole (10,000 cycles)
2. 0.7 G Cornering (100,000 cycles)
3. 0.8G forward braking cases (100,000 cycles)

The durability analysis results are shown in Section 5.5 of this report.

4.9.3 Drivability, Ride & Handling

The targets for drivability are not based on any benchmark vehicle measurements. The LWV was assessed using an ADAMS mathematical simulation model. The model was used to confirm the suspension characteristics. The ride and handling tests which were analyzed for the LWV are as follows:

1. Fish-hook Test
2. Double Lane Change Maneuver (ISO 38881)

The ‘Fishhook Test’ was used in conjunction with the Static Stability Factor (SSF) to rate the propensity for vehicle rollover.

Further description and results of these tests is shown in Section 5.4 of this report.

5 LWV Design Approach

5.1 Key Assumptions

As discussed above, NHTSA, as part of its work on fuel economy standards for MYs 2017-2025, released a project solicitation (DTNH22-10-R-00429) with the goal "*to design a lightweight vehicle that can, at minimum, meet the performance functions (as defined below) of the original baseline vehicle while controlling for both direct and in-direct cost to maintain affordability*". 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 (RPE) [104] markup) with the baseline vehicle with ±10% variation[105]

- The design shall maintain vehicle size and performance functionalities compared to the baseline vehicle, including:
  - Safety
  - Noise, vibration and harshness (NVH)
  - Towing
  - Acceleration
  - Manufacturability
  - Aesthetics
  - Ergonomics
  - Durability
  - Serviceability

- Using crash simulations, the target vehicle model shall
  - Demonstrate structural performance in NHTSA's New Car Assessment Program (NCAP) frontal, side, and side pole test programs equivalent to or better than the baseline vehicle.
  - Demonstrate compliance with FMVSS No. 216 "Roof crush resistance."
  - Obtain at least equivalent ratings to the baseline vehicle in the each of the structural or intrusion ratings of the IIHS offset and side impact tests

- The design shall use material and manufacturing processes that will likely be available in the model years 2017-2025 time frame, with a target model year of 2020.

- The design shall be commercially feasible for high volume production (around 200,000 units per year) by the target model year at 2020. If the contractor considered mass reduction technologies that are not in mass production now or not mature yet, those technologies have to be mature enough for mass production judged by technical experts in the fields of those technologies. Risk must be identified with these technologies.

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[104] 1.47 used for this study; Source: Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers" EPA report EPA-420-R-09-003, February 2009

[105] 10% of the baseline MSRP is $2198 based on Honda Accord 4DR-LX Window Sticker shown in Figure 3

- The contractor shall provide an incremental mass and cost difference between the powertrain chosen and the baseline powertrain without a full scaled powertrain study. The powertrain analysis only needs to confirm that the performance of the baseline vehicle is met by LWV.

In addition to these enumerated baseline requirements and assumptions, the Electricore Team and NHTSA made and documented key decisions as the project progressed which impacted the vehicle design, cost, and performance. Figure 83 below lists these assumptions.

Component	Decision	Comment
Fuel Tank Driving Range	The fuel tank size is reduced to maintain 500 mile driving range, same as the baseline Accord.	Driving range is maintained because it is a key consumer requirement
Maximum Vehicle Speed	The maximum vehicle speed is reduced from 127 mph to 112 mph because the engine is downsized from 2.4L to 1.8L NA engine.	112 mph is well above the speed limit on almost all roads in US. The change in maximum vehicle speed should not be noticed by drivers in normal driving conditions, so no loss of value to the consumer should be assumed for this reduction.
Powertrain	Only examine naturally aspirated four cylinder engine without turbo-charging, similar technology as the baseline vehicle.	Turbo-charged engine, as well as other advanced powertrain technology selection will be incorporated into the rulemaking analysis by NHTSA separately
Transmission	A scaled down version of the 5 Speed ATX, similar to the baseline vehicle will be considered for the LWV	advanced transmission designs will be incorporated into rulemaking analysis by NHTSA
Design components for multi-platforms	Components will be optimized for Accord only, not other platforms	Limited information on other platforms prevents multi-platform designs in this project
Spare Tire	Vehicle will have spare tire and jack	Spare tire is maintained because it is treated as a functional requirement for consumers.
Materials Analysis	No detailed material analysis (No coupon testing) will be performed on baseline vehicle	Team will identify and categorize all components from baseline vehicle (steel, aluminum, plastic, etc.), but project cost and time limitations prevent detailed analysis
Retail Price Equivalent	Use Honda-specific RPE of 1.47 when converting between retail prices and direct manufacturing cost.	See Chapter 9 for cost analysis study

Figure 83: Key Design Assumptions and Decisions

5.2 Introduction

Our approach to meet the program objective of identifying mass saving potential for the baseline vehicle during MYs 2017-2025 is to investigate possible material choices and manufacturing technologies for each vehicle sub-system. The systems with the most mass saving potential, such as the vehicle body structure, closures (doors, hood and trunk-lid), 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 (CAE) optimization techniques. The recommended design for these systems were verified by GWU to meet all the relevant FMVSS crash requirements and achieve comparable crash performance for NCAP and IIHS tests comparing to baseline vehicle using LSDYNA finite element analysis simulations and may 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 on technologies available and mature in the time frame of MY2020 and the components were resized as appropriate to meet the performance goals of the projected vehicle.

The overall LWV project methodology is illustrated in Figure 84 and Figure 85 below.

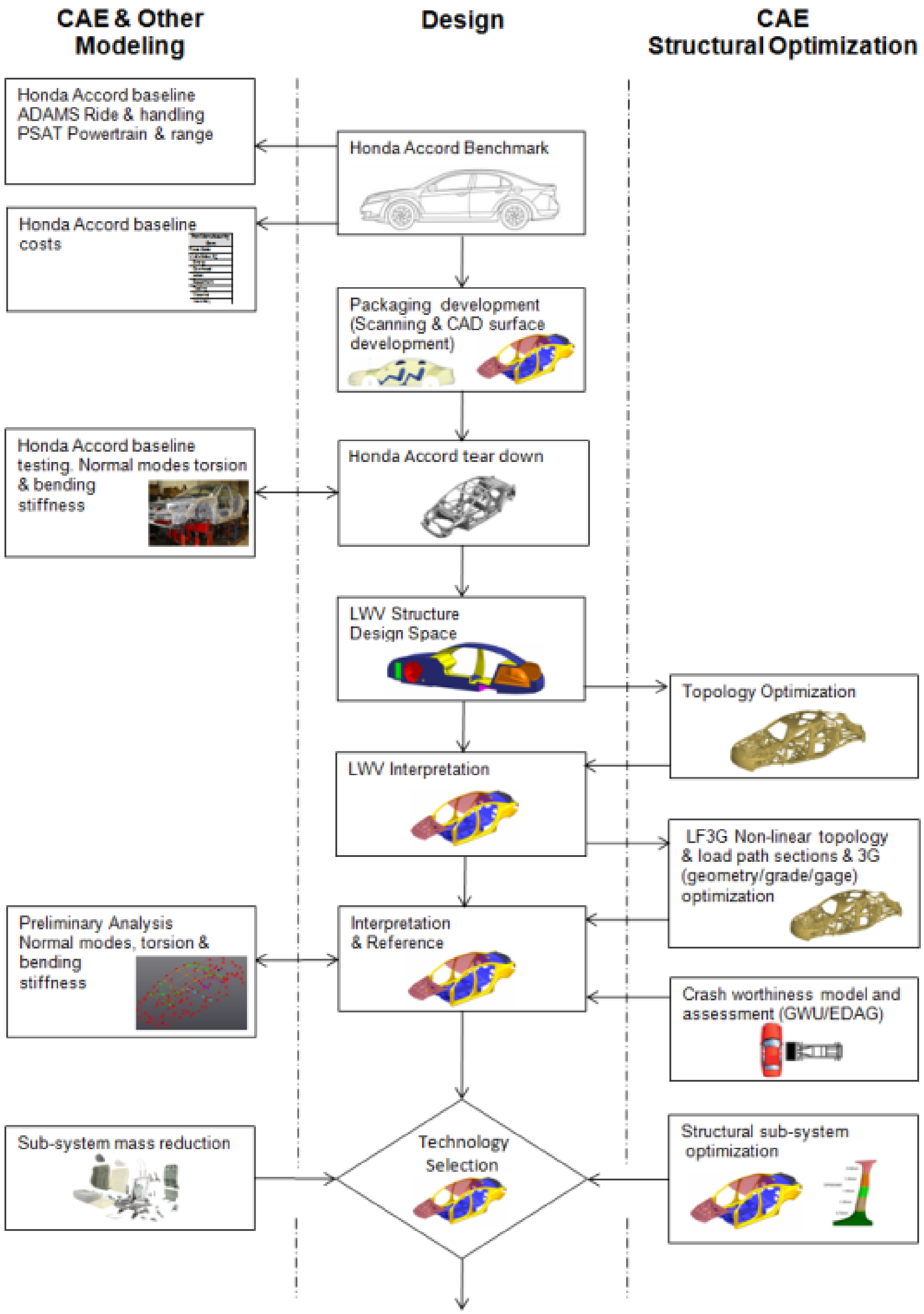


Figure 84: Light Weight Vehicle (LWV) Program Approach

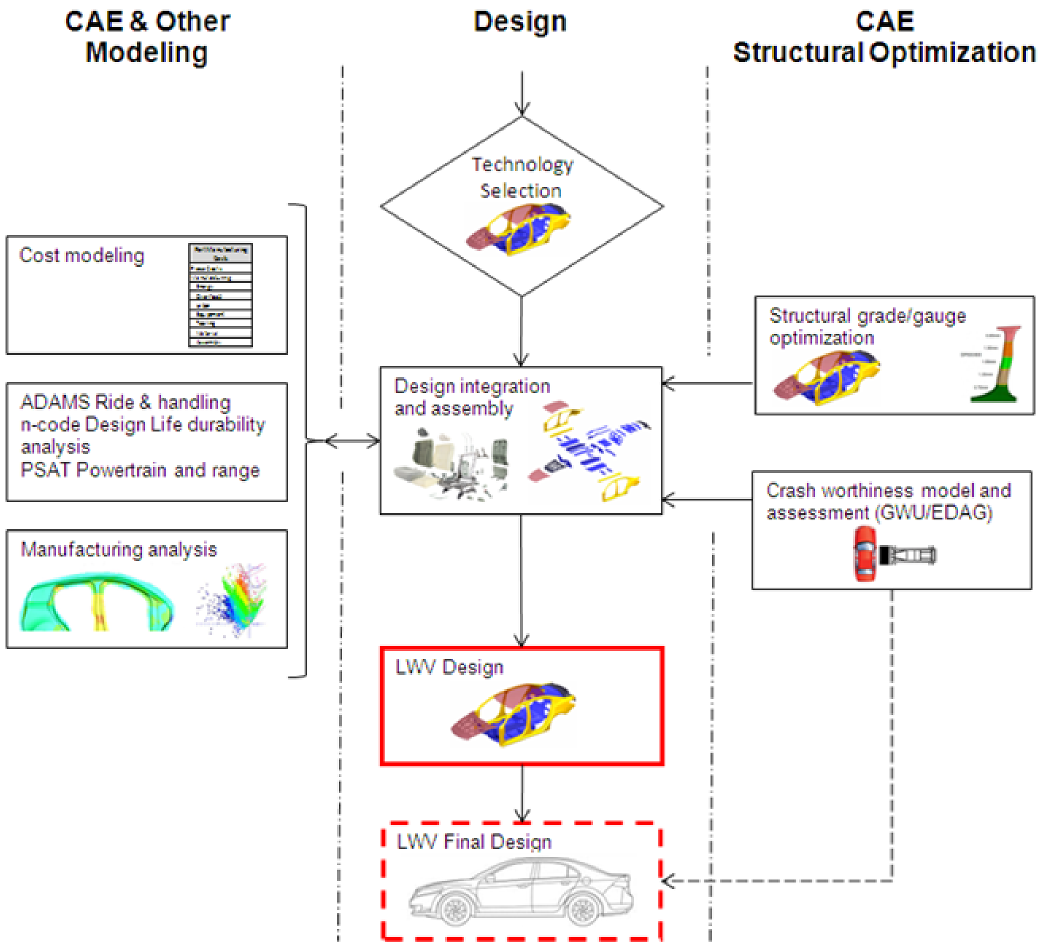
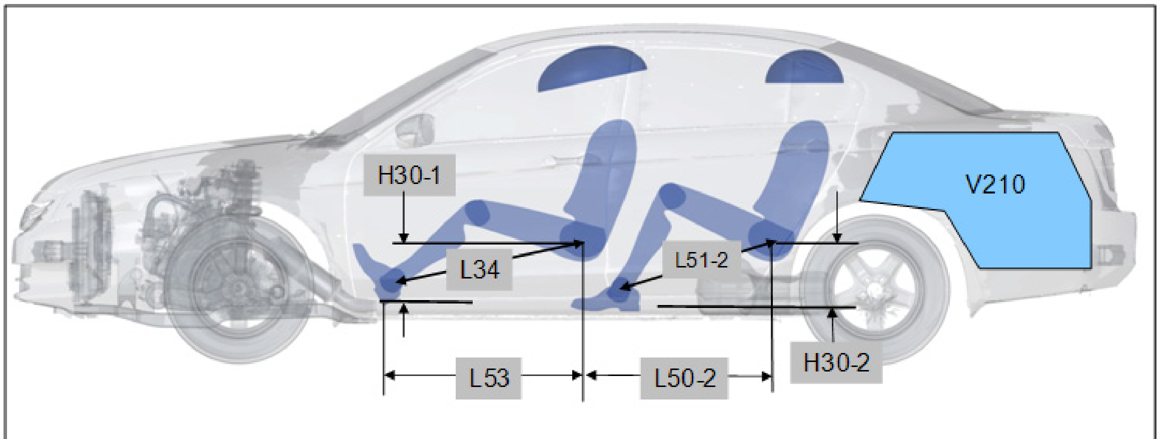


Figure 85: Light Weight Vehicle (LWV) Program Approach (contd.)

5.2.1 Packaging Requirements

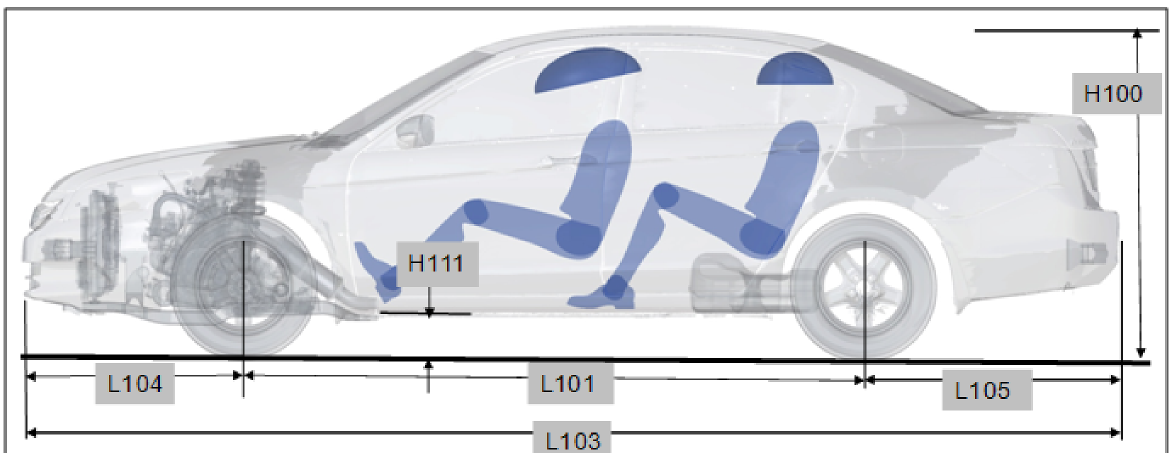
The vehicle packaging space is based on the benchmark Honda Accord vehicle. The laser scanned surfaces of the interior form the bases of the key interior dimensions related to occupant seating positions, H point, leg-room, head clearances to the interior surfaces, and critical vision angles for visibility. This approach is also applied to maintain the same ease of entry and egress from the vehicle and same luggage volume. To achieve the same utility/functionality in terms of driving the vehicle on typical road surfaces the LWV will be designed with same ground clearances as the baseline vehicle. The Honda Accord interior dimensions are shown in Figure 86.



	L34	L53	H30-1	L50-2	L51-2	H30-2	V210
Dimensions MM	1080	945	275	800	825	325	425 L

Figure 86: Honda Accord Interior Dimensions as Measured

The external dimensions of the Honda Accord are shown in Figure 87. The wheelbase and front overhang, and hence the total vehicle length, depend on the choice/size of the powertrain. If the powertrain is assumed to be an internal combustion engine (ICE) based, the front end of the vehicle can be a common design. Due to the fact that LWV 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 smaller front end over-hang while still maintaining similar amount of crush distance as the baseline vehicle.



	H100	H111	L101	L103	L104	L105
Dimensions MM	1476	185	2799	4950	895	1256

Figure 87: Honda Accord Exterior Dimensions

5.2.2 Design Strategy for the Front End

The discussion from the above paragraph about smaller engine block which will free up more packaging space at the front end explains the basis for the team's design for the front end layout. Because the LWV can take a smaller powertrain unit without sacrificing performance, some front end space is freed up that can be utilized for more efficient structural load paths. The additional packaging space allows for front rails with larger stable sections. The larger sections are generally more efficient in managing the loads. In both the baseline vehicle and the LWV, the front rail load path is also complimented with a second load path generally referred to as the "shotgun." The shotgun is a structural member that extends forward from the windshield side A-Pillar section, as shown in Figure 88 below. By extending the shotgun structure further forward with controlled curvature and crush initiators, it can be used to tailor the deceleration pulse, and balance the crush loads during the early part of the crush event. The baseline vehicle structure takes advantage of a similar upper load path (Honda calls this by the trade mark name "ACE,"[106]which stands for Advanced Compatibility Engineering structure), as also shown in Figure 88 below. The ACE front end structure also raises the height of the bumper beam in the central zone to reduce the tendency of the vehicle's bumper to under-ride in collisions with larger vehicles with higher bumper heights. This feature is also enhanced by a built-in upper radiator support member, which feeds the crush loads into the shotgun. The LWV also takes advantage of similar utilization of the upper radiator support member and shotgun as an additional load path shown in Figure 89. To maintain similar crash performance as the baseline Honda Accord, LWV front end design is similar to Honda ACE structure but with larger section front rails.

[106]ACE structure is a unique design used in Honda's vehicles.

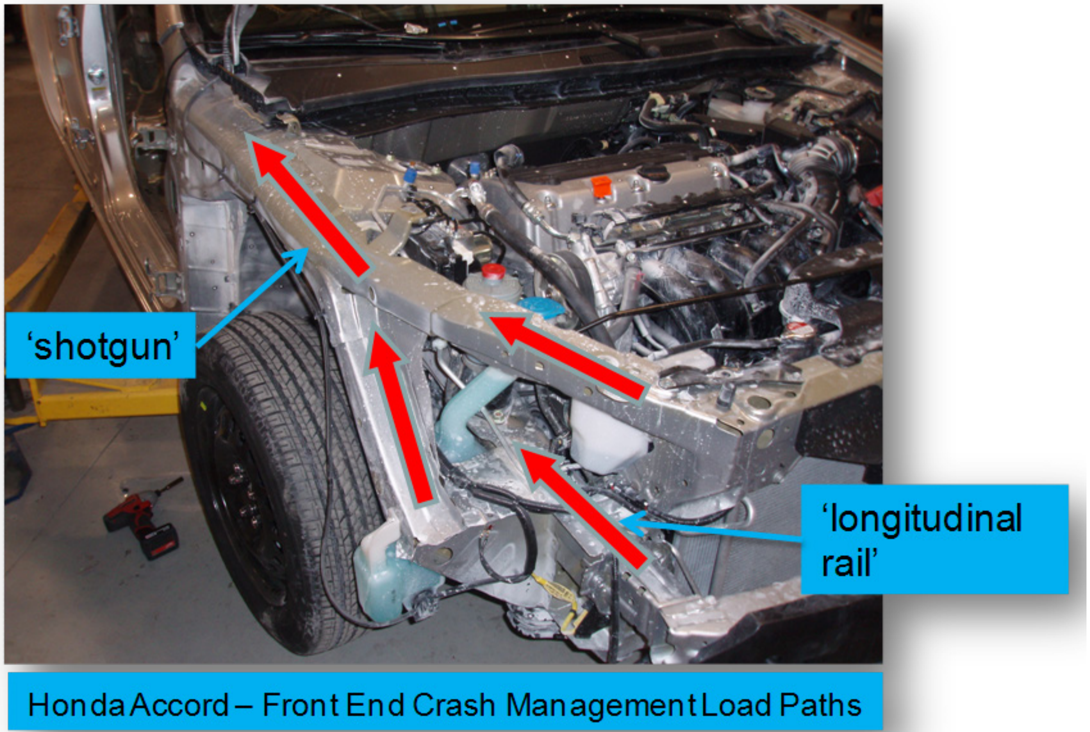


Figure 88: Honda Accord Front Structure

Different from baseline Accord front end design, the front end layout of the LWV makes effective use of the engine cradle as a third load path member that crushes and absorb energy. On the baseline vehicle the engine cradle is designed to withstand a high enough load without crushing to cause the rear engine mount to fail. On the LWV the three described load paths with the integrated radiator support structure work together to manage frontal crash events with minimal intrusions into the passenger compartment. With the combination of the three active load paths (longitudinal rails (2), extended shotgun (3) and engine cradle (4), as shown in Figure 89), the deceleration pulse of the structure can be tailored to achieve a more desirable front end structure during the 0 to 30 millisecond crash time frame and then reduced to a normal level during the 30 to 60 millisecond time frame when the occupant is interacting with the airbag/restraint system. This approach has been shown to be beneficial for the occupants of smaller/lighter vehicles when involved in frontal crashes with larger vehicles[107].

[107] Jeremy J. Blum et al: Vehicle Related Factors that Influence Injury Outcome in Head-On Collisions. 52nd AAAM Annual Conference, Annals of Advances in Automotive Medicine, October 2008

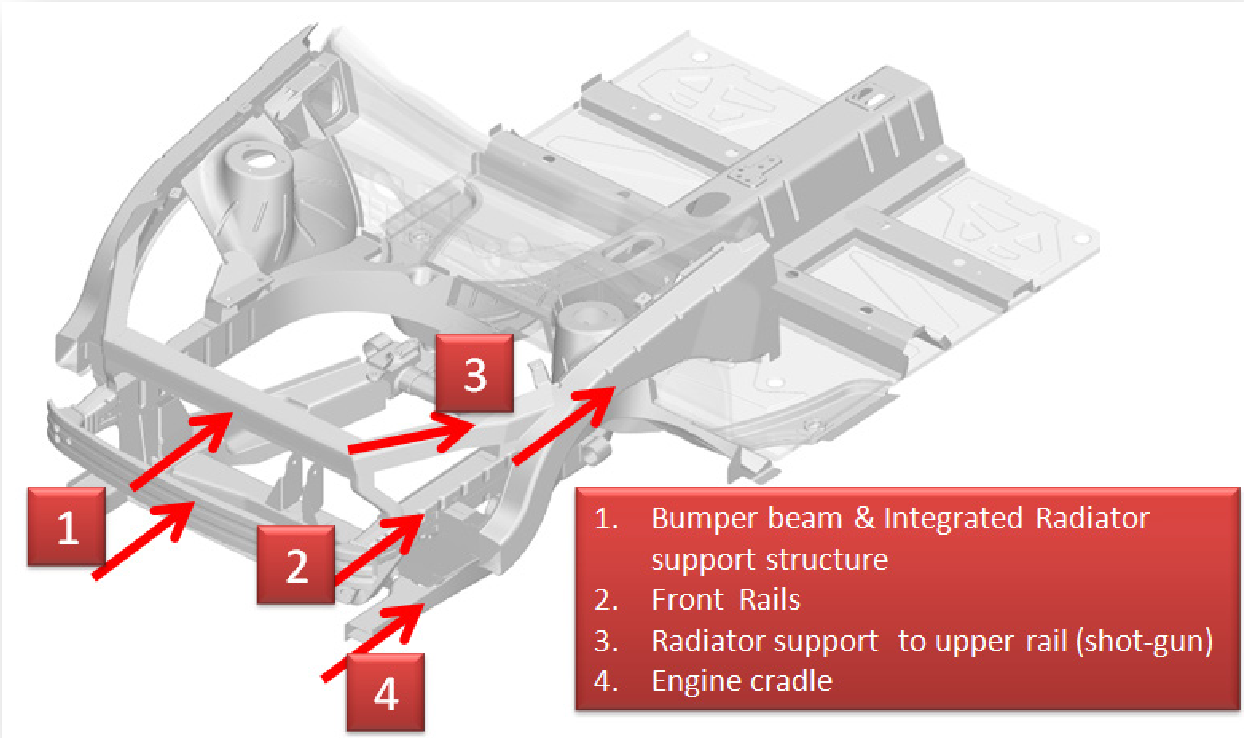


Figure 89: LWV Front Structure Load Paths

5.2.3 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[108], developed by Altair Engineering, Inc. The vehicle package created from the scanned surfaces of the baseline Accord was used as the basis for the LWV Topology Optimization Model shown in Figure 90.

The following load cases were used to identify optimized structural load paths for the LWV:

- Stiffness Bending & Torsion
- Frontal NCAP Full Barrier
- IIHS 40% ODB Front Crash
- IIHS Side
- FMVSS No. 214 (Pole Impact)
- FMVSS No. 301 (Rear Crash)
- FMVSS No. 216 (Roof Crush)

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[108] http://www.altairhyperworks.com/HWTemp3Product.aspx?product_id=19&item_name=Benefits&top_nav_str=1&AspxAutoDetectCookieSupport=1

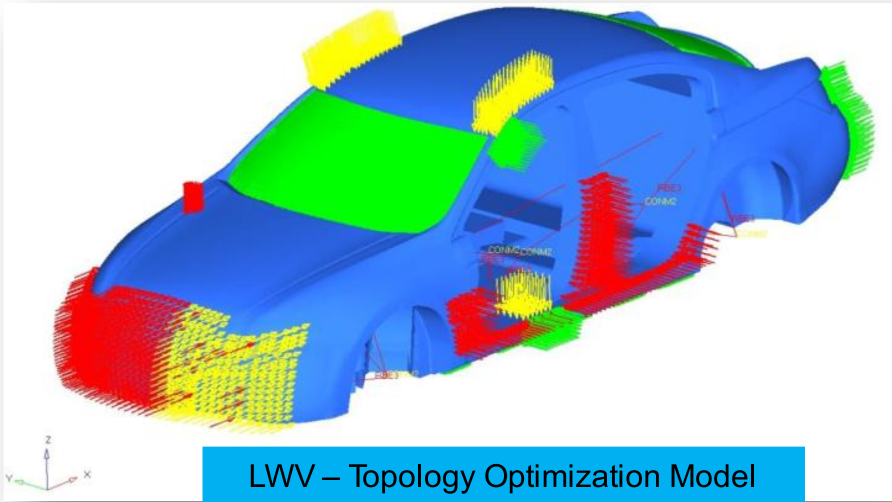

Figure 90: LWV Topology Optimization Model showing load cases

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 “state of the art” 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 manufacture-able design. The results for Topology Optimization using Optistruct for the LWV body structure design are shown in Figure 91. The load paths predicted by Topology Optimization illustrated as ‘pink’ color are superimposed on the final chosen design ‘gray’ color are shown in Figure 91.

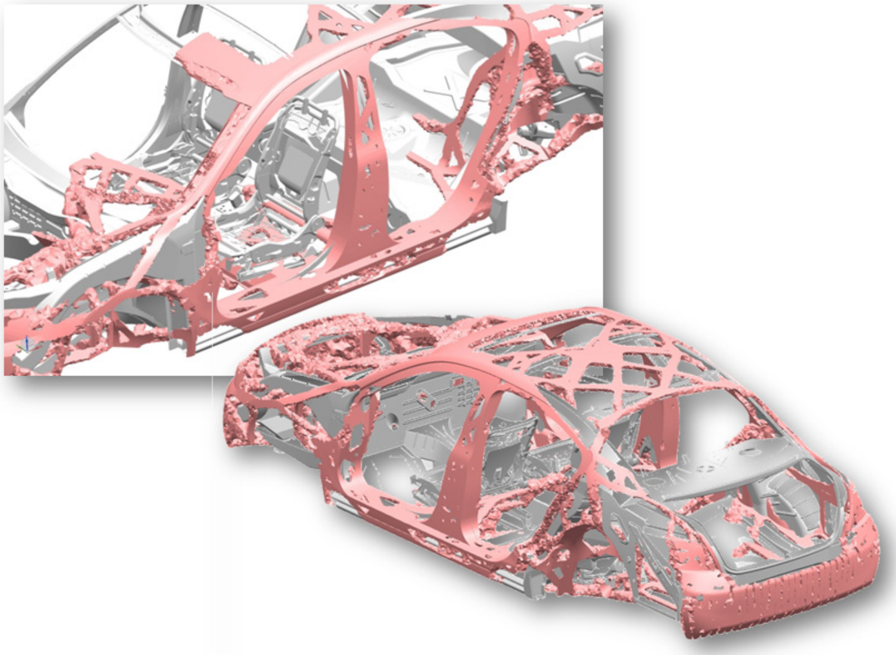

Figure 91: LWV Topology Results

The roof structure of the baseline Honda Accord is designed to accommodate an optional sun-roof. This feature is also allowed for in the LWV design, although it limits the optimal positioning of some structural cross members identified by the Topology Optimization, as shown in Figure 92. Maintaining the option of a sunroof in the LWV thus makes the design somewhat less structurally efficient than it could potentially otherwise be.

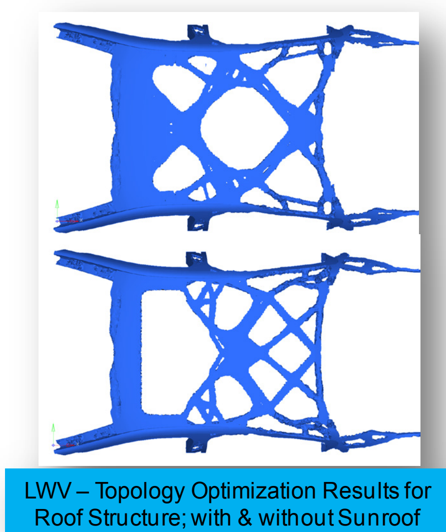

Figure 92: Topology Optimization Results – Roof Structure

Another feature on the baseline vehicle that the team attempted to preserve and that makes the LWV somewhat structurally inefficient is the rear folding seat back with an opening to the trunk-space for stowing larger items. As can be seen in Figure 93, the cross bracing predicted by the Topology Optimization analysis is directly in the way of the required seat back opening. As this is an important feature to increase the utility of the vehicle to carry larger items, the LWV design allows for it.

Figure 93: Topology Optimization Results – Rear Seat Back

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. Figure 94 shows a comparison of Topology Optimization results (in pink) overlaid on the team's interpreted structural design (in gray) of the LWV body structure.

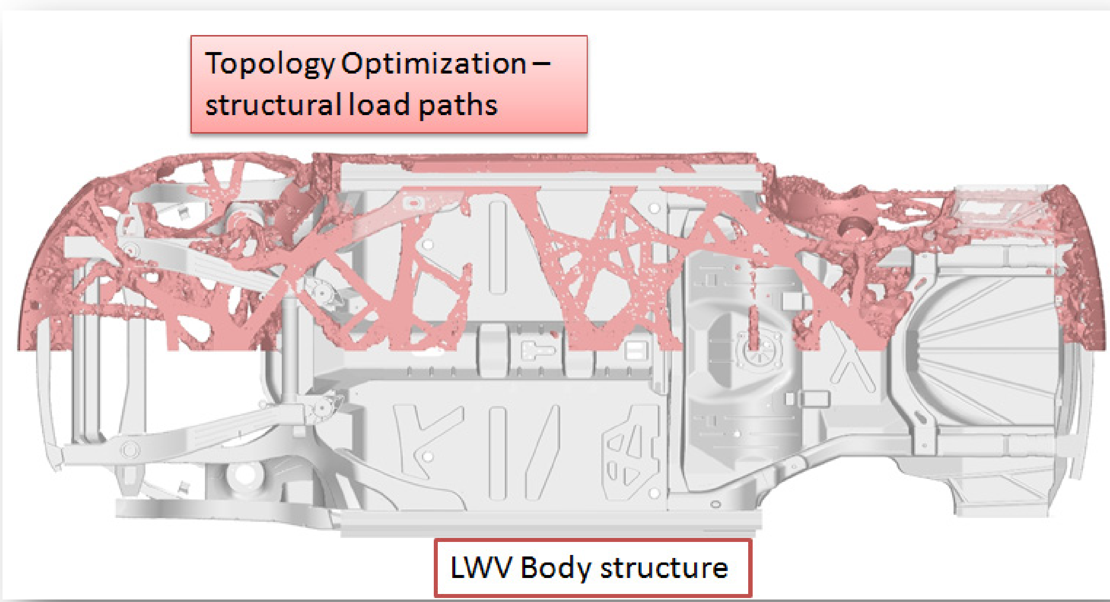

Figure 94: Topology Optimization Results Interpretation

5.2.4 Low Fidelity 3G Optimization (LF3G)

In this step of the Computer Aided Optimization process, the structural parts that form the 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 utilizes the “state of the art” analysis technique applied to a complete vehicle structure. The following computer programs were setup to work in a continuous optimization loop to converge on to most optimal stable mass efficient solution:

- HEEDS (Red Cedar Technologies, Inc.)[109]
- SFE CONCEPT software [110]
- LSDYNA (LSTC, Inc.)

The optimization process simultaneously considers the requirements of all the specified loads cases, which include the following:

- Stiffness Bending & Torsion
- Frontal NCAP Full Barrier
- IIHS 40% 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 5.7 for the Bending and Torsion Stiffness loads cases and in Section 6 of this report for the crash load cases.

The result of this task is identification of optimized load paths. Computer based LF3G is an advanced state of the art CAE technique which yield optimized unconventional load bearing geometry. An example of one such load path for the “rocker section,” which is the main load bearing member, one on each side, of the vehicle body structure is shown in Figure 95.

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[109]HEEDS interfaces with CAE applications to automate the design optimization process. For more information visit http://www.redcedartech.com/

[110]SFE applies numerical methods in order to solve complex problems in the field of engineering physics. For more information visit http://www.sfe-berlin.de/

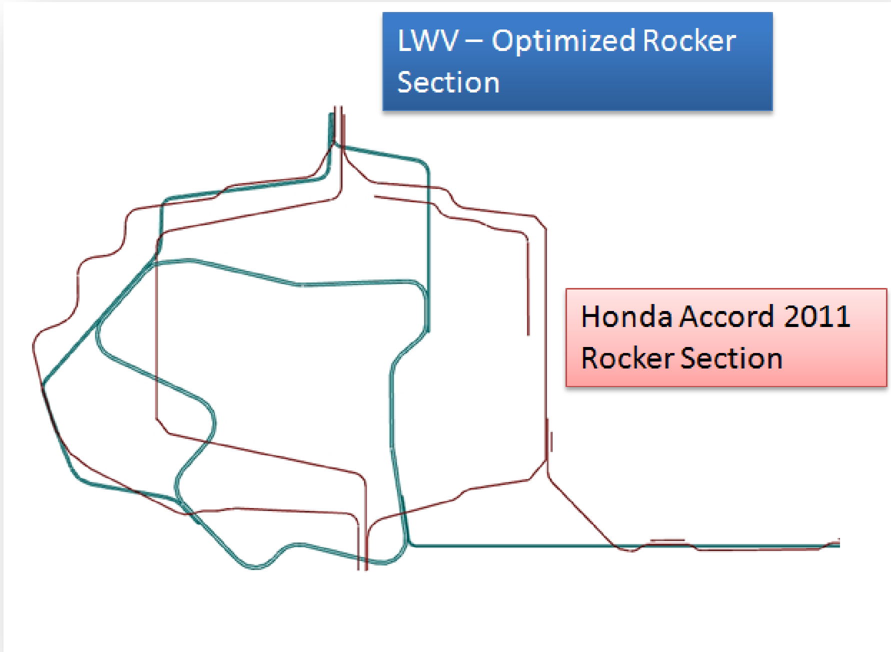

Figure 95: Comparison of Optimized Rocker Section: LWV versus Honda Accord 2011

5.3 Vehicle Performance Modeling

The software used for the LWV powertrain performance simulation analysis was the Powertrain System Analysis Toolkit (PSAT). PSAT is a plug-and-play architecture software that allows the user to build and evaluate a vehicle's fuel economy and powertrain performance under varying load conditions and drive cycles. It uses MATLAB in a Simulink environment to record data, calculate and input powertrain requirements based on driver demand and current powertrain values. The software is sponsored by the U.S. Department of Energy and developed by Argonne National Laboratory (ANL).[111]

In order to verify and validate the LWV for fuel economy and powertrain performance, a simulation model for the baseline MY 2011 Honda Accord was first built by EDAG team in PSAT. This baseline model was built as close as possible to the specifications of the 2011 Honda Accord. The engine efficiency curves for the 1.8L 121HP Toyota Corolla engine, which are available to users in the PSAT data base, were scaled to simulate the 2011 Honda Accord 2.4L 177HP engine after consulting with ANL. Other parameters used in the PSAT model are shown in Figure 96.

[111]PSAT; http://www.transportation.anl.gov/modeling_simulation/PSAT/index.html

LWV Base Vehicle	
Description	Value
Vehicle Weight (Curb Weight+Driver Weight at 90 kg)	1570 kg
Weight Distribution (Frt/Rr)	60/40
Drag Coefficient	0.31
Engine Size	2.4L
Engine Horsepower	177@6500 rpm
Transmission Gear Ratios	1st: 2.652 2nd: 1.517 3rd: 1.037 4th: 0.738 5th: 0.537 Reverse: 2.000
Transmission Final Ratio	4.44
Wheel Size	P216/60 R16
Wheel Rolling Resistance	0.007

Figure 96: LWV Baseline Vehicle Parameters

The baseline vehicle performance test results versus the performance predicted by the PSAT models are summarised in Figure 97. As can be seen, the predicted results are all within approximately five percent of the actual test results for the baseline vehicle.

Description	Actual Honda Accord	Source	Base PSAT	Base PSAT-14%	Base PSAT-20%
Fuel Ecomomy City (MPG)	23	EPA	24.3	26.6	28.59
Fuel Ecomomy Hwy (MPG)	34	EPA	32.3	34.6	36.4
Fuel Ecomomy Combined (MPG)	27	EPA	27.3	29.7	31.6
0-60 Mph (sec)	9.1	Car & Driver (Aug-2010)	8.7	8.8	8.7
0-30 Mph (sec)	3.1	Popular Machanics	3.1	3.2	3.2
Quarter Mile (sec/mph)	16.06/87.4	Popular Machanics	16.6/85.96	16.7/85.6	16.8/85.4

Description	Honda Accord 2011	Base PSAT	Base PSAT -14%	Base PSAT -20%
Engine Size	2.4L-4Cyl	2.4L-4Cyl	1.8L-4Cyl	1.8L-4Cyl
Engine Power	177HP@6500rpm	177HP@6500rpm	154HP@6500rpm	143HP@6500rpm
Transmission	5 Speed Auto	5 Speed Auto	5 Speed Auto	5 Speed Auto
Weight	1480kg (Curb)	1480kg (Curb+Driver)	1280kg (Curb+Driver)	1184kg (Curb+Driver)

Figure 97: Baseline Vehicle and LWV PSAT Results

The correlated baseline PSAT model was used to conduct further studies to establish vehicle performance for lower weight vehicle conditions. The vehicle weights evaluated were the base vehicle weight at 1570 kg, base vehicle less 100 kg (1470 kg), base vehicle less 200 kg (1370 kg) and base vehicle less 300 kg (1270 kg).

The following six performance metrics were evaluated at each vehicle weight:

1. 0-60 MPH acceleration time
2. 0-30 MPH acceleration time
3. Gradeability Maximum speed
4. Quarter mile time and maximum speed at that time
5. Fuel economy

5.3.1 Acceleration 0 to 60 mph

The vehicle acceleration test establishes the time required to accelerate from 0 to 60 mph. The 2011 Honda Accord 0 to 60 mph time was 9.1s (Car & Driver August 2010)[112]. Several runs were made with varying engine size to establish engine power required to attain 9.1 s for various vehicle weights. The PSAT model for the baseline vehicle predicted a time of 8.7 s for the 0 to 60 mph which is within 5% of the 9.1 s value. Figure 98 shows the relationship between engine size, vehicle weight and 0-60 mph time derived from the PSAT simulation runs. As can be seen from Figure 98, there is a direct proportional relationship of engine size to vehicle weight. For the LWV weight at 1145 kg (plus 90 kg for driver weight– 1235kg), the engine can be downsized to 140 HP while maintaining 0-60 mph time.

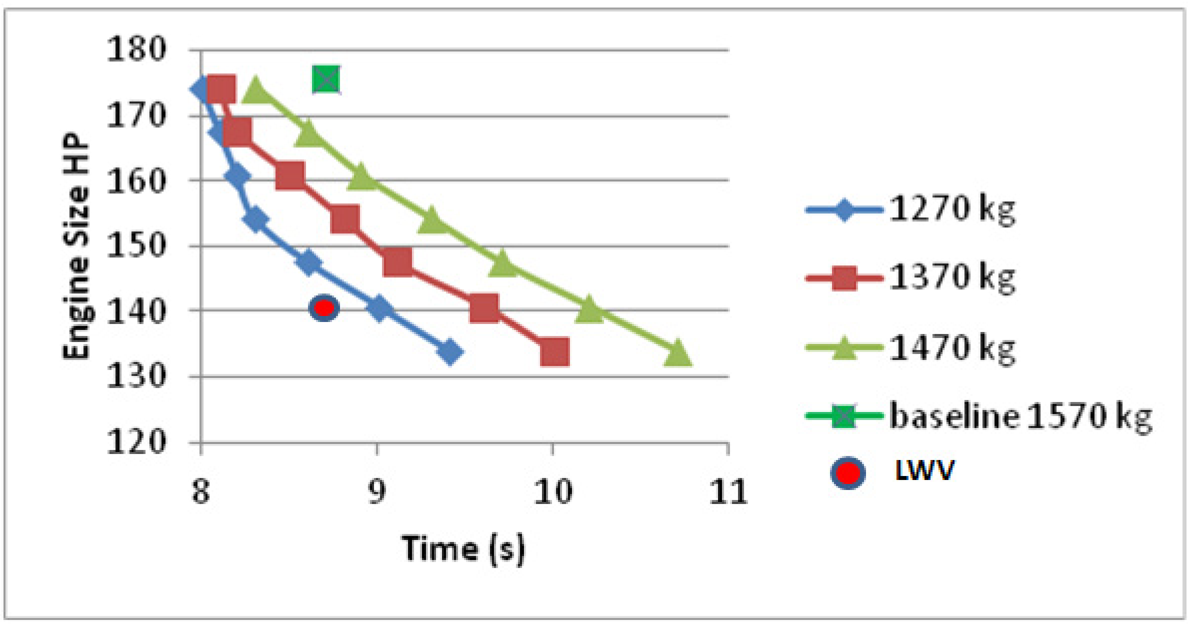

Figure 98: Acceleration 0-60mph Time versus Engine Power

[112] http://www.caranddriver.com/reviews/honda-accord-review-2011-honda-accord-se-sedan-drive

5.3.2 Acceleration 0 to 30 mph

The 2011 Honda Accord 0 to 30 mph value is listed as 3.1s (PSAT simulation results are listed in Figure 99 for different vehicle weights and engine sizes. Based on the results in Figure 99 and the LWV weight at 1145 kg plus 90 kg for the driver, the engine for the LWV can be downsized to 140 HP while maintaining 0-30 mph time very close to 3.1s.

Acceleration 0-30 mph		
Weight (Kg)	Time (s)	Engine Size (HP)
1570	3.1	175.7
1370	3.2	154.2
1270	3.1	147.5
1235	3.2	141.5

Figure 99: Acceleration 0-30 mph

5.3.3 Gradeability

The gradeability cycle was run on the base vehicle to determine the maximum speed the vehicle could be driven on a 10 percent grade. PSAT simulation shows that the maximum speed for the baseline vehicle with 2.4L engine was 79.4 mph. The maximum speeds for the varying weights and engine sizes are shown in Figure 100. For the LWV weight at 1145 kg (plus 90 kg – 1235kg) the engine can be downsized to 140 HP while maintaining gradeability.

Gradeability			
Weight (Kg)	Grade %	Speed (mph)	Engine Size (HP)
1,570	10	79.4	176
1,470	10	79.4	168
1,470	10	79.0	161
1,370	10	79.4	161
1,370	10	79.2	154
1,270	10	79.2	148
1,235	10	79.2	141

Figure 100: Results for driving the vehicle on 10% grade

5.3.4 Maximum Speed

The maximum speed of Honda Accord baseline vehicle is limited 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 2011 Honda Accord is 127 mph (Section 4.5-3). The speeds predicted by the PSAT model for varying weights and engine sizes are listed in Figure 101. Based on the results shown in Figure 101 the base engine for the LWV maximum speed of 127 mph cannot be reached by using a 140 HP engine. Therefore it is recommended that the speed be limited to 112 mph as this still significantly higher than the US speed limits.

Maximum Speed		
Weight (Kg)	Speed (mph)	Engine Size (HP)
1570 kg	137.3	175.7
1470 kg	132.7	167.6
1470 kg	126.9	160.9
1370 kg	135.2	167.6
1370 kg	128.6	160.9
1270 kg	130.7	160.9
1370 kg	128.6	160.9
1270 kg	124.6	154.2
1235 kg	123.2	147.5

Figure 101: Maximum Speed

5.3.5 Quarter Mile Time and Maximum Speed

The baseline vehicle can complete a quarter mile drive in 16.06 s and reaches a speed of 87.4 mph at that time.[113] The LWV PSAT run results for the quarter mile are listed in Figure 102.

Weight (Kg)	Time (s)	Maximum Speed (mph)	Engine Size (HP)
1570	**16.6**	**86.0**	**175.7**
1370	**16.7**	**85.6**	**154.2**
1270	**16.6**	**86.0**	**147.5**
1235	**16.7**	**85.6**	**140.4**

Figure 102: LWV PSAT Run Results for Quarter Mile

5.4 Minimum turning radius

The baseline Honda Accord has a relatively short turning radius of 18.9 feet for good low-speed manoeuvrability. The suspension of the LWV has a turning radius of 18.8 feet which is a little better than the baseline vehicle. The turning radius is illustrated in Figure 103. The wheels and tires on a vehicle are considered to enhance the car's appearance, as well as being very critical for enhanced grip during acceleration, cornering and braking. The 2011 Accord Sedan models are available with the P215/60R16 and P225/50R17 tire and wheel sizes. The LWV front and rear suspension and body structure is designed to accommodate both wheel sizes.

[113]Popular Mechanics based on the 190 HP engine 2.4L I4 5speed automatic

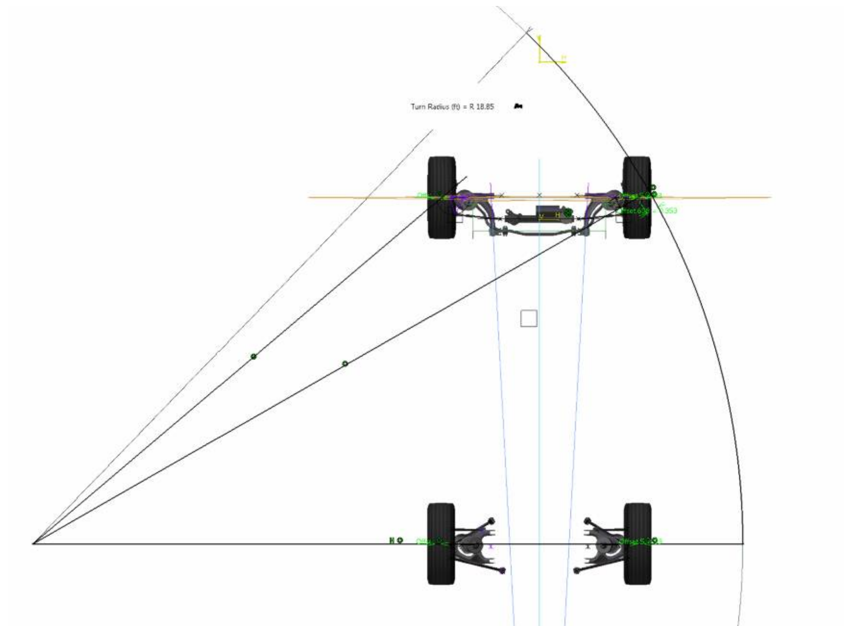

Figure 103: LWV Turning Radius

5.5 Ride and Handling

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 LWV was evaluated using MSC/ADAMS (Macneal-Schwendler Corporation/Automatic Dynamic Analysis of Mechanical Systems) software. The following five maneuvers were simulated:

- Fish-hook Test
- Double Lane Change Maneuver (ISO 38881)
- Pothole Test
- 0.7G Constant Radius Turn Test
- 0.8G Forward Braking Test

5.5.1 ADAMS Vehicle Information

The LWV model includes the body, front McPherson strut suspension, rear multilink suspension, front and rear PAC 89 tire model, front and rear anti-roll bars, and powertrain as shown in Figure 104. Vehicle specifications are listed in Figure 105.

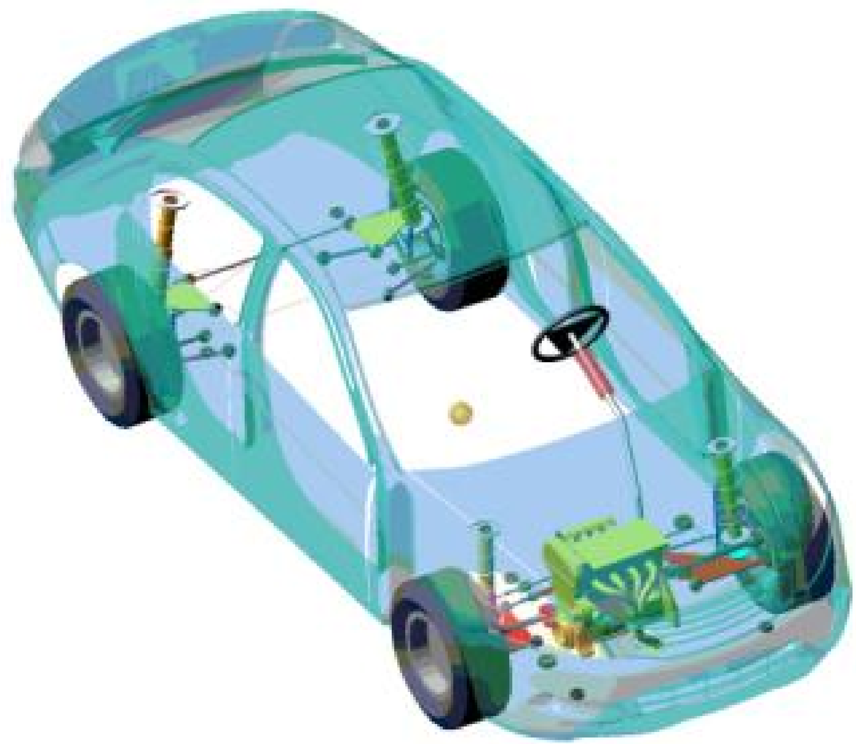

Figure 104: LWV ADAMS Model

ADAMS LWV SPECIFICATION	
Curb Weight	1184 kg
Front Weight Distribution	60%
Center Of Mass Height From Ground	527 mm
Wheelbase	2799 mm
Tire Size	P215/60 R16
Track Width	1580 mm
Front Spring Rate	28 N/mm
Rear Spring Rate	33 N/mm
Front Anti-Roll Bar Rate	28760 Nmm/deg
Rear Anti-Roll Bar Rate	4607 Nmm/deg
Front Suspension Type	MacPherson Strut
Rear Suspension Type	Multi-link

Figure 105: Adams LWV Specification

5.5.2 Fishhook Maneuver

5.5.2.1 Test Summary

The fishhook test is used in conjunction with the static stability factor (SSF) by the National Highway Traffic Safety Administration (NHTSA) to rate the propensity for vehicle rollover[114]. The SSF in conjunction with whether or not the vehicle tips up during the fish hook 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 LWV vehicle is calculated to be 1.5. Figure 106 shown below shows the curves which NHTSA uses to determine the vehicle rollover star rating. Less than a 10% chance of rollover is a 5 star rating, 10-20% is a 4 star rating, 20-30% is a 3 star rating, 30-40% is a 2 star rating and more than 40% is a 1 star rating.

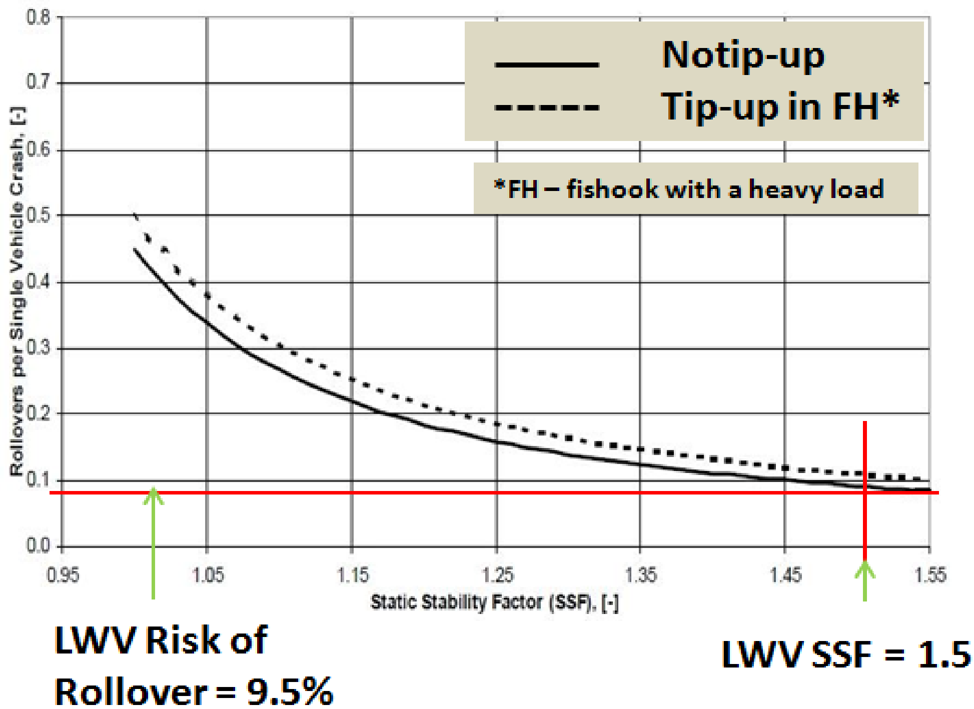

Figure 106: Static Stability Factor (SSF)

5.5.2.2 Test Procedure

The fishhook maneuver analysis was run in MSC/ADAMS with the driver, three rear passengers and instrumentation. The LWV test weight used was 1417.8 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 107) and counters to the same hand wheel angle value (i.e. –A in Figure 107) as shown inFigure 107. The hand wheel angle amplitude is determined by running the Slowly Increasing Steer Maneuver.

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[114]Department of Transportation NHTSA, 49CFR Part 575, Docket No. NHTSA-2001-9663; Notice 3

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[115]. 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.

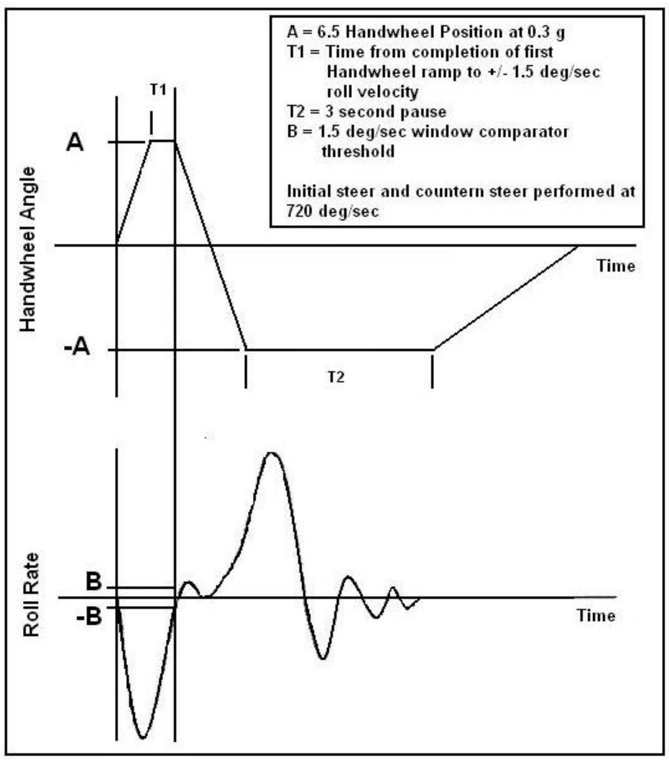

Figure 107: Steering Wheel Angle Fishhook Test

5.5.2.3 Performance Target

The chosen LWV target was to meet the 2011 Honda Accord Target, *i.e.*, Five Star 9.5% rollover risk with no wheel lift-off.

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[115]Department of Transportation NHTSA, 49CFR Part 575, Docket No. NHTSA-2001-9663; Notice 3

5.5.2.4 Performance Results

No vehicle tip up was found during the simulated fishhook test. Given that the LWV has a Static Stability Factor of 1.5, this is equivalent to a 5 star rating for rollover, the same as the baseline Honda Accord.

5.5.3 Double Lane Change Maneuver (ISO 38881-1)

5.5.3.1 Test Summary

The double lane change maneuver[116] is an industry standard subjective test. 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.

5.5.3.2 Test Procedure

The double lane change maneuver was run in MSC/ADAMS with driver and instrumentation. Test weight was 1352 kg. Course parameters can be seen in Figure 108 and Figure 109. The test was run at 80 +/- 3kph, and the throttle was varied to maintain test speed.

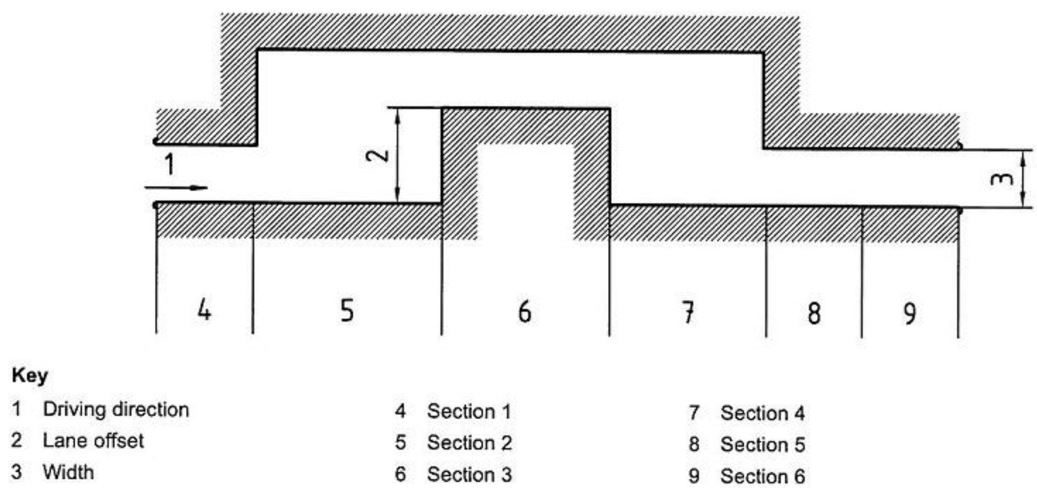


Figure 108: Course Parameters

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 109: ISO Lane Change Road Dimensions

[116]Double Lane Change Maneuver, ISO 3888-1

5.5.3.3 Performance Target
The vehicle must be able to manipulate the track without exceeding the lane boundaries.

5.5.3.4 Performance Results

The LWV 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.

5.5.4 Durability Loads

The ADAMS model of the LWV was used to predict loads at all of the chassis to body structure mounting points for the front and rear suspension. For each of the mounting point a time based digital data file (DAC file) with force function is produced. This data is for input into the Design Life 6.0 fatigue life prediction program. Fatigue analysis with these loads is further explained in Section 5.6 of this report.

Each OEM has its own testing schedules and durability requirements. The LWV body was evaluated using body mounting point loads extracted from the ADAMS model for the following load cases:

- Pothole Test
- 0.7G Constant Radius Turn Test
- 0.8G Forward Braking Test

5.5.5 Pothole Test

5.5.5.1 Test Summary

The pothole test consists of driving a vehicle over a pothole on the left or right side of the vehicle at a speed of 48.2 kph[117] Suspension to body bushing loads are recorded and used to evaluate vehicle fatigue performance.

5.5.5.2 Test Procedure

The pothole test was run in ADAMS with driver, three rear passengers and instrumentation. The test weight was 1417.8 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 110.

[117]Double Lane Change Maneuver, ISO 3888-1

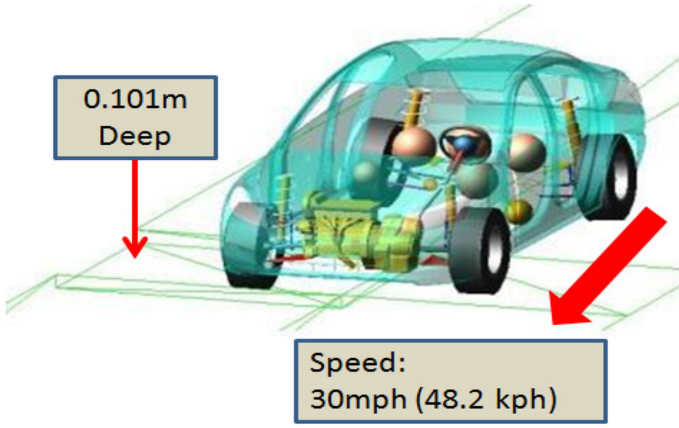


Figure 110: Pothole Test

5.5.6 0.7G Constant Radius Turn Test

5.5.6.1 Test Summary

The constant radius turn ADAMS pre-defined test manoeuvre was used. Suspension to body bushing loads were recorded and used to evaluate vehicle fatigue performance.

5.5.6.2 Test Procedure

The test was run with driver. Test weight was 1263 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.

5.5.6.3 Performance Results

For the 0.7 G constant radius turn the reaction forces at mounting point to body 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 (see Section 5.6).

5.5.7 Forward Braking Test 0.8g Longitudinal Deceleration

5.5.7.1 Test Summary

The forward braking manoeuvre is driving a vehicle in a straight line and subsequently applying a 0.8G brake load. Suspension to body bushing loads were recorded and used to evaluate vehicle fatigue performance.

5.5.7.2 Test Procedure

The 0.8G brake test was run with driver, 3 rear passengers and instrumentation. The test weight was 1417.8 kg. The ADAMS pre-defined braking straight line event was applied. The initial velocity was 100 kph. The longitudinal applied deceleration was 0.8G.

5.5.7.3 Performance Results

For the 0.8 G brake loads, the reaction forces at mounting point to body 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 (see Section 5.6).

5.6 Durability Analysis

5.6.1 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 Electricore team evaluated the structural durability of the LWV through a strain-based analysis based on the following road load cases:

- Pot hole (same pot hole size as in Section 5.5.5 Pothole Test)
- 0.8G forward braking
- 0.7 G Cornering

5.6.2 Process and tools used

By running the LWV – 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 body mounting locations were recorded in DAC files (see Section 5.5):

1. Front shocks (left and right side)
2. Rear shocks (left and right side)
3. Lower control arm to front sub frame front (left and right side)
4. Lower control arm to front sub frame rear (left and right side)
5. Upper control arm to rear sub frame front (left and right side)
6. Upper control arm to rear sub frame rear (left and right side)
7. link1 to sub frame (left and right side)
8. link2 to sub frame (left and right side)
9. link3 to sub frame (left and right side)

These loading points are shown in Figure 111 and Figure 112.

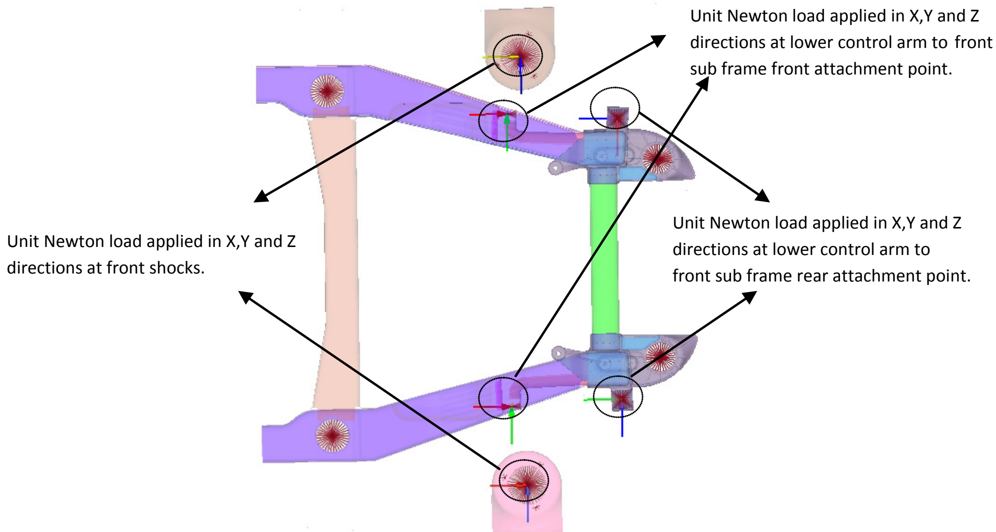


Figure 111: Front Sub-Frame Loading Points

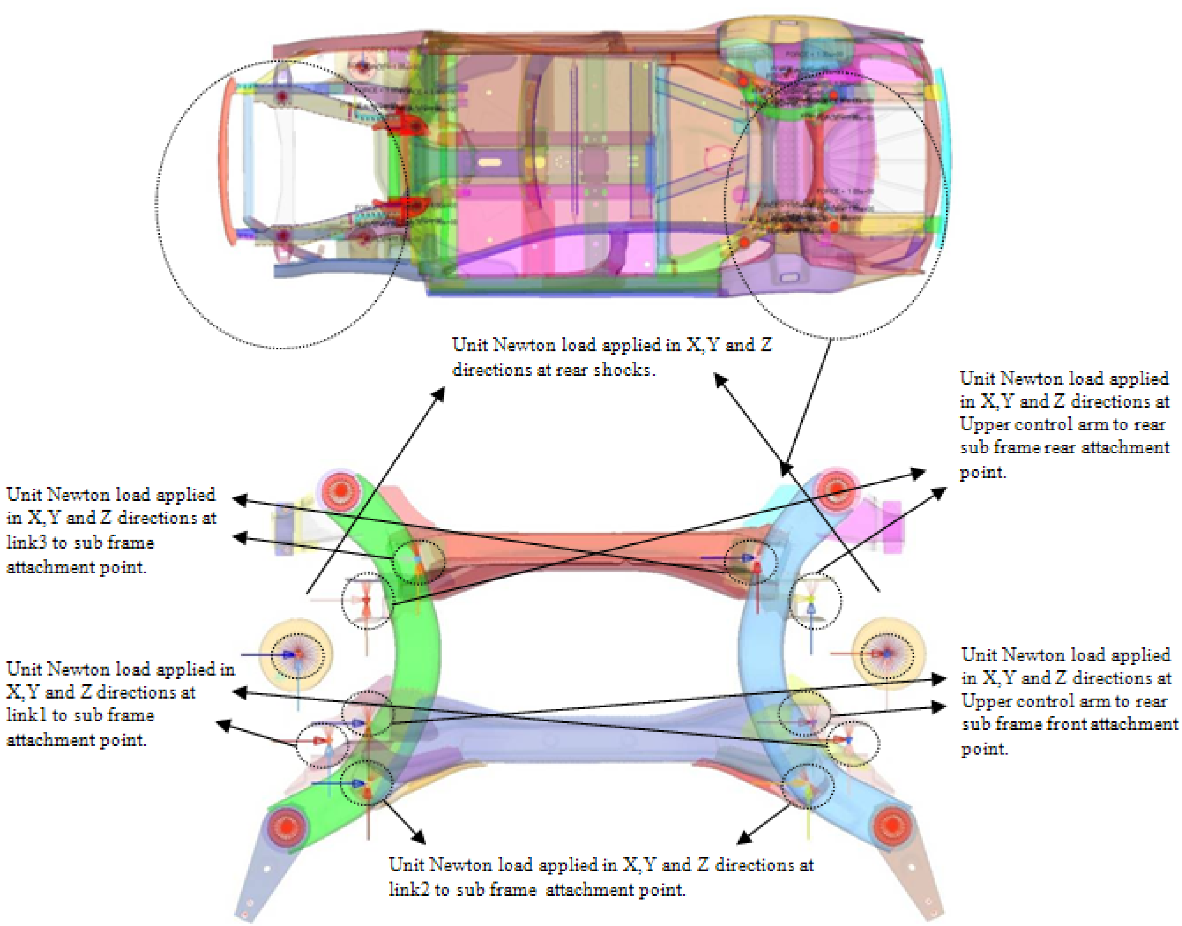


Figure 112: Rear Sub-Frame Loading Points

The load histories from the ADAMS analysis are combined with stress output results from MSC/NASTRAN by the following to 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 113.

		Thickness (mm)		Gage	YS (MPa)	YS (MPa)	UTS (MPa)	UTS (MPa)	Tot EL (%)	N-value	Modulus of	Fatigue Strength	K Value
Item #	Steel Grade	Min t	Max t	Length	Min	Typical	Min	Typical	Typical	Typical	Elasticity (MPa)	Coeff (MPa) *	(MPa)
1	Mild 140/270	0.35	4.60	A50	140	150	270	300	42-48	0.24	21.0×10^4	645	541
2	BH 210/340	0.45	3.40	A50	210	230	340	350	35-41	0.21	21.0×10^4	695	582
4	BH 280/400	0.45	2.80	A50	280	325	400	420	30-34	0.16	21.0×10^4	765	690
8	HSLA 350/450	0.50	5.00	A80	350	360	450	470	23-27	0.16	21.0×10^4	815	807
9	DP 300/500	0.50	2.50	A80	300	345	500	520	30-34	0.18	21.0×10^4	865	762
13	DP 350/600	0.60	5.00	A80	350	385	600	640	24-30	0.17	21.0×10^4	985	976
21	DP 500/800	0.60	4.00	A50	500	520	800	835	14-20	0.14	21.0×10^4	1180	1303
26	TWIP 500/980	0.80	2.00	A50M	500	550	980	990	50-60	0.40	21.0×10^4	1335	1401
27	DP 700/1000	0.60	2.30	A50	700	720	1000	1030	12-17	0.12	21.0×10^4	1375	1521
30	MS 950/1200	0.50	3.20	A50M	950	960	1200	1250	5-7	0.07	21.0×10^4	1595	1678
31	CP 1000/1200	0.80	2.30	A80	1000	1020	1200	1230	8-10	0.10	21.0×10^4	1575	1700
35	HF 1050/1500	0.60	4.50	A80	1050	1220	1500	1600	5-7	0.06	21.0×10^4	1945	2161

Figure 113: Material Properties used for fatigue life calculations

5.6.3 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.

5.6.3.1 Pot Hole

For the Pot Hole load case, the predicted life of 14,830 cycles found at top of the rear shock tower, is above the target value of 10,000 cycles (Section 4.9.2) as shown in Figure 114.

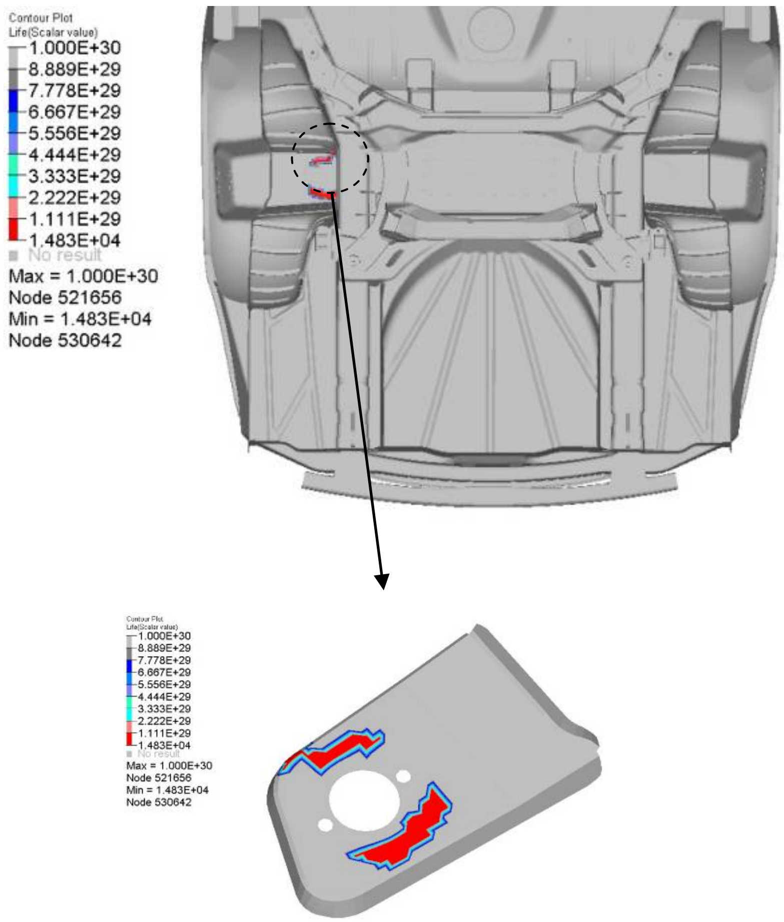


Figure 114: Pot hole contour plot

5.6.3.2 0.8G Forward Braking

For 0.8G forward braking, the minimum fatigue life of 611,500 cycles found at engine cradle rear cross member, is significantly higher than the target value of 100,000 cycles, (Section 4.9.2), as shown in Figure 115.

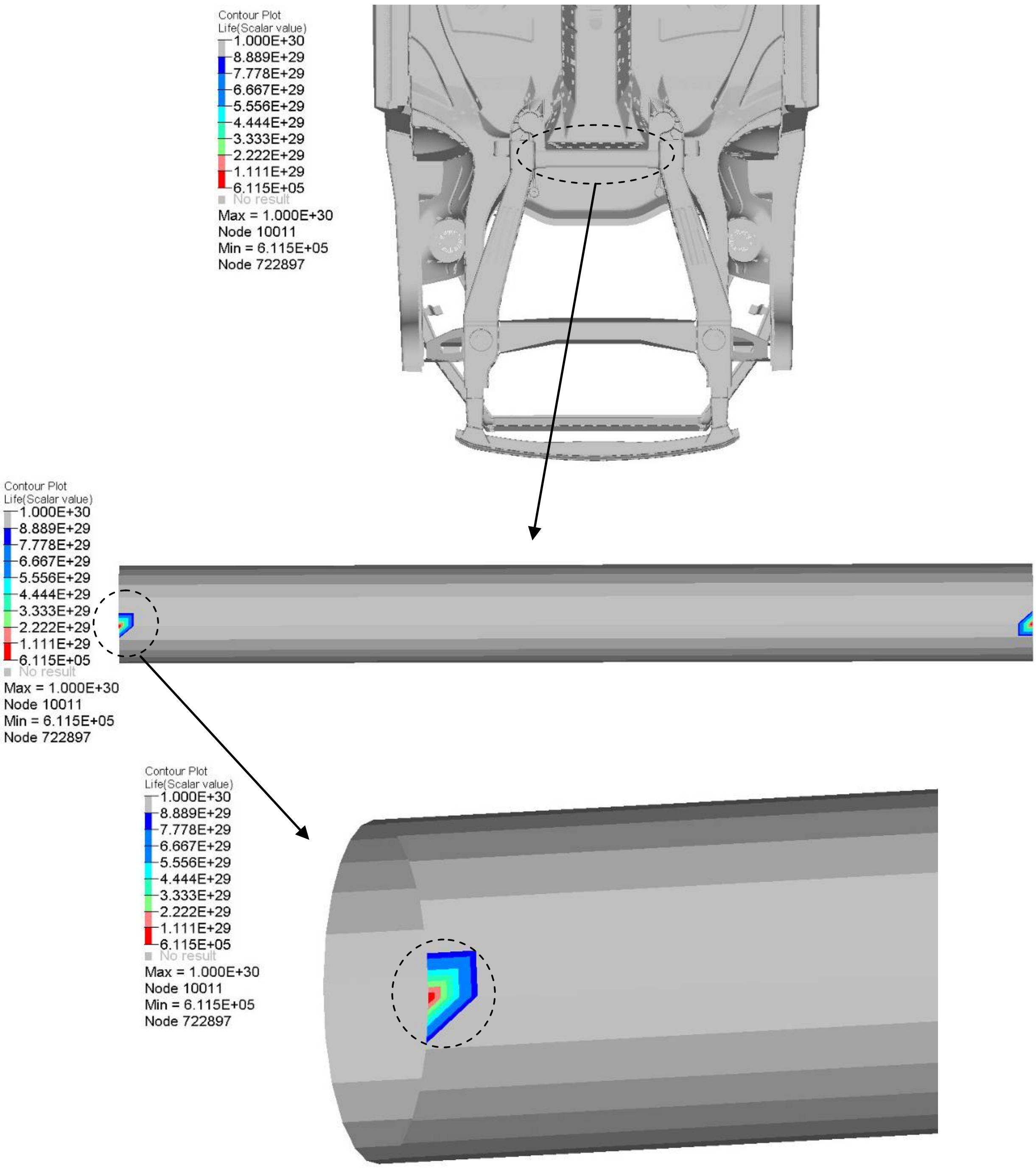


Figure 115: 0.8G Forward braking contour plot

5.6.3.3 0.7 G Cornering

For 0.7G Cornering load, the LWV has infinite fatigue life. The results are shown in Figure 116 below.

Loading Type	Predicted life cycles	Target life cycles
3G Pot hole	14,830	10,000
0.8G Forward Braking	611,500 for front sub frame and Infinite life for Body Structure	100,000
0.7G Cornering	Infinite life	100,000

Figure 116: Durability Test Simulation Results

5.6.4 Conclusion

The results presented in Figure 116 above indicate that, for all the durability load cases, the life of the LWV body structure exceeds the set targets.

5.7 Vehicle Stiffness

The baseline 2011 Honda Accord body structure torsional and bending stiffness are a signature of the vehicle structure's performance. Vehicles with higher stiffness are generally associated with refined ride and handling qualities.

A detailed FEA model of the LWV structure was created and analyzed using the MSc/NASTRAN computer simulation program. The FEA model was continually updated during the design phase of this program and used to guide the design decisions to meet the set stiffness targets. The LWV structure was designed to meet or exceed the baseline vehicle measured results.

The FEA model includes the body structure with glass (windshield and rear glass) and bolted assemblies instrument panel beam, front and the rear bumpers. The structure in this state is generally referred to as Body-In-Prime (BIP) and is shown in Figure 117.

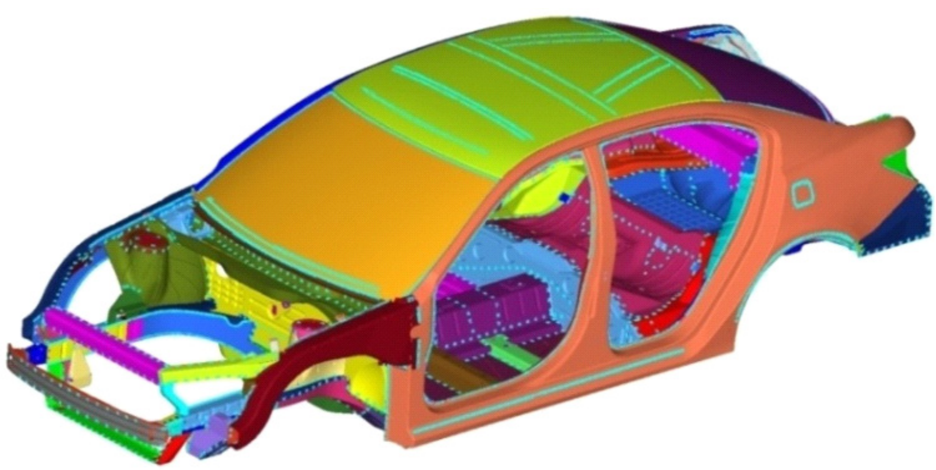


Figure 117: FEA Model BIP

5.7.1 Torsional Stiffness

For the LWVBIP a static torsion stiffness target of 12.5 KN-m/deg was set, based on the Honda Accord test value of 12.33 KN-m/deg. The test results and the target for torsion stiffness are shown in Section 4.7 of this report.

5.7.1.1 Boundary Conditions

The FEA model of the BIP is constrained at the rear left body support along x, y, z and the rear right body support along x, z. Additionally, one more point on the mid-plane of the front bumper beam along z is constrained as shown in Figure 118 and Figure 119.

The torsion loads are applied at the front supports. Vertical loads of 1200 N are applied in opposite directions on the left and right mounts as shown in Figure 118 and Figure 119.

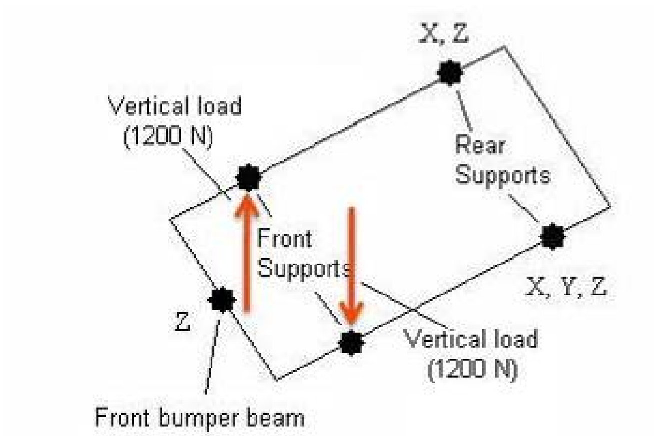


Figure 118: Torsion Constraints and LoadingTorsion Constraints and Loading

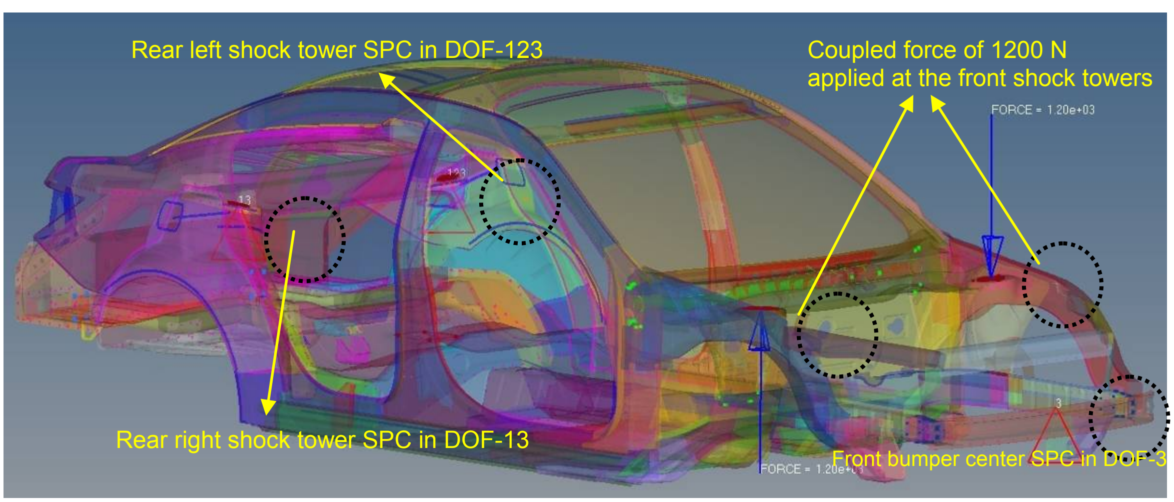


Figure 119: FE-Model setup for torsion stiffness

5.7.1.2 Torsion stiffness results

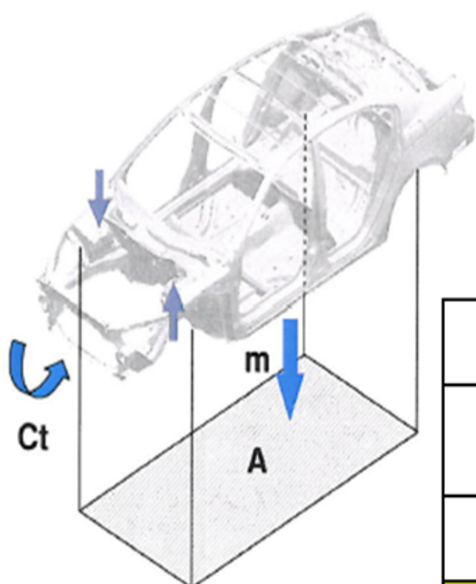
The predicted torsional stiffness of the final recommended LWV design of 16.25kN-m/deg exceeded the target value of 12.5kN-m/deg by 30%, which implies the LWV body structure will have better ride and handling and improved NVH performance compared with the baseline vehicle.

Description	Honda Accord testing stiffness	LWV Target stiffness	LVW stiffness
Torsion stiffness (kN-m/deg)	12.33	12.5	16.25

Figure 120: Torsion stiffness results

5.7.2 Light Weight Index

The torsion stiffness number is also used to calculate the Lightweight Design Index, which represents the comparative efficiency of the body structure with other vehicles. Figure 121 below shows the equation used for calculating the Lightweight Design Index. The Lightweight Design Index has no particular value that is regarded as acceptable. It is an Index which engineers like to use for comparison purposes; lower value compared with the baseline vehicle indicates increased structural efficiency. For comparison, the Honda Accord baseline structure has a Lightweight Index of 5.96 is shown in Section 4.7.1 of this report. A lightweight index of 3.48 for the LWV is a significant improvement over the baseline structure. The results for the lightweight index are shown in Figure 121.



$$L = \frac{m}{A \times Ct}$$

m: Body mass (Kg)
A: Wheel base x Tread (m^2)
Ct: Static rigidity (KNm/deg)

	Honda Accord 2011	LWV
BIW Mass (kg)	327	252
Torsional Stiffness (kNm/deg)	12.33	16.25
Area A (m^2)	4.45	4.45
Light Weight Index	5.96	3.48

Figure 121: Honda Accord 'Lightweight Design Index'

5.7.3 Bending Stiffness

For the LWVBIP a static bending stiffness target of 9,000 N/mm was set, based on the Honda Accord test value of 8,690 N/mm (see Section 4.7 of this report).

5.7.3.1 Boundary Conditions

The FEA model of the BIP is constrained at the rear left body support along x, y, z and the rear right body support along x, z, and also at the front left body support along y, z and the front right body support along z, as shown in Figure 122.

The bending loads of 1,668 N were applied in a downward Z direction at the middle of both the front and rear seat mounts, as shown in Figure 122.

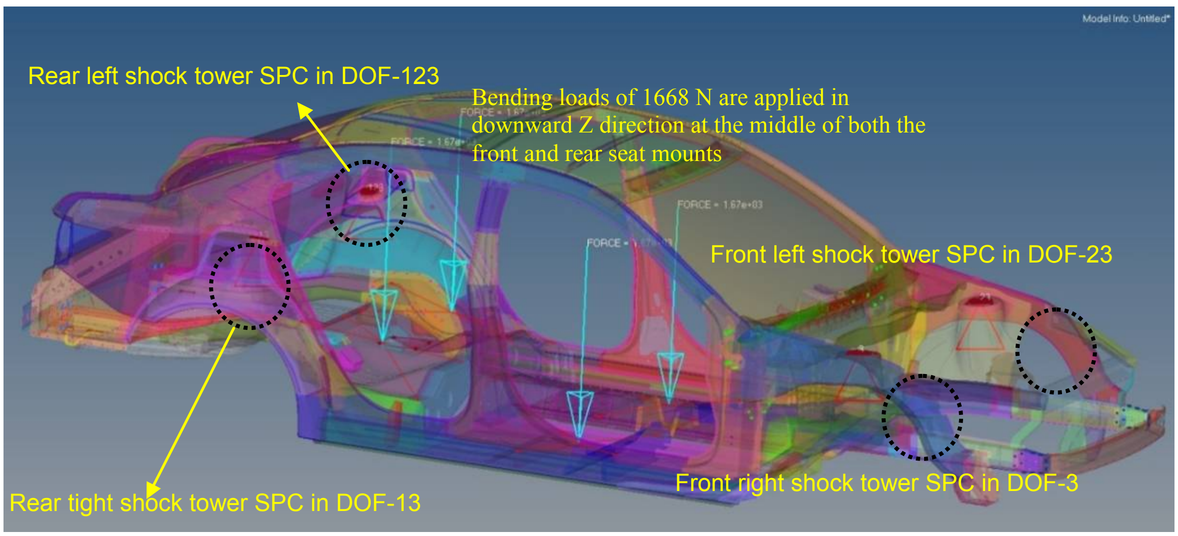


Figure 122: FE-Model setup for bending stiffness

5.7.3.2 Bending stiffness results

The predicted bending stiffness of the final recommended design of LWV of 12,636 N/mm exceeds the target value of 9,000 N/mm by 40%, as shown in Figure 123. Vehicles with higher stiffness are generally associated with a refined ride and handling qualities, a vehicle with a rigid structure helps to minimize noise, vibration and harshness (NVH) in the passenger compartment which also contributes to the vehicles ride quality, comfort and interior quietness.

Description	Honda Accord testing stiffness	LWV Target stiffness	LVW stiffness
Bending stiffness (N/mm)	8,690	9,000	12,636

Figure 123: Bending stiffness results

5.7.4 Normal Modes Frequency

Adequate dynamic stiffness of the body structure is essential for acceptable overall NVH performance of a vehicle. Acceptable results from this are generally deemed sufficient for initial assessment of NVH outcome of the vehicle. For a vehicle to be dynamically stiff it is important to have high natural frequencies for the global modes. For the LWV BIP targets were set for these critical global modes based on the Honda Accord test values (test results are shown in Section 4.7 of this report). Figure 124 through Figure 127 show the mode shapes.

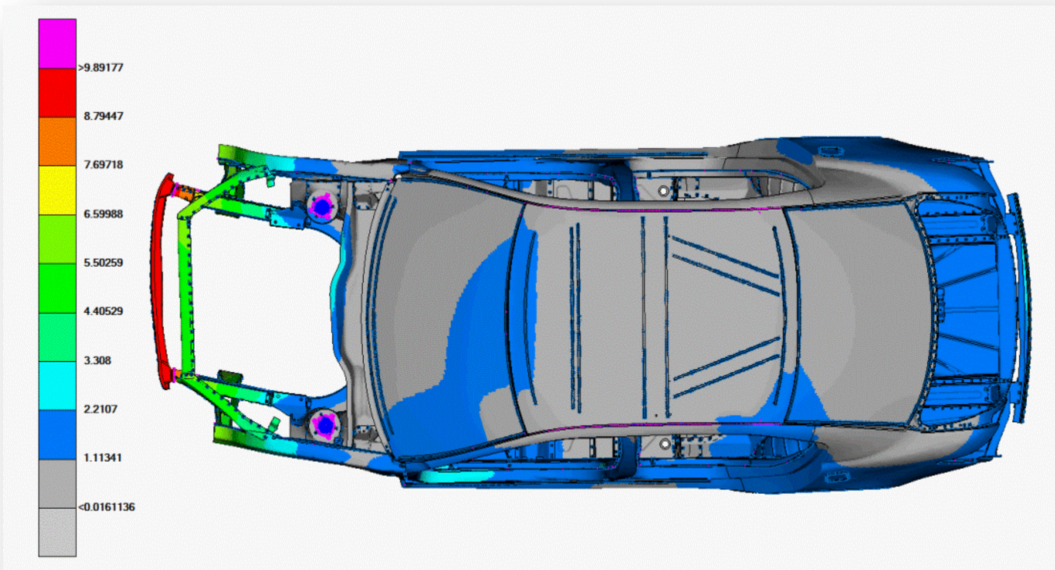


Figure 124: Front end lateral mode 41.78 Hz

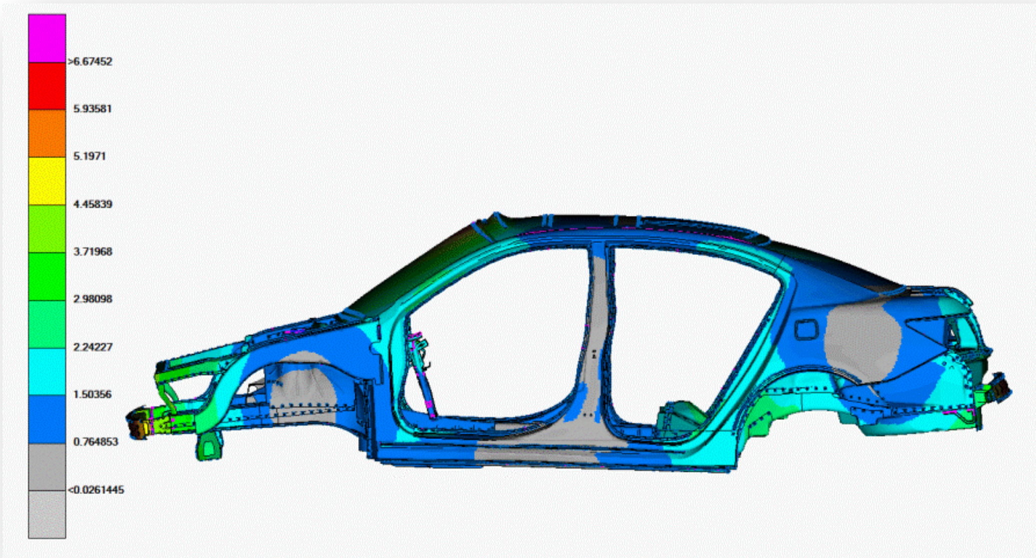


Figure 125: Second order bending mode 41.12 Hz

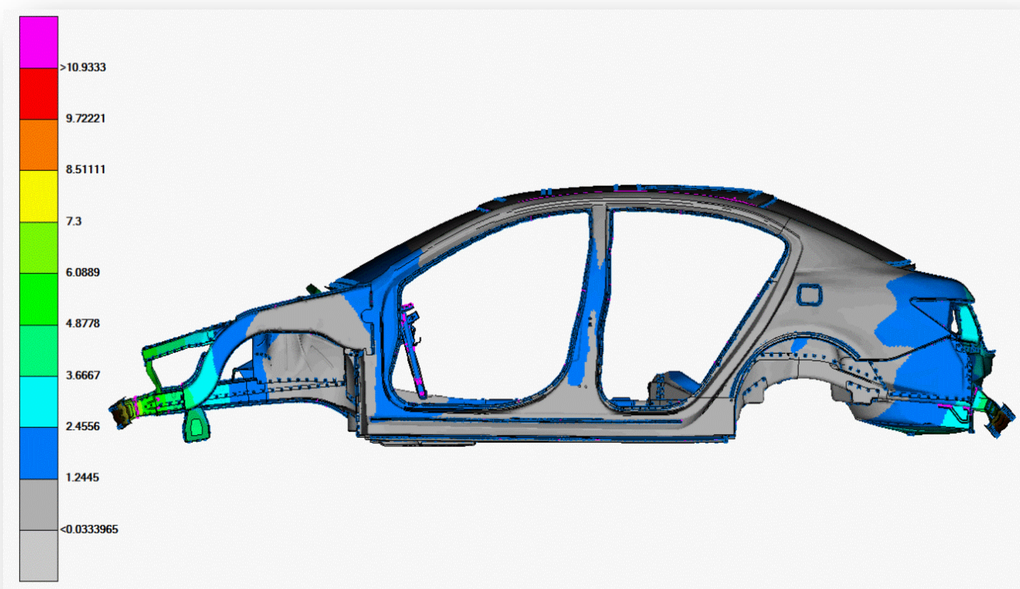


Figure 126: Vertical bending mode 47.18 Hz

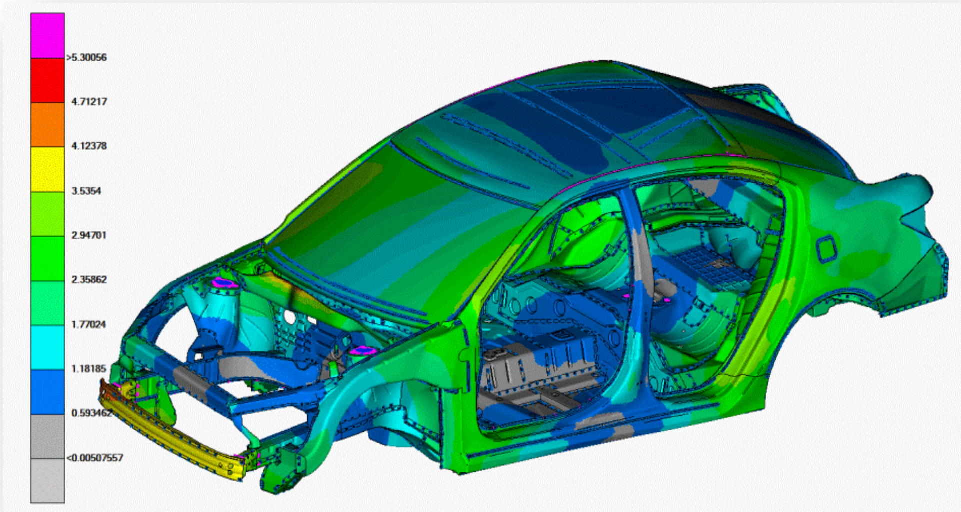


Figure 127: Torsion mode 48.97 Hz

5.7.4.1 Global modes Results

As can be seen from Figure 128, the target values were exceeded for the first three resonance modes of vibration. Torsion mode 48.97 Hz is within 2.3% of the targets value 50.1 Hz and is considered in the equivalent level comparing to the baseline vehicle. These results show that LWV body structure has improved structural responses compared with the baseline vehicle.

Frequency type	Target Frequency (Hz)	LWV Frequency (Hz)
Front end lateral mode	35.10	41.78
Second order bending mode	39.30	41.12
First order bending mode	44.20	47.18
Torsion mode	50.10	48.97

Figure 128: Global modes results

5.7.5 Manufacturability

The manufacturability of all proposed body structure panels 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. Single step stamping simulation is a quick process for getting an approximate idea about whether a component can be stamped or not for a given blank shape and size. The single step simulation method in HYPER-FORM is very helpful in the product development stage, and informative for our question about manufacturability.

For the LWV, single step simulation was done on most of the major parts of the body structure using Hyper form Radioss One Step (Altair Hyperworks 11.0). From that simulation, the team found that most of the parts of the body structure can be made through cold and hot forming.

Parts that play an important role in crashworthiness, like B-pillars and roof rails are made using a hot stamping process. The hot stamping process is also simulated using single step process by assuming IF Steel forming properties. Although Single Step simulation is done on all the body structure parts, it cannot replace the incremental analysis process. Some parts which have complicated shapes like body side outer require the incremental analysis method for predicting the manufacturing results more accurately. The detailed incremental forming simulation requires the stamping tool geometry to be developed so it can be used in the simulation. For this light weighting project, detailed incremental forming simulation is not performed due to time and budget constraints. Even though these single step simulations do not have the accuracy as incremental simulations, they can bring the results to close proximity of the more accurate incremental analyses and meet the fidelity requirement of this study.

Whether a stamped component design is safe or whether it will fail is determined through the Forming Limit Diagram (FLD). This is an empirical curve showing the biaxial strain levels beyond which failure may occur in sheet metal forming. For example, the single step stamping simulation done on the tunnel top reinforcement as shown in Figure 129 was analyzed with a FLD diagram. The tunnel top is a hot-stamped panel 0.8 mm thick made from a boron steel grade HF 1050/1500.

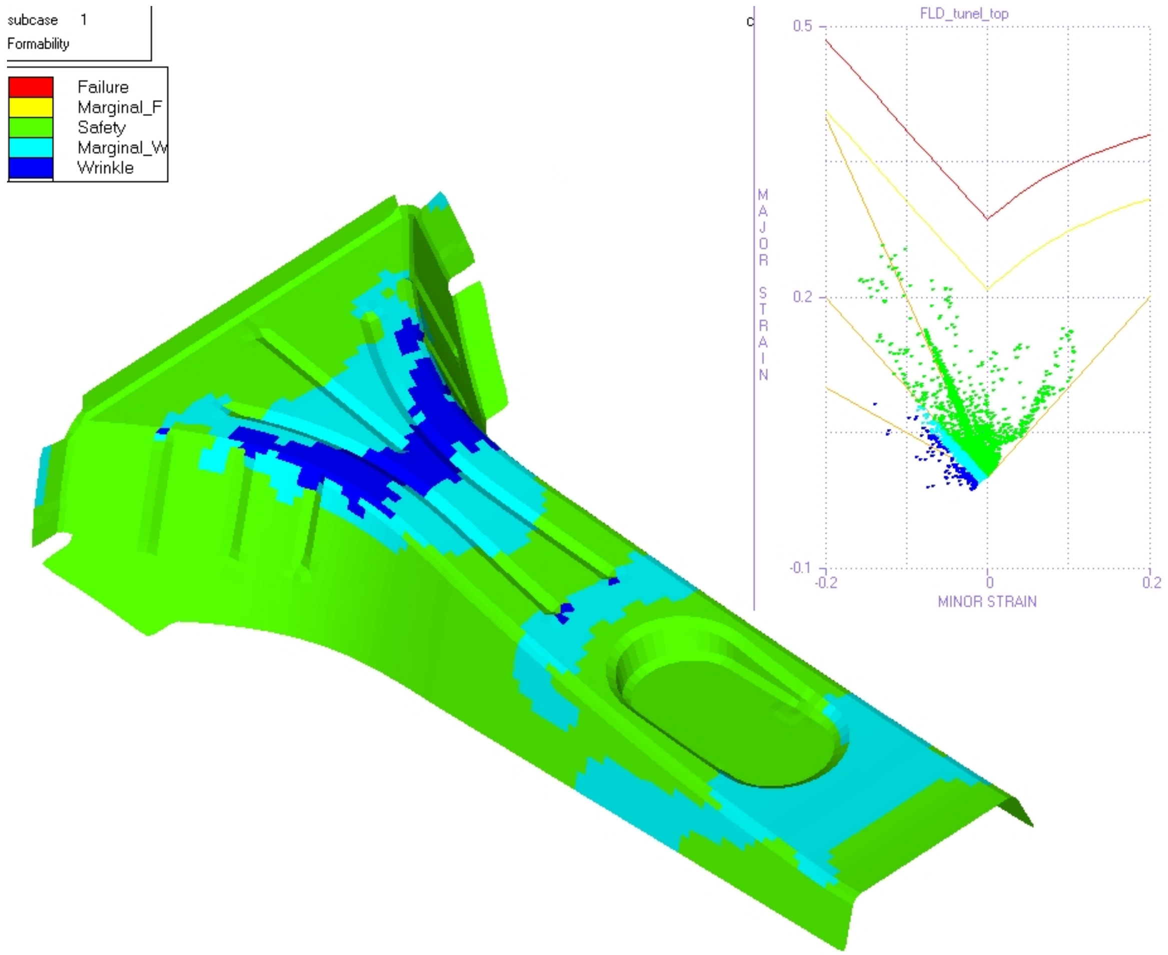


Figure 129: Tunnel Top Reinforcement Single Step Stamping Simulation

The FLD diagrams shown above predict no failure for tunnel top. There are little areas where wrinkling can occur and these can be easily improved by implementing minor design changes to the CAD data. The benefit of this single step simulation is that the team was able to avoid the time consuming process of incremental analysis which includes preparation of blank holders, addendum surfaces and draw beads. Single step stamping simulations gives the approximate results very quickly whenever there is any change in the CAD data.

Figure 130 and Figure 131 below shows the single step simulation results for shock tower and rear cargo floor. Shock tower is 1.4 mm thick with properties of stainless steel and rear cargo floor is 0.6 mm thick and DP 350/600 steel.

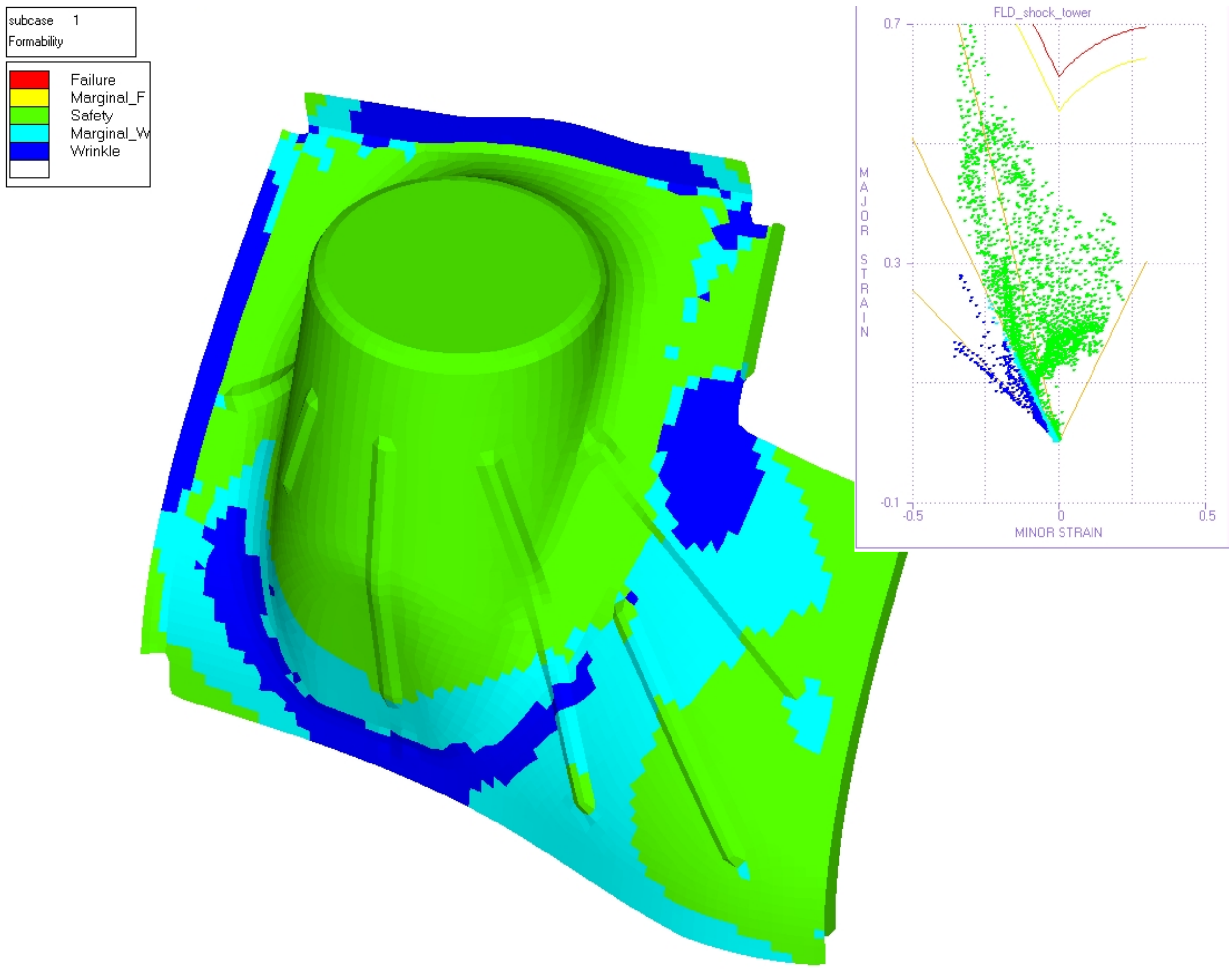


Figure 130: Single step results for Shock Tower

Figure 130 above shows that there was no failure in the shock tower and only a few wrinkles exist on a few localize areas, which can be easily modified in the CAD.

Figure 131 below predicts no failure in the rear cargo floor.

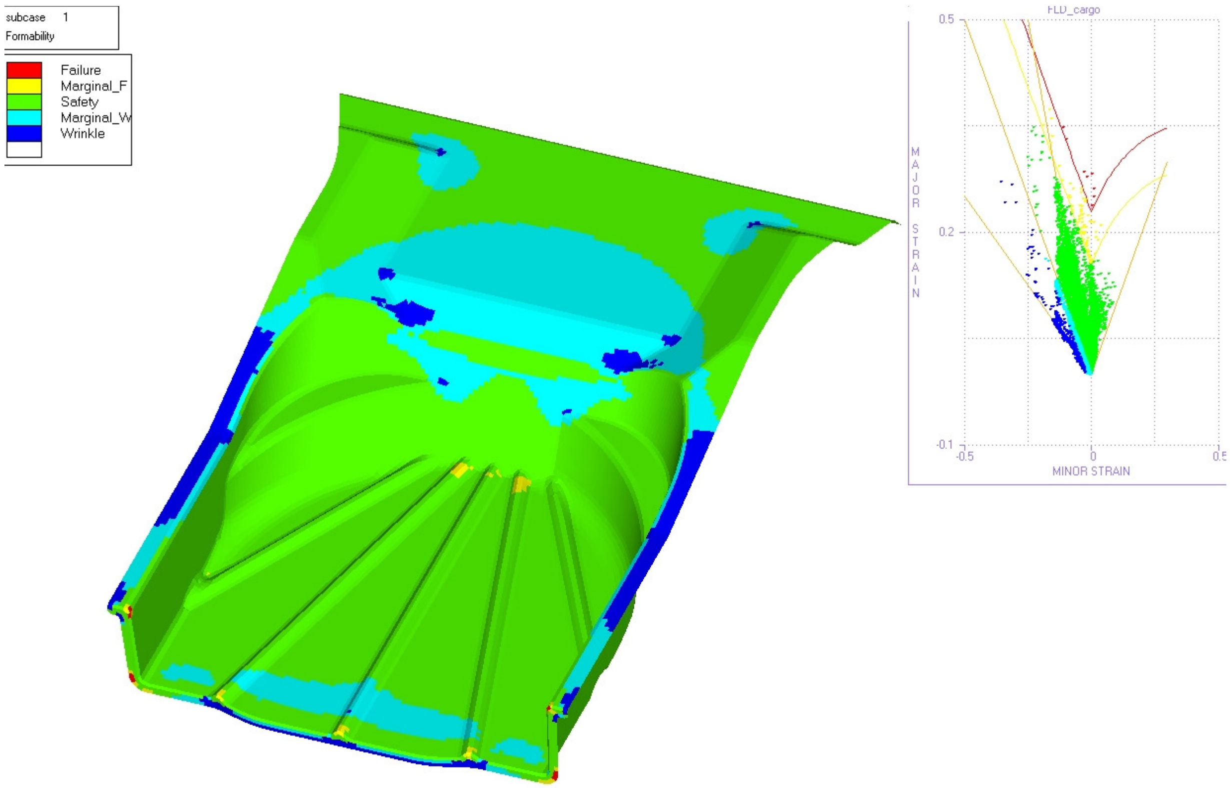


Figure 131: Single step results for Rear Cargo Floor

5.7.6 Serviceability and Repair-ability

Serviceability and reparability were given due to care engineering consideration during the design stage of all proposed solutions for the LWV.

All OEMs have documented guidelines for serviceability design in one form or another. The guidelines address the issue of corrective and preventive maintenance, and diagnostic capabilities. Design for Serviceability (DFS) takes into account repair costs from part accessibility which includes labor, parts and repair times.

5.7.6.1 Body Repair as a Result of Collision Repair

Each vehicle has its own issues when the body structure requires repair as a result of a vehicle collision. An insurance appraiser will assess the repair costs related to the total vehicle cost. Generally, there is a cut-off between 70% and 75% of the vehicle cost below which it is cost effective to repair the vehicle. The 70-75% of the vehicle cost accounts not only for the repair cost for the body structure but also for repair costs for all exterior and interior trim parts. With the introduction of high strength steels and the increasing degree of difficulty of completing the repair these cut-off percentages becomes a critical factor. Closures, doors, hoods fenders and tailgates are an easy repair fix as these parts are bolt-on and can be easily removed for repair, small amounts of damage can be repaired or when the damage is excessive the part will be replaced.

For the repair of the body structure there are mainly two repair methods used, push/pull and section and replace. These operations are completed on a vehicle body repair rig. See Figure 132 for a typical vehicle repair rig.

Figure 132: Typical vehicle body repair rig.

Push/pull type of repair is done with a distorted part, which is out of position due to collision damage. These parts are either pulled or pushed to the correct position by using a chain and a hydraulic ram that is mounted on the vehicle repair rig.

See Figure 133 showing the straightening of a Front Rail and Figure 134 for the repositioning of the Front Shock Tower in a body repair rig.

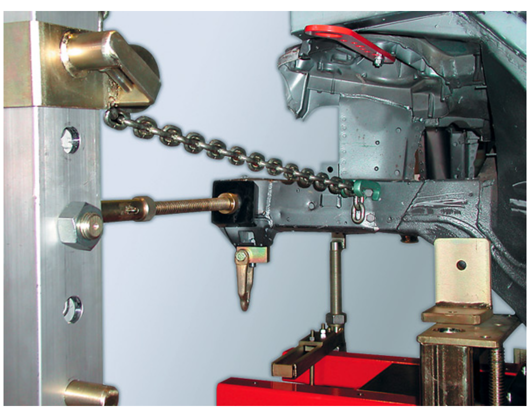


Figure 133: Straightening of a Front Rail

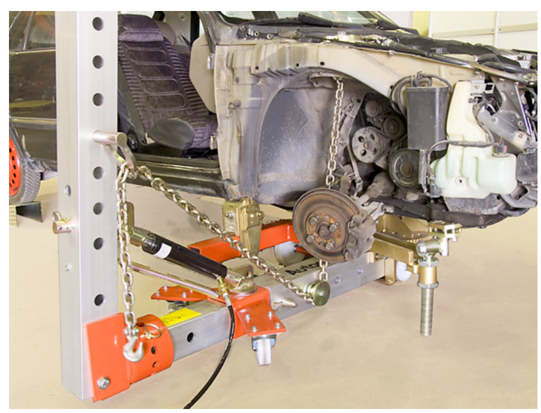


Figure 134: Pulling of the Front Shock Tower

Section and replace repair is done when a damaged part is cut from the body structure and replaced. The OEMs in conjunction with their internal service department determine where the body structure, for example, is to be cut (sectioned) for the body repair. Typically for the body side a notch or indent is added to the body side outer door flanges during the stamping process to define the cut plane. During the repair the part is then cut at the place marked and removed from the body structure and an OEM service part is then welded to the body to complete the repair. Service parts are special parts reworked from a complete stamping, for example the Body Side panel would result in an A-Pillar lower, B-Pillar outer service parts.

Where MIG welding is used to attach the service part to the body structure, there would be slots and holes added along the joining flange to allow for MIG welding. This would be used when spot weld gun access is not feasible due to the other body components being in-place on the complete body or when the body is laser welded using a reduced welding flange width. The MIG weld would then be ground flush to complete the repair. Where the original joint is spot welded a similar joining process would be used, depending on weld gun access. In the case of an overlap joint MIG welding is used either on the edge of the part or 'puddle' welding to complete the repair. See Figure 135 for typical body side service parts.

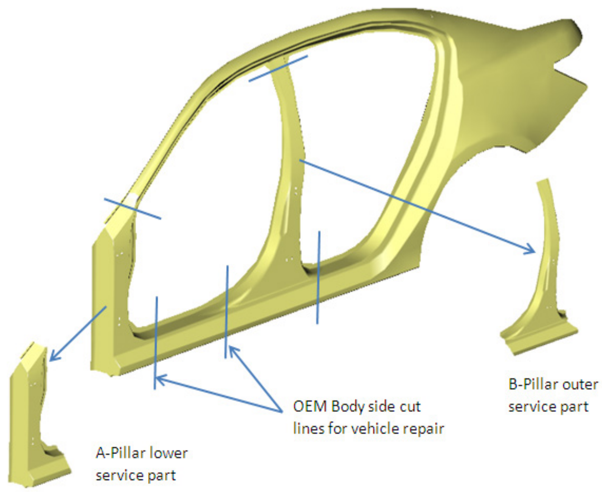


Figure 135: Body Side service parts from body side outer production panel

The use of Ultra-High-Strength-Steel (UHSS) in the body structure presents its own repair issues. For example when there is minor deformation, the B-pillar that has a component of UHSS with a tensile strength of 1200MPa or higher could be straightened in a repair rig. See Figure 136 for the straightening of the B-Pillar in a repair rig with a section of the body side outer removed.

Figure 136: Straightening of a b-pillar in a repair rig

When there is a major damage to the B-Pillar, the pillar would normally be cut/sectioned at the upper door hinge level, if steel below a tensile strength of 750MPa is used. But when the pillar has components of UHSS with a tensile strength of 1,200Mpa or higher as in hot stamped parts the OEMs recommend that the pillar should be completely replaced and not cut/sectioned.
The GM Cadillac SRX collision repair guide states that the B-Pillar is to be fully replaced due to the UHSS content. In this case the service B-Pillar will come as a complete assembly which includes the inner panel reinforcement with a section of the outer panel. It also recommends that any part with a tensile strength greater than 800MPa cannot be repaired and should be replaced.
The final operation after the body has been repaired is a dimensional check, which is completed on a dimensional rig, to ensure that the body is within the OEM's recommended dimensional tolerances. Figure 137 show a typical body dimensional checking rig.

Figure 137: Body dimensional checking rig

The LWV which has a high percentage of AHSS and UHSS will adopt the above body repair methods and procedures. These methods are already in place at most body repair shops.

5.7.7 Ergonomics

The seating position and the drivers reach to control all vehicle functions on the proposed vehicle are similar to the baseline vehicle.

5.7.8 Aesthetics

The look and feel of interior surfaces is a key user feature in vehicle preference, comfort and safety. Materials chosen for the interior of the LWV conform to acceptable surface aesthetics, durability and interior safety. All interior surfaces that are within the contact zone with the occupants head have to meet FMVSS No. 201 "Occupant Protect Interior Impacts" requirements. Although the detail design of the trim elements is outside the scope of this study, due care engineering guidelines were used to determine the suitability of the chosen materials. For example, during accidents interior surfaces should exhibit safe modes of failure without sharp jagged edges, and the interior surface elements chosen for the LWV are the similar to the baseline vehicle. These materials are known to be safe. For aesthetics purposes, the exterior visible surface is classed as 'class A' and required to have a very high quality surface that is suitable for taking the required surface treatment to accept automotive grade paint.

5.8 Light Weight Vehicle System Technology Assessment, Costing and Selection

5.8.1 Cost and Mass Assessment of Technology Options

For each of the recommended technology option 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 over the baseline vehicle was then calculated. This cost number was used to establish a preliminary cost for mass savings (calculated in $/kg 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 still consistent with the other parameters of the study during the proof of concept stage, was implemented in the final LWV design. Further, the project team performed a detailed incremental cost analysis on the Honda Accord LWV as discussed in Section 9.

The estimated cost developed in the proof of concept stage for each design option was based upon material substitution from the current baseline vehicle design with AHSS, aluminum and magnesium 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 majority of the materials the base material prices were attained from published sources and by consulting material suppliers or buyers. The average cost of the different material grades were established based on 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 (more than 590 MPa). The base prices of steel, aluminum and magnesium are discussed in Section 9.5.1. The prices for gray iron and SMC are not available through published sources, and hence were established based on consultation with industry experts including data from manufacturers of components using the specific material. The scrap return premiums were attained from MetalPrices.com[118]

2. Manufacturing Process Scrap, Material Cost with Manufacturing and Manufacturing Difficulty – 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 is the effective material price after taking into consideration also the manufacturing process scrap and scrap return premium. The manufacturing difficulty takes into account factors such as cycle time and the feasibility of the technology for high volume production[119]. These parameters were established based on consultation with industry experts including data from manufacturers of components using the specific material.

[118]http://www.metalprices.com/introduction/description_of_services.htm
[119] A typical annual production of 200,000 used for this study (refer Figure 399 for the general assumptions)

The material cost and manufacturing factors assumed for the initial cost estimated are summarized in Figure 138. The cost analysis of the final LWV 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 138 were used in the proof of concept stage and only for the preliminary cost assessment of the different options; the LWV incremental cost analysis is discussed in Section 9. LWV costs are calculated based on the design of the vehicle after the vehicle design is finalized.

Material	Material Cost ($/kg)	Manufacturing Process Scrap (%)	Scrap return premium ($/kg)	Manufacturing Difficulty Factor	Material Cost with Manufacturing ($/kg)	Reference (Material Cost)
Steel upto 590 MPa strength - Average	1.14	45%	0.44	1.00	1.46	Platts - WorldAutoSteel
Steel AHSS Average	1.44	45%	0.44	1.10	2.08	Platts - WorldAutoSteel
Aluminum Sheet	4.26	45%	2.38	1.10	5.62	Platts
Aluminum Cast	2.54	3%	2.22	1.30	3.31	Platts
Magnesium Cast	4.98	3%	2.44	1.30	6.57	Platts
Vynel Ester Compound	4.24	10%	0.00	1.10	5.13	DAS 2010
Fiber Glass	1.50	20%	0.00	1.50	2.70	DAS 2010
Carbon Fiber	17.60	20%	0.00	2.00	42.24	DAS 2010
Gray Iron/steel	1.50	5%	0.44	1.30	2.02	Supplier
SMC	3.00	5%	0.00	1.30	4.10	Supplier

Figure 138: Material Costs and Manufacturing Factors[120]

5.9 Body Structure

5.9.1 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 structure for high and low volume production are illustrated in Figure 139. For high volume (over 100,000 annual) production vehicles the economic choice for material is generally steel and Advanced High Strength Steel (AHSS), with spot welding as 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 on existing platforms. For example, the Honda Accord shares the platform with several other medium size Honda vehicles (such as the Acura Sedan, Japan Minivan, European/Japan Accord, etc.).[121] Due to some of the required compromises inherent in platform sharing, since a platform has to work for all vehicle models built on it, this generally leads to higher mass solutions that permit reduced research and development and reduced tooling costs.

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

[121] M. Sasaki et al: The New Honda Accord – International Circle of Experts Car Body Engineering 16/17/18 October 2007, Bad Nauhelm, Frankfurt "EuroCarBody 2007"

Use of aluminum is thus far more common in high performance, high premium cost vehicles. The assemblies of these structures make greater use of adhesive bonding and mechanical fasteners. These coupled with laser welding leads to increased structural performance and hence lower structure mass.

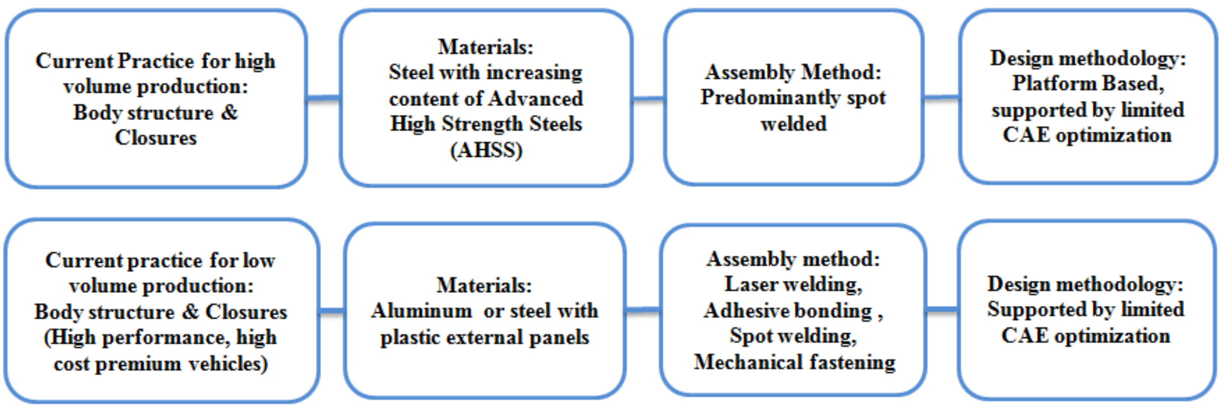


Figure 139: Material, Assembly Method and Design Methodology for High and Low Volume Production Body Structures

The baseline 2011 Honda Accord body structure is a modern unibody monocoque structure constructed from High Strength Steel (HSS). The mass of the painted body structure with the sprayed-on sound deadening material was weighed to be 339 kg. By removing the typical allowance for paint and sprayed-on sound deadening of 12 kg, the structure of the Body in White (BIW) mass of the Accord is estimated to be 328 kg. This is 22% of the total weight of the baseline Honda Accord. Previously published data by Honda[122] shows the HSS usage on the body structure to be 48% of the mass as shown in Figure 140. This is equivalent to an average tensile strength of 412 MPa.

[122] M. Sasaki et al: The New Honda Accord – International Circle of Experts Car Body Engineering 16/17/18 October 2007, Bad Nauhelm, Frankfurt “EuroCarBody 2007”

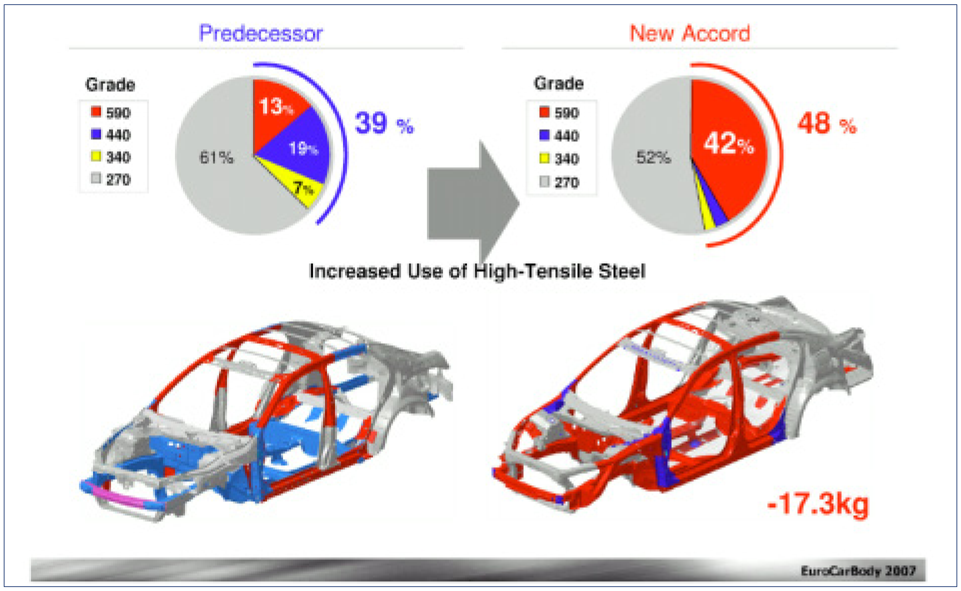


Figure 140: Honda Accord Body Structure Use of HSS

5.9.2 Selection of Technology for Body Structure

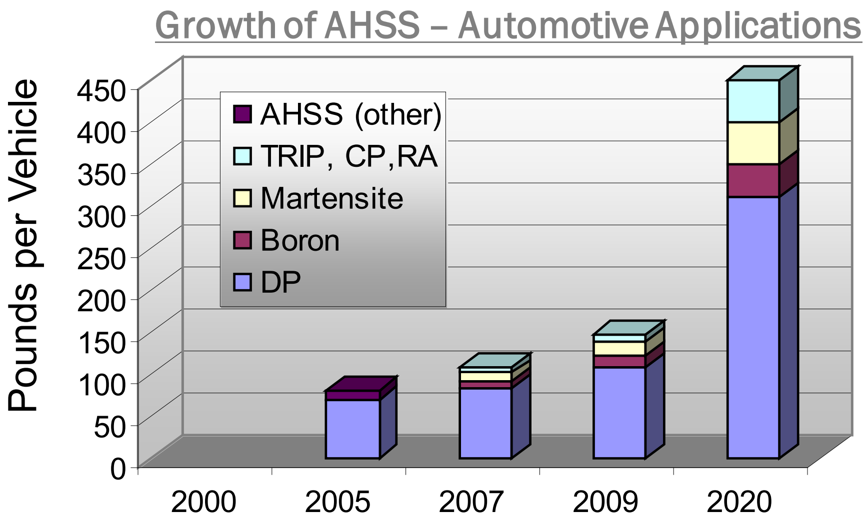
5.9.2.1 Option 1: Advanced and Ultra High Strength Steel

One possibility for reducing mass is maximizing the use of AHSS for the body structure. As the body structure is subject to several high energy absorption crash requirements (front, side and rear high speed impacts, and roof crush), advanced ultra-high strength steels with extremely high tensile strength (up to 1500 MPa), offer a good solution at fairly low cost premiums. This has led to a significant growth in the use of AHSS for automotive applications as shown in Figure 141.[123]

Some of the Advanced and Ultra High Strength Steel grade alloys (AHSS/UHSS) under consideration for the LWV are:

- Transformation Induced Plasticity (TRIP)
- Complex Phase (CP) steel
- Recovery Annealed (RA) steel
- Martensite steel
- Boron steel for Hot-Stamping
- Dual Phase (DP) steel

[123] Drucker Worldwide (2009)



Source: *Ducker Worldwide (2009)*

Figure 141: Use of AHSS for automotive applications

The baseline Honda Accord makes use of 590 MPa grade of steel, achieving an average tensile strength of 412 MPa for the total body structure. Advantage can be taken of much higher grades of steel in areas of the body 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 the World Auto Steel on Future Steel Vehicle, with use of Ultra High Strength grades and use of Hot-Stamping manufacturing techniques, the average tensile strength of steel can be increased to over 700 MPa, with a mass saving potential of 25%.[124]

Further reductions in weight can be achieved over what is described in Option 1 above (that is, simply maximizing use of AHSS in the body structure) by filling selected structural components 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 implemented on LWV body structure due to concerns expressed by some team members about difficulty in 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 be (easily) removed from the scrapped vehicle for recycling. Even though there is no regulation requirement for recycling in US currently, there are these requirements in other markets, such as Europe and Japan. If the vehicle is designed for multiple markets, OEMs would possibly try to avoid these technologies.

For Option 1, an overall mass reduction of 22%equates to a mass savings of 72.8 kg with the actual body structure of the LWV weighing in at 255.2 kg compared to the baseline Honda Accord's weight of 328 kg. See Figure 142 for details on the mass delta.

[124]Source: WorldAutoSteel – FutureSteelVehicle
http://www.worldautosteel.org/Projects/Future-Steel-Vehicle

Body Structure	Honda Accord Mass	Mass Reduction		
		%	LWV Mass (kg)	Mass Savings (kg)
AHSS	328.0	22%	255.2	72.8

Figure 142: LWV Body Structure Option 1 Mass Delta Relative to Baseline Honda Accord Body Structure - Material AHSS

AHSS, with its high tensile strength, offers a good solution at a fairly and comparatively low cost premium. From a cost perspective, Option 1 would result in an increase of $2.02 per kg for direct manufacturing cost, or an overall incremental increase of $147 per each body structure. The Option 1 incremental costs are discussed further in Section 9.6.1.

Material	Incremental Cost Increase ($)	Cost Increase Premium ($ / kg)
AHSS	$147	$2.02

Figure 143: LWV Body Structure Option 1 –Direct Manufacturing Cost Incrementalto Baseline Honda Accord Body Structure[125]

5.9.3 Option 2: AHSS based multi-material structure

Further reductions in weight can be achieved beyond that described by Option 1 by selectively replacing some of the steel panels with lower density materials. Example candidates for this option are the roof panel and the rear floor panels. Aluminum roof panels, for example, are currently in production on vehicles such as BMW's 7[126] series and Land Rover's Evoke[127]. The roof panel on the baseline Honda Accord, as shown in Figure 144, is a typical construction using 0.7mm thick Mild Steel (Mild 140/270) grade, which weighs 10.3 kg. For the AHSS body design (Option 1) the roof panel is constructed from 0.6mm Dual Phase (DP 300/500) grade steel, with a weight of 8.8 kg. By changing to an aluminum roof panel of 1.1mm thick grade AA6457, the weight is reduced to 5.5 kg. This is a mass saving of 4.7 kg from the baseline design, and 3.25 kg from Option 1.

[125]Cost Increase Premium is calculated by dividing the estimated incremental costs by the respective component/system mass savings

[126] Source: 12th International Car Body Benchmark Conference "EuroCarBody 2010"

[127] Source: 12th International Car Body Benchmark Conference "EuroCarBody 2010"

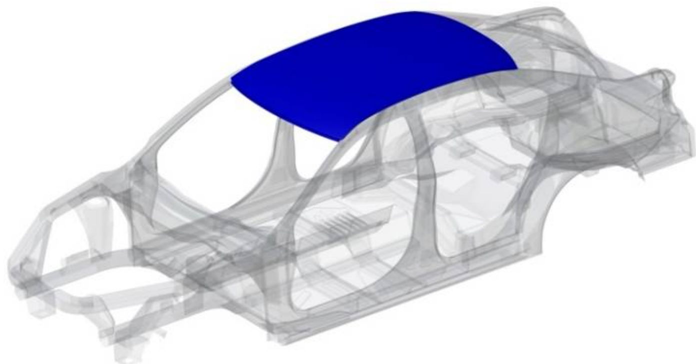


Figure 144: Roof Panel

The integration of an aluminum roof panel into a steel body structure cannot be accomplished using any of the welding technologies due to dissimilar metals. Instead, it has to be done using mechanical fixing and adhesive bonding. This can create its own complications during the vehicle manufacturing process. For one, if the roof is bonded to the body structure in the body shop prior to painting, due to the un-equal coefficient of expansion between steel and aluminum, problems can be encountered with rippling of the class-A surface of the roof panel. On the BMW 7, the roof panel goes through the paint shop un-attached to the body structure, and is adhesively bonded to the structure after painting in the vehicle assembly shop. This may be fine for a high cost and low volume production vehicle such as the BMW 7, 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 Land Rover – Evoke, the roof panel is bonded prior to the paint shop; Land Rover solved the problem through development of special adhesive and mechanical fastenings and optimizing the process parameters through computer simulations.[128] This approach may not be suitable for other vehicle architecture with different curvature roof panels.

The rear floor area of the body structure, as shown in Figure 145, is another area where alternate lower density material can be used to achieve mass reduction. This has been implemented in production, for example, on the Audi A8.[129] Some support structure in steel will still be required underneath the floor area. For any multi-material approach, an effective end-of-life has to be considered and solutions implemented for maximum recyclability. The various materials have to be separated (disassembled) and recycled.

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[128] Source: 12th International Car Body Benchmark Conference “EuroCarBody 2010”
[129] Source: 12th International Car Body Benchmark Conference “EuroCarBody 2010”

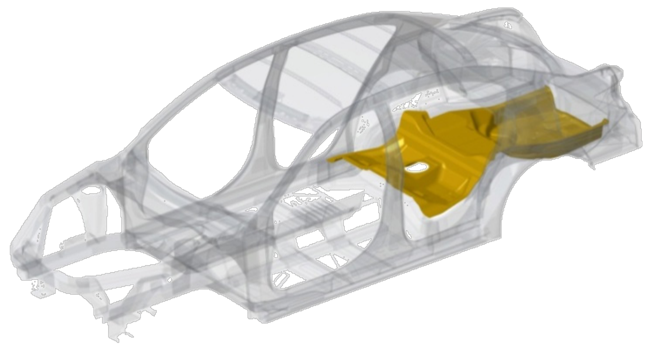

Figure 145: Rear Floor Glass Fibre Reinforced Composite Structure

One way to reduce mass by changing the rear floor area of the body structure is to use glass-filled polypropylene. Using this approach, 10.7 kg of the baseline structure can be replaced with 5.7 kg of glass-filled polypropylene, achieving additional mass saving of 5.0 kg. See Figure 146 for mass delta. Option 2 involves a body structure of AHSS weighing 236.2 kg, the roof panel would be aluminum and weigh 5.8 kg, the floor and shelf would be plastic composite and weigh 5.7 kg for a total weight of 247.7 kg. This "Option 2" (AHSS body structure with aluminum roof and glass-filled polypropylene rear floor area) leads to a mass reduction of 24.5% for the body structure, which equates to an overall mass savings of 80.3 kg.

	Body Structure	Honda Accord Mass	Mass Reduction		
			%	LWV Mass (kg)	Mass Savings (kg)
Option 2	Body Structure - AHSS	306.79	23%	236.2	70.6
	Roof Panel - Aluminum	10.5	45%	5.8	4.7
	Floor –Glass Fibre Reinforced Composite	10.71	47%	5.7	5.0
	AHSS + Aluminum + Glass Fibre Reinforced Composite	328.0	24.5%	247.7	80.3

Figure 146: LWV Body Structure Option 2 - Incremental Mass Compared with Baseline Honda Accord Body Structure

From a cost perspective, the incremental direct manufacturing cost over the baseline vehicle body structure is equal to $175.7. The implementation of this option poses a higher risk of not meeting high volume manufacturing schedules; because of un-conventional joining methods that will have to be developed and implemented that achieve high level of class A surfaces. See Figure 147 for incremental direct manufacturing cost for this option relative to baseline vehicle body structure cost.

	Material	Incremental Cost Increase ($)	Cost Increase Premium ($ / kg)	Incremental from Option 1 – AHSS ($ / kg)
Option 2	Body Structure - AHSS	$142.3	$2.02	
	Roof Panel - Aluminum	$17.2	$3.63	
	Floor -Glass Fibre Reinforced Composite	$16.3	$3.23	
	AHSS + Aluminum + Glass Fibre Reinforced Composite	$175.7	$2.19	$3.84

Figure 147: LWV Body Structure Option 2 - Incremental Direct Manufacturing Cost Compared with Baseline Honda Accord Body Structure

5.9.4 Option 3: Aluminum Body Structure

Another mass reduction alternative would be to maximize use of aluminum, combined with the use of plastic for some large non-structural body panels (as demonstrated on the Audi A8)[130]. 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 35%. A cost comparison study from 2001[131] showed that the cost of an aluminum body structure compared with a steel structure to be typically $600 more for the manufacturing and assembly. This is also a rule of thumb used in the industry by some of the body design engineers.

The 2011 Audi A8 body structure has an aluminum space-frame. The actual space-frame consists of a combination of aluminum extruded sections, stampings and castings that are welded to each other. The structure is illustrated in Figure 148.

[130] Source: 12th International Car Body Benchmark Conference "EuroCarBody 2010"
[131] Source: Kelkar et al: Automobile Bodies: Can Aluminum Be an Economical Alternative to Steel? August 2001 Issue of JOM., 53 (8) (2001)pp. 28-32.

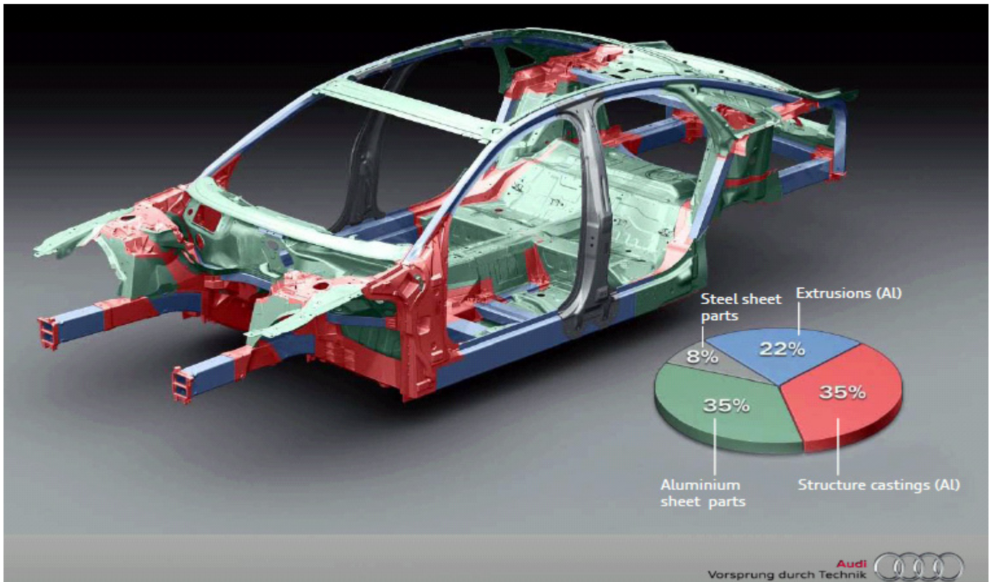

Figure 148: Audi A8 Aluminum Intensive Body Structure[132]
(Total Weight Body-in-White without Doors, Closures, and Fenders—213 kg)

Several grades of aluminum 3000, 5000 and 6000 series are used in the construction of the structure. For maximum recyclability and end-of-life process has to 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.[133]

The calculated weight for the LWV body structure for this option is 213 kg, as shown in Figure 149. The 35% weight saving is equivalent to 114.8 kg mass reduction when compared with the baseline Honda Accord. The 213 kg body structure mass is comparable to the 231 kg mass for the Audi A8 space frame structure. Interestingly, the Audi A8 is similar size dimensionally comparing to Honda Accord but is considerably heavier, due it its heavier (luxury) content and larger engine.

From a mass reduction standpoint, an aluminum-intensive approach seems to be a good alternative to AHSS. However, a cost comparison study shows that the cost of an aluminum body structure compared to that of AHSS structure to be $$573.4 higher ($720.2 compared to the baseline). Additional mass reduction achieved by aluminum intensive body structure is 42 kg over the AHSS solution, equivalent to $13.65 per kg mass saving.

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[132] Source: 12th International Car Body Benchmark Conference "EuroCarBody 2010"
[133] Source: 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

Body Structure	Honda Accord Mass	Mass Reduction		
		%	LWV Mass (kg)	Mass Savings (kg)
Aluminum Intensive	328.0	35%	213.2	114.8

Figure 149: LWV Body Structure Option 3 - Incremental Mass Compared with Baseline Honda Accord

Material	Incremental Cost Increase ($)	Cost Increase Premium ($ / kg)	Incremental from Option 1 (AHSS) ($ / kg)
Aluminum Intensive	$720.2	$6.27	$13.65

Figure 150:LWV Body Structure Option 3 - Incremental Mass Compared with Baseline Honda Accord

5.9.5 Option 4 – Composite Body Structure

Composites offer many advantages compared to traditional materials, such as significant mass reduction and superior corrosion resistance. Nevertheless, it is still believed by many in the industry that a good understanding of composites at the engineering level for automotive applications is lacking. In our opinion to implement composites on a large scale bases to high volume production, four major breakthroughs are required:

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

This type of advancement and high volume implementation is highly unlikely over two to three vehicle design cycles by MY 2020. The application of composites to date has been limited to a few premium vehicles with low production volume. The most excitement in this field has been created by BMW's announcement of applying composites to the body structure for an electric vehicle (I3) to be available in 2013, as shown in Figure 151. The projected annual production volume for the BMW i3 is 30,000 vehicles. BMW claims a mass savings potential of 50% using the composites. Calculations based on this figure would estimate a mass savings of 164 kg for the LWV body structure as shown in Figure 152.

Figure 151: BMW i3 – Composite and Aluminum Structure – Production Year 2013

Body Structure	Honda Accord Mass	Mass Reduction		
		%	LWV Mass (kg)	Mass Savings (kg)
Composite	328	50%	164.0	164.0

Figure 152: LWV Body Structure Option 4 - Incremental Mass Compared with Baseline Honda Accord Body Structure

The calculated costs for the composite Option 4 are shown in Figure 153.

Material	Incremental Cost Increase ($)	Cost Increase Premium ($ / kg)	Incremental from Option 1 (AHSS) ($ / kg)
Composite	$2,512.1	$15.32	$25.94

Figure 153: LWV Body Structure Option 4 - Incremental Direct Manufacturing Cost Compared with Baseline Honda Accord Body Structure

Another option for weight reduction of body structures is a multi-materials approach, such as a hybrid structure made from several readily available materials, such as AHSS, aluminum, magnesium and plastic composites. This would, however, require several innovations in joining the dissimilar materials which have not yet occurred at high production volume level, 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% 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[134]. This increase in cost is due to higher cost of the material used and joining methods. The joining methods implemented on the SLC add 2.00€ per kg mass saving. With the 10% increase limit in retail cost of the proposed LWV, this option would be too expensive to implement and unlikely to be a viable solution for 2020 model year vehicle for high volume production.

[134] Source: 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

5.9.6 Risks and Trade-offs Body 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 the traditional stamping materials. Stamping forming simulation has to be used extensively to determine forming parameters at tool design stage to determine the narrow forming window required for the AHSS.

The body structure is subjected to several high energy absorption crash requirements (front, side and rear high-speed impacts, and roof crush). Using AHSSs with extremely high tensile strengths (up to 1,500 MPa) offers a structurally safe solution at fairly low cost premiums.

The different body structure weight reduction options are summarized in Figure 154.

Component	Technology Options	Benefits	Risks and Trade-offs
Body structure	Option 1: AHSS and Ultra High Strength Steel	Weight savings up to 25% , low cost	Manufacturing limitations, Spring back
	Option 2: AHSS based multi-material, Aluminum Roof, Glass Fibre Reinforced Composite Floor, Glass Fibre Reinforced Composite Shelf	Weight savings 25% to 30%	Higher costs, Manufacturing & Assembly limitations, end of life recycling
	Option 3: Aluminum	Weight savings up to 35%	Higher costs, Manufacturing & Assembly limitations
	Option 4: Composites/Multi-material	Weight savings over 35%	High Cost of material, Manufacturing & Assembly. Further development for high volume production

Figure 154: Body structure weight reduction options summary

5.9.7 Body Structure Selection

The team decided to design the future LWV body structure with AHSS. This choice of material has several driving factors. The study shows that there are other, lighter, materials producing a larger mass savings with the same structural integrity. However, their overall material cost and lack of cost effective manufacturability for high volume does not make them an optimal choice.

The current design of AHSS for the LWV weighs 255.2 kg. The baseline 2011 Honda Accord is 328 kg with a difference between the new design and the baseline of 72.8 kg. There is a cost increase premium incurred of 2.02 ($/kg) with the overall incremental cost increase of $147 with this choice.

The multi-material choice (AHSS, Aluminum and Composite) has a weight of 247.7 kg with the difference from the baseline Honda Accord being 80.3 kg. The cost premium increase incurred with this choice is 2.19 ($/kg) with the overall incremental cost increase of $175.7 (an incremental cost increase of 3.84 ($/kg) from the AHSS option). This option would only save an additional 7.5 kg and is hard to justify the cost increase with the mass savings.

A choice of an aluminum intensive body structure would weigh 213.2 kg producing a difference between the baseline Honda Accord of 114.8 kg. There is a cost increase premium incurred of 6.27 ($/kg) with the overall incremental cost increase of $720.2 with this choice (an incremental cost increase of 13.65 ($/kg) from AHSS).

The option of a composite body structure would weigh 164.0 kg producing a difference between the baseline Honda Accord of 164.0 kg. There is a cost increase premium incurred of 15.32 ($/kg) with the overall incremental cost increase of $2512.1 with this choice (an incremental cost increase of 25.94 ($/kg) from AHSS). While this creates a weight reduction of 50% over the current model design, it too cannot be justified with the large cost increase and additional manufacturing limitations. The composite choice far exceeds the overall cost limit of this study which is 10% cost parity with the baseline vehicle[135].

Steel has almost always been found to be the most cost-effective option given the high production volumes found in the overwhelming majority of vehicle models. The maximum use of AHSS for the body structure is a conservative possibility for reducing mass. Pound for pound, AHSS is more costly than regular steel. But since it has much higher strength, less material is required; the net effect is that lower weight structures are achieved with minimal cost premium.

Comparison between the Baseline and LWV Body Structure material grade strength levels are shown in Figure 155. The baseline Honda body structure which weighs 328kg is designed using high strength steel[136] with an average tensile strength of 412 MPa. The LWV body structure achieved a weight reduction of 22% (72.8 kg) by utilizing optimized designs in advanced and ultra high strength steels with high tensile strength (>1000 MPa). The average tensile strength of the steel grades selected for the LWV body structure is 757 MPa. As the body structure is

[135] 10% of the baseline MSRP - $2198; based on Honda Accord 4DR-LX Window Sticker shown in Figure 3
[136] M. Sasaki et al: The New Honda Accord – International Circle of Experts Car Body Engineering 16/17/18 October 2007, Bad Nauhelm, Frankfurt "EuroCarBody 2007"

subjected to several high energy absorption crash requirements ultra-high strength steels offer a structurally mass efficient solution.

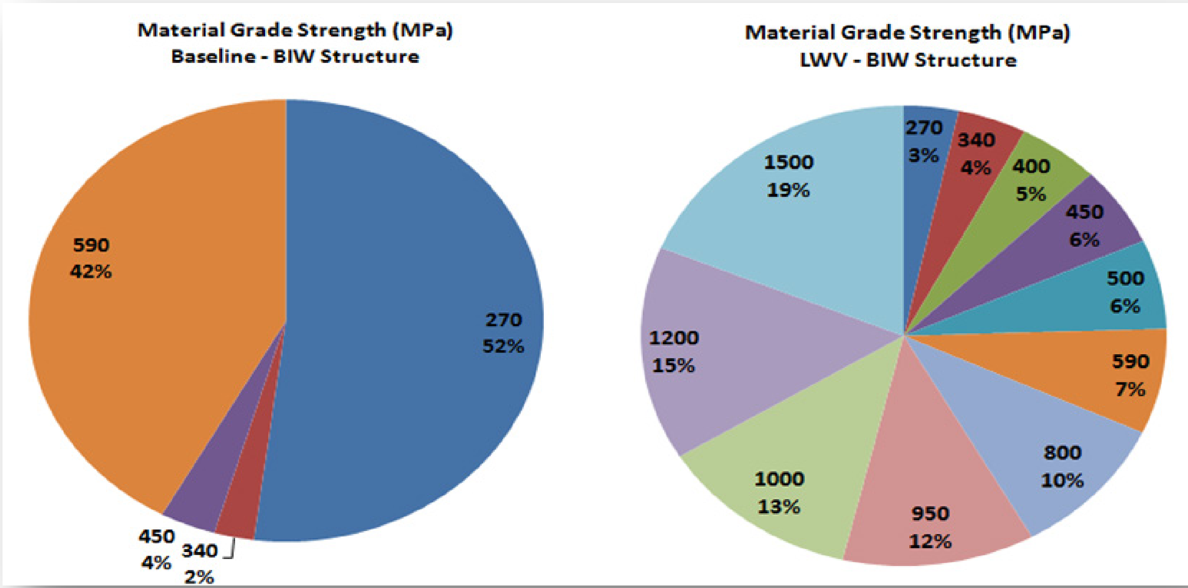

Figure 155: BIW Structure – Material Grade Strength Comparison – Baseline[137] v LWV

The LWV body structure also maintains manufacturing feasibility for high volume production by applying favorable designs and taking advantage of the additional formability within the same tensile strength of certain grades of steel such as DP (Dual Phase) and TRIP (Transformation induced plasticity). The availability of the specified AHSS grades and thicknesses used for the body structure panels were confirmed with North American steel suppliers. The LWV body structure material portfolio is illustrated in Figure 156.

[137] M. Sasaki et al: The New Honda Accord – International Circle of Experts Car Body Engineering 16/17/18 October 2007, Bad Nauhelm, Frankfurt "EuroCarBody 2007"

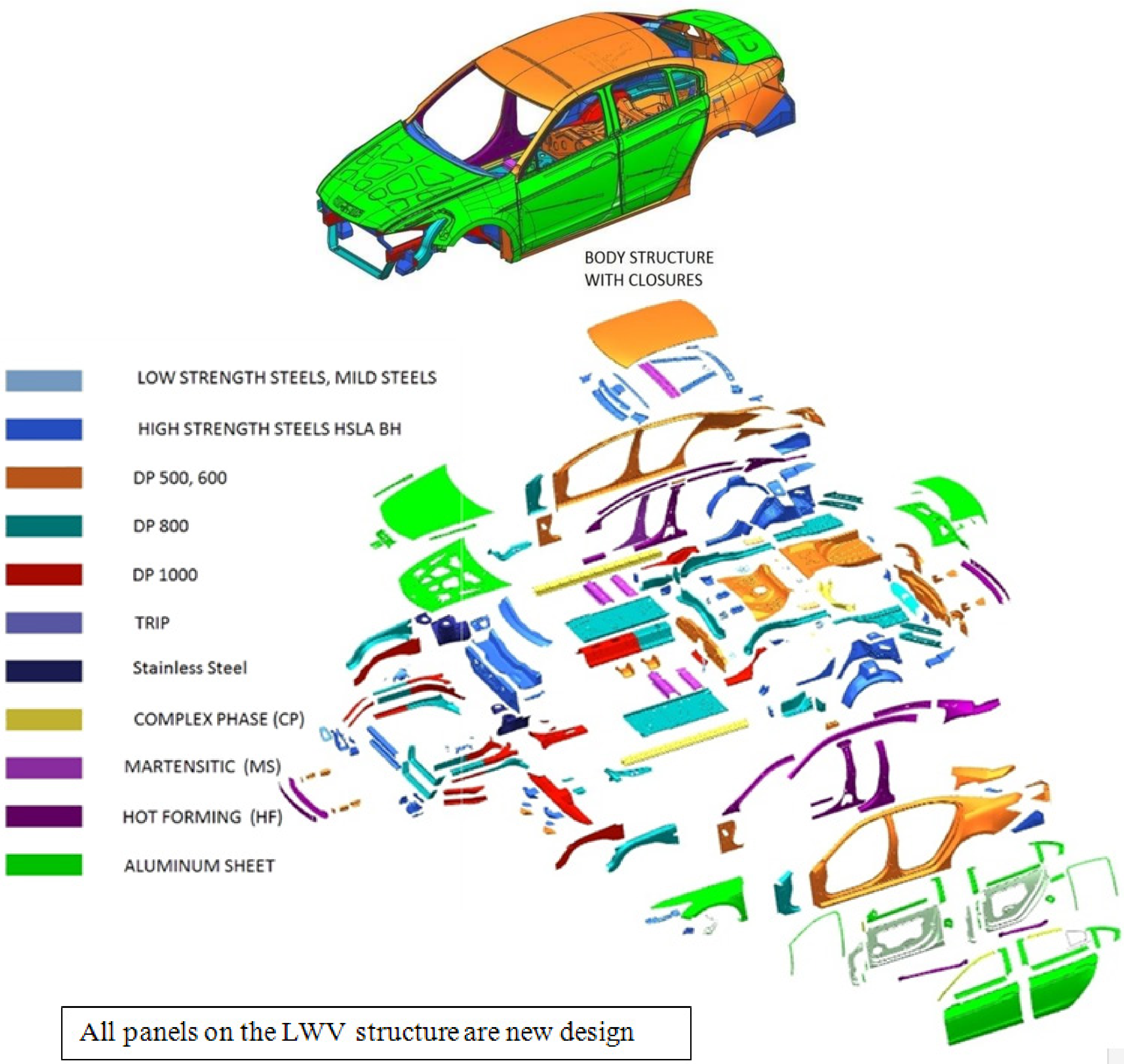

Figure 156: LWV Material Portfolio

5.10 Closures and Fenders

The closures on a vehicle are defined as the doors, hood and decklid. The fenders, being bolt-on parts, are also included with the closures in this section. The closures are shown in Figure 157. The total mass of these assemblies as shown in Figure 158 includes every part of the complete assembly; all primary structure, mechanisms, linkages, hinges, latches, locks, electrical components, glass, mirrors, seals, trim, brackets, reinforcements and fasteners. The total mass of the closures and fenders on the baseline 2011 Honda Accord is 147 kg. The structural mass 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. The structural mass of the closures and fenders is 92kg, making up 6% of the total vehicle mass (1480 kg).

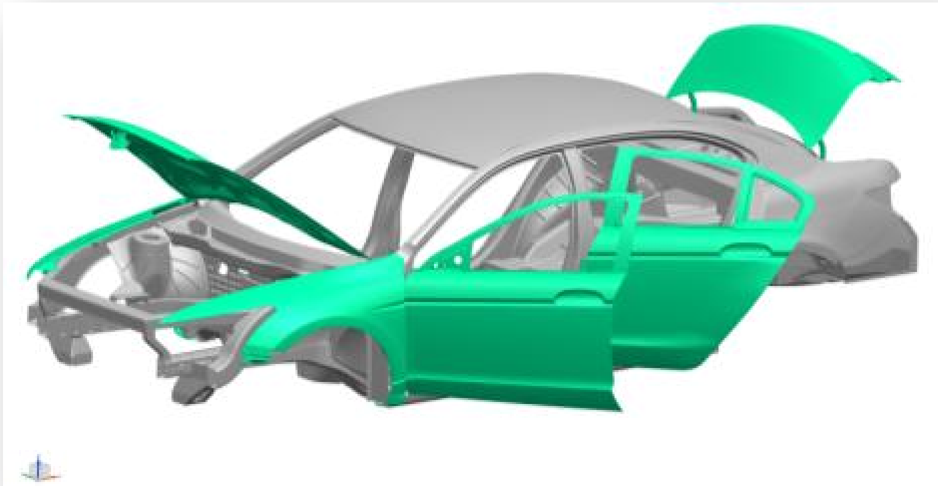

Figure 157: Components Included as Closures and Fenders

	Total Mass (kg)	Structural Mass (kg)	Construction
Front Doors	58.99	32.78	Steel Stamping Outer & Laser Welded Blank Inner
Rear Doors	47.46	26.76	Steel Stamping Outer & Laser Welded Blank Inner
Hood	17.89	15.20	Steel Stamping Outer & Inner
Deck Lid	12.37	9.95	Steel Stamping Outer & Inner
Fenders	7.35	7.35	Steel
Total	**144.06**	**92.04**	

Figure 158: Summary of Baseline Closures Mass

The use of Advanced High Strength Steel (AHSS) provides the potential for approximately 15% mass savings for closures. This is not as high as the potential for mass savings due to AHSS in the body structure because the loading requirements are different for the two areas of the vehicle. The design of the body structure is mostly dependent upon the tensile strength of the material, while closures are more dependent upon the stiffness (the modulus of elasticity). The benefit of AHSS is its increased tensile strength; the modulus is unchanged from that of standard steel. One closures 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 body structure, and there are more choices of mature technologies currently available that can offer significant mass reduction opportunities. For example, aluminum hoods are already in use on several high volume production vehicles. Stamped aluminum doors are used, for example, on the Audi A6 and A8, the BMW 5 series and the Jaguar XJ8. The use of magnesium castings for decklids and tail gates (e.g., the 2010 Lincoln MKT) and door inner panels could lead to mass savings up to 50% on some structural components of these assemblies. These options will be discussed below.

Carbon fibre hoods and fenders are used on some premium, low volume vehicles such as the Corvette ZR1 and Lexus LFA. Carbon fibre construction has a tremendous mass saving advantage over steel structures. Carbon fibre 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 which 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 (RTM) and Vacuum Injection (VI) are the principal processes used for automotive applications of composite materials. In these processes the reinforcing materials (carbon fibres, fibreglass, etc.) can be inserted into the mold in sheets and have the thermoset or thermoplastic resin injected into the closed mold, or chopped fibres 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. Other factors to consider are that the 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 Honda Accord.

5.10.1 Cost and Mass Assessment of Technology Options

For each of the closure assemblies (front and rear doors, hood, decklid and fenders), the options for construction material and manufacturing technologies and the associated estimated mass savings were first identified. For each design option, an increase or decrease in the cost over the baseline vehicle was then calculated. This cost number was used to establish a cost for mass savings (calculated in $/kg mass saved) to assess the effectiveness of each option. The option considered to be the most cost effective was implemented in the final LWV design.

It should be noted that when the project team worked on the technology selection for the closure assemblies, the estimated initial cost of each design option was based upon material substitution from the current baseline vehicle design with AHSS, aluminum and magnesium, along with appropriate manufacturing process factors developed through EDAG team experience (summarized in Figure 138). The cost analysis of the final LWV design for each closure and fender assembly was refined as the design matured from the preliminary concepts to the final design; the LWV incremental cost analysis is discussed in Section 9.

5.10.2 Front Doors

5.10.2.1 Baseline

The front doors of the baseline 2011 Honda Accord are constructed of cold rolled sheet steel of various bake hardenable (BH) grades. The driver's front door assembly is shown in Figure 159. The major components of the complete door assembly are shown in Figure 160. These 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. The combined mass of both complete front door assemblies is 58.99 kg, as shown in Figure 161.

Figure 159: Baseline Front Door Assembly

Figure 160: Baseline Front Door Exploded View

Baseline Door Component	Mass (kg)
Frame	32.78
Glass	5.55
Glass regulator	2.24
Seals	2.16
Wiring Harness	0.87
Speakers	0.61
Hinges & Latch	3.26
Front Outside Mirrors	2.64
Trim (Plastic)	5.38
Miscellaneous Parts and Fasteners	3.50
Total	**58.99**

Figure 161: Baseline Front Door Mass – Combined Driver and Passenger

The combined mass of the door frame components is 32.78 kg. The inner panel carries the glass actuation hardware and the interior trim. The outer panel has a class 'A' surface which 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. The front door frame assembly can be seen in Figure 162. An exploded view is shown in Figure 163.

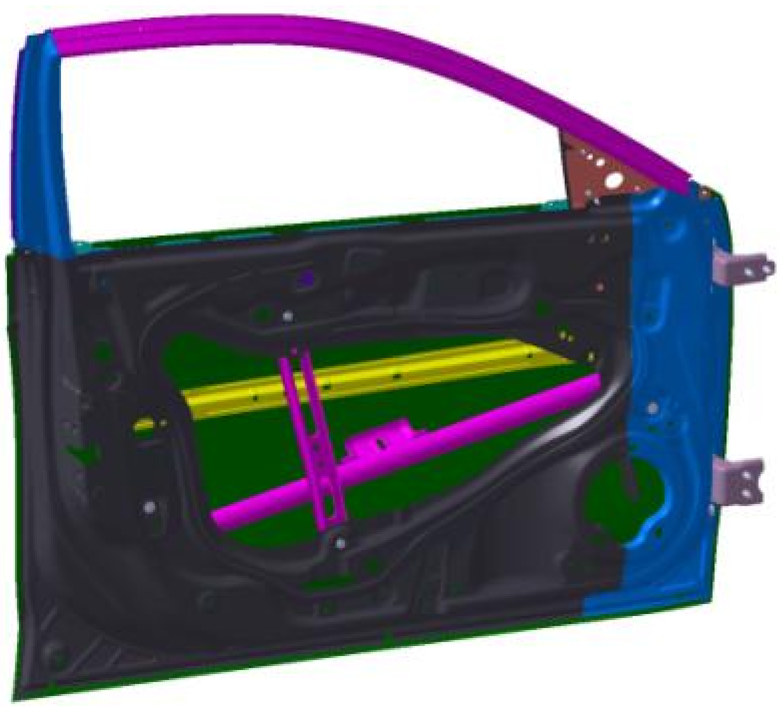

Figure 162: Baseline Front Door Frame Assembly

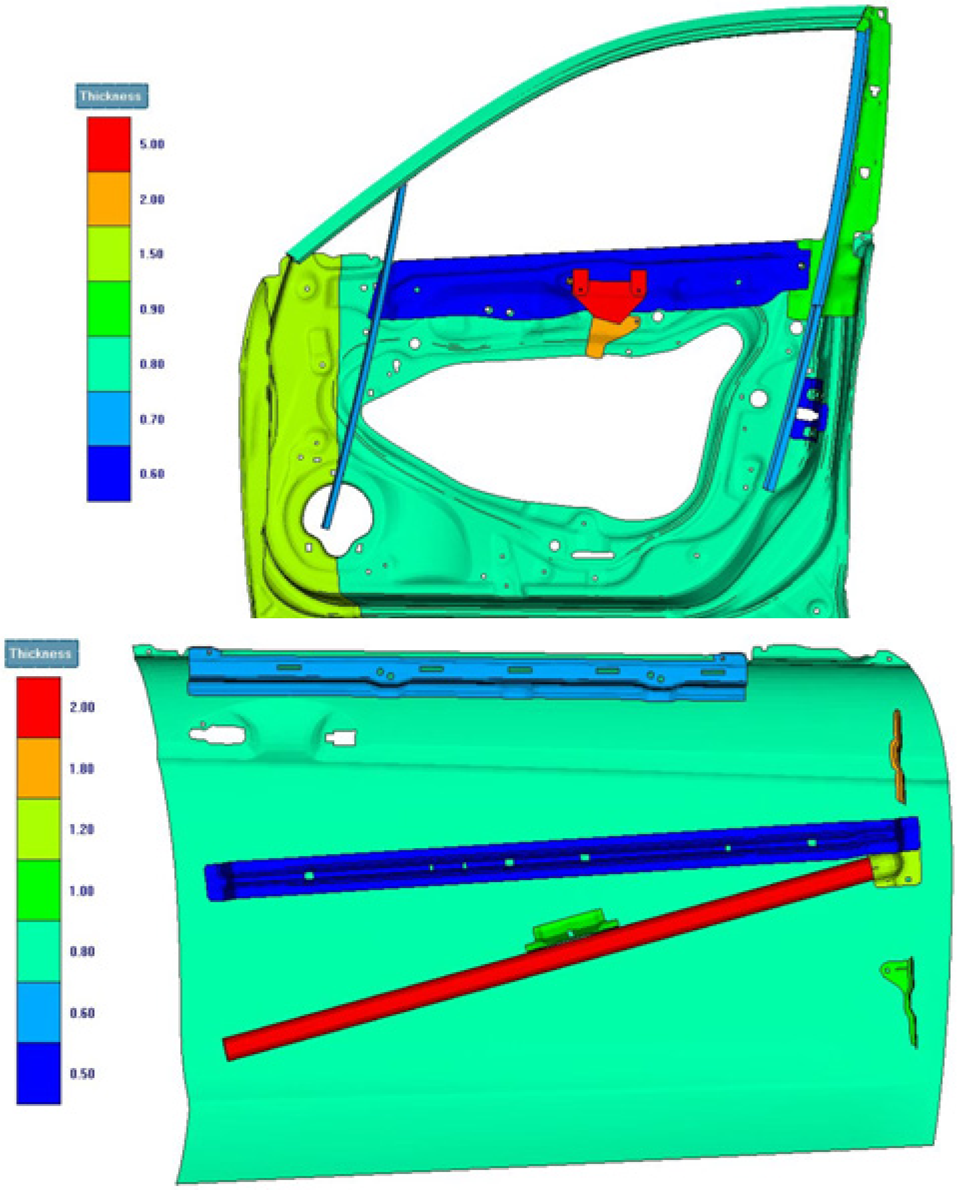

Figure 163: Baseline Front Door Frame Material (steel) Thickness (mm) Map

5.10.2.2 Front Door Technology Options

Three design options were considered for mass saving potential of the front doors. The rationale for the final selection is 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 to verify its feasibility and to demonstrate 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 recommended for the LWV.

Other components of the door assembly, such as the glass, seals, electrical components and trim, offer mass reduction potential, but were not addressed during the preliminary concept studies. The savings for these components would be similar for all the options and would not affect the selection of the LWV option. These parts were evaluated while developing the final design and the mass savings included in the final design analysis. 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 are carried over from the baseline.

The materials and manufacturing processes that are investigated for mass and cost of the door frame components are shown in Figure 164.

Technology Options	Benefits	Risks/Trade-offs
Option 1: Advanced High Strength Steel (AHSS)	Weight savings approximately 15%, existing production stamping presses can be used	Safe choice, conventional technology
Option 2: Aluminum Stamping	Weight savings 35% to 45%, existing production stamping presses can be used	Higher material costs, limitations in manufacturing & assembly
Option 3: Multi-material – Magnesium casting for inner panel and aluminum stamping for outer panel	Weight savings up to 50%, modularity of parts, outer panel can be stamped using existing stamping presses	High material cost, inner panel requires over 2500 Ton capacity High Pressure Die Casting Press, limitations in manufacturing & assembly, further development needed for high volume production

Figure 164: Door Frame Construction Options

5.10.2.3 Option 1 AHSS Front Door

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 (LWB), which is roller hemmed to a stamped outer door panel. The door frame, including intrusion beam, brackets and reinforcements, is constructed entirely of Advanced High Strength Steel (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. The mass of each AHSS front door frame is 13.94 kg, a 2.46 kg reduction per door from the baseline mass of 16.40 kg (15% decrease). For the vehicle, this is a mass savings of 4.92 kg. The incremental cost increase for the Option 1 front door is $5.12 (USD) per door. This is equivalent to a cost increase premium of $2.08 per kg.

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.

5.10.2.4 Option 2 Aluminum Stamping Front Door

The Option 2 front door design utilizes 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 would be all aluminum. The intrusion beam, reinforcement plates, brackets, door hinges and door lock striker would be steel. The result is a 8.45 kg door frame yielding a mass saving of 7.95 kg per door over the 16.40 kg baseline (a 48% decrease). The incremental cost increase over the baseline steel door is $24.80 (USD) per door, representing a $3.12 per kg cost increase premium per door.

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.

5.10.2.5 Option 3 Magnesium Casting Front Door

The Option 3 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 steel. A representation of this design can be seen in Figure 165. The aluminum outer panel has a mass of 2.70 kg per door for a savings of 2.90 kg (52%) compared with the 5.60 kg baseline design. The mass of the magnesium inner door module is 3.31 kg. The mass of the comparable components in the baseline design is 6.50 kg, giving a savings of 3.19 kg (49%). The beltline reinforcement and other miscellaneous parts have a combined mass of 2.58 kg, which is 1.72 kg (40%) less than the baseline mass of 4.30 kg. The total mass of the Option 3 door is 8.59 kg, 7.81 kg (48%) less than the 16.40 kg baseline mild steel door. At the vehicle level, this represents a total mass savings of 15.62 kg.

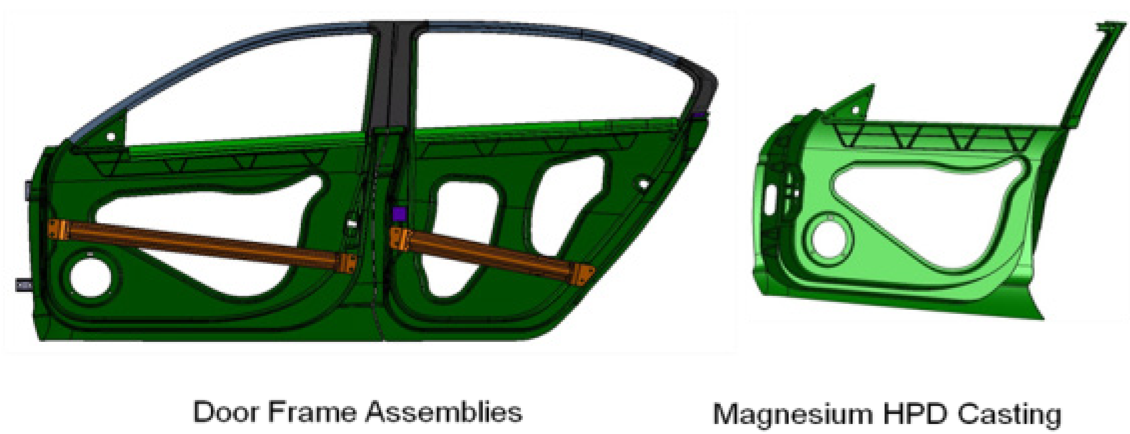

Figure 165: Option 3 (Magnesium Casting) Door Frame Concept

Compared with the baseline, the incremental cost increase for the stamped aluminum outer door panel is $9.00 per door, representing a cost premium of $3.12 per kg saved. The incremental cost increase for the cast magnesium inner door module includes a factor for the material cost as well as for investment/risk, because the magnesium casting requires the use of a high tonnage (approximately 2500 tons), high-pressure die casting press. Currently there is an insufficient manufacturing base capacity of high-pressure die casting presses in North America to support such high volume production. It is estimated that production of the LWV front doors alone will require three high pressure presses operating full time for two production shifts per day. It is not known whether this additional capacity will be available in the 2017-2025 time frame. Therefore, a cost factor accounting for the capital investment into the presses, as well as a factor accounting for the uncertainty of this capacity becoming available has been included. The team collaborated with Meridian, one of the premier suppliers of magnesium automotive components, to develop an estimate that takes these factors into account. The incremental cost increase for the magnesium castings is $16.67 ($5.22 per kg). The incremental cost increase for the beltline reinforcement and miscellaneous parts is, collectively, $8.23 which represents a cost increase premium of $4.79 per kg. Overall, the incremental cost increase of the Option 3 front door is $33.90 per door, or $4.35 per kg.

Like the baseline design and Options 1 and 2, the Option 3 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 which combines several inner door elements into a single module. This is the major contributing factor in the design being the lightest of the three 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. These considerations have been included in the cost increases shown in Figure 166.

5.10.2.6 Option Selection

The mass and cost results of the front door design options are summarized in Figure 166.

The aluminum stamping design (Option 2) has been chosen for the LWV front door design. While the cost of Option 1 is much lower ($5.12 vs. $24.80), the mass savings of Option 2 are more than three times as great (48% vs. 15%), and Option 2 was therefore determined to be more cost effective. Option 3 slightly exceeded the mass savings of Option 2 and closely followed it in cost, but the uncertainty of the manufacturing capacity reinforced the selection of Option 2 for the LWV. The Option 2 incremental costs are discussed further in Section 9.6.2.

Design	Strategy	Honda Accord Mass (kg)	LWV Mass Per Door (kg)	Mass Savings Per Door (kg)	Mass Savings (%)	Cost Increase Per Door ($ USD)	Cost Increase Premium Per Door ($/kg)
Option 1	AHSS	16.40	13.94	2.46	15	5.12	2.08
Option 2	**Aluminum Stamping**	**16.40**	**8.45**	**7.95**	**48**	**24.80**	**3.12**
Option 3	Aluminum Stamping (Outer)	5.60	2.70	2.90	52	9.0	3.12
	Magnesium Casting (Inner)	6.50	3.31	3.19	49	16.67	5.22
	Other Parts (Aluminum)	4.30	2.58	1.72	40	8.23	4.79
	Total	16.40	8.59	7.81	48	33.9	4.35

Figure 166: Summary of Front Door Frame Design Options

5.10.2.7 Final LWV Front Door Design

The LWV front door frame design was completed using aluminum stampings and extrusions in place of the baseline steel for the inner and outer panels and upper frame members, reducing the density of these components from the 7.85 g/cm^3 of steel to the 2.70 g/cm^{3}of aluminum. The steel intrusion beam, brackets and reinforcements were replaced with AHSS designs, allowing their thicknesses to be reduced. In addition to these, other mass reduction features were incorporated into the LWV which had not been included in the preliminary concept study. These include replacing the conventional copper wiring with aluminum wiring and substituting MuCell® (refer to Section 5.13 for a description of MuCell® technology) for the standard polypropylene in the door trim panels. Both of these changes are expected to be cost neutral according to the feedback received from the respective leading automotive suppliers. As was explained in the Front Doors Technology Options discussion, some components, such as the handle/lock/latch, hinges and fasteners were carried over from the baseline with little or no change because the potential mass savings did not justify the cost and time required to develop these components. Replacing the conventional glass windows with low density polycarbonate was investigated as it offered a potential 50% mass savings (2.8 kg per vehicle). However, this substitution is not recommended for side windows as the stiffness of polycarbonate is much less than that of glass, leading to problems with the window operation. The lower modulus polycarbonate can flex under compressive loading while the window is being operated, leading to binding and possibly damage to 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 polycarbonate windows, but these are not expected to reach production capability within the 2017-2025 time frame.[138]

Finite element analysis and LS-DYNA simulation software were used to optimize the structure as well as to ensure that it is able to meet or exceed all the safety and performance requirements of the baseline door. The overall geometry is similar to that of the baseline (refer to Figure 159 and Figure 160), but as can be seen in Figure 167 and Figure 168, the door component aperture of the inner panel has been redesigned for the aluminum material used in the design.

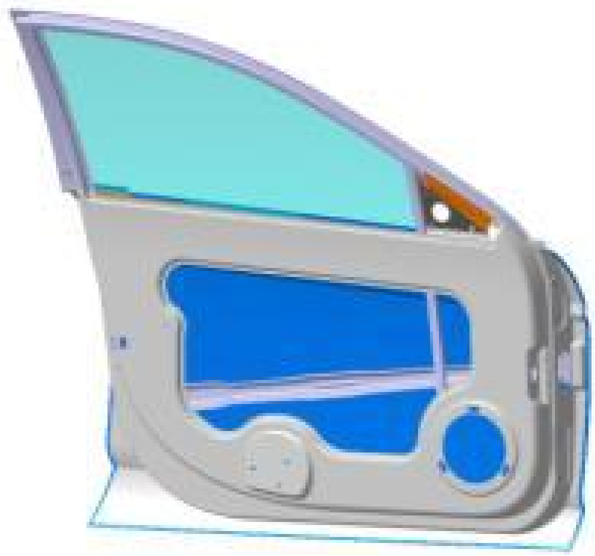

Figure 167: LWV Front Door Frame Assembly

[138] Source: http://www.just-auto.com/analysis/polycarbonate-auto-glazing-offers-designers-new-vision_id94895.aspx

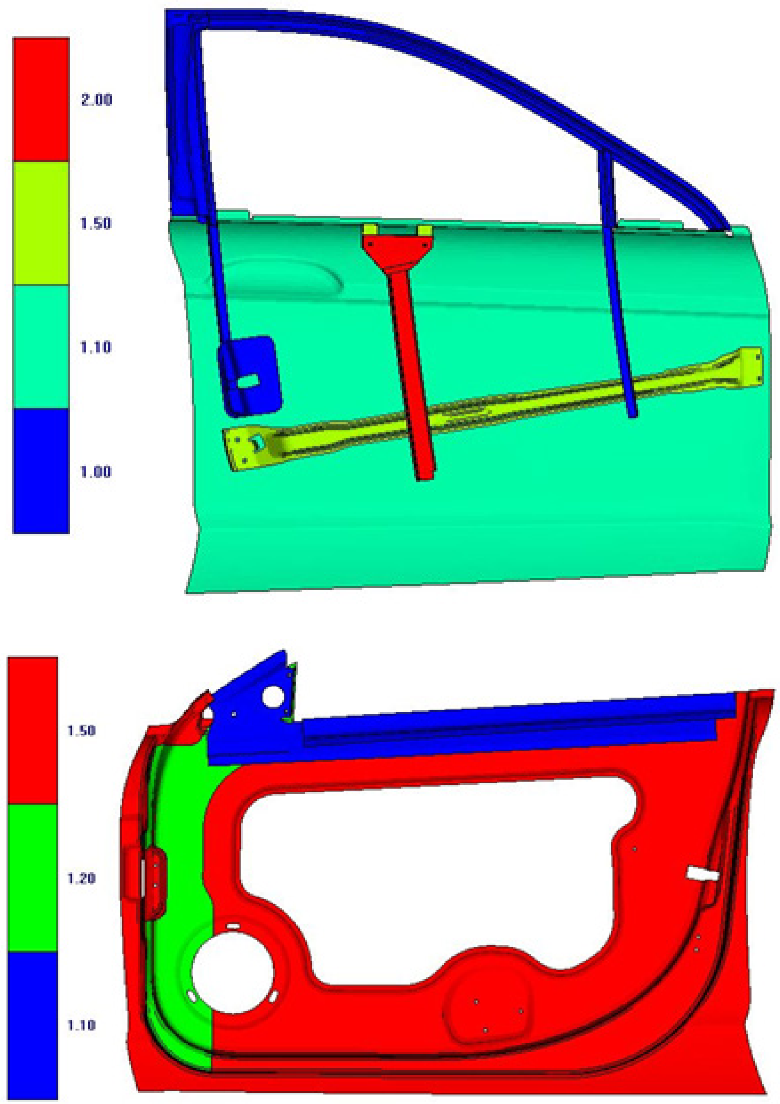

Figure 168: LWV Front Door Frame Material Aluminum – Thickness (mm) Map

The LWV front door frame mass is 8.45 kg per door, or 16.90 kg per vehicle for both driver and passenger side front doors. For the vehicle, this is a total mass reduction of 15.88 kg, or 48% mass reduction compared to the frame for the baseline front doors at 32.78 kg. The total mass of the LWV front door assemblies, including the modifications to the wiring and trim panels, is 41.47 kg, a mass savings of 17.52 kg per vehicle (30%) compared with the baseline 58.99 kg. The cost increase for the complete front door assemblies is $49.6 per vehicle ($2.83 per kg). A summary of the LWV front door mass and cost savings is shown in Figure 169.

Door Component	Strategy	Honda Accord Mass Per Vehicle (kg)	LWV Mass Per Vehicle (kg)	Mass Savings Per Vehicle (kg)	Mass Savings (%)	Cost Increase Per Vehicle ($ USD)	Cost Increase Premium Per Vehicle ($/kg)
Frame	Aluminum stampings	32.78	16.90	15.88	48	49.6	3.12
Glass	c/o	5.55	5.55	0.00	0	0.00	0.00
Regulator	c/o	2.24	2.24	0.00	0	0.00	0.00
Seals	c/o	2.16	2.16	0.00	0	0.00	0.00
Wiring Harness	Aluminum wiring	0.87	0.57	0.30	34	0.00	0.00
Speakers	c/o	0.61	0.61	0.00	0	0.00	0.00
Hinges & Latch	c/o	3.26	3.26	0.00	0	0.00	0.00
Front Outside Mirrors	c/o	2.64	2.64	0.00	0	0.00	0.00
Trim (Plastic)	MuCell® polymer	5.38	4.04	1.34	25	0.00	0.00
Misc. & Fasteners	c/o	3.50	3.50	0.00	0	0.00	0.00
Total		58.99	41.47	17.52	30	49.6	2.83

Figure 169: LWV Mass and Cost Summary for Driver and Passenger Front Doors

5.10.3 Rear Doors

5.10.3.1 Baseline

The rear doors of the baseline 2011 Honda Accord are, like the front doors, constructed of bake-hardenable, cold rolled sheet steel. The major components of the complete rear door assembly, shown in Figure 170, 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. The combined mass of both rear doors is 47.46 kg (refer to Figure 171).

Figure 170: Baseline Rear Door Exploded View

Baseline Rear Door Component	Mass (kg)
Frame	26.76
Glass (moveable)	4.74
Glass (fixed)	1.46
Glass Regulator	2.00
Seals	1.93
Wiring Harness	0.33
Hinges & Latch	2.81
Trim (plastic)	4.53
Miscellaneous & Fasteners	2.90
Total	**47.46**

Figure 171: Baseline Rear Door Mass - Combined Driver and Passenger[139]

The construction of the rear door frame is much as was described for the front door, with the inner and outer panels joined by roller hemming. The structural components of the rear door frame are all constructed of roll formed or stamped steel. The baseline rear door frame assembly can be seen in Figure 172 and an exploded view is shown in Figure 173.

[139] A2Mac1

Figure 172: Baseline Rear Door Frame Assembly

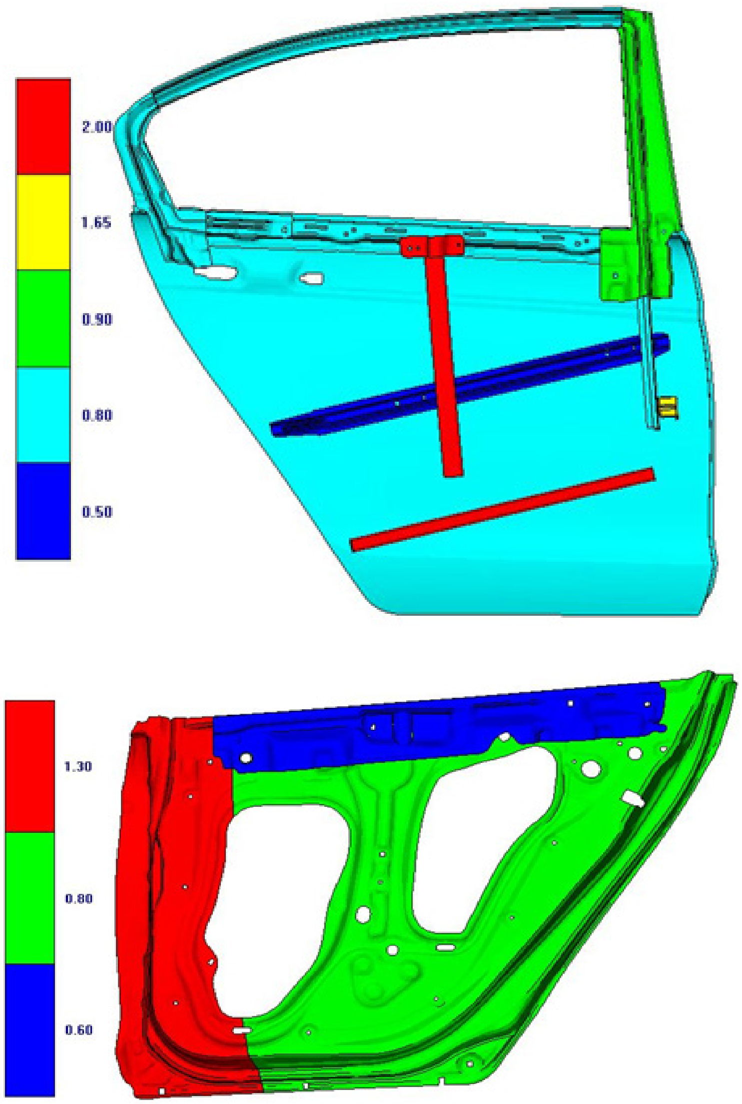

Figure 173: Baseline Rear Door Frame Steel – Thickness (mm) Map

5.10.3.2 Rear Door Technology Options

Three design options were considered for mass saving potential of the rear doors. The rationale for selecting one of them for the LWV is 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 used to develop the rear doors is exactly the same as that of the front doors, with the option selection being followed by a detailed design and analysis phase to optimize the structure and to verify 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 phase 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 were evaluated during the final design phase and incorporated where feasible. Again, the door hinges and lock/latch/striker system were carried over from the baseline to the LWV. The materials and manufacturing processes investigated for mass and cost of the rear door frame components are 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.

5.10.3.3 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. The hinges and door lock striker are carried over from the baseline. The mass of the AHSS rear door frame is calculated to be 11.39 kg. This is a reduction of 2.01 kg per door, a 15% decrease in mass compared with the baseline door frame mass of 13.40 kg. For both driver and passenger side rear doors, this is a mass reduction of 4.02 kg per vehicle. The incremental cost increase for the Option 1 rear door is $4.18 (USD) per door based upon a cost increase premium of $2.08 per kg.

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 in Section 5.9.2, increases in total tooling costs associated with using the AHSS material have been incorporated into the cost increase figures for the door frame construction shown in Figure 162.

5.10.3.4 Option 2 Aluminum Stamping Rear Door

The Option 2 rear door design utilizes aluminum stampings in place of the baseline mild steel. 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. The result is a 7.43 kg door frame; a mass saving of 5.97 kg per door from the 13.40 kg baseline (a 45% decrease). This represents a mass savings of 11.94 kg per vehicle. The incremental cost over the baseline mild steel door is $26.60 (USD) per door, representing a $4.46 per kg cost increase premium.

Manufacturing of the Option 2 design can be accomplished using the same stamping presses, roller hemming equipment and fabrication sequences as the baseline door. As with the front door, the aperture of the aluminum inner door panel may differ in shape from that of the baseline and Option 1 rear doors as it will be optimized for the aluminum material used in the design. 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 shown in Figure 172.

5.10.3.5 Option 3 Magnesium Casting Rear Door

The Option 3 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 steel. A representation of this design can be seen in Figure 165. The aluminum outer panel has a mass of 2.24 kg for a savings of 2.19 kg (49%) compared with the 4.43 kg baseline design. The mass of the magnesium inner door module is 3.25 kg. The mass of the comparable components in the baseline design is 6.00 kg, giving a savings of 2.75 kg (46%). The beltline reinforcement and other miscellaneous parts have a combined mass of 1.78 kg, which is 1.19 kg (40%) less than the baseline mass of 2.97 kg. The total mass of the Option 3 door is 7.27 kg, 6.13 kg (46%) less than the 13.40 kg baseline mild steel door. The combined mass savings for both left and right Option 3 rear door frames is 12.26 kg per vehicle.

The cost increase to produce the aluminum outer panel is $9.76, which is a $4.46 per kg cost increase premium over the baseline mild steel design. As was discussed in the front door section, the incremental cost to produce the magnesium inner door casting must take into account the material cost increase for the magnesium as well as the investment/risk cost of the high pressure die casting presses. It is estimated that an additional three presses operating full time for two production shifts per day would be required to produce the 400,000 LWV rear doors annually for 200,000 vehicles. As was mentioned previously, it is not a certainty that this capacity will be available in time for production of the LWV. Taking these factors into account, the total incremental cost increase for the magnesium castings is $14.44 ($5.25 per kg). The incremental cost increase to produce the miscellaneous minor parts is $5.69 for a cost increase premium of $4.79 per kg. The total incremental cost increase of Option 3 is $29.88per door, which is a $4.88per kg cost increase premium over the baseline design.

As was discussed in the front door section, the manufacturing process for the Option 3 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. These considerations have been included in the cost increases shown in Figure 174.

5.10.3.6 Option Selection

The mass and cost results of the rear door frame design options are summarized in Figure 174.

The aluminum stamping design (Option 2) has been chosen for the LWV rear door. While Option 3 provides a slightly higher mass savings (46% vs. 45%), the cost increase is greater ($29.88 vs. $26.60 per door) and the North American manufacturing capacity constraint issue is enough of a concern to preclude further consideration of this option for the rear doors in the 2017-25 time frame. Additionally, much of the Option 2 design can be produced using the same stamping sequences and equipment as the baseline design, avoiding any additional capital investment. The same can be said for the Option 1 AHSS design, but the mass saving for Option 1 is significantly less than Option 2 (15% vs. 45%). After a thorough review of all design options, it is clear that for high volume production in the 2017-25 time frame, the mass saving provided by the Option 2 design makes it a superior choice to the other designs. The Option 2 incremental costs are discussed further in Section 9.6.2.

Design	Strategy	Honda Accord Mass per Door (kg)	LWV Mass Per Door (kg)	Mass Savings Per Door (kg)	Mass Savings (%)	Cost Increase Per Door ($ USD)	Cost Increase Premium Per Door ($/kg)
Option 1	AHSS	13.40	11.39	2.01	15	4.18	2.08
Option 2	**Aluminum Stampings**	**13.40**	**7.43**	**5.97**	**45**	**26.60**	**4.46**
Option 3	Aluminum Stamping (Outer)	4.43	2.24	2.19	49	9.76	4.46
	Magnesium Casting (Inner)	6.00	3.25	2.75	46	14.44	5.25
	Other Parts (Aluminum)	2.97	1.78	1.19	40	5.69	4.79
	Total	13.40	7.27	6.13	46	29.88	4.88

Figure 174: Summary of Rear Door Frame Design Options

5.10.3.7 Final LWV Rear Door Design

The LWV rear door frame design follows the same approach as was used on the front doors, in which aluminum stampings and extrusions replaced the baseline steel for the inner and outer panels and upper frame members. The intrusion beam was changed from conventional steel to AHSS (Hot Stamping). In addition, other mass reduction features were incorporated into the LWV that had not been addressed in the preliminary concept. The copper wiring was replaced with aluminum wiring, reducing the mass of that component from 0.33 kg to 0.22 (a 33% savings). The door trim panels were replaced with MuCell® nitrogen bubble-filled plastic, yielding a 25% mass reduction, from 4.53 kg to 3.40 kg. As in the front doors, the windows were carried over from the baseline due to the lower modulus of polycarbonate compared with conventional automotive glass (refer to the front door section for more discussion). The regulator, hinges, latch and fasteners were, as in the front doors, carried over from the baseline.

Finite element analysis and LS-DYNA simulation software were used to optimize the structure as well as to help ensure that it was able to meet or exceed all the safety and performance requirements of the baseline door. The overall geometry is similar to that of the baseline, but as can be seen in Figure 175 and Figure 176, the door component aperture of the inner panel was optimized for the aluminum material used in the design.

Figure 175: LWV Rear Door Frame Assembly

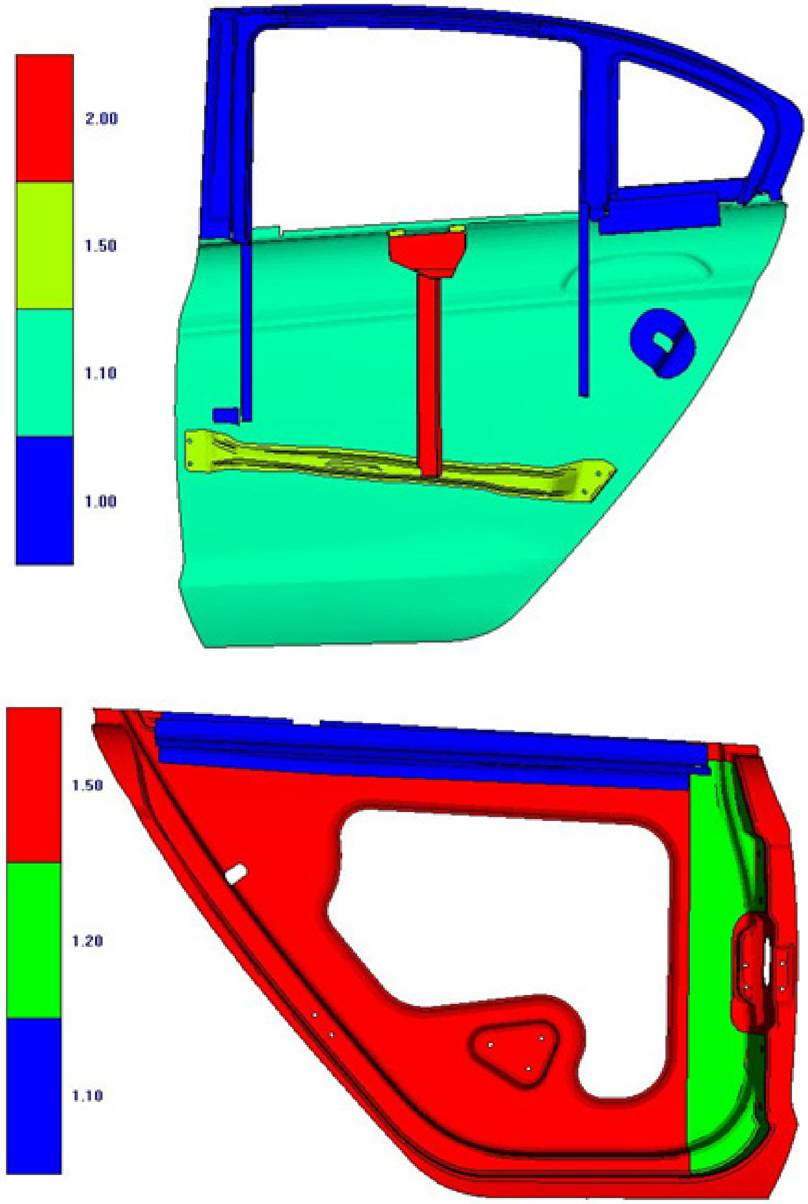

Figure 176: LWV Rear Door Frame Aluminum – Thickness (mm) Map

The combined mass for both LWV rear door frames is 14.86 kg. This is a mass reduction of 11.90 kg (45%) from the 26.76 kg baseline. The incremental cost increase over the baseline is $53.2. Including the glass, regulator, trim and other door components gives a total mass for both rear door assemblies of 34.32 kg, a reduction of 13.14 kg from the 47.46 kg baseline, or 28%. As the wiring and trim changes are expected to be cost neutral, the cost increase for both complete rear door assemblies is $53.2, or $4.05 per kg. These results are summarized in Figure 177.

Door Component	Strategy	Honda Accord Mass Per Vehicle (kg)	LWV Mass Per Vehicle (kg)	Mass Savings Per Vehicle (kg)	Mass Savings (%)	Cost Increase Per Vehicle ($ USD)	Cost Increase Premium Per Vehicle ($/kg)
Frame	Aluminum stampings	26.76	14.86	11.90	45	53.2	4.46
Glass	c/o	6.20	6.20	0.0	0	0.00	0.00
Regulator	c/o	2.00	2.00	0.0	0	0.00	0.00
Seals	c/o	1.93	1.93	0.0	0	0.00	0.00
Wiring Harness	Aluminum Wiring	0.33	0.22	0.11	33	0.00	0.00
Hinges & Latch	c/o	2.81	2.81	0.0	0	0.00	0.00
Trim (Plastic)	MuCell® polymer	4.53	3.40	1.13	25	0.00	0.00
Misc. & Fasteners	c/o	2.90	2.90	0.0	0	0.00	0.00
Total		**47.46**	**34.32**	**13.14**	**28**	**53.2**	**4.05**

Figure 177: LWV Mass and Cost Summary for Left and Right Rear Doors

5.10.4 Hood

5.10.4.1 Baseline

The hood of the baseline 2011 Honda Accord is constructed of bake-hardenable (BH) cold rolled sheet steel and can be seen in Figure 178. An exploded view is shown in Figure 179. The total mass of the hood assembly is 17.90 kg, of which 15.20 kg is the frame structure (inner and outer panels and reinforcements). The remaining 2.70 kg of the hood assembly are made up of the hinges, latch, striker and their associated hardware.

Figure 178: Baseline Hood Assembly

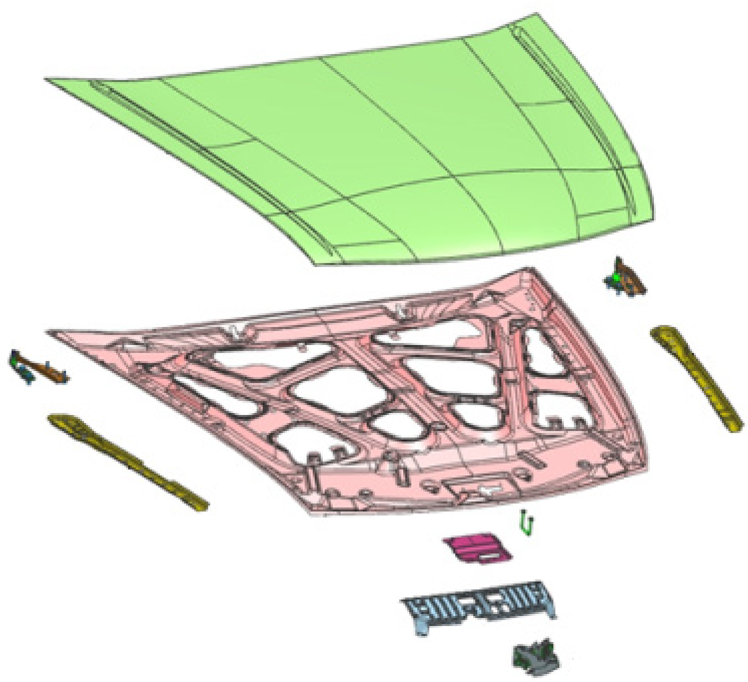

Figure 179: Baseline Hood Exploded View

5.10.4.2 Hood Technology Options

Three design options were considered for mass saving potential of the hood. The option selected for the LWV is that which best exemplifies mass savings while taking into account manufacturing and cost considerations. The chosen design was then further developed through more advanced design and analysis efforts, resulting in a new, completely developed hood. The inner and outer hood panels, including reinforcements, account for 85% of the hood mass. They are targeted in mass reduction efforts on this assembly. The hinges, latch and striker are carried over from the baseline as they are safety-critical items and comprise a small amount of the hood mass. Developing lightweight substitutes would require considerable time and cost; the potential mass savings to cost ratio are not beneficial.

In addition to the three design options discussed below, consideration was given to using fiber reinforced plastic (FRP) for the hood outer panel. As was mentioned earlier in this report, carbon fiber hoods are used on premium low volume vehicles such as the Corvette ZR1 and Lexus LFA, resulting in mass savings. However, as was explained in beginning of Section 5.9, the technology is not yet mature enough for high volume production applications such as the Honda Accord, and the team does not anticipate that it would be sufficiently mature in the 2017-2025 time frame to use on the LWV due to the long cycle times and complex integration of manufacturing processes and materials.

5.10.4.3 Option 1 AHSS Hood

The Option 1 hood design incorporates inner and outer panels made with AHSS. Use of the higher strength steel allows the gauges to be reduced, lowering the mass of the Option 1 hood structure from 15.20 kg to 12.92, which is a 2.28 kg (15%) mass saving. The incremental cost increase for the AHSS construction is $4.74 (USD) over the conventional steel material used in the baseline hood. This represents a $2.08 per kg cost increase premium.

Manufacturing the Option 1 hood would be performed with the same production techniques, presses and equipment as used for the baseline hood. Option 2 Aluminum Stamping Hood

The Option 2 hood uses aluminum stampings to replace the baseline steel inner and outer panels. Steel reinforcements are also replaced by lighter weight aluminum parts. The mass of this hood structure is 7.49 kg, a 7.71 kg mass savings (51%) over the conventional steel design of the baseline vehicle. The incremental cost for the Option 2 construction is $21.26, for a cost premium increase of $2.76 per kg. The Option 2 incremental costs are summarized in Figure 180 and discussed further in Section 9.6.2.

5.10.4.4 Option 3 Magnesium Casting Hood

The Option 3 hood construction features a one-piece cast magnesium inner hood which consolidates several separate pieces (support structure and reinforcements) into a single part. The outer hood panel is stamped aluminum rather than the baseline steel. The mass of the outer hood panel is 4.36 kg for a savings of 3.67 kg (46%) over the 8.03 kg baseline outer panel. The mass of the inner hood casting is 2.20 kg, while that of the comparable components in the baseline mild steel design is 4.50 kg. This represents a mass savings of 2.30 kg (51%). Other miscellaneous parts add up to a total of 1.60 kg, 1.07 kg (40%) less than those in the baseline at 2.67 kg. As with the other options, the hinges, latch and striker are carried over from the baseline. This is the lightest design option at a total mass of 8.16 kg and offers the greatest mass reduction at 7.04 kg (a 46% mass reduction) over the 15.20 kg baseline mild steel design.

The incremental cost increase to produce the aluminum outer panel is $12.80, which is a $3.49 per kg cost increase premium over the baseline mild steel design. The incremental cost increase to produce the inner panel in cast magnesium, as was discussed in the doors section, includes consideration of the material cost as well as the investment/risk of developing the manufacturing capacity to produce these parts. The incremental cost increase for the magnesium casting is $13.41 ($5.83 per kg). The incremental cost for the miscellaneous parts is $5.11 ($4.79 per kg). The incremental cost of the entire Option 3 hood assembly is $31.32, which is a $4.45 per kg cost increase premium over the baseline design.

Manufacturing complexity of the Option 3 hood is simplified due to the one-piece cast magnesium inner hood support structure. This is the major factor contributing to the design being the lightest of the three options considered. As with the other hood options and doors, the baseline production presses, roller hemming equipment and sequences can be used for the stamped aluminum outer panel. However, new tooling, equipment and processes are required for the magnesium casting. These considerations have been included in the cost increases shown in Figure 180.

5.10.4.5 Option Selection

The mass and cost results of the hood design options are summarized in Figure 180.

The aluminum stamping design (Option 2) has been chosen for the LWV. Option 2 provides more mass savings than Option 3(7.71 kg vs. 7.04 kg) though the cost of Option 2 is lower ($21.26 vs. $31.32). Option 1 has the lowest cost at $4.74, but far less mass savings at only 2.28 kg, or 15%. All of the Option 1 and Option 2 parts can be produced with the existing processes and equipment, avoiding any additional capital investments. As with the doors, the manufacturing capacity uncertainty of Option 3, along with its higher costs, makes it undesirable for the LWV project. After a thorough review of all design options, it is clear that for high volume production in the 2017-25 time frame, the mass saving provided by the Option 2 design makes it a superior choice to the other designs. The Option 2 incremental costs are discussed further in Section 9.6.2.

Design	Strategy	Honda Accord Mass (kg)	LWV Mass (kg)	Mass Savings (kg)	Mass Savings (%)	Cost Increase ($ USD)	Cost Increase Premium ($/kg)
Option 1	AHSS	15.20	12.92	2.28	15	4.74	2.08
Option 2	**Aluminum Stampings**	**15.20**	**7.49**	**7.71**	**51**	**21.26**	**2.76**
Option 3	Aluminum Stamping (Outer)	8.03	4.36	3.67	46	12.80	3.49
	Magnesium Casting (Inner)	4.50	2.20	2.30	51	13.41	5.83
	Other Parts	2.67	1.60	1.07	40	5.11	4.79
	Total	15.20	8.16	7.04	46	31.32	4.45

Figure 180: Summary of Hood Frame Design Options

5.10.4.6 Final LWV Hood Design

The final LWV hood design consists of aluminum outer and inner panels very similar geometrically to the baseline steel. The hinge reinforcements, striker plate panel and striker reinforcements are also aluminum rather than steel. The hinges, latch and striker are carried over from the baseline hood assembly. The total mass of the LWV hood assembly is 10.19 kg, 7.71 kg (43%) less than the 17.90 kg baseline. The incremental cost increase for the LWV hood is $21.26, a cost increase premium of $2.76 per kg as shown in Figure 181. The incremental costs are discussed further in Section 9.6.2.

Hood Component	Strategy	Honda Accord Mass (kg)	LWV Mass (kg)	Mass Savings Per Vehicle (kg)	Mass Savings (%)	Cost Increase Per Vehicle ($ USD)	Cost Increase Premium Per Vehicle ($/kg)
Frame Structure	Aluminum stamping	15.20	7.49	7.71	51	21.26	2.76
Hinges, Striker, Latch & Hardware	c/o	2.70	2.70	0.00	0	0.00	0.00
Total		**17.90**	**10.19**	**7.71**	**43**	**21.26**	**2.76**

Figure 181: LWV Mass and Cost Summary for Hood

5.10.5 Decklid

5.10.5.1 Baseline

The decklid of the baseline 2011 Honda Accord is built from cold rolled sheet steel and is composed of the inner and outer panels, hinges, torsion rods, latch/lock, striker and reinforcements. Figure 182 shows the decklid assembly, while an exploded view is shown Figure 183.

The mass of the complete decklid is 12.37 kg, and structural components (inner and outer panels and reinforcements) account for 9.95 kg of this weight. The remaining 2.42 kg are made up of the hinges, latch/lock and striker.

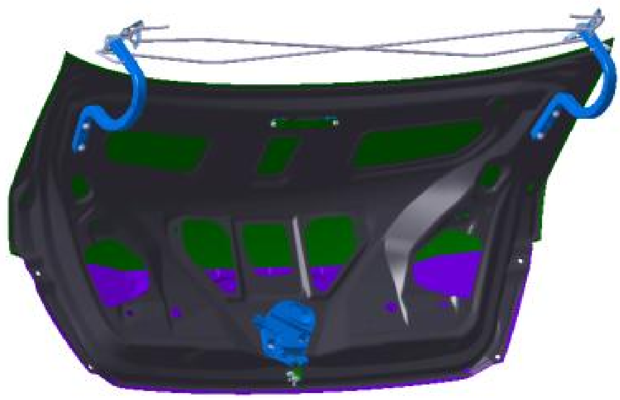

Figure 182: Baseline Decklid Assembly

Figure 183: Baseline Decklid Exploded View

5.10.5.2 Decklid Technology Options

Three design options were considered for mass saving potential of the decklid. The option selected for the LWV is that which best exemplifies mass saving while taking into account manufacturing and cost considerations. That design was then further developed through more advanced design and analysis efforts, resulting in a new, completely developed decklid. As with the hood, the decklid structural components account for the majority of the total mass (80%). For that reason they are the focus of the mass reduction efforts. The cost of developing and validating lower weight replacement hinges, torsion rods, latch/lock and striker assemblies is not justified by the combined potential mass savings of approximately 1 kg. Therefore, those parts are carried over from the baseline. The outer panel of the baseline vehicle is made of two separate pieces, as can be seen in Figure 184. In all of the design options, these separate pieces are incorporated into a single outer panel, shown in Figure 184. The single piece decklid outer is the most common design used on current sedans.

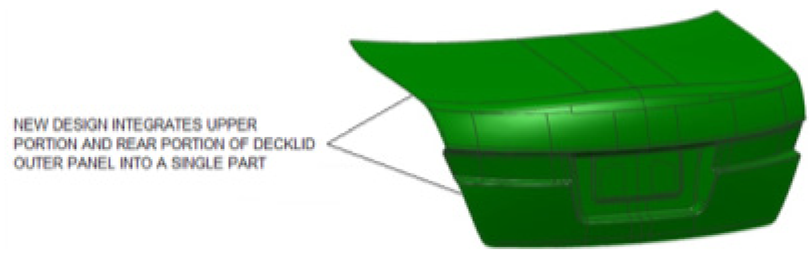

Figure 184: Decklid Outer Panel - Single Piece Design

5.10.5.3 Option 1 AHSS Decklid

The Option 1 decklid design replaces the baseline steel stampings with AHSS for the outer decklid panel, inner decklid support structure and reinforcements. The use of AHSS allows for reduced material thicknesses resulting in mass savings. The decklid hinges, torsion rods, latch/lock mechanism and striker, carried over from the baseline, are constructed of steel. The mass of the complete decklid assembly is 8.46 kg, which is a 1.49 kg mass saving (15%) over the conventional mild steel baseline design of 9.95 kg. The incremental cost increase for the Option 1 design is $3.11, a cost increase premium of $2.08 per kg.

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

5.10.5.4 Option 2 Aluminum Stamping Decklid

The Option 2 decklid replaces the baseline steel stampings with aluminum for the outer panel, inner panel and reinforcements. As with Option 1 the hinges, torsion rods, latch/lock and striker are carried over from the baseline. As shown in Figure 185, the mass of this design is 4.74 kg, providing a 5.21 kg mass savings (52%) over the conventional steel design of the baseline vehicle. The incremental cost increase for the Option 2 construction is $17.04, for a cost increase premium of $3.27 per kg. The incremental costs are discussed further in Section 9.6.2.4.

5.10.5.5 Option 3 Magnesium Casting Decklid

The Option 3 decklid design features a one-piece cast magnesium inner decklid support structure which combines the inner panel and reinforcements into a single part. The outer panel, like that in Option 2, is stamped aluminum. The hinges, torsion rods, latch/lock and striker are carried over from the baseline. The mass of the outer decklid panel is 2.98 kg for a savings of 2.52 kg (46%) over the 5.50 kg baseline outer panel. The mass of the inner decklid casting is 2.00 kg, while that of the comparable components in the baseline mild steel design is 4.00 kg. This represents a mass savings of 2.00 kg (50%). Other miscellaneous parts have a combined mass of 0.27 kg, which is 0.18 kg (40%) less than the 0.45 kg baseline. Option 3 is the lightest design option at 5.25 kg and offers the greatest mass reduction at 4.70 kg (47%) over the 9.95 kg baseline mild steel design.

The incremental cost to produce the cast magnesium inner decklid follows the same rationale as for the door and hood castings. The total incremental cost increase of $11.66 ($5.83 per kg) over the baseline includes the material costs as well as consideration for the investment/risk. The incremental cost increase to produce the aluminum outer panel is $8.73, which is a $3.47per kg cost increase premium over the baseline steel design. The incremental cost for the other miscellaneous parts is $0.86 ($4.79 per kg). The total incremental cost increase of the Option 3 decklid is $21.26, which is a $4.52 per kg cost increase premium over the baseline design.

Manufacturing complexity of the Option 3 decklid is simplified due to the one-piece cast magnesium inner decklid support structure. This is the major contributing factor in this design being the lightest of the three options considered. The production presses and manufacturing sequences used for the baseline outer panel can be used for the stamped aluminum outer panel, though the tool life will be slightly shorter and maintenance costs higher due to the material substitution. The magnesium casting would require high pressure presses and new production sequences. These factors have been included in the costs listed in Figure 185.

5.10.5.6 Option Selection

The mass and cost results of the design options for the decklid structure are summarized in Figure 185. Option 2 (aluminum stampings) has been chosen for the LWV. While Option 3 provides slightly higher mass savings (47% vs. 45%), the costs are significantly more ($21.26 vs. $17.04).This cost differential and concerns regarding the North American manufacturing capacity constraint issue for producing its inner die cast decklid panels precludes further consideration of this option for the 2017-25 time frame. Option 1 has the lowest cost increase at $3.11, but the mass savings are only 15%. All of the Option 1 and Option 2 parts can be produced using the same stamping equipment as the baseline design, avoiding any additional capital investment. After a thorough review of all design options, it is clear that for high volume production in the 2017-25 timeframe, the mass saving provided by the Option 2 design makes it a superior choice to the other designs. The Option 2 incremental costs are discussed further in Section 9.6.2.4.

Design	Strategy	Honda Accord Mass (kg)	LWV Mass (kg)	Mass Savings (kg)	Mass Savings (%)	Cost Increase ($ USD)	Cost Increase Premium ($/kg)
Option 1	AHSS	9.95	8.46	1.49	15	3.11	2.08
Option 2	**Aluminum Stampings**	**9.95**	**4.74**	**5.21**	**52**	**17.04**	**3.27**
Option 3	Aluminum Stamping (Outer)	5.50	2.98	2.52	46	8.73	3.46
	Magnesium Casting (Inner)	4.00	2.00	2.00	50	11.66	5.83
	Other Parts	0.45	0.27	0.18	40	0.86	4.78
	Total	9.95	5.25	4.70	47	21.26	4.52

Figure 185: Summary of Decklid Structure Design Options

5.10.5.7 Final LWV Decklid Design

The LWV decklid is made of aluminum stampings instead of the baseline steel. The two-piece outer panel has been redesigned as a single piece, reducing mass and complexity. The inner panel is stamped aluminum, as are the reinforcements. Hinges, torsion rods, latch/lock mechanism and striker are carried over from the baseline. The mass of the complete LWV decklid is 7.16 kg, a mass savings of 5.21 kg (42%) over the 12.37 kg baseline. The incremental cost increase for the LWV decklid is $17.04, a cost increase premium of $3.27 per kg. A summary of the mass and cost for the LWV decklid is shown in Figure 186. The incremental costs are discussed further in Section 9.6.2.4.

Decklid Component	Strategy	Honda Accord Mass (kg)	LWV Mass (kg)	Mass Savings Per Vehicle (kg)	Mass Savings (%)	Cost Increase Per Vehicle ($ USD)	Cost Increase Premium Per Vehicle ($/kg)
Frame Structure	Aluminum stamping	9.95	4.74	5.21	52	17.04	3.27
Hinges, Latch, Lock, Striker & Hardware	c/o	2.42	2.42	0.00	0	0.00	0.00
Total		**12.37**	**7.16**	**5.21**	**42**	**17.04**	**3.27**

Figure 186: LWV Mass and Cost Summary for Decklid

5.10.6 Fenders

5.10.6.1 Baseline

The front fenders, like the rest of the closure components on the baseline 2011 Honda Accord, are built from cold rolled sheet steel. They are each composed of the primary structure, a lower extension, brackets and reinforcements. Figure 187shows the left front fender assembly and Figure 188 shows an exploded view. The left and right front fenders are symmetrical with a mass of 3.68 kg each.

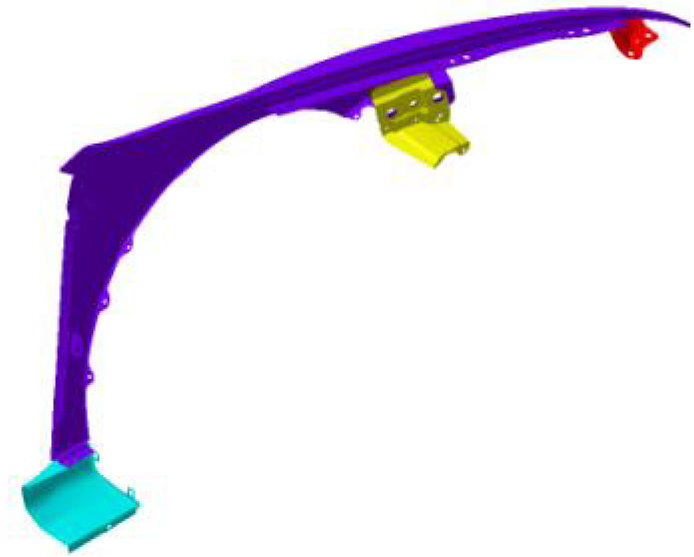

Figure 187: Baseline Left Front Fender Assembly

Figure 188: Baseline Left Front Fender Exploded View

5.10.6.2 Fender Technology Options

Three design options offering mass saving potential were considered for the front fenders. The option selected for the LWV is that which best exemplifies mass saving while taking into account manufacturing and cost considerations. The fender is a simple component with the design primarily driven by styling. Therefore, mass reduction options focused on material substitutions rather than fundamental design changes. In all three options the separate lower extension was integrated into the fender, slightly reducing mass and complexity.

5.10.6.3 Option 1 AHSS Fender

The Option 1 design utilizes 100% AHSS for the fender construction, including support brackets and reinforcements. The lower rear extension, a separate piece in the baseline, has been incorporated into the basic fender stamping. That change and the reductions in thickness account for the mass savings in the Option 1 design. The mass of the Option 1 front fenders is 6.22 kg. This is a mass saving of 1.13 kg (15%) over the baseline fender mass of 7.35 kg.

The incremental cost to manufacture the front fenders in AHSS is $1.41 per fender, for a cost increase premium of $1.25 per kg (AHSS < 590 MPa are recommended for fenders being Class A surfaces). Manufacturing of the Option 1 fender can be accomplished using the same production presses and fabrication sequences as the baseline fender. The associated increased cost is shown in Figure 189.

5.10.6.4 Option 2 Aluminum Stamping Fender

The Option 2 fender construction replaces the steel stampings with aluminum. This includes the basic fender structure as well as the brackets and reinforcements. The lower rear extension, a separate piece in the baseline, has been incorporated into the basic fender stamping. The mass of the Option 2 fender design is 4.08 kg. This represents a mass saving of 3.27 kg (44 %) over the baseline construction. The Option 2 incremental costs are discussed further in Section9.6.2.5.

The incremental cost increase to produce the Option 2 fender is $12.60, which represents a cost increase premium of $3.86 per kg over the baseline. As with the Option 1 design, the Option 2 fender can be produced using the same presses as the baseline vehicle fender.

5.10.6.5 Option 3 Plastic Glass Fiber Reinforced Composite Fender

The Option 3 design is a molded plastic fender constructed primarily of SMC with aluminum brackets and reinforcements. This is the same construction method that was used on several Saturn vehicles such as the SC1 and SC2. As with the other options, the lower rear extension is part of the fender structure, not a separate piece. The mass of the glass fiber reinforced composite fenders is 5.55 kg, a mass savings of 1.80 kg, or 24%. The cost increase is $2.61 ($1.45 per kg). With this option all manufacturing equipment, processes and facilities are new; only the brackets and reinforcements use processes common with the baseline.

5.10.6.6 Option Selection

As can be seen in Figure 189, the Option 2 (aluminum) design provides the greatest mass savings at 44%, but at the highest cost ($12.6). Option 1 has the lowest cost, but also the lowest mass savings at 15%. The Option 3 plastic composite fender has advantages with it low cost and moderate mass savings, but experiences on previous production vehicles have been unsatisfactory due to persistent issues with thermal expansion and fit/finish. The plastic composite fenders on Saturn vehicles were eventually replaced with stamped steel for these reasons. Superior mass savings of aluminum vs. plastic fenders was also verified in a 2011 Mercedes-Benz study for the SLK roadster[140]. For the LWV program, Option 2 has been selected. The higher cost premium was justified by the superior mass savings and reservations over the thermal expansion and fit/finish issues mentioned above. The Option 2 incremental costs are discussed further in Section 9.6.2.5.

Design	Strategy	Honda Accord Mass Fenders (kg)	LWV Mass Fenders (kg)	Mass Savings Fenders (kg)	Mass Savings Fenders (%)	Cost Increase Fenders ($ USD)	Cost Increase Premium Fenders ($/kg)
Option 1	AHSS	7.35	6.22	1.13	15	1.41	1.25
Option 2	**Aluminum Stamping**	**7.35**	**4.08**	**3.27**	**44**	**12.6**	**3.86**
Option 3	**Glass Fiber Reinforced Composite**	7.35	5.55	1.80	24	2.61	1.45

Figure 189: Summary of Front Fenders (both sides) Design Options

5.10.6.7 Final LWV Front Fender Design

The final LWV front fender design uses aluminum stampings for the entire structure, including brackets and reinforcements. This density reduction, along with incorporating the lower extension into the basic stamping, provides a mass of 2.04 kg per fender. This is a mass savings of 3.27 kg (44%). The incremental cost increase for the LWV fenders is $12.6, a cost increase premium of $3.86 per kg.

5.10.7 Bumpers

5.10.7.1 Baseline

The bumper system on the baseline 2011 Honda Accord vehicle is fabricated from roll-formed steel with a tensile strength of 590 MPa. Stiffening gussets added to the non-impact side of the bumper beam provide localized rigidity at various points where crush must be controlled during

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[140]The Bodyshell of the New Mercedes-Benz SLK," Gunther Ast, Daimler AG, presented at Aachen Body Engineering Days, Sep 21, 2011

an impact event. The forward surface of the front bumper beam utilizes a center mounted front plate to distribute crash energy more evenly across the bumper beam in frontal impacts. Two small longitudinal collapsible sections, or crush cans, attach to the bumper beam along with mounting brackets for attachment to the front rails. The bumper assembly transfers energy to the left and right shotguns and to the front/rear rails to absorb the energy of the directional impact. The front bumper assembly can be seen in Figure 190, while an exploded view is shown in Figure 191. The rear bumper assembly and exploded view are shown in Figure 192 and Figure 193. The mass of the baseline front bumper assembly is 7.96 kg while that of the rear bumper is 7.84 kg.

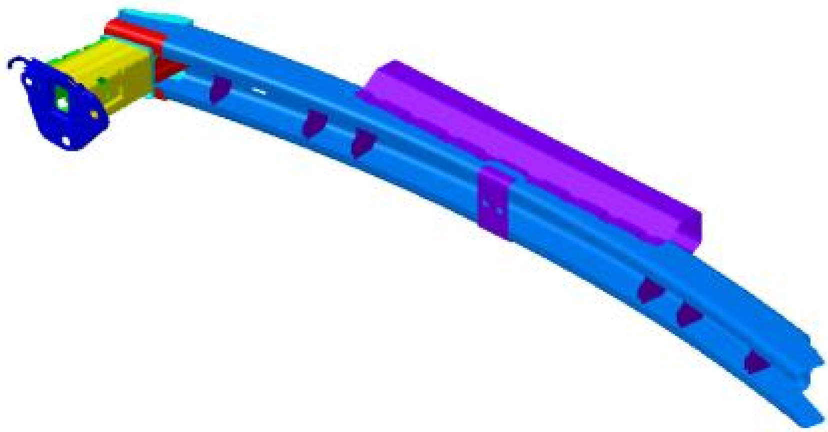

Figure 190: Baseline Front Bumper Assembly

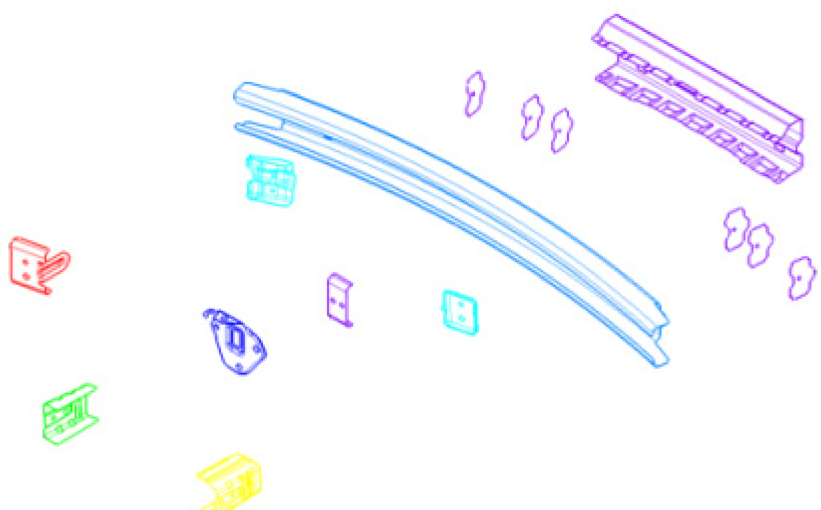

Figure 191: Baseline Front Bumper Exploded View

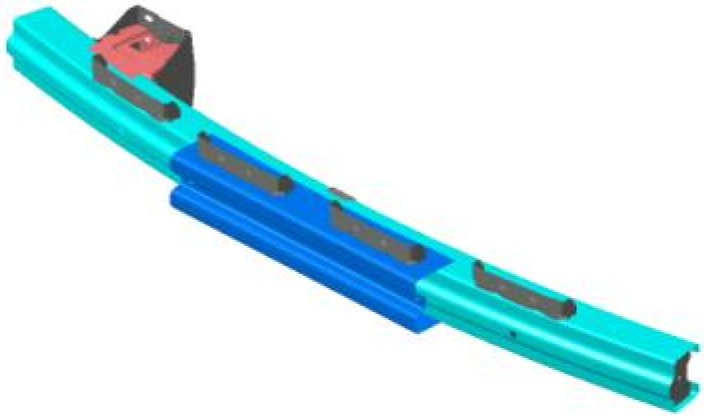

Figure 192: Baseline Rear Bumper Assembly

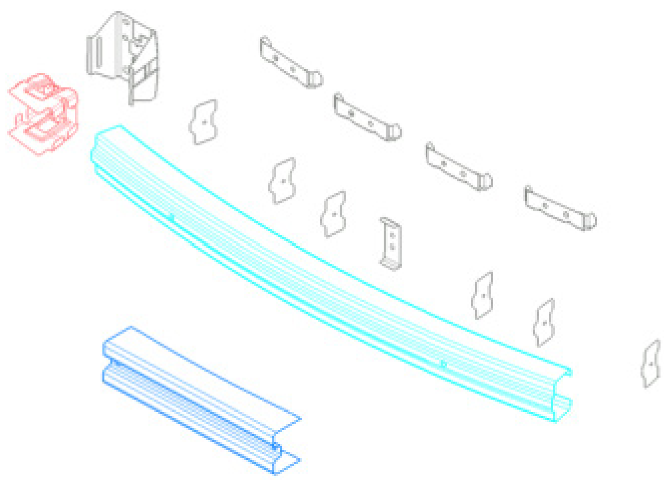

Figure 193: Baseline Rear Bumper Exploded View

5.10.7.2 Bumper Technology Options

Three design options were considered for mass saving potential of the front and rear bumpers. The rationale for the final selection is 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 to verify its feasibility and to help demonstrate its ability to match or exceed all the safety and performance requirements of the baseline bumpers.

The bumper system is very critical to overall safety and to the vehicle's IIHS rating as tested during low speed impact tests. To help ensure that the performance of the LWV bumpers would not be compromised in comparison with that of the baseline vehicle bumper design, LS-DYNA software was used to simulate regulatory tests. Each of the bumper system solutions was designed to meet the same performance as the baseline 2011 Honda Accord for the specific regulatory requirements, 49 Code of Federal Regulations (CFR) Part 581, as well as IIHS and Research Council for Automobile Repairs (RCAR) guidelines.

5.10.7.3 Option 1 AHSS Bumper

The Option 1 front and rear bumper designs maintain the geometry of the original baseline designs, but substitutes AHSS for the baseline steel, allowing the metal gauges to be reduced. This material substitution results in a front bumper mass of 4.37 kg for a mass savings of 3.59 kg (45%) over the baseline 7.96 kg. The rear bumper mass is 4.33 kg, a savings of 3.51kg (45%) over the baseline 7.84 kg. The incremental cost impact to produce the Option 1 front bumper is a decrease in costs of $0.88, while that for the rear bumper is an increase of $2.10.

Manufacturing of the Option1 design can be done using the same production presses and processes as the baseline steel bumper design. The Option 1 incremental costs are discussed further in Section 9.6.3.

5.10.7.4 Option 2 Aluminum Stamping Bumper

The Option 2 front and rear bumper designs replace the baseline steel stampings with aluminum. This reduces the mass to 5.17 kg for the front bumper and 5.10 for the rear, the same masses as in the Option 1 designs. This is a mass saving of 2.79 kg (35%) for the front and 2.74 kg (35%) for the rear compared with the baseline bumpers. The incremental cost increase for the Option 2 front bumper is $17.48 and $17.21 for the rear, a cost increase premium of $6.27 per kg.

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

5.10.7.5 Option 3 Composite Bumper

The Option 3 front and rear bumpers are made from carbon fibre composites. The mass of the Option 3 front bumper is 3.58 kg, for a mass savings of 4.38 kg (55%) over the baseline steel bumper. The rear bumper mass is 3.53 kg, for a mass savings of 4.31 kg (55%). As was discussed in Section 6.3, the production costs of fabricating composite structures are high. The incremental cost increase for the Option 3 front bumper design is $53.71 while that of the rear bumper is $52.90. This represents a cost increase premium of $12.27 per kg.

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; this is a disadvantage of this option.

5.10.7.6 Option Selection

A summary of the front bumper designs can be seen in Figure 194 and Figure 195. The Option 3 composite design offers the greatest mass saving potential of all the designs considered, with 55% for both the front and rear bumpers, but it also has the highest cost increase premium at $12.27 per kg. Fibre reinforced composite parts have been discussed previously in this report. While they do offer mass savings, the team does not believe either the technology is mature enough yet for high volume production applications such as Honda Accord or will it be mature enough in the 2017-2025 time frame. The mass savings potential of Option 1 AHSS is higher than of the Option 2 aluminum designs for both the front and rear bumpers. Also, the Option 1 design has the lowest cost increase premium of all the options. The Option 1 AHSS (hot stamped) design has been chosen for the LWV front and rear bumper design as the most cost effective solution considering the mass savings of 45% for a cost savings compared to the Option 3 Composite with 55% mass savings for a cost increase. The Option 1 incremental costs are discussed further in Section 9.6.3.

Design	Strategy	Honda Accord Mass (kg)	LWV Mass (kg)	Mass Savings (kg)	Mass Savings (%)	Cost Increase ($ USD)	Cost Increase Premium ($/kg)
Option 1	**AHSS**	**7.96**	**4.37**	**3.59**	**45**	**-0.88**	**-0.25**
Option 2	Aluminum Stamping	7.96	5.17	2.79	35	17.48	6.27
Option 3	Composite	7.96	3.58	4.38	55	53.71	12.27

Figure 194: Summary of Front Bumper Design Options

Design	Strategy	Honda Accord Mass (kg)	LWV Mass (kg)	Mass Savings (kg)	Mass Savings (%)	Cost Increase ($ USD)	Cost Increase Premium ($/kg)
Option 1	**AHSS**	**7.84**	**4.33**	**3.51**	**45**	**2.1**	**0.59**
Option 2	Aluminum Stamping	7.84	5.10	2.74	35	17.21	6.27
Option 3	Composite	7.84	3.53	4.31	55	52.90	12.27

Figure 195: Summary of Rear Bumper Design Options

5.10.7.7 Final LWV Bumper Design

The final LWV front and rear bumper designs are hot stamped using AHSS with 1,500 MPa tensile strength. This result in a mass of 4.37 kg for the front bumper and 4.33 kg for the rear, representing mass savings of 3.59 kg (45%) and 3.51 kg (45%) compared with the baselines. The cost of the LWV front bumper is $0.88 less than that of the baseline, for a cost savings of $0.25 per kg. The rear bumper costs $2.09 more than the baseline, giving a cost increase of $0.59 per kg.

5.10.8 Fuel Filler Door

The fuel filler door assembly is primarily made of stamped steel with a mass of 0.40 kg. The steel could be replaced by AHSS, aluminum or plastic composite, but the potential mass savings of approximately 0.10 kg do not justify the costs, particularly in the case of plastic in which new tooling and processes would be required. In addition, like the roof panel described in Section 5.8.3, the rear body side panel housing the fuel filler door is a welded part of the steel body structure. Introducing an aluminum fuel filler door would not be advisable due to the potential galvanic corrosion issues present with dissimilar metals. Taking these factors into consideration, the LWV will carry over the baseline fuel filler door.

5.11 Chassis

5.11.1 Front Suspension

5.11.1.1 Baseline
The front suspension of the baseline 2011 Honda Accord is a standard double wishbone design, shown in Figure 196.

This assembly includes the K-frame (engine cradle), upper and lower A-arms, steering knuckle, stabilizer bar, damper/spring and other miscellaneous parts, as can be seen in Figure 197.

The combined mass of these components is 81.33 kg. Other than a small amount of elastomeric material, the front suspension module is constructed of steel and iron.

Figure 196: Baseline Front Suspension Exploded View[141]

[141] A2Mac1

Item	Mass (kg)
K-Frame	33.263
K-Frame Rear Reinforcement	1.333
K-Frame Front Reinforcement	0.985
K-Frame Front Frame Member Linkages	1.192
Arm Suspension System – Lower Triangle	14.389
Arm Suspension System – Upper Triangle	3.140
Stabilizer Bar	3.906
Stabilizer Bar Silentbloc	0.134
Stabilizer Bar Support	0.275
Stabilizer Bar Link	0.405
Complete Steering Knuckle	10.428
Steering Knuckle	6.878
Steering Knuckle Hub	2.173
Front Wheel Bearing	1.007
Vibrations Absorber – Rear Mass	1.432
Vibrations Absorber – Rear Support	0.390
Total:	**81.330**

Figure 197: Baseline Double Wishbone Suspension Parts Breakdown

5.11.1.2 Front Suspension Technology Options

The majority of mid-size passenger cars use either a MacPherson strut or a double wishbone front suspension system. The MacPherson strut is simpler, lighter and less expensive, while the double wishbone offers slightly better handling in high speed cornering maneuvers. The double wishbone is used on many high end products such as Bentley, BMW, Infiniti, Jaguar, Acura and Lexus, and high performance products like Lamborghini, Maserati, Lotus and Ferrari. The MacPherson strut system is used by most of the entry level and mid-range manufacturers (Nissan, Chevrolet, Toyota, Chrysler, Mazda, Buick, Hyundai, Kia, Ford, Volkswagen, etc.).

The Honda Insight and Civic, with curb weights of 1232 kg and 1252 kg respectively, are both lighter vehicles than the 1480 kg Accord, and are close to the weight anticipated for the LWV. They both use similar MacPherson strut front suspensions. The Honda MacPherson strut system is composed of 10 major components and weighs 40.6 kg (refer to Figure 198 and Figure 199). This is 40.7 kg less than the baseline Accord, a 50% mass saving. Other benefits offered by a MacPherson strut suspension compared with a double wishbone include reduced number of mounting points on the body structure and reduced packaging width.

Figure 198: Honda MacPherson Strut Suspension Exploded View[142]

Item	Mass (kg)
K-Frame	12.509
Lower Triangle	11.133
Stabilizer Bar	3.061
Stabilizer Bar – Silentbloc	0.100
Stabilizer Bar Support	0.256
Stabilizer Bar Link	0.811
Complete Steering Knuckle	6.481
Steering Knuckle	4.139
Steering Knuckle Hub	1.410
Front Wheel Bearing	0.711
Total	**40.611**

Figure 199: Honda MacPherson Strut Parts Breakdown

The LWV could incorporate a MacPherson strut front suspension similar to those used in the Insight and Civic. Additional mass could be saved by replacing the steel engine cradle with either aluminum or AHSS having strength and performance equivalent or superior to the baseline Accord. The mass savings would be 17.5 kg (58%) for the aluminum at a cost increase of $27.33 ($1.56 per kg). The AHSS engine cradle would have a mass savings of 16.8 kg (44%) with a cost decrease of $8.9 ($0.67per kg). Both of these designs are acceptable solutions, with the aluminum offering greater mass savings and the AHSS offering a lower cost. The aluminum engine cradle was chosen, maximizing mass savings at a reasonable cost increase premium. The baseline engine cradle and the LWV engine cradle design are shown in Figure 200. The high amount of mass saving achieved for the LWV engine cradle compared with the baseline cradle is

[142] A2Mac1

mainly due the fact that the baseline cradle is designed to have additional strength to fail (shear) the rear cradle mount to control frontal crash behaviour of the baseline vehicle. The LWV is designed not to have this feature and in fact is designed to have a controlled failure mode to absorb energy in the frontal crash testing.

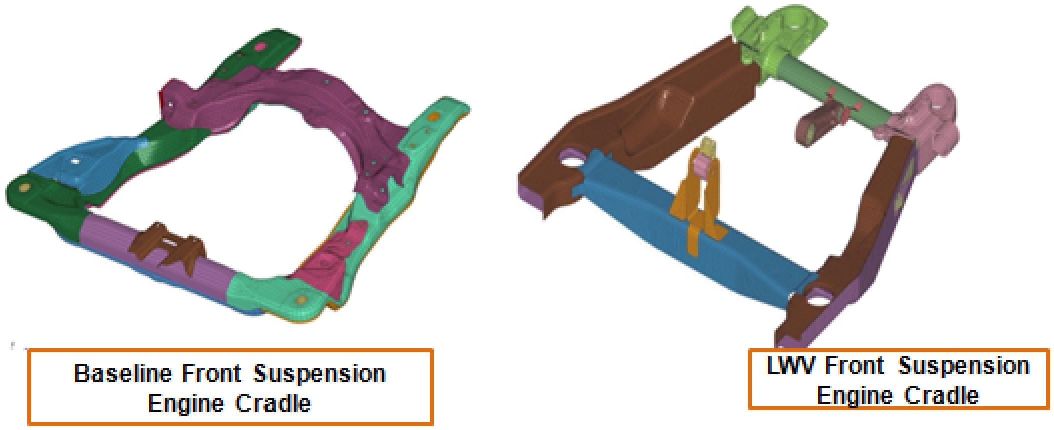

Figure 200: Front Suspension Engine Cradle – Baseline and LWV Design

Similarly, the baseline steel A-arms could be replaced with aluminum or AHSS. The mass savings with aluminum are 10.2kg (58%) at a cost increase of $15.58 ($1.53 per kg). The mass savings with AHSS are 9.8 kg (56%) at a cost savings of $24.7 ($2.51 per kg). In this case the AHSS was chosen because the mass savings of the aluminum alternative are not significantly greater than those of the AHSS and the cost is significantly lower compared to the equivalent aluminum design. The baseline control arms and the LWV control arms design are shown in Figure 201. This decision is in agreement with the findings of a 2010 study published by the Auto Steel Partnership (A/SP). [143]

[143]Reference: "A/SP Lightweight Suspension (ASP-340) Front Lower Control Arm Study Final Report," Fuchs, Hannes PhD, April 15, 2010

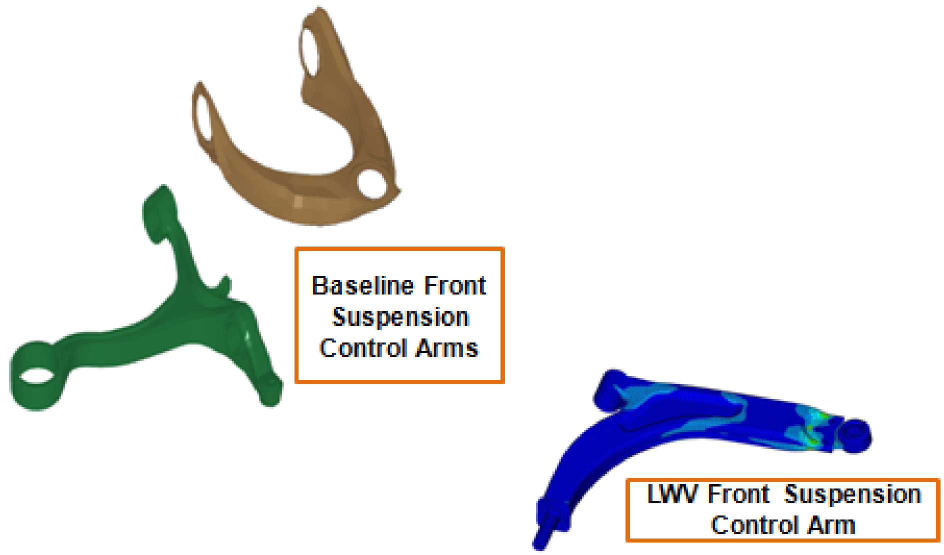

Figure 201: Front Suspension Control Arms – Baseline and LWV Design

The stabilizer bar could be downsized to a mass similar to that of the Civic, but must remain high strength steel due to the torsional performance requirements. This reduces the mass from 3.91 kg to 3.15 kg, a 19% mass savings.

The steering knuckle could be downsized and replaced with aluminum on the LWV, achieving a mass savings of 7.7 kg (62%) at a cost decrease of $12.57. It must be noted the size and mass of the knuckle on the base line vehicle is significantly larger to accommodate double wish-bone suspension design, as illustrated in Figure 202. Approximately half of the 62% mass saving is due to the change in suspension design geometry to MacPherson strut.

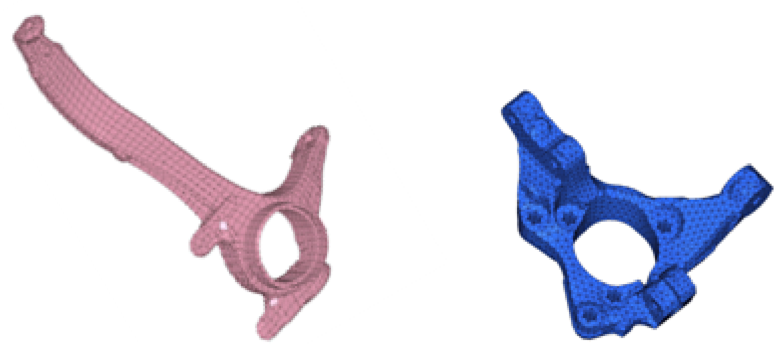

Figure 202: Steering Knuckle – Baseline and LWV Design

The use of aluminum suspension components is a proven approach, as they have been used successfully on many vehicle programs in the past decade, including the Aston Martin DB9, Chevrolet Corvette and Traverse, BMW X5 SUV, BMW 5- and 7-series sedans, Dodge Charger and Journey, Cadillac XLR, Nissan Altima and Maxima, Lincoln MKT, and even Oshkosh's

Mine Resistant Ambush Protected All-Terrain Vehicle (MRAP) for the US Army. Successful usage of aluminum suspension components on these vehicles, some of them high volume production, some high performance, and even one military, has demonstrated that these components meet durability, ride & handling and production capability requirements equal to or greater than those of the LWV[144,145,146].

5.11.1.3 Final LWV Front Suspension Design

The LWV will replace the baseline double wishbone front suspension with a MacPherson strut system similar to those used on the Honda Civic and Insight. As shown in Figure 203, the engine cradle, steering knuckles and some miscellaneous parts will be aluminum while the A-arms and stabilizer bar will be AHSS for the reasons given above. The total mass of the LWV front suspension is 41.4 kg; a savings of 39.9 kg (44%) compared with the baseline 81.33 kg. The overall cost decrease is $11.0, or $0.28 per kg. The component costs shown also include the supplier mark-ups; the incremental cost estimation methodology and results are discussed further in Section 9.6.4.

Vehicle Subsystem	Strategy	Honda Accord Mass (kg)	LWV Mass (kg)	Mass Savings (kg)	Mass Savings (%)	Cost Increase ($ USD)	Cost Increase Premium ($/kg)
Engine Cradle	Aluminum	30.2	12.65	17.5	58	27.33	1.56
A-Arms	AHSS	17.5	7.7	9.8	56	-24.65	-2.51
Stabilizer Bar	AHSS	3.9	3.15	0.8	19	-1.11	-1.45
Steering Knuckles	Aluminum	12.3	4.6	7.7	62	-12.57	-1.64
Other Parts	Various materials	17.5	13.3	4.2	24	0.00	0.00
	Total	**81.3**	**41.4**	**39.9**	**49**	**-11.0**	**-0.28**

Figure 203: Final LWV Front Suspension Mass and Cost Summary

[144] http://aluminumintransportation.org/applications/applications/suspension
[145] http://www.alcoa.com/global/en/news/news_detail.asp?pageID=20101025006331en&newsYear=2010
[146] http://www.alcoa.com/global/en/news/news_detail.asp?pageID=20041005005932&newsYear=2004

5.11.2 Rear Suspension

5.11.2.1 Baseline

The baseline 2011 Honda Accord uses a multi-link rear suspension, shown in Figure 204. The basic components of the rear suspension are the rear K-frame and reinforcement, multi-link suspension arms, bearing hub, rear casing and stabilizer, along with other miscellaneous parts such as the damper/spring, heat shield, rear knuckle and bushings. The total mass of the system is 53.17 kg. Steel is the primary material used in the rear suspension module with the exception of the rear knuckles (aluminum) and a small amount of elastomeric material.

Figure 204: Baseline Multi-Link Rear Suspension Exploded View[147]

5.11.2.2 Rear Suspension Technology Options

Replacement of the baseline multi-link rear suspension with a torsion beam suspension was given serious consideration because the torsion beam is simpler, lighter, less expensive and requires less packaging space. For these reasons most compact cars use this type of rear suspension. However, this is only a partially independent rear suspension (the wheels are connected by a torsion beam, and often a stabilizer bar), thus the ride and handling characteristics are inferior to those of the fully independent multi-link system. Most mid-size and full size passenger cars (Acura, Ford, Hyundai, BMW, Nissan-Infiniti, Mercedes-Benz, Chevrolet, Lexus, Buick, Mazda, Chrysler, Audi, Cadillac, Honda, etc.) use multi-link rear suspension systems to take advantage of the improved ride and handling, and also because the multi-link system offers better adjustability, allowing it to be fine-tuned for a precise ride feel. The potential mass savings of the torsion beam do not justify degrading the performance of the current rear suspension; therefore it was not selected for the LWV.

The reduction of the overall mass of the LWV compared with the baseline vehicle reduces the loads on the suspension, allowing the components to be downsized without degrading performance. In addition, replacing some of the steel components with equivalent aluminum parts, like those of the Audi A8, offers even more mass savings. The LWV rear K-frame and reinforcement could be downsized and replaced with aluminum, resulting in a reduction of mass from 24.20 kg to 13.05 kg (46%) at a cost of $48.51, or $4.35 per kg. The suspension arms,

[147] A2Mac1

bearing hub, stabilizer system and other miscellaneous parts can also be downsized. However, the additional mass savings that could be achieved by replacing the steel with aluminum is not large enough to justify the cost increase. Therefore, these components will be downsized, but will remain steel. This results in mass reductions of 1.25 kg, 0.29 kg, 0.57 kg and 0.01 kg respectively, as shown in Figure 205.

As was mentioned in the discussion of the front suspension, aluminum suspension components have been used successfully by several recent vehicle programs, providing the same or improved performance compared with steel parts. The same manufacturing equipment and processes as those currently used on the baseline rear suspension would be used to produce the LWV parts. The incremental costs are discussed further in Section 9.6.5.

Vehicle Subsystem	Baseline Mass (kg)	LWV Mass (kg)	Mass Savings (kg)	Mass Savings (%)	Cost Increase ($)	Cost Increase Premium ($/kg)
Rear K-Frame and Reinforcement (Aluminum)	24.20	13.05	11.15	46	48.51	34.35
Suspension Arms (Steel)	12.50	11.25	1.25	10	-2.65	-2.12
Bearing Hub (Steel)	6.09	5.80	0.29	5	-0.66	-2.18
Stabilizer System (Steel)	2.97	2.40	0.57	19	-1.33	-2.23
Other Parts	7.41	7.40	0.01	0	0.00	0.00
Total	**53.2**	**39.90**	**13.27**	**25**	**43.87**	**3.30**

Figure 205: Potential Mass Savings for Rear Suspension Components

5.11.2.3 Final LWV Rear Suspension Design

The LWV will use the same multi-link type of rear suspension as the baseline vehicle, with the components downsized to take advantage of the overall vehicle weight reduction. In addition, the K-frame and reinforcement will be constructed of aluminum rather than steel. FEA modeling was used to verify that the strength of the re-designed parts is equal to or better than the baseline. The mass of the complete rear suspension module for the LWV is 39.90 kg, a reduction of 13.27 kg (25%) compared with the baseline. The cost increase is$43.87, or $3.30 per kg. The incremental costs are discussed further in Section 9.6.5.

5.11.3 Tire/Wheels

5.11.3.1 Baseline

The baseline tire and wheel system consists of four tires, four wheels, a spare tire/wheel and the jack. The mass of the entire system is 93.86 kg, as shown in Figure 433. The tires are standard tubeless tires while the wheel rims and jack are steel. As is standard in most current passenger cars, the spare tire and wheel are smaller than the road tires/wheels.

Item	Mass (kg)
4 Wheels	40.10
4 Tires	37.10
Spare tire/wheel	13.20
Jack	3.46
Total	93.86

Figure 206: Baseline Tire/Wheel System Parts Breakdown

5.11.3.2 Tires / Wheels Technology Options

Reducing the tire and wheel size was one mass reduction possibility considered. However, the tires and wheels on a vehicle are seen to enhance the car’s appearance, as well as being very critical for adequate grip during acceleration, cornering and braking. Therefore, the baseline P215/60R16 and P225/50R17 tire and wheel sizes were not changed for the LWV. The front and rear suspension and body structure of the LWV are designed to accommodate both sizes.

Revising the wheel material from steel to AHSS, aluminum or carbon fibre composite was considered. Each of these would reduce mass by allowing thinner steel gauges or by using lower density materials. Aluminum wheels also allow wheel covers to be eliminated through styling. Composite wheels present the greatest mass reduction potential, but this technology is not yet advanced to the point where it can supply a high volume program like the Honda Accord in a cost effective manner, and the team does not anticipate that it will be sufficiently advanced for that purpose in the 2017-2025 time frame.

Another possibility investigated was replacing the conventional tires with run-flat tires and eliminating the spare. This removes the mass and cost of the spare tire, wheel and jack but adds the cost increase of the four run-flats over conventional tires. Current industry pricing indicates that run flat tires cost an average of 40% more than standard tires (approximately $50.00 per tire or $200.00 per vehicle). The most common type of run flat tire in production is the Self-Supporting Tire (SST) which uses heavily reinforced sidewalls to support the weight of the vehicle if air pressure is lost. This extra reinforcement adds approximately 10% (1 kg) to the mass of each tire, reducing the mass savings from 16.66 kg (13.20 kg for the spare and 3.46 kg for the jack) to 12.66 kg. Run flat tires have significant disadvantages that must be considered. They give a much harder and noisier ride than standard tires due to the extra stiffness in the sidewalls, which would be perceived as degradation in ride quality. They are not repairable, needing replacement after any loss of pressure due to the damage to the sidewall. Many run flat tires have shown much higher tread wear, requiring replacement twice as often as conventional tires. These additional costs would not be acceptable to consumers of a medium price vehicle like the Honda Accord. For these reasons, run flat tires were not selected for the LWV.

Eliminating the spare tire and providing an aerosol canned tire repair kit was also considered, and did offer an additional savings of 16.16 kg of tire, wheel and jack mass (this includes the addition of 0.5 kg for the canned repair kit). This was not chosen as a primary option because many consumers view this in a negative light, seeing the lack of a spare tire as a downgrading of the vehicle content and a loss of functionality. Finally, a search of the current market was conducted to determine if there are currently available tires with lower mass and equivalent performance to the baseline tires.

5.11.3.3 Final LWV Tires / Wheels Design

The four wheel rims will be constructed of AHSS for the LWV rather than standard high strength steel used on the baseline Accord. This allows the thicknesses to be reduced by approximately 15%with no effect on performance for the LWV, generating a mass reduction of 6.04 kg for the four wheels, or 15% (from 40.10 kg to 34.06).The incremental cost of this is $8.80, or $1.46 per kg. The AHSS thicknesses used for the wheel are shown in Figure 207.

	Baseline Vehicle	LWV
Rim Thickness (mm)	2.80	2.40
Disc Thickness (mm)	3.60	3.00

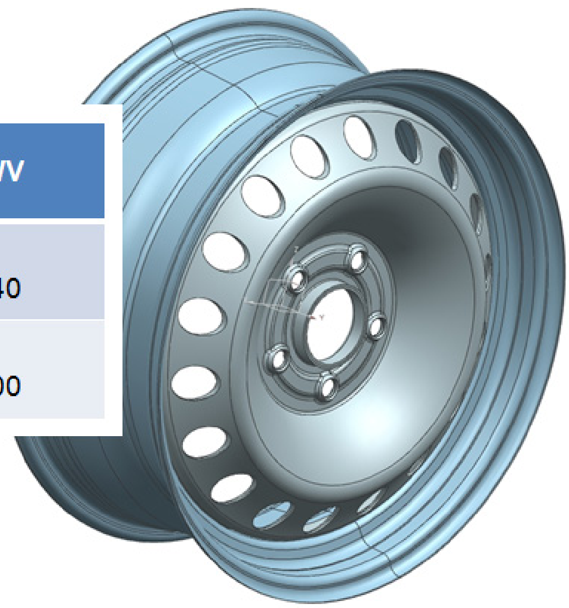

Figure 207: LWV – AHSS Wheel

Goodyear offers a tire called the “Efficient” which is the lightest weight tire currently on the market. Replacing the four tires on the LWV with Goodyear Efficients reduces the combined mass by 4.45 kg (12%) at no additional cost.

Due to the lower weight of the LWV compared with the baseline, the spare tire and wheel can be downsized to the same mass as the Honda Civic, resulting in an 18% mass reduction (2.34 kg). Similarly, the jack can be downsized to one similar to the Civic. This reduces the mass of the jack to 2.05 kg, a savings of 1.41 kg (41%) compared with the baseline. The changes to the spare tire and jack are expected to be cost neutral.

The overall mass reduction for the Tire/Wheel system is 14.2 kg (15%) at a cost increase of $8.8, or $0.62 per kg. The mass and cost details can be seen in Figure 208. The incremental costs of the wheels are discussed further in Section 9.6.6.

Vehicle Subsystem	Baseline Mass (kg)	LWV Mass (kg)	Mass Savings (kg)	Mass Savings (%)	Cost Increase ($)	Cost Increase Premium ($/kg)
Wheels	40.10	34.06	6.04	15	8.80	1.46
Tires	37.10	32.65	4.45	12	0.00	0.00
Spare Tire/Wheel	13.20	10.86	2.34	18	0.00	0.00
Car Jack	3.46	2.05	1.41	41	0.00	0.00
Total	**93.86**	**79.62**	**14.24**	**15**	**8.80**	**0.62**

Figure 208: Final LWV Tire and Wheel System Mass and Cost Summary

5.11.4 Brakes

5.11.4.1 Baseline

The baseline Honda Accord features a conventional 4-wheel antilock disc brake system. This system includes the master cylinder, hydraulic fluid and lines, discs, calipers, brake pads, parking brakes, ABS/ESC system and various shields, brackets and sensors.

5.11.4.2 Brakes Technology Options

The reduced weight of the LWV allows the brake system to be downsized to the same weight as the brake system on the Honda Civic. The calipers, pads, discs, ABS system and vacuum pump could be reduced in size without degrading vehicle performance. In addition, the cast iron front and rear calipers could be replaced with aluminum calipers. The performance and production capability of aluminum calipers has been demonstrated through usage on several vehicles over time. For example, in the 2009 model year alone at least 12 production vehicles included 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[148]. These changes could provide a combined mass savings over 15 kg for the LWV front and rear brakes.

Another opportunity for mass reduction in the brake systems would be to replace the mechanical parking brake system 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 3.31 kg to 2.32 kg, a 30% (0.99 kg) weight savings. Electric parking brake (EPB) systems are already

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

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. The LWV will integrate an EPB to replace the baseline mechanical parking brake. The mass reductions and cost impact of each brake component are shown in Figure 209. The incremental costs are discussed further in Section 9.6.7.

Vehicle Subsystem	Baseline Mass (kg)	LWV Mass (kg)	Mass Savings (kg)	Mass Savings (%)	Cost Increase ($)	Cost Increase Premium ($/kg)
Master Cylinder	3.16	3.16	0	0	0.00	0.00
Front Discs	16.03	10.17	5.86	37	-16.45	-2.81
Front Calipers (Aluminum)	11.23	5.99	5.24	47	6.95	2.81
Front Pads	1.77	1.50	0.27	15	0.00	0.00
Rear Discs	8.18	5.20	2.98	36	-7.00	-2.35
Rear Calipers (Aluminum)	6.00	4.59	1.41	24	2.42	1.34
Rear Pads	0.89	0.75	0.14	16	0.00	0.00
Parking Brake	3.31	2.32	0.99	30	0.00	0.00
ABS System	3.10	1.93	1.17	38	0.00	0.00
Vacuum Pump	0.95	0.80	0.15	16	0.00	0.00
Brake Lines	1.95	1.95	0	0	0.00	0.00
Miscellaneous	2.43	2.43	0	0	0.00	0.00
Total	**59.00**	**40.79**	**18.21**	**31**	**-14.09**	**-0.89**

Figure 209: Brake System Mass and Cost Summary

5.11.4.3 Final LWV Brake Design

The LWV brake system will use the same technology as the baseline vehicle, but the size of many of the components will be reduced and the calipers will be aluminum rather than cast iron. The parking brake will be replaced by an EPB, eliminating the handle and linkages. The total mass of the LWV brake system is 40.79 kg, a reduction of 18.21 kg (31%) from the baseline 59.00 kg. The downsizing of the brake components will result in an estimated incremental cost savings of $14.09, or $0.89 per kg. The incremental costs are discussed further in Section 9.6.7.

5.12 Powertrain

5.12.1 Engine

5.12.1.1 Baseline

The engine used in the baseline 2011 Honda Accord is an all-aluminum block, 2.4 liter displacement, four-cylinder engine (see Figure 210). The engine is naturally aspirated and produces 132 kW of power and 218 Nm of torque (177 hp and 161 ft-lb). The mass of the engine is 169.9 kg.

Figure 210: Baseline 2.4L Engine[149]

5.12.1.2 Engine Technology Options

Several technologies were discussed for light-weighting the engine, with a goal of maintaining the baseline vehicle's power-to-weight ratio at the smallest displacement possible. These technologies included gasoline direct injection (GDI), forced induction (super-charging / turbo-charging), electrically driven auxiliary accessories and reduced displacement. These were in addition to ongoing engine efficiency technologies such as friction reduction, variable valve actuation timing (VVT), cylinder deactivation, and variable (tuned) volumetric efficiency improvements. Most of these technologies are deployed in concert with each other, with the ultimate objective of improving engine efficiency and reducing losses. This higher efficiency allows the engine displacement to be reduced; hence, engine-block mass.

5.12.1.3 Final LWV Engine Design

After much deliberation between the team and NHTSA, it was decided to focus the powertrain development toward downsizing the engine from the original 2.4 L, four cylinder engine in the baseline 2011 Honda Accord to a 1.8 L naturally aspirated engine such as that used in Honda Civic. Mass reduction is only one of the technologies employed in NHTSA's rulemaking analysis to develop fuel economy standards. Powertrain technologies, such as those mentioned

[149] A2Mac1

previously, are accounted for separately from mass reduction in NHTSA's analysis, and their cost and effectiveness characteristics are accounted for separately as well. Consequently, NHTSA requested that for this project, efforts should be focused on mass reduction rather than engine efficiency technologies. The engine and transmission selection in this study is mainly for use in verifying whether the performance of the vehicle can be maintained, and for properly sizing the fuel and exhaust systems, although the downsized engine and transmission geometry and mass are used in crash simulations with the LWV.

In order to maintain an equivalent power-to-weight ratio with the baseline vehicle, the downsized engine specified for the LWV will be the naturally aspirated 1.8 liter, four cylinder engine currently used in the Honda Civic, as shown in Figure 211. The engine mass is 141.3 kg, a savings of 28.6 kg (17%) over the baseline engine. The Civic engine produces 104 kW of power and 173 Nm of torque (140 hp &128 ft-lb). With the overall vehicle weight reduced from 1480 kg to 1122 kg, the power-to-weight ratio of the LWV with the smaller engine exceeds that of the baseline vehicle (0.093 for the LWV vs. 0.089). Powertrain Simulation Analysis Toolkit (PSAT) was used to verify that the power provided by this engine was adequate for the LWV. The cost impact of using the smaller engine is a savings of $31.31 (only based on material costs savings as discussed in Section 9.6.10).

Figure 211: Honda Civic 1.8L Engine[150]

5.12.2 Transmission

5.12.2.1 Baseline

The baseline 2011 Honda Accord comes equipped with a 5-speed automatic transmission. The mass of the transmission is 96.7 kg.

5.12.2.2 Transmission Technology Options

As with the engine, there are several promising technologies that can be deployed to improve the efficiency of the transmission with the ultimate objective to reduce vehicle fuel consumption. In particular, discussion has centered on wet/dry dual clutch multi-speed (6+) transmissions.

[150] A2Mac1

However, these efficiency improvement technologies are beyond the scope of this study. The scope of this study is mass reduction while meeting the performance of the baseline vehicle. Therefore, the goal in choosing a transmission for the LWV is to achieve mass savings while maintaining a level of performance equivalent to that of the baseline vehicle.

Since the LWV, at 1122 kg, is 358 kg lighter than the 1480 kg baseline vehicle, the powertrain size (both performance and mass) can be reduced while still meeting or exceeding the power-to-weight ratio of the current baseline vehicle. As was discussed in the previous section, the engine specified for the LWV has been downsized to provide an equivalent level of performance to the baseline vehicle. For the same reasons a downsized transmission of reduced capacity can also be specified.

5.12.2.3 Final LWV Transmission Design

The transmission chosen for the LWV is the one currently paired in the Honda Civic with the 1.8 liter engine which has been specified for the LWV. This transmission is a conventional 5-speed automatic with a mass of 68.8 kg. This substitution provides a mass savings of 27.9 kg (29%) over the baseline transmission while still providing the necessary level of performance and durability, based on mass and power inputs, as the baseline vehicle. This change also results in a cost savings of $67.28 (only based on material costs savings as discussed in Section 9.6.10), As discussed in Section 9.6.10, the transmission selected for this project is primarily used to calculate the fuel economy so that the fuel system can be properly sized.

5.12.3 Drive Shafts

5.12.3.1 Baseline

The baseline Honda Accord is a front wheel drive vehicle and uses conventional steel drive shafts.

5.12.3.2 Drive Shaft Technology Options

Lightweighting the drive shafts could be done through material substitution by replacing the baseline steel with aluminum or carbon fiber composites. Both of 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. Rear wheel drive cars and trucks have long drive shafts, offering the potential of significant mass reduction by replacing steel with aluminum or composite. Front wheel drive midsize vehicles like the Honda Accord have very short drive shafts, so the team concluded that 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.

In addition to substituting materials, the baseline Honda Accord drive shafts can be scaled down to a size more appropriate to the scaled down engine and transmission selected for the LWV. This would allow the drive shafts to be comparable to those of the Honda Civic.

5.12.3.3 Final LWV Drive Shaft Design

The LWV drive shafts will be reduced to the size of those used in the Civic. The technology will be the same as that in the Civic and the baseline Accord. This reduces the mass from 15.2 kg to 11.7 kg, a reduction of 3.5 kg (23%).The cost impact of this is savings of $5.3 from the material reduction as there are no changes to the manufacturing processes and parameters.

5.12.4 Fuel System

5.12.4.1 Baseline

The baseline Honda Accord has a plastic fuel tank with a capacity of 18.5 gallons. The mass of the tank (including lines and fittings) is 12.0 kg and that of the fuel is 50.89 kg.

5.12.4.2 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 tank itself while also reducing the mass of the fuel carried. The performance criterion that must be maintained is the vehicle range provided by a tank of gas. Because the LWV is lighter than the baseline 2011 Honda Accord, vehicle fuel economy is improved, allowing the vehicle to travel the same distance using less fuel. The baseline vehicle has a stated average fuel economy of 27 mpg, giving it a range of 500 miles with the 18.5 gallon fuel tank. As shown by the PSAT simulation results in Figure 97, the LWV has an average fuel economy of 31.6 mpg, requiring a 15.8 gallon fuel tank to maintain the same 500 mile range. The LWV has a mass reduction of 22.4%. The fuel economy for the LWV can also be calculated as; 6.5%*22.4%/10% = 15%. Therefore the final fuel economy for the LWV is 27 x (1+0.15) = 31 mpg.

Replacing the baseline fuel tank with a 15.8 gallon fuel tank on the LWV reduces the fuel mass from 50.89 kg to 43.47 kg, a mass savings of 7.43kg (15%). The cost decrease from the fuel mass savings is a part of the dealer cost (included in indirect cost) and is considered as cost neutral to the vehicle manufacturer. In addition, the mass of the tank itself is reduced from 12.0 kg to 10.3 kg, a mass savings of 1.75kg (15%). Less material is required to fabricate the smaller fuel tank; but the manufacturing process is unchanged compared to the baseline fuel tank. The baseline fuel tank is made of high density polyethylene (HDPE) 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 are proposed for this component.

5.12.4.3 Final LWV Fuel System Design

The LWV replaces the baseline 18.5 gallon fuel tank with a 15.8 gallon tank of the same material, construction and meeting the same technical requirements as the baseline. As stated previously, the mass of the LWV tank is 10.3 kg, a savings of 1.75kg (15 %) over the baseline. This reduces the mass of the fuel by 7.43kg and the total mass by 9.12 kg (from 62.89 to 53.77

kg, a reduction of 15%). The cost impact of this is savings of $7.2 from the material reduction resulting from the downsized fuel tank; there are no changes to the manufacturing processes and parameters. Detailed discussion about the cost can be found in Chapter 9.

5.12.5 Cooling System

5.12.5.1 Baseline

The 2011 Honda Accord uses a conventional water cooled engine with a radiator, water pump, fan, thermostat, hoses and fittings.

5.12.5.2 Cooling System Technology Options

With the reduction of vehicle mass and engine/transmission sizes, the engine cooling components can also be scaled down to the component sizes used on the Civic as shown in Figure 442. This will result in an overall mass savings of 1.89 kg (13%) compared with the baseline.

Vehicle Subsystem	Baseline Mass (kg)	LWV Mass (kg)	Mass Savings (kg)	Mass Savings (%)	Cost Increase ($)	Cost Increase Premium ($/kg)
Radiator	4.42	4.00	0.42	10	0.00	0.00
Radiator Support	0.43	0.40	0.03	7	0.00	0.00
Hoses	1.77	1.50	0.27	15	0.00	0.00
Fan System	7.06	6.00	1.06	15	0.00	0.00
Expansion Bottle	1.11	1.00	0.11	10	0.00	0.00
Total	**14.79**	**12.90**	**1.89**	**13**	**0.00**	**0.00**

Figure 212: Engine Cooling Mass and Cost Summary

5.12.5.3 Final LWV Cooling System Design

The LWV will use smaller components in the engine cooling system, reducing mass without affecting vehicle performance. These components use the same manufacturing processes as are used for the baseline and the Honda Civic. The cooling system for the LWV is assumed to be cost neutral compared with the baseline vehicle.

5.12.6 Exhaust

5.12.6.1 Baseline

The baseline Honda Accord uses a conventional exhaust system composed of exhaust pipes, catalytic converter, muffler, heat shields and hangers. 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 20.75 kg.

5.12.6.2 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 to sizes similar to those of the Honda Civic, as shown in Figure 213.

Substituting lower density materials, such as aluminum or composite, was not feasible in this application due to the high temperature requirements. The baseline steel was selected 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 which offer mass saving potential in the 2017-2025 timeframe.

Vehicle Subsystem	Baseline Mass (kg)	LWV Mass (kg)	Mass Savings (kg)	Mass Savings (%)	Cost Increase ($)	Cost Increase Premium ($/kg)
Exhaust on Body	14.29	13.00	1.29	9	-2.99	-2.33
Exhaust on Engine	5.42	5.00	0.42	8	-0.98	-2.33
Heat Shields	1.04	1.04	0.04	4	0.00	0.00
Total	**20.75**	**19.04**	**1.71**	**8**	**-3.97**	**-2.33**

Figure 213: Exhaust System Mass and Cost Summary

5.12.6.3 Final LWV Exhaust Design

The exhaust system of the LWV will use the same technology as the baseline vehicle, but with the components downsized to match those of the Civic. The cost impact of this is savings of $2.33 from the material reduction as there are no changes to the manufacturing processes and parameters. Vehicle performance will not be affected by the changes and the cost impact is neutral.

5.13 Interior Systems

The Honda Accord interior is primarily composed of plastics, metal, insulation, carpeting, foam, fabric and fasteners. The benchmarking tool, A2Mac1, shows that plastics account for 47% of the interior mass (33.78 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, a recent technology from Trexel, Inc., called MuCell®, offers a promising opportunity to reduce significant mass with no cost penalty.

Most automotive plastic parts can benefit from the application of MuCell® technology, in which 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 10% with a simple material substitution or as much as 25% if the part is redesigned to take full advantage of the MuCell® process. In the future, part costs could possibly be reduced through shorter processing times, less required raw material, smaller molding machines and improved product quality. Interior trim panels, ducting, IP retainers and bezels are ideal candidates for this technology. For the LWV the part cost is assumed to be neutral based on supplier feedback.

It should be noted that, due to surface appearance concerns, MuCell® material is not recommended for use on Class A surfaces, though work is currently underway by Trexel to improve this. For the LWV 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.

5.13.1 Instrument Panel

5.13.1.1 Baseline

The instrument panel of the baseline 2011 Honda Accord is constructed of a cross-car beam, upper and lower shell, HVAC ducting and vents, glove box and door, electronics (instrument cluster, radio, HVAC controls, center display and various control modules), inflatable restraint system, center console (parking brake lever, shifter, etc.), 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, center console and passenger airbag 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. An exploded view of the baseline assembly is shown in Figure 214. The mass of the entire baseline I/P assembly is 31.90 kg.

Figure 214: Baseline I/P Exploded View

5.13.1.2 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. The mass of this assembly is 11.88 kg. It is replaced in the LWV with a cast magnesium cross-car beam similar to that shown in Figure 215. The brackets and mounts are incorporated into the basic casting, reducing the complexity and part count significantly and improving geometric tolerance. The mass of the magnesium casting in the LWV is 6.50 kg, a savings of 5.38 kg (45%) compared with the baseline. 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 trucks, Jeep Grand Cherokee and Ford GT. Honda designed and implemented a cast magnesium instrument panel on its 2008 FCX, documenting a 40% mass savings[151].

[151](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)

Figure 215: Cast Magnesium I/P Beam (GM Epsilon shown)

The various plastic parts in the I/P structure have a combined mass of 14.10 kg. Parts with Class A surfaces account for 3.70 kg. The remaining parts could be replaced in the LWV with MuCell® nitrogen-infused plastics, reducing their mass from 10.40 kg to 7.80 kg, a savings of 2.60 kg as the parts will be redesigned to take full advantage of MuCell material (25%). In this way the total mass of these plastic parts could be reduced from 14.10 kg to 11.50 kg, an 18% savings. Similar technology is incorporated into the electronic and audio component housings, reducing their masses from 3.14 kg to 2.36, and from 2.78 kg to 2.09 kg, a savings of 25% in each case. To achieve this level of mass reduction the parts and tooling would be designed with the MuCell® process in mind. This does not incur any additional cost as the design process and tooling resources are the same for MuCell® as for the baseline parts. The team concluded that it would not be necessary to verify compliance with FMVSS 201 head impact requirements through analysis because no modifications are being proposed to surfaces which could be impacted by occupants.

The total mass of the LWV instrument panel assembly with magnesium beam and MuCell® components is 22.45 kg, a reduction of 9.46 kg (30%) compared with the baseline. Based upon inputs from magnesium beam suppliers, the incremental cost increase of these changes is $15.43 (USD), representing a $1.63 per kg cost increase premium over the baseline I/P assembly. The parts in which MuCell® replaces the baseline plastic are cost neutral as was mentioned previously. A summary of the mass and cost results for the instrument panel can be seen in Figure 216.The incremental costs are discussed further in Section 9.6.9.

Vehicle Subsystem	Baseline Mass (kg)	LWV Mass (kg)	Mass Savings (kg)	Mass Savings (%)	Cost Increase ($)	Cost Increase Premium ($/kg)
I/P Beam	11.88	6.50	5.38	45	15.43	2.87
Plastic Parts	14.10	11.50	2.60	18	0.00	0.00
Instrumentation	3.14	2.36	0.78	25	0.00	0.00
Audio System	2.78	2.09	0.69	25	0.00	0.00
Total	**31.90**	**22.45**	**9.45**	**30**	**15.43**	**1.63**

Figure 216: Instrument Panel Mass and Cost Summary

Instrument panel cluster design is rapidly evolving, presenting several possible technologies which could reduce mass. Ultra-thin, flat screen, light emitting displays like those shown in Figure 217 give the appearance of traditional displays and can be customer configured for several different graphical display styles. Liquid Crystal Display (LCD), Passive Matrix Organic Light Emitting Diode (PM-OLED) and Active Matrix Organic Light Emitting Diode (AM-OLED) are some of the emerging cluster technologies. These displays are thinner than conventional displays and have no moving parts, reducing mass. At this time the cost of these advanced display technologies is still too high to compete favourably with the baseline parts, and suppliers are reluctant to predict future prices. Therefore, as the data is speculative at this time, the team decided not to include these technologies on the LWV, but recommend revisiting them as the costs come down in the future.

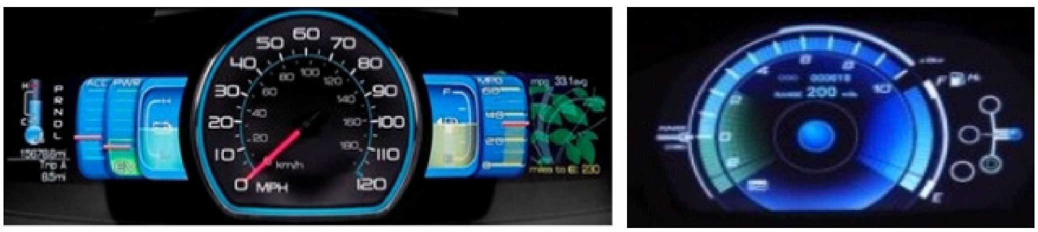

Figure 217: Examples of LCD Instrument Clusters[152]

5.13.1.3 Final LWV Instrument Panel Design

The LWV I/P will use a cast magnesium cross-car beam, incorporating the various brackets and mounts into a single structure. The plastic materials in the I/P structure, electronics and audio which are not Class A surfaces will make use of Trexel's MuCell® hydrogen-filled polymer, incorporating the associated design advantages. The total mass of the LWV I/P is 22.45 kg, a reduction of 9.46 kg (30%) compared with the baseline. The overall cost increase is $15.43, or $1.63 per kg. The incremental costs are discussed further in Section 9.6.9.

5.13.2 Seats

5.13.2.1 Front Seats - Baseline

The baseline 2011 Honda Accord front bucket seats 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. An exploded view of one entire seat assembly can be seen in Figure 218.

[152] Ford and Honda

Figure 218: Baseline Front Seat Exploded View[153]

The frame (seat back and spring suspension) 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 are 45.80 kg (refer to Figure 219).

Baseline Front Seat Components	Mass (kg)
Frame and Mechanisms (Steel)	32.00
Foam for cushions	5.50
Covers	2.74
Garnish trim (plastics)	4.12
Miscellaneous Parts and Fasteners	1.38
Total	**45.74**

Figure 219: Baseline Front Seat Mass – Combined Driver and Passenger

5.13.2.2 Rear Seat – Baseline

The rear seat assembly, shown in Figure 220, consists predominantly of foam cushioning, a 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 21.03 kg, as can be seen in Figure 221.

[153] A2Mac1

Figure 220: Baseline Rear Seat Exploded View[154]

Baseline Rear Seat Components	Mass (kg)
Frame and Mechanisms (Steel)	7.95
Foam for cushions	7.12
Covers (Fabric)	1.90
Garnish trim (plastics)	0.62
Miscellaneous – Locking Mechanisms & Fasteners	3.44
Total	**21.03**

Figure 221: Baseline Rear Seat Mass

5.13.2.3 Seats – Technology Options

5.13.2.4 Seat Frame Construction

The Honda Accord seat frame utilizes a conventional stamped steel design. This is a proven approach from both performance and cost effectiveness perspectives. See Figure 222 for a typical steel seat frame design, which 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.

[154] A2Mac1

Figure 222: Typical Steel Seat Frame

For the next generation (MY 2014-2016) of seat construction, the team believes that replacing the steel seat frame material with Advanced High Strength Steel (AHSS) 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 requirements. While there is time before the 2017-2025 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.

Lear Corporation has developed an advanced seating system called the Evolution Seat[155] shown in Figure 223. 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% lighter than conventional structures because they integrate lightweight mechanisms and rails, and avoid the use of exotic metals.

[155] Source: http://www.sae.org/mags/aei/inter/8268

Figure 223: The Evolution Seat by Lear Corporation

Other seat frame construction materials under review are cast aluminum, cast magnesium and composites. Incorporating cast magnesium or aluminum for the seat frame bottom is a lightweight option for the 2016-2018 timeframe. 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 224. The use of magnesium casting of this type is equivalent to a mass saving of 45% compared with similar steel structure.

Figure 224: 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[156]. The seatback is molded from a polycarbonate (PC) and acrylonitrile butadiene styrene polymer (ABS) blend and includes a built-in head restraint and provisions for mounting a side airbag as shown in Figure 225. 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 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

[156] Source: SAE Paper No. 299-51528

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 225: Dow Automotive Plastic Composite Seatback

Composites offer an attractive design possibility for the 2018 – 2020 timeframe. Fibre-reinforced composite rear seat structures achieve even greater mass reduction than magnesium, aluminum or ultra-high strength steels, providing the lowest mass design at a reasonable cost. 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 226 are:

- Up to 50% mass reduction compared to steel
- Less complex parts and fewer process steps reduce development and manufacturing time
- Structural behaviour and crash strength equivalent to current production seats

Figure 226: Fiber-Reinforced Composite Rear Seat Back (JCI)[157]

[157]http://www.johnsoncontrols.com/publish/etc/medialib/jci/ae/naias_2011/pds_seating.Par.0943.File.dat/modular_rear_seat_structure_composite_concept_en.pdf

5.13.2.5 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 utilizing structural foam as an alternative to the metal wire frame that is commonly used in seat cushions and backs[158]. Typical weight savings achieved for rear seat cushions were in the range of 20-40%. The technology was patented and trademarked with the name StructureLite® and is currently available in two types of foam: Polyurethane (PU) or Expanded Polypropylene (EPP).

5.13.2.6 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 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% recycled content, leading to reduced landfill content, conservation of natural resources and lower energy usage for production.

5.13.2.7 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. The designs need to be validated by finite element model analysis first, 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. 202 ”Head restraints”, FMVSS No. 201 (occupant protection in an interior impact), FMVSS No. 207 “Seating Systems”, and FMVSS No. 210 (seatbelt assembly anchorages). As was discussed previously, the risers, tracks and adjustment mechanisms will be 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 227.

[158] Source: SAE Paper2011-01-0424 Published04/12/2011

Component	Technology	Benefits	Risks/Trade-offs
Seat Frame	Advanced High Strength Steel	Lower mass & costs	
	Hydro-formed seat back	Lower mass & costs	
	Die-cast Mg/Al	Lower mass	Higher costs
	Blow-molded seat back	Lower mass & costs	
	Composites	Lower mass	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 227: Seating Sub-System Weight Reduction Summary

5.13.2.8 Seat Technologies Summary

The following future automotive seat technologies matrix was developed through discussion with major seat suppliers.

	Baseline 2009 Honda Accord		Next Generation 2014 - 2016		Generation 2 2016 - 2018		Generation 3 2018 - 2020	
	1st Row	2rd row	1st Row	2rd row	1st Row	2rd row	1st Row	2rd row
Mass (kg)	45.74	21.03	-10%	-10%	-20%	-20%	-30%	-30%
Cost			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 (15%) polyols in foam (soy, castor, palm)		Increase natural polymers (20%+) in foam		TPU replacement for PU foam	
			Add inert gases to foam (CO2)		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 228: Seating Technologies Matrix

Based upon the Seating Technologies Matrix as shown in Figure 228, the calculated mass and cost for the LWV front and rear seats are shown in Figure 229.

For year 2020, the baseline vehicle seating mass of 67 kg is reduced by 30%, equivalent to a mass savings of 20 kg. The increase in cost over the baseline vehicle is$96.84. The LWV 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 a full design and validation of the seat concepts selected for the LWV. Seat design is complicated and has to 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 and meet customer satisfaction. Due to time and resource limitation, we relied on the supplier expertise.

Time Frame	Honda Accord Mass (kg)	LWV Mass (kg)	Mass Savings (kg)	Mass Savings (%)	Cost Increase ($)
Next Generation 2014 - 2016	66.77	60.09	6.68	10	32.28
Generation 2 2016 - 2018	66.77	53.42	13.35	20	64.56
Generation 3 2018 - 2020	66.77	46.74	20.03	30	96.84

Figure 229: LWV Seating Mass and Cost Summary[159]

5.13.3 Insulation

The interior insulation in the baseline Honda Accord consists of conventional cotton fiber batting with a total mass of 9.35 kg. This insulation is located in the closures, front of dash, floor and overhead. Three lower mass options were considered as potential replacements for the baseline insulation. 3M offers a product called Thinsulate™ which has been used on such vehicles as the Toyota Prius and is in use on up level Honda Accord models. This is a non-woven polypropylene blend which can reduce the mass of conventional insulation by as much as 44% while maintaining the same or better acoustic protection. In addition, this is a hydrophobic material eliminating the need for waterproofing barriers and resisting mold and mildew growth. However, Thinsulate™ is not recommended by 3M for under-carpet applications, which account for 0.69 kg of the insulation in the baseline vehicle. CTA Acoustics provides a glass fiber based insulation called QuietBlend® which can reduce mass by as much as 25-30% 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%. All of these materials are in current use and are excellent candidates for high volume production.

The 3M Thinsulate™ material has been selected for the LWV with the exception of under-carpet areas, resulting in an average mass savings of 35% (3.03 kg), reducing the mass of the insulation to 5.63 kg. Under the carpet, the baseline insulation is replaced by CTA Acoustics' QuietBlend®. This reduces the mass to 0.52 kg, a savings of 0.17 kg (25%). The total insulation mass in the LWV is 6.15 kg, a savings of 3.20 kg (34%). The cost impact of this change is expected to be neutral according to the feedback received from the part supplier.

5.13.4 Interior 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

[159]Based on feedback from leading seat suppliers

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 panels with MuCell® can provide mass savings up to 25% on interior trim and other molded parts. As shown in Figure 230, this can reduce the mass from 26.26kg to 23.23 kg. The cost impact of incorporating the MuCell® technology is neutral, as was explained in the beginning of Section 5.13.

Vehicle Subsystem	Baseline Mass (kg)	LWV Mass (kg)	Mass Savings (kg)	Mass Savings (%)	Cost Increase ($)	Cost Increase Premium ($/kg)
Trim	3.46	2.60	0.86	25	0.00	0.00
Carpets	11.70	11.70	0	0	0.00	0.00
Headliner	2.42	2.42	0	0	0.00	0.00
Other	8.68	6.51	2.17	25	0.00	0.00
Total	**26.26**	**23.23**	**3.03**	**12**	**0.00**	**0.00**

Figure 230: Interior Trim Mass and Cost Summary

5.13.5 Closure Trim

As was discussed in the previous section, many environmentally friendly materials are being introduced into closure trim, though this will not generally affect part mass. The use of MuCell® technology will be used to reduce the mass of plastic closure trim parts (refer to Section 6.3 for more discussion and mass reduction information about the closure trim).

5.13.6 Entertainment

The baseline Honda Accord includes a conventional AM/FM/CD Radio with six speakers as standard equipment. The mass of the radio is 2.00 kg and is a purchased part from Clarion. The speakers are provided by Pioneer and have a combined mass of 0.95 kg. Several technologies with mass reduction potential were investigated. Low density MuCell® housings could reduce the mass of the current component. LCD and LED head unit systems could eliminate mechanical controls and incorporate thin displays. The possibility of eliminating the CD player and including only an iPod/MP3 input jack with the radio was considered. Lower mass speaker systems were investigated.

Deleting the CD player would likely be seen as unacceptable by the consumer, so this option was eliminated. While there is a possibility that CD players could be phased out by the 2017-2025 time frame, the team decided that there is not enough certainty of that possibility to include it in the LWV. The baseline speaker system is already a very lightweight system and no lower mass replacements, current or future, were found. The only plastic that might be replaced with MuCell® is the faceplate, which is a Class A surface and, therefore, not a candidate. Introducing an LCD or LED faceplate would reduce the mass of the knobs and tuning mechanism, but not that of the CD player which makes up the majority of the head unit mass. The simplest and most cost effective solution for the LWV is to simply replace the baseline Clarion head unit with an existing lower mass unit which has equivalent features and price. A survey of 30 currently available audio systems showed an average mass of 1.46 kg. The JVC KD-R620 meets or exceeds the features and performance of the baseline audio head unit and weighs 1.21 kg, a reduction of 0.79 kg (40%). Since no new technologies are involved and both the baseline and LWV audio head units are currently available, the cost impact is expected to be neutral. The baseline speakers are carried over to the LWV.

The baseline Honda Accord does not include navigation or video systems, so these were not investigated.

5.13.7 Control Systems

The Honda Accord control systems include the accelerator pedal, brake pedal, parking brake lever, gear selector handle and housing assembly, linkages, brackets and switches. Steering controls will be discussed in Section 5.14.

Changes to the accelerator and brake pedals of the sort proposed on the parking brake 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 6.43 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 LWV will carry over these components from the baseline. The parking brake system was discussed in Section 5.11.

5.13.8 Door Locks/Latches/Hinges

As was discussed in Section 5.10, the door locks, latches and hinges will be carried over from the baseline Honda Accord.

5.14 Steering

5.14.1 Steering Shaft and Rack

The baseline Honda Accord steering shaft is a tubular steel structure, 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 shaft has a total mass of 9.02 kg. The steering shaft and steering rack, like other systems in the LWV, can be scaled down to the size of the equivalent Civic components without affecting vehicle performance. Therefore, the steering shaft assembly can be reduced to 5.98 kg, a savings of 3.04 kg (34%) and the steering rack can be reduced from 8.24 kg to 6.91 kg, a mass savings of 1.33 kg (16%). The cost impact of these changes includes savings due to material reductions (-$7.20) and negligible increases due to tooling changes since there are no changes to the design, technology or manufacturing processes.

5.14.2 Steering Wheel

The steering wheel of the baseline Honda Accord is constructed of a magnesium casting covered with a nylon overwrap and the air bag assembly. The mass of the steering wheel is 2.81 kg, while that of the air bag assembly is 1.01 kg. The design of the airbag assembly has been highly refined through years of development and testing. Also, like the steering column, it is 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 will be carried over to the LWV.

5.14.3 Power Steering

The 2011 Honda Accord uses a conventional hydraulic power steering system composed of the power steering pump, pulley, tank, cylinder, lines, fittings and hydraulic fluid. The total mass of this system is 5.54 kg. The system can be scaled down to the size of the Civic power steering system (4.66 kg) without adversely affecting vehicle performance. This results in a mass reduction of 0.88kg (16%) with no cost impact.

Consideration was given to incorporating an Electric Power Steering (EPS) system, in which the hydraulic pump/pulley, tank, cylinder, hoses and fluid are replaced with an electric control module, motor and wiring. In addition to reducing the mass by 2 to 3 kg, the EPS is a much simpler system to manufacture and maintain. It also results in increased fuel efficiency because there is no hydraulic pump being driven by the powertrain. However, in order to avoid double counting, this system will be considered in the context of vehicle electrification technologies used in NHTSA's CAFE analysis, not mass reduction, so it will not be included in this LWV study.

5.15 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 (CFC) emissive refrigerant type as regulated by law. Therefore, the primary components (compressor, condenser, lines and refrigerant) will be carried over from the baseline Honda Accord.

The best opportunity for mass reduction in the HVAC system is to replace the remaining component, the plastic ducting, with MuCell® technology, achieving a 25% mass reduction with no expected cost impact (as was explained in Section 5.13). This reduces the mass of the ducting from 10.3 to 7.7 kg, a savings of 2.6 kg. The only changes to the geometry of the ducting will be to incorporate advantages available with MuCell® (rib and wall thicknesses, boss dimensions, injection gate locations, etc.).

5.15.1 Compressor

The LWV air conditioning compressor will be carried over from the baseline vehicle.

5.15.2 Condenser

The LWV air conditioning condenser will be carried over from the baseline vehicle.

5.15.3 Lines

The LWV HVAC lines will be carried over from the baseline vehicle.

5.16 Electrical

5.16.1 Battery

The baseline Honda Accord uses a standard lead-acid automotive battery with a mass of 12.4 kg. Replacing this with a lithium-Ion (Li-Ion) battery was considered as this could reduce the mass to 4.6 kg, saving 7.8kg (63%). However, the cost of the Li-Ion battery exceeds that of the baseline by several hundred dollars, making it an unacceptable business case for the purposes of this project.

The LWV will replace the baseline battery with the 11.3 kg Honda Civic battery, a mass savings of 1.1 kg (9%). The technology is the same, but the smaller Civic battery is adequate for the smaller LWV engine with no loss in performance. The cost impact is expected to be neutral.

5.16.2 Wiring and Wire Harness

The baseline 2011 Honda Accord uses conventional insulated copper wiring in all its harnesses. The most promising mass reduction alternative to that is aluminum wiring, in which the conductive copper strands are replaced with aluminum. Although the electrical conductivity of aluminum is only 66% 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. Replacing all intermediate and large size wiring harnesses (3 mm^2 – 160 mm^2) with aluminum in the Honda Accord can reduce the overall harness mass from 21.7 kg to 17.4 kg, a 20% reduction. 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. Delphi aluminum wiring, currently in production, will be used on 2012 model year vehicles.

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 2017-2025 timeframe.

The LWV will use aluminum wiring to replace the conventional copper wiring in its intermediate and large size harnesses, reducing mass by 20%. The incremental costs are assumed to be neutral with a possibility for cost reduction proportional to the extent of its application on high volume production vehicles, based on feedback from a leading automotive wiring supplier.

5.16.3 Lighting

The 2011 baseline Honda Accord uses standard lighting components throughout the vehicle. 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 headlamp and tail lamp (low/high beam, turn signal, daytime running lights, position lights, rear stop lamp and vehicle lighting) were realized using LED technology. Lighting systems being produced today can provide mass savings along with significant improvements in system performance. While headlamp and tail lamp assemblies for a vehicle with conventional lighting typically weigh approximately 10 kg, an equivalent LED lighting system weighs approximately 6.3 kg, a savings of 3.7 kg (37%).

Some advantages of LED lighting systems include:

- Produce more light per watt than incandescent lamps
- Consume approximately 90% less energy than conventional lighting systems
- Can emit light of an intended color without the need for filters
- Flexible packaging of LEDs can be used to focus light
- Do not change color when in a dimming mode
- Ideal for frequent on-off applications such as turn signals
- Solid state components are resistant to damage from external shock
- Long life, estimated at up to 50,000 hours
- Quick light-up to full brightness
- Do not contain any environmental contaminants

Some disadvantages include:

- Much higher cost than conventional lighting
- Performance can be affected by ambient temperature
- Heat sinking is required to maintain long life
- Must be supplied with the correct current and need a regulated power supply
- Blue and white LEDs may exceed safe limits for "Blue Light Hazard" as defined in eye safety specification ANSI/ESNA RP-27.1-05

The baseline Honda Accord headlamp assemblies have a mass of 6.86 kg per vehicle, while the tail lamp assemblies have a mass of 2.54 kg per vehicle, as can be seen in Figure 231. A vehicle set of LED headlamp assemblies redesigned to take advantage of the MuCell® housings has a mass of 3.60 kg, a reduction of 3.26 kg (48%) per vehicle. A set of LED tail lamps has a mass of 1.62 kg, a reduction of 0.92 kg (36%) per vehicle. However, though the cost of LED headlamp and tail lamp assemblies is decreasing as the technology matures, and will drop even further when low profile styling reduces the size of the encapsulations, it is still extremely high compared with conventional lighting systems. For that reason LED lighting systems are mainly used on higher end vehicles at this time. For the LWV the cost increase for the headlamps is $430.00 per vehicle, or $131.90 per kg of mass saved. For the tail lamps the incremental cost increase is $96.00, or $104.35 per kg. This gives an overall savings of 4.18 kg per vehicle (44%) at a cost increase of $526.00, or $125.84 per kg.

Vehicle Subsystem	Baseline Mass per Vehicle (kg)	LWV Mass per Vehicle (kg)	Mass Savings per Vehicle (kg)	Mass Savings (%)	Cost Increase per Vehicle ($)	Cost Increase Premium per Vehicle ($/kg)
Headlamps	6.86	3.60	3.26	48	430.00*	131.90
Tail Lamps	2.54	1.62	0.92	36	96.00*	104.35
Total	**9.40**	**5.22**	**4.18**	**44**	**526.00**	**125.84**

Figure 231: Lighting Mass and Cost Summary with LED and MuCell® Technologies
***based upon Tier 1 lighting supplier estimates**

If only a substitution of MuCell® technology for the baseline plastic housings is incorporated, the mass of the headlamps is reduced to 5.15 kg per vehicle with no cost impact (as was explained in Section 5.13). The mass of the tail lamps is reduced to 1.91 kg per vehicle. This gives a total mass savings of 2.34 kg per vehicle (25%) with no cost impact, as can be seen in Figure 232. In the 2017-2025 timeframe, the team anticipates that the cost increase of the LED technology exceeds the mass reduction benefits, so the LWV will use the current headlamp and tail lamp technology with the housings redesigned to take advantage of the MuCell® material.

Vehicle Subsystem	Baseline Mass per Vehicle (kg)	LWV Mass per Vehicle (kg)	Mass Savings per Vehicle (kg)	Mass Savings (%)	Cost Increase per Vehicle ($)	Cost Increase Premium per Vehicle ($/kg)
Headlamps	6.86	5.15	1.71	25	0	0
Tail Lamps	2.54	1.91	0.63	25	0	0
Total	**9.40**	**7.06**	**2.34**	**25**	**0**	**0**

Figure 232: Final LWV Lighting Mass and Cost Summary (MuCell® Technology Only)

5.17 Other Components

5.17.1 Fixed Glass

The fixed glass on the baseline Honda Accord includes the windshield, rear window and a small portion of the rear door windows. The overall dimensions of the fixed glass components on the LWV will remain the same as the baseline. Mass reduction would come from replacing the conventional laminated glass with a lower density material, such as polycarbonate (PC). The density of conventional laminated glass is 2.5 g/cm^3 while that of PC is 1.2 g/ cm^3, giving a mass reduction of 52%. Replacing the windshield with PC is not an accepted practice in the automotive industry as there are concerns with the weatherability and abrasion resistance of the material compared with that of standard laminated glass. Strict guidelines on light transmission and abrasion resistance are defined in FMVSS 205 and UNECE R-43. While there have been great improvements in polycarbonate with respect to UV and abrasion resistance, it is not certain that this material is ready yet for the LWV windshield or rear glass, even by the 2017-2025 time frame, so these components will be carried over from the baseline vehicle. The amount of fixed glass on the rear doors that could be replaced with polycarbonate does not provide enough mass savings (less than 1 kg per vehicle) to present a positive business case for this project.

5.17.2 Windows/Mirrors

As was discussed in Section 5.10.2 and 5.10.3, polycarbonate was considered for the moveable glass on the side doors but rejected because the lower modulus of the PC compared with the conventional tempered glass would cause issues with flexing and binding while raising and lowering the window. Replacing the outside mirror housings with MuCell plastic was considered, but MuCell is not recommended for use on Class A surfaces because the finish is not quite as smooth as standard plastics. Therefore the windows and mirrors on the LWV will be carried over from the baseline vehicle.

5.17.3 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 LWV will carry over the wiper/washer system from the baseline vehicle.

5.17.4 Spare Tire/Tools

Refer to Section 5.11.3 for a discussion of mass reduction options for the spare tire and jack.

5.17.5 NVH Insulation

Refer to Section 5.13.3 for a discussion of mass reduction options relating to insulation.

5.17.6 Safety Systems

Automotive safety restraints (seatbelts and airbags) 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 airbags are lightweight polyester and nylon. These materials are mounted to control surfaces and pyrotechnic devices, such as airbag inflators, that are typically constructed of steel to withstand the forces and heat generated during deployment.

The safety systems in the Honda Accord are conventional designs as described above. The combined masses of the driver, passenger and curtain airbag systems are 9.3 kg, while those of all seat belt systems are 8.9 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 Honda global portfolio; any modifications would need to be validated for all affected vehicle lines. Therefore, the LWV restraints will be carried over from the baseline Honda Accord.

5.17.7 Bumper Fascias and Exterior Trim

The front and rear bumper fascias on the Honda Accord are constructed of polypropylene (PP), as are the air inlet panel and most exterior trim. The masses of the front fascia/grille, rear fascia and air inlet panel are 5.90 kg, 4.54 kg and 1.59 kg, respectively. The combined mass of the remaining exterior trim is 0.54 kg. Because these components are Class A surfaces, they are not candidates for MuCell® technology. The density of polypropylene is already very low compared with most automotive materials (0.91 g/cm^3) so these parts do not present significant mass reduction opportunities. For this reason the bumper fascias, exterior trim and air inlet panel will be carried over from the baseline Honda Accord.

5.18 Summary of Selected Technologies

The selected technologies for the LWV are summarised in Figure 233. The technology options shown were included in the detail design of the LWV. The recommended design for LWV achieves a vehicle mass saving of 22.4% (332 kg). To achieve same vehicle performance as the baseline vehicle the size of the engine is proportionally reduced from the baseline 2.4L (177 HP) to 1.8L (140HP) for the LWV. Without the mass and cost reduction allowance for the powertrain the mass saving for the LWV 'glider' is 23.7% (264 kg).

Figure 234 shows four different vehicles built up scenarios from various technologies that were reviewed for future mass saving potential. The four light weighting options range from a vehicle mass saving of 19.2% to 28.5%.

1. An all Advanced High Strength Steel (AHSS) design, including body structure, closures, front chassis frame and seat frames. This option leads to total vehicle mass saving of 19.2%.
2. Design with AHSS body structure and aluminum closures, chassis frames and magnesium seats, achieves a mass saving of 22.4%.
3. An aluminum intensive solution, using aluminum for body structure, closures, chassis frames and magnesium for seats leads to a mass saving of 25.1%
4. An advanced carbon fiber and multi-material Solution, using carbon fiber reinforced composite body structure, magnesium/aluminum closures, aluminum chassis frames and magnesium/composite seat structures, achieves a total vehicle mass saving of 28.5%.

For all four options the rear chassis frame is in aluminum and the instrument panel beam is in magnesium. In the mass calculations, all four options include the same powertrain a 1.8L (140 HP) engine with 5 speed automatic transmission. The costs for these options are reported in Section 9 of this report.

Vehicle System	Honda Accord System Mass (kg)	Technology Implemented	Light Weight Vehicle Mass Saving (kg)
Body Structure	328.0	Advanced High Strength Steel	72.8
Doors Front	32.8	Aluminum Stampings	15.9
Doors Rear	26.8	Aluminum Stampings	11.9
Hood	15.2	Aluminum Stampings	7.7
Decklid	10.0	Aluminum Stampings	5.2
Fenders	7.3	Aluminum Stampings	3.3
Bumpers	15.8	AHSS Hot Stamping	7.1
Front Suspension	81.3	Assembly - various materials	39.9
Rear Suspensions	53.2	Assembly - various materials	13.3
Seats Front	45.7	Magnesium Base and back frame	13.7
Seat Rear	21.0	Composite Back	6.3
Instrument Panel	31.9	Magnesium IP Beam	9.5
Engine Transmission	266.6	Down Sized from 2.4L to 1.8L, 5Speed Auto	56.5
Fuel System	12.0	Down Sized from 18.5G tank to 15.8G	1.8
Fuel, oil, coolant	68.7	15.8 Gallons	8.1
Wheels	93.9	AHSS	14.2
Trim	26.3	Mucell© (Non Class-A)	3.0
Wiring	21.7	Aluminum/copper	4.3
Battery	12.4	Downsized to Civic (same materials)	1.1
Headlights	9.4	Mucell© Housing	2.4
Exhaust	20.7	Downsized to Civic exhaust (same materials)	1.7
Brakes	59.0	Aluminum Calipers & Civic rotors	15.8
Brake Fliuid	0.5		0.0
Drive Shafts	15.2	Downsized to Civic (same materials)	3.5
HVAC & Cooling System	37.9	Downsized to Civic (same materials)	4.5
Ducting- HVAC & Engine Intake	0.0		0.0
Safety Systems	19.3		0.0
Steering System	20.3	Downsized Power Steering to Civic	4.8
Front & Rear Fascia	13.5		0.0
Wiper system	6.0		0.0
Window Washer Fluid	4.8		0.0
Paint	12.0		0.0
Noise Insulation	9.4	3M© Thinsulate™, QuietBlend® under	3.2
Glass	33.5		0.0
Latches/fastners/mirrors-Misc	47.8		0.0
Total - with Powertrain	1,480		332
Total - without Powertrain	1,112	Powertrain includes Engine-Transmission, Fuel system, Fuel, Oil, Coolant & Exhaust	264

Figure 233: Technologies Selected for LWV

Vehicle System	Honda Accord System Mass (kg)	AHSS BIW, Closures, Chassis Frames & Seats		AHSS BIW & Aluminum Closures, Chassis Frames, Mag Seats		Aluminum BIW, Closures, Chassis Frames, Mag Seats		Composite BIW & Mag/Alu Closures, Aluminum Chassis	
		Mass Saving (kg)	Mass Saving (%)	Mass Saving (kg)	Mass Saving (%)	Mass Saving (kg)	Mass Saving (%)	Mass Saving (kg)	Mass Saving (%)
Body Structure	328.0	72.8	-22.2%	72.8	-22.2%	114.8	-35.0%	164.0	-50.0%
Doors Front	32.8	4.9	-15.0%	15.9	-48.5%	15.6	-47.6%	15.6	-47.6%
Doors Rear	26.8	4.0	-15.0%	11.9	-44.6%	12.3	-45.7%	12.3	-45.7%
Hood	15.2	1.5	-9.8%	7.7	-50.7%	7.0	-46.3%	7.0	-46.3%
Decklid	10.0	1.5	-15.0%	5.2	-52.4%	4.5	-45.0%	4.5	-45.0%
Fenders	7.3	2.3	-30.6%	3.3	-44.5%	3.3	-44.5%	3.3	-44.5%
Bumpers	15.8	7.1	-44.9%	7.1	-44.9%	7.1	-44.9%	7.1	-44.9%
Front Suspension	81.3	35.8	-44.0%	39.9	-49.1%	39.9	-49.1%	39.9	-49.1%
Rear Suspensions	53.2	13.3	-25.0%	13.3	-25.0%	13.3	-25.0%	13.3	-25.0%
Seats Front	45.7	4.6	-10.0%	13.7	-30.0%	13.7	-30.0%	13.7	-30.0%
Seat Rear	21.0	2.1	-10.0%	6.3	-30.0%	6.3	-30.0%	6.3	-30.0%
Instrument Panel	31.9	9.5	-29.6%	9.5	-29.6%	9.5	-29.6%	9.5	-29.6%
Engine Transmission	266.6	56.5	-21.2%	56.5	-21.2%	56.5	-21.2%	56.5	-21.2%
Fuel System	12.0	1.8	-14.6%	1.8	-14.6%	1.8	-14.6%	1.8	-14.6%
Fuel, oil, coolant	68.7	8.1	-11.8%	8.1	-11.8%	8.1	-11.8%	8.1	-11.8%
Wheels	93.9	14.2	-15.2%	14.2	-15.2%	14.2	-15.2%	14.2	-15.2%
Trim	26.3	3.0	-11.6%	3.0	-11.6%	3.0	-11.6%	3.0	-11.6%
Wiring	21.7	4.3	-20.0%	4.3	-20.0%	4.3	-20.0%	4.3	-20.0%
Battery	12.4	1.1	-9.0%	1.1	-9.0%	1.1	-9.0%	1.1	-9.0%
Headlights	9.4	2.4	-25.0%	2.4	-25.0%	2.4	-25.0%	2.4	-25.0%
Exhaust	20.7	1.7	-8.2%	1.7	-8.2%	1.7	-8.2%	1.7	-8.2%
Brakes	59.0	15.8	-26.8%	15.8	-26.8%	15.8	-26.8%	15.8	-26.8%
Brake Fliuid	0.5	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
Drive Shafts	15.2	3.5	-23.1%	3.5	-23.1%	3.5	-23.1%	3.5	-23.1%
HVAC & Cooling System	37.9	4.5	-11.8%	4.5	-11.8%	4.5	-11.8%	4.5	-11.8%
Ducting- HVAC & Engine Intake	0.0	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
Safety Systems	19.3	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
Steering System	20.3	4.8	-23.6%	4.8	-23.6%	4.8	-23.6%	4.8	-23.6%
Front & Rear Fascia	13.5	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
Wiper system	6.0	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
Window Washer Fluid	4.8	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
Paint	12.0	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
Noise Insulation	9.4	3.2	-34.2%	3.2	-34.2%	3.2	-34.2%	3.2	-34.2%
Glass	33.5	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
Latches/fastners/mirrors-Misc	47.8	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
Total - with Powertrain	1,480	284	-19.2%	332	-22.4%	372	-25.1%	421	-28.5%
Total - without Powertrain	1,112	216	-19.4%	264	-23.7%	304	-27.4%	353	-31.8%

Figure 234: Vehicle Technology Options for LWV

The design modifications described throughout Section 5 incurred changes in material distributions in every part of the vehicle, as can be seen in Figure 235. The usage of steel was reduced by 283 kg per vehicle (from 698 kg in the baseline vehicle to 415 kg in the LWV). Cast/forged iron was reduced from 76 kg to 23 kg. Usage of cast aluminum increased from 187 kg to 201 kg while sheet aluminum, which was not used at all in the baseline vehicle, amounted to 78 kg in the LWV. No changes were made to the glazing, so usage of glass was constant at 34 kg. Copper usage was reduced from 20 kg to 10 kg. Plastics, which amounted to 191 kg in the baseline vehicle, were reduced to 145 kg in the LWV. Magnesium was not used in the baseline vehicle, but 15 kg were used in the LWV. Fluid mass dropped from 69 kg to 61 kg due to the reduced fuel tank capacity.

Material Mass (kg)	Baseline Vehicle	EDAG - LWV	Body	Closures	Bumpers	Engine Cradle	A Arms	Front Knuckle	Brake Fr/Rr	Rear K Frame	Engine & Trans	Interior	Misc
Steel	698	415	-72.8	-93.4	-7.1	-30.2	7.7			-24.2	-24.0	-38.4	
Cast/Forge Iron	76	23					-17.5	-12.3	-23.1				
Alum Cast / Forging	187	201						4.6	10.0		-15.1		15.0
Aluminum Sheet	0	78		52.2		12.7				13.1			
Glass	34	34											
Copper	20	10											-10.0
Plastics	191	145										-7.9	-38.1
Magnesium	0	15										15.3	
Fluids	69	61										-8.1	
Misc	208	171											-37.0
Total	1,481	1,152	-72.8	-41.3	-7.1	-17.5	-9.8	-7.7	-13.1	-11.2	-39.2	-39.0	-70.1

Figure 235: Material Mass Distribution of Baseline vs. LWV

Figure 236 shows the impact of the LWV design modifications on each of these materials, while Figure 237 shows how the distribution of materials has changed from the baseline vehicle to the LWV, in terms of total mass.

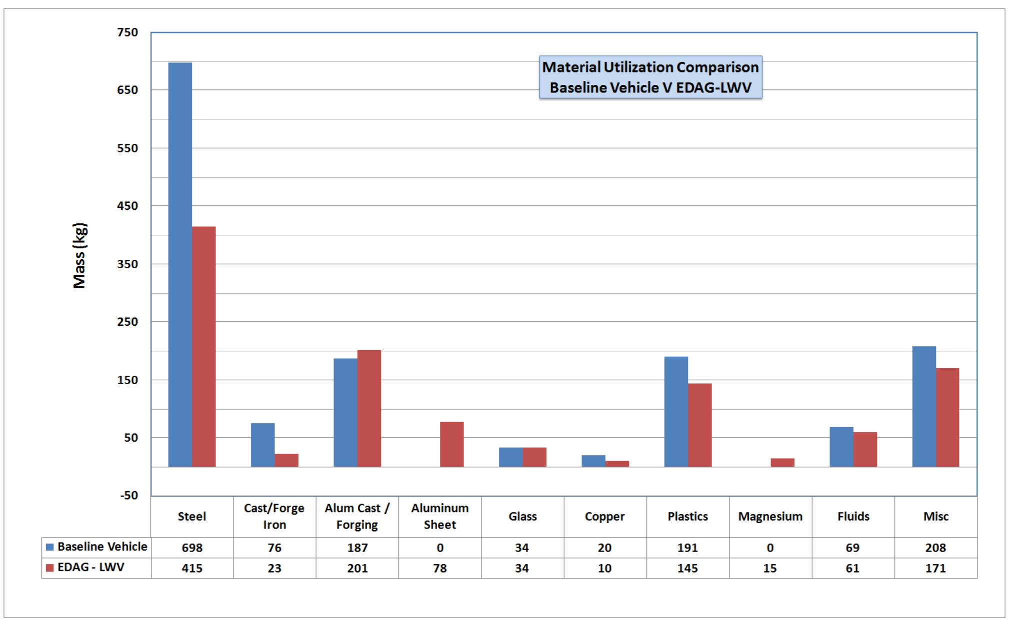

Figure 236: Material Changes From Baseline to LWV

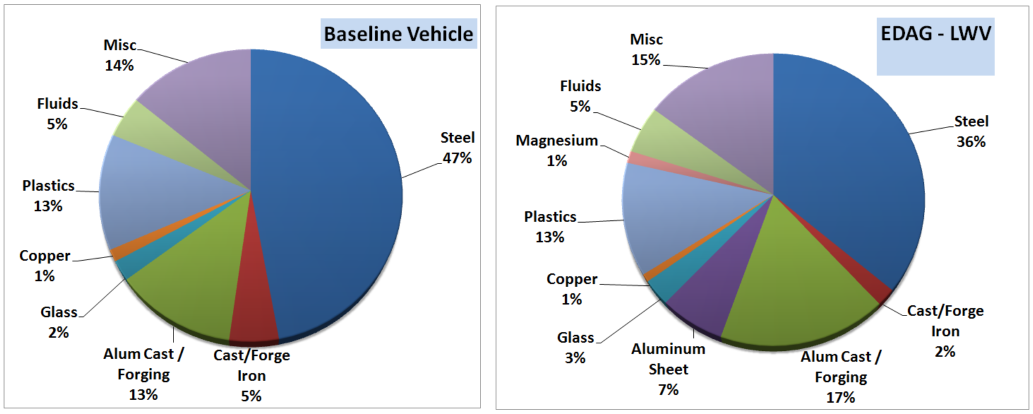

Figure 237: Mass Distribution of Materials in Baseline and LWV

When considering the future high volume production outlook of the LWV, it is important to note that most of the material changes have been reductions in quantity. Those materials which experienced an increase in usage (cast/forged aluminum, 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 2017-2025. Therefore, the feasibility of high volume production of the LWV is not at risk due to unavailability of materials.

6 Crashworthiness Analysisfor LWV

The safety performance of the LWV is compared to the safety rating of the baseline MY2011 Honda Accord for six consumer-information crash tests in this section. The seventh crash test is a rear impact in which the safety of the gas tank is investigated for any fracture or crush. The seven crash tests are described in Section 4.8. Also included in this section below is a how the LWV design manages the crash energy in the various test configurations considered and the robustness of the LS-DYNA model.

6.1 LWV Crash Modeling Software

Finite element (FE) analysis methods and models have been 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 was used by the GWU NCAC and EDAG for LWV FEM analysis. LS-DYNA finite element software is the industry standard software for crash simulation and modeling. LS-DYNA software is based on computer programs originally developed by Lawrence Livermore National Laboratory for impact and defense applications. 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 utilizing nonlinear FE analysis and rigid body dynamics have become effective tools in optimizing and evaluating vehicle safety systems.

6.2 Material Properties and Modeling

There are several major types of materials, mainly steel and aluminum, used in this LWV study. The following sections discuss how steel and aluminum are modeled in this study.

6.2.1 Steel

The purpose of this section is to give: (1) a short introduction to Advanced High Strength Steel (AHSS) and its application in LWV design, (2) the difference in elongation of conventional HSS and AHSS as used in automobiles, and (3) a failure criterion based on testing steel in tension.

6.2.1.1 Introduction to AHSS and its Application in LWV Design

Shaw and Zuidema note that high strength steels are those steels with yield strengths that range from about 210 to 550 MPa and the ultra-high strength steels are steels with yield strengths greater than 550 MPa.[160] The yield strengths of AHSS overlap the range of strengths of high strength and ultra-high strength steels. Figure 238 illustrates that higher yield-strength steels generally have lower elongation.

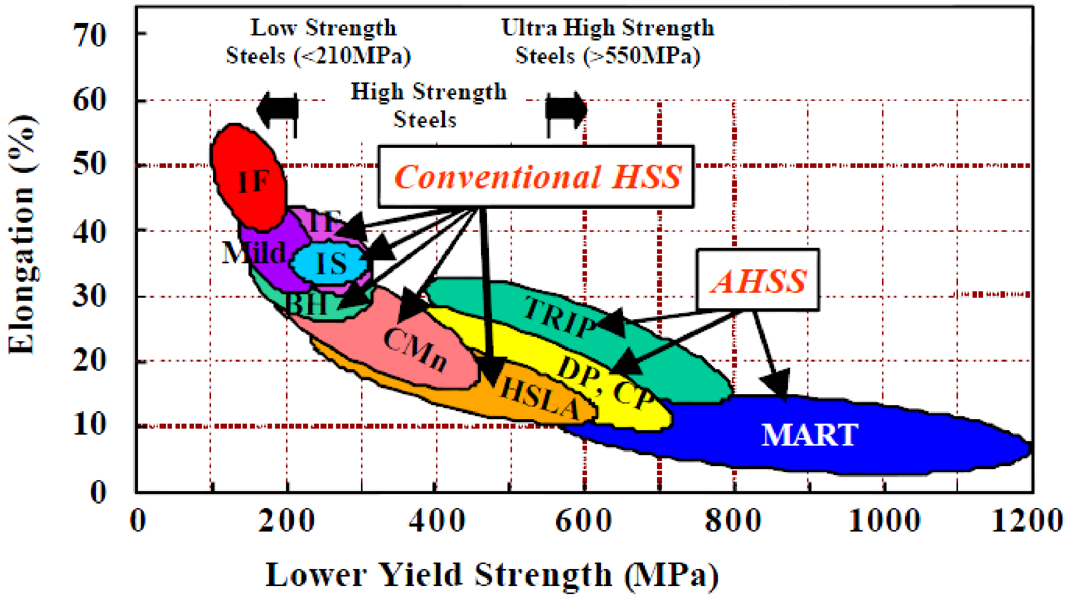

Figure 238: Strength-formability relationship for mild, conventional HSS, and Advanced HSS steels[161]

In addition, under high speed impact conditions, steel exhibits a significant increase in strength owing to the effect of strain rate. Figure 239 shows the stress-strain performance of HSLA 350/450 and DP 350/600 under static and dynamic loading. A significant increase in strength is observed at the higher loading rate. This shows that for vehicle crash simulation, the strain rate effects of steel should be included in the finite element material modeling. Researchers have demonstrated that correct simulations of frontal crashes require the incorporation of strain rate effects for steel. [162] In this study, GWU NCAC employed stress-strain curves for both the static and dynamic loading condition for steel in modeling the LWV. In addition, the discontinuous end point of the stress-strain curve at the highest value of stain is modeled in the material as a rupture of the steel.

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[160]Shaw, J.R. and Zuidema, B.K., "New High Strength Steels Help Automakers Reach Future Goals for Safety, Affordability, Fuel Efficiency and Environmental Responsibility," Society of Automotive Engineers International Body Engineering Conference and Exhibition, Detroit, Michigan, Report No. 2001-01-3041, October 16 – 18, 2001.
[161]Shaw, J.R. and Zuidema, B.K., "New High Strength Steels Help Automakers Reach Future Goals for Safety, Affordability, Fuel Efficiency and Environmental Responsibility," Society of Automotive Engineers International Body Engineering Conference and Exhibition, Detroit, Michigan, Report No. 2001-01-3041, October 16 – 18, 2001
[162]Zeng, D., Liu, S.D., Makam, V., Shetty, S., Zhang, L., and Zweng, F., "Specifying Steel Properties and Incorporating Forming Effects in Full Vehicle Impact Simulation," SAE World Congress, Detroit, Michigan, Report No. 2002-01-0639, March 4 – 7, 2002.

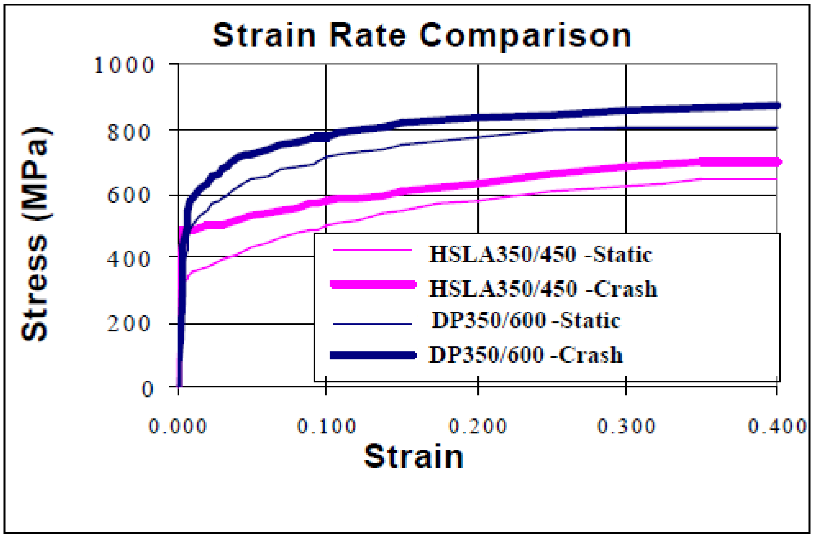


Figure 239: Static and Crash (i.e. dynamic) stress versus strain curves for a conventional HSS and an Advanced HSS[163]

EDAG used AHSS extensively throughout the design of the LWV. Figure 240 shows the structural components of the LWV design and its steel composition. The LWV body structure takes advantage of very high strength levels afforded by steel. The average tensile strength of steels used in structural components of the LWV is 757 MPa, comparing to 412MPa for the baseline MY2011 Honda Accord vehicle.

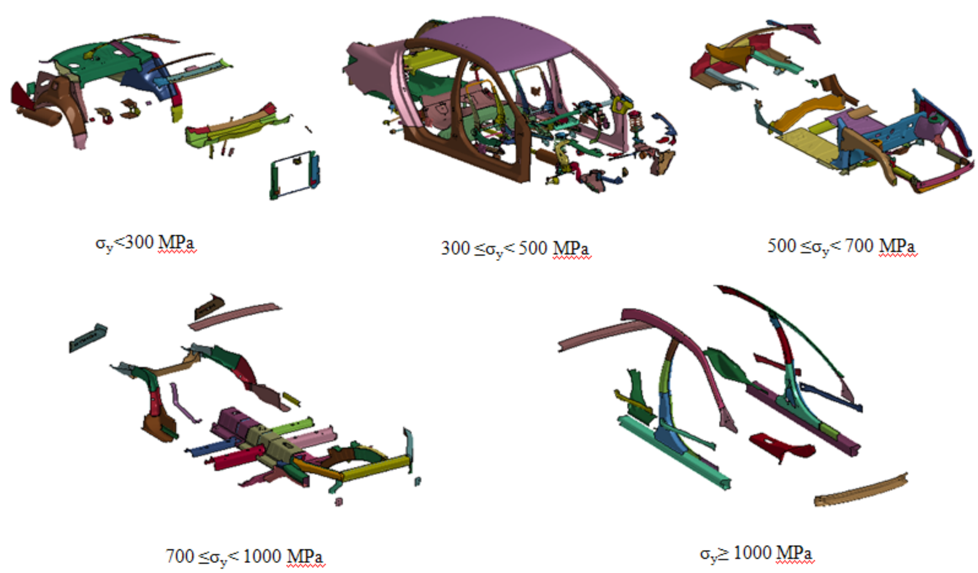


Figure 240: Structural components of the LWV and their type of steel

[163]Shaw, J.R. and Zuidema, B.K., "New High Strength Steels Help Automakers Reach Future Goals for Safety, Affordability, Fuel Efficiency and Environmental Responsibility," Society of Automotive Engineers International Body Engineering Conference and Exhibition, Detroit, Michigan, Report No. 2001-01-3041, October 16 – 18, 2001.

Figure 241 and Figure 242 show data used to define the static and dynamic stress versus strain for the various types of steel used in the finite element model of the LWV. Figure 243 lists the common material properties of the steels used in the LS-DYNA model.

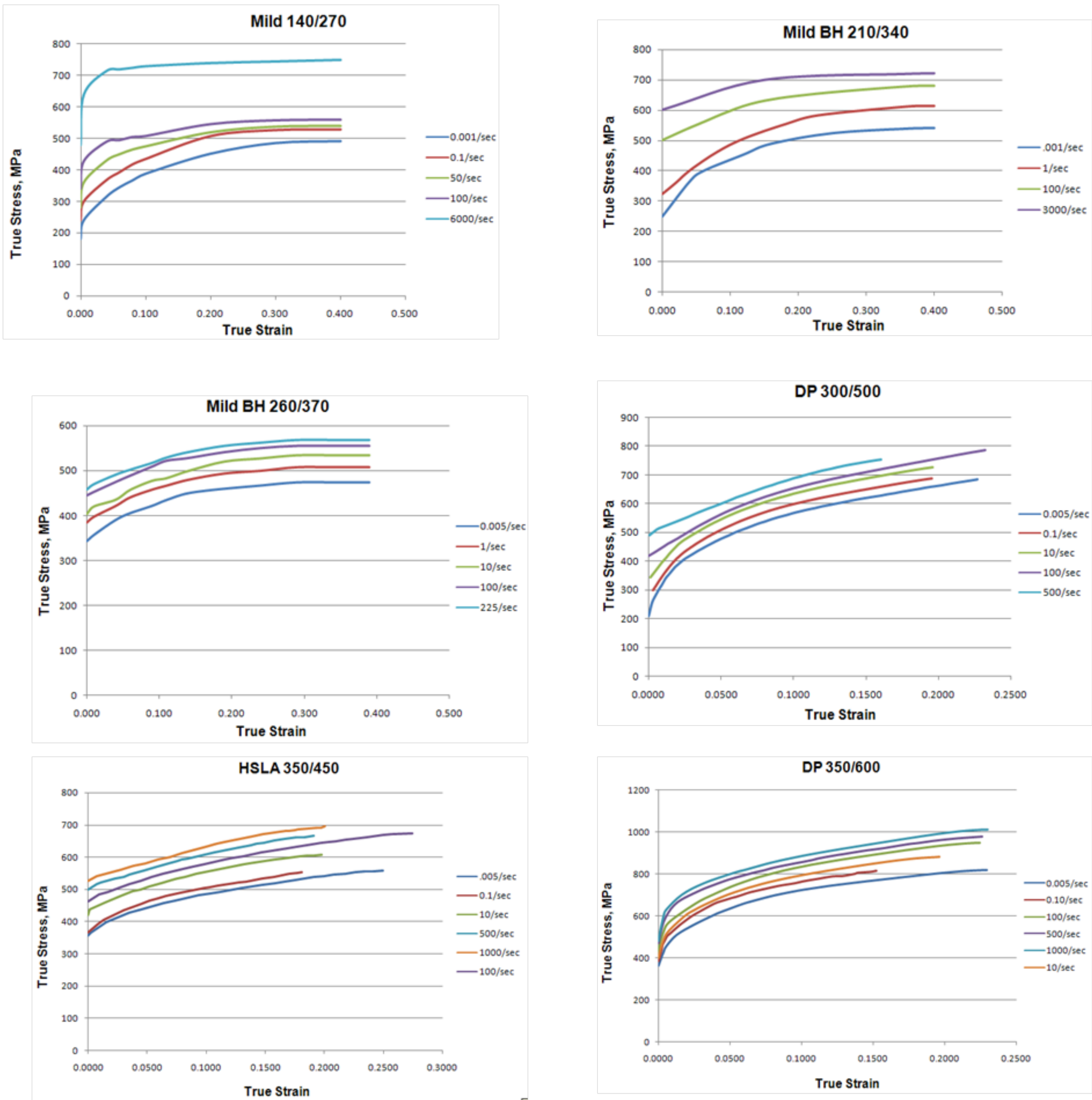


Figure 241: Material curves of stress versus stain used for steel in model – Part I[164]

[164]WorldAutoSteel, the automotive group of the World Steel Association; http://worldautosteel.org/

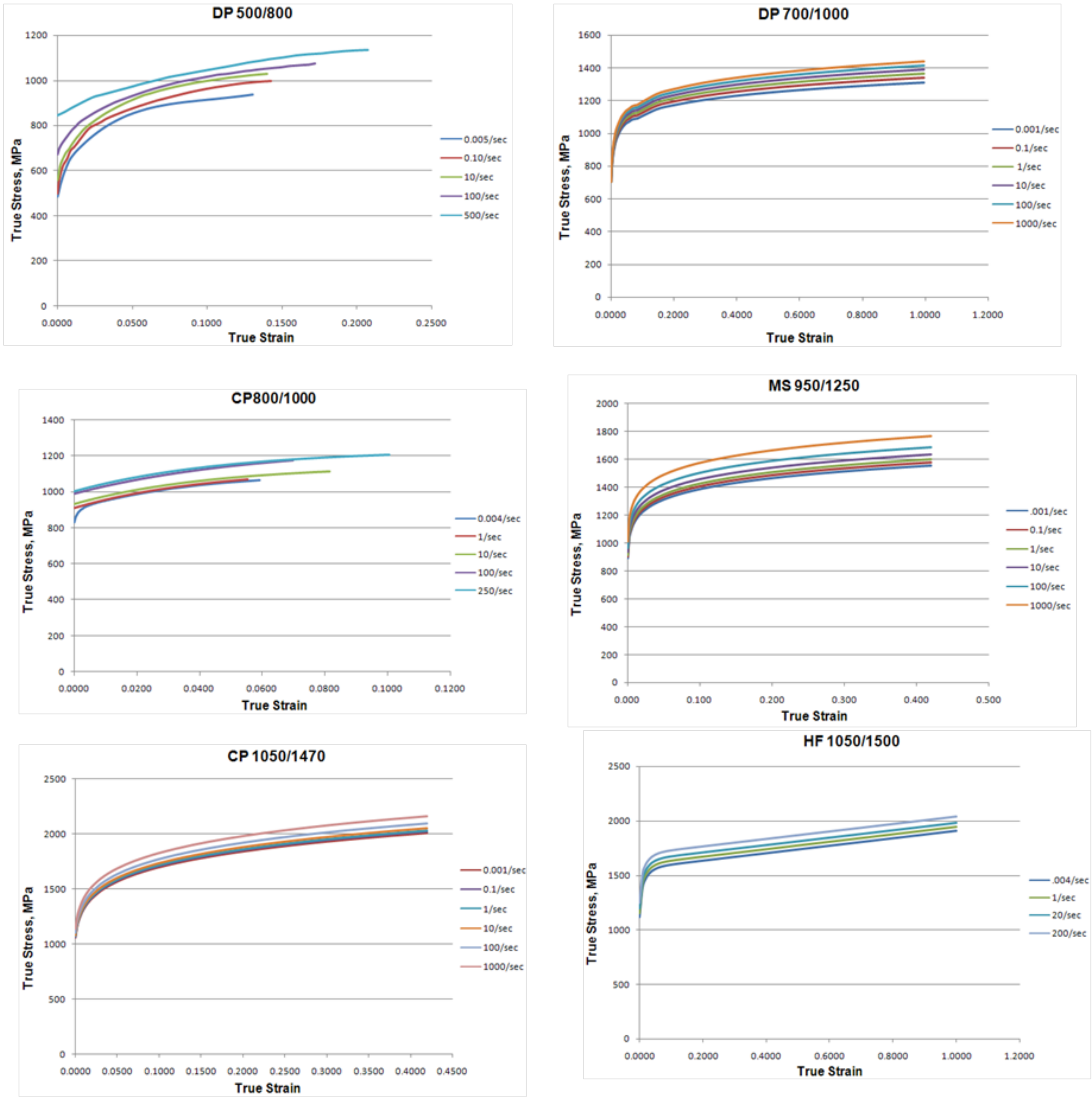


Figure 242: Material curves of stress versus stain used for steel in model – Part II[165]

[165]WorldAutoSteel, the automotive group of the World Steel Association; http://worldautosteel.org/.

Steel Grade	Density(t/mm^3)	Poisson's ratio	Modulus of Elasticity (MPa)	Lower YS (MPa)	Ultimate Tensile Strength (MPa)	Tot EL (%)
Mild 140/270	7.850e-09	0.3	21.0 x 10^4	140	270	42-48
Mild BH 210/340	7.850e-09	0.3	21.0 x 10^4	210	340	35-41
Mild BH 260/370	7.850e-09	0.3	21.0 x 10^4	260	370	32-36
DP 300/500	7.850e-09	0.3	21.0 x 10^4	300	500	30-34
HSLA 350/450	7.850e-09	0.3	21.0 x 10^4	350	450	23-27
DP 350/600	7.850e-09	0.3	21.0 x 10^4	350	600	24-30
DP 500/800	7.850e-09	0.3	21.0 x 10^4	500	800	14-20
DP 700/1000	7.850e-09	0.3	21.0 x 10^4	700	1000	12-17
CP 800/1000	7.850e-09	0.3	21.0 x 10^4	800	1000	8-13
MS 950/1200	7.850e-09	0.3	21.0 x 10^4	950	1250	5-7
CP 1050/1470	7.850e-09	0.3	21.0 x 10^4	1050	1470	7-9
HF 1050/1500	7.850e-09	0.3	21.0 x 10^4	1050	1500	5-7

Figure 243: Table of common engineering properties of steels used in the LWV model[166]

6.2.1.2 Difference in Elongation of conventional HSS and AHSS

The elongation of steel can first be described by considering the AHSS grades CP 1050/1470 and HF 1050/1500 listed in Figure 243. These steels have lower yield strengths of 1050 MPa, and are placed in the B-pillar and the rood rails where high stiffness is needed for side impact and roof crush. As Figure 240 shows, these steels with elongations of 5 percent to 9 percent are in a region of the car where great elongation is to be avoided for occupant protection. The AHSS DP 500/800 and DP 700/1000 have lower yield strengths of 500 MPa – 700 MPa (see Figure 243). They are used (see Figure 240) for the longitudinal front rails and the transverse rocker-to-rocker cross members where their elongation of 12 percent to 20 percent is acceptable. The conventional HSS like DP 300/500, HSLA 350/450, and DP 350/600 have lower yield strengths of 300 MPa – 350 MPa (see Figure 243). They are used (see Figure 240) in regions such as the A-pillar, C-pillar, and rockers where lower stiffness and elongation of 23 percent – 34 percent are allowable.

6.2.1.3 Failure Criterion Modeling for LWV Based on Testing Steel in Tension

It is shown in Figure 243 that the LWV design uses some grades of AHSS with elongation less than 10%. To account for possible premature failure of components made of these low-elongation grades when subjected to severe impact, an LS-DYNA failure criterion was imposed at the element level of the model. The failure criterion for these grades of AHSS is based on major principal in plane strain for tension. The LWV simulations used a material model provided

[166]WorldAutoSteel, the automotive group of the World Steel Association; http://worldautosteel.org/

by LS-DYNA, referred to as *MAT_MODIFIED_PIECEWISE_LINEAR_PLASTICITY, for the purpose of the failure criterion. This material model has a similar formulation to the most commonly used material model in LS-DYNA, *MAT_PIECEWISE_LINEAR_PLASTICITY, but has a more enhanced failure criterion. LS-DYNA states that the failure in this material model is based on effective plastic strain, plastic thinning, major principal in plane strain component, and a minimum time step size. This means that the major principal in plane strain failure is used in this study to capture the failure of AHSS components used in the LWV design. LS-DYNA computes the plastic 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 of the LWV. The data used for both static loading and dynamic loading failure of HSS and AHSS are presented in Figure 241 and Figure 242. Both the static loading curves and dynamic loading strain-rate curves are used in the failure criterion.

6.2.2 Aluminum

Aluminum is mainly used in the closure design for LWV. The modeling approach for aluminum is well understood as the automotive industry has been modeling this material satisfactorily for many years. The aluminum parts used in the LWV finite element model (FEM) are shown in Figure 244. There are two types of aluminum used in this study, AA5182 and AA6451. The stress-strain curves and table of common properties for aluminum used in the LS-DYNA model are presented in Figure 245 and Figure 246 respectively. The aluminum was not used for energy-absorbing components. Because of their use, strain rate effects were not used for aluminum.

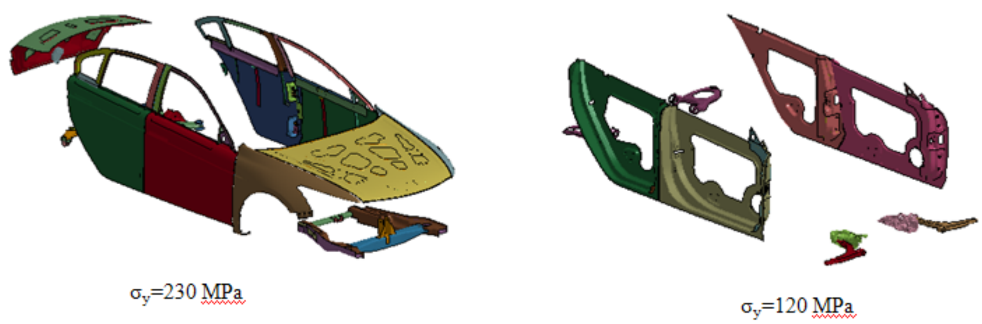
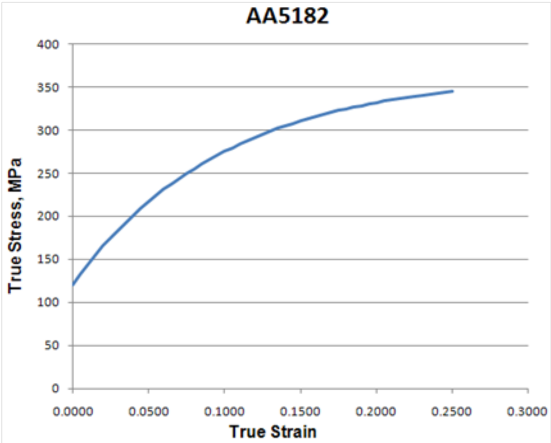


Figure 244: Light weight vehicle components made of aluminum



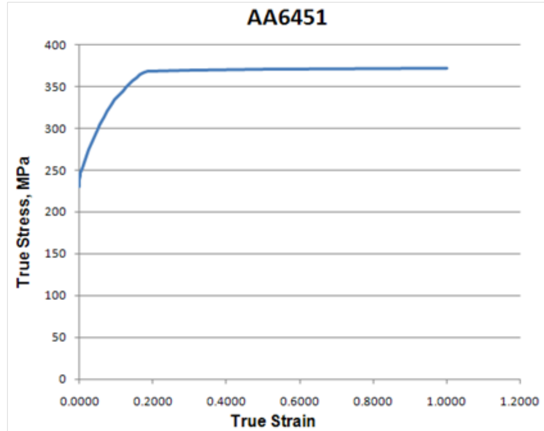


Figure 245: Material curves of stress versus strain used for aluminum in LS-DYNA model

Aluminum Alloy Grade	Density(t/mm^3)	Poisson's ratio	Modulus of Elasticity (MPa)	YS (MPa)
AA5182	2.65e-009	0.33	6.970e+004	120
AA6451	2.7e-009	0.33	7.000e+004	230

Figure 246: Table of common engineering properties of aluminum used in the light weight vehicle model

6.3 Summary for LWV Crash Model

The LWV model is briefly summarized in Chapter 5. The researchers of this study understand that automotive companies have finite element models of their vehicles ranging in size of 1 to 4 million elements. For competitive reasons, these finite element models are not distributed outside the automotive company building the model. In terms of publically-available, open-source finite element models of automobiles, the largest models are about 1 million elements. As shown in Figure 247 the finite element description of the LWV model is extensive.

Number of Parts	702
Number of Nodes	1,403,378
Number of Shells	1,210,307
Number of Beams	4,763
Number of Solids	272,214
Total Number of Elements	1,487,424

Figure 247: Summary of light weight vehicle model

6.4 Frontal NCAP Test

The frontal impact test of the NCAP, undertaken by the NHTSA, is a full frontal barrier test at a vehicle speed of 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 LWV model used in the US

NCAP analysis has a test weight of 1325 kg, which includes curb weight of vehicle as1150 kg, 80 kg weight of Hybrid III 50th percentile male driver, 50 kg Hybrid III 5th percentile female front passenger weight, and 45 kg cargo weight for the instrumentation.

The frontal NCAP test determines the crashworthiness of a vehicle based on the injury-based data (HIC, Nij, chest compression, and femur forces) obtained from the dummies. The scope of work of this study did not encompass simulation of dummy occupants in the finite element model of the crash. Therefore, the LWV is evaluated based on structural-based safety parameters (crash pulse and occupant compartment intrusion) and compared with the safety rating of the MY2011 baseline Honda Accord.

The LS-DYNA set up for the frontal crash test of the LWV model into a rigid barrier is shown in Figure 248.

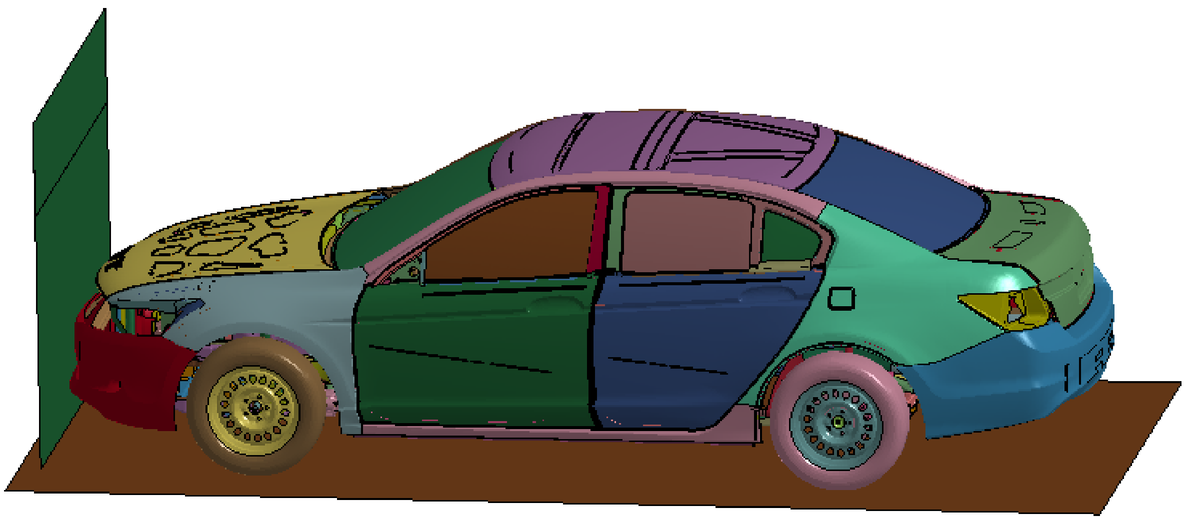
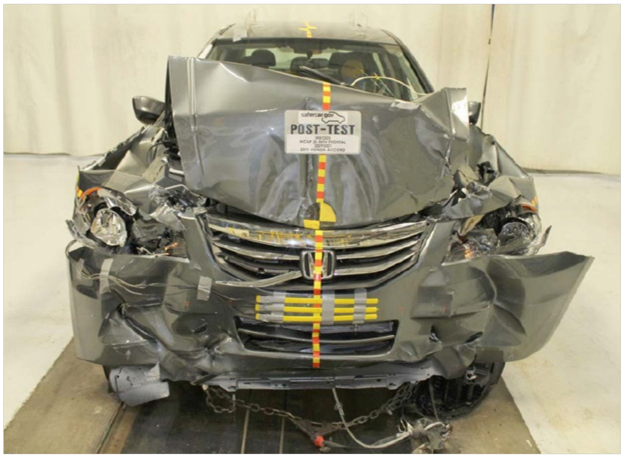
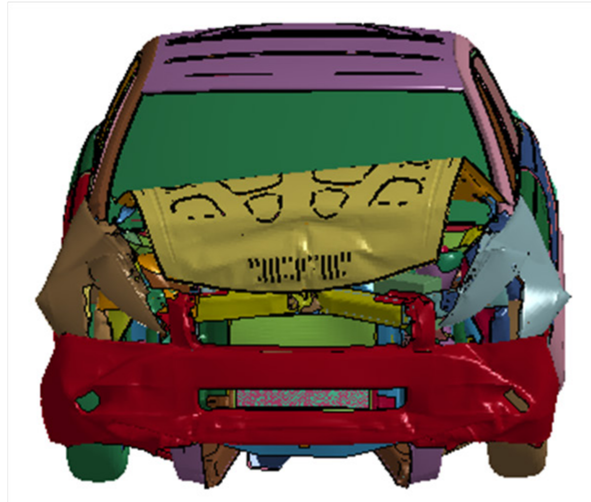


Figure 248: LS-DYNA set up for frontal rigid wall test

Images of the post-crash vehicles for the actual laboratory crash and the simulation are in Figure 249.



Post-crash Picture of MY2011 Honda Accord
(from Real Vehicle Test)



Post-crash Picture of LWV
(from Simulation)

Figure 249: Post-crash Pictures of MY2011 Honda Accord and LWV

The crash pulse for the left rear sill is shown in Figure 250, indicating that the maximum acceleration of the FEM simulation is close to the actual laboratory pulse. The 115 msec time width of the FEM acceleration pulse is close to the 120 msec time width of the Honda Accord. The sharp drop in acceleration of the Honda Accord 2011 between 40 ms to 50 ms is due to the engine cradle rear mount dropping from the body structure designed at predetermined loads to control the front end crash behavior. This is a design feature used on some vehicles to control the magnitude of intrusion into the foot well area of the occupant compartment. The LWV is designed to limit the foot well intrusion without this feature. The LWV engine cradle is extended forward to become active early in crash event and as a result it becomes an energy absorbing member. This design feature alleviates the need for dropping the engine mount in the NCAP frontal test. It was also believed that modeling the time of the release of the engine cradle from the body structure may be difficult, and it would appear that for this study the crash pulse is more easily managed by having the front structure absorb all the energy without designing a drop at the rear mount of the engine.

As discussed in section 5.2.2, the front end structure of the baseline Honda Accord is optimized using 3G optimization approach. The newly design front end structure has three load paths (longitudinal rails, extended shotgun and engine cradle). With the combination of the three active load paths, the deceleration pulse of the structure achieved a more desirable front end structure during the 0 to 30 millisecond crash time frame and then reduced to a normal level during the 30 to 60 millisecond time frame when the occupant is interacting with the airbag/restraint system. Even though the overall structure of the LWV is stiffer as measured in bending, torsional stiffness is similar compared to the overall frontal stiffness baseline Honda Accord. Energy-absorbing design features were employed on the primary longitudinal frontal rails to help achieve these results. Figure 250 for the response at the left-rear sill shows the simulation done with the failure criterion, which is necessary because steel can only elongate so much before it ruptures. If the failure criterion is true, then the simulation with and without the failure criterion should be identical if the elements do not fail. Figure 250 shows that the simulation with and without the failure criterion is similar with crash result with failure criterions being a little worse. It turns out that for all the simulations done in this report, failures were localized and not global in nature, i.e., the structure, such as a B-pillar, did not completely rupture. Throughout this study when the steel did not fail, the researchers found that the failure criterion simulation with LS-DYNA gave the similar answers as the simulation without the failure criterion. For clarity and from a more conservative perspective, future figures will show only the simulation done with the failure criterion.

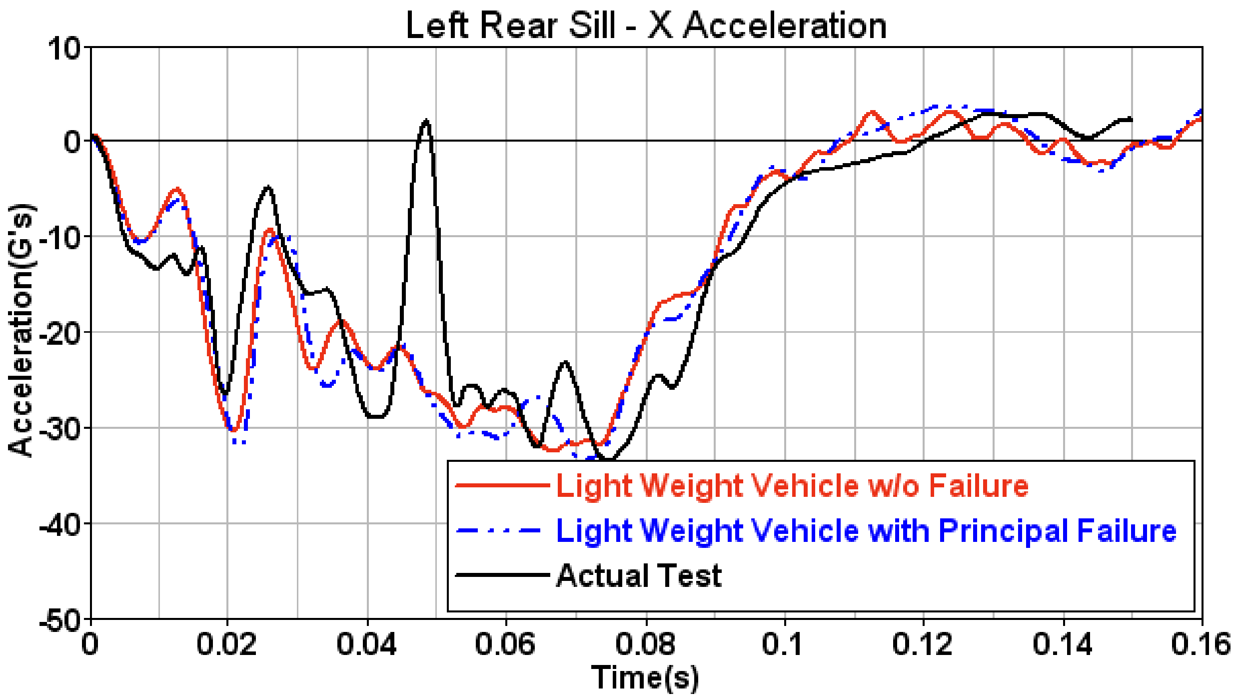


Figure 250: Acceleration pulse of Honda Accord and LWV for left-rear sill in rigid wall crash

Timely airbag deployment is very critical in keeping the occupant injuries to the minimum and in meeting the 5 star safety ratings. Figure 251 shows the acceleration plot from 0 to 0.02 seconds. 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 airbags. As can be seen from Figure 251 the LWV has average pulse value of -8.5G's during this time frame, indicating that the instruments can be correlated to identify the event in a timely manner similar to the baseline vehicle.

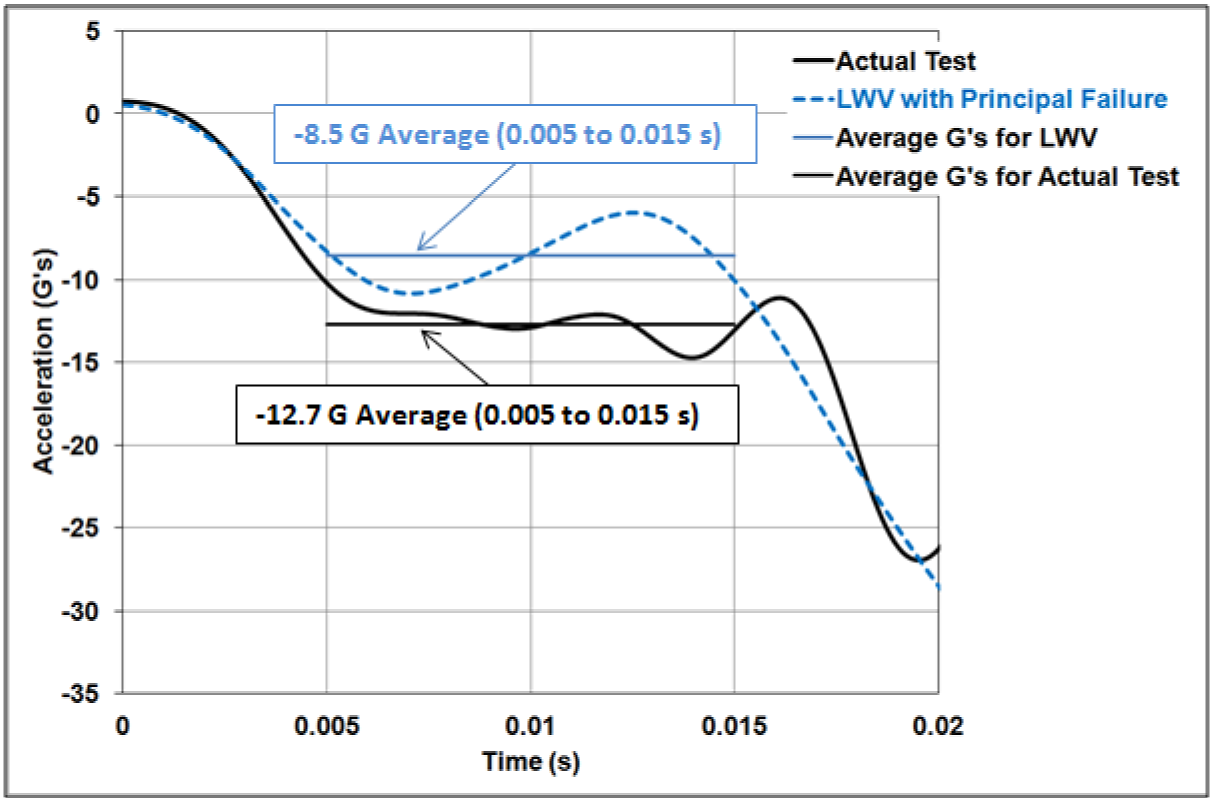


Figure 251: Acceleration pulse of Honda Accord and LWV for left-rear sill in rigid wall crash 0 to 0.02 seconds

Figure 252 is the velocity plots for baseline MY2011 Honda Accord and LWV at the left-rear sill. This figure shows that the structure of the LWV stops (i.e., goes from the initial velocity to zero) about 6 ms more quickly than the structure of the baseline Honda Accord. While it would be safer to stop the vehicle more slowly, 6 msec is a very short time difference and the restraint engineer can manage this time difference in terms of protecting the occupant. It is believed that restraint designers can change the air bag and safety belt to accommodate a 6 ms difference in stopping time.

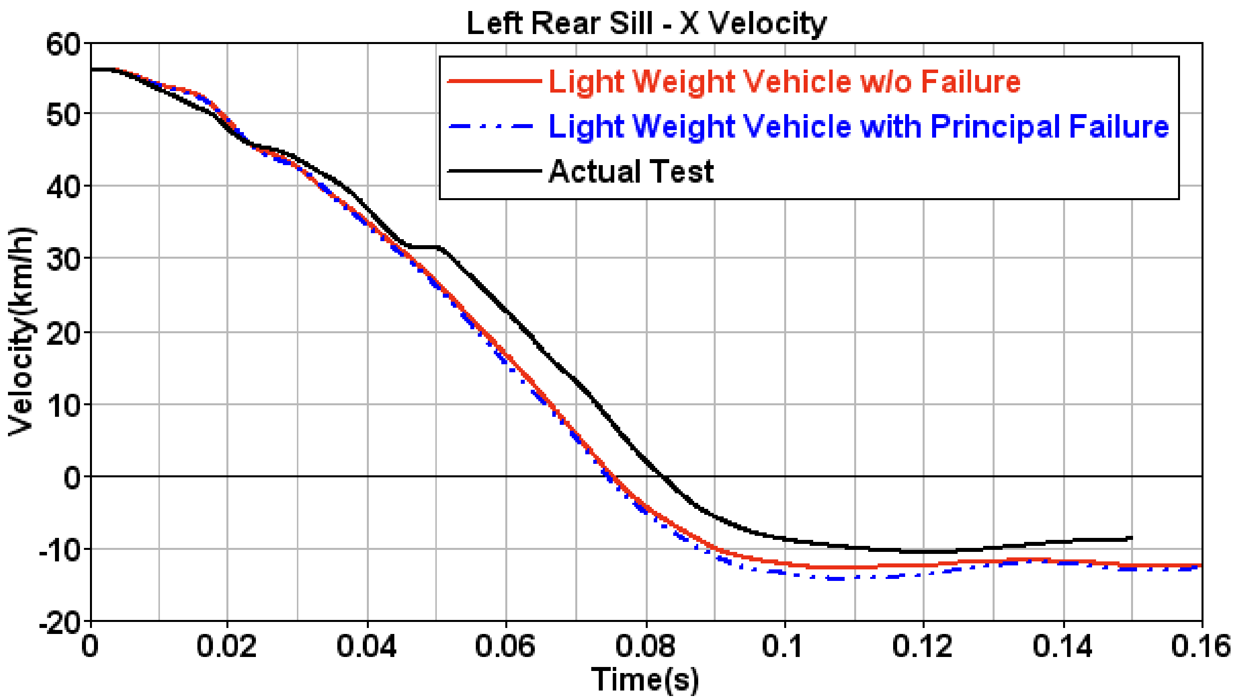


Figure 252: Velocity of Honda Accord and LWV for left-rear sill in rigid wall crash

Based on physics and for similar frontal stiffness, a lighter vehicle will generally stop more quickly than a more massive vehicle. Small vehicles, such as the 2006 Honda Civic[167] and the 2011 Chevrolet Cruze[168], have a similar aggressive crash pulse and have received the best rating in the frontal NCAP test.

The acceleration and velocity for the right-rear sill are shown in Figure 253 and Figure 254. The curves of the left-rear sill acceleration and velocity are like the curves of the right-rear sill acceleration and velocity. The discussion of the left-rear sill accelerations and velocity can be equally applied to the right-rear sill acceleration and velocity.

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[167] KARCO Engineering, LLC, *New Car Assessment Program (NCAP) Frontal Barrier Impact Test 2006 Honda Civic LX 4-Door Sedan*, Report No. TR-P26001-04-NC, 9270 Holly Road, Adelanto, California 92301, December 8, 2005.

[168]MGA Research Corporation, *New Car Assessment Program (NCAP) Frontal Barrier Impact Test 2011 Chevrolet Cruze LS 4-Dr Sedan*, Report No. NCAP-MGA-2011-044, 5000 Warren Road, Burlington, WI 53105, December 28, 2010.

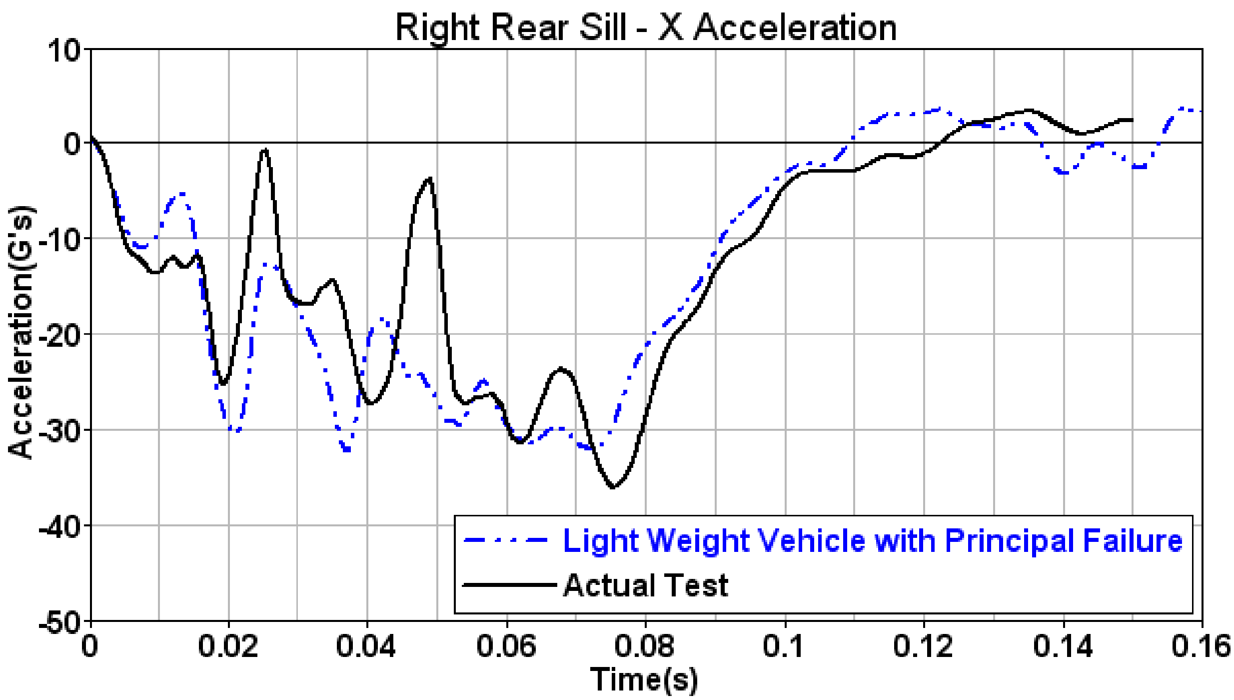


Figure 253: Acceleration pulse of Honda Accord and LWV for right-rear sill in rigid wall crash

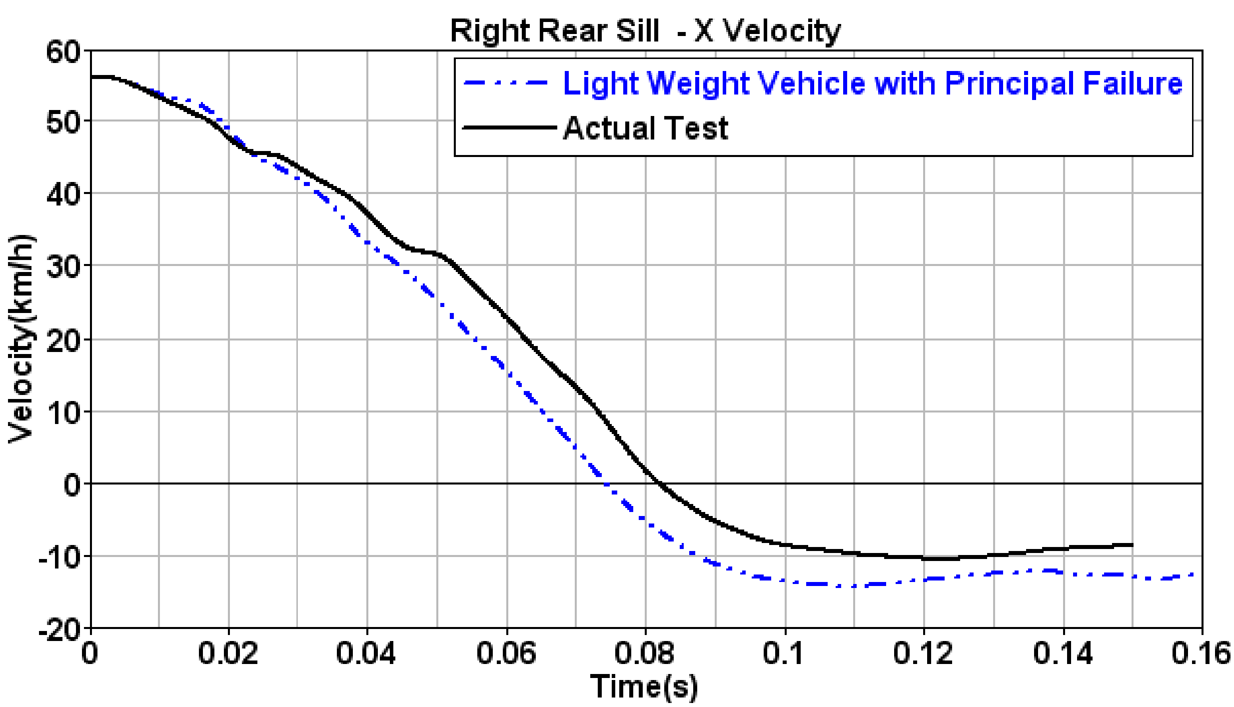


Figure 254: Velocity of Honda Accord and LWV for right-rear sill in rigid wall crash

Figure 255 lists the intrusion (post-crash deformation) into the occupant compartment for the Honda Accord and the LWV. The foot rest intruded 14 mm, which is a relatively small interior deformation and consistent with the intrusion recorded in the baseline MY2011 Honda Accord. The brake pedal intruded 16 mm back toward the front of the vehicle, which should attain a "good" safety rating in terms of brake pedal movement when compared with the criteria established by IIHS.[169]In assessing the difference in measured intrusion, the LWV had less intrusion of the brake pedal toward the driver when compared to the 2011 Honda Accord. The LWV had 6 mm more intrusion at the foot rest than the 2011 Honda Accord, which difference is less than half an inch. The front design of the LWV does not include dropping the engine cradle, but the LWV has an equivalent safety rating when compared to the safety rating of the 2011 Honda Accord.

Vehicle	Brake pedal intrusion in NCAP frontal test (mm)	Foot rest intrusion in NCAP frontal test (mm)
2011 Honda Accord	-3	8
Light Weight Vehicle	-16	14

Figure 255: Occupant intrusion for Honda Accord and light weight vehicle in NCAP frontal test

The finite elements that eroded (those deleted because they exceeded the strain criterion in tension) in the simulation are depicted as black boxes in Figure 256. Note that only a few elements exceeded the failure criterion. This figure suggests that high strength AHSS is failing only in small, localized regions for the NCAP frontal crash test.

[169]Insurance Institute for Highway Safety, *Frontal Offset Crashworthiness Evaluation Guidelines for Rating Structural Performance,* 1005 N. Glebe Road, Arlington, VA 22201, April 2002.

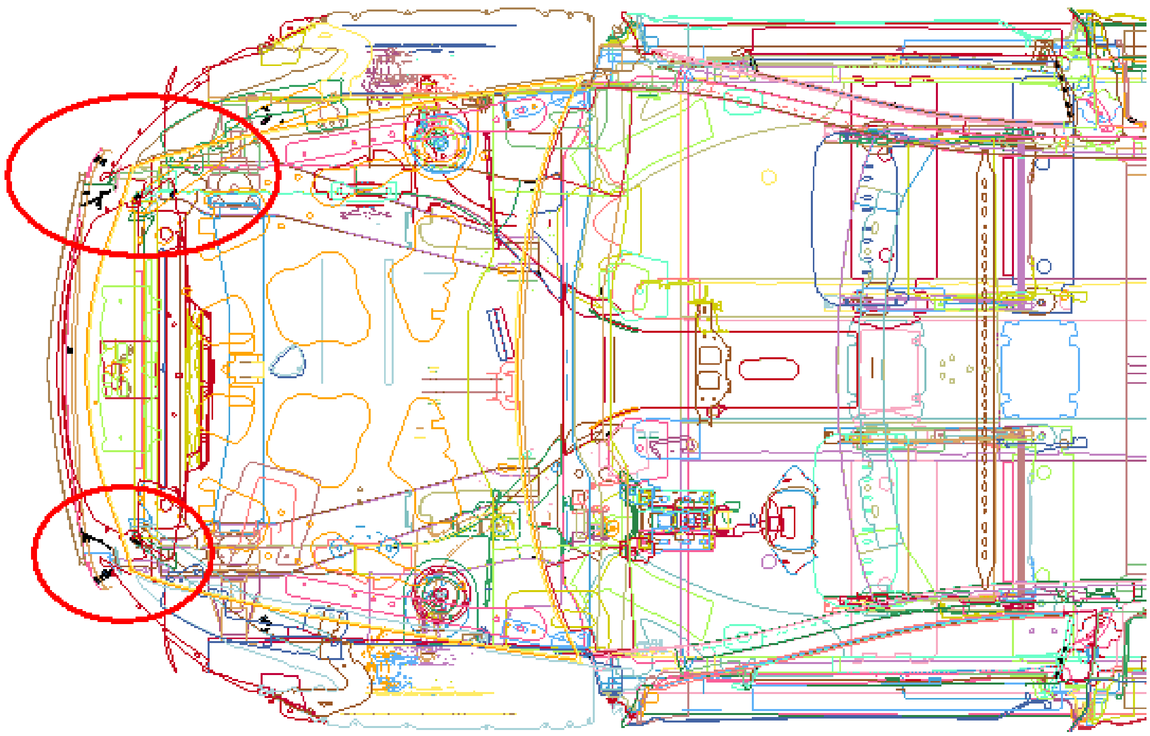


Figure 256: In LS-DYNA simulation of NCAP frontal test, those elements that eroded are pictured as a black box

Figure 255 shows the major energy-absorbing structure of the LWV before the NCAP frontal test. During the crash, a significant amount of energy is absorbed by multiple load paths which include the front rails, bumper beam, crush cans and shotgun as shown below in Figure 258. Energy management is consistent with the baseline Honda Accord ACE structure except the rear engine cradle dropping design on the baseline Honda Accord.

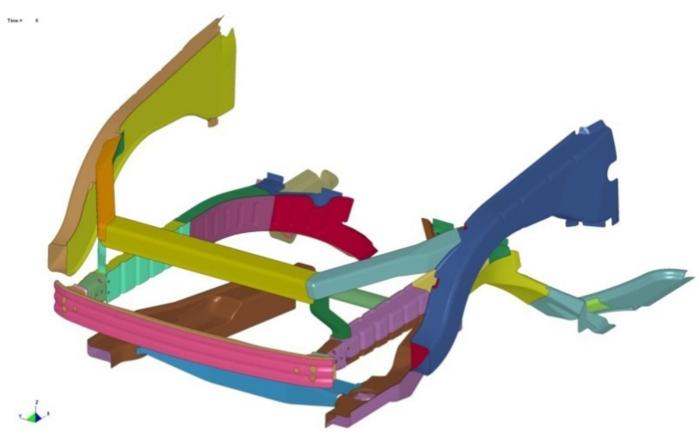


Figure 257: Energy-absorbing structure for NCAP frontal crash

Figure 258 shows the deformed shape of the front end after the frontal impact. Figure 259 is a graph of the energy absorbed by the front end parts over the period of the NCAP frontal test. The graph also shows the energy balance, indicating a good overall analysis solution.

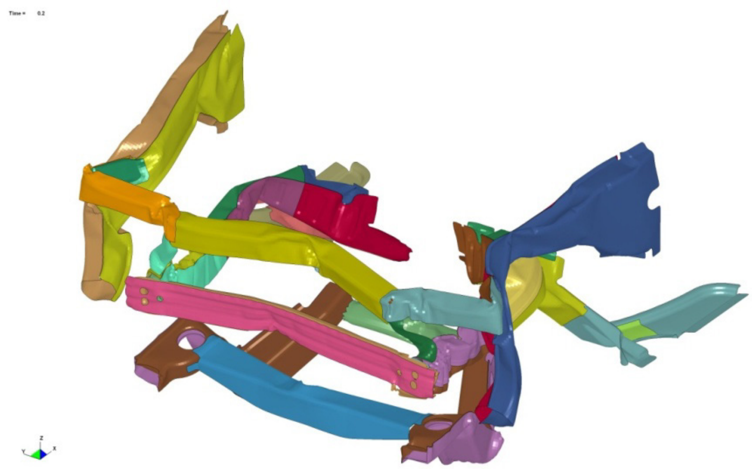


Figure 258: Crush of five key structural parts over the time of the NCAP frontal test

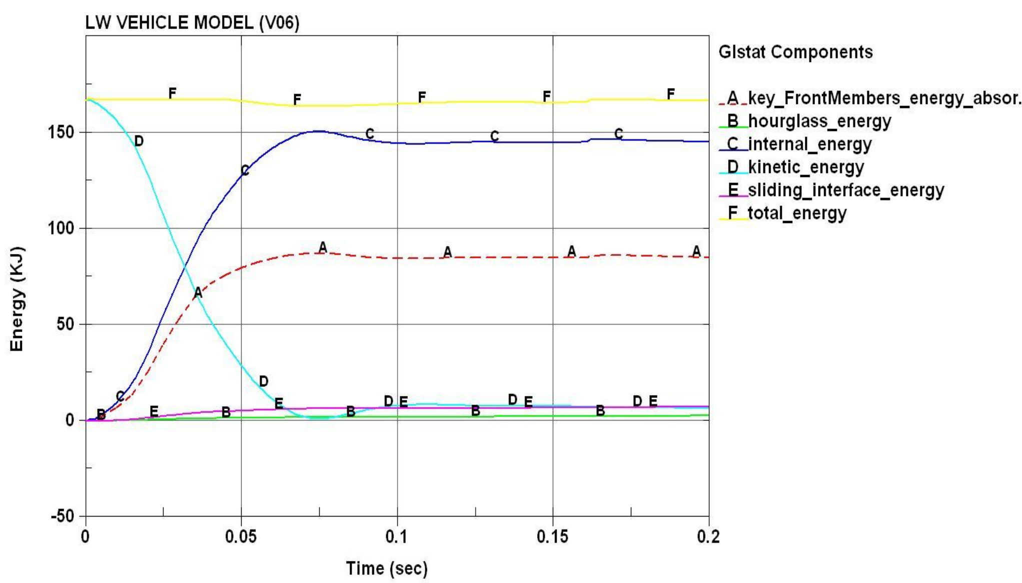


Figure 259: Energy Balance for the NCAP frontal test

After the crash, the fuel tank should remain physically intact to prevent fuel leakage from fuel tank after crash. Figure 260 and Figure 261 below show that there is no damage to the fuel tank or the surrounding structure in the rear, and therefore there should be no leakage of gas from the tank.

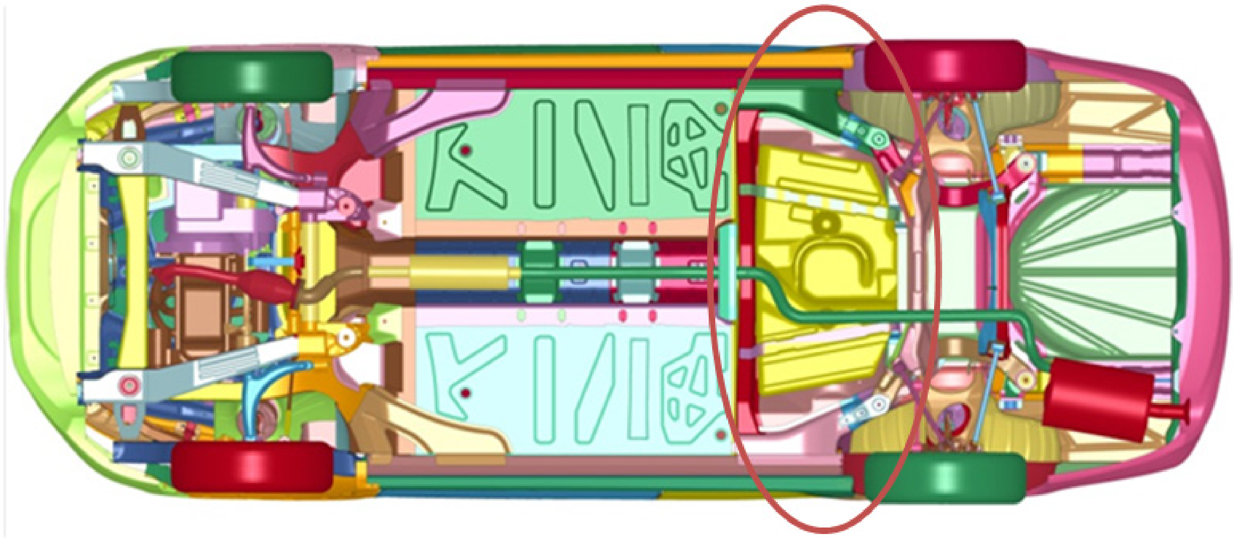


Figure 260: Bottom view of LWV before NCAP frontal crash test

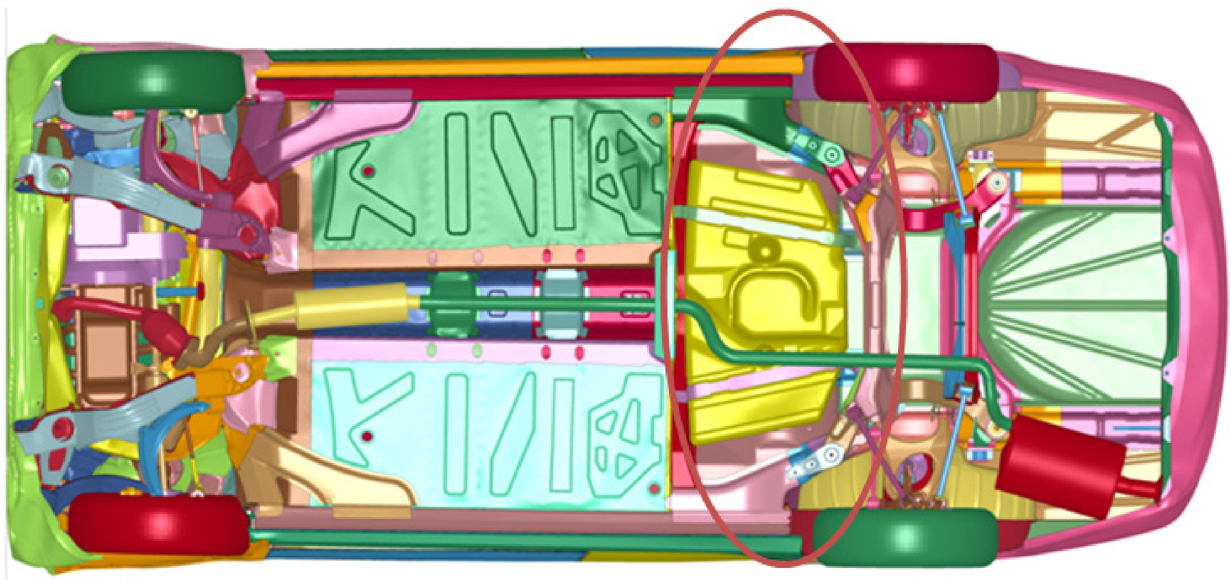


Figure 261: Bottom view of LWV after NCAP frontal crash test

6.5 Lateral NCAP Moving Deformable Barrier Test

In this crash test, a moveable deformable barrier (MDB), with a mass of 1370 kg impacts the LWV on the driver's side with velocity of 60.9 kph ± 0.8 kph. The finite element model accounts for a 50th percentile male dummy with weight of 80 kg on the driver seat and a 5th percentile female dummy with weight of 50 kg on the passenger seat just behind the driver seat with 45 kg cargo weight in the rear.

The LS-DYNA set up for the NCAP side impact crash test of the LWV model with a moving deformable barrier is exemplified in Figure 262. Images of the post-crash vehicles for the actual laboratory crash and the simulation are shown in Figure 263. Figure 264 shows exterior crush profile for level 2, which is located at approximately the H-point level of the driver dummy. In setting up a crash test with the occupant seated in the vehicle, the location of the H-point is determined above the vehicle seat. The H refers to hip, essentially the axis of rotation between the upper torso and the upper segment of the legs. The H-point may be visualized as the approximate location of the hip of a mid-size male sitting on the seat of the vehicle. Figure 264 is a numerical grid where the value zero on the x-axis means the initial impact point of the MDB against the struck vehicle. All values along the x-axis are the distance rearward from the initial contact point. The value zero on the y-axis means the initial uncrushed side of the vehicle. All crush on the y-axis is measured as distance away from the initial uncrushed side of the vehicle.

Figure 265 shows exterior crush profile for level 3, which is located at approximately the mid-door level. The level 3 indicates a line extending along the side of the vehicle, which is at the mid-door location. Figure 263 is a numerical grid following the convention explained for the previous figure.

These figures show the simulation done with the failure criterion, which is necessary because steel can only elongate so much before it ruptures. If the failure criterion is accurate, the simulation with and without the failure criterion should be identical as long as the elements do not fail. Previously, for the NCAP frontal tests, the simulations with and without the failure criterion were shown to be the same. For all the simulations done for the six NCAP and IIHS tests, the researchers found that the simulations with and without the principle stain criterion were the same. For clarity, future figures will show only the simulation done with the failure criterion.

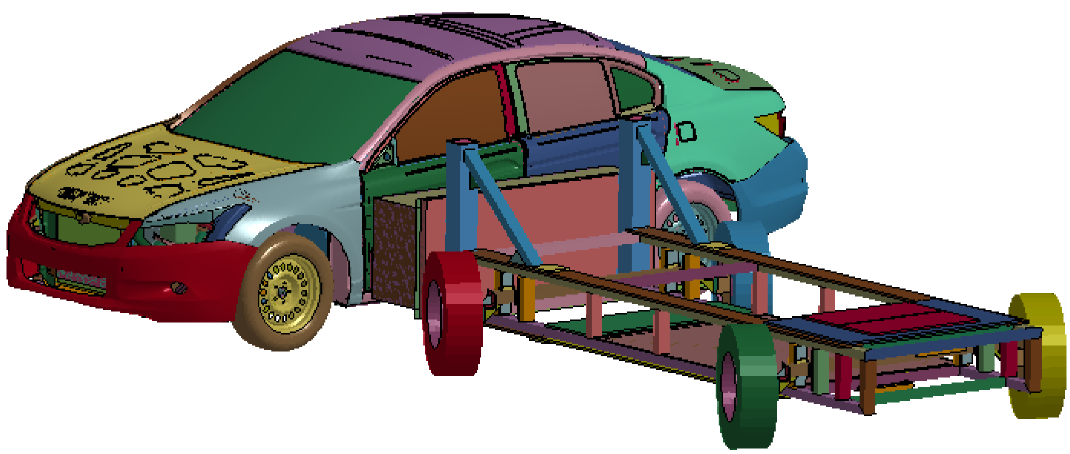


Figure 262: LS-DYNA set up for the NCAP moving deformable barrier lateral test

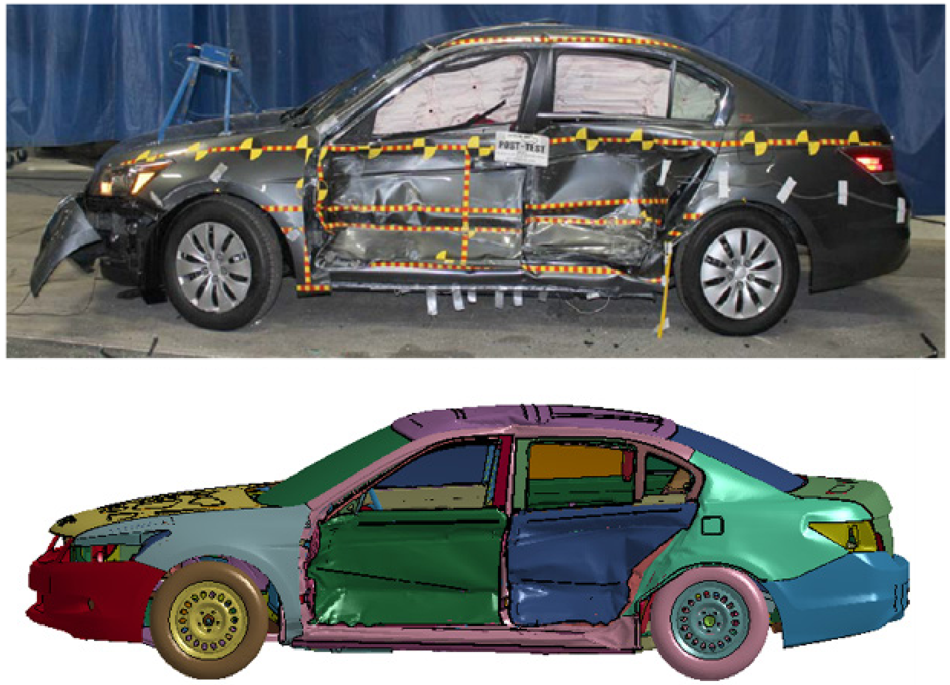


Figure 263: Post-crash picture of baseline MY2011 Honda Accord and LS-DYNA LWV

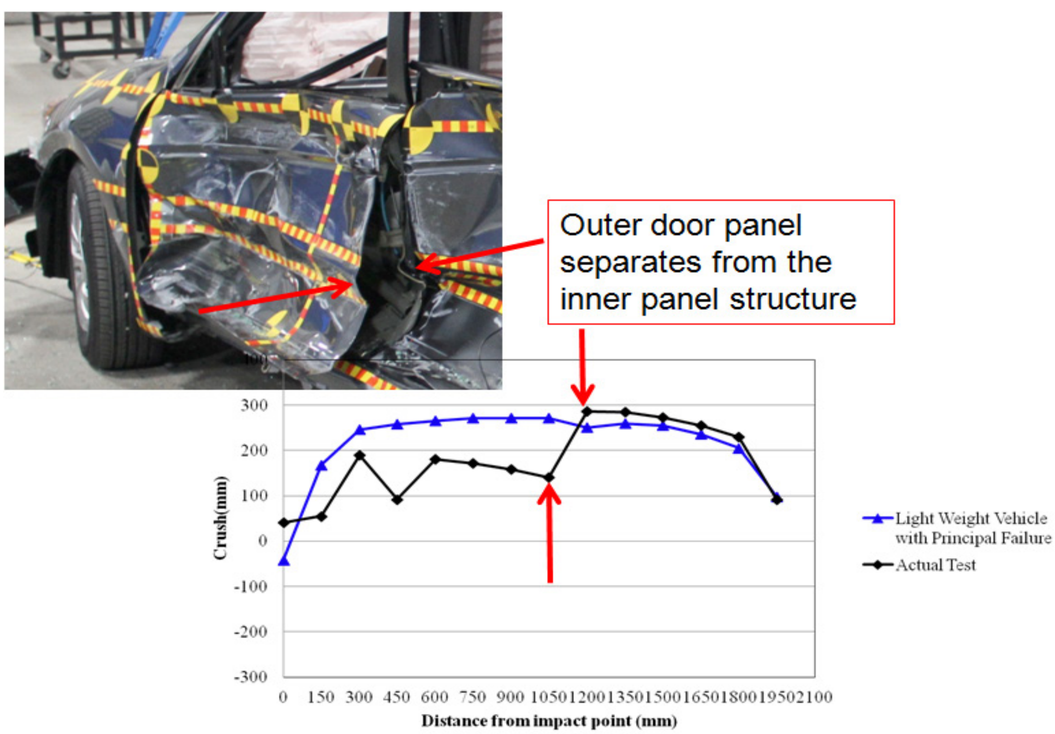


Figure 264: Exterior crush for level 2, approximately the H-point level of the driver dummy in NCAP MDB side test

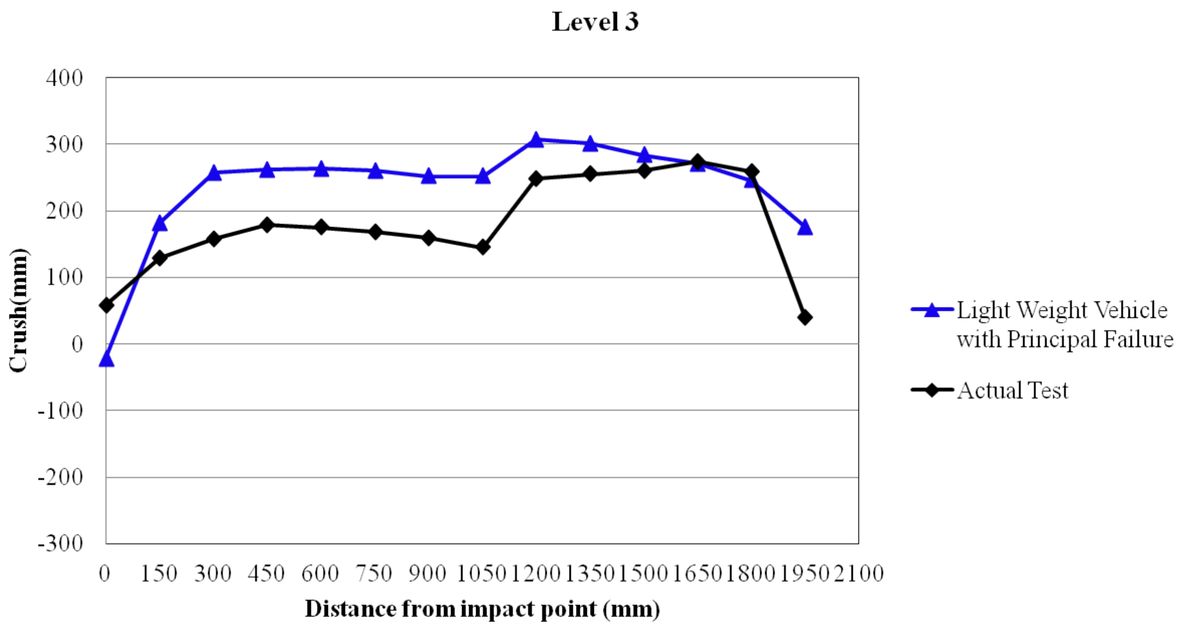


Figure 265: Exterior crush for level 3, approximately the mid-door level in NCAP MDB side test

The exterior crush profiles of the baseline MY2011 Honda Accord and the LWV model are close toward the rear of the vehicles. The sudden drop in the exterior intrusion values shown in Figure 264 and Figure 265 are due to front door outer panel separating from the door inner structure as shown in Figure 264. The profile of the door intrusion beams are shown in Figure 266 below. The 'open section' profile of the beam on the LWV opens up during impact and this leads to slightly higher external intrusions of the outside surface of the door when compared with the baseline Honda Accord. The inner door intrusions however, which are more critical to the occupant, would be similar to the original Accord.

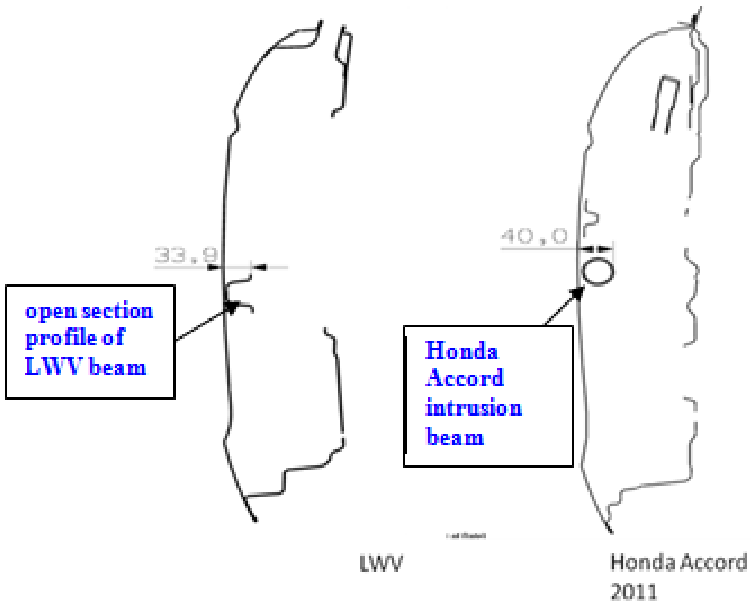


Figure 266: Profile of front door – LWV and Honda Accord

The test vehicle was brought out of storage and further measurements were taken using the IIHS measurement method[170] for the interior surfaces (door inner and b-pillar inner). The inner surface intrusions, which are more critical to the occupant, are similar to the baseline vehicle as shown in Figure 267. The NCAP side barrier test does not have an intrusion rating for safety. To determine the safety of a vehicle, the NCAP side barrier test uses the forces, deformation, and accelerations measures in the occupants of the vehicle. The LWV researchers used the IIHS safety rating scheme to assess the implications of the intrusions in the NCAP side barrier test. Following the IIHS rating scheme,[171] Figure 267 illustrates the pre- and post-crush and intrusion for the LWV in the NCAP side barrier test. Figure 267 illustrates that the LWV is in the region for the NCAP side barrier test.

[170]Insurance Institute for Highway Safety, *Side Impact Crashworthiness Evaluation: Crash Test Protocol (Version V)*, 1005 N. Glebe Road, Arlington, VA 22201, May 2008.
[171]Insurance Institute for Highway Safety, *Side Impact Crashworthiness Evaluation: Crash Test Protocol (Version V)*, 1005 N. Glebe Road, Arlington, VA 22201, May 2008.

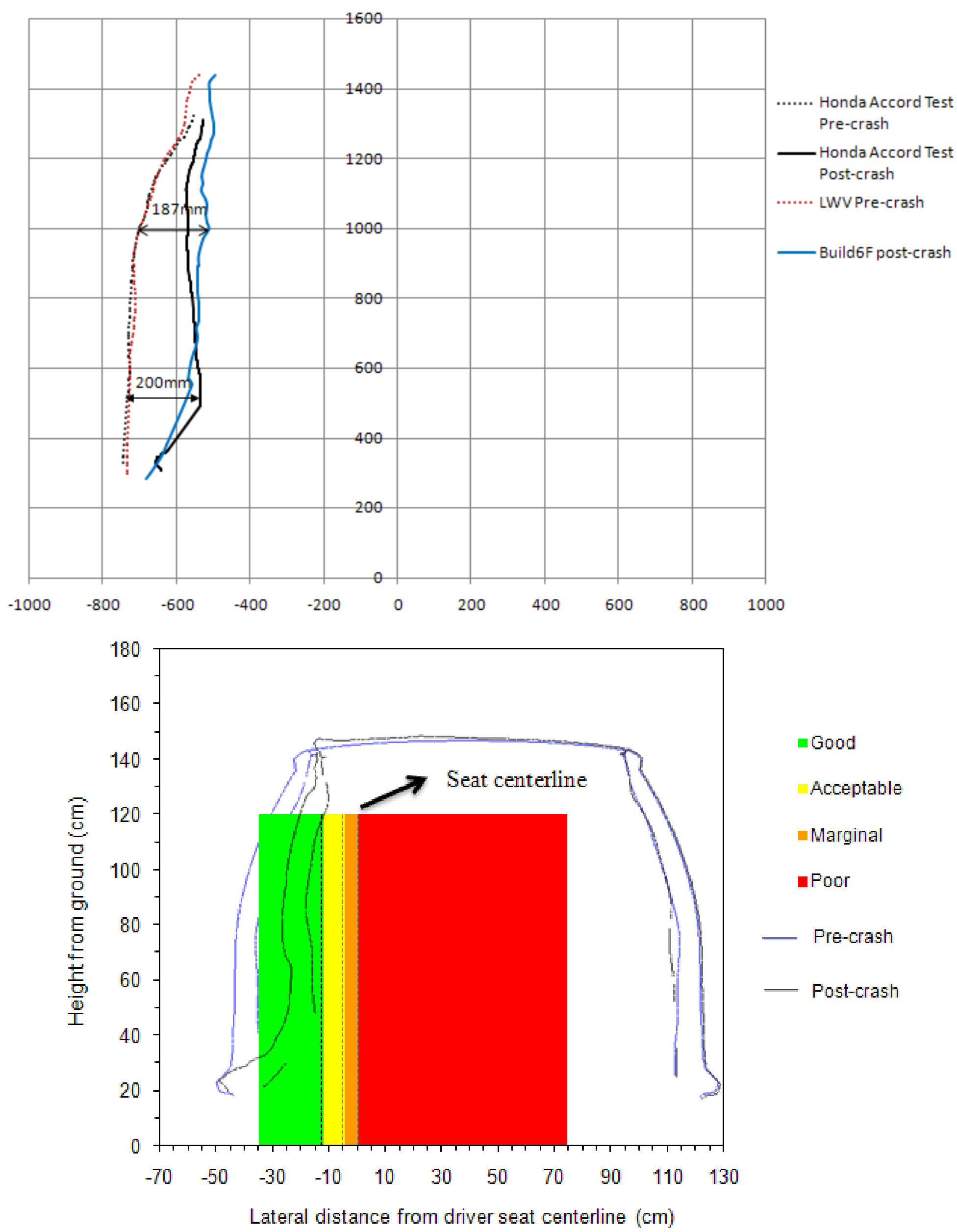


Figure 267: LWV is in the "Green" region for the NCAP side barrier test[172]

The 'B-Pillar' inner panel and reinforcement was modified to increase its strength. The results of NCAP Side barrier Impact analysis, the deformed geometry plot shown in Figure 268, show no material fracture. The mass impact of this change approximately 3.0kg is accounted for in the LWV total mass.

[172] Insurance Institute for Highway Safety, *Side Impact Crashworthiness Evaluation: Crash Test Protocol (Version V)*, 1005 N. Glebe Road, Arlington, VA 22201, May 2008.

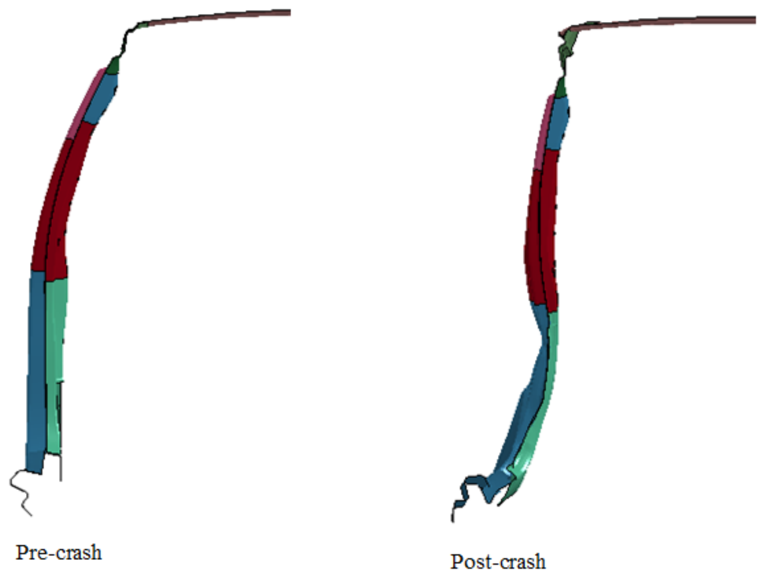


Figure 268: Reinforced B-Pillar NCAP Side Impact Results – showing no fracture of material

Figure 269 shows a graph of the lateral acceleration at the center of gravity for the LWV and the MY2011 Honda Accord. Figure 270 shows a plot of the lateral velocity at the center of gravity for the LWV and the baseline MY2011 Honda Accord. Naturally, the LWV has a lower mass than the 2011 Honda Accord. The scientific law of the conservation of momentum dictates that the lower-mass LWV has to experience a greater change-of-velocity than the 2011 Honda Accord. Indeed, the figure of velocity versus time shows the LWV has a higher velocity change. Vehicles of a lower vehicle weight class routinely go through higher velocity changes and can obtain the best NCAP safety rating. Small vehicles, such as the 2012 Ford Focus[173] and the 2011 Chevrolet Cruze[174], go through a similar velocity change (ΔV) in the NCAP side barrier test and have received the best rating in the NCAP side barrier test. Therefore it follows that restraint designers can safely manage the velocity change of the LWV.

173KARCO Engineering, LLC, *New Car Assessment Program (NCAP) Moving Deformable Barrier Side Impact Test 2012 Ford Focus 4-Door Sedan*, Report No. SINCAP-KAR-12-005, 9270 Holly Road, Adelanto, California 92301, October 20, 2011.

174MGA Research Corporation, *New Car Assessment Program (NCAP) Moving Deformable Barrier Side Impact Test 2011 Chevrolet Cruze LS 4-Dr Sedan*, Report No. SINCAP-MGA-2011-045, 5000 Warren Road, Burlington, WI 53105, December 28, 2010.

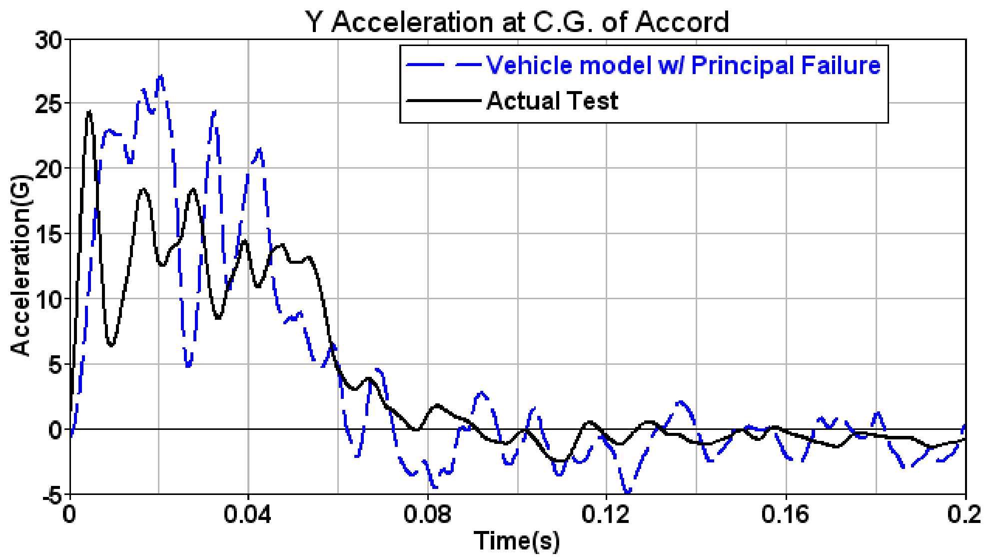


Figure 269: Lateral acceleration at the center of gravity of LWV and Honda Accord 2011 in NCAP side barrier test

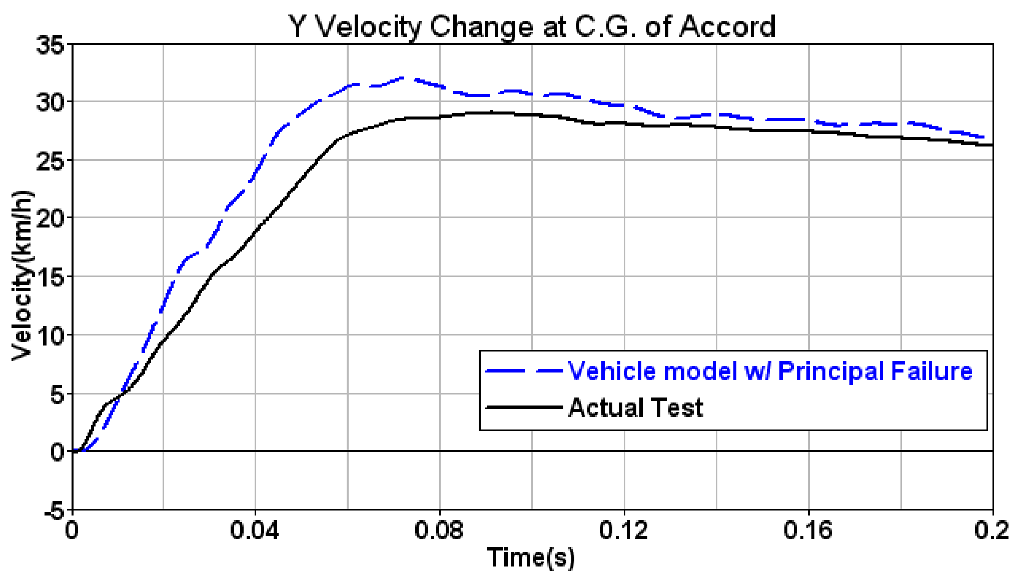
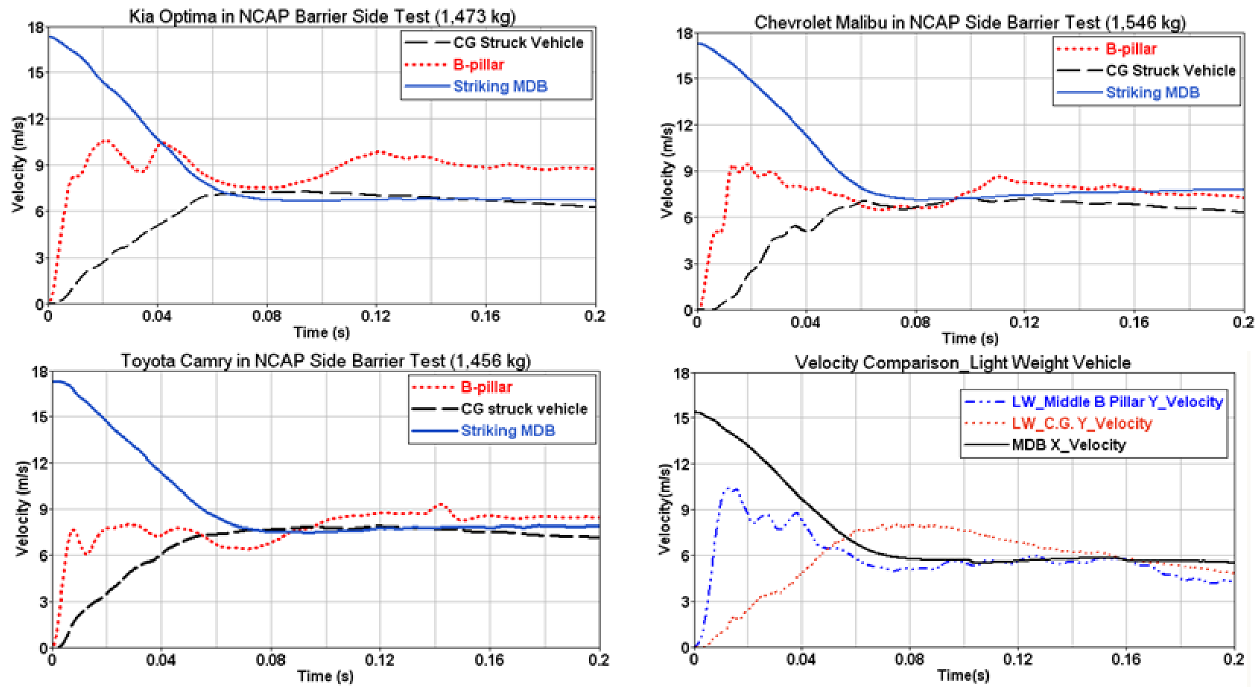


Figure 270: Lateral velocity at the center of gravity of LWV and Honda Accord 2011 in NCAP side barrier test

The magnitude of the velocity and the maximum intrusion of interior surface of the 'B-Pillar' for three other 5 star rated vehicles are shown in Figure 271 and Figure 272 respectively. As can be seen the LWV has comparable performance.



	Kia Optima	Chev Malibu	Toyota Camry	Light Weight Vehicle
Peak of Mid B Pillar Velocity	10.6m/s	9.5m/s	9.3m/s	10.3m/s

Figure 271: Mid 'B-Pillar' Velocity relative to C of G of Vehicles

	Kia Optima	Chev Malibu	Toyota Camry	Light Weight Vehicle
Crush between B-pillar and CG	300mm	213mm	147mm	221mm

Figure 272: Mid 'B-Pillar' Intrusion Values

The finite elements that eroded (those deleted because they exceeded the strain criterion in tension) in simulation are depicted as black boxes as shown in Figure 273. Note that only a few elements exceeded the failure criterion.

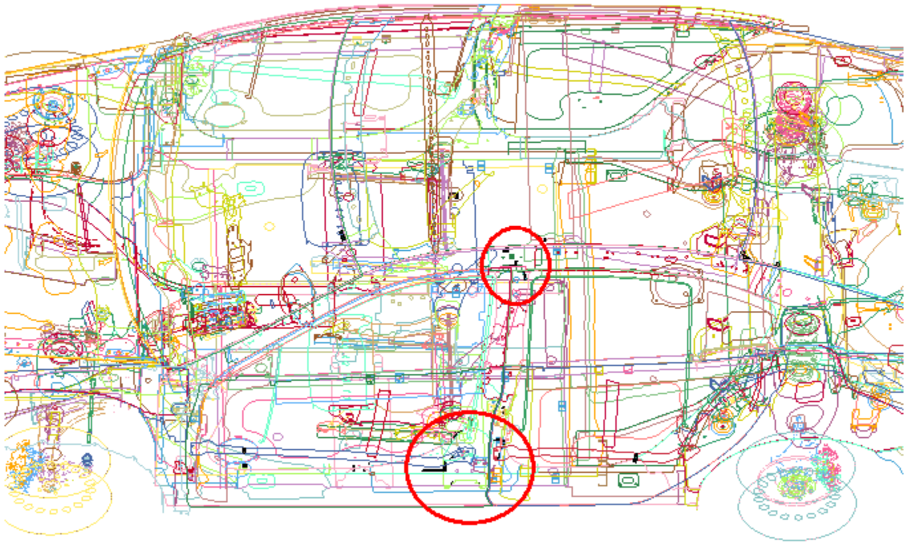


Figure 273: In LS-DYNA simulation of NCAP moving deformable barrier side test, those elements that eroded are shown

The body side structure of the LWV shown Figure 274 takes advantage of roll formed rocker section manufactured from complex phase steel (CP1000/1200) with 1000 MPa yield strength. The B pillar and roof rail are constructed from laser welded blanks (LWB) and hot-stamped form HF1050/1500 grade of boron steel. The body side outer panel is a dual phase grade (DP300/500) 0.7mm steel. The door beams are constructed of AHSS with yield stress greater than 1000 MPa. The combination of the very high strengths of the steels used for the body side and the CAE optimization of Gauge and Geometry leads to a mass efficient structure design used on the LWV. The hot-stamped B-Pillar inner panel is 'tailor quenched' to achieve up to 12% material elongation in selected zones to avoid premature material failure.

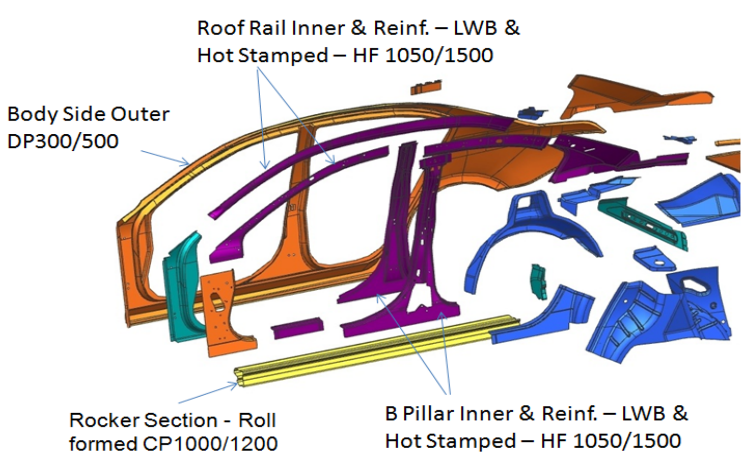


Figure 274: LWV Body Side Design

This side group includes five key parts: (1) outer and inner panel of left front and left rear doors, (2) rocker sill, (3) door beams, (4) B-pillar, and (5) roof sill. Figure 275 shows the outline of the vehicle parts, with the body side structural parts in color for clarity. In Figure 276, the crush of the key structural parts is shown over the time of the crash. Figure 277 is a graph that shows the energy absorbed by the side structural parts over the period of the NCAP side barrier test. As shown in this figure, all the key parts perform well to control the intrusion into the occupant compartment, including the B-pillar and the door beams.

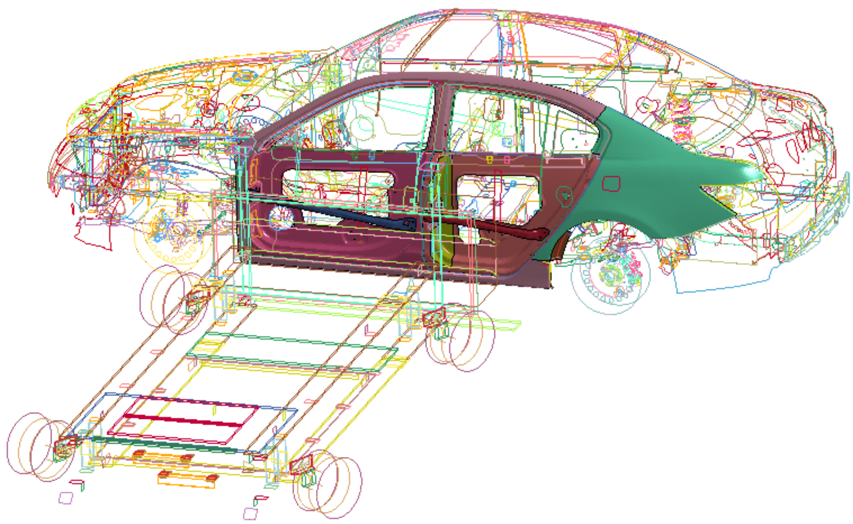


Figure 275: Schematic of LWV showing five key structural parts in color for NCAP side barrier test

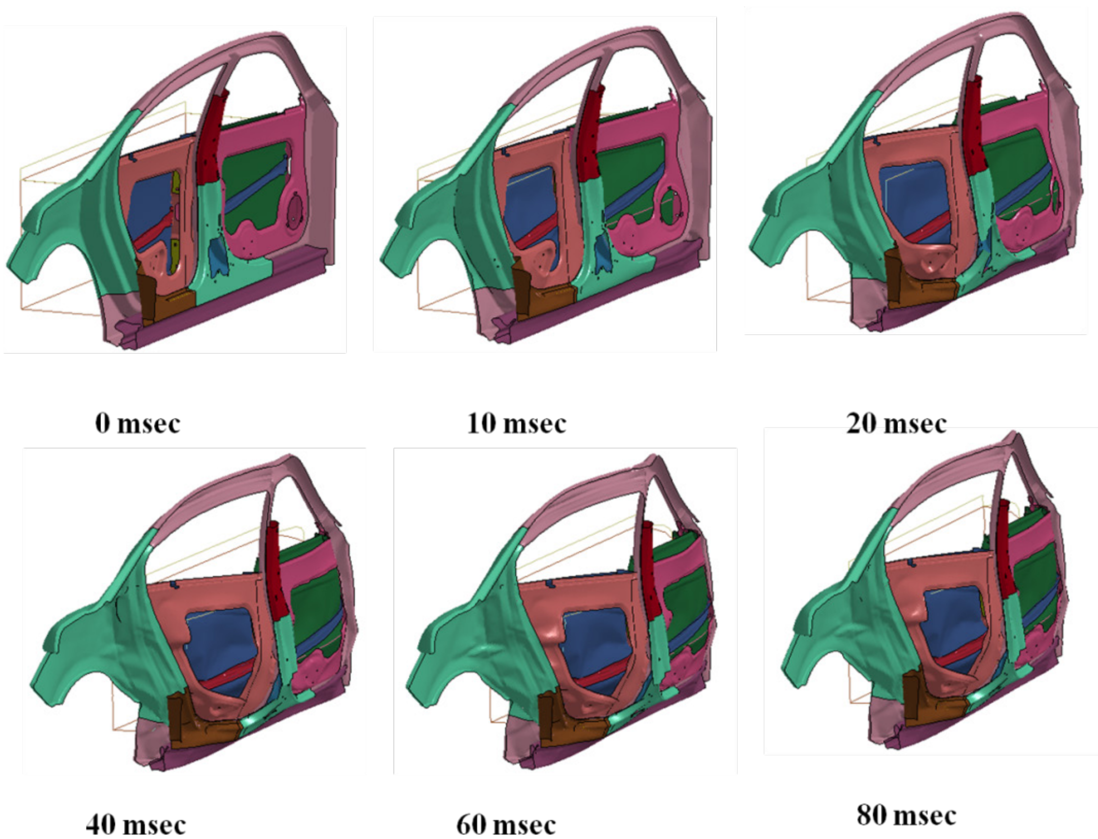


Figure 276: Crush of five key structural parts over the time of the NCAP side barrier test

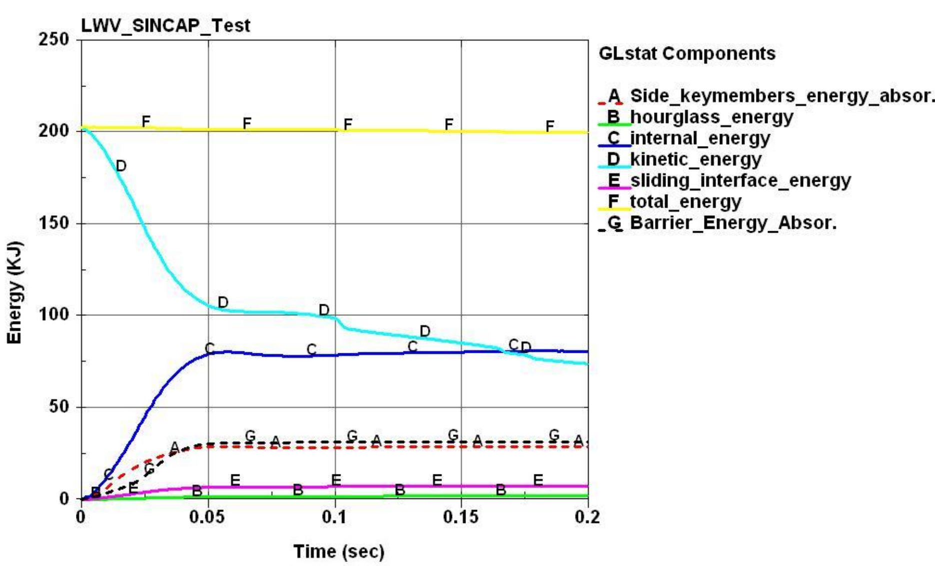


Figure 277: Energy Absorption Plot for the NCAP side barrier test

6.6 Lateral NCAP Pole Test

In this test the LWV impacts the rigid pole laterally at a speed of 32 km/h such that its line of forward motion forms an angle of 75 degrees with the vehicle's longitudinal axis, simulating a real-world crash in which the vehicle hits a tree while sliding on the road.

The rigid pole is a vertically oriented metal structure with: (1) a diameter of 254 mm, (2) beginning no more than 102 mm above the lowest point of the tires on the struck side of the fully loaded test vehicle, and (3) extending at least 150 mm above the highest point of the roof of the test vehicle. The direction of vehicle motion is such that the pole is always aligned with the CG of the head of the driver. This impact set up is shown in Figure 278.

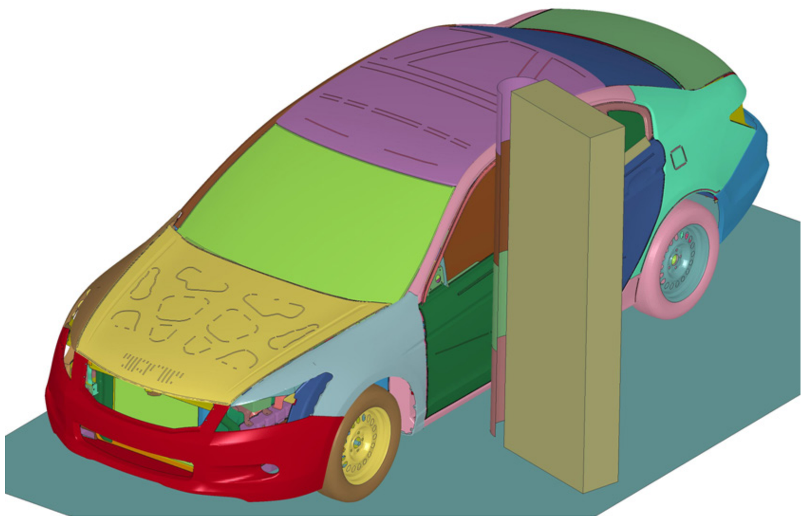


Figure 278: Test set up for the NCAP side pole test

The LS-DYNA set up for the side impact crash test of the LWV model with a pole is shown in Figure 279. Images of the post-crash vehicles for the actual laboratory crash and the simulation are shown in Figure 280. The intruding side interior on the struck side presents a threat to the driver. To understand this treat, it is helpful to examine instrumentation near the intruding side interior near the driver. The B-pillar was close to the driver and had an accelerometer that functioned properly during the pole side impact. The velocity versus time plot at the mid-B-pillar (i.e., at a point half way between the floor sill and roof header) is in Figure 281, indicating that the FEM predicted response for LWV is close to the actual laboratory velocity. Figure 282 shows the velocity versus time at the CG of the 2011 Honda Accord. The velocity of the LWV is similar to the velocity of the 2011 Honda Accord.

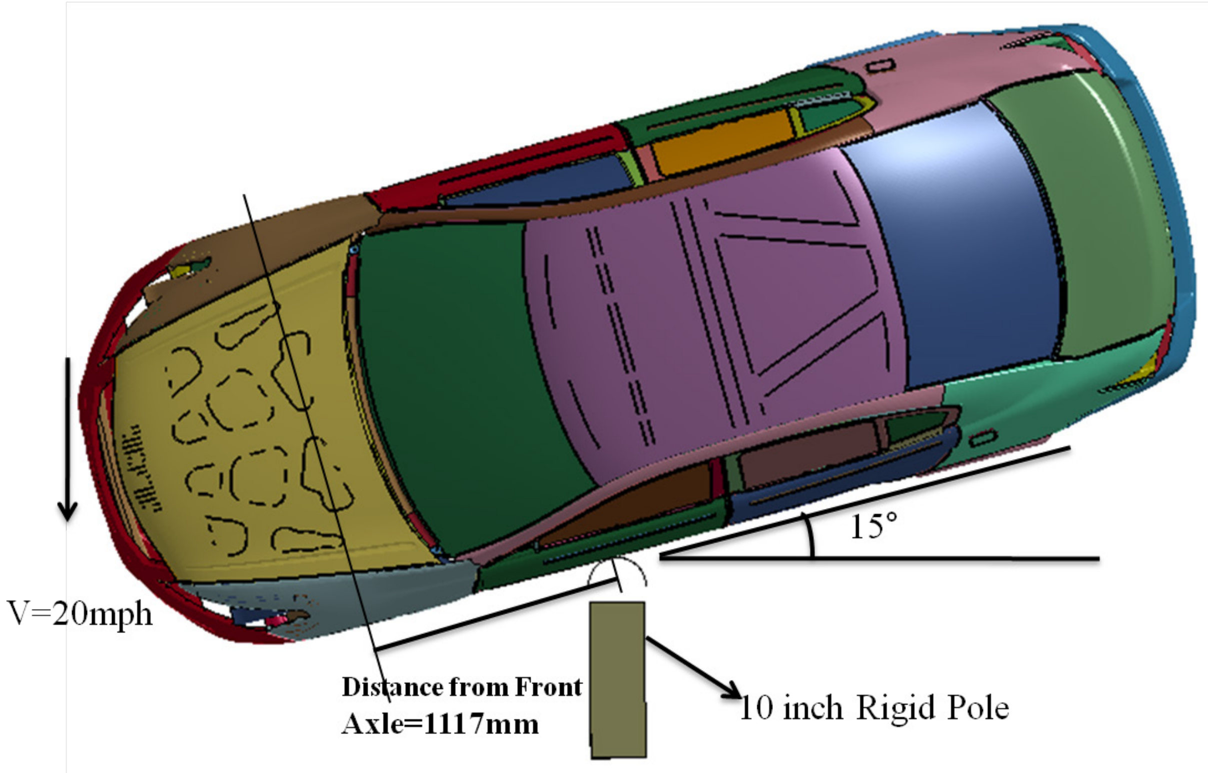


Figure 279: LS-DYNA set up for the NCAP pole lateral test

Figure 280: Post-crash vehicles for the actual laboratory crash and the simulation in lateral pole test

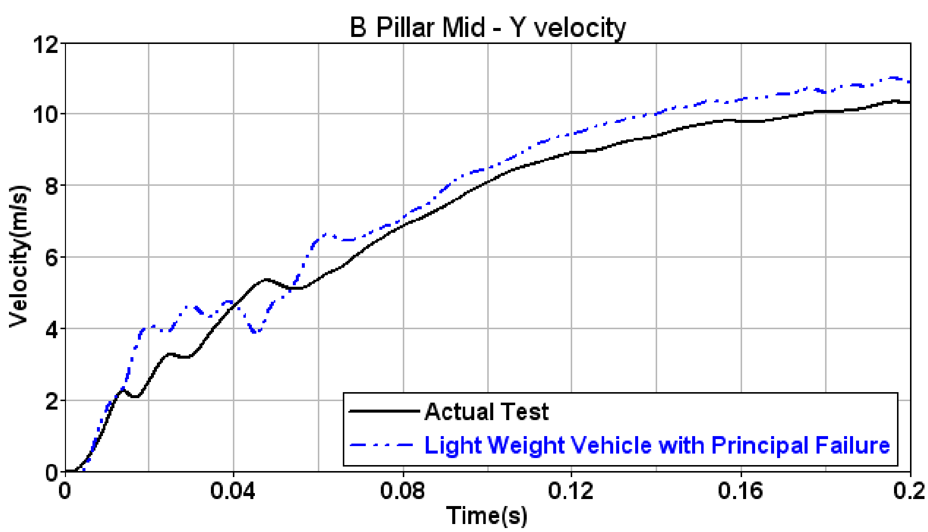


Figure 281: Velocity versus time for the mid-B-pillar on the struck side in lateral pole test

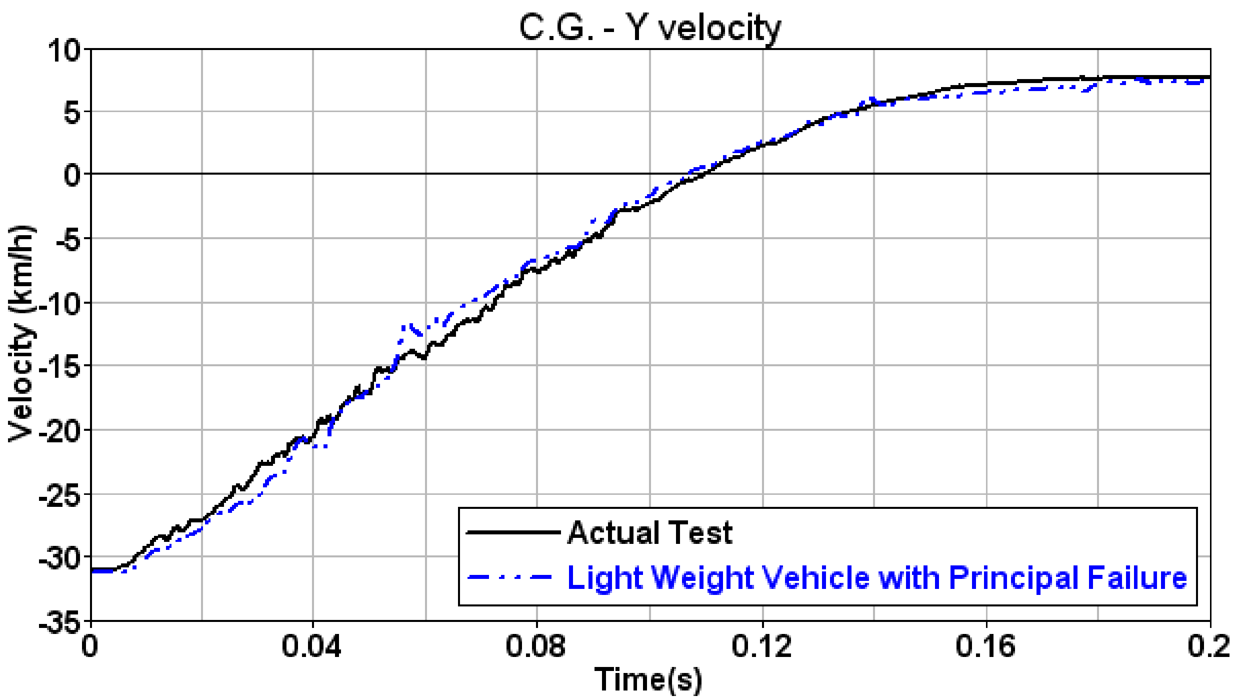


Figure 282: Lateral velocity at the center of gravity of LWV and Honda Accord 2011 in NCAP side pole test

Figure 283 shows the exterior crush profile for level 2, which is located at approximately the H-point level of the driver dummy. Figure 284 shows the exterior crush profile for level 3, which is located at approximately the mid-door level. Figure 285 shows exterior crush for level 4, approximately the window sill level. In setting up a crash test with the occupant seated in the vehicle, the location of the H-point is determined above the vehicle seat. The H refers to hip, essentially the axis of rotation between the upper torso and the upper segment of the legs. The H-point may be visualized as the approximate location of the hip of a mid-size male sitting on the seat of the vehicle. The external crush is similar for the Honda Accord and the LWV, i.e., the safety of the LWV with properly tuned restraints to protect the head and torso should have a comparable safety rating to the Honda Accord based upon the B-pillar velocity and residual crush results from the simulation.

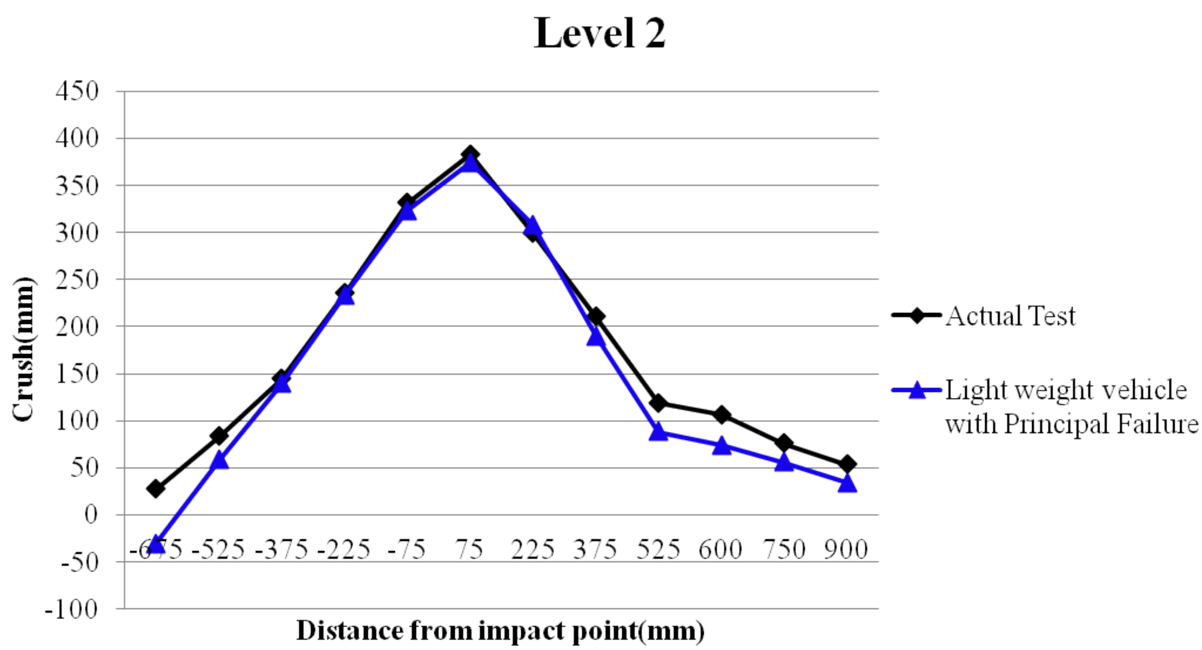


Figure 283: Exterior crush for level 2, approximately the H-point level in lateral pole test

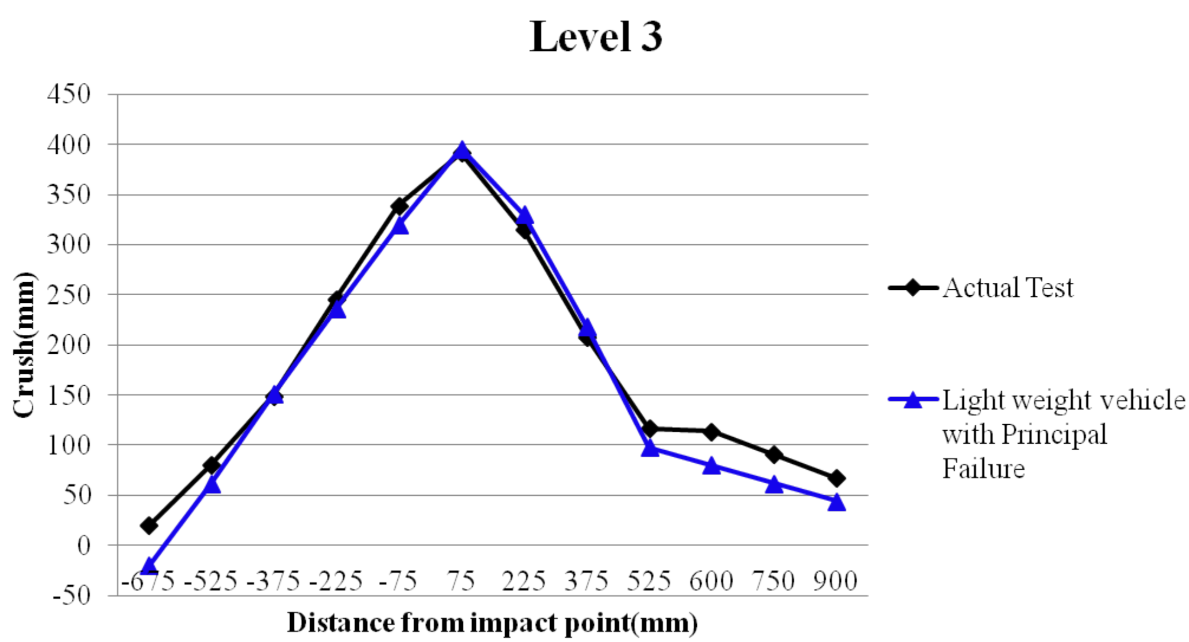


Figure 284: Exterior crush for level 3, approximately the mid-door level in lateral pole test

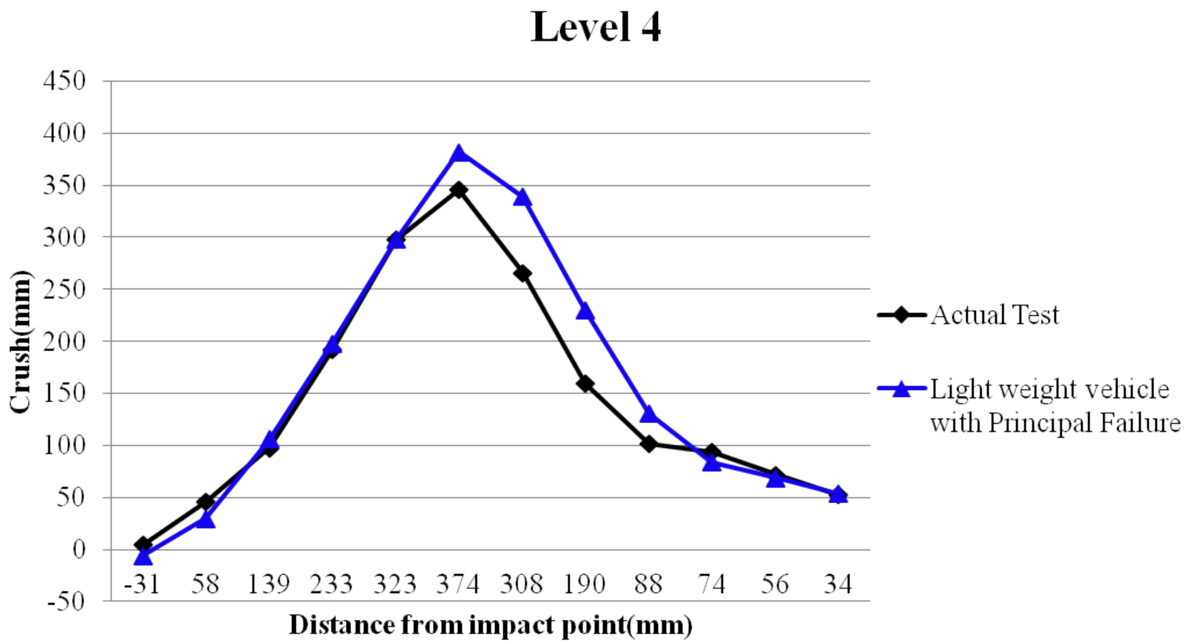


Figure 285: Exterior crush for level 4, approximately window sill level in lateral pole test

The finite elements that eroded (those deleted because they exceeded the strain criterion in tension) in simulation are depicted as black boxes in Figure 286. Note that only a few elements exceeded the failure criterion, indicating the structure controls the crush satisfactorily.

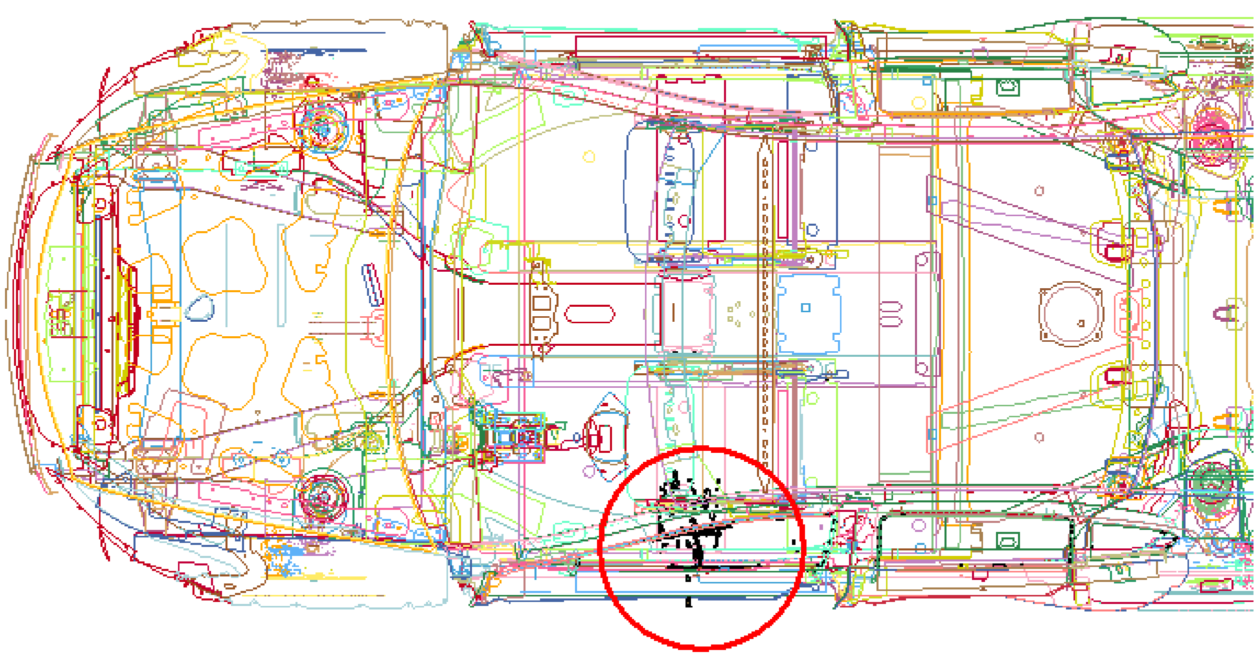


Figure 286: In LS-DYNA simulation of NCAP lateral pole test, those elements that eroded are pictured as a black box

In a pole impact, parts that absorb much of the crash energy are: (1) left-front door, (2) rocker sill, (3) door reinforcement beam, (4) lower B-pillar, (5) roof, and (6) floor structure. Figure 287 shows the outline of the vehicle parts, with the six structural parts in color for clarity. In Figure 288, there is no damage to the fuel tank or the surrounding structure in the rear, and one could expect that there should be no leakage of gas from the tank.

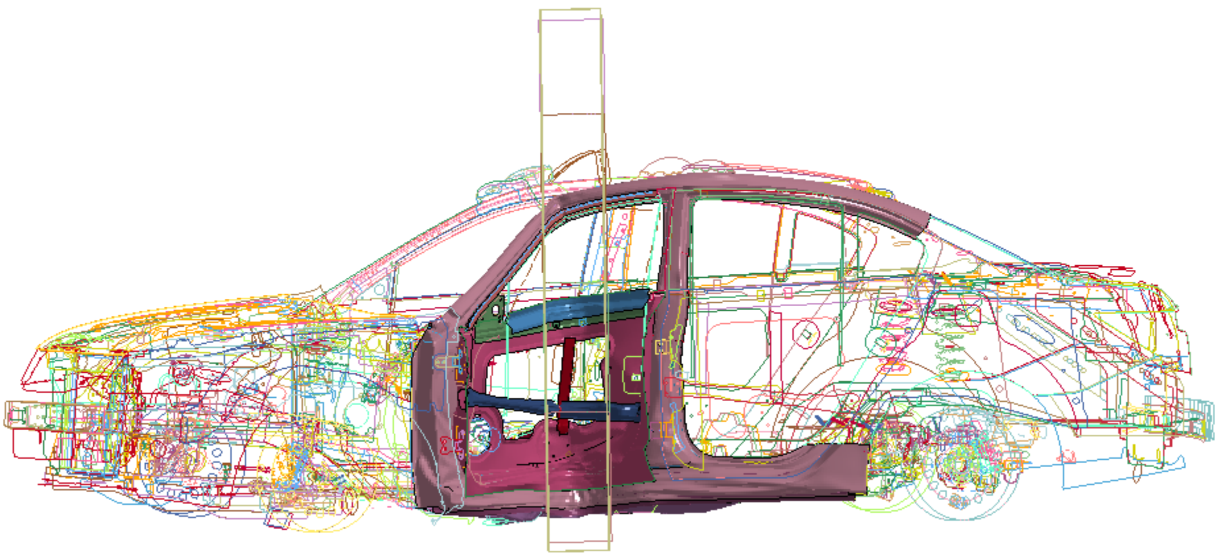


Figure 287: Schematic of LWV showing six key structural parts in color for NCAP side pole test

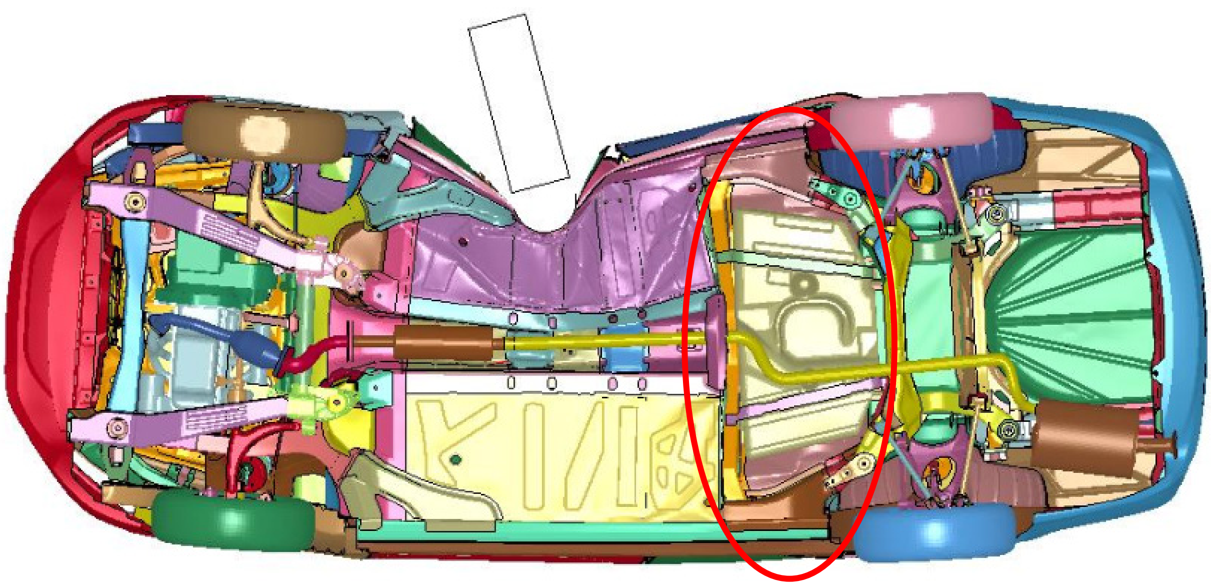


Figure 288: Schematic of LWV showing six key structural parts in color for NCAP side pole test

The crush of the six key structural parts over the time of the crash is presented in Figure 289. Figure 290 is a graph that follows the energy absorbed by the six structural parts over the period of the NCAP side pole test.

Figure 289: Crush of six key structural parts over the time of the NCAP side pole test

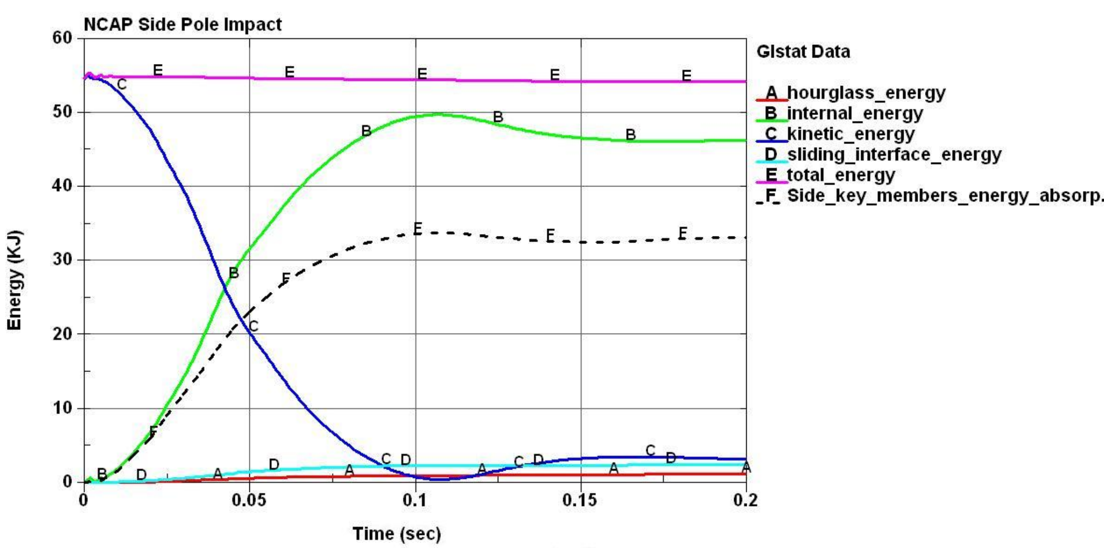


Figure 290: Energy absorbed by the six key structural parts during the NCAP side pole test

6.7 IIHS Roof Crush 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. The LWV is held rigidly with clamps about the rocker section. Both NHTSA and IIHS do a roof crush test. The Federal Motor Vehicle Safety Standard No. 216 specifies that roof structure should sustain a load three times the vehicle curb weight. The IIHS roof crush rating stipulates that the roof structure must sustain loading of four times the curb weight for a *good* ratings. The NHTSA roof crush test is FMVSS No. 216, and is a regulation, which 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 NHTSA tested the 2008 Honda Accord. The IIHS tested the 2009 Honda Accord. For this study, the researchers analyzed the IIHS roof crush test because (1) the IIHS vehicle was a more recent model year sedan and (2) the IIHS test gives a higher-level safety rating, with which the LWV can be compared.

The LS-DYNA set up for the IIHS roof crush test of the LWV model is shown in Figure 291. The force versus platen displacements are given in Figure 292 for the actual test and the LS-DYNA simulation. Figure 293 gives the strength to weight ratio (SWR), which is the force divided by curb weight, versus platen displacement. The SWR for the LWV is in the 'good' zone.

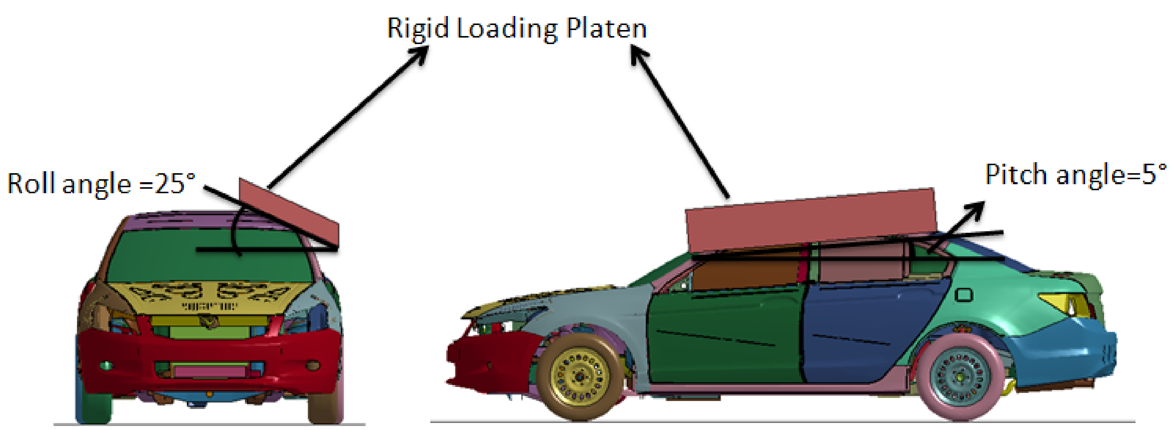


Figure 291: LS-DYNA set up for the IIHS roof crush test

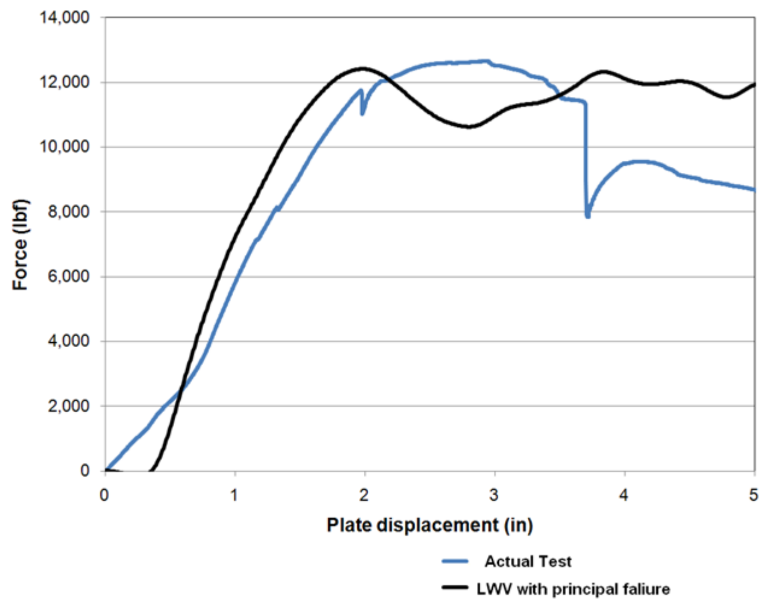


Figure 292: Force versus platen displacement for Honda Accord and LWV in IIHS roof crush test

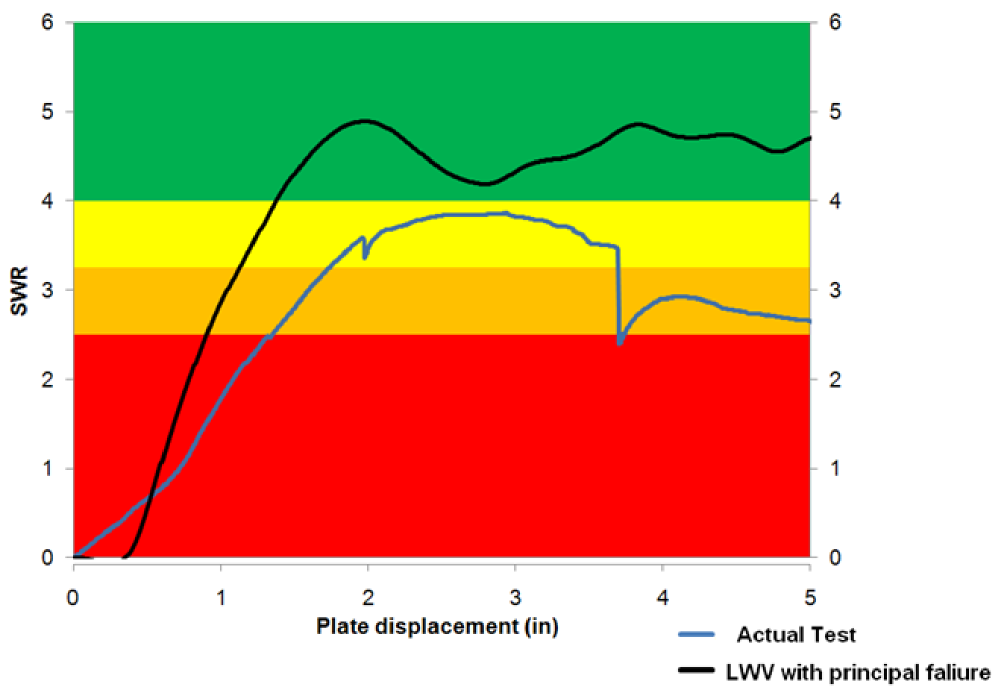


Figure 293: Force divided by curb weight versus platen displacement for MY2011 baseline Honda Accord and LWV in IIHS roof crush test

In the IIHS roof crush test, parts that provide the resistance and absorb much of the crash energy are (1) upper B-pillar, (2) roof side rail, (3) roof cross members. The roof side rail and the B-pillar are constructed of AHSS with yield strength of greater than 1000 MPa. The roof is to be steel with yield strength between 300 MPa – 500 MPa. Figure 294 shows the outline of the vehicle parts, with the structural parts in color for clarity. The crush of the key structural parts over the time of the test is presented in Figure 295. Figure 296 is a graph that follows the energy absorbed by the structural parts over the period of the IIHS roof crush test.

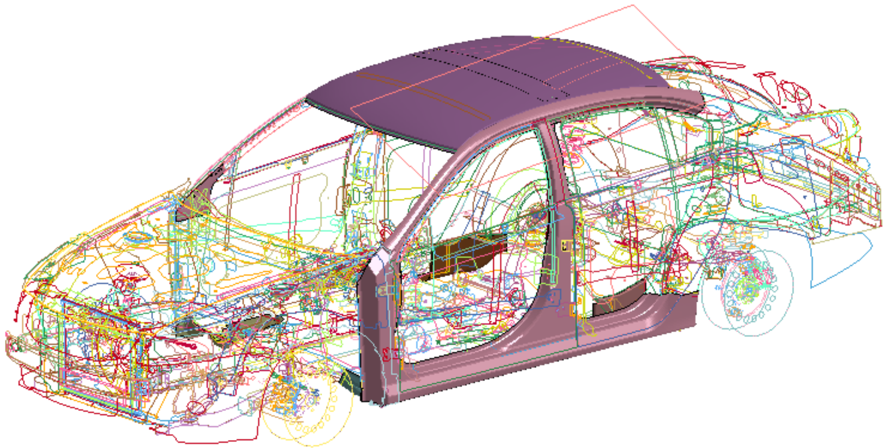


Figure 294: Schematic of LWV showing four key structural parts in color for IIHS roof crush test

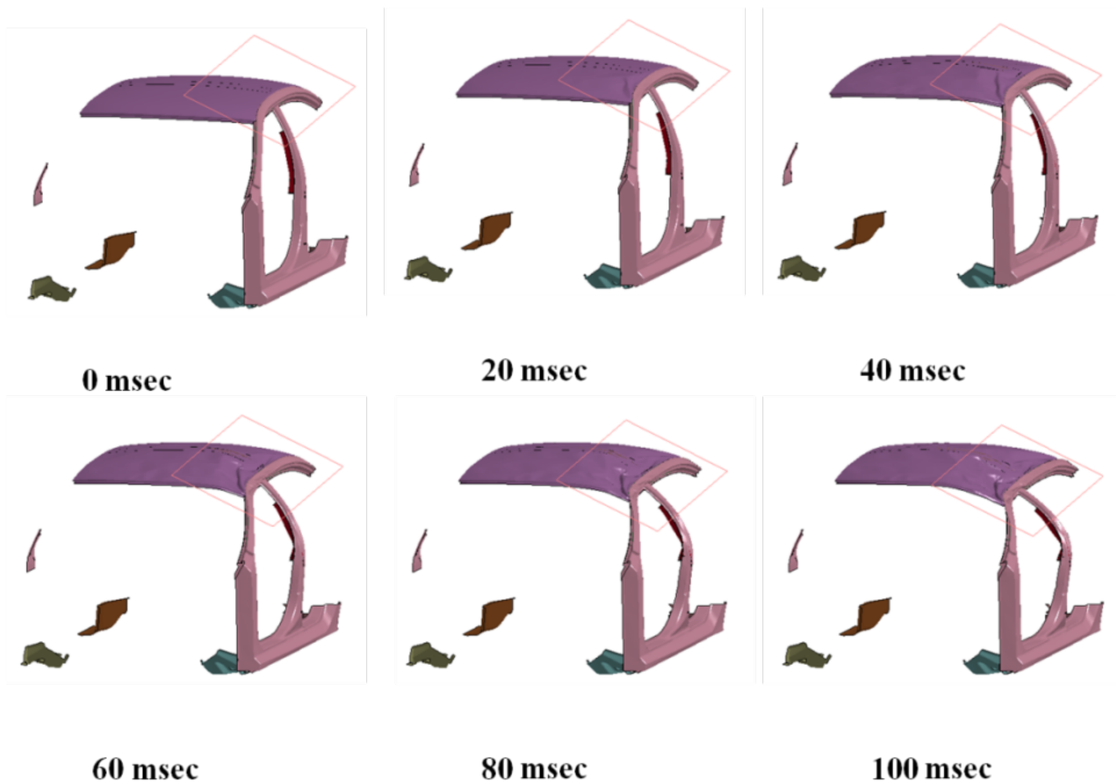


Figure 295: Crush of four key structural parts over the time of the IIHS roof crush test

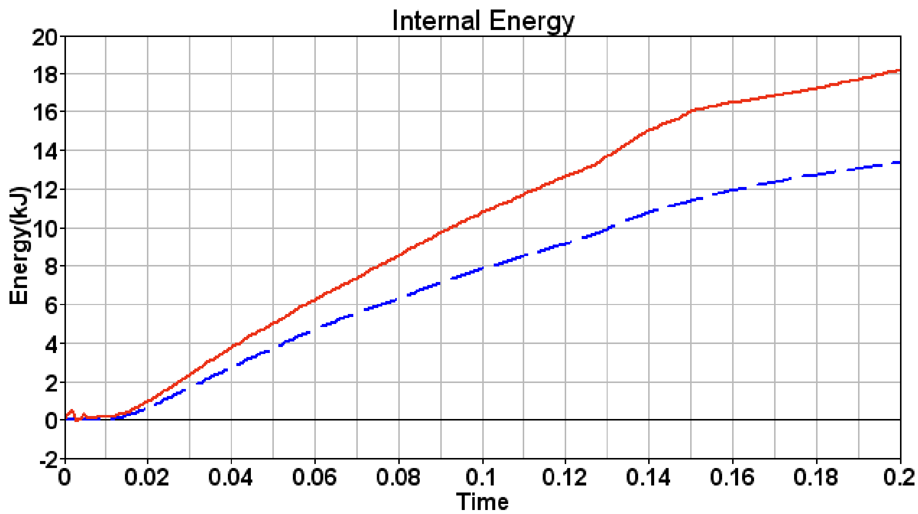


Figure 296: Total energy absorbed (red) and four key structural parts energy absorbed (blue) during the IIHS roof crush test

6.8 IIHS Lateral Moving Deformable Barrier Test

In the IIHS side barrier test, the front end of the MDB represents the front end of an SUV, with a test weight of 1500 kg. The MDB impacts the LWV on the driver's side with a velocity of 50 km/has shown in Figure 297. The LWV carries the weight of two 5th percentile test dummies (45 kg each), one in the driver's seat and the other in the rear passenger seat directly behind the driver dummy. The vehicle also carries 32 kg of weight in the cargo area and 59 kg (instrumentation and camera) of weight on the non-struck front and rear side doors.

The LS-DYNA set up for the IIHS side impact crash test of the LWV model with a moving deformable barrier is presented in Figure 297. Images of the post-crash vehicles for the actual laboratory crash and the simulation are shown in Figure 298. The velocity versus time plot at the right rear sill on the non-struck side is shown in Figure 299. This figure indicates that the FEM predicted velocity is close to the actual measured laboratory velocity behavior of the MY2011 baseline Honda Accord. Figure 300 shows the pre- and post-crush and intrusion of the LWV. Figure 301 illustrates that the LWV intrusions are located in the "goo*d"* region for the IIHS rating format. The exterior crush (at the mid-door level) for the M2011 baseline Honda Accord and the LWV model are shown in Figure 302. The MY2011 baseline Honda Accord and the LWV intrusions are observed to be equivalent in the IIHS lateral crash test.

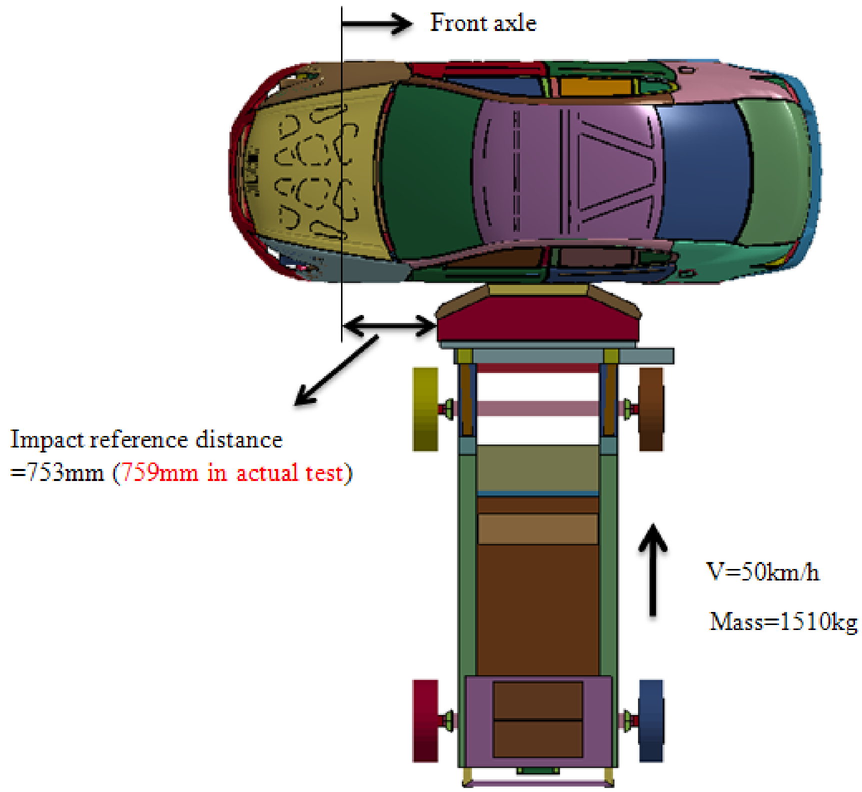


Figure 297: LS-DYNA set up for the IIHS lateral impact test

Figure 298: Post-crash vehicles for the actual laboratory crash and the simulation in IIHS lateral impact test

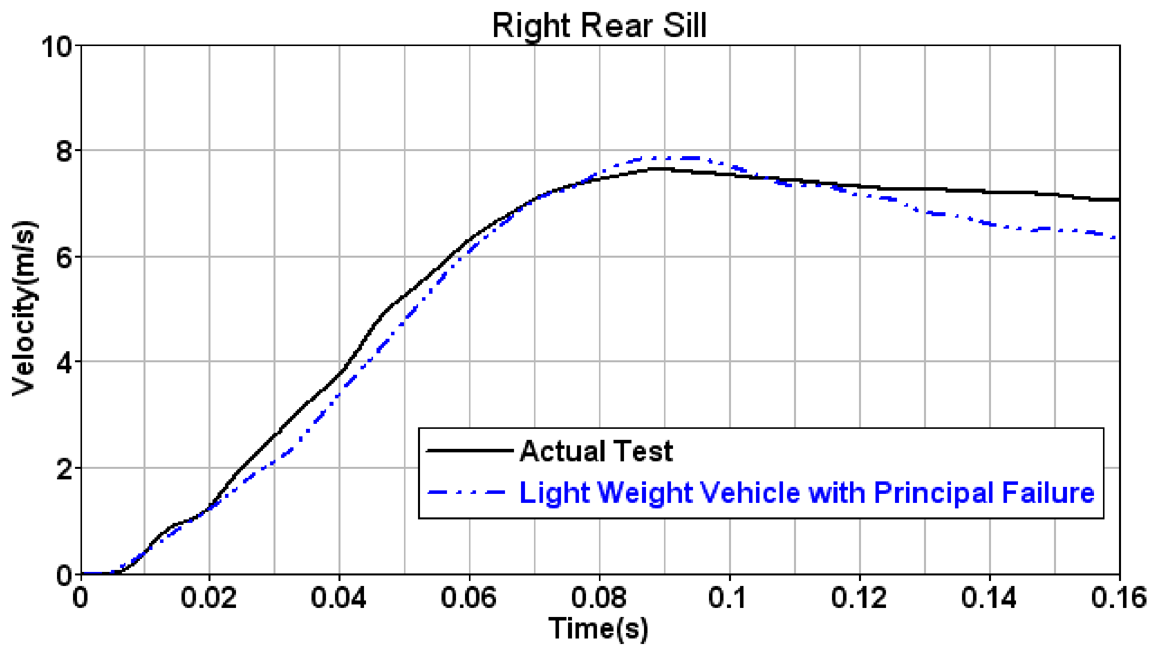


Figure 299: Velocity versus time plot at the right-rear sill on the non-struck side of the MY2011 baseline Honda Accord and LWV

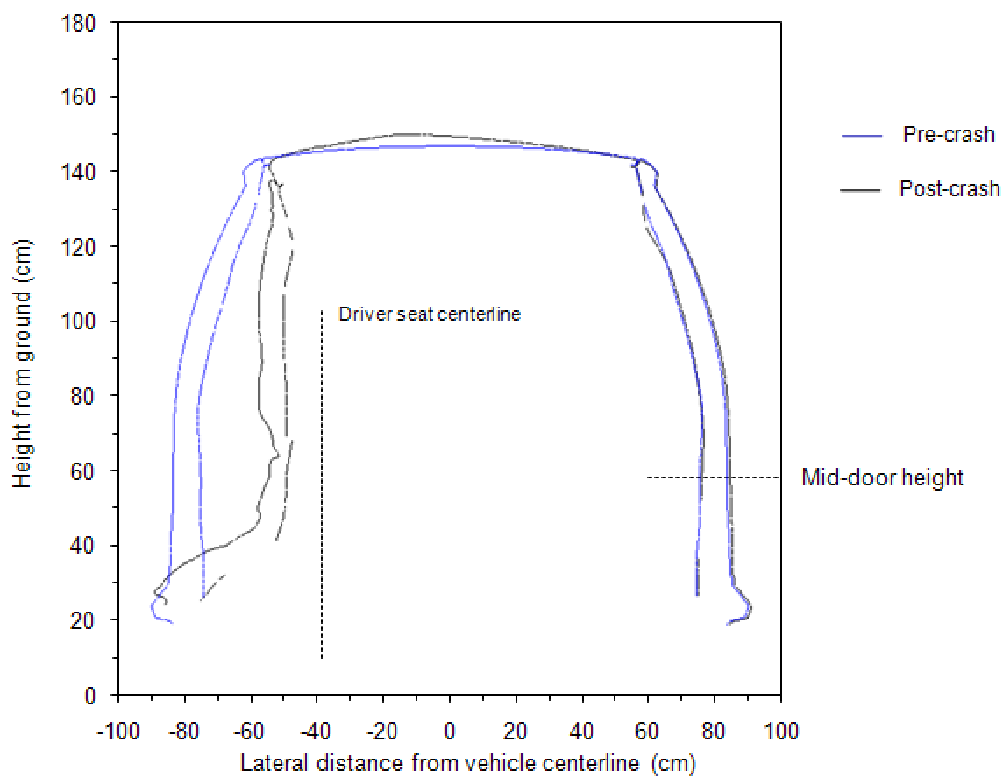


Figure 300: Pre- and post-crush and intrusion for the LWV in the IIHS lateral test

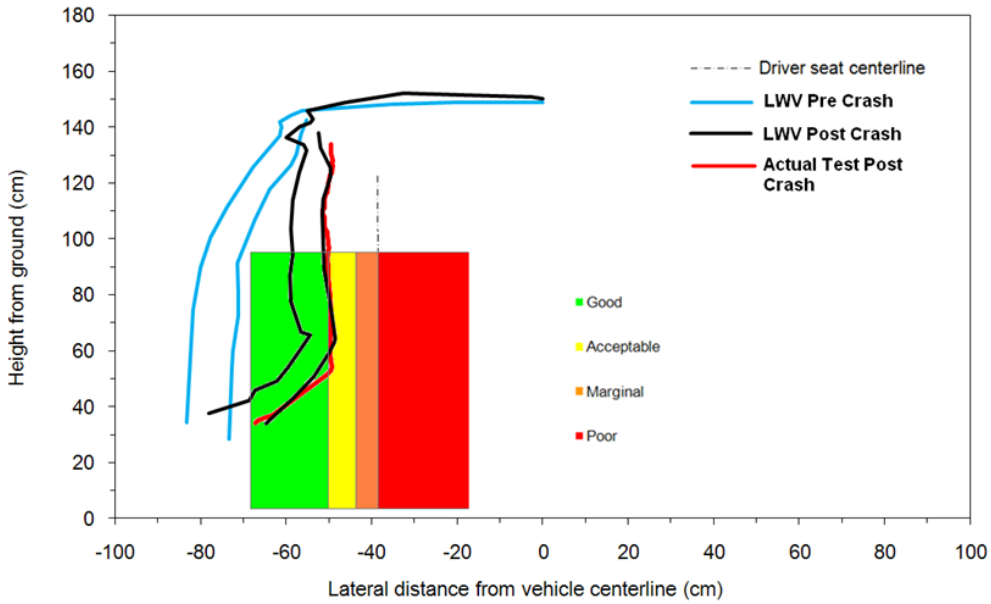


Figure 301: LWV is in the "good" region for the IIHS lateral test[175]

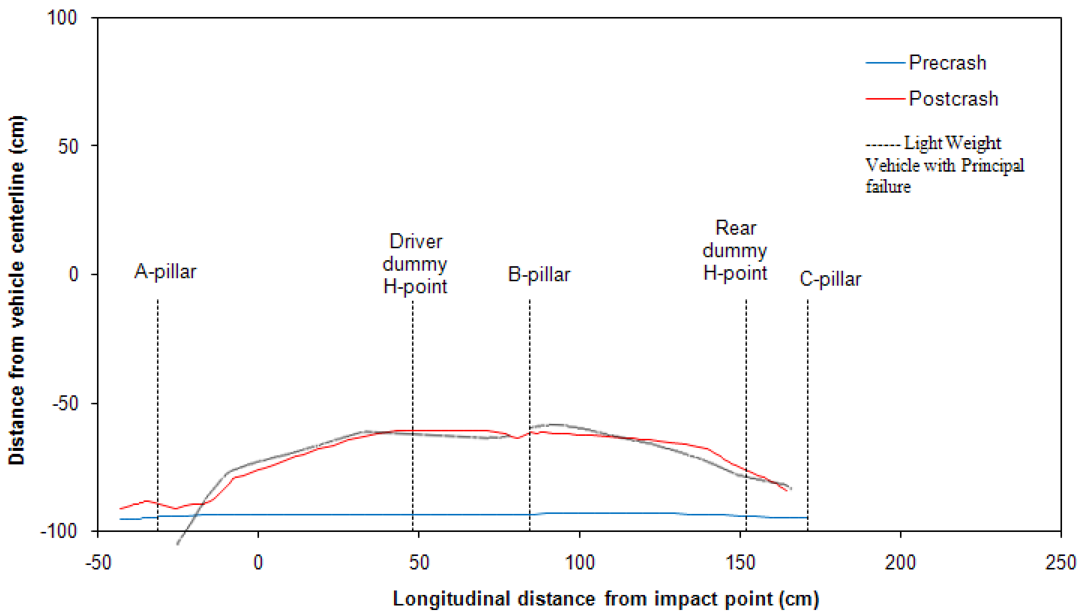


Figure 302: Plan View Crush Profile at Mid-Door Level

175 Insurance Institute for Highway Safety, *Side Impact Crashworthiness Evaluation: Crash Test Protocol (Version V)*, 1005 N. Glebe Road, Arlington, VA 22201, May 2008

Vehicle parts that absorb much of the crash energy in the IIHS side barrier test are: (1) outer and inner panel of left front and left rear doors, (2) rocker sill, (3) door reinforcement beams, (4) B-pillar, and (5) roof sill. Figure 303 shows the outline of the vehicle parts, with the five structural parts in color for clarity. Special attention was paid to using AHSS in the B-pillar, where high strength along with low intrusion is needed. The crush of the five key structural parts over the time of the crash is presented in Figure 304. Figure 305 is a graph that follows the energy absorbed by the five structural parts over the period of the IIHS side barrier test.

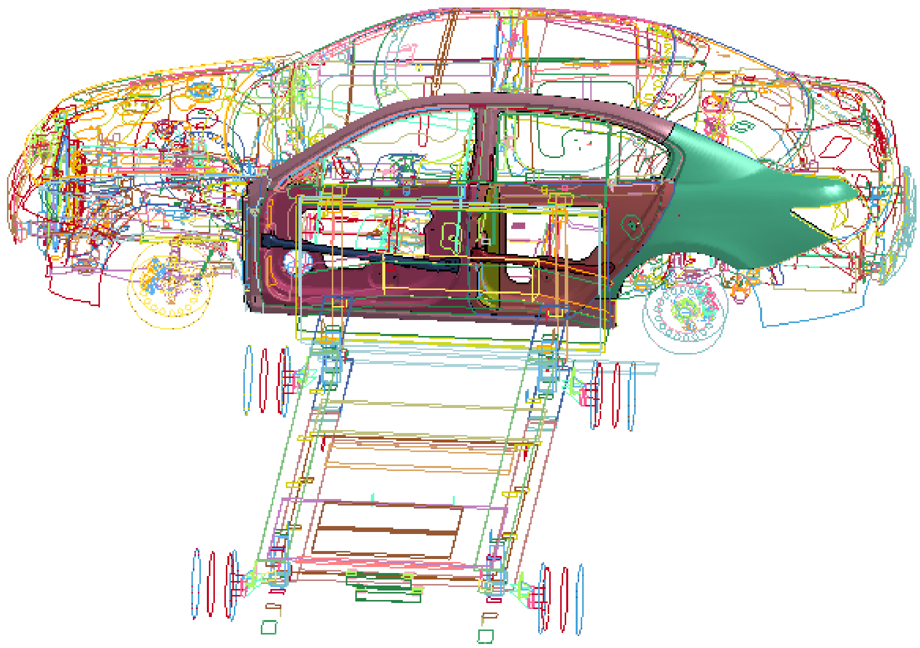


Figure 303: Schematic of LWV showing five key structural parts in color for IIHS side barrier test

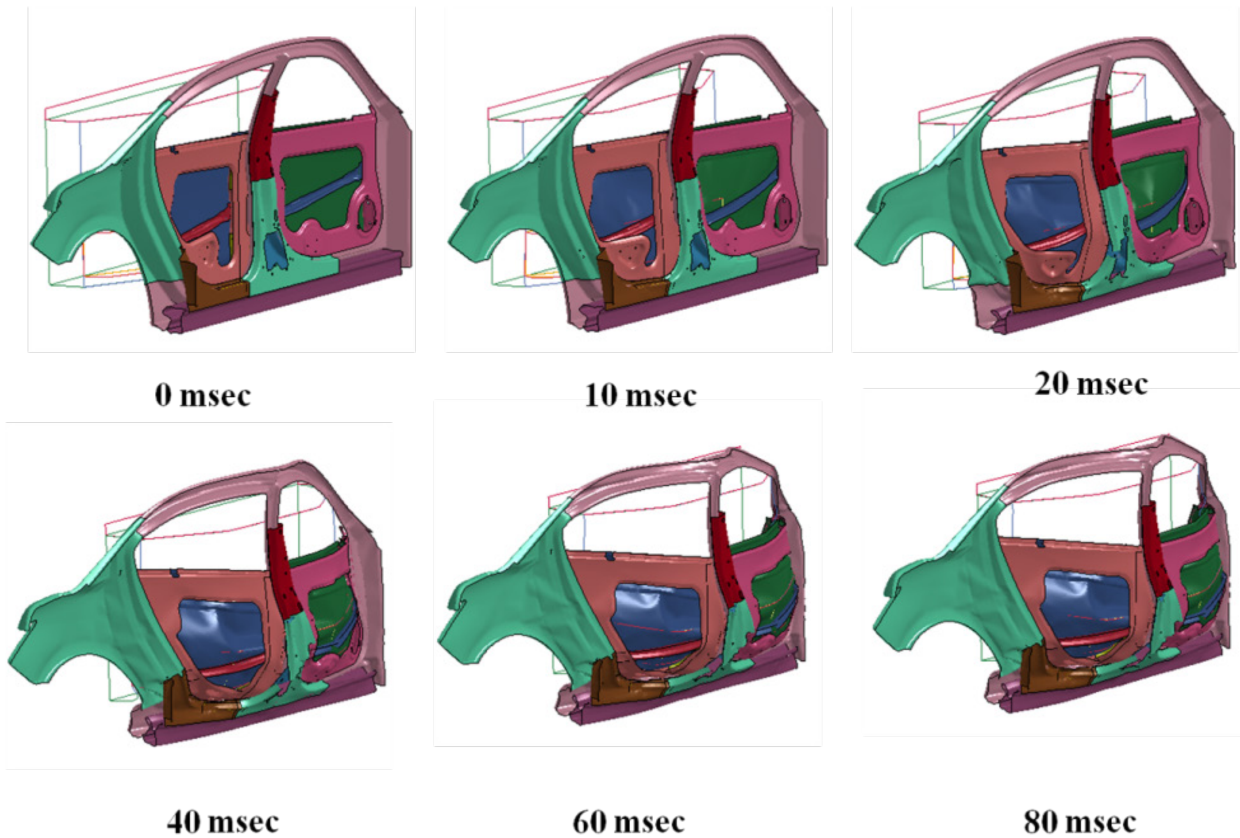


Figure 304: Crush of five key structural parts over the time of the IIHS side barrier test for LWV

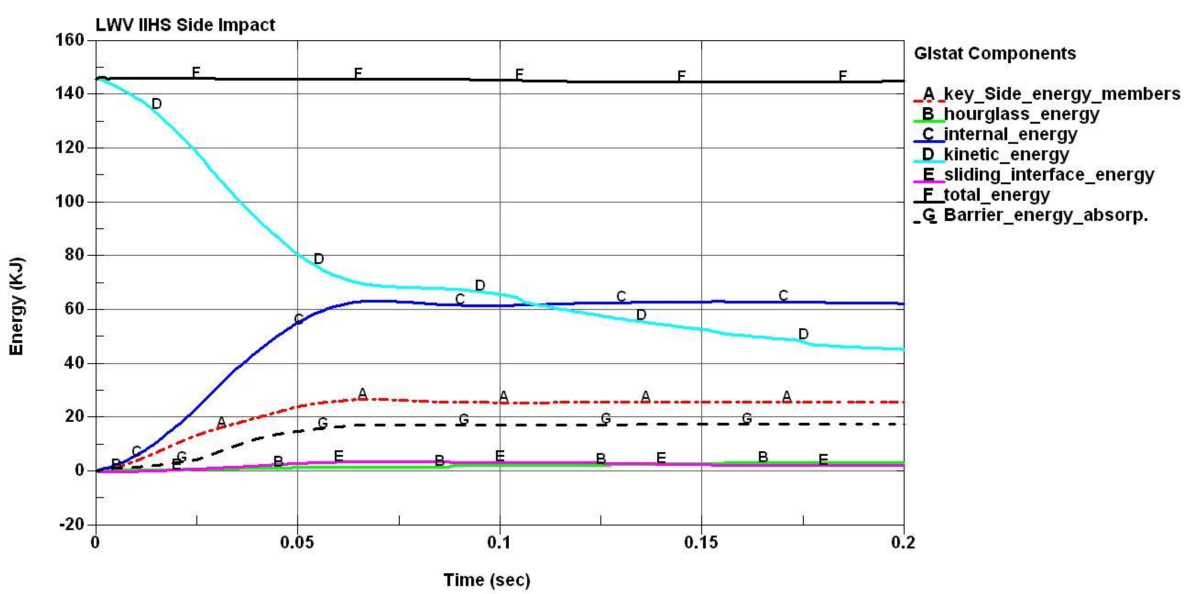


Figure 305: Energy balance for the IIHS side barrier test for LWV

Figure 306 and Figure 307 show that there is no damage to the fuel tank, and one could expect that there should be no leakage of gas from the tank after the IIHS side barrier test.

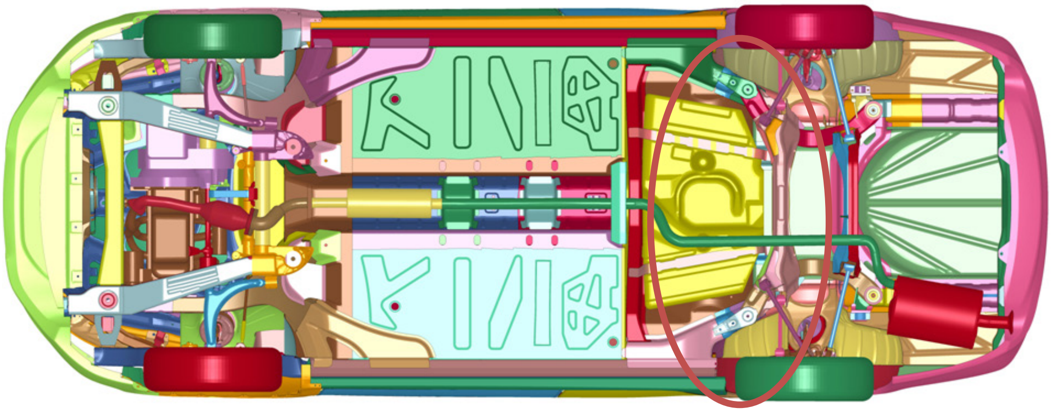


Figure 306: Bottom view of LWV before IIHS side barrier test

Figure 307: Bottom view of LWV after IIHS side barrier test

6.9 IIHS Frontal Offset Test

For IIHS frontal offset test, the LWV hits the deformable aluminum honeycomb barrier at a velocity of 64 km/h (40 mph). Forty percent of the total width of the vehicle strikes the barrier on the driver's side. A Hybrid III dummy representing an average-size (50th percentile) man is positioned in the driver seat. At the time of this report, IIHS had not performed the frontal offset barrier test on the MY2011 Honda Accord. For comparison purposes, the MY2011 Honda Crosstour safety rating results are used. The Honda Crosstour has a frontal body structure similar to the Honda Accord 2011 vehicle. The front structure of the 2010 Honda Crosstour and the 2011 Honda Accord are the same design and build. Therefore, the crash behavior of the 2010 Honda Crosstour and the 2011 Honda Accord should be the same in a frontal crash.

The LS-DYNA set up for the 40% offset frontal crash test of the LWV model into a deformable barrier is presented in Figure 308.

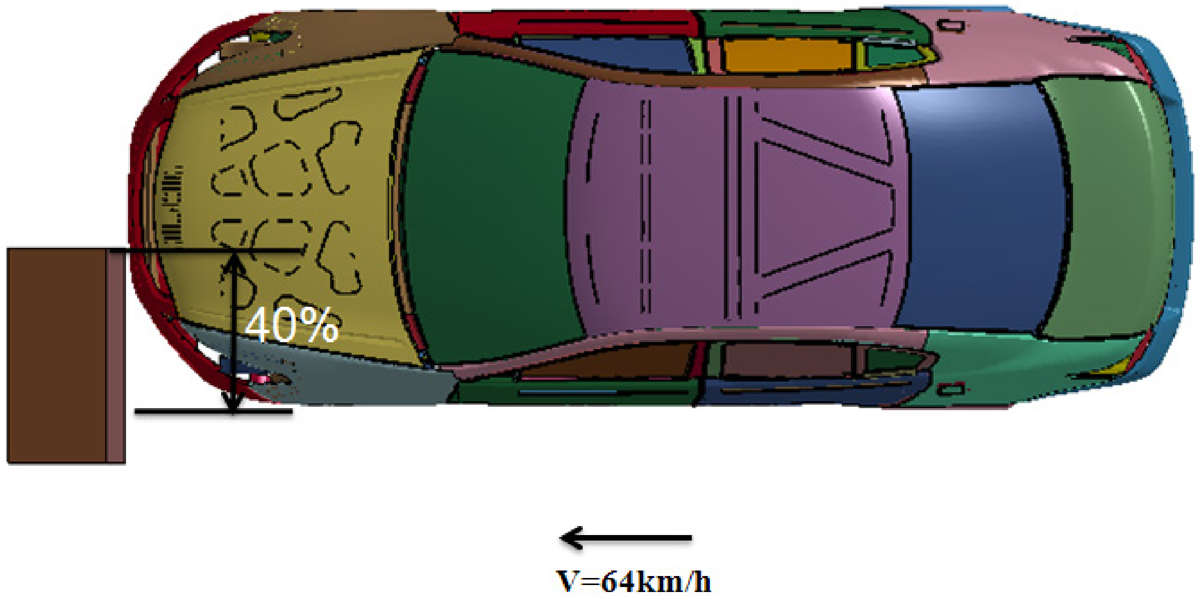


Figure 308: LS-DYNA set up for the 40% offset frontal crash test into a deformable barrier of the LWV

The post-crash vehicles for the actual laboratory crash and the simulation are shown in Figure 309. The crash pulse in the x-direction for the center of gravity (CG) is shown in Figure 310, where it is observed that the FEM predicted crash pulse is consistent to the measured Honda Crosstour laboratory pulse. In the NCAP frontal test, the accelerometers are located at the rear-seat in the x-direction. The NCAP test does not have an accelerometer at the CG in the frontal direction. In the IIHS frontal crash test, the accelerometer is placed at the CG. The IIHS frontal test does not have accelerometers located at the rear seat in the X-direction.

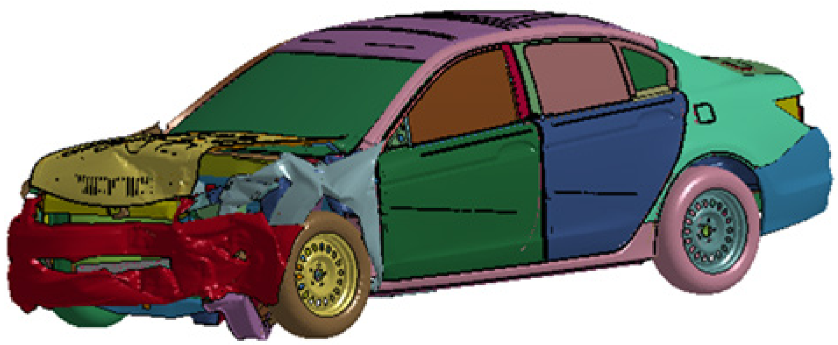


Figure 309: Post-crash vehicles for the MY 2011 Honda Crosstour actual laboratory crash and the simulation for LWV in the IIHS 40% offset frontal test

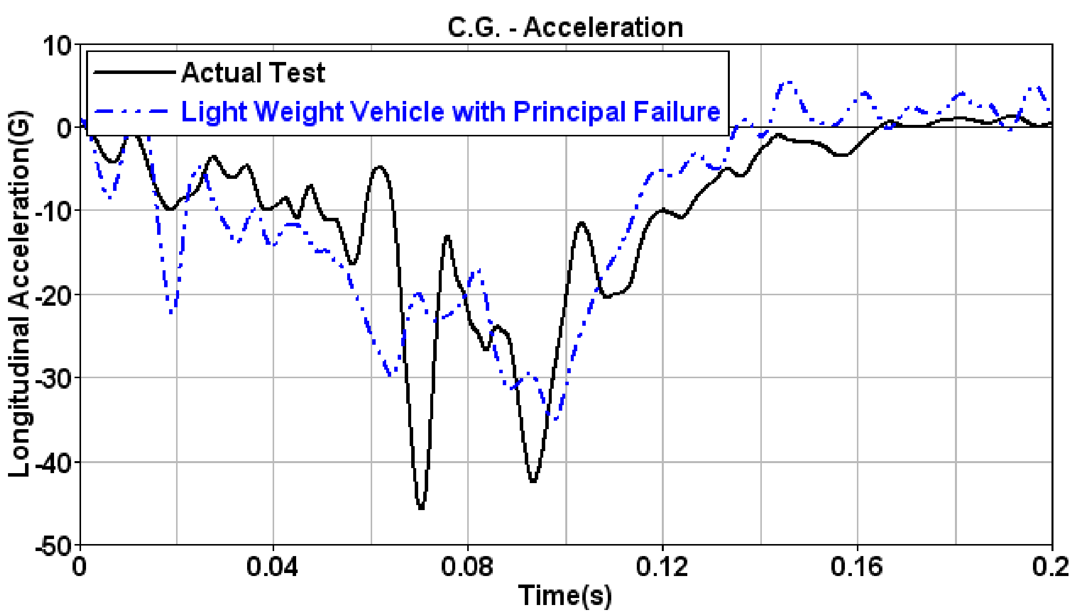


Figure 310: Crash pulse in the x-direction for the center of gravity of the MY2011 Honda Crosstour and the LWV in IIHS frontal test

The IIHS structural measuring scheme is illustrated in Figure 311. This scheme indicates that the LWV has slightly higher intrusion than the Honda Crosstour, but is within the "good" zone. The difference in the left toe pan is about 35 mm, which is slightly over an inch. However, the left toe pan intrusion of the LWV remains well within the corridor for the "good" rating.

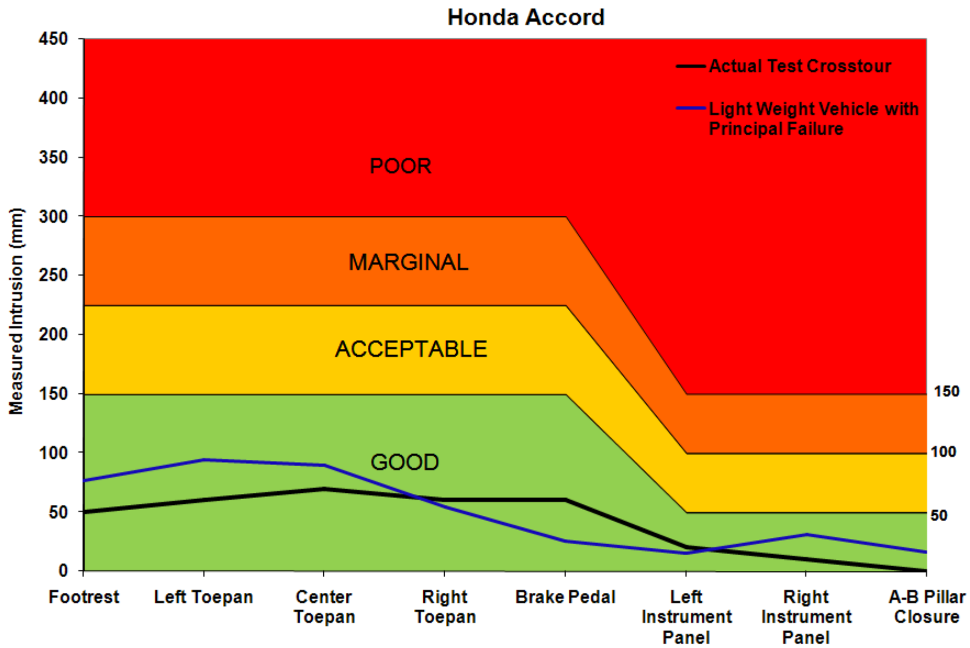


Figure 311: Intrusions of MY2011 Honda Crosstour and the LWV on the IIHS structural measuring scheme[176]

Vehicle parts that absorb much of the crash energy in the IIHS frontal offset barrier test are the: (1) front bumper, (2) left longitudinal rail, (3) left sub-frame rail, (4) left shotgun, and (5) toe pan. Figure 312 shows the outline of the vehicle parts, with the five structural parts in color for clarity. The crush of the five key structural parts over the time of the crash is presented in Figure 313. Figure 314 is a graph that follows the energy absorbed by the five structural parts over the period of the IIHS frontal offset barrier test.

[176] Insurance Institute for Highway Safety, *Frontal Offset Crashworthiness Evaluation Guidelines for Rating Structural Performance,* 1005 N. Glebe Road, Arlington, VA 22201, April 2002.

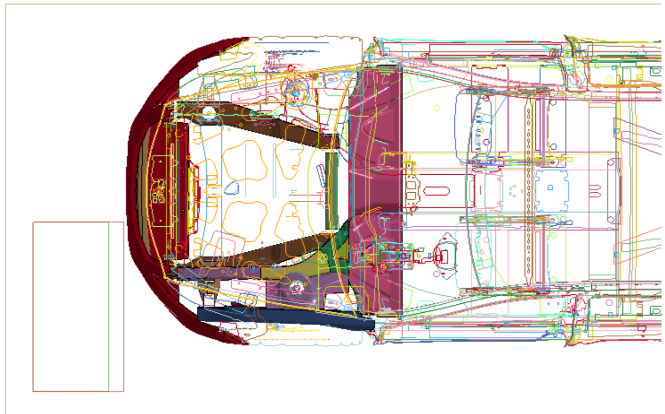


Figure 312: Schematic of LWV showing five key structural parts in color for IIHS frontal offset test

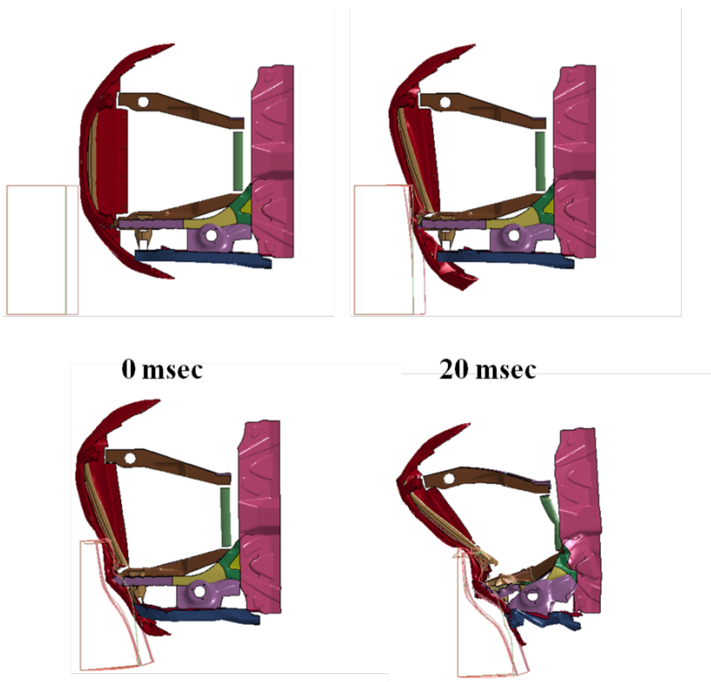


Figure 313: Crush of LWV five key structural parts over the time of the IIHS frontal offset test

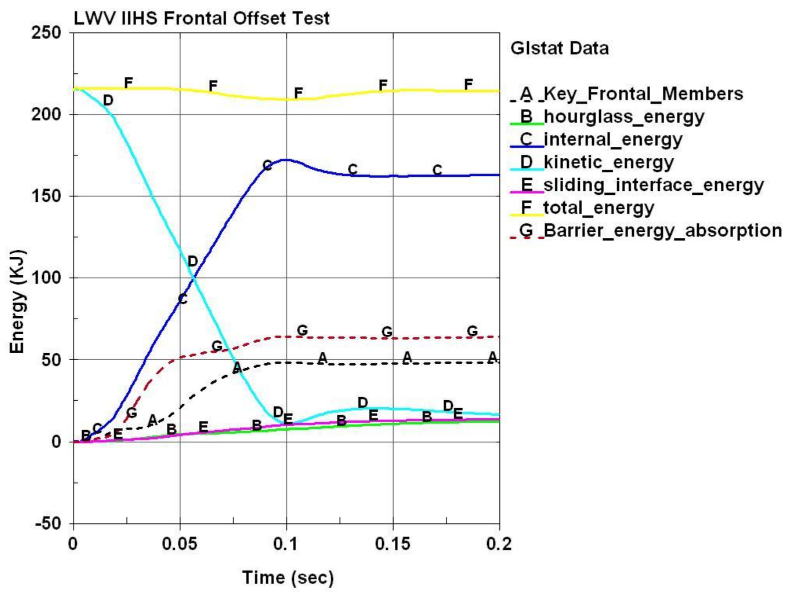


Figure 314: Energy absorbed by the LWV five key structural parts during the IIHS frontal offset test

A bottom view of the LWV is shown in Figure 315 and Figure 316. These two figures indicate there is no visible support of damage to the fuel tank after the crash test.

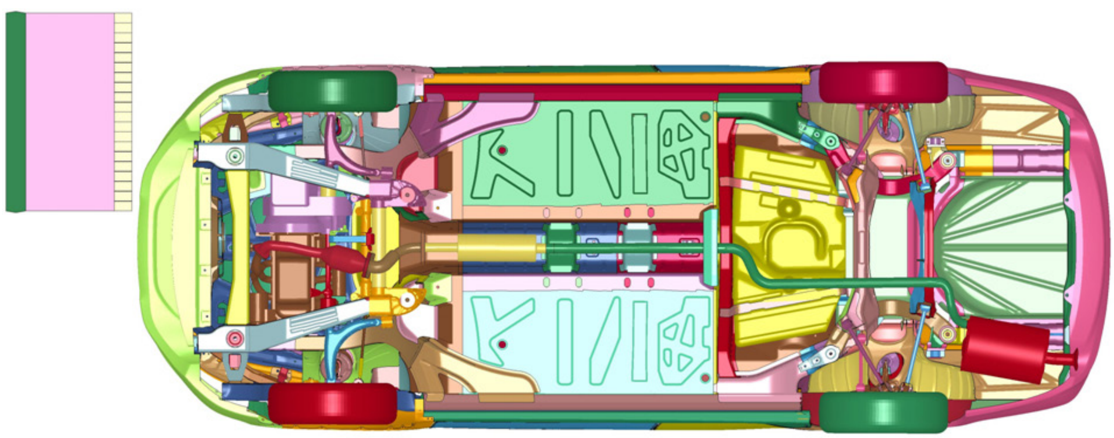


Figure 315: Bottom view of LWV before IIHS frontal offset test

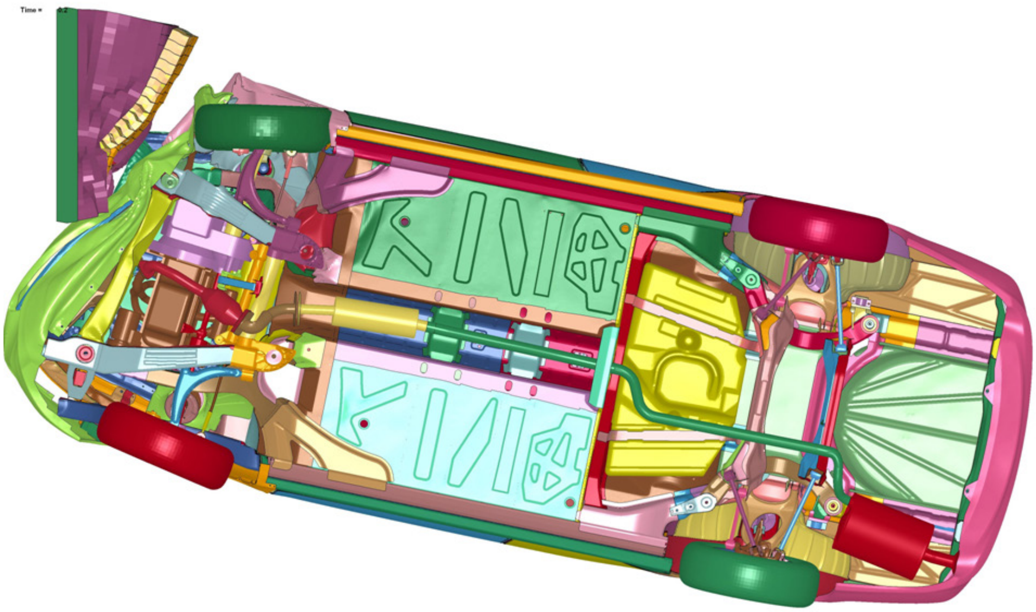


Figure 316: Bottom view of LWV after IIHS frontal offset test

6.10 FMVSS No. 301 Rear Impact Test

For due diligence, an additional rear-impact test was simulated with the LWV. This supplementary test is not among the six consumer information tests that are analyzed throughout this report. Federal Motor Vehicle Safety Standard (FMVSS) No. 301 specifies a rear-impact test. The rear-impact test is designed to promote the crashworthiness of the body structure and fuel tank. 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% as shown in Figure 317. The MDB used in the rear-impact test weighs 1380 kg.

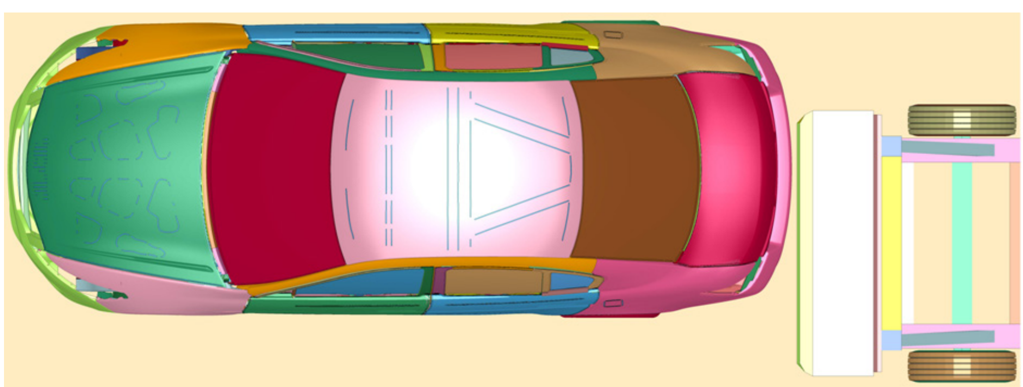


Figure 317: Test set up for FMVSS No. 301

The pre-test view of the back of the LWV is shown in Figure 318. Post-test views of the vehicle are presented in Figure 319 and Figure 320. These two figures indicate there is no visible damage to the fuel tank after the rear-impact crash test.

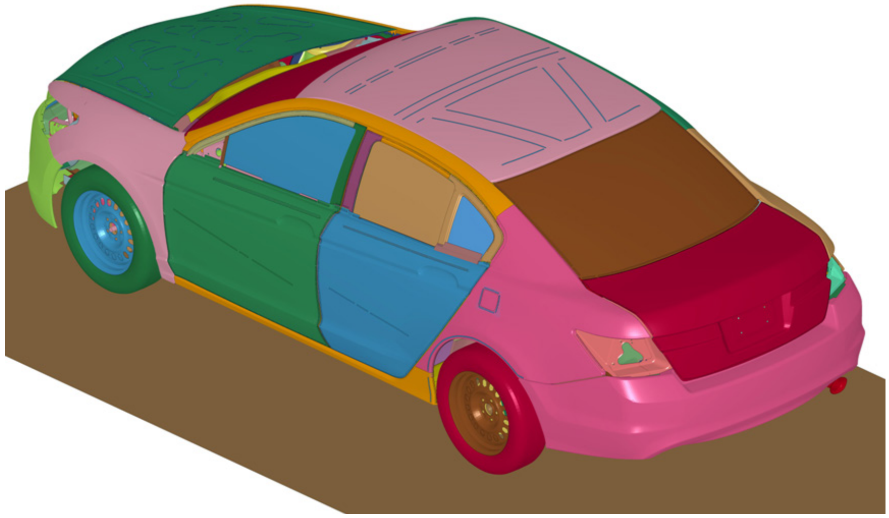


Figure 318: Pre-test view of rear of LWV

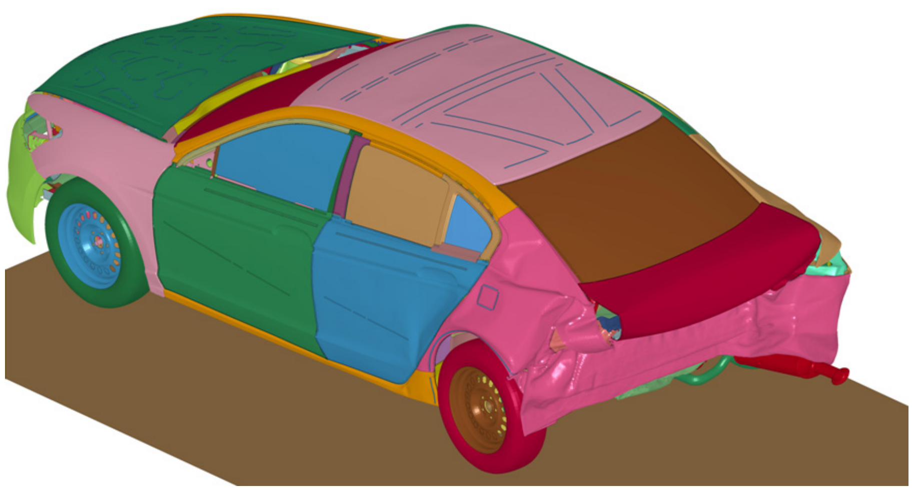


Figure 319: Isometric view of rear of LWV after FMVSS No. 301 test

Figure 320: Bottom view of LWV after FMVSS No. 301 test

6.11 Summary of Crash Simulation Results

Figure 321 summarizes the crashworthiness comparison of the LWV with the safety rating of the MY2011 baseline Honda Accord. Based on the seven crash tests, the overall safety performance of the LWV model is "good," which is comparable to the safety rating of the baseline MY2011 Honda Accord.

For the NCAP frontal test, the acceleration versus time curves are similar. To reduce the level of intrusion into the occupant compartment, the front structure of the LWV had to be designed to be soft in order to crush and absorb energy in front of the firewall. The intrusion into the occupant compartment of the LWV is minuscule. In the NCAP side barrier test, the intrusion of the LWV is slightly higher than the baseline 2001 Honda Accord near the driver space, but both vehicles satisfy the requirements for a "good" safety rating. In the NCAP pole test, the LWV is the same as the baseline 2011 Honda Accord in terms of intrusion. For the IIHS roof crush test, the LWV satisfies the requirements for a better safety rating compared to the baseline 2011 Honda Accord. In the IIHS side barrier test, the LWV responded the same and satisfied the requirements for the same safety rating as the baseline 2011 Honda Accord. In the IIHS frontal test, the LWV had similar acceleration and velocity as the baseline 2011 Honda Accord. In the IIHS frontal test, the LWV had minutely higher intrusion, but was well within the "good" region. In the FMVSS No. 301 test, the fuel tank of the LWV appeared to be uncrushed.

Structural Response of the LWV		
Test	**Dynamic**	**Static**
NCAP frontal	Acceleration magnitude and the pulse time width are similar to the baseline Honda Accord. For airbag deployment the average acceleration during 0.005 to 0.015 seconds is -8.5G's	Comparable to baseline Honda Accord
NCAP side with moving deformable barrier	The velocity at the CG and B-Pillar interior intrusion values of the LWV are similar to the values of the baseline vehicle.	Comparable to baseline Honda Accord and in the "good" range for IIHS rating scheme
NCAP pole	Comparable to the baseline Honda Accord	Comparable to the baseline Honda Accord
IIHS roof crush	Strictly a static test and not a dynamic examination	Comparable to the baseline Honda Accord and LWV in "good" range
IIHS side with moving deformable barrier	Comparable to the baseline Honda Accord	Comparable to the baseline Honda Accord
IIHS 40% offset frontal	Acceleration about same magnitude as the Honda Crosstour and the pulse time width is about the same as the pulse width of the Honda Crosstour	Comparable to the Honda Crosstour and in the "good" range for IIHS rating scheme
FMVSS No. 301 Rear Impact Test	Meaningful comparison not possible since no rear impact tests have been run on the baseline Honda Accord	Fuel leakage unlikely because fuel system was not damaged

Figure 321: Comparison of safety performance of LWV with safety of Honda Accord

6.12 Weight Impacts of Future Required Safety Standards

The National Highway Traffic Safety Administration (NHTSA) has issued the following safety standards that become effective for passenger cars and light trucks between MY 2008 and MY 2018.

1. FMVSS 126, Electronic Stability Control
2. FMVSS 202a, Head Restraints
3. FMVSS 206, Door Locks
4. FMVSS 208, 5th Female 35 mph Tests
5. FMVSS 214, Side Impact Oblique Pole Test
6. FMVSS 216, Roof Crush
7. FMVSS 226, Ejection Mitigation
8. FMVSS 301, Fuel System Integrity

Figure 322 below indicates the NHTSA estimated mass for each of the requirements. The LWV is designed to meet most of the requirements as shown in Figure 322.

S No.	Final Rules By FMVSS No.	NHTSA Estimate for Passenger Cars Added Weight (kg)	LWV Additional Mass (kg)
1	126 ESC	.96	0.00
2	202a Head Restraint	.27	0.00
3	206 Door locks	0.0	0.00
4	208 5th Female 35 mph Test	0.0	0.00
5	214 Side Pole Test	5.64	0.00
6	216 Roof Crush	5.28	0.00
7	226 Ejection Mitigation	.91	0.91
8	301 Fuel Tank	.50	0.00
	Final Rule Subtotal	**13.56**	**0.91**

Figure 322: Final Rules by FMVSS Number

Figure 323 below shows the weight impacts of proposed or potential rules that may become effective for MY 2017 and later vehicles. There is no guarantee that these requirements will become final rules.

1. FMVSS 111, Rear Visibility (Cameras)
2. Pedestrian Protection
3. Forward Collision Warning and Crash Imminent Braking
4. Lane Departure Warning
5. Oblique/Low Offset Frontal Collision
6. Event Data Recorders (EDR)

S No.	Potential Rules	NHTSA Estimate for Passenger Cars Added Weight (kg)	LWV Additional Mass (kg)
1	111 Rear Cameras	.19	0.19
2	Pedestrian Protection	9.07	9.07
3	Forward Collision Warning	.91	0.91
4	Lane Departure Warning	.91	0.91
5	Oblique/Offset Frontal	9.07-18.14	9.07-18.14
6	Part 563 EDR	.45	0.45
	Potential Rules Subtotal	**20.60-29.67**	**20.60 – 29.67**

Figure 323: Potential Future Rules

The additional mass impact of the FMVSS 226 Ejection Mitigation rule of 0.91 kg (Figure 323) and 20.60 to 29.67 kg for the future potential rules shown in Figure 323 are not fully accounted for in the LWV design. The Curb Vehicle Weight (CVW) of the LWV crash analysis model is 1,150 kg versus the LWV bill of material mass of 1,148 kg. Therefore only 2.00 kg mass can be applied toward these requirements. No computer modeling was done to simulate the Oblique/Offset Frontal impact as part of this study.

7 Manufacturing

The manufacture of a vehicle Body-In-White (BIW) that includes the body structure, closures and hang-on parts 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. The LWV follows an assembly process that is common within the major OEMs and is considered to be main-stream. This section gives an overview of the technologies that have been considered for the manufacture of the LWV for the year 2020. The topics include:

- Material and manufacturing technologies overview and maturity
- Manufacturing and Assembly Technologies
  - Stamping technology
  - Joining technologies (spot & laser welding and adhesives)

7.1 Material and Manufacturing Technologies Overview and Maturity

For this study, the choices for materials with their corresponding manufacturing technologies were reviewed for availability and readiness for high volume production for model year 2020. The materials considered include:

- Steel
- Aluminum
- Magnesium
- Plastics
- Composites.

The suitability and maturity of each material for major vehicles systems, body structure, closures, chassis and powertrain is shown in Figure 324 for the model year 2011 and model year 2020 time frame. Figure 325 shows the suitability and maturity of each material manufacturing assembly technologies for major vehicles systems, such as the body structure, closures, chassis and powertrain for the model year 2011 and model year 2020 time frame

In this study, manufacturing and assembly technologies are classified as:

- **Mature (M)** – Mature technologies are those materials and manufacturing technologies that are currently suitable for high volume production (200,000 plus products per year).
- **Mid-Term (MT)** – 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 model year 2020.
- **Long Term (LT) –** 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. For higher production volumes an affordable cost for the material and technologies has to be developed to take advantage of these long term technologies.

Manufacturing & Materials Technologies

		Body Structure 2011	Body Structure 2020	Closures 2011	Closures 2020	Chassis, Engine, Transmission 2011	Chassis, Engine, Transmission 2020
Steel	**Steel**	M	M	M	M	M	M
	Stamping	M	M	M	M	M	M
	Regular	M	M	M	M	M	M
	Laser Welded Blanks	M	M	M	M	M	M
	Tailor Rolled Blanks	M	M	M	M	M	M
	Hot Direct & In-Direct	M	M	M	M	M	M
	Roll Forming	M	M	M	M	M	M
	Hydroforming	M	M	M	M	M	M
	Forging					M	M
	Casting					M	M
	Powder Metal Technologies					M	M
Aluminum	**Aluminum**	MT	M	M	M	M	M
	Stamping	M	M	M	M	M	M
	Regular	M	M	M	M	M	M
	Laser Welded Blanks	M	M	M	M	M	M
	Super forming	LT	MT	LT	MT	LT	MT
	Roll forming	M	M	M	M	M	M
	Hydroforming	M	M	M	M	M	M
	Extrusion	M	M	M	M	M	M
	High Pressure Diecasting	M	M	M	M	M	M
	Forging	M	M	M	M	M	M
Magnesium	**Magnesium**	LT	MT	MT	M	MT	MT
	High Pressure Diecasting	LT	MT	MT	M	MT	MT
	Forgings			MT	MT	MT	MT
	Stamping			LT	LT	LT	LT
	Warm forming			LT	LT	LT	LT
Plastics	**Plastics**	M	M	M	M	M	M
	Injection Molding	M	M	M	M	M	M
	PolyPropylene (PP) + Glass	M	M	M	M	M	M
	Over Moulding (with insert)	MT	M	MT	M	MT	M
	Sheet Molding Compound (SMC)	MT	MT	M	M	M	M
Composites	**Composites**	LT	LT	LT	LT	LT	LT
	Fibre Glass Reinforced Plastic (FGRC)	LT	LT	LT	LT	LT	LT
	Carbon Fibre Reinforced Plastic (CFRC)	LT	LT	LT	LT	LT	LT
	Sheet Molding Compound (SMC)	LT	LT	LT	LT	LT	LT
	Resin Transfer Molding (RTM)	LT	LT	LT	LT	LT	LT

M - Mature	Available now for high volume production - cost reduction through time base learning
MT - Mid term	At present suitable for low volume (up to 50,000) production - for high volume require further development - cost reduction through technology improvement and learning
LT - Long Term	At present suitable for very low volume (up to 5,000) premium products - for high volumes require further development and significant cost reduction in material cost

Figure 324: Materials and Manufacturing Technologies Assessment

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 15 seconds. 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.

Aluminum-intensive body structures are produced by one of two main methods, either by stamping and welding of aluminum sheet to form a unibody structure, a process similar to a steel vehicle body, or by constructing a "space frame". An advantage of the stamped aluminum unibody 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. These stamped aluminum parts can also be manufactured in approximately 15 seconds each using the same stamping process as that for steel. The stamping cycle time is generally higher than a steel stamping partly due to aluminum having lower elongation than steel.

A space frame construction uses extruded aluminum profiles that are welded to cast aluminum nodes and then the stamped sheet aluminum outer skin is added. The aluminum space frame approach was pioneered by Audi for the A8 resulting from a ten year development program. While tooling costs are comparable to steel stamping tools, overall production volumes are limited due to the complexity of the assembly. This complexity is a result of needing multiple welding fixtures to complete the body structure.

Manufacturability is a critical issue with composites, particularly when used in a load bearing application. Composite manufacturing methods have been used in the aerospace industry for stressed member applications in limited volumes. No manufacturing methods for load-bearing structures have been developed yet that are suitable for automotive applications for volumes of 200,000 or more per year. A number of manufacturing issues must be resolved first to use composites for automotive applications. The main issue is being able to achieve a part manufacturing cycle time in the order of 60 seconds per part. Currently part cycle time for composites is approximately 15 minutes for the molding process while the cycle time for steel parts is only 15 seconds. For composite molded parts to be competitive against a steel part, an order of magnitude improvement to the part cycle time of the molding process will be needed. Presently technology to achieve this cycle time is not available.

		Body Structure		Closures		Chassis, Engine, Transmission	
		2011	2020	2011	2020	2011	2020
Manufacturing Assembly	Spot Welding	M	M	M	M		
	Laser Welding	M	M	MT	M	M	M
	MIG Welding	M	M	M	M	M	M
	Laser Brazing	M	M	M	M		
	Adhesive Bonding	MT	M	MT	MT		
	Mechanical Fastenings	MT	MT	MT	MT	M	M

Figure 325: Manufacturing Assembly Technologies Assessment

7.2 Manufacturing and Assembly Technologies Summary

This section summarizes the different manufacturing and assembly technologies used for the LWV body and closures. Specifically addressed are:

- Stamping Technology
- Joining Technology

7.2.1 Stamping Technology

Body-In-White (BIW) manufacture begin in the stamping shop where parts are produced using a number of different stamping presses, and uses materials of different properties , thicknesses and material coatings. Processes suitable for high volume production 200,000 per year are follows:

- Stamping (Stand alone, tandem and transfer press lines)
- Hot Stamping
- Roll forming

Various grades of sheet steel and aluminum material for these processes are available in the form of coils. These coils can be either:

- Single material
- Laser welded coils with different thicknesses and grades along the width
- Tailor rolled coils with varying thicknesses the length

These coils or sheet steel can be further processed into blanks and the following tubes or tubular products:

- Conventional blanks
- Tailor Rolled blanks (TRB)
- Laser Welded Blanks (LWB)

Figure 326 shows body structure parts made from Laser Welded Blanks.

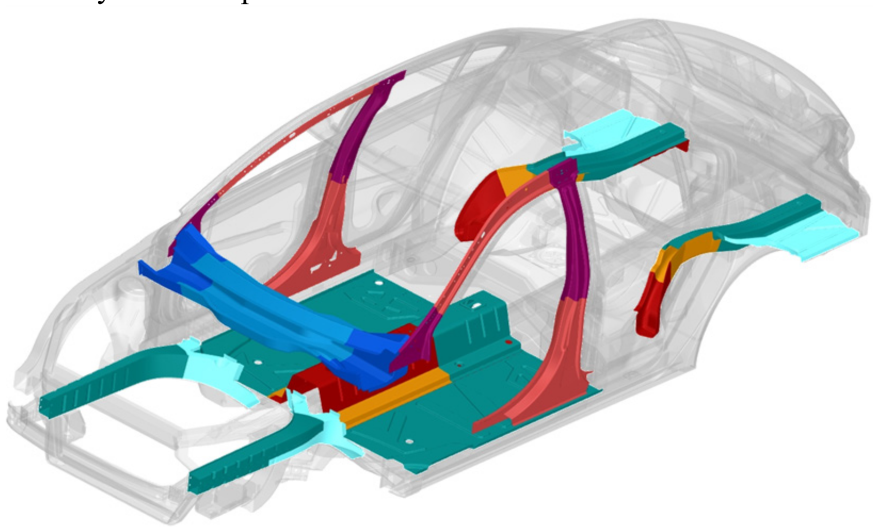


Figure 326: LWV Body Structure Stamped parts made from Laser Welded Blanks

7.2.1.1 Stamping Presses

The type of press used is generally determined by the part being produced, volume of production per year, and part material. The two types of presses are used in this study are:

- Conventional Stamping Presses
- Direct and In-Direct Hot Stamping Presses

Conventional stamping presses can also be classified according to three main drive mechanisms. These mechanisms are:

- Hydraulic
- Mechanical
- Servo

7.2.1.1.1 Conventional Stamping Presses

Hydraulic Press

Hydraulic presses use hydraulic cylinders to apply the stamping pressure and typically run at up to 200 strokes per minute. Unlike mechanical presses, hydraulic presses deliver full stamping force at any position in the stroke range, which gives greater flexibility in the stamping cycle than a mechanical press. Hydraulic press capacities range from 0 to around 10,000 tons with press strokes to 32 inches.

Mechanical Press

Mechanical stamping presses use flywheels, driven by motors, to produce the stamping force. Mechanical presses can operate at higher speeds than hydraulic presses at above 1,000 strokes per minute, but the press strokes are shorter than hydraulic presses due to the fact that full force develops in a mechanical press at the end of the press stroke. With their high-speed capability, mechanical presses are used for high volume stampings where the parts are relatively flat with shallow draw depths. Mechanical press capacities range from 20 to about 6,500 tons, with press strokes to 20 in. A mechanical press can be either of a single or dual-action type.

Servo Presses

The use of servo-driven presses is becoming more common. Servo presses, technically classed as mechanical presses, employ servo drives to provide power, eliminating the need for flywheels. Advantages of servo presses include the ability to control the stamping press stroke length and the speed of the stroke. Servo presses also allow for a dwell time at the bottom of a press stroke, which is ideal when material must be given time to flow into a part shape. This feature gives servo press the benefits of both mechanical and hydraulic presses, providing flexibility to the manufacturer. Servo press tonnage can be up to 3,000 ton with a typical press stroke up to 28 inches.

7.2.1.2 Direct and In-Direct Hot Stamping Presses

The hot stamping process is used to manufacture parts that use ultra-high-strength steels (UHSS) up to 1500 MPa by either a direct or indirect hot stamping process. Due to the high strength material used for these parts and reduced material elongation using a conventional stamping process is not possible. The direct hot stamping process, as shown in Figure 327 uses blanks heated in a continuous feed furnace to temperatures between 900 and 950°C. During this heating process an austenitic material structure is formed. Blanks are then transferred to a stamping die to form the correct geometry; minimal stamping operations can be completed in the hot stamping die other than forming. After the forming process has been completed, the die is then rapidly cooled while the die remains shut to quench/cool the part transforming it into a martensitic steel with a tensile strength of up to 1500 MPa. The part is then removed from the die and de-scaled using a media-blast process. The holes and trim edges are then laser cut.

Figure 327: Hot stamping process

Indirect hot stamping, while similar to direct hot stamping, has an additional operation to complete the part stamping process. The part is first stamped using a conventional cold stamping process where up to 100% of the part's final geometry is produced, including holes, slots, and trim edges prior to transfer to a continuously feed furnace. The part is then transferred to the hot stamping die where the part is held to its final form and then rapidly cooled. During this operation there are minimal geometry changes to the part. As all the features are added to the part during the cold stamping stage, there are minimal to no post trimming operations. See Figure 328 for indirect hot stamping process.

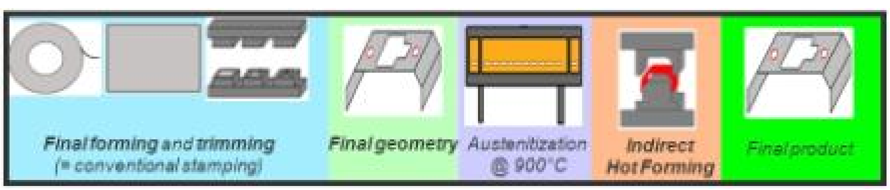


Figure 328: Indirect hot stamping process

Hot stamped parts used in the LWV body structure are shown Figure 329.

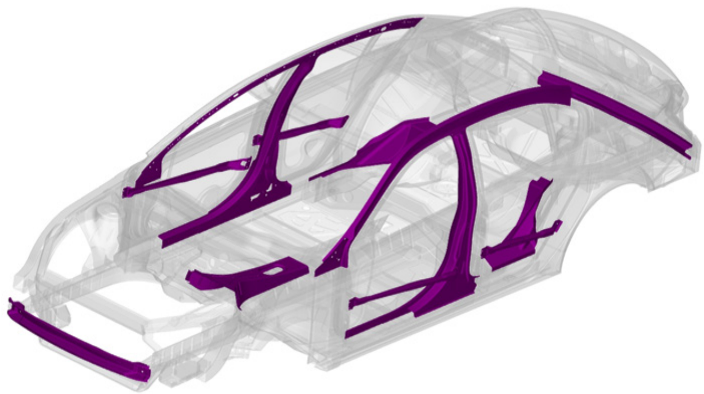


Figure 329: LWV Hot Stamped Body Panels

Oxidation of the part due to exposure to the ambient atmosphere may occur in both direct and indirect hot stamping processes. A de-scaling operation is necessary to remove this scale. High die wear may result due to the extreme hardness of the scale and movement of the part in the die during the stamping and cooling process. Coatings can be employed for certain steels to reduce scaling and extend the lifetime of the forming dies.

Stand Alone Stamping Press

A single stand-alone press has a single die where parts with simple geometry or limited stamping operations are produced. The part material would be coil fed into the die, with the final parts either automatically unloaded or fall unassisted in to a parts bin. Standalone presses are also used in a progressive stamping die configuration where a coil strip is automatically fed into the die in sequence with the press stroke. This type of arrangement is also used as a blanking press to produce a blank that would then be utilized in either a tandem or transfer press line. See Figure 330 for a typical stamping press.

Figure 330: Typical stamping press

Tandem Stamping Press Line

As opposed to individual standalone press, where relative simple parts are produced, tandem press line refers to a line of individual presses where a single die in each press completes the processing of a part or parts from blank to finished stamping. Parts generally require a number of stamping operations, blanking, forming, pierce and trim to complete the part. See Figure 331 showing a typical part that is stamped in a tandem press line.

Figure 331: Typical part, B-Pillar inner lower, stamped in a tandem press line

Automation equipment is placed in between the separate presses to handle the transfer of the part from press to press; this can be either achieved by robot or a pick and place mechanism. See Figure 332 for a typical tandem press line.

Figure 332: Typical tandem press line

Transfer Press Line

Transfer lines are presses where a single press can hold a number of dies, allowing for the entire stamping process to be complete while the part remains in the single press. Most commonly these types of presses contain all the automation needed to transfer the part from one stamping station to the next. These presses normally have an automated die change system when the complete die sets can be changed typically in less than two minutes when a new part is required to be produced. See Figure 333 for a typical transfer press line.

Figure 333: Typical Transfer Press Line for a door inner panel.

Parts produced in this type of press are generally of the more complex type, for example a body side panel, or are of a larger size that cannot be accommodated in a tandem press line. See Figure 334 for typical parts that would be produced in a transfer press line.

Figure 334: Typical parts, Body Side outer panel and Door Inner panel that would be stamped using a transfer press line.

7.2.1.3 Roll Forming

Roll forming is a continuous forming process that produces a part with a constant profile. During the roll forming process a flat strip from a coil is continuously fed through either powered or unpowered metal forming stands that carry a series of upper and lower rollers gradually forming the part to the required profile in a step-by-step rolling process. After the part is fully formed it is cut to the desired length. This gives the roll forming process very little scrap compared to other stamping methods. The part can be of an open or closed profile. In the case of a closed profile, an edge welding operation is added by using either high frequency or a laser welding process. Figure 335 shows the roll formed parts used on the LWV body structure.

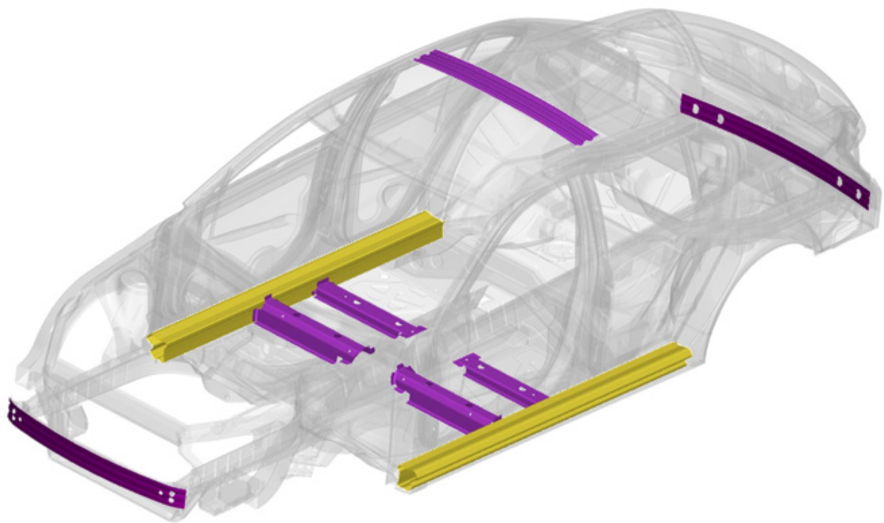


Figure 335: Rolled formed parts used on the LWV

The part can be bent at the end of the forming process, using rollers with differential pressures, into a curve. Holes and slots can also be added prior to the coil entering the forming rollers. The typical step-by-step process for roll forming consists of:

1. Uncoiler
2. Hydraulic hole & notch punch
3. Roll forming main machine
4. Straightener
5. Automatic cutting station
6. Control System
7. Product unload station

See Figure 336 for the roll forming process.

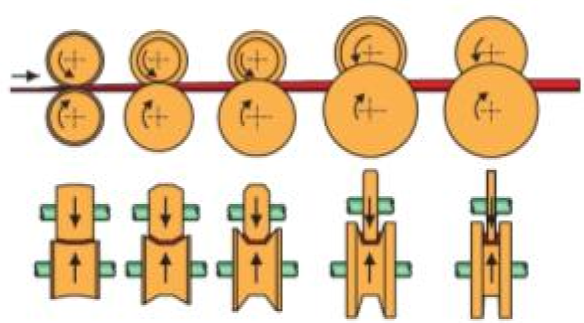


Figure 336: Roll forming process

See Figure 337 for typical roll forming machine.

Figure 337: Typical roll forming machine

7.2.2 Joining Technology

Integral to the manufacture of the LWV body structure and closures is the individual part and sub-assembly joining methods. These processes will impact the assembly sequence and the manufacturing equipment used. There are a number of joining methods generally available to complete the body structure assembly. Figure 338 shows the joining methods available and those selected for the LWV.

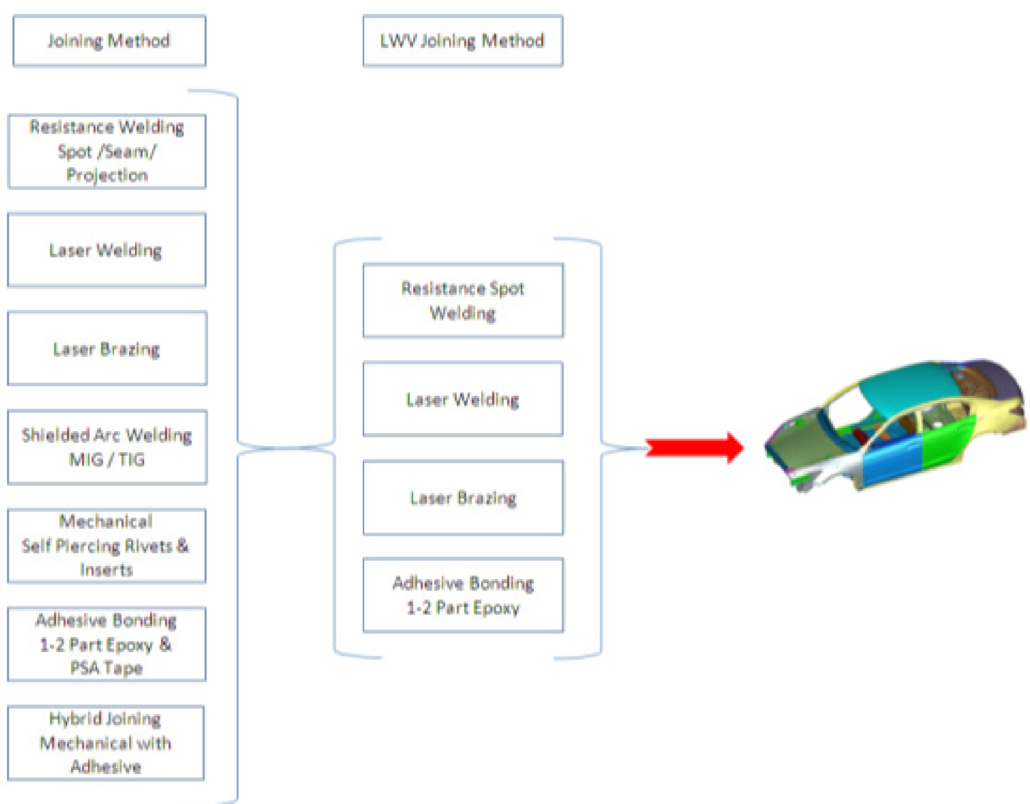


Figure 338: Light Weight Vehicle joining methods

From the seven available joining methods, four were selected for the LWV. The joining methods not selected include mechanical self-piercing rivets and inserts, hybrid joining mechanical with adhesive and shielded arc welding. Mechanical self-piercing rivets and inserts and hybrid joining mechanical with adhesive methods are generally used where the body structure is made from aluminum or other alloys, a combination of these. Shielded arc welding and MIG welding were also discounted as these are normally used in the framing station to weld the shot gun assembly to the body side. Normally the MIG welding of the shotgun to the body would be completed in its own ‘standalone’ welding station. This welding cell would require its own screens to eliminate the glare from the welding operation plus environmental measures that would be necessary, for fume extraction for example. When we use laser welding for this operation and combining the welding of the shotgun to the body in the same cell as the laser brazing of the roof panel these measures would not be necessary, as a laser cell by its nature requires a light-tight enclosure plus the laser operation being a clean welding process fume extraction is not required.

Laser welding and brazing was selected due to anticipated growth of this technology up to the year 2020. Laser welding also gives the opportunity to reduce the welding flange width, thereby saving weight. Laser welding also has the advantage of adding stiffness therefore improving of the performance of the body structure.

7.2.2.1 Resistance Spot Welding

The majority of the body structure, closures and hang-on parts utilize spot welding as the joining method via robot mounted spot welding equipment. Generally speaking when using resistance spot welding as the joining method, the weld flange is considered to be in the order of 16 mm in width. This allows for the weld tip and clearance between the weld shank and the adjacent part. See Figure 339 for spot weld flange condition.

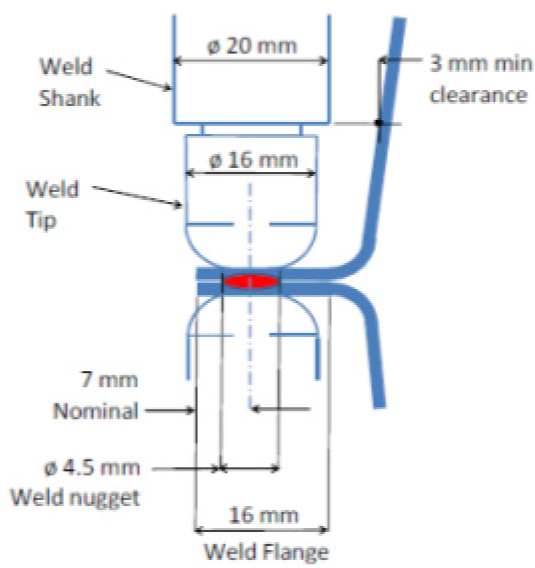


Figure 339: Spot weld flange requirements

Laser welding was used in certain conditions where weld gun access is considered an issue due to part geometry restricting the space available for the weld gun to complete the welding operation or when joining parts to a closed structure. For example, this is true for welding the body side to the roll formed rocker. If spot welding was considered for these conditions a single-sided spot weld operation would be needed. This would add complexity to the tooling due to a backing ‘copper’ electrode that would need to be added to the assembly station. As laser welding is a single sided operation and does not require backing copper or additional equipment to complete the welding operation. Laser welding it is an ideal solution for welding parts to a closed profile or to solve the issue of reduced weld access when spot welding. When spot welding is used, care must be taken with the spacing of the spot weld between each other. When the weld spacing is 25 mm or lower, there is a high possibility that the weld current will “shunt” between the weld being made and the adjacent weld resulting in a weld of poor quality and reduced strength. Laser welding does not have this issue.

The spot welds used to assemble the LWV body structure are shown Figure 340.

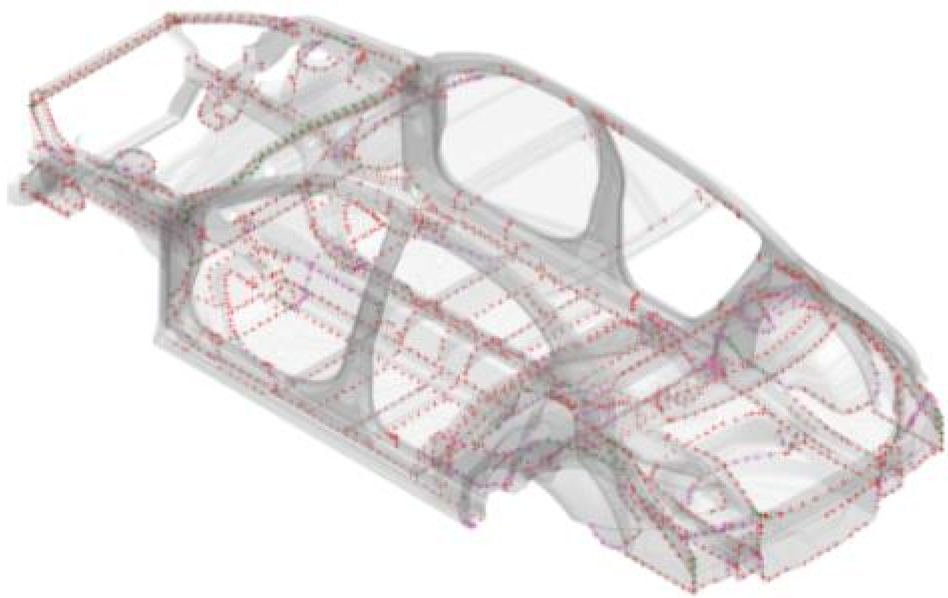


Figure 340: Body structure spot welds

7.2.2.2 Laser Welding

With the growing usage of laser welding by the worlds OEMs, particularly in Europe, along with the growing interest in welding high strength steels, laser welding has become a viable alternative to spot welding. The development of remote laser welding offers greater flexibility over conventional laser welding. In a conventional laser welding configuration the laser welding unit is located on the robot head, the robot arm is repositioned and moves for each weld. Remote laser welding involves a laser welding head either mounted on a robot arm or a gantry or changing the focusing optics to position the laser independent to the position of the laser welding head.

The remote laser head can be positioned up to 500 mm above the part and can make a weld of approximately 150 mm before the need to reposition the welding head. This gives higher positioning speeds and allows greater access to the part than when using a conventional laser welding arrangement. Laser welding also eliminates many clearance issues that occur with spot welding as the laser head is located up to 500 mm above the part being welded. To achieve a good quality spot weld the welding tip needs to be perpendicular to the weld flange, this is not required when remote laser welding is used.

Figure 341 shows a remote laser welding head. By using a diode laser the light source can be remotely located from the laser welding cell. This could be next to the laser welding cells or even in a different building. The laser beam is delivered from a single source to up to four separate laser welding cells via fiber optic cables. This is achieved by using a switching device that directs the beam to individual stations by sequencing each welding station's weld cycle times.

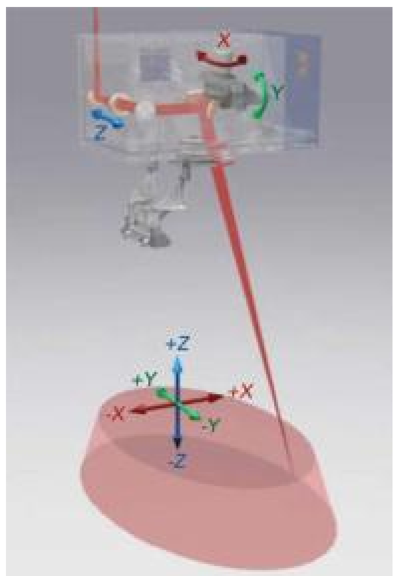


Figure 341: Remote laser optics and work area

The weld flange requirements are different when laser welding than those needed for spot welding. The flange width can be reduced from a nominal 16 mm required for spot welding to an 8 mm width using laser welding, giving substantial weight savings. See Figure 342 for weld flange comparison of spot weld versus laser welding. See Figure 343 for weld flange requirements for laser welding.

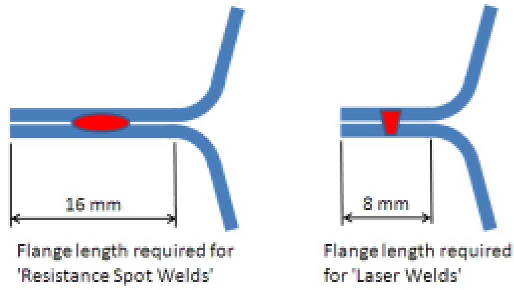


Figure 342: Weld flange comparison spot welding vs. laser welding

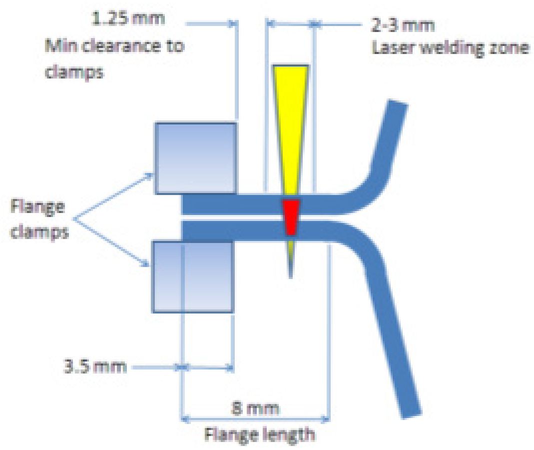


Figure 343: Flange requirements for laser welding

In addition to flange width reduction there is also a space saving of up to 50% when you consider the body shop assembly area floor foot print. This is a result of a laser welding unit being able to replace a number of spot welding robots saving floor space. See Figure 344 for a typical spot-weld assembly station versus a laser welding station.

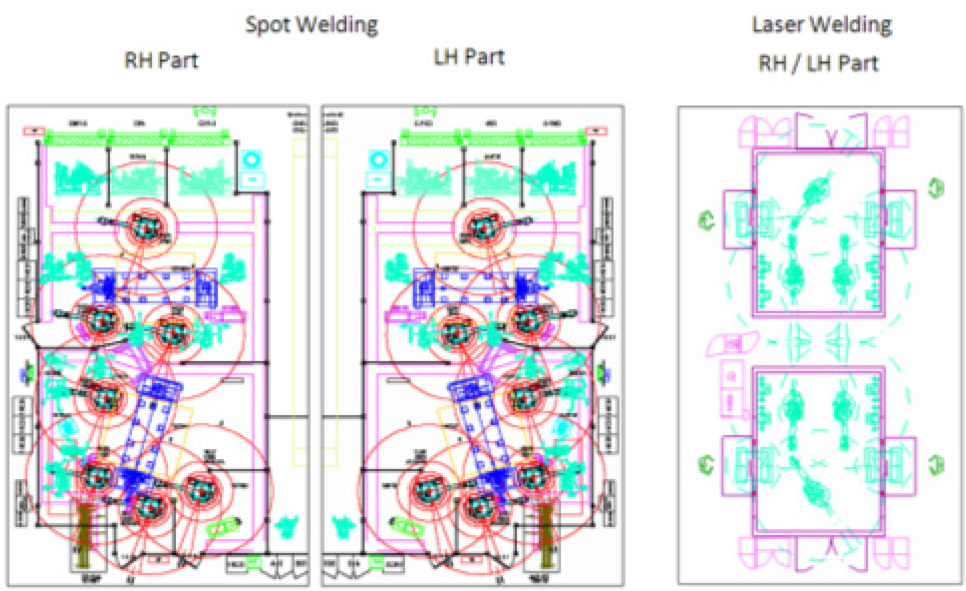


Figure 344: Spot welding cell v. laser welding cell

7.2.2.3 Advantages of laser welding vs. spot welding

With remote laser welding the laser beam is positioned by internal optics with remote laser welding and not by the robot as in spot welding. This gives higher welding speeds than spot welding. Typically a single spot weld is completed in approximately three seconds. This includes the positioning of the weld gun to the part being welded, weld tip clamping and unclamping and performing the spot weld which is dependent on the materials being welded, weld parameters, panel thickness and material stack-up. For example, the process to complete these 10 spot welds for a part would require approximately 30 seconds not accounting for robot repositioning between spot welds using a single spot welding robot. Using a typical spot weld spacing of 45 mm, this will result in a distance of 405 mm between the first and last spot weld. 405 mm of continuous laser welding can be completed in approximately five seconds with a laser welding speed of 80 mm per second. This clearly demonstrated how laser welding has a weld cycle time advantage over spot welding.

Other advantages of laser welding over spot welding include:

- High positioning speeds
- High welding speeds
- Minimal part distortion
- Localized heat impact
- Precise placement of weld
- Weld depth control
- Flexibility in programming
- Non-contact process
- Single side access
- Reduction in weld flange width

The LWV body structure laser welding is shown in Figure 345.

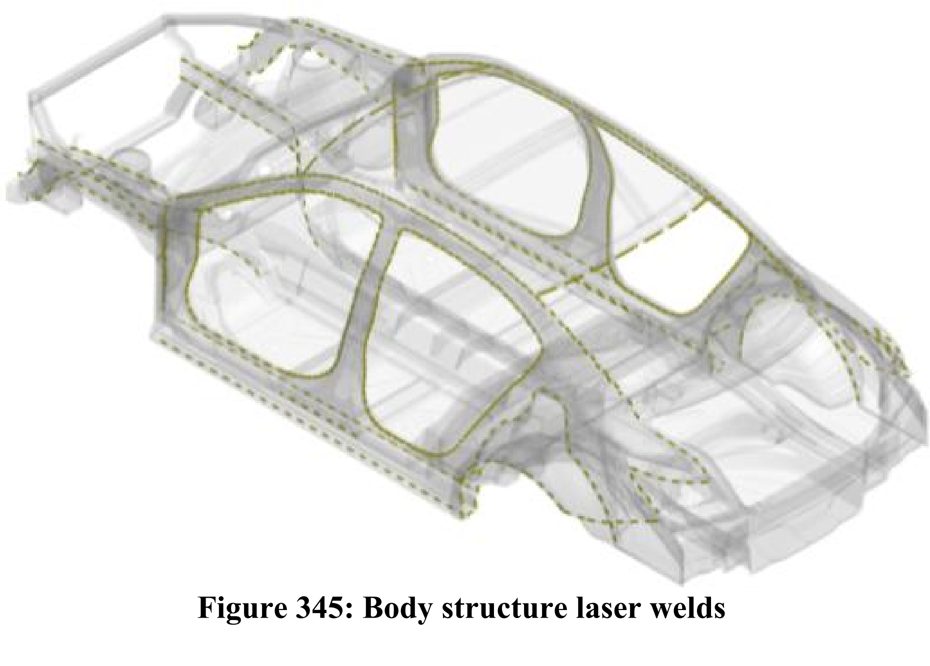


Figure 345: Body structure laser welds

A separate study was conducted by the team to compare the mass savings and costs associated with converting the assembly of body structure from a resistance spot welding joining process, to laser welding joining process. This study is discussed further in Chapter 10.

7.2.2.4 Laser Brazing

Laser brazing of the roof panel to the body side is bcomming more common with the major OEMs adopting this process. The LWV also followed this approach, which also gives the added advantage of eliminating the need for a roof ditch molding.

The joint geometry of the LWV's roof panel and body side have been engineered for a laser brazing application were the filler wire can be 'guided' along the joint gap between the roof and body side. The filler wire used is dependant on the part materials that are to be brazed together withthe most common material being a copper-based alloy with a melting point of between 900 and 1025°C. The melting of the filler wire is caused by the laser beam which also locally heats the surrouding part area which is necessary to complete the brazing process.

The correct positioning of both the laser beam and the filler wire to the joint gap is critical to prevent a one sided joint connection resulting in poor weld quality. The laser beam has a diameter of approximately 2 to3 mm and the filler wire has a 1 mm diameter. Laterial misalignment of the laser beam of just 0.3 mm can result in joint failures. One method used to correct this issue is to use a self-tracking laser head where the laser beam and wire feed are controlled by guiding optical sensors that continuously give feed-back to the positioning of the laser head maintaining the correct laser alignment and wire feed to the roof to body joint. See Figure 346 for laser-braze application of roof to body side.

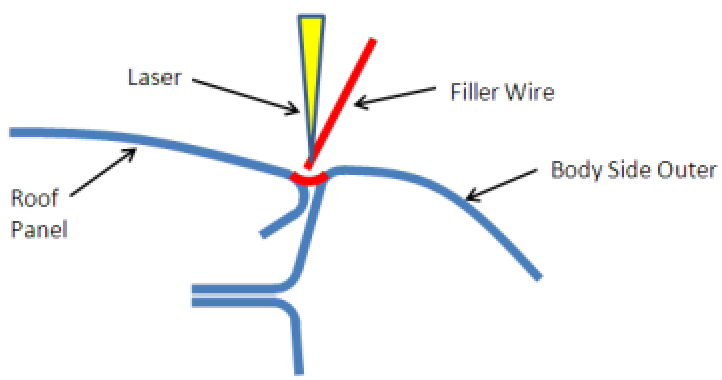


Figure 346: Typical laser braze application roof to body side

7.2.2.5 Adhesive Bonding

Three types of adhesives are envisaged for the LWV, including:

- Structure adhesive
- Anti-flutter adhesive
- Hem adhesive

Structural Adhesive

Structural adhesive is used to improve impact resistance, stiffness, noise vibration and harshness (NVH), performance and durability of the body structure. Adhesive is added to the body structure in the LWV design for this study. The type of structural adhesive considered is a one part curable epoxy based impact resistance adhesive. This adhesive can be used with electro-galvanized, hot dipped galvanized, galvannealed and uncoated steel. The adhesive is weld-through capable and will reach its maximum strength during the paint process when heat cured in the electro-coat bake oven that operates at temperatures between 155° and 190°C.

For optimum adhesion, the adhesive must thoroughly 'wet out' to the surface to be bonded. "Wetting out" means the adhesive flows and covers a surface to maximize the contact area and the attractive forces between the adhesive and bonding surface. For structural adhesive a flange with of 16 mm is recommended to allow for the desired 10 mm wide 'wet-out' area. See Figure 347for flange requirements for structural adhesive.

When adding structural adhesive, the spacing of the spot welds along the adhesive flange can be increased from a nominal spacing of 40 mm to up to 100 mm depending on the part geometry. The ideal joint conditions for structural adhesive requires a small gap of 0.2 to0.5 mm between parts. This gap can be achieved by a dimpling operation or by adding small depressions along the adhesive flange during the part stamping process. From the design data it has been determined that 7296 mm of structural adhesive is used for the LWV body structure.

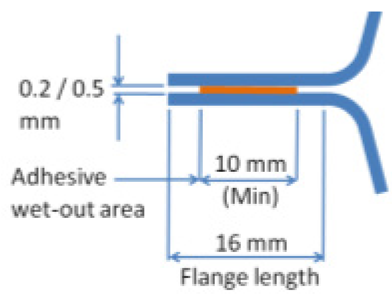


Figure 347: Flange requirements for structural adhesive

Anti-flutter Adhesive

Anti-flutter adhesive is used on the upper structure, doors, hood and decklid to improve stiffness and NVH performance. The anti-flutter adhesive selected is a cold-applied, pumpable adhesive designed to expand when subjected to heat to form a soft closed-cell foam. This is applied to the front and rear headers, roof bows between the roof panel, between the inner and outer panels of the hood and decklid and between the outer panels and side intrusion beams in the doors. This adhesive is applied during the assembly process of the body structure and the closures. The anti-flutter adhesive remains in its green state until the paint process were it cures in the electro-coat bake oven at temperatures between 155° and 190°C to create a closed cell form. Typically this will result in an approximate 30% expansion. Higher expansion rates can be achieved by selecting an adhesive for specific application, for example to seal a gap between two adjacent panels resulting from the assembly process. See Figure 348 for anti-flutter adhesive used between front-rear headers and roof bows and the roof panel before and after heat curing. Anti-flutter adhesive used on the LWV body structure totals 8957 mm.

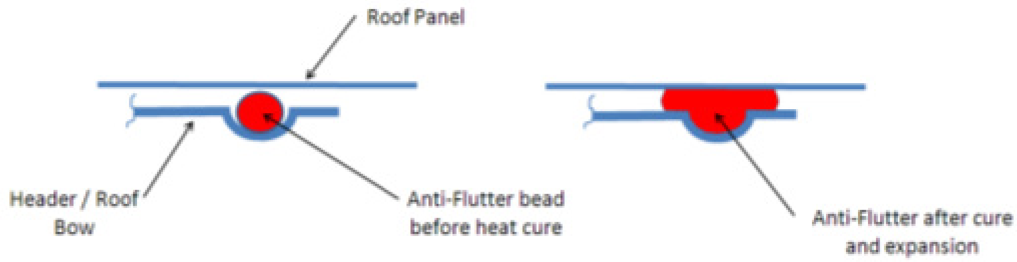


Figure 348: Anti-flutter adhesive used on the LWV body structure

Figure 349 shows the application of structural and anti-flutter adhesive used on the LWV.

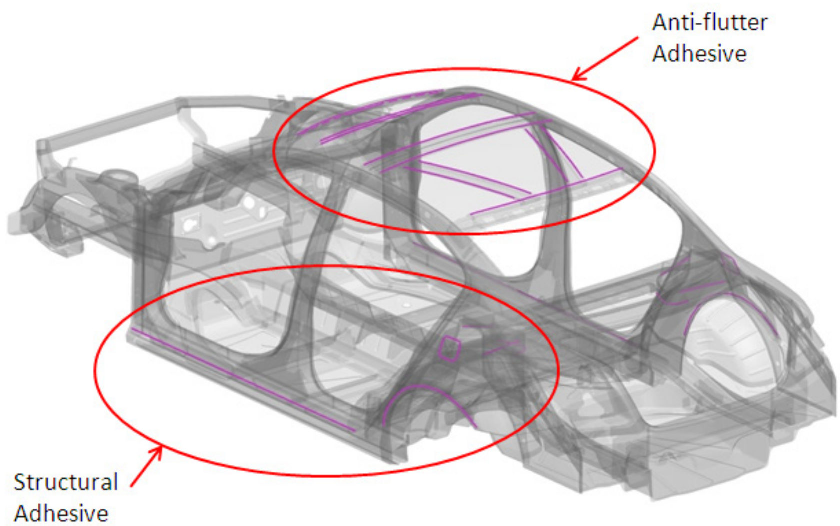


Figure 349: Application of structural and anti-flutter adhesive on the LVW body structure

Hem Adhesive

Hem adhesive is applied between the inner and outer panels of the LVW doors, hood, decklid and fuel filler flap prior to the roller hemming operation. The adhesive is a two-part epoxy formulated specifically for steel hem flanges featuring low activation temperatures to minimize panel distortion and is cured during the paint process in the electro-coat bake oven to create closed cell foam. See Figure 350 for hem adhesive application.

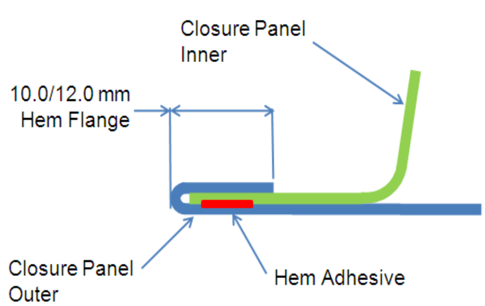


Figure 350: Typical hem adhesive application

From the LWV design data it was determined that the closures have approximately 18,067 mm of hem adhesive. This is broken down to:

- Front Door Lh/Rh 4874 mm
- Rear Door Lh/Rh 4120 mm
- Hood 4878 mm
- Decklid 3727 mm
- Fuel Filler Flap 468 mm

Joining Method Summary

The number of spot welds and length of laser welds used for the LWV body structure and closures is shown in Figure 351 and Figure 352 below.

Major Sub-system	# Spot Welds	Laser Weld/ Braze (mm)	MIG Welding (mm)
Body Structure	1859	43,850	
Framing Station	954	6,770	
Closures	281		
Hang-on Parts	177		840
Total	3271	50,620	840

Figure 351: Body-In-White major sub-system welding

Sub-system	# Spot Welds	Laser Weld (mm)	MIG (mm)
Framing Station	954	6,770	
Front Structure	773	8144	
Rear Floor	437		
Front Floor	258		
Body Side Lh	119	17,853	
Body Side Rh	119	17,853	
Package Tray	94		
Rear Bumper	80		480
Front Bumper	62		360
Front Door Lh	60		
Front Door Rh	60		
Back Panel	59		
Rear Door Lh	56		
Rear Door Rh	56		
Hood	37		
Battery Tray	14		
Decklid	12		
Front Fender Lh	9		
Front Fender Rh	9		
Fuel Door	3		
Roof Structure	Framing Station		
Total	3271	50,620	840

Figure 352: Body-In-White welds per sub-system

Further detailed assembly information - block diagrams and illustrations for all of the sub-assemblies plus the vehicle framing line can be seen in Appendix D, including those in the lists below.

The LWV body structure includes the following sub-assemblies:

- Front Structure
- Front Floor
- Rear Floor
- Rear Back Panel
- Package Tray
- Body Side Lh/Rh
- Upper Roof Structure and Shotgun Outer Lh/Rh

Closures would include:

- Hood
- Front Doors Lh/Rh
- Rear Doors Lh/Rh
- Decklid

Hang-on parts for the LWV include:

- Front Fenders Lh/Rh
- Battery Tray
- Fuel Filler Door
- Bumper Beam Front/Rear
- Cross member Rear Tunnel

8 Mass Reduction for Other Light-duty Vehicles (Optional Task 1)

8.1 Introduction

The mass reduction technologies evaluated for the LWV were judiciously applied to other light-duty passenger vehicles to estimate the mass reduction while still maintaining the vehicle size, performance and functionality. This assessment was done for the following light-duty vehicles classes:

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

The chosen mass reduction technologies are feasible within the time frame of model years 2017 to 2025 and would be available across the passenger car and light-truck vehicle fleet. Further to the introduction of weight saving technologies consideration was also given to supplier capabilities to deliver these mass saving measures to the automotive industry 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. Pick representative vehicle for each vehicle subclass using A2Mac1 database;
3. Calculate average vehicle metrics for each vehicle subclasses;
4. Apply appropriate light weighting technologies used in the midsize passenger car study as discussed in Chapter 5 to each representative vehicle and calculate vehicle mass reduction amount.
5. The calculated mass reduction percentage is then applied to the '2010 Class Average'[177][178]to estimate the '2020 Class Average'.

8.2 Analytical Approach

The options for light weighting technologies and the solutions applied to LWV are fully discussed in Section 5 of this report. Suitable choice of materials and manufacturing technologies based on the lessons learned from the LWV program were applied to each class of vehicles. It

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[177]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: http://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/2017-25_CAFE_Joint_TSD_Compiled_Signature_Version_11162011b.pdf.

[178]"2010 Class Average" is the average for vehicles listed in NHTSA's 2010 market data file for MY2017-2020 NPRM analysis.

must be noted that the amount of percentage mass reductions determined for the LWV are not applied exactly 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 for the LWV an iron/steel part is replaced with an aluminum part, the percentage mass reduction is likely to be significantly high and this high value cannot be applied to the vehicle system if it is already made from aluminum. Each sub-system was reviewed by the team and a suitable mass reduction was determined and applied to each system. To maintain the performance of the selected vehicles, engine, powertrain, and fuel system were resized using the mass compounding. For every one kg saving in vehicle GVW the powertrain mass is reduced by 0.21 kg (see Section 9 of this report). The sub-system content and weights, for each selected vehicle within a vehicle sub-class was obtained from A2Mac1 benchmark database.

The baseline vehicles used for each sub-class are either available in Europe or in the United States. The benchmark data used in this study for some of the vehicles uses the European version of the vehicle. Due to additional safety measures necessary for the US market the US version of these vehicles tend to have a greater weight than the European version. Sub-systems affected by these additional measures include the body side structure for side impact crash requirements and the front and rear doors. This additional weight has not been taken into account when determining the mass reduction system by system. However the calculated percentage reduction applied to the '2010 Class Average' to determine the '2020 Class Average' should be representative and accurate estimation.

The average values for the vehicle length, width, wheel-base, track (front, Rear) and curve weight as shown in Figure 355 (and other similar Figures for the other classes) represent the '2010 Class Averages' calculated for the total number of vehicles in each class (NHTSA 2010 File). The exception to this is the annual sales average volume, which is calculated just for the vehicles.

Vehicle sub-systems that were considered for weight reduction are:

1. Body Structure (Minus paint, sealer & 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)
8. Front Bumper Beam
9. Front Fascia (Minus bumper beam)

10. Bumpers Rear (Complete)
11. Rear Bumper Beam
12. Rear Fascia (Minus bumper beam)
13. Front Suspension (Complete with-out damper)
    a. Frame
    b. Suspension Arms Lh/Rh
    c. Knuckle Lh/Rh
    d. Spring damper Front Lh/Rh
14. Rear Suspension (Complete with-out damper)
    a. Frame
    b. Suspension Arms Lh/Rh
    c. Spring Damper Rear Lh/Rh
15. Engine/Transmission
    a. Engine
    b. Engine Oil
    c. Transmission
    d. Transmission Fluid
16. Drive Shafts Lh/Rh
17. Exhaust System
18. Fuel System
    a. Fuel
19. Wheels
    a. Rim
    b. Tire
20. Spare Wheel
21. Brakes Front (Complete)
    a. Front Rotors
    b. Front Calipers
22. Brakes Rear (Complete)
    a. Rear Rotors
    b. Rear Calipers
23. Seats Front Driver/Passenger
24. Seat Rear (Plus 3rd Row where applicable)
25. Instrument Panel
    a. IP Beam
    b. Plastic trim
    c. Instrumentation
    d. Center Console
26. Trim Interior
27. Wiring
28. Battery
29. Lighting
30. HVAC & Cooling
    a. Cooling System (Water)
31. Safety Systems
32. Steering System

33. Wiper system (Minus washer fluid)
    a. Washer Fluid
34. Noise Insulation
35. Glass (Windshield, back & side glass)
36. Accessories
37. Brackets/fasteners/misc. items

From the LWV program it was determined that for every 1kg of vehicle weight saving the powertrain weight could be reduced by 0.21kg per kg saved. Resizing of the powertrain, engine and transmission, was considered when calculating the weight reduction for the vehicles in each sub-class. 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% mass saving generally leads to 6.5% improvement in fuel economy when the powertrain is resized to match the lower mass of the vehicle.

8.3 Vehicle Classification System

For regulatory purposes, NHTSA and EPA both 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 twelve separate categories that distinguish performance and non-performance passenger cars. In this study, eight separate categories are considered as shown in Figure 353. NHTSA uses this set of vehicle classification in its technology analysis modeling, the Volpe model. Under passenger cars there are four categories; Subcompact, Compact, Mid-size, and Large. For other vehicles the four classes are: Small SUV/LT (light truck), Mid-Sized SUV/LT and Large SUV/LT and Mini-vans (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 353: Vehicle classification criteria

8.4 Technology

8.4.1 Availability

All the technologies used in the weight saving assessment for the LWV and other vehicle segments are considered to be mature in nature and are available either at present or will be mature in model years 2017 to 2025.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 and fenders to aluminium could put some strain on the aluminium sheet suppliers if introduced all at once across all vehicle classes. Changes of this order are generally gradual and it gives the supplier industry to keep up with the increased demand.

Currently there is limited magnesium high pressure die casting manufacturing capacity within 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 discussing with major magnesium suppliers in the industry.

8.5 Baseline Vehicle Selection

8.5.1 Primary Vehicle and Vehicle Sub-class Selection

For the mass reduction of other light duty vehicle sub-classes, vehicles listed in NHTSA 2010 market input file were utilized. This file consists of 1,171vehicles with various levels of trim from a number of vehicle manufacturers. Information on each vehicle contained the following:

- Vehicle footprint (Wheelbase x Track width)
- Type of vehicle body structure
- Vehicle style
- Drive axle ratio
- Vehicle length and width
- Vehicle track width of the front and rear axle
- Vehicle wheelbase.

This information was supplemented from the vehicle manufactures and number of other web-sites listed at the end of this section. The information obtained through various manufacturer websites plus online car guide websites were used. Information obtained from these sites includes vehicle curb weight ranges for different trim models, sales volumes, and whether or not A2Mac1 contained benchmark data for the selected vehicles. The A2Mac1 benchmark database is readily available and contains detailed information for the sub-systems for the selected representative vehicles. This data was used to refine and narrow the search for the representative vehicle for each vehicle sub-class. After the representative vehicle for each vehicle sub-classes was identified, light weighting technologies determined during the LWV study were applied to these representative vehicles to determine the amount of mass reduction feasible for each vehicle sub-class. Mass savings for the vehicle subclasses shown in Figure 353 were identified.

8.5.2 Subcompact passenger cars

The NHTSA 2010 vehicle market file contains 79 sub-compact passenger cars. Some of the vehicles in class are two seater sports cars; these were removed from the list for the class average calculations, see Section 8.2 Analytical Approach. Figure 354 shows the four vehicles that were selected as representative vehicles for the sub-compact class.

- Chevrolet Aveo
- Honda Fit
- Toyota Yaris
- Ford Fiesta

Figure 354: Sub-compact vehicles selected for the light-duty vehicle study

Figure 355 shows data for the representative sub-compact vehicles used for the light-duty vehicle study. Ford Fiesta is picked as the representative vehicle for sub-compact class. There are two main reasons for this selection. First, the Fiesta's curb-weight range resembles the sub-compact class better than that of Toyota Yaris. Secondly, A2Mac1 bench mark data available for the Ford Fiesta is for year 2008 versus 2006 for the Yaris.

The Ford Fiesta is of a front wheel drive configuration with a suspension arrangement of MacPherson strut for the front and torsion beam for the rear suspension; this is typical for this class of vehicles. The front engine cradle is of steel construction as is the rear torsion beam assembly.

Sub-Compacts	Length (mm)	Width (mm)	Wheelbase (mm)	Track (mm)		Curb Weight (kg)	Footprint LxW (m^2)	Sales	A2Mac1
				Front	Rear				
Chevrolet Aveo	4,310	1,709	2,480	1,450	1,430	1,155-1,165	3.93	28,482	n/a
Honda Fit	4,105	1,694	2,500	1,490	1,475	1,132-1,192	3.66	47,968	n/a
Toyota Yaris	3,825	1,689	2,460	1,480	1,470	1,041-1,050	3.76	57,794	2006
Ford Fiesta	4,067	1,722	2,490	1,465	1,465	1,151-1,161	3.65	57,225	2008
Sub-Compact Fleet Average	4,289	1,755	2,558	1,488	1,483	1,261	3.80	47,867	

Figure 355: Sub-Compact vehicle list

8.5.3 Compact passenger cars

The compact vehicle class consists of 97 vehicles in the NHTSA 2010 market file. Out of these the following three as shown in Figure 356 were chosen for detailed comparison.

- Hyundai Elantra
- Chevrolet Cruze
- Honda Civic

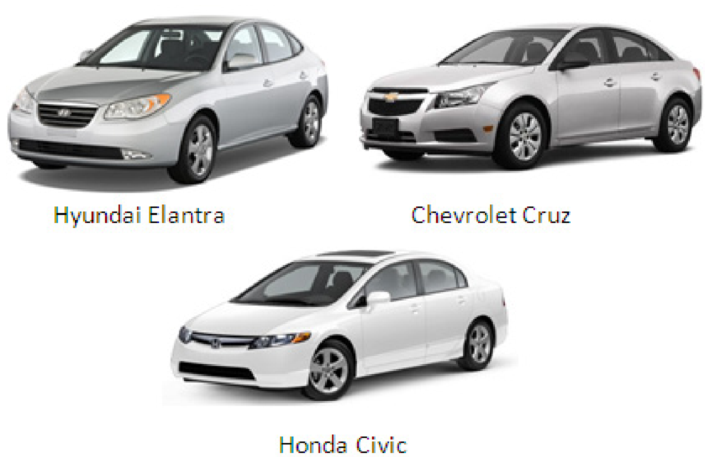

Figure 356: Compact vehicles selected for the light-duty vehicle study

Figure 357 shows the detailed information for these three selected vehicles and fleet average for compact passenger car. Data shows that Honda Civic weight range resembles the compact car sub-class average weight the best. Also benchmarking data for Honda Civic exists in the A2Mac1 database.

The Honda Civic has a front wheel drive configuration the front suspension is MacPherson strut with an engine cradle of steel construction the rear suspension is of the transversal arm type mounted directly to the body structure and is constructed from steel.

Compacts	Length (mm)	Width (mm)	Wheelbase (mm)	Track (mm) Front	Track (mm) Rear	Curb Weight (kg)	Footprint LxW (m^2)	Sales	A2Mac1
Hyundai Elantra	4,529	1,775	2,700	1,562	1,574	1,207-1,279	4.08	147,922	n/a
Chevrolet Cruze	4,597	1,796	2,624	1,541	1,557	1,292	4.16	187,524	n/a
Honda Civic	4,503	1,753	2,700	1,498	1,529	1,183-1,320	4.01	167,384	2007
Compact Fleet Average	4,515	1,766	2,644	1,527	1,529	1,345	4.03	167,610	

Figure 357: Compact Car vehicles list

8.5.4 Mid-Sized passenger cars

The mid-size passenger car class has 100 vehicles listed in the NHTSA 2010 market file. From these 100 vehicles, four chosen for evaluation are shown Figure 358:

- Chevrolet Malibu
- Ford Fusion
- Honda Accord
- Toyota Camry

Figure 358: Mid-sized vehicles selected for the light-duty vehicle study

The Accord's features such as length, width and wheelbase, all can be matched by its competitors. The availability of teardown data from A2Mac1 set the Honda Accord apart from the others. The Honda Accord has a front wheel drive configuration and has a front suspension of double wishbone type with a steel engine cradle and a multi-link independent rear suspension with a k-frame of steel construction. Figure 359 shows details for mid-sized vehicle.

Mid-Size	Length (mm)	Width (mm)	Wheelbase (mm)	Track (mm)		Curb Weight (kg)	Footprint LxW (m^2)	Sales	A2Mac1
				Front	Rear				
Chevrolet Malibu	4,874	1,786	2,852	1,513	1,524	1,557-1,655	4.35	198,770	n/a
Ford Fusion	4,841	1,834	2,728	1,567	1,557	1,490-1,687	4.28	188,439	n/a
Honda Accord	4,930	1,847	2,800	1,590	1,590	1,459-1,635	4.32	181,014	2009
Toyota Camry	4,806	1,821	2,776	1,584	1,574	1,447-1,540	4.35	229,251	n/a
Mid-Sized Fleet Average	4,873	1,830	2,779	1,566	1,562	1,561	4.34	199,369	

Figure 359: Mid-Sized vehicle list

The Honda Accord is also the baseline vehicle for design optimization for technologies used for mass savings for the NHTSA Lightweight Weight Vehicle (LWV).

8.5.5 Large passenger cars

The Large passenger car subclass consists of 64 vehicles in the NHTSA 2010 market file. Out of these 64 vehicles, five selected for comparison, are shown in Figure 360:

- Ford Taurus
- Audi A8
- Buick Lacrosse
- Chrysler 300
- Chevrolet Impala

Figure 360: Large passenger vehicles selected for the light-duty vehicle study

Audi A8 was included as an acceptable choice for the large passenger vehicle sub-class because its benchmark data is available in the A2Mac1 benchmark database. But Audi A8 does not ideally represent the average weight and size of the large car subclass. The Chrysler 300 better represents the average curb weight than the Audi A8.Benchmark data for Chrysler 300 also exists in the A2Mac1 database.

Chevrolet Impala has the highest sales volume among the five vehicles considered, but its curb weight and footprint falls out of the average range for the vehicle class, plus benchmark data for the Chevrolet Impala does not exist in the A2Mac1 database. Therefore it was not chosen as the representative vehicle.

The Buick Lacrosse is another large passenger car option, but it has a smaller footprint comparing to the average vehicles within the large car sub-class. Therefore it was not chosen as the representative vehicle, plus benchmark data was not available. Figure 361 lists large passenger vehicles used for this study.

Large	Length (mm)	Width (mm)	Wheelbase (mm)	Track (mm)		Curb Weight (kg)	Footprint LxW (m^2)	Sales	A2Mac1
				Front	Rear				
Ford Taurus	5,154	1,935	2,868	1,658	1,663	1,821-1,981	4.77	47,538	n/a
Audi A8	5,136	1,946	2,992	1,643	1,635	2,000-2,020	4.75	4,179	2010
Buick Lacrosse	5,001	1,856	2,837	1,567	1,574	1,736-1,834	4.49	4,045	n/a
Chrysler 300	5,044	1,905	2,852	1,610	1,620	1,814-1,980	4.87	23,376	2006
Chevrolet Impala	5,090	1,852	2,806	1,584	1,562	1,613-1,655	4.37	138,122	n/a
Large Fleet Average	5,063	1,880	2,903	1,594	1,595	1,752	4.63	43,452	

Figure 361: Large passenger vehicle list

The Chrysler 300 has a permanent rear wheel drive configuration with an unequal arm independent front suspension with a steel engine cradle and a multi-link rear suspension with a k-frame also of steel construction.

8.5.6 Mini-Vans

Out of the two sub-classes for vans, minivans and large vans, minivan body structures are all of a unibody construction, which distinguishes minivan from large vans which are of body on frame construction. Minivan sub-class includes a small listing of vehicles of only 20 vans, of which the three shown in Figure 362 were selected as representatives of the sub-class and they are:

- Honda Odyssey
- Chrysler Town & Country
- Toyota Sienna

Figure 362: Minivan vehicles selected for the light-duty vehicle study

For this analysis, the Toyota Sienna was selected as the representative vehicle for the minivan sub-class. Honda Odyssey benchmark data is not available in the A2Mac1 database. The curb weight, footprint and sales volume for Chrysler Town & Country fulfills our selection criteria, but its benchmark data does not exist in the A2Mac1 database. For our analysis the Toyota Sienna was selected as the primary choice for the representative vehicle with-in the minivan sub-class. The Toyota Sienna is of a front wheel drive configuration with a non permanent all wheel drive availability. The front suspension is of MacPherson strut type with a steel engine cradle. The rear suspension is a torsion beam of steel construction.

Figure 363 lists the minivan vehicles used for the study.

MiniVan	Length (mm)	Width (mm)	Wheelbase (mm)	Track (mm)		Curb Weight (kg)	Footprint LxW (m^2)	Sales	A2Mac1
				Front	Rear				
Honda Odyssey	5,154	2,012	3,000	1,729	1,732	1967-2068	5.08	76,021	n/a
Toyota Sienna	5,085	1,984	3,030	1,719	1,719	1939-2148	5.10	83,188	2005
Chrysler Town & Country	5,151	1,999	3,078	1,666	1,645	2110	5.07	71,917	n/a
MiniVan Fleet Average	5,118	1,950	3,045	1,661	1,661	2,035	5.06	77,042	

Figure 363: Minivan vehicle list

8.5.7 Small CUV/SUV/trucks

The small SUVs/pickups sub-class from the NHTSA 2010 market file consists of 105 vehicles, of which four shown in Figure 364 were selected for the study, these being:

- Ford Ranger (pickup)
- Toyota Rav4
- Ford Escape
- Honda CR-V

Figure 364: Small SUV/truck vehicles

Of these four vehicles, one is a small pickup, Ford Ranger. This was considered due to the vehicle sales numbers when compared to other small pickups. The Ford Ranger footprint being significantly higher than the sub-class average plus benchmark data not being available therefore it was not selected. Similarly the Ford Escape was not selected due to the unavailability of benchmark data. The Honda CR-V and Toyota Rav4 benchmark data is available from A2Mac1 for these two vehicles. As for other vehicle selection criteria, the Toyota Rav4 is consistent with the sub-class averages, and is comparable to the Honda CR-V, except for vehicle sales in which the Honda CR-V vehicle sales numbers are higher than the Toyota Rav4. Due to the high sales volume the Honda CR-V was selected as the primary vehicle for this sub-class.
See Figure 365 for the small SUV/Trucks vehicle list.

Small SUV/Pickup	Length (mm)	Width (mm)	Wheelbase (mm)	Track (mm)		Curb Weight (kg)	Footprint LxW (m^2)	Sales	A2Mac1
				Front	Rear				
Ford Ranger	4,811	1,760	2,824	1,485	1,455	1,422	4.45	49,788	n/a
Toyota Rav4	4,620	1,816	2,660	1,559	1,559	1524-1678	4.15	96,120	2007
Ford Escape	4,437	1,806	2,620	1,541	1,529	1466-1729	4.04	187,850	n/a
Honda CR-V	4,554	1,819	2,620	1,564	1,564	1536-1612	4.09	161,035	2007
Small SUV/Pickup Fleet Average	4,568	1,808	2,664	1,545	1,542	1,592	4.11	123,698	

Figure 365: Small SUV/Truck vehicle list

The Honda CR-V is front wheel drive with a non permanent 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.

8.5.8 Midsize CUV/SUV/trucks

This sub-class has the second largest number of vehicles listed in NHTSA 2010 market input file at 198. From those 198 vehicles, five were selected for consideration for the mid-size subclass, these being:

- Ford explorer
- Chevrolet Equinox
- Honda Pilot
- GMC Canyon (pickup).
- Audi Q5

See Figure 366 for vehicles selected for the mid-sized SUV/truck vehicle class

Figure 366: Mid-sized SUV/truck vehicles selected for the light-duty vehicle study

The GMC Canyon pickup in this subclass had the smallest footprint plus the curb weight is the lowest of the considered vehicles. Also the GMC Canyon has the lowest vehicle sales at 7,992 vehicles which is well below the sub-class average sales of 69,852 vehicles. For these reasons including footprint, curb weight and sales, the GMC Canyon was not considered to represent this class.

The Ford Explorer was also considered for the mid-size SUV, the footprint of the Ford Explorer is within average range for this vehicle sub-class, but the curb weight is significantly higher. The remaining vehicles, Chevrolet Equinox, Honda Pilot and the Audi Q5 were also considered and proved to be candidates for the selected vehicle. Of all vehicles considered for this sub-class, only the Audi Q5 had available benchmark data from A2Mac1. Even though the Audi Q5 sales numbers were below the sub-class average, the Audi Q5 was selected as the representative mid-sized SUV vehicle.

Mid-Sized SUV/Pickup	Length (mm)	Width (mm)	Wheelbase (mm)	Track (mm)		Curb Weight (kg)	Footprint LxW (m^2)	Sales	A2Mac1
				Front	Rear				
Ford Explorer	5,006	2,004	2,860	1,701	1,701	2,067-2,146	4.49	96,957	n/a
Audi Q5	4,629	1,898	2,807	1,617	1,612	1778	4.53	17,571	2009
Chevrolet Equinox	4,770	1,842	2,857	1,597	1,577	1,713-1,811	4.52	145,035	n/a
Honda Pilot	4,849	1,994	2,774	1,719	1,714	1,950-2090	4.76	81,703	n/a
GMC Canyon	4,887	1,717	2,827	1,460	1,460	1,527-1,671	4.24	7,992	n/a
Mid-Sized SUV/Pickup Fleet Average	4,827	1,899	2,865	1,609	1,607	1,916	4.60	69,852	

Figure 367: Mid-Sized SUV/Truck vehicle list

The Audi Q5 is front wheel drive with an optional non permanent all wheel drive availability. The front suspension is of the 5-link independent type with an aluminum engine cradle. The rear is of the trapezoidal-link independent suspension with a steel k-frame. The Audi Q5 body structure differs from the other vehicles as being of steel construction with integrated aluminium and magnesium components

8.5.9 Large CUV/SUV/light duty trucks

Apart from the mid-size SUV sub-class the large SUV/truck sub-class has the highest vehicle sales volume as listed in the NHTSA 2010 market file, plus the greatest number of vehicles at 312. Out of these 312 SUV/pickups three vehicles were considered for this class as shown in Figure 368:

- Chevrolet Silverado
- Dodge Ram
- Ford F150

Figure 368: Large SUV/truck vehicles selected for the light-duty vehicle study

Details of the three vehicles in class are shown in Figure 369. The Chevrolet Silverado was considered for this sub-class vehicle but its vehicle curb weight and footprint fall below the sub-class average.

Benchmark data from A2Mac1 is available for the Dodge Ram but when we consider the relatively lower vehicles sales numbers and lower curb weight comparing to the sub-class averages the Dodge Ram was not selected for the representative vehicle for the large SUV/truck sub-class.

The Ford F150 was selected as the best representative vehicle for this sub-class as its bests fits the sub-class averages than the other vehicles plus the availability of benchmark data. See Figure 369 for the large SUV/truck vehicle list.

Large SUV/Pickup	Length (mm)	Width (mm)	Wheelbase (mm)	Track (mm)		Curb Weight (kg)	Footprint LxW (m^2)	Sales	A2Mac1
				Front	Rear				
Chevrolet Silverado	5,222	2,029	3,023	1,729	1,701	2,024-2,202	5.19	296,436	n/a
Dodge Ram	5,309	2,017	3,060	1,727	1,714	2050-2,178	5.28	178,108	2006
Ford F150	5,415	2,012	3,198	1,701	1,701	2,125-2665	5.46	416,388	2007
Large SUV/Pickup Fleet Average	5,643	2,007	3,454	1,710	1,703	2,391	5.89	296,977	

Figure 369: Large SUV/Truck vehicle list

This vehicle subclass differs from vehicles in the other segments. Most of the vehicles in other vehicle subclasses are of unibody construction while most vehicles in large SUV/Truck subclass, such as the Ford F150, are of the body-on-frame type of construction. The F150 is also built with a rear pickup box with a standard truck type tailgate. The F150 has a rear wheel drive configuration with a double wishbone front suspension and a solid live axle rear suspension.

Figure 370 shows the selected vehicle, Ford F150 Lariat, for the large SUV/truck class of vehicles.

Figure 370: Ford F150-Lariat selected for the representative large SUV/truck.

8.5.10 Large vans

The large van sub-class only has limited number of vehicles in the NHTSA 2010 market file that could be considered as viable candidates for the mass reduction of other light duty vehicles study, therefore no primary representative vehicles were selected. However two vehicles were considered due to having similar features and usage to each other. The two potential vans are:

- GMC Savana
- Ford Econoline

Both vehicles being considered for this class are rear wheel drive with an unequal arm front suspension and a solid live rear axle. See Figure 371 for vehicles selected for the large van vehicle class.

Figure 371: Large van vehicles selected for the light-duty vehicle study

The two vehicles serve as passenger, cargo or utility vehicles and as such do not have a standard configuration. Due to the large option range for these vehicles that affects the vehicle curb weight it proves difficult when selecting one vehicle as a representative vehicle for this sub-class. In addition these vehicles generally carry passenger or cargo loads greater than the passenger and other vehicles. Due to these passenger and cargo load factors mass savings would only play a minor role in any vehicle fuel economy savings. Because of these factors a weight saving on this sub-class was not estimated. See Figure 372 for details of large van vehicle.

Large Van	Length (mm)	Width (mm)	Wheelbase (mm)	Track (mm)		Curb Weight (kg)	Footprint LxW (m^2)	Sales	A2Mac1
				Front	Rear				
GMC Savana	5,692	2,017	3,429	1,722	1,722	2560-2906	5.93	13,942	n/a
Ford E150	5,085	1,984	3,030	1,785	1,704	2611-3012	6.05	89,199	n/a
Large Van Fleet Average	5,389	2000	3,226	1745	1413	2772	5.99	51,571	

Figure 372: Large van vehicle list

8.5.11 Summary of chosen baseline vehicles

For each vehicle class the chosen vehicle and its mass comparison with the 2010 class average is shown in Figure 373. The mass of the chosen vehicle is within +/- 10% of the class average.

Vehicle Class	Selected Baseline Vehicle	Baseline Vehicle CVW (kg)	2010 Class Average CVW (kg)	Differnce in Mass (%)
Sub-Compact Car	Ford Fiesta 1.6 TDCi (2008)	1,147	1,261	9.1%
Compact Car	Honda Civic 1.8 LX (2007)	1,252	1,345	6.9%
Mid-Sized Car	Honda Accord 2.2 i-DETC ES (2008)	1,550	1,561	0.7%
Large Car	Chrysler 300 C AWD (2006)	1,871	1,752	-6.8%
MiniVans	Toyota Sienna LTD (2011)	2,154	2,035	-5.8%
Small SUV/LT	Honda CR-V 2.0 (2006)	1,541	1,592	3.2%
Mid-Sized SUV/LT	Audi Q5 2.0 Tdi (2009)	1,779	1,916	7.2%
Large SUV/LT	Ford F150 (2003)	2,406	2,391	-0.6%

Figure 373: Comparison of Selected Baseline Vehicle versus Class Average

8.6 Results

8.6.1 Subcompact passenger cars

The vehicle selected for the sub-compact segment is a 2008 1.6 TDCi Ford Fiesta rated at 90hp, manufactured in Germany for the European market with a front wheel drive manual transmission. The Fiesta has a curb vehicle weight (CVW) of 1146.75kg.

The results for the Fiesta are shown in Figure 376. For the body structure a 20% mass reduction with the adoption of AHSS is assumed. This is 3% lower than the detailed design LWV body structure mass. Due to limited packaging space on a sub-compact compared with a mid-size vehicle, same amount of optimization will not be realised for the sub-compact structure. For the Fiesta body structure the 20% mass saving is equivalent to 46.5kg. For all the closures, which include hood, fenders, front & rear doors and the tailgate, aluminum leads to mass saving of 31.2kg. The percentage mass reduction applied to the closures is 40% to 45%. These numbers are approximately 5% lower than what was achieved for the LWV design, due to the Fiesta door frames to be of light weight steel construction.

The Ford Fiesta front suspension shown in Figure 374, utilizes steel K-Frame (engine cradle) and steel for other suspension components. For light weighting the K-Frame with use of AHSS construction and other selected suspension components in aluminium, leads to a mass reduction of 9.0kg and for the rear suspension a mass saving of 4.0kg. The rear suspension is shown in Figure 375.

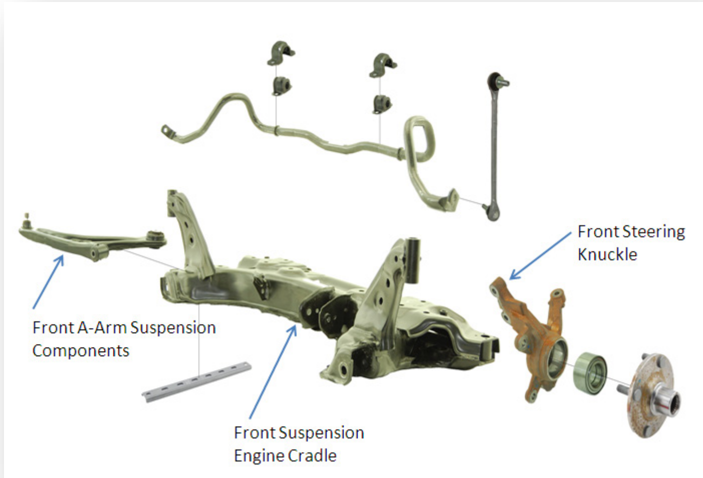

Figure 374: Ford Fiesta front suspension[179]

The rear suspension uses a torsion beam as the main suspension component this was selected to change to advanced high strength steel (AHSS) design.

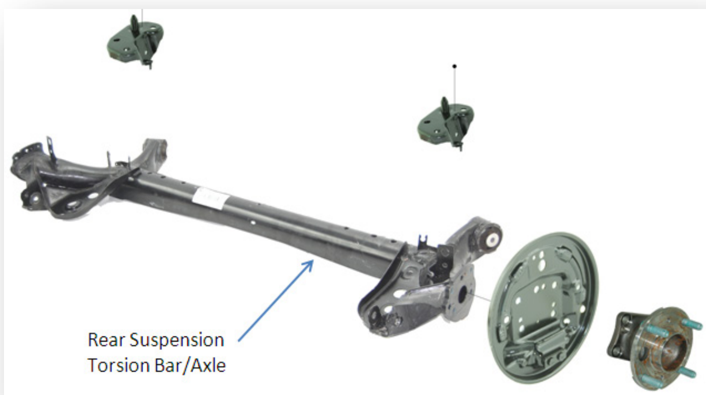

Figure 375: Fiesta torsion bar rear suspension[180]

As a result of all the proposed light weighting options implemented as shown in Figure 376, a total weight savings of 203.1kg (17.7%) is achieved. This reduction includes 35.6kg due to powertrain downsizing and 5.3 kg for resizing the fuel system, while maintaining vehicle size and vehicle performance functionalities.

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[179] A2Mac1
[180] A2Mac1

Ford Fiesta 1.6 TDCi
Weight kg: 1146.75
Model Year: 2008
Power Train: 1.6 TDCi (Diesel) 90hp. Transmission: Manual. Drive: FWD
Market: Europe. Manf Plant: Germany Europe.
Seat Capicity: 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)	232.50	232.50	186.00	-46.5	-20%	Advanced High Streength Steel (AHSS)
Paint	12.00					Estimated by body size
Door Front Lh/Rh (Complete)	58.70					Incls trim/hardware, glass, paint & sealer
Frame		26.73	16.04	-10.7	-40%	Aluminum stampings inner/outer
Trim		6.35	5.72	-0.6	-10%	
Door Rear Lh/Rh (Complete)	45.10					
Frame		21.56	12.94	-8.6	-40%	Aluminum stampings inner/outer
Trim		5.59	5.03	-0.6	-10%	
Hood (Complete)	15.33					
Frame		11.73	6.45	-5.3	-45%	Aluminum stampings inner/outer
Trim		0.89	0.80	-0.1	-10%	
Decklid/Tailgate (Complete)	22.46					
Frame		11.40	6.27	-5.1	-45%	Aluminum stampings inner/outer
Trim						
Fenders LH/RH	3.44	3.44	1.89	-1.5	-45%	Aluminium stamping
Bumpers Front (Complete)	16.15					
Front Bumper Beam		8.34	4.59	-3.8	-45%	AHSS Hot Stamping
Front Fascia (Minus bumper beam)		7.81	7.03	-0.8	-10%	
Bumpers Rear (Complete)	8.14					
Rear Bumper Beam		3.22	2.41	-0.8	-25%	AHSS Hot Stamping
Rear Fascia (Minus bumper beam)		4.92	4.43	-0.5	-10%	
Front Suspension (Complete with-out damper)	37.64					
Frame		14.42	10.10	-4.3	-30%	Aluminum
Suspension Arms Lh/Rh		5.34	3.74	-1.6	-30%	AHSS
Knuckle Lh/Rh		6.92	3.81	-3.1	-45%	Aluminum
Spring damper Front Lh/Rh	11.47	11.47	10.32	-1.1	-10%	
Rear Suspension (Complete with-out damper)	29.03					
Frame		19.76	15.81	-4.0	-20%	Torsion beam
Suspension Arms Lh/Rh						
Spring Damper Rear Lh/Rh	6.03	6.03	5.42	-0.6	-10%	
Engine/Transmission						
Engine	107.52	107.52	83.69	-23.82	-22.2%	Resize
Engine Oil	2.90	2.90	2.75	-0.14	-5%	Reduction due to resizing
Transmission	53.15	53.15	41.37	-11.78	-22.2%	Incls clutch/tourqe convertor system
Transmission Fluid	4.41	4.41	4.19	-0.22	-5%	Reduction due to resizing
Drive Shafts Lh/Rh	12.82	12.82	10.25	-2.6	-20%	AHSS
Exhaust System	23.61	23.61	21.25	-2.4	-10%	
Fuel System	9.98	9.98	8.83	-1.1	-11.5%	Reduce as per powertrain resizing
Fuel (Existing tank 11 Gal)	36.44	36.44	32.25	-4.2	-11.5%	Reduce as per powertrain resizing
Wheels	64.26					
Rim		32.16	28.94	-3.2	-10%	AHSS
Tire		31.52	28.37	-3.2	-10%	
Spare Wheel	10.86	10.86	9.77	-1.1	-10%	
Brakes Front (Complete)	21.35					
Front Rotors		11.22	10.10	-1.1	-10%	
Front Calipers		8.21	4.92	-3.3	-40%	Aluminum calipers
Brakes Rear (Complete)	12.40					
Rear Rotors		7.91	6.72	-1.2	-15%	
Rear Calipers		n/a				
Seats Front Driver/Passenger	37.20	37.20	26.04	-11.2	-30%	Composite & magnesium frame
Seat Rear (Plus 3rd Row where applicable)	25.35	25.35	17.74	-7.6	-30%	Composite & magnesium frame
Instrument Panel	24.93					
IP Beam		8.60	4.73	-3.9	-45%	Magnesium IP beam
Plastic trim		12.43	10.56	-1.9	-15%	Non Class A - MuCell
Instrumentation		3.91	3.44	-0.5	-12%	
Center Console	2.82	2.82	2.54	-0.3	-10%	
Trim Interior	19.27	19.27	16.38	-2.9	-15%	Non Class A - MuCell
Wiring	19.23	19.23	15.38	-3.8	-20%	Aluminum/copper
Battery	18.32	18.32	16.49	-1.8	-10%	
Lighting	8.12	8.12	6.50	-1.6	-20%	Same technology with MuCell Housings
HVAC & Cooling	18.87	18.87	15.10	-3.8	-20%	Same technology with MuCell Housings
Cooling System (Water)	6.80	6.80	6.46	-0.3	-5%	
Safety Systems	15.21					Seat belts,air bags & modules
Steering System	18.94	18.94	16.10	-2.8	-15%	Optimize
Wiper system (Minus washer fluid)	6.15	6.15	5.54	-0.6	-10%	Optimize
Washer Fluid	3.31					
Noise Insulation	11.72	11.72	10.55	-1.2	-10%	
Glass (Windshield, back & side glass)	16.80					
Accessories	3.26					
Brackets/fastners/misc items	32.81					
Total with Powertrain	1146.8	978.8	775.7	-203.1	-17.7%	
Total without Powertrain	978.8	810.9	643.7	-167.1	-17.1%	

Figure 376: Ford Fiesta sub-system / component weight savings

8.6.2 Compact passenger cars

The vehicle selected for the compact segment is a 1.8L Honda Civic, production year 2007 manufactured in the US for the US market with a vehicle weight of 1252.38kg.

The results for the Honda Civic are shown in Figure 369. For the body structure a 22% mass reduction with the adoption of AHSS is assumed. This is 1% lower than the detailed design LWV body structure mass. For the body structure the mass saving is equivalent to 60.3kg. For all the closures, which include hood, fenders, front & rear doors and the tailgate, in aluminum leads to mass saving of 29.2kg. The percentage mass reduction applied to the closures is 35% to 45% as shown in Figure 376. These numbers are approximately 5% to 10% lower than what was achieved for the LWV design. The Civic front and rear doors frames are already of light weight steel construction, therefore it was judged that 35% mass reduction will be achieved by the application of aluminum.

The Honda Civic front suspension shown in Figure 377, utilizes steel K-Frame (engine cradle) and steel for other suspension components. For light weighting the K-Frame with use of AHSS construction and other selected suspension components in aluminium, leads to a mass reduction of 11.4kg and for the rear suspension a mass saving of 3.7kg. The mass saving applied to the Civic front suspension are lower than the LWV, as the MacPherson strut design is maintained and the mass reduction is due mainly from material substitution.

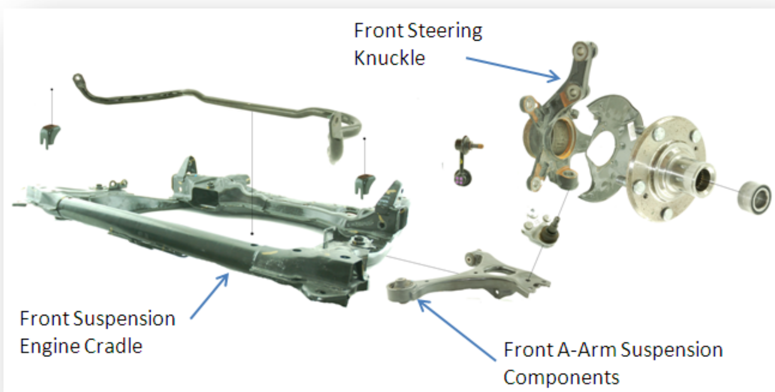


Figure 377: Honda Civic front suspension[181]

The Honda Civic has a rear suspension shown in Figure 378, utilizes a transversal arm arrangement that is direct mounted to the body structure without the need of a supporting K-Frame. For light weighting this arm assembly is manufactured using AHSS.

[181] A2Mac1

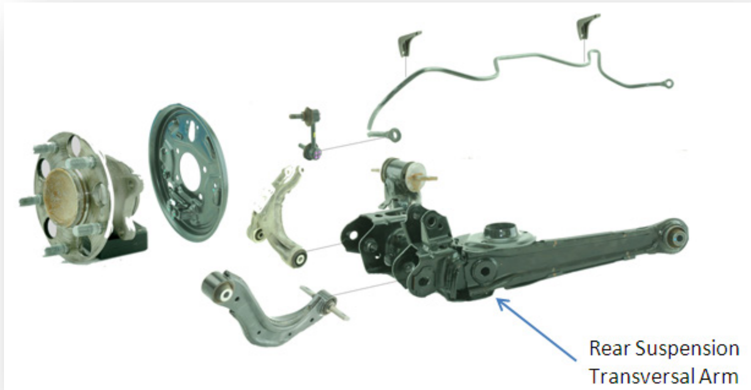


Figure 378: Honda Civic rear suspension[182]

As a result of all the proposed light weighting options implemented as shown in Figure 379, a total weight savings of 228.2kg (18.2%) is achieved. This reduction includes 40.0kg due to powertrain downsizing and 7.2 kg for resizing the fuel system, while maintaining vehicle size and vehicle performance functionalities.

[182] A2Mac1

Honda Civic 1.8 LX
Weight kg: 1252.38
Model Year: 2007
Power Train: 1.8 (Gasoline) 140hp. Transmission: Automatic. Drive: FWD
Market: North America. Manf Plant: Ohio USA.
Seat Capicity: 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)	274.00	274.00	213.72	-60.3	-22%	Advanced Hight Streength Steel (AHSS)
Paint	12.00					Estimated by body size
Door Front Lh/Rh (Complete)	55.20					Incls trim/hardware, glass, paint & sealer
Frame		28.95	18.82	-10.1	-35%	Aluminum stampings inner/outer
Trim		4.40	3.96	-0.4	-10%	Soft trim panel only
Door Rear Lh/Rh (Complete)	45.70					Incls trim/hardware, glass, paint & sealer
Frame		25.16	16.35	-8.8	-35%	Aluminum stampings inner/outer
Trim		3.45	3.11	-0.3	-10%	Soft trim panel only
Hood (Complete)	9.97					Incls trim/hardware, glass, paint & sealer
Frame		8.09	4.45	-3.6	-45%	Aluminum stampings inner/outer
Trim						Soft trim panel only
Decklid/Tailgate (Complete)	12.24					Incls trim/hardware, glass, paint & sealer
Frame		8.43	4.64	-3.8	-45%	Aluminum stampings inner/outer
Trim						Soft trim panel only
Fenders Front/Rear	6.51	6.51	3.58	-2.9	-45%	Aluminium stamping
Bumpers Front (Complete)	12.11					
Front Bumper Beam		4.45	2.45	-2.0	-45%	AHSS Hot Stamping
Front Fascia (Minus bumper beam)		7.67	6.90	-0.8	-10%	
Bumpers Rear (Complete)	8.89					
Rear Bumper Beam		4.44	3.11	-1.3	-30%	AHSS Hot Stamping
Rear Fascia (Minus bumper beam)		4.45	4.01	-0.4	-10%	
Front Suspension (Complete with-out damper)	45.20					
Frame		20.93	14.65	-6.3	-30%	Aluminum
Suspension Arms Lh/Rh		6.33	4.43	-1.9	-30%	Aluminum
Knuckle Lh/Rh		7.93	4.76	-3.2	-40%	Aluminum
Spring damper Front Lh/Rh	13.91	13.91	12.52	-1.4	-10%	
Rear Suspension (Complete with-out damper)	31.02	12.50	10.62	-1.9	-0.2	AHSS
Frame						Transversal arm suspension direct to body
Suspension Arms Lh/Rh		18.53	14.82	-3.7	-0.2	AHSS
Spring Damper Rear Lh/Rh	8.59	8.59	7.73	-0.9	-10%	
Engine/Transmission						
Engine	101.54	101.54	79.38	-22.16	-21.8%	Resize
Engine Oil	3.82	3.82	3.63	-0.19	-5%	Reduction due to resizing
Transmission	81.87	81.87	64.01	-17.87	-21.8%	Incls clutch/tourqe convertor system
Transmission Fluid	3.29	3.29	3.12	-0.16	-5%	Reduction due to resizing
Drive Shafts Lh/Rh	11.66	11.66	9.32	-2.3	-20%	AHSS
Exhaust System	22.21	22.21	19.98	-2.2	-10%	
Fuel System	18.44	18.44	16.26	-2.2	-11.8%	Incls fuel lines & tank
Fuel (Existing tank 11 Gal)	42.16	42.16	37.17	-5.0	-11.8%	Reduce as per powertrain resizing
Wheels	88.59					
Rim		36.52	31.04	-5.5	-15%	AHSS
Tire		39.19	35.27	-3.9	-10%	
Spare Wheel		10.86	9.77	-1.1	-10%	
Brakes Front (Complete)	20.95					
Front Rotors		10.17	8.64	-1.5	-15%	
Front Calipers		8.55	5.13	-3.4	-40%	Aluminum calipers
Brakes Rear (Complete)	12.23					
Rear Rotors		7.64	6.50	-1.1	-15%	Drum brakes
Rear Calipers		n/a				
Seats Front Driver/Passenger	45.82	45.82	32.08	-13.7	-30%	Composite & magnesium frame
Seat Rear (Plus 3rd Row where applicable)	17.24	17.24	12.07	-5.2	-30%	Composite & magnesium frame
Instrument Panel	24.81					
IP Beam		10.97	5.49	-5.5	-50%	Magnesium IP beam
Plastic trim		9.26	7.87	-1.4	-15%	
Instrumentation		4.58	3.44	-1.1	-25%	
Center Console	4.84	4.84	4.35	-0.5	-10%	
Trim Interior	23.24	23.24	19.75	-3.5	-15%	
Wiring	15.25	15.25	12.20	-3.1	-20%	Aluminum/copper
Battery	12.25	12.25	11.02	-1.2	-10%	
Lighting	8.26	8.26	6.61	-1.7	-20%	
HVAC & Cooling	22.88	22.88	18.30	-4.6	-20%	
Cooling System (Water)	10.09	10.09	9.08	-1.0	-10%	
Safety Systems	18.19					Seat belts,air bags & modules
Steering System	20.77	20.77	18.69	-2.1	-10%	
Wiper system (Minus washer fluid)	7.16	7.16	6.44	-0.7	-10%	
Washer Fluid	3.38					
Noise Insulation	2.54	2.54	2.29	-0.3	-10%	
Glass (Windshield, back & side glass)	21.17					
Accessories	4.11					
Brackets/fastners/misc items	48.30					
Total with Powertrain	1252.4	1081.8	853.5	-228.2	-18.2%	
Total without Powertrain	1061.9	891.3	703.4	-187.9	-17.7%	

Figure 379: Honda Civic sub-system / component weight savings

8.6.3 Mid-Sized passenger cars

The vehicle selected for the mid-sized segment is a Honda Accord, production year 2008 manufactured in Japan for the European market, weight of 1,550.2kg. The vehicle is equipped with diesel engine with a manual transmission. The North American version of Honda Accord 2011 is used as the baseline vehicle for the LWV, which is the subject of this study. The North American vehicle weighs1, 480kg and is equipped with gasoline engine with a 5 speed automatic transmission. The both vehicles share the same platform.

The Accord uses a double-wishbone type of front suspension shown in Figure 380, with a steel engine cradle, suspension components and steering knuckle. For the LWV program that uses the Accord as the baseline vehicle the front suspension arrangement was changed to MacPherson strut design, that is less complex, lower mass and cost. For mass calculation for this study the change to MacPherson strut is not implemented. For light weighting the engine cradle with use of AHSS construction and other selected suspension components in aluminium, leads to a mass reduction of 26.5kg and for the rear suspension a mass saving of 9.9kg.

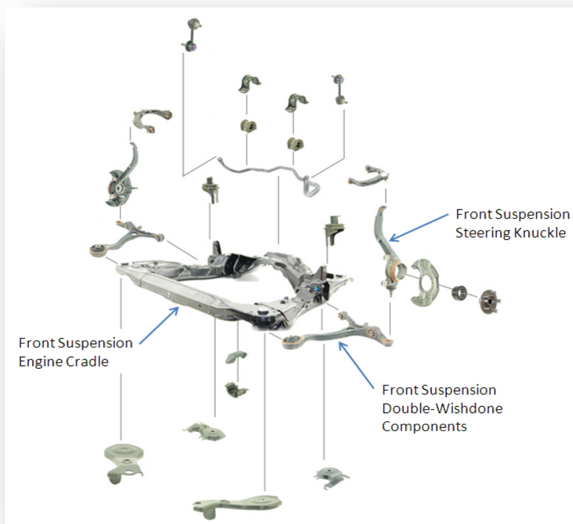


Figure 380: Honda Accord front suspension[183]

The results for the Honda Accord are shown in Figure 381. For the body structure a 22% mass reduction with the adoption of AHSS is assumed. This is same as the detailed design LWV body structure mass. For the body structure the mass saving is equivalent to 70.4kg. For all the closures, which include hood, fenders, front & rear doors and the tailgate, in aluminum leads to mass saving of 34.4kg. The percentage mass reduction applied to the closures is similar to what was achieved for the LWV design. As a result of all the proposed light weighting options implemented as shown in Figure 381, a total weight savings of 286.8kg (18.5%) is achieved. This reduction includes 50.3kg due to powertrain downsizing and 7.7 kg for resizing the fuel system, while maintaining vehicle size and vehicle performance functionalities.

[183] A2Mac1

Honda Accord 2.2 i-DETC ES
Weight kg: 1550.21
Model Year: 2008
Power Train: 2.2 i-DETC (Diesel) 150hp. Transmission: Manual. Drive: FWD
Market: Europe. Manf Plant: Japan.
Seat Capicity: 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)	320.00	320.00	249.60	-70.4	-22%	Advanced Hight Streength Steel (AHSS)
Paint	12.00					Estimated by body size
Door Front Lh/Rh (Complete)	65.45					Incls trim/hardware, glass, paint & sealer
Frame		32.27	19.36	-12.9	-40%	Aluminum stampings inner/outer
Trim		6.14	5.52	-0.6	-10%	Soft trim panel only
Door Rear Lh/Rh (Complete)	46.30					Incls trim/hardware, glass, paint & sealer
Frame		23.44	15.24	-8.2	-35%	Aluminum stampings inner/outer
Trim		4.24	3.82	-0.4	-10%	Soft trim panel only
Hood (Complete)	16.94					Incls trim/hardware, glass, paint & sealer
Frame		13.38	7.36	-6.0	-45%	Aluminum stampings inner/outer
Trim		1.60	1.44	-0.2	-10%	Soft trim panel only
Decklid/Tailgate (Complete)	15.19					Incls trim/hardware, glass, paint & sealer
Frame		9.27	5.10	-4.2	-45%	Aluminum stampings inner/outer
Trim						Soft trim panel only
Fenders Front/Rear	6.57	6.57	3.61	-3.0	-45%	Aluminium stamping
Bumpers Front (Complete)	14.36					
Front Bumper Beam		4.59	3.44	-1.1	-25%	AHSS Hot Stamping
Front Fascia (Minus bumper beam)		9.78	8.80	-1.0	-10%	
Bumpers Rear (Complete)	8.72					
Rear Bumper Beam		2.99	2.09	-0.9	-30%	AHSS Hot Stamping
Rear Fascia (Minus bumper beam)		5.73	5.15	-0.6	-10%	
Front Suspension (Complete with-out damper)	81.33					
Frame		33.26	19.96	-13.3	-40%	Aluminum
Suspension Arms Lh/Rh		17.53	10.52	-7.0	-40%	AHSS
Knuckle Lh/Rh		13.76	7.57	-6.2	-45%	Aluminum
Spring damper Front Lh/Rh	16.62	16.62	14.96	-1.7	-10%	
Rear Suspension (Complete with-out damper)	55.93					
Frame		22.59	15.81	-6.8	-30%	Aluminum
Suspension Arms Lh/Rh		15.42	12.34	-3.1	-20%	AHSS
Spring Damper Rear Lh/Rh	10.01	10.01	9.01	-1.0	-10%	
Engine/Transmission						70.076
Engine	166.06	166.06	131.90	-34.16	-20.6%	Resize
Engine Oil	4.68	4.68	4.45	-0.23	-5%	Reduction due to resizing
Transmission	78.51	78.51	62.36	-16.15	-20.6%	Incls clutch/tourqe convertor system
Transmission Fluid	1.96	1.96	1.86	-0.10	-5%	Reduction due to resizing
Drive Shafts Lh/Rh	15.16	15.16	12.13	-3.0	-20%	AHSS
Exhaust System	35.22	35.22	33.46	-1.8	-5%	
Fuel System	22.24	22.24	19.57	-2.7	-12.0%	Incls fuel lines & tank
Fuel (Existing tank 11 Gal)	58.50	58.50	51.47	-7.0	-12.0%	Reduce as per powertrain resizing
Wheels	77.54					
Rim		34.06	30.65	-3.4	-10%	AHSS
Tire		42.88	38.59	-4.3	-10%	
Spare Wheel	10.86	10.86	9.77	-1.1	-10%	Est from similar vehicle size
Brakes Front (Complete)	30.17					
Front Rotors		16.03	12.82	-3.2	-20%	
Front Calipers		11.23	6.74	-4.5	-40%	Aluminum calipers
Brakes Rear (Complete)	16.35					
Rear Rotors		8.18	6.54	-1.6	-20%	
Rear Calipers		6.00	3.60	-2.4	-0.4	
Seats Front Driver/Passenger	44.81	44.81	31.37	-13.4	-30%	Composite & magnesium frame
Seat Rear (Plus 3rd Row where applicable)	21.03	21.03	14.72	-6.3	-30%	Composite & magnesium frame
Instrument Panel	30.60					
IP Beam		11.52	6.34	-5.2	-45%	Magnesium IP beam
Plastic trim		13.16	11.18	-2.0	-15%	
Instrumentation		5.92	4.44	-1.5	-25%	
Center Console	5.38	5.38	4.84	-0.5	-10%	
Trim Interior	25.92	25.92	22.03	-3.9	-15%	
Wiring	19.82	19.82	15.86	-4.0	-20%	Aluminum/copper
Battery	20.22	20.22	18.20	-2.0	-10%	
Lighting	8.95	8.95	7.16	-1.8	-20%	
HVAC & Cooling	25.96	25.96	20.77	-5.2	-20%	
Cooling System (Water)	12.08	12.08	10.87	-1.2	-10%	
Safety Systems	19.30					Seat belts,air bags & modules
Steering System	26.78	26.78	22.76	-4.0	-15%	
Wiper system (Minus washer fluid)	5.97	5.97	5.37	-0.6	-10%	Optimize
Washer Fluid	4.82					
Noise Insulation	10.26	10.26	9.23	-1.0	-10%	
Glass (Windshield, back & side glass)	21.38					
Accessories	6.49					
Brackets/fastners/misc items	53.79					
Total with Powertrain	1550.2	1338.5	1051.7	-286.8	-18.5%	
Total without Powertrain	1299.0	1087.3	851.2	-236.1	-18.2%	

Figure 381: Honda Accord 2008 sub-system / component weight saving

8.6.4 Large passenger cars

The vehicle selected for the large car segment is a Chrysler 300, production year 2006: Manufactured in the US for the North American market, vehicle weight of 1870.75kg.

The results for the Chrysler 300 are shown in Figure 382. For the body structure a 25% mass reduction with the adoption of AHSS is assumed. This is 2% higher than the detailed design LWV body structure mass. The higher mass saving percentage applied reflects the older 2006 model year for the Chrysler 300 baseline vehicle, which probably uses lower percentage of high strength steel (HSS). For the body structure the mass saving is equivalent to 89.1kg. For all the closures, which include hood, fenders, front & rear doors and the tailgate, in aluminum leads to mass saving of 44.3kg. The percentage mass reduction applied to the closures is 45%. These numbers are of the same order as what was achieved for the LWV design.

The Chrysler 300 front suspension, utilizes steel K-Frame (engine cradle) and steel for other suspension components. For light weighting the K-Frame with use of AHSS construction and other selected suspension components in aluminium, leads to a mass reduction of 21.6kg and for the rear suspension a mass saving of 17.8kg.

As a result of all the proposed light weighting options implemented as shown in Figure 382, a total weight savings of 344.9kg (18.4%) is achieved. This reduction includes 60.5kg due to powertrain downsizing and 9.4 kg for resizing the fuel system, while maintaining vehicle size and vehicle performance functionalities.

Chrysler 300 C AWD
Weight kg: 1870.75
Model Year: 2006
Power Train: 3.5Lt (gasoline) 250hp. Transmission: Automatic. Drive: AWD Permanent
Market: North America. Manf Plant: USA.
Seat Capicity: 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)	356.50	356.50	267.38	-89.1	-25%	Advanced Hight Streength Steel (AHSS)
Paint	14.00					Estimated by body size
Door Front Lh/Rh (Complete)	82.00					Incls trim/hardware, glass, paint & sealer
Frame		39.67	21.82	-17.9	-45%	Aluminum stampings inner/outer
Trim		7.71	6.94	-0.8	-10%	Soft trim panel only
Door Rear Lh/Rh (Complete)	63.60					Incls trim/hardware, glass, paint & sealer
Frame		34.07	18.74	-15.3	-45%	Aluminum stampings inner/outer
Trim		7.25	6.52	-0.7	-10%	Soft trim panel only
Hood (Complete)	14.36					Incls trim/hardware, glass, paint & sealer
Frame		10.69	5.88	-4.8	-45%	Aluminum stampings inner/outer
Trim		0.87	0.78	-0.1	-10%	Soft trim panel only
Decklid/Tailgate (Complete)	11.40					Incls trim/hardware, glass, paint & sealer
Frame		6.61	3.63	-3.0	-45%	Aluminum stampings inner/outer
Trim						Soft trim panel only
Fenders Front/Rear	7.29	7.29	4.01	-3.3	-45%	Aluminium stamping
Bumpers Front (Complete)	17.32					
Front Bumper Beam		10.30	6.70	-3.6	-35%	AHSS Hot Stamping
Front Fascia (Minus bumper beam)		7.02	6.32	-0.7	-10%	
Bumpers Rear (Complete)	18.22					
Rear Bumper Beam		8.72	5.67	-3.1	-35%	AHSS Hot Stamping
Rear Fascia (Minus bumper beam)		9.50	8.55	-0.9	-10%	
Front Suspension (Complete with-out damper)	75.76					
Frame		19.58	13.71	-5.9	-30%	Aluminum
Suspension Arms Lh/Rh		19.79	12.86	-6.9	-35%	AHSS
Knuckle Lh/Rh		17.52	8.76	-8.8	-50%	Aluminum
Spring damper Front Lh/Rh	20.43	20.43	18.38	-2.0	-10%	
Rear Suspension (Complete with-out damper)	66.37					
Frame		32.67	19.60	-13.1	-40%	Aluminum
Suspension Arms Lh/Rh		15.61	10.92	-4.7	-30%	AHSS
Spring Damper Rear Lh/Rh	14.70	14.70	12.49	-2.2	-15%	
Engine/Transmission						
Engine	170.68	170.68	141.91	-28.77	-16.9%	Resize
Engine Oil	4.98	4.98	4.73	-0.25	-5%	Reduction due to resizing
Transmission	188.12	188.12	156.41	-31.71	-16.9%	Incls clutch/tourqe convertor system
Transmission Fluid	4.07	4.07	3.87	-0.20	-5%	Reduction due to resizing
Drive Shafts Lh/Rh	11.15	11.15	8.92	-2.2	-20%	AHSS
Exhaust System	48.92	48.92	46.47	-2.4	-5%	
Fuel System	22.08	22.08	19.44	-2.6	-12.0%	Incls fuel lines & tank
Fuel	56.63	56.63	49.84	-6.8	-12.0%	Existing fuel tank 18gal
Wheels	119.84					
Rim		48.38	41.12	-7.3	-15%	AHSS
Tire		54.10	48.69	-5.4	-10%	
Spare Wheel		16.68	15.01	-1.7	-10%	Est from similar vehicle size
Brakes Front (Complete)	33.02					
Front Rotors		20.62	16.50	-4.1	-20%	Cast Iron
Front Calipers		8.82	5.29	-3.5	-40%	Aluminum calipers
Brakes Rear (Complete)	25.18					
Rear Rotors		16.56	13.25	-3.3	-20%	
Rear Calipers		4.66	3.26	-1.4	-30%	Aluminum
Seats Front Driver/Passenger	46.95	46.95	32.86	-14.1	-30%	Composite & magnesium frame
Seat Rear (Plus 3rd Row where applicable)	25.41	25.41	17.79	-7.6	-30%	Composite & magnesium frame
Instrument Panel	29.75					
IP Beam		10.16	5.59	-4.6	-45%	Magnesium IP beam
Plastic trim		12.73	10.82	-1.9	-15%	
Instrumentation		6.87	5.15	-1.7	-25%	
Center Console	10.42	10.42	8.85	-1.6	-15%	
Trim Interior	40.77	40.77	34.65	-6.1	-15%	
Wiring	21.20	21.20	16.96	-4.2	-20%	Aluminum/copper
Battery	21.66	21.66	19.49	-2.2	-10%	
Lighting	7.57	7.57	6.06	-1.5	-20%	
HVAC & Cooling	26.75	26.75	21.40	-5.3	-20%	
Cooling System (Water)	15.10	15.10	13.59	-1.5	-10%	
Safety Systems	18.32					Seat belts,air bags & modules
Steering System	23.96	23.96	21.57	-2.4	-10%	
Wiper system (Minus washer fluid)	4.46	4.46	4.01	-0.4	-10%	Resize
Washer Fluid	5.04					
Noise Insulation	11.03	11.03	9.93	-1.1	-10%	
Glass (Windshield, back & side glass)	22.93					
Accessories	5.71					
Brackets/fastners/misc items	87.10					
Total with Powertrain	1870.7	1608.0	1263.1	-344.9	-18.4%	
Total without Powertrain	1502.9	1240.1	956.2	-283.9	-18.9%	

Figure 382: Chrysler 300 sub-system / component weight savings

8.6.5 Minivans

The baseline vehicle selected for the Minivan segment is a Toyota Sienna with a production year of 2011 manufactured in the US for the North American market; this vehicle has a weight of 2153.8kg.

The results for the Toyota Sienna are shown in Figure 400. For the body structure a 20% mass reduction with the adoption of AHSS is assumed. This is 3% lower than the detailed design LWV body structure mass. The lower mass saving percentage applied reflects the newer 2011 model year for the Toyota Sienna baseline vehicle, which probably uses higher percentage of high strength steel (HSS).   For the body structure the mass saving is equivalent to 89.6kg. For all the closures, which include hood, fenders, front & rear doors and the tailgate, in aluminum leads to mass saving of 55.7kg. The percentage mass reduction applied to the closures is 45% as shown in Figure 381. These numbers are of the same order as what was achieved for the LWV design.

The Toyota Sienna front suspension MacPherson strut design is shown in Figure 382. It utilizes steel K-Frame (engine cradle) and steel for other suspension components. For light weighting the K-Frame with use of AHSS construction and other selected suspension components in aluminium, leads to a mass reduction of 18.3kg.

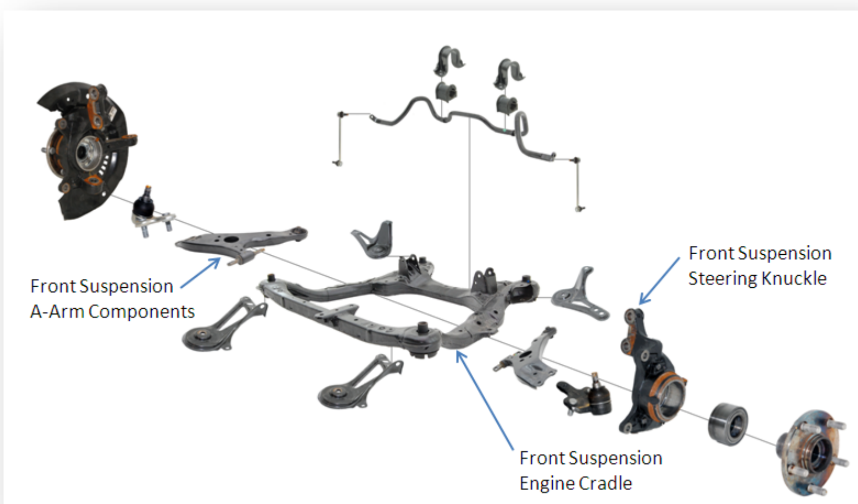


Figure 383: Toyota front suspension[184]

The Toyota rear suspension uses a steel torsion bar/axle as shown in Figure 384. The estimated mass saving for the rear suspension components is 6.8kg.

[184] A2Mac1

Figure 384: Toyota rear suspension showing torsion bar/axle[185]

High weight of seats for the Toyota Sienna 180 kg (47kg Driver and Front Passenger and 133.7kg second and third row) is a consequence of the functionality of the vehicle which seats 7 people and needs to allow access to the 3rd row rear seats. Figure 385 shows the Toyota Sienna 3rd row rear seat arrangement. Estimated mass saving for all the seats is 54.1 kg, using similar seating technology specified for the LWV, discussed in Section 5 of this report.

Figure 385: Toyota Sienna 3rd row rear seat[186]

As a result of all the proposed light weighting options implemented as shown in Figure 386, a total weight savings of 396.3kg (18.4%) is achieved. This reduction includes 70.1kg due to powertrain downsizing and 9.6 kg for resizing the fuel system, while maintaining vehicle size and vehicle performance functionalities.

[185] A2Mac1
[186] A2Mac1

Toyota Sienna LTD
Weight kg: 2153.79
Model Year: 2011
Power Train: 3.9Lt (Gasoline) 266hp. Transmission: Automatic. Drive: AWD Permanent
Market: North America. Manf Plant: USA.
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)	447.79	447.79	358.23	-89.6	-20%	Advanced Hight Streength Steel (AHSS)
Paint	16.00					Estimated by body size
Door Front Lh/Rh (Complete)	77.93					Incls trim/hardware, glass, paint & sealer
Frame		40.08	22.05	-18.0	-45%	Aluminum stampings inner/outer
Trim		6.73	6.06	-0.7	-10%	Soft trim panel only
Door Rear Lh/Rh (Complete)	100.94					Incls trim/hardware, glass, paint & sealer
Frame		46.93	25.81	-21.1	-45%	Aluminum stampings inner/outer
Trim		5.57	5.01	-0.6	-10%	Soft trim panel only
Hood (Complete)	14.69					Incls trim/hardware, glass, paint & sealer
Frame		12.79	7.03	-5.8	-45%	Aluminum stampings inner/outer
Trim		0.23	0.20	0.0	-10%	Soft trim panel only
Decklid/Tailgate (Complete)	42.99					Incls trim/hardware, glass, paint & sealer
Frame		18.03	9.92	-8.1	-45%	Aluminum stampings inner/outer
Trim		2.82	2.54	-0.3	-10%	Soft trim panel only
Fenders Front/Rear	6.27	6.27	3.45	-2.8	-45%	Aluminium stamping
Bumpers Front (Complete)	17.09					
Front Bumper Beam		7.99	5.19	-2.8	-35%	AHSS Hot Stamping
Front Fascia (Minus bumper beam)		9.09	8.18	-0.9	-10%	
Bumpers Rear (Complete)	18.70					
Rear Bumper Beam		9.97	6.48	-3.5	-35%	AHSS Hot Stamping
Rear Fascia (Minus bumper beam)		8.73	7.85	-0.9	-10%	
Front Suspension (Complete with-out damper)	68.46					Assembly - various materials
Frame		27.43	19.20	-8.2	-30%	Aluminum
Suspension Arms Lh/Rh		18.28	12.80	-5.5	-30%	AHSS
Knuckle Lh/Rh		11.54	6.93	-4.6	-40%	Aluminum
Spring damper Front Lh/Rh	22.50	22.50	20.25	-2.2	-10%	
Rear Suspension (Complete with-out damper)	43.26					Assembly - various materials
Frame		33.95	27.16	-6.8	-20%	AHSS
Suspension Arms Lh/Rh						
Spring Damper Rear Lh/Rh	13.40	13.40	12.06	-1.3	-10%	
Engine/Transmission						
Engine	165.30	165.30	131.49	-33.81	-20.5%	Resize
Engine Oil	5.33	5.33	5.06	-0.27	-5%	Reduction due to resizing
Transmission	174.47	174.47	138.78	-35.68	-20.5%	Incls clutch/tourqe convertor system
Transmission Fluid	5.57	5.57	5.30	-0.28	-5%	Reduction due to resizing
Drive Shafts Lh/Rh	18.79	18.79	15.03	-3.8	-20%	AHSS
Exhaust System	36.48	36.48	32.83	-3.6	-10%	
Fuel System	23.74	23.74	20.90	-2.8	-12.0%	Incls fuel lines & tank
Fuel	56.65	56.65	49.88	-6.8	-12.0%	Existing tank 20.8 gal
Wheels	126.58					
Rim		63.57	54.03	-9.5	-15%	AHSS
Tire		62.70	56.43	-6.3	-10%	
Spare Wheel	16.68	16.68	15.01	-1.7	-10%	Est from similar vehicle size
Brakes Front (Complete)	34.94					
Front Rotors		17.99	14.40	-3.6	-20%	
Front Calipers		13.84	8.30	-5.5	-40%	Aluminum calipers
Brakes Rear (Complete)	22.53					
Rear Rotors		11.35	9.08	-2.3	-20%	
Rear Calipers		9.40	5.64	-3.8	-40%	Aluminum calipers
Seats Front Driver/Passenger	46.92	46.92	32.85	-14.1	-30%	Composite & magnesium frame
Seat Rear (Plus 3rd Row where applicable)	133.73	133.73	93.61	-40.1	-30%	Composite & magnesium frame
Instrument Panel	33.50					
IP Beam		10.94	6.02	-4.9	-45%	Magnesium IP beam
Plastic trim		14.19	12.06	-2.1	-15%	
Instrumentation		8.37	7.11	-1.3	-15%	
Center Console	11.42	11.42	10.28	-1.1	-10%	
Trim Interior	42.21	42.21	35.88	-6.3	-15%	
Wiring	27.62	27.62	22.09	-5.5	-20%	Aluminum/copper
Battery	19.29	19.29	17.36	-1.9	-10%	
Lighting	10.77	10.77	8.62	-2.2	-20%	
HVAC & Cooling	37.30	37.30	29.84	-7.5	-20%	
Cooling System (Water)	11.02	11.02	9.92	-1.1	-10%	
Safety Systems	22.92					Seat belts,air bags & modules
Steering System	24.65	24.65	20.95	-3.7	-15%	
Wiper system (Minus washer fluid)	6.16	6.16	5.54	-0.6	-10%	Resize
Washer Fluid	3.83					
Noise Insulation	3.87	3.87	3.48	-0.4	-10%	
Glass (Windshield, back & side glass)	26.96					
Accessories	18.88					
Brackets/fastners/misc items	95.67					
Total with Powertrain	2153.8	1840.5	1444.2	-396.3	-18.4%	
Total without Powertrain	1803.1	1489.8	1163.6	-326.2	-18.1%	

Figure 386: Toyota Sienna sub-system / component weight savings.

8.6.6 Small CUV/SUV/trucks

The baseline vehicle selected for the Small SUV segment is a Honda CR-V which was produced in 2006, in the UK for the European market, vehicle weight1540.6kg.

The results for the Honda CR-V are shown in Figure 381. For the body structure a 22% mass reduction with the adoption of AHSS is assumed. This is 1% lower than the detailed design LWV body structure mass. For the body structure the mass saving is equivalent to 64.7kg. For all the closures, which include hood, fenders, front & rear doors and the tailgate, in aluminum leads to mass saving of 33.1kg. The percentage mass reduction applied to the closures is 35% to 45%. These numbers are approximately 5% to 10% lower than what was achieved for the LWV design. The Honda CR-V front and rear doors frames are already of light weight steel construction, therefore it was judged that 35% mass reduction will be achieved by the application of aluminum.

The Honda CR-V front suspension a MacPherson strut design is shown in Figure 387. It utilizes steel K-Frame and suspension components. For light weighting the K-Frame with use of AHSS construction and with other selected suspension components in aluminium, leads to a mass reduction of 19.8kg and for the rear suspension a mass saving of 9.4kg.

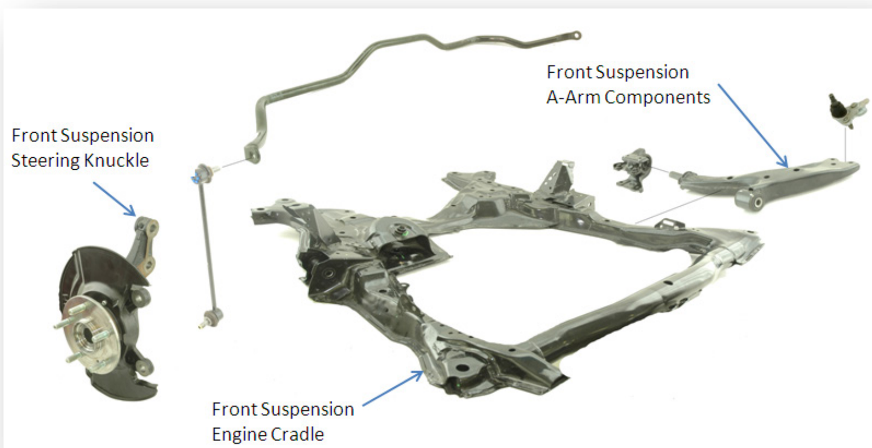


Figure 387: Honda CR-V front suspension[187]

As a result of all the proposed light weighting options implemented as shown in Figure 388, a total weight savings of 286.1kg (18.6%) is achieved. This reduction includes 50.2kg due to powertrain downsizing and 7.4 kg for resizing the fuel system, while maintaining vehicle size and vehicle performance functionalities.

[187] A2Mac1

Honda CR-V 2.0
Weight kg: 1540.55
Model Year: 2006
Power Train: 2.0 (Gasoline) 150hp. Transmission: Manual. Drive: AWD Semi-permanent
Market: Europe. Manf Plant: UK.
Seat Capicity: 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)	294.00	294.00	229.32	-64.7	-22%	Advanced Hight Streength Steel (AHSS)
Paint	14.00					Estimated by body size
Door Front Lh/Rh (Complete)	69.19					Incls trim/hardware, glass, paint & sealer
Frame		33.05	19.83	-13.2	-40%	Aluminum stampings inner/outer
Trim		5.95	5.36	-0.6	-10%	Soft trim panel only
Door Rear Lh/Rh (Complete)	49.02					Incls trim/hardware, glass, paint & sealer
Frame		25.41	17.79	-7.6	-30%	Aluminum stampings inner/outer
Trim		6.06	5.46	-0.6	-10%	Soft trim panel only
Hood (Complete)	14.44					Incls trim/hardware, glass, paint & sealer
Frame		10.89	5.99	-4.9	-45%	Aluminum stampings inner/outer
Trim						Soft trim panel only
Decklid/Tailgate (Complete)	24.80					Incls trim/hardware, glass, paint & sealer
Frame		11.06	6.08	-5.0	-45%	Aluminum stampings inner/outer
Trim		5.58	5.03	-0.6	-0.1	Soft trim panel only
Fenders left/right	5.25	5.25	2.89	-2.4	-45%	Aluminium stamping
Bumpers Front (Complete)	12.52					
Front Bumper Beam		3.45	3.11	-0.3	-10%	AHSS Hot Stamping
Front Fascia (Minus bumper beam)		9.07	8.16	-0.9	-10%	
Bumpers Rear (Complete)	9.44					
Rear Bumper Beam		3.60	2.88	-0.7	-20%	AHSS Hot Stamping
Rear Fascia (Minus bumper beam)		5.83	5.25	-0.6	-10%	
Front Suspension (Complete with-out damper)	63.42					
Frame		27.49	19.24	-8.2	-30%	Aluminum
Suspension Arms Lh/Rh		12.54	8.78	-3.8	-30%	AHSS
Knuckle Lh/Rh		17.34	9.54	-7.8	-45%	Aluminum
Spring damper Front Lh/Rh	18.43	18.43	16.58	-1.8	-10%	
Rear Suspension (Complete with-out damper)	52.57	21.26	18.07	-3.2	-0.2	
Frame		12.56	10.05	-2.5	-20%	AHSS
Suspension Arms Lh/Rh		18.75	15.00	-3.7	-0.2	AHSS
Spring Damper Rear Lh/Rh	10.28	10.28	9.25	-1.0	-10%	
Engine/Transmission						
Engine	113.53	113.53	88.64	-24.89	-21.9%	Resize
Engine Oil	3.27	3.27	3.11	-0.16	-5%	Reduction due to resizing
Transmission	115.44	115.44	90.14	-25.31	-21.9%	Incls clutch/tourqe convertor system
Transmission Fluid	2.01	2.01	1.91	-0.10	-5%	Reduction due to resizing
Drive Shafts Lh/Rh	14.33	14.33	11.46	-2.9	-20%	AHSS
Exhaust System	30.04	30.04	27.04	-3.0	-10%	
Fuel System	19.67	19.67	17.29	-2.4	-12.1%	Incls fuel lines & tank
Fuel (Existing tank 11 Gal)	41.46	41.46	36.45	-5.0	-12.1%	Reduce as per powertrain resizing
Wheels	130.77					
Rim		58.60	49.81	-8.8	-15%	AHSS
Tire		54.73	49.26	-5.5	-10%	
Spare Wheel		16.41	13.95	-2.5	-15%	Est from similar vehicle size
Brakes Front (Complete)	29.36					
Front Rotors		16.04	12.83	-3.2	-20%	
Front Calipers		11.05	6.63	-4.4	-40%	Aluminum calipers
Brakes Rear (Complete)	20.45					
Rear Rotors		10.22	8.17	-2.0	-20%	
Rear Calipers		5.49	4.39	-1.1	-0.2	
Seats Front Driver/Passenger	51.82	51.82	36.27	-15.5	-30%	Composite & magnesium frame
Seat Rear (Plus 3rd Row where applicable)	46.88	46.88	32.82	-14.1	-30%	Composite & magnesium frame
Instrument Panel	28.88					
IP Beam		11.14	6.13	-5.0	-45%	Magnesium IP beam
Plastic trim		12.31	10.47	-1.8	-15%	
Instrumentation		5.43	4.07	-1.4	-25%	
Center Console	3.92	3.92	3.53	-0.4	-10%	
Trim Interior	32.03	32.03	27.22	-4.8	-15%	
Wiring	17.03	17.03	13.62	-3.4	-20%	Aluminum/copper
Battery	14.67	14.67	13.20	-1.5	-10%	
Lighting	11.03	11.03	8.83	-2.2	-20%	
HVAC & Cooling	23.26	23.26	18.61	-4.7	-20%	
Cooling System (Water)	9.67	9.67	8.70	-1.0	-10%	
Safety Systems	21.08					Seat belts,air bags & modules
Steering System	25.51	25.51	21.68	-3.8	-15%	
Wiper system (Minus washer fluid)	7.51	7.51	6.76	-0.8	-10%	Resize
Washer Fluid	4.61					
Noise Insulation	3.92	3.92	3.53	-0.4	-10%	
Glass (Windshield, back & side glass)	17.93					
Accessories	3.45					
Brackets/fastners/misc items	59.70					
Total with Powertrain	1540.6	1346.3	1060.2	-286.1	-18.6%	
Total without Powertrain	1306.3	1112.0	876.4	-235.7	-18.0%	

Figure 388: Honda CR-V sub-system / component weight savings

8.6.7 Midsize CUV/SUV/trucks

The vehicle selected for the mid-sized SUV segment is an Audi Q5, production year 2009 manufactured in Germany for the European market with a vehicle weight of 1778.8kg.

The results for the Audi Q5 are shown in Figure 391. For the body structure a 20% mass reduction with the adoption of AHSS is assumed. This is 3% lower than the detailed design LWV body structure mass. For the body structure the mass saving is equivalent to 72.6kg. For all the closures in aluminum, leads to mass saving of 35.7kg. The percentage mass reduction applied to the closures is 35% to 45% as shown in Figure 391. These numbers are approximately 5% to 10% lower than what was achieved for the LWV design. The Audi Q5 front door frame is already of light weight steel construction, therefore a 35% mass reduction is applied.

The Audi Q5 has a relatively higher content of aluminium. For example aluminum is already implemented for the engine cradle, front suspension 'A' Arms and knuckles. Therefore the mass reduction for the front suspension is estimated to be only 2.7 kg. The front suspension components are shown in Figure 389.

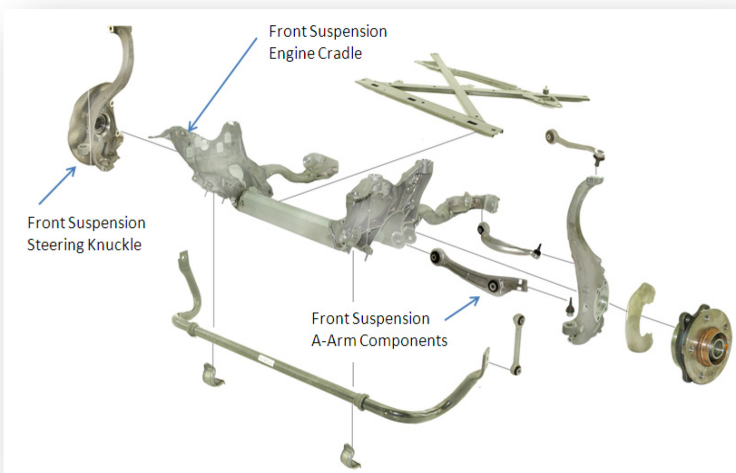


Figure 389: Audi Q5 front suspension[188]

The Audi-Q5 rear suspension shown in Figure 390, utilizes steel K-Frame and suspension components. For light weighting the K-Frame with use of AHSS construction with other selected suspension components in aluminium, leads to a mass reduction of 11.8kg.

[188] A2Mac1

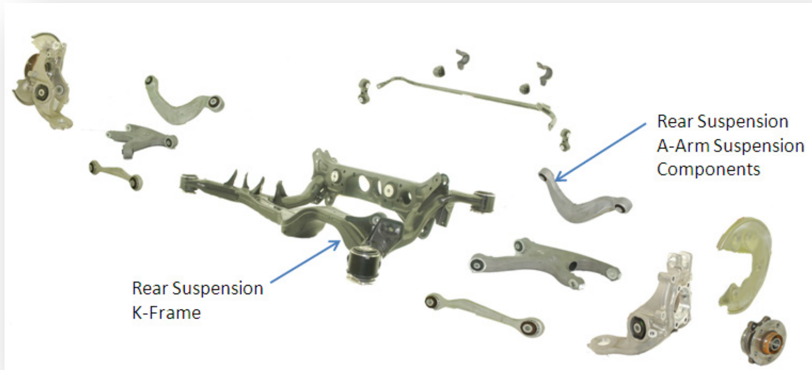


Figure 390: Audi Q5 rear suspension[189]

As a result of all the proposed light weighting options implemented as shown in Figure 391, a total weight savings of 289.1kg (16.3%) is achieved. This reduction includes 51.1kg due to powertrain downsizing and 9.0 kg for resizing the fuel system, while maintaining vehicle size and vehicle performance functionalities.

[189] A2Mac1

Audi Q5 2.0 TDi
Weight kg: 1778.81
Model Year: 2009
Power Train: 2.0 TDi (Diesel) 170hp. Transmission: Manual. Drive: AWD Non-permement
Market: Europe. Manf Plant: Germany Europe.
Seat Capicity: 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)	363.00	363.00	290.40	-72.6	-20%	Advanced Hight Streength Steel (AHSS)
Paint	14.00					Estimated by body size
Door Front Lh/Rh (Complete)	70.96					Incls trim/hardware, glass, paint & sealer
Frame		33.31	19.99	-13.3	-40%	Aluminum stampings inner/outer
Trim		7.14	6.43	-0.7	-10%	Soft trim panel only
Door Rear Lh/Rh (Complete)	54.66					Incls trim/hardware, glass, paint & sealer
Frame		26.09	16.96	-9.1	-35%	Aluminum stampings inner/outer
Trim		5.69	5.12	-0.6	-10%	Soft trim panel only
Hood (Complete)	15.79					Incls trim/hardware, glass, paint & sealer
Frame		11.89	6.54	-5.4	-45%	Aluminum stampings inner/outer
Trim		0.46	0.42	0.0	-10%	Soft trim panel only
Decklid/Tailgate (Complete)	27.97					Incls trim/hardware, glass, paint & sealer
Frame		11.12	6.11	-5.0	-45%	Aluminum stampings inner/outer
Trim		4.39	3.95	-0.4	-0.1	Soft trim panel only
Fenders Front/Rear	6.45	6.45	3.55	-2.9	-45%	Aluminium stamping
Bumpers Front (Complete)	14.33					
Front Bumper Beam		5.08	3.81	-1.3	-25%	AHSS Hot Stamping
Front Fascia (Minus bumper beam)		9.25	8.32	-0.9	-10%	
Bumpers Rear (Complete)	12.34					
Rear Bumper Beam		2.57	2.57	0.0	0%	AHSS Hot Stamping
Rear Fascia (Minus bumper beam)		9.77	8.79	-1.0	-10%	
Front Suspension (Complete with-out damper)	47.39					
Frame		11.48	10.33	-1.1	-10%	Audi frame is aluminium
Suspension Arms Lh/Rh		10.15	9.14	-1.0	-10%	Audi suspension arms are aluminium
Knuckle Lh/Rh		4.52	4.07	-0.5	-10%	Audi steering knuckel is aluminium
Spring damper Front Lh/Rh	20.76	20.76	18.68	-2.1	-10%	
Rear Suspension (Complete with-out damper)	59.19	20.15	16.12	-4.0	-0.2	
Frame		25.52	20.42	-5.1	-20%	AHSS
Suspension Arms Lh/Rh		13.51	10.81	-2.7	-20%	Aluminium
Spring Damper Rear Lh/Rh	11.70	11.70	10.53	-1.2	-10%	
Engine/Transmission						
Engine	160.37	160.37	134.64	-25.74	-16.0%	Resize
Engine Oil	4.79	4.79	4.55	-0.24	-5%	
Transmission	155.51	155.51	130.56	-24.96	-16.0%	Resize
Transmission Fluid	3.68	3.68	3.50	-0.18	-5%	
Drive Shafts Lh/Rh	10.69	10.69	8.55	-2.1	-20%	AHSS
Exhaust System	28.95	28.95	26.06	-2.9	-10%	
Fuel System	17.66	17.66	15.80	-1.9	-10.6%	Incls fuel lines & tank
Fuel	66.96	66.96	59.88	-7.1	-10.6%	Existing fuel tank 19.8 gal
Wheels	107.69					
Rim		43.54	37.01	-6.5	-15%	AHSS
Tire		64.66	58.19	-6.5	-10%	
Spare Wheel	16.68	16.68	15.01	-1.7	-10%	Est from similar vehicle size
Brakes Front (Complete)	36.76					
Front Rotors		19.73	15.78	-3.9	-20%	
Front Calipers		13.70	8.22	-5.5	-40%	Aluminum calipers
Brakes Rear (Complete)	21.78					
Rear Rotors		10.29	8.23	-2.1	-20%	
Rear Calipers		9.58	5.75	-3.8	-40%	Aluminum calipers
Seats Front Driver/Passenger	50.20	50.20	35.14	-15.1	-30%	Composite & magnesium frame
Seat Rear (Plus 3rd Row where applicable)	53.11	53.11	37.18	-15.9	-30%	Composite & magnesium frame
Instrument Panel	23.90					
IP Beam		6.42	4.82	-1.6	-25%	Magnesium IP beam
Plastic trim		12.56	10.68	-1.9	-15%	
Instrumentation		4.92	4.18	-0.7	-15%	
Center Console	4.47	4.47	4.03	-0.4	-10%	
Trim Interior	45.44	45.44	38.62	-6.8	-15%	
Wiring	25.97	25.97	20.78	-5.2	-20%	Aluminum/copper
Battery	26.76	26.76	24.08	-2.7	-10%	
Lighting	14.20	14.20	11.36	-2.8	-20%	
HVAC & Cooling	21.93	21.93	17.55	-4.4	-20%	
Cooling System (Water)	12.01	12.01	10.81	-1.2	-10%	
Safety Systems	15.64					Seat belts,air bags & modules
Steering System	23.50	23.50	21.15	-2.3	-10%	
Wiper system (Minus washer fluid)	5.61	5.61	5.05	-0.6	-10%	
Washer Fluid	4.29					
Noise Insulation	13.91	13.91	12.52	-1.4	-10%	
Glass (Windshield, back & side glass)	14.19					
Accessories	9.66					
Brackets/fastners/misc items	63.97					
Total with Powertrain	1778.8	1561.8	1272.7	-289.1	-16.3%	
Total without Powertrain	1454.5	1237.4	999.4	-238.0	-16.4%	

Figure 391: Audi Q5 sub-system / component weight savings.

8.6.8 Large CUV/SUV/light duty trucks

The baseline vehicle selected for the Large SUV/Light Duty Truck segment is a Ford F150 Lariat, production year 2003, manufactured in the US for the North American market with a vehicle weight of 2,406.4kg. This vehicle differs from all vehicles in the other segments, which are all of unibody construction, were the Ford F150 is of a body-on-frame construction. The F150 is also built with a rear pickup box with a standard truck type tailgate. See Figure 392 for Ford F150 body configuration.

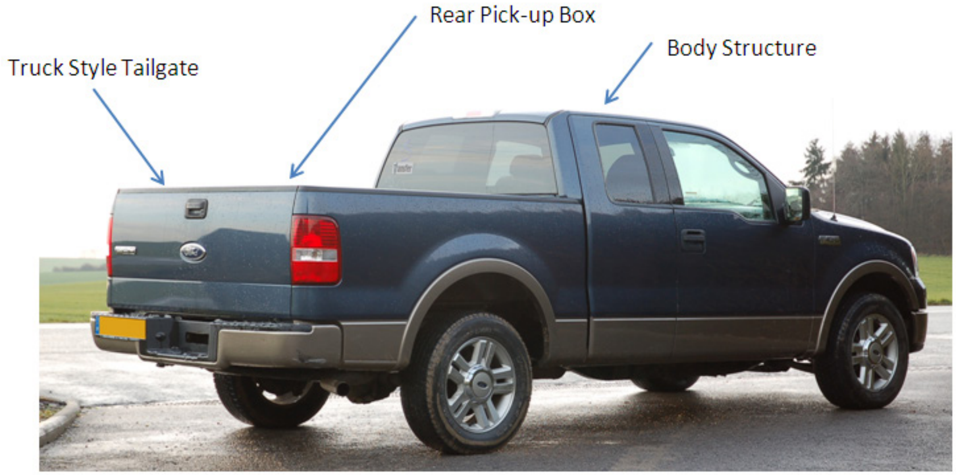


Figure 392: F150 Vehicle - Body structure, pick-up box and tailgate[190]

The Ford F150 being a vehicle with a body on frame construction, the underbody frame plays a greater role in crash performance. The suspension and powertrain are also directly mounted on to the frame structure. For crash performance and high strength required to react the suspension loads, advantage can be taken of advanced high strength steel (AHSS) to achieve a mass efficient structure with 15% (33 kg) mass saving.

The cab body structure shown in Figure 393 is mounted on to the frame through flexible rubber bushing to isolate the cab/occupants from vibration and structure borne noise. Apart from the vehicle roll over roof crush strength requirement the cab structure performance is mainly stiffness dependent. Due to the limited high crash loads seen by the cab structure, aluminum is chosen as the construction material. With choice of aluminum for the cab a mass reduction of up to 35% (93 kg) can be achieved.

[190] A2Mac1

Figure 393: F150 Cab body structure[191]

The rear pickup box shown in Figure 394 and tailgate remains as steel construction but with higher AHSS content leading to a mass reduction of 20.6kg.

Figure 394: F150 rear pick-up box[192]

With the hood, fenders and doors designed in aluminium, leads to mass saving of 33.1kg.The percentage mass reduction applied to the closures is 40% to 45% as shown in Figure 395. This is of the same order as what was achieved for the LWV design.

As a result of all the proposed light weighting options implemented as shown in Figure 395, a total weight savings of 465kg (19.3%) is achieved. This reduction includes 82.2kg due to powertrain downsizing and 12.6kg for resizing the fuel system, while maintaining vehicle size and vehicle performance functionalities.

[191] A2Mac1
[192] A2Mac1

Ford F150
Weight kg: 2406.36
Model Year: 2003
Power Train: 5.4Lt (Gasoline) 90hp. Transmission: Automatic. Drive: RWD
Market: North America. Manf Plant: USA.
Seat Capicity: 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)	265.10	265.10	172.32	-92.8	-35%	Aluminium stamping
Paint	10.00					Estimated by body size
Pick-up Box (Minus paint, sealer)	103.10	103.10	87.64	-15.5	-15%	Advanced Hight Streength Steel (AHSS)
Paint	8.00					Estimated
Chassis (Minus paint)	219.50	219.50	186.58	-32.9	-15%	AHSS
Paint	12.00					Estimated
Door Front Lh/Rh (Complete)	106.38					Incls trim/hardware, glass, paint & sealer
Frame		54.39	32.63	-21.8	-40%	Aluminum stampings inner/outer
Trim		6.00	5.40	-0.6	-10%	
Door Rear Lh/Rh (Complete)	69.56					Incls trim/hardware, glass, paint & sealer
Frame		40.43	24.26	-16.2	-40%	Aluminum stampings inner/outer
Trim		6.00	5.40	-0.6	-10%	
Hood (Complete)	19.49					Incls trim/hardware, glass, paint & sealer
Frame		10.50	5.77	-4.7	-45%	Aluminum stampings inner/outer
Trim		0.55	0.49	-0.1	-10%	Soft trim panel only
Decklid/Tailgate (Complete)	26.00					Incls trim/hardware, glass, paint & sealer
Frame		20.26	15.20	-5.1	-25%	AHSS
Trim		2.53	2.27	-0.3	-10%	Soft trim panel only
Fenders	15.37	15.37	8.45	-6.9	-45%	Aluminium stamping
Bumpers Front (Complete)	36.17					
Front Bumper Beam		19.72	10.85	-8.9	-45%	AHSS Hot Stamping
Front Fascia (Minus bumper beam)		16.45	14.81	-1.6	-10%	
Bumpers Rear (Complete)	29.59					
Rear Bumper Beam		17.09	11.11	-6.0	-35%	AHSS Hot Stamping
Rear Fascia (Minus bumper beam)		12.50	11.25	-1.3	-10%	
Front Suspension (Complete with-out damper)	68.00					
Frame						Suspension components direct to chassis
Suspension Arms Lh/Rh		23.70	16.59	-7.1	-30%	Aluminum
Knuckle Lh/Rh		28.34	17.01	-11.3	-40%	Aluminum
Spring damper Front Lh/Rh	24.75	24.75	22.27	-2.5	-10%	
Rear Suspension (Complete with-out damper)	62.12					
Rear Axle		52.63	42.10	-10.53	-20.0%	Solid rear axle
		n/a				
Spring Damper Rear Lh/Rh	62.52	62.52	56.26	-6.25	-10.0%	Incls shock & spring blade system
Engine/Transmission						
Engine	237.73	237.73	184.67	-53.07	-22.3%	Resize
Engine Oil	5.25	5.25	4.99	-0.26	-5%	Reduction due to resizing
Transmission	127.48	127.48	99.02	-28.46	-22.3%	Incls clutch/tourqe convertor system
Transmission Fluid	8.05	8.05	7.65	-0.40	-5%	Reduction due to resizing
Drive Shafts Lh/Rh	23.41	23.41	18.73	-4.7	-20%	AHSS
Exhaust System	65.58	65.58	59.02	-6.6	-10%	
Fuel System	23.33	23.33	20.40	-2.9	-12.6%	Incls fuel lines & tank
Fuel	77.38	77.38	67.66	-9.7	-12.6%	Existing tank 29.9 gal
Wheels	147.18					
Rim		51.74	43.98	-7.8	-15%	AHSS
Tire		60.04	54.03	-6.0	-10%	
Spare Wheel		32.15	27.33	-4.8	-15%	Est from similar vehicle size
Brakes Front (Complete)	50.85					
Front Rotors		29.71	23.77	-5.9	-20%	
Front Calipers		16.92	10.15	-6.8	-40%	Aluminum calipers
Brakes Rear (Complete)	30.19					
Rear Rotors		21.20	16.96	-4.2	-20%	
Rear Calipers		10.79	6.47	-4.3	-40%	Aluminum calipers
Seats Front Driver/Passenger	64.60	64.60	45.22	-19.4	-30%	Composite & magnesium frame
Seat Rear (Plus 3rd Row where applicable)	34.98	34.98	24.48	-10.5	-30%	Composite & magnesium frame
Instrument Panel	28.56					
IP Beam		13.17	7.24	-5.9	-45%	Magnesium IP beam
Plastic trim		9.52	8.09	-1.4	-15%	
Instrumentation		5.87	4.40	-1.5	-25%	
Center Console	9.23	9.23	8.31	-0.9	-10%	
Trim Interior	24.35	24.35	20.70	-3.7	-15%	
Wiring	24.54	24.54	19.63	-4.9	-20%	Aluminum/copper
Battery	21.79	21.79	19.61	-2.2	-10%	
Lighting	9.47	9.47	7.58	-1.9	-20%	
HVAC & Cooling	29.42	29.42	23.54	-5.9	-20%	
Cooling System (Water)	17.54	17.54	15.79	-1.8	-10%	
Safety Systems	26.12					Seat belts,air bags & modules
Steering System	36.24	36.24	30.80	-5.4	-15%	
Wiper system (Minus washer fluid)	5.63	5.63	5.07	-0.6	-10%	
Washer Fluid	3.74					
Noise Insulation	3.43	3.43	3.09	-0.3	-10%	
Glass (Windshield, back & side glass)	23.51					
Accessories	6.28					
Brackets/fastners/misc items	102.85					
Total with Powertrain	2406.4	2102.0	1637.0	-464.9	-19.3%	
Total without Powertrain	2027.8	1723.5	1340.7	-382.7	-18.9%	

Figure 395: Ford F150 sub-system / component weight reduction

8.7 Conclusions

The estimated mass reduction for the baseline vehicle in each class is shown in Figure 396. The mass saving potential for all the classes is in a range from 16.3% to 19.3%. This range of results is lower than the results obtained for the LWV mass reduction of 22.4%. This is mainly due the baseline Honda Accord front suspension change from double wish-bone to the MacPherson strut design implemented on LWV. Other material choices and manufacturing technologies implemented to achieve the mass reduction are similar to the detail design option of the LWV.

The baseline vehicle for the Large SUV/Light Duty Truck, the Ford F150 construction differs from vehicles in the other sub-classes as it has a body-on-frame construction with a rear pickup box and a conventional truck tailgate. The F150 had the highest weight at 2,406.4 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 other vehicles.

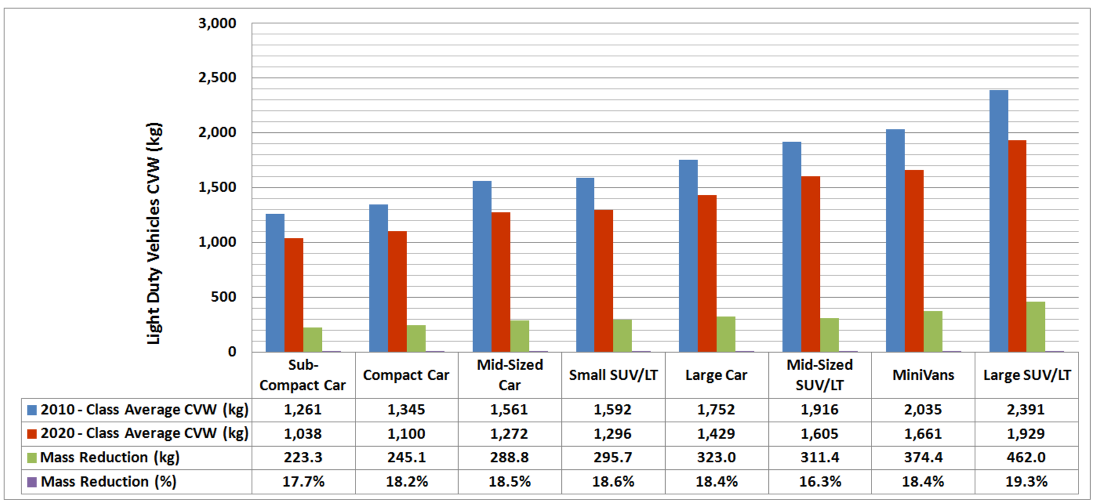
Vehicle Class	Selected Baseline Vehicle	Baseline Vehicle CVW (kg)	2020 - LWV CVW (kg)	Mass Reduction (kg)	Mass Reduction (%)
Sub-Compact Car	Ford Fiesta 1.6 TDCi (2008)	1,147	944	203	17.7%
Compact Car	Honda Civic 1.8 LX (2007)	1,252	1,024	228	18.2%
Mid-Sized Car	Honda Accord 2.2 i-DETC ES (2008)	1,550	1,263	287	18.5%
Large Car	Chrysler 300 C AWD (2006)	1,871	1,526	345	18.4%
MiniVans	Toyota Sienna LTD (2011)	2,154	1,758	396	18.4%
Small SUV/LT	Honda CR-V 2.0 (2006)	1,541	1,254	286	18.6%
Mid-Sized SUV/LT	Audi Q5 2.0 Tdi (2009)	1,779	1,490	289	16.3%
Large SUV/LT	Ford F150 (2003)	2,406	1,941	465	19.3%

Figure 396: Summary of vehicle sub-class weight saving results

In addition to the weight savings estimated for the selected vehicles within each sub-class, the percentage reduction determined from of the sub-classes results was applied to the average vehicle weight for each sub-class. Figure 397 and Figure 398 show the estimated 2020 Class average mass compared with the 2010 Vehicle Class averages.

Vehicle Class	2010 - Class Average CVW (kg)	2020 - Class Average CVW (kg)	Mass Reduction (kg)	Mass Reduction (%)
Sub-Compact Car	1,261	1,038	223.3	17.7%
Compact Car	1,345	1,100	245.1	18.2%
Mid-Sized Car	1,561	1,272	288.8	18.5%
Small SUV/LT	1,592	1,296	295.7	18.6%
Large Car	1,752	1,429	323.0	18.4%
Mid-Sized SUV/LT	1,916	1,605	311.4	16.3%
MiniVans	2,035	1,661	374.4	18.4%
Large SUV/LT	2,391	1,929	462.0	19.3%
Light Duty Vehicle Average	1,732	1,416	315.5	18.2%

Figure 397: Comparison between 2010 and 2020 Class Average weights



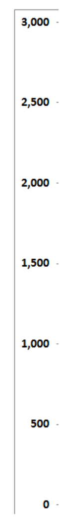


Figure 398: Comparison between 2010 and 2020 Class Average weights

In conclusion all of the weight reduction technologies developed for the LWV program using the Honda Accord as the baseline vehicle can readily be introduced to all of the selected vehicles within each of the vehicle sub-classes, sub-compact to large SUV/light truck, to achieve weight savings from 16.3% to 19.3%.

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 LWV, 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.

8.8 Data Sources:

1. www.leftlanenews.com
2. www.zeroto60times.com
3. www.Edmunds.com
4. www.automobile-catalogue.com
5. www.carguideweb.com
6. www.chevrolet.com
7. www.mazdausa.com
8. www.kia.com
9. www.suzukiauto.com
10. www.miniusa.com
11. www.scion.com
12. www.saabusa.com
13. www.chrysler.com
14. www.dodge.com
15. www.rolls-roycemotorcars.com
16. http://www.gminsidenews.com/forums/gallery/showphoto.php?photo=7142&size=big&cat
17. www.buyersguide.carnaddriver.com
18. www.finance.yahoo.com
19. www.marketwatch.com
20. www.newcarnet.tv
21. www.carsdirect.com
22. www.nissanusa.com
23. www.ford.com
24. http://www-nrd.nhtsa.dot.gov/pubs/809979.pdf
25. http://online.wsj.com/mdc/public/page/2_3022-autosales.html

9 Incremental Cost Analysis on Mid-size Vehicle (Optional Task 2)

9.1 Background

The project team performed an incremental cost analysis on a Honda Accord LWV in this study. The cost in the study uses 2010 dollars. All material costs in this study are 2010 cost because accurately forecasting variables such as future material prices and future labor rates are very challenging and, at times, can yield unpredictable results. There are statistical methods available for predicting the future material prices or labor rates such as regression analysis. However, these predictions are mainly based on the past trends; there are unpredictable global economic conditions such as the financial crisis of 2008-2009 that have an impact on the actual prices. All the estimated technology costs shown in this report represent costs of the LWV as of model year 2010. EDAG has applied learning to the immature technologies, specifically laser welding, so that the cost of that technology is reduced from currently cost to MY2020 cost.

EDAG used two cost assessment methods to establish the baseline vehicle and LWV costs due to the different design levels of the LWV components, their corresponding manufacturing technologies and component source (i.e., OEMs or suppliers). The two methods include:

- Technical Cost Modeling[193] - The team applied a Technical Cost Modeling (TCM) approach to the entire body structure, 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 a higher potential for weight savings. These vehicle systems were then re-designed to reduce weight by EDAG and confirmed they meet the same performance and safety requirements through CAE analysis. The detailed design data provided all of the inputs necessary to perform a technical cost assessment. The technical cost modeling methodology is explained in detail in Section 9.4.
- Supplier Assessments – The team obtained the anticipated mass reduction technologies and the corresponding estimated cost to the OEM for the year 2020 from the leading suppliers of each respective system or componentor 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[194] and through available internal expertise at EDAG (using previous benchmarking and sourcing data).

[193] Frank Field, Randolph Kirchain and 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

[194] "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 Last accessed February 9, 2012

The two cost assessment methods discussed above allowed the team to calculate the 'OEM Manufacturing Cost' including the purchased costs of all the supplier parts for the baseline Accord and the LWV.

Even though the primary focus of the LWV 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 door components results in a projected cost decrease compared to the equivalent stamped baseline designs. Similarly, there was significant mass savings with negligible incremental costs by replacing the double wishbone front suspension with a MacPherson strut system. Some of the design changes adopted for the LWV that result in lower costs are specific to the Honda Accord LWV and may not be possible in another vehicle that does not share the same design features. Additionally, the LWV designs of certain systems reduced the overall number of components. For example, the optimized LWV front bumper design using a hot stamped bumper beam eliminated local reinforcements in the baseline front bumper. Such cost savings due to increased technology efficiencies and part consolidation could be applied to a 2020 baseline vehicle as well even if mass reduction is not the primary goal.

9.2 Approach

The incremental costs of majority of the LWV components were estimated by EDAG using the TCM approach developed by the Massachusetts Institute of Technology (MIT) Materials Systems Laboratory's researchers[195]. 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 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.

9.2.1 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

[195] Frank Field, Randolph Kirchain and 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

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)[196]. 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 utilized 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[197] 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 LWV design along with the detailed costs elements.

9.2.2 TCM History and Usage

TCM was initially developed to support the World Auto Steel ULSAB-AVC (Ultra Light Steel Auto Body - Advanced Vehicle Concepts), a program intended "to demonstrate and communicate steel's capability to help fulfill society's demands for safe, affordable and environmentally responsible vehicles for the 21st Century."[198] Subsequently, EDAG expanded the cost model to support the Future Steel Vehicle program which assessed body structure costs while also applying future manufacturing technologies.[199] 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 LWV. TCM model is also employed by the Department of Energy for costing exercises for its vehicle technologies program. Other examples of TCM model application in automotive related studies include "Cost Modeling of Fuel Cell Systems for Automobiles"[200] and "Economic Assessment of Alternative Manufacturing Processes for the Camshaft[201]. Major Components of the Cost Model

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[196]Stewart, Richard M. Wyskida, James D. Johannes: Cost Estimator's Reference
[197] Inputs such as equipment type, cycle time etc. specific to the process
[198]http://www.worldautosteel.org/Projects/ULSAB-AVC/Programme-Detail.aspx (last accessed February 9, 2012)
[199]http://www.worldautosteel.org/Projects/Future-Steel-Vehicle.aspx

[201]Nallicheri, N., Clark, J., and Field, F., "An Economic Assessment of Alternative Manufacturing Processes for the Camshaft," SAE Technical Paper 901741, 1990, doi:10.4271/901741.

For the LWV incremental cost assessment, only the direct costs for manufacturing the parts and assembly of the parts were considered. The engineers assumed that paint shop costs are neutral because the exterior (styling and surface area) of the LWV is the same as the baseline vehicle. Similarly, they assumed the costs would be the same for the final trim assembly line since there are no changes made to the overall assembly of the LWV. 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 (e.g., pallets, equipment, shipping labor, etc.)
- Non-dedicated investment for plant not directly connected to the manufacturing or assembly process (e.g., IT, administration)
- Hourly and salaried labor not directly connected to the manufacturing process (e.g., maintenance and sales)
- 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

9.3 Cost Model Assumptions

9.3.1 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 (or a facility new from the ground up) in the United States. The cost assessment encompassed the raw material (steel, aluminum alloy etc.) entering the plant to the complete vehicles leaving.

Honda Accord's typical life-cycle has been five years, with mid-life cycle face lift changes.[202] The mid-life cycle face lift changes to the vehicle are usually changes such as interior upgrades

[202] http://www.edmunds.com/honda/accord/history.html

that do not involve major design changes. The researchers used an annual production volume of 200,000 with a production life of five years for the cost assessment in order to represent an average high sales volume vehicle. The other general cost model inputs that are typical of a high volume manufacturing facility are summarized in Figure 399.

Parameters	Assumptions
Cost Model Scope	Only Direct Manufacturing and Assembly Costs[203]
Annual Production Volume	200,000 parts/year
Production Location	USA
Building Unit Cost	$1,500/Square Meter
Building Life	25 Years
Production Life	5 years
Working Days	240 days/year
Number of Shifts per Day	2
Hours per Shift	8 hours
Unplanned Downtime per Day	1 hour
Unpaid Breaks per Shift	0.5 hour
Annual Available Plant Time	3360 hours[204]
Annual Paid Time for Two Shift per Day	3600 hours[205]

Figure 399: Cost Model General Assumptions

9.3.2 Cost Model Tooling 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. Any design change made to a component necessitates a manufacturing tooling change in most of the cases. These tooling changes can range from minor design changes (cost neutral or low cost impact) to requiring completely new tool designs (high cost impact). Therefore, most any design change, irrespective of the degree of the change, results in a change in tooling cost. Moreover, the tooling costs are directly linked to the specific fabricated or assembled part because a unique set of tools is required for every component or system. As mentioned earlier, the direct costs include the costs that can be directly related to the total manufacturing costs of the vehicle; hence the team assumed that tooling costs are part of the direct costs.

[203] OEM indirect costs are estimated using RPE multiplier.
[204] (2 shift/day x 8 hrs/shift -1 hr – 2shift/day x 0.5 hrs) x 240 days/year = 3360 hrs
[205] (2 shift/day x 8 hrs/shift -1 hr) x 240 days/year = 3600 hrs

Further, since the tooling investment is unique for each part, the amortization period of the tooling investment is the tool life which is the duration of the respective program (5 years in this study). The tooling assumptions are summarized in Figure 400.

Parameter	Tooling Assumptions
Interest Rate	**7.03%[206]**
Amortization Period	**5 years**

Figure 400: Tooling Investment Assumptions

9.3.3 Cost Model Equipment 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 majority of the equipment used in manufacturing sheet metal parts in the body structure and closures, the team assumed the amortization period is twenty years. The useful life of most of the assembly equipment (welding, transfer robots etc.) is the same as the life of two programs (10 years) according to the experience of assembly experts at EDAG and feedback from other suppliers[207]. The equipment assumptions are summarized in Figure 401.

Parameter	Equipment Assumptions
Interest Rate	**7.03%[208]**
Amortization Period (Manufacturing Equipment)	**20 years**
Amortization Period (Assembly Equipment)	**10 years**

Figure 401: Equipment Investment Assumptions

9.4 Cost Modeling Process

9.4.1 Manufacturing Cost Modeling Process

As discussed above, the TCM uses an approach in which each of the elements that contribute to the fabrication cost is estimated individually; the final manufacturing cost is a sum total of all the cost elements. The manufacturing cost assessment methodology is illustrated in Figure 402. The

[206] Automotive Cost of Capital as of January, 2011: http://www.stern.nyu.edu/~adamodar/pc/archives/wacc10.xls
[207] "The second main pillar of EDAG's services is the development of complete production systems. In addition to the engineering services we provide, we also, in conjunction with our sister company FFT EDAG Produktionssysteme, implement turn-key production facilities for body in white and vehicle assembly plants." http://www.edag.de/en/automotive-industry.html (last accessed February 9, 2012)
[208] Automotive Cost of Capital as of January, 2011: http://www.stern.nyu.edu/~adamodar/pc/archives/wacc10.xls

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 process information sheets for all the key information from engineering review
4) Input the component specific parameters into the Part Cost Model

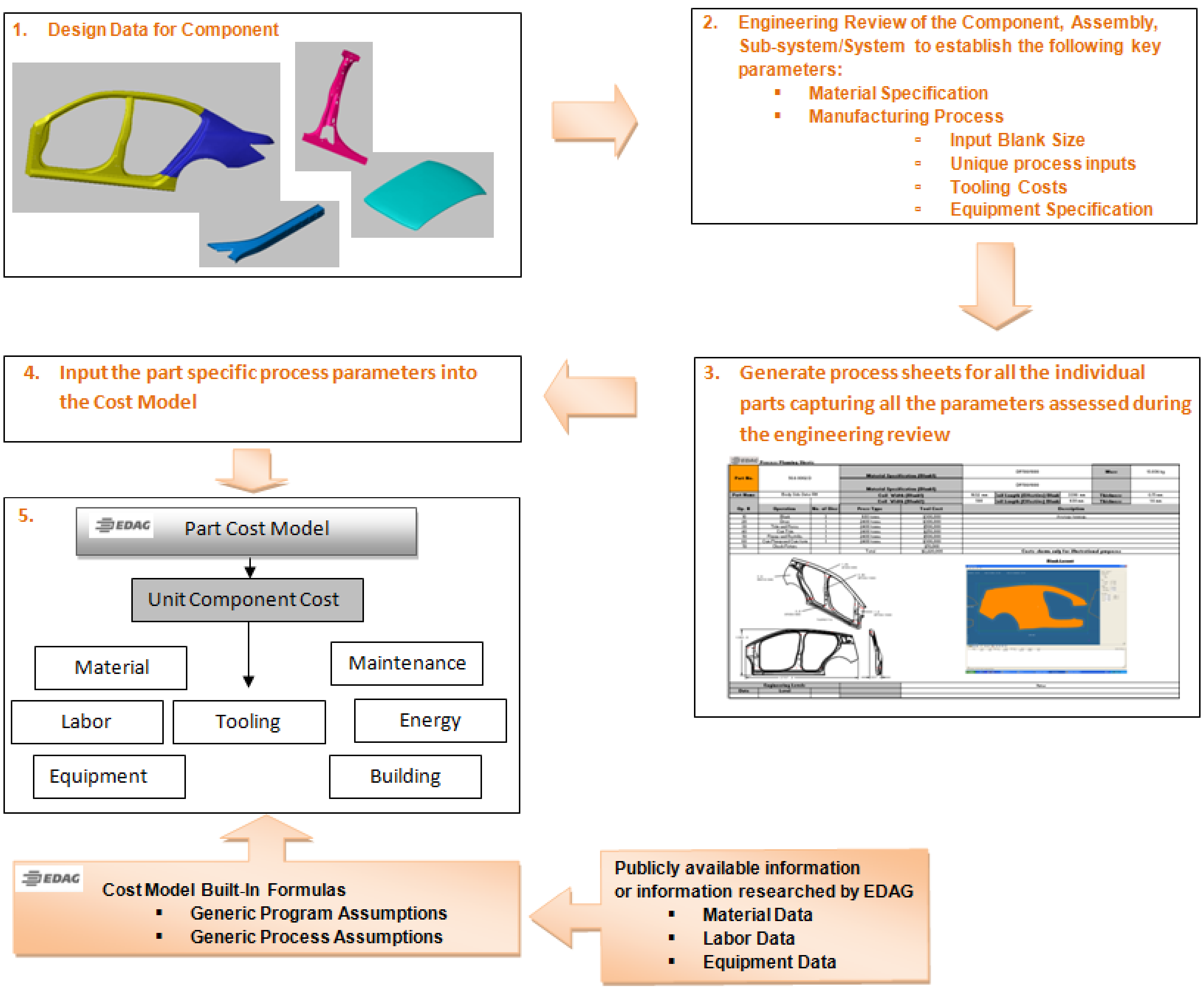

Figure 402: Fundamental Steps in Part Manufacturing Cost Assessment

9.4.2 Assembly Cost Modeling Process

The assembly costs of the body structure and other sub-systems were estimated using a technical cost modeling approach similar to the manufacturing cost assessment methodology explained in Section 9.4.1. However, the key parameters for the assembly cost assessment were established based on a detailed engineering review of each individual assembly or sub-assembly[209].

The assembly cost assessment methodology is illustrated in Figure 403. 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 bond (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

[209] The scope of this cost study was only an incremental cost analysis; the assembly costs were assessed only for the systems with different assembly structure compared to the baseline.

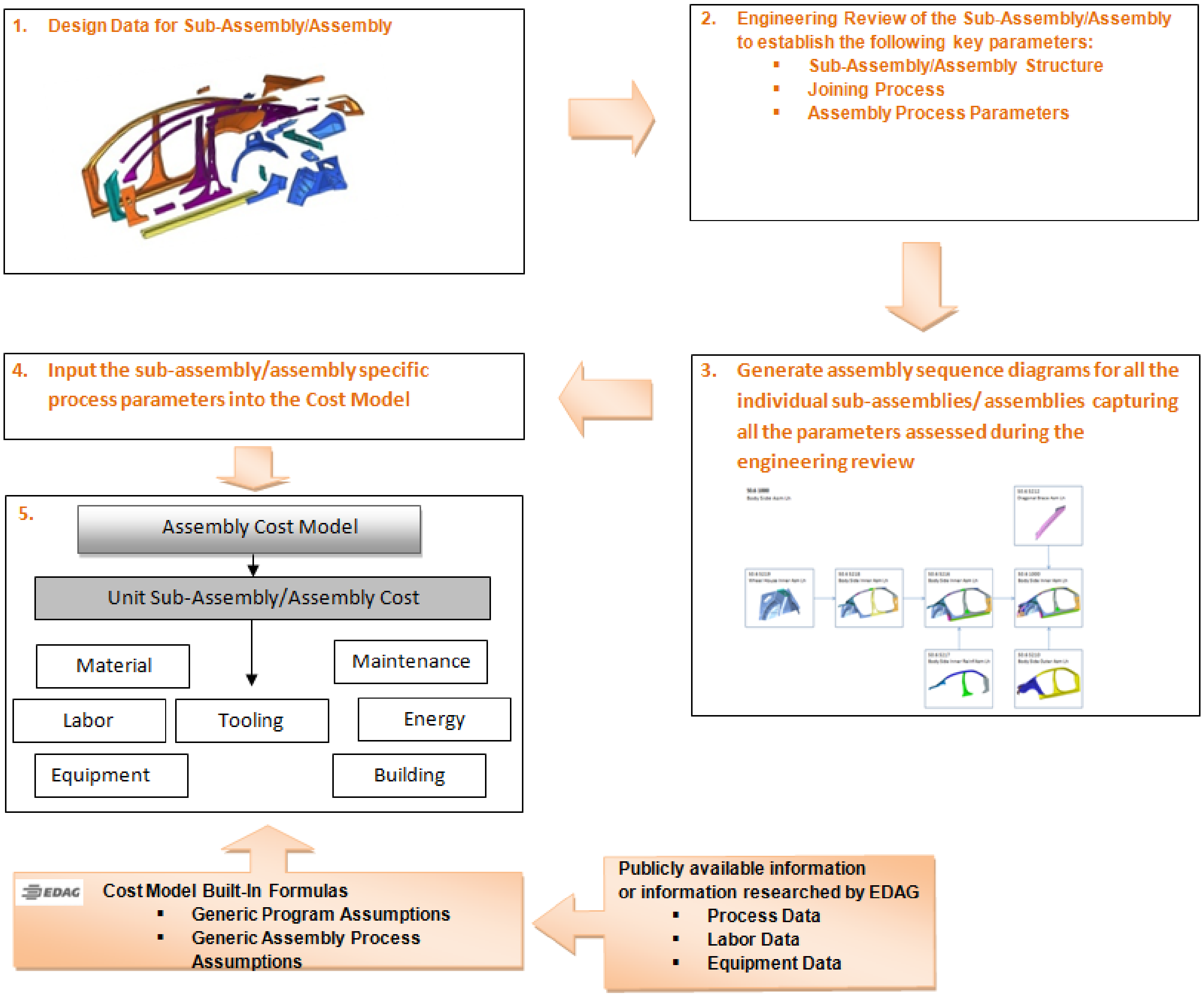

Figure 403: Fundamental Steps in Assembly Cost Assessment

9.4.3 Special Consideration for Purchased Parts

Since this study only estimates the purchased part 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 (SG&A) and profit to determine the final purchased price of the sub-system.

9.4.3.1 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

- 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 between 4-6 % 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 applied was 4.5%. This mark-up rate was attained based on Intellicosting's prior consulting and sourcing projects data.

9.4.3.2 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% based on historical data available from suppliers and OEMs. Also, all the purchased items analyzed in this study are mature with respect to the manufacturing feasibility and supplier availability.

9.4.4 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 (explained in Sections 9.4.1 and 0) 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 etc. 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 Retail Price Equivalent (RPE) multiplier (specific RPE multiplier for Honda, 1.47 used for this study)[210], to determine the retail price of the LWV.

[210]Source: Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers" EPA report EPA-420-R-09-003, February 2009

9.5 Cost Model Inputs

9.5.1 Raw Material Cost

Raw material pricing is an important assumption for cost estimates. Accurately forecasting future material prices is very challenging. Adding to the challenges, material prices can undergo volatility both over time and across geographic locations. For example the fluctuation of cold rolled steel is shown in Figure 404; this volatility is not exclusive to any particular material but the magnitude can vary, especially for materials such as precious metals. As already mentioned, predictions using methods such as regressions analysis are mainly based on the past price trends of the particular material and there could be unpredictable global economic conditions with a significant impact on the material prices.

For the LWV study, material price assumptions were based on the average of the available North American 2011 material prices data adjusted to 2010 dollars by using a the gross domestic product (GDP)[211] 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 a published source were established based on consultation with industry experts including data from manufacturers of components using the specific material.

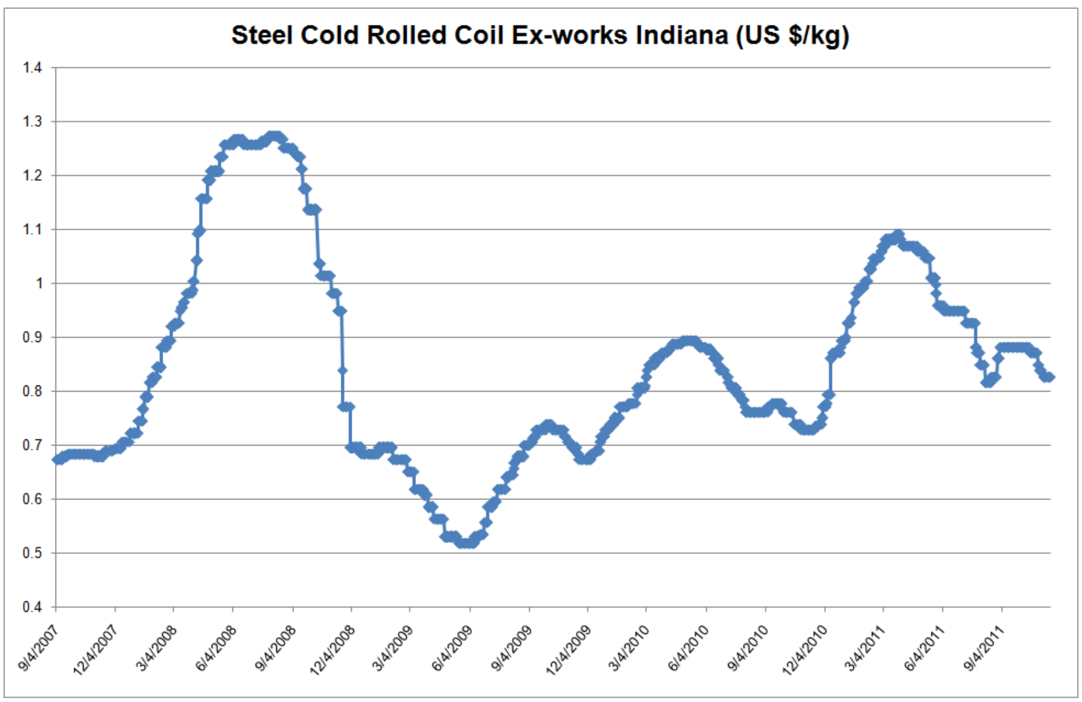

Figure 404: Steel (cold rolled coil) Ex-works Indiana prices[212]

[211]See Table 1.1.9: Implicit Price Deflators for Gross Domestic Product, Bureau of Economic Analysis, U.S. Department of Commerce. Available at http://www.bea.gov/national/nipaweb/TableView.asp?SelectedTable=13&Freq=Qtr&FirstYear=2001&LastYear=2011. Last accessed, February 14, 2012."

[212]Source: Platts (Nominal Prices)

9.5.2 Steel Prices

The fluctuation of the cold rolled steel coil base prices throughout 2011 are shown in Figure 405 including the nominal prices and the prices adjusted to 2010 dollars. The team used the 2011 average steel price for the LWV cost assessment, $0.93 USD/kg adjusted to 2010 dollars.

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 (HD), tailor rolled coils and tubes. 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 406. For example, if DP 700/1000 is the specified material for a part, a grade premium of $0.38 is added to $0.93 to get the material price of $1.31 USD/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 $1.86 USD/kg.

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[213]. Hence a base price of $1.5 /kg for cast iron was assumed for this study based on benchmarking data[214].

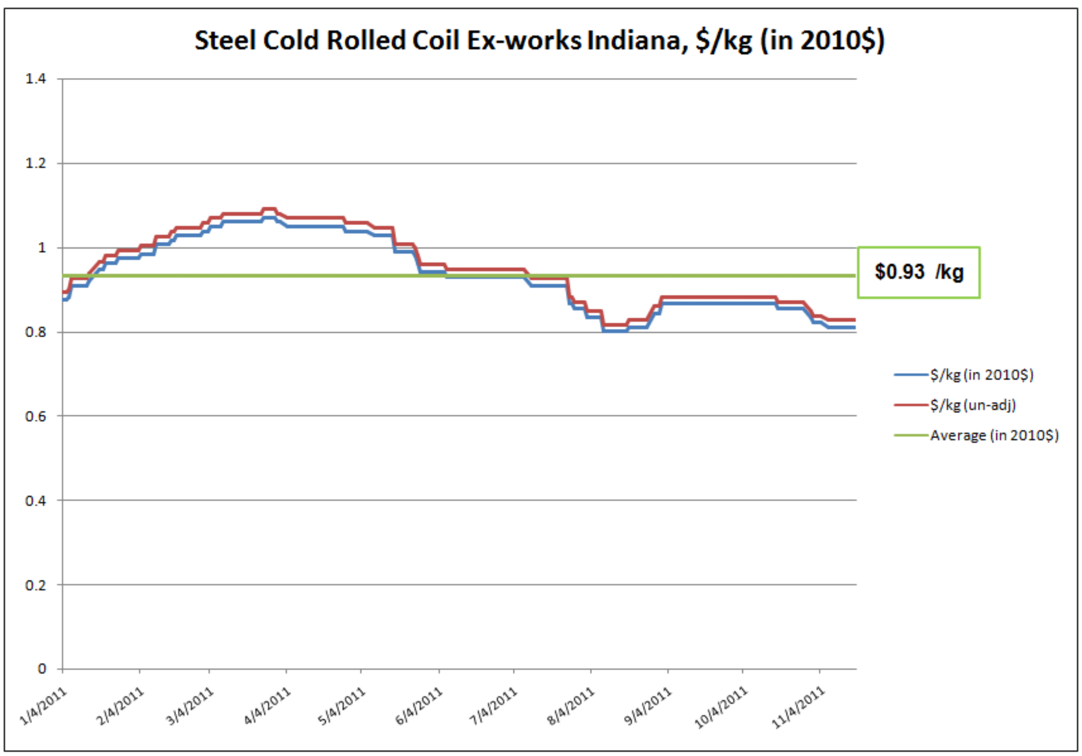

Figure 405: 2011 Prices of Steel Cold Rolled Coil Ex-works Indiana, $/kg adjusted to 2010 dollars[215]

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[213] Platts, Metal prices

[214] EDAG/Intellicosting design and sourcing consultation projects

Item #	Steel Grade	Ref Material Price ($/kg)	Grade	HDG	Exposed	Tailor Rolled Coil	Tubes (straight, as shipped)	Multiwall Tube Blank
			Premium ($/kg)	Premium ($/kg)	Premium ($/kg)	Premium ($/kg)	Premium ($/kg)	Premium ($/kg)
1	Cold Rolled Reference - Mild 140/270	**0.93**	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**		0.10	0.55	0.30	0.70
6	IF 300/420		**0.10**		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**	0.00	NA	0.55	0.45	1.25
9	HSLA 490/600		**0.16**	0.00	NA	0.55	0.45	1.65
10	HSLA 550/650		**0.35**	0.00	NA	0.55	0.45	1.65
11	HSLA 700/780		**-**	-	-	-	-	-
12	SF 570/640		**0.35**	0.00	NA	NA	0.45	2.05
13	SF 600/780		**0.35**	0.00	NA	NA	0.45	2.05
14	TRIP 350/600		**0.40**	0.00	NA	NA	0.45	1.25
15	TRIP 400/700		**0.45**	0.00	NA	NA	0.45	1.65
16	TRIP 450/800		**0.50**	0.00	NA	NA	0.50	1.30
17	TRIP 600/980		**0.55**	0.00	NA	NA	0.55	1.35
18	FB 330/450		**0.20**	0.00	NA	0.55	0.30	1.10
19	FB 450/600		**0.25**	0.00	NA	0.55	0.45	1.65
20	DP 300/500		**0.20**	0.00	0.10	0.55	0.45	0.85
21	DP 350/600		**0.26**	0.00	0.10	0.55	0.45	1.25
22	DP 500/800		**0.31**	0.00	NA	0.55	0.50	0.90
23	DP 700/1000		**0.38**	0.00	NA	NA	0.55	0.95
24	DP 800/1180		**-**	-	-	-	-	-
25	DP 1150/1270		**0.38**	0.00	NA	NA	0.55	0.95
26	CP 500/800		**0.31**	0.00	NA	NA	0.50	1.30
27	CP 600/900		**0.35**	0.00	NA	NA	0.52	1.32
28	CP 750/900		**0.40**	0.00	NA	NA	0.52	1.32
29	CP 800/1000		**0.45**	0.00	NA	NA	0.55	1.35
30	CP 1000/1200		**0.47**	0.00	NA	NA	0.60	1.40
31	CP 1050/1470		**0.47**	0.00	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**	0.00	NA	NA	0.60	1.80
35	MS 1250/1500		**0.51**	0.00	NA	NA	0.65	1.05
36	HF 1050/1500 (22MnB5)		**0.75**	NA	NA	0.55	0.65	1.05

Figure 406: Price for different grades and finished forms of steel[216]

[215]Source: Nominal Prices based on data received from Platts; Adjusted Prices take into account the GDP deflator in 2010

[216] Source: www.worldautosteel.org

9.5.3 Aluminum Prices

The base aluminum price used for the cost assessment was $2.56 USD/kg. The 2011 average price was adjusted to 2010 dollars using the GDP deflator, as shown in Figure 407. 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 408.

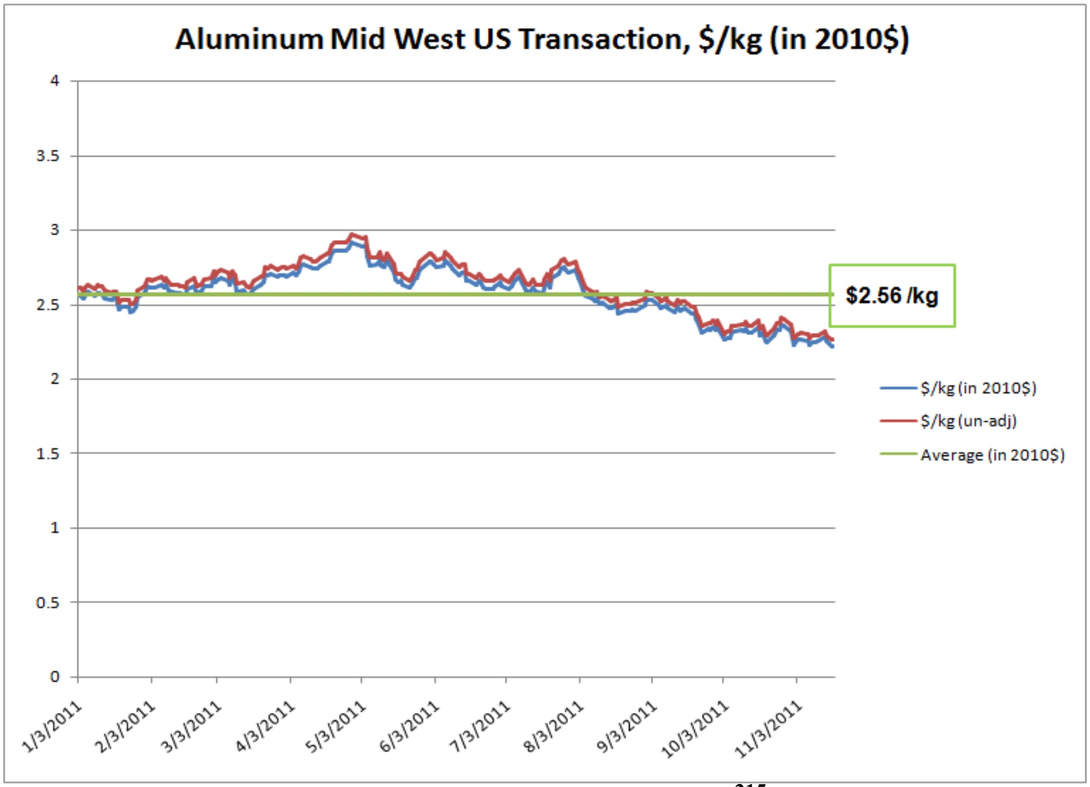


Figure 407: Aluminum Prices[215]

Item #	Aluminum Grade	Ref Material Price ($/kg)	Finished Form	Grade Premium ($/kg)	Process Premium ($/kg)	Exposed Surface ($/kg)	Total ($/kg)
1	Aluminum Midwest USA (Platts)	$ 2.56					
2	A380 (Casting Alloy)		Ingot	-$0.02	$0.00		$2.54
3	A356 (Casting Alloy)		Ingot	$0.19			$2.75
4	5454 (Sheet Alloy)		Sheet	$0.10	$1.80		$4.46
5	6013 (Sheet Alloy)		Sheet	$0.10	$1.95	$0.07	$4.68
6	6061 (Extrusion alloy)		Billet	$0.10	$0.65		$3.31

Figure 408: Price for different grades and finished forms of Aluminum

9.5.4 Magnesium Prices

The magnesium material price used for the cost assessment was $4.98 /kg, the 2011 average of magnesium die cast alloy prices adjusted to 2010 dollars using a GDP deflator in as shown in Figure 409. The instrument panel cross-car beam is the only component designed using cast magnesium material which used the base price.

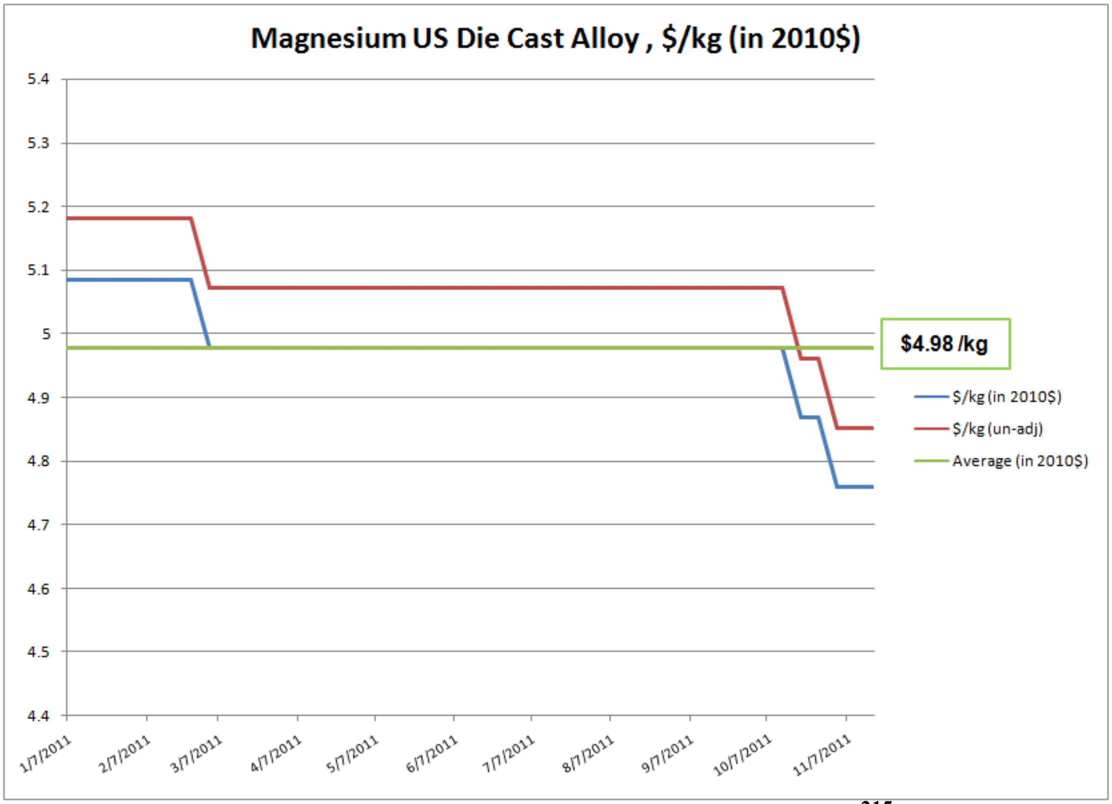


Figure 409: Magnesium (Die Cast alloy) prices[215]

9.5.5 Labor Rates

The team applied an appropriate labor rate for the LWV 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 researchers 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 LWV. The base labor rates for the required types of labors were acquired from the Bureau of Labor Statistics (BLS), North American Industry Classification System (NAICS) 336100 – Motor Vehicle Manufacturing (OEMs). All the rates are based on the data as available from BLS on May 2010.

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 base labor rates are shown in Figure 410.

Standard Occupational Classification System(SOCS) Code (BLS)	Mean hourly wage ($ USD per hr)
51-1011 First-Line Supervisors of Production and Operating Workers	$32.75
51-2022 Electrical and Electronic Equipment Assemblers	$20.70
51-2031 Engine and Other Machine Assemblers	$25.97
51-2041 Structural Metal Fabricators and Fitters	$22.18
51-2091 Fiberglass Laminators and Fabricators	$17.78
51-2092 Team Assemblers	$22.54
51-2099 Assemblers and Fabricators, All Other	$25.39
51-4011 Computer-Controlled Machine Tool Operators, Metal and Plastic	$17.49
51-4021 Extruding and Drawing Machine Setters, Operators, and Tenders, Metal and Plastic	$24.69
51-4031 Cutting, Punching, and Press Machine Setters, Operators, and Tenders, Metal and Plastic	$15.84
51-4061 Model Makers, Metal and Plastic	$32.86
51-4081 Multiple Machine Tool Setters, Operators, and Tenders, Metal and Plastic	$27.12
51-4121 Welders, Cutters, Solderers, and Brazers	$21.95
51-4122 Welding, Soldering, and Brazing Machine Setters, Operators, and Tenders	$25.13
51-4192 Layout Workers, Metal and Plastic	$24.18
51-4199 Metal Workers and Plastic Workers, All Other	$21.78
51-6093 Upholsterers	$13.61
51-9022 Grinding and Polishing Workers, Hand	$21.13
51-9031 Cutters and Trimmers, Hand	$18.30
51-9061 Inspectors, Testers, Sorters, Samplers, and Weighers	$23.78
51-9121 Coating, Painting, and Spraying Machine Setters, Operators, and Tenders	$23.56
51-9122 Painters, Transportation Equipment	$23.42
51-9198 Helpers--Production Workers	$15.13
51-9399 Production Workers, All Other	$28.23

Figure 410: Base Labor Rates for Cost Assessment[217]

However, only 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% from the BLS (Figure 411) to the wages shown in Figure 410. The total labor rate is illustrated in Figure 412.

[217] Source: www.bls.gov: http://www.bls.gov/oes/current/naics4_336300.htm

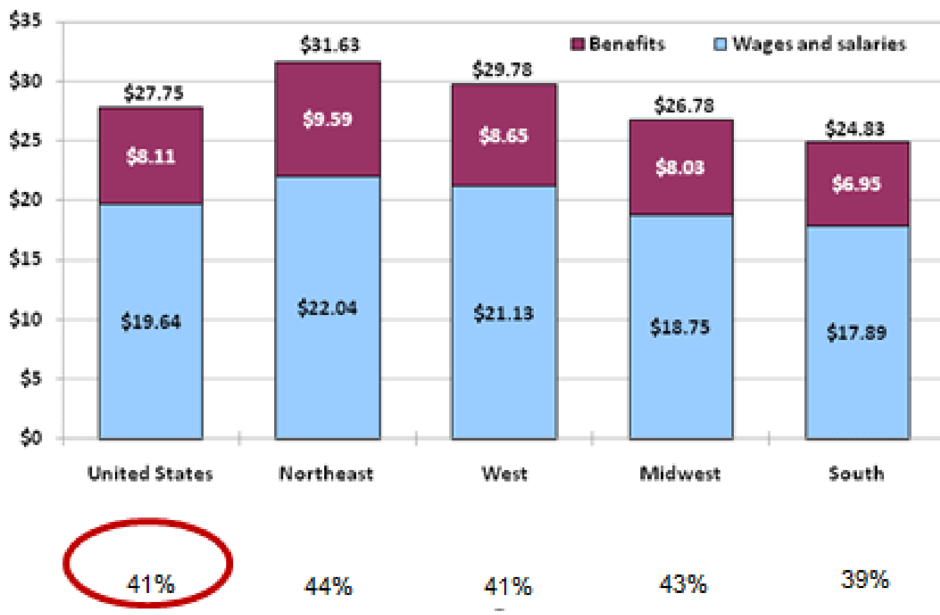


Figure 411: Employer Costs for Employee Compensation[218]

Standard Occupational Classification System(SOCS) Code (BLS)	Mean hourly wage ($ USD per hr)	Benefits (41%)	Labor Rates ($ USD per hr)
51-1011 First-Line Supervisors of Production and Operating Workers	$32.75	$13.43	$46.18
51-2022 Electrical and Electronic Equipment Assemblers	$20.70	$8.49	$29.19
51-2031 Engine and Other Machine Assemblers	$25.97	$10.65	$36.62
51-2041 Structural Metal Fabricators and Fitters	$22.18	$9.09	$31.27
51-2091 Fiberglass Laminators and Fabricators	$17.78	$7.29	$25.07
51-2092 Team Assemblers	$22.54	$9.24	$31.78
51-2099 Assemblers and Fabricators, All Other	$25.39	$10.41	$35.80
51-4011 Computer-Controlled Machine Tool Operators, Metal and Plastic	$17.49	$7.17	$24.66
51-4021 Extruding and Drawing Machine Setters, Operators, and Tenders, Metal and Plastic	$24.69	$10.12	$34.81
51-4031 Cutting, Punching, and Press Machine Setters, Operators, and Tenders, Metal and Plastic	$15.84	$6.49	$22.33
51-4061 Model Makers, Metal and Plastic	$32.86	$13.47	$46.33
51-4081 Multiple Machine Tool Setters, Operators, and Tenders, Metal and Plastic	$27.12	$11.12	$38.24
51-4121 Welders, Cutters, Solderers, and Brazers	$21.95	$9.00	$30.95
51-4122 Welding, Soldering, and Brazing Machine Setters, Operators, and Tenders	$25.13	$10.30	$35.43
51-4192 Layout Workers, Metal and Plastic	$24.18	$9.91	$34.09
51-4199 Metal Workers and Plastic Workers, All Other	$21.78	$8.93	$30.71
51-6093 Upholsterers	$13.61	$5.58	$19.19
51-9022 Grinding and Polishing Workers, Hand	$21.13	$8.66	$29.79
51-9031 Cutters and Trimmers, Hand	$18.30	$7.50	$25.80
51-9061 Inspectors, Testers, Sorters, Samplers, and Weighers	$23.78	$9.75	$33.53
51-9121 Coating, Painting, and Spraying Machine Setters, Operators, and Tenders	$23.56	$9.66	$33.22
51-9122 Painters, Transportation Equipment	$23.42	$9.60	$33.02
51-9198 Helpers--Production Workers	$15.13	$6.20	$21.33
51-9399 Production Workers, All Other	$28.23	$11.57	$39.80

Figure 412: Labor Rates (including benefits)

Finally, a markup of 25% was applied to account for the indirect labor from the same source. In this study a markup factor of 25% was used consistently for all the components including the

[218] Source: Bureau of Labor Statistics, December 2010

TCM models for both the baseline and the LWV. This mark-up will be different for different manufacturers. 25% was used as a typical number.

9.5.6 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

9.5.7 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
- Stamping Tailor Rolled Blank (TRB)
- Stamping Laser Welded Blank (LWB)
- Hot Stamping
- Hot Stamping Tailor Rolled Blank
- Hot Stamping Laser Welded Blank
- Closed Rollforming
- Open Rollforming
- Hydroforming
- Hydroforming Laser Welded Tube
- Casting
- Injection Molding

The unit assembly cost employs one of the following costs models based on the selected assembly processes:

- Resistance Spot welding
- Metal Inert Gas (MIG) welding
- Laser welding
- Laser braze
- Adhesive bonding
- Roller Hemming

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 413.

Process Parameter	Stamping Assumptions
Energy consumption rate	150 kW/hr
Space requirement	150 m^2/line
Unplanned downtime	1 hrs/day
Maintenance Percentage	10%
Material loss percent	0.5%
Press line die average change time	30 minutes
Press line lot size	1500 parts/lot

Figure 413: Stamping Press Line General Process Parameters

Similar to the process parameters shown in Figure 413, 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 must consider the sequence of the different operations, to estimate the overall manufacturing component cost for the various technologies as shown in Figure 414.

	Manufacturing Portfolio					
	Stamping	Stamping Tailor Rolled Blank	Stamping Laser Welded Blank	Hot Stamping	Hot Stamping Laser Welded Blank	Injection Molding
Material Price	Steel/Aluminum Material Prices	Steel Material Prices w/ Rolling Premium	Steel Material Prices	Steel Material Prices	Steel Material Prices	Heat Plastic
Operation #1	Blanking (Single)	Blanking	Blanking	Blanking	Blanking	Injection
Operation #2	Stamping	Stamping	Laser Welding	Blank heating	Laser Welding	Mold
Operation #3	Trimming	Trimming	Stamping	Hot forming	Blank heating	Cooling
Operation #4			Trimming	Laser	Hot forming	Ejection
Operation #5					Laser	

	Manufacturing Portfolio					
	Closed Roll Form	Open - Roll Form	Hydroform	Hydroform Laser Welded Tubes (LWT)	Casting	Aluminium Extrusion
Material Price	Steel Material Prices	Steel Material Prices	Steel Material Prices w/ Tubing Premium	Steel Material Prices	Magnesium/ Aluminum	Aluminum Material Prices
Operation #1	Forming	Forming	Bending	Blanking	Melting	Cutting Billet
Operation #2	Welding	Trimming	Pre-forming	Laser Welding	Die Casting	Extrusion
Operation #3	Trimming		Hydroforming	Master	Trimming	Straightening
Operation #4			Trimming	Tube	Machining	Hydrosizing
Operation #5				Bending		Machining
Operation #6				Pre-forming		
Operation #7				Hydroforming		
Operation #8				Trimming		

Figure 414: 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) and equipment investment ($).The material costs also takes into account the scrap rate from each unit operation in the manufacturing process. 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. The facility costs assumed in the cost model is $1500 per square meter. Similarly, the maintenance costs in the model is for maintaining the tools, equipment and building and is proportional to the actual utilization for manufacturing and assembly which is also directly linked to the manufacturing process. These building and maintenance costs are different from the building and maintenance cost calculated using RPE. The building and maintenance costs covered by RPE account for the costs not directly linked to manufacturing or assembly, but linked to non-manufacturing and assembly facilities, 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. The cost model can then re-calculate the unit costs to reflect the changes.

9.6 Cost Modeling of Individual Component and Sub-Systems

This report shows, in detail, the approach the researchers used to calculate the incremental costs of the body structure which is a completely re-designed assembly and a purchased sub-assembly, the front suspension. Because the approach is similar for all of the other re-designed and purchased components, the report only shows summaries for the results of the other systems. The detailed results and cost break-down can be found in the cost models (Microsoft Excel files) published with this report.

9.6.1 Body Structure

9.6.1.1 Manufacturing Cost Model Inputs

For both the baseline vehicle and the LWV, a detailed engineering review was conducted of the body structure and closures, to determine every individual part’s material and manufacturing process. The team characterized the material in the baseline vehicle by analyzing the material properties of the FEA data. Even though stamping is the predominant manufacturing process for vehicle body sheet metal parts, the team further analyzed the geometry of each part in the baseline vehicle to confirm that a different primary manufacturing processes was not used, such as roll forming, hydroforming etc.. Similarly, the team determined the secondary manufacturing processes such as laser welded blanks, trimming etc.

9.6.1.2 Blank Size

The engineers evaluated the CAD data of the parts using manufacturing simulation tools to determine the optimal blank size, including the required addendum necessary for blank holder, draw beads for control of material flow, etc. The blank size determined for the dash panel is illustrated Figure 415.

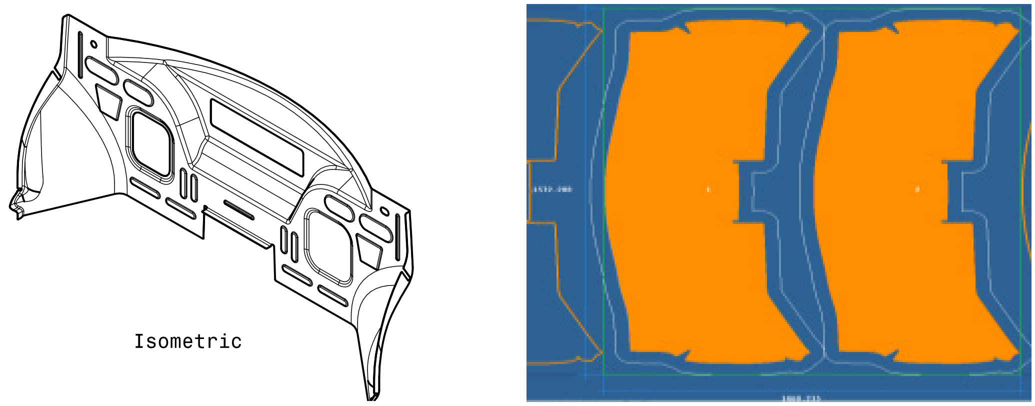


Figure 415: Dash Panel CAD Design and Blank Size

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 part nesting exercise for the B-Pillar Reinforcement design is shown in Figure 416.

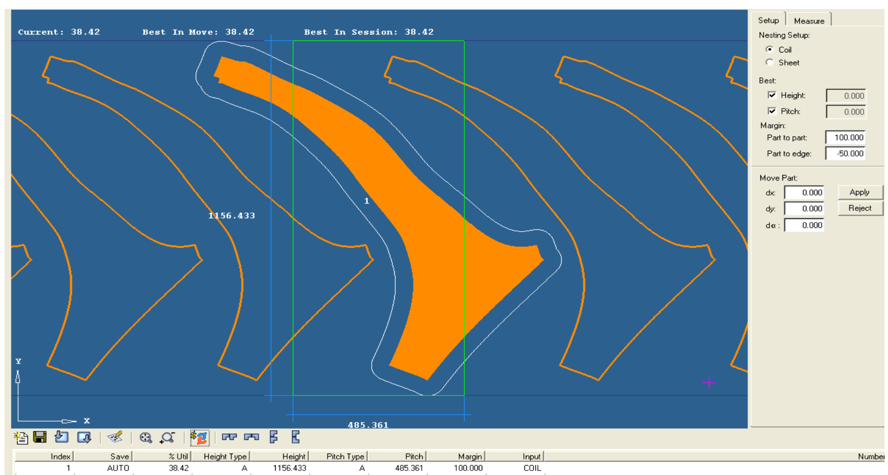


Figure 416: B-Pillar Reinforcement Part Nesting (for illustration only)

9.6.1.3 Tooling Investment and Cycle Time

Once the engineers established the process for manufacturing the part, they reviewed each operation for fabricating the part to determine its tooling investment and cycle time. The part design and complexity was reviewed to determine the tooling costs which include the following: tool design, manufacturing machining, tryouts, and checking fixtures.

9.6.1.4 Equipment Specification

The team also reviewed the part design and complexity to determine the suitable equipment to produce the part at a high quality and cost effectively in a high production volume scenario. The model assumed that the press lines are not fully dedicated to the manufacturing of one specific part. This means that in the remaining time other parts can be fabricated, and the associated costs are distributed across all of the parts it stamps.

9.6.1.5 Assembly Cost Model Inputs

In an assembly line, the individual components are assembled together to form separate sub-assemblies. Furthermore, all the sub-assemblies are then combined on an assembly line to form the complete assembly. The team performed an engineering review on all the parts of each sub-assembly to ensure they are assembled in a proper sequence so the workers have sufficient access to the parts at work station. As part of the review, the team also determined other process inputs such as type of the welds, number of welds, etc. The team performed a similar review on the combination of the sub-assemblies into a full assembly. The team prepared a unique assembly sequence diagram for each individual sub-assembly and assembly. As an example, the LWV body side panel assembly sequence is illustrated in Figure 417.

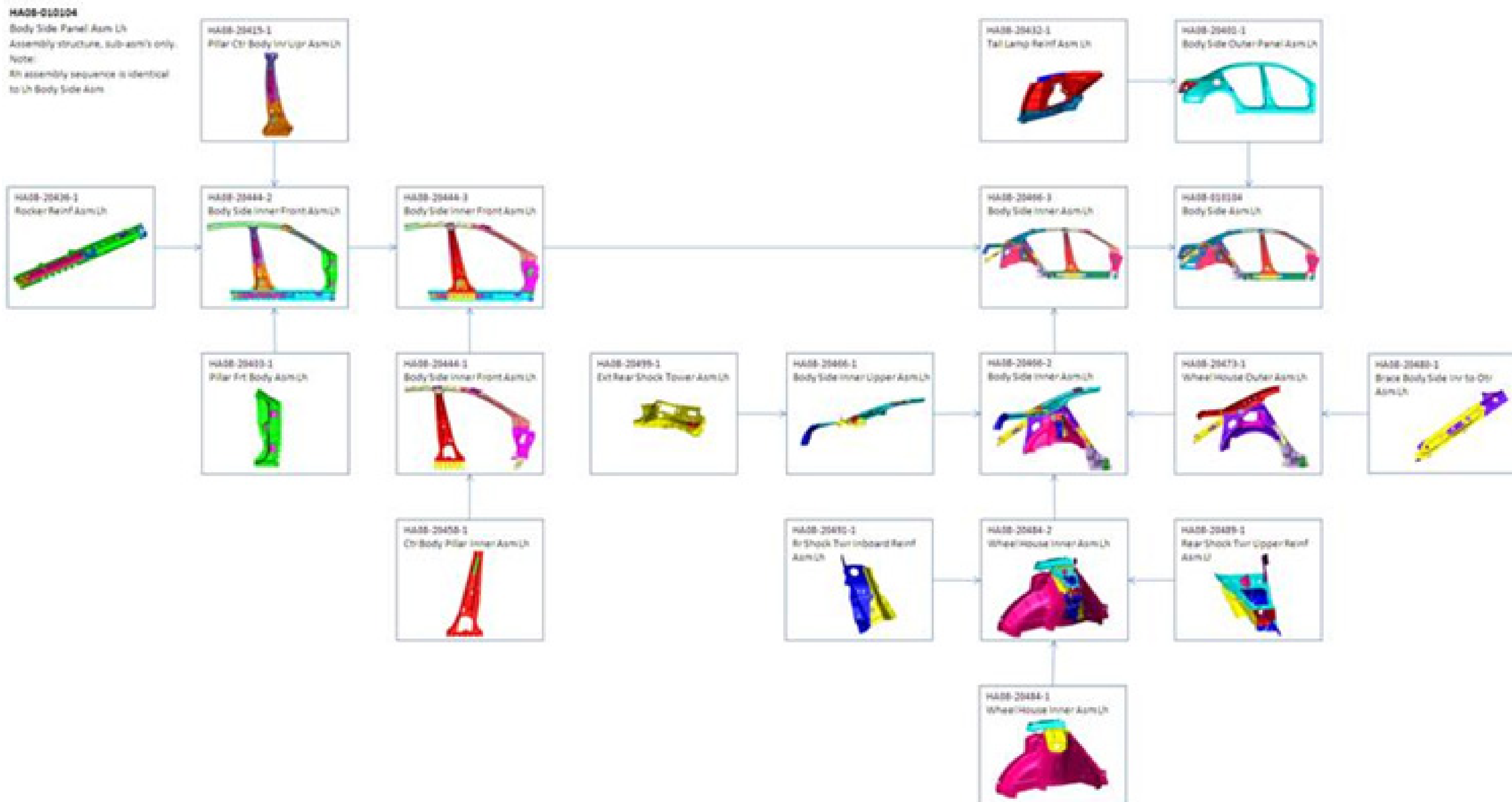


Figure 417: Body Side Panel Assembly Sequence Block Diagram (for illustration only)

The assembly parameters for the baseline vehicle were based on the available process information in the benchmark CAD data and an engineering evaluation of the assembly sequence. The latter may not represent the actual sequence followed by the manufacturer of the baseline vehicle. Also, the manufacturer could purchase certain components of the body structure as sub-assemblies. Without specific information, the team was not able to differentiate between the manufactured and purchased parts or sub-assemblies, so, they considered all of them as individually assembled parts. The same assumptions were also made for the LWV assembly parameters. The team believes that the estimated incremental costs are rational since the cost assessment was made on a consistent set of assumptions for both the baseline and the LWV assembly.

9.6.1.6 Baseline Body Structure Costs

Approximately 93% of the parts in the baseline body structure are conventional stamped parts. The remaining 7% of the stamped parts are designed using laser welded blanks. This reduces weight through the use of multiple steel grades and thicknesses, thereby avoiding the need for local reinforcements to strengthen the part. The baseline vehicle body structure manufacturing and assembly costs are summarized in Figure 418. The cost breakdown of the baseline body structure manufacturing costs is summarized in Figure 419.

Manufacturing Technology	Parts Weight (kg)	Parts Cost ($ USD)
Stamping	306	$713
Stamping -Laser Welded Blanks	22	$56
Hot Stamping	0	$0
Rollforming	0	$0
Body Structure Manufacturing (Baseline)		**$769**
Body Structure Assembly (Baseline)		**$218**
Total Body Structure (Baseline)	**328**	**$987**

Figure 418: Baseline Vehicle Body Structure Manufacturing and Assembly Costs

Body Structure Cost Breakdown	Manufacturing Costs	Assembly Costs	Baseline Costs ($ USD)
Building	$4	$17	$21
Maintenance	$18	$10	$27
Energy	$30	$24	$54
Overhead	$41	$30	$72
Labor	$46	$58	$105
Equipment	$87	$61	$148
Tooling	$81	$17	$98
Material	$462	$1	$463
Total	$769	$218	**$987**

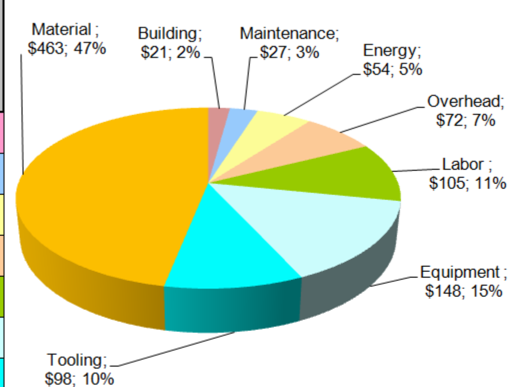


Figure 419: Baseline Vehicle Body Structure Costs Breakdown

9.6.1.7 LWV Body Structure Costs

The predominant manufacturing technology used in the LWV is also conventional stamping (approximately 62% of the total LWV body structure weight). However, the LWV body structure is designed using a higher percentage of laser welded blanks (20%) compared to the baseline body structure (7%). Approximately 9% of the body structure parts are designed in advanced high strength boron steel which requires hot stamping manufacturing technology. Some of the LWV body structure parts are also designed to enable the use of roll forming manufacturing technology. Based on the geometry of the specific LWV part, the team chose most cost effective process to manufacture a high quality part in a high production volume scenario. The LWV vehicle body structure manufacturing and assembly costs are summarized in Figure 420 and the cost breakdown is summarized in Figure 421. The assembly costs shown in Figure 420 and Figure 421 are based on the LWV assembly weld details as summarized Figure 352. However, to take into account the effect of learning on the laser welding costs, a 20% cost reduction has been applied to the laser welding based on the results attained from a separate effects of learning study conducted by the team. The purpose of this study is to compare the mass savings and costs associated with converting the assembly of body structure from a resistance spot welding joining process, to laser welding joining process. This study is discussed in detail in Chapter 10.

Manufacturing Technology	Parts Weight (kg)	Parts Cost ($ USD)
Stamping	158	$568
Stamping -Laser Welded Blanks	50	$168
Hot Stamping	10	$67
Hot Stamping - Laser Welded Blanks	12	$69
Rollforming	23	$32
Body Structure Manufacturing (LWV)		$905
Body Structure Assembly (LWV)		$229
Total Body Structure (LWV)	**255**	**$1,134**

Figure 420: LWV Body Structure Manufacturing and Assembly Costs

LWV Body Structure				
Body Structure Cost Breakdown	Manufacturing Costs	Assembly Costs (w/o Effect of Learning)	Assembly Costs (Effect of Learning on Laser Welding)	LWV Costs ($ USD)
Building	$8	$18	$18	$26
Maintenance	$21	$11	$10	$31
Energy	$27	$22	$22	$49
Overhead	$37	$28	$28	$65
Labor	$49	$62	$62	$110
Equipment	$101	$68	$65	$165
Tooling	$87	$21	$20	$107
Material	$575	$4	$4	$580
Total	$905	$234	$229	**$1,134**

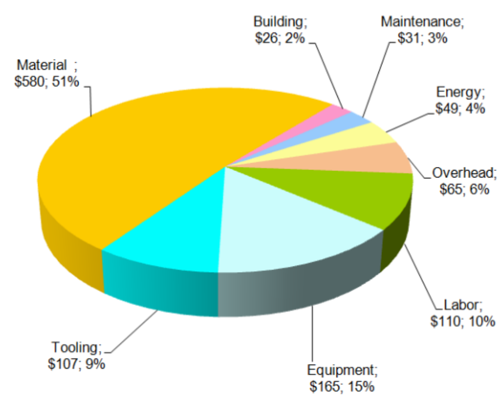


Figure 421: LWV Body Structure Costs Breakdown

9.6.1.8 LWV Body Structure Cost Increment

The LWV body structure incremental costs compared to the baseline vehicle are summarized in Figure 422. Some of the adopted LWV body structure lightweight technologies also result in cost savings due to increased technology efficiencies and part consolidation.

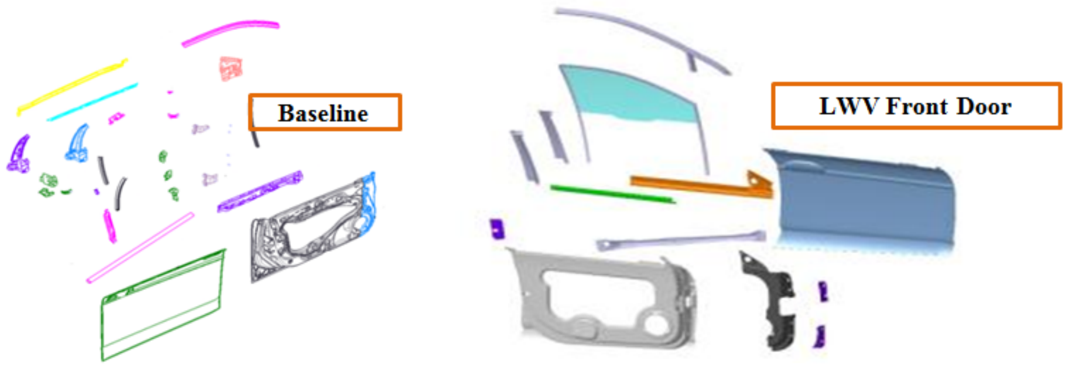
Body Structure Cost Breakdown	Baseline Costs ($ USD)	LWV Costs ($ USD)	Incremental Costs ($ USD)
Building	$21	$26	$5
Maintenance	$27	$31	$4
Energy	$54	$49	-$5
Overhead	$72	$65	-$7
Labor	$105	$110	$6
Equipment	$148	$165	$18
Tooling	$98	$107	$9
Material	$463	$580	$117
Total	**$987**	**$1,134**	**$147**

Figure 422: LWV Body Structure Incremental Costs Summary

9.6.2 Closures and Fenders Cost Increment

9.6.2.1 Front Door

The LWV front door design replaces the baseline steel components with aluminum stampingsand extrusions. The intrusion beam and hinge reinforcement plates are AHSS. The other components such as the hinges, door lock striker and glass windows are carried over from the baseline. The LWV front doors incremental costs are summarized in Figure 423.

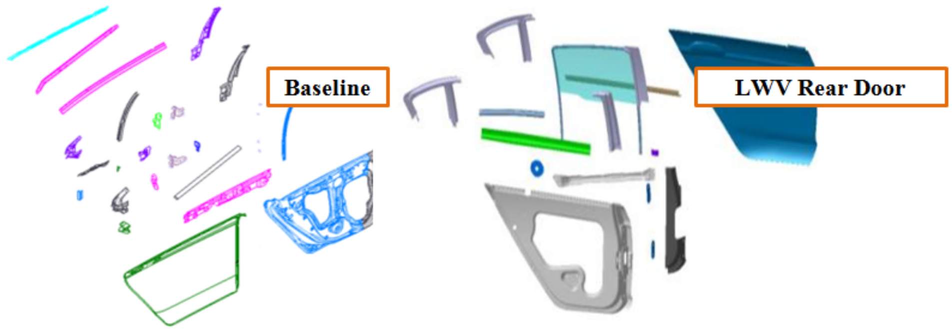


Front Doors (RH & LH) Cost Breakdown	Baseline Costs ($ USD)	LWV Costs ($ USD)	Front Doors Incremental Costs ($ USD)
Building	$4.4	$4.5	$0.1
Maintenance	$3.4	$3.9	$0.5
Energy	$3.4	$2.5	-$0.9
Overhead	$11.4	$10.9	-$0.5
Labor	$17.7	$16.6	-$1.0
Equipment	$17.9	$16.7	-$1.2
Tooling	$11.3	$11.7	$0.4
Material	$41.2	$93.4	$52.2
Total	**$110.7**	**$160.4**	**$49.6**

Figure 423: LWV Front Doors Incremental Costs (Manufacturing & Assembly) Summary

9.6.2.2 Rear Door

The rear door design approach is similar to the front doors with aluminum stampings and extrusions replacing the baseline steel components. The intrusion beam and hinge reinforcement plates are AHSS. The windows, hinges and door lock striker are carried over from the baseline rear doors. However, the LWV rear door incremental costs do not follow the same pattern which is attributed to the design parameters of the individual door components compared to the baseline door components. The cost elements such as tooling, material costs, scrap etc. are unique for each design and hence the corresponding costs. The LWV rear doors incremental costs are summarized in Figure 424.



Rear Doors (RH & LH) Cost Breakdown	Baseline Costs ($ USD)	LWV Costs ($ USD)	Rear Doors Incremental Costs ($ USD)
Building	$4.0	$4.2	$0.1
Maintenance	$3.2	$3.7	$0.5
Energy	$3.4	$2.8	-$0.6
Overhead	$10.3	$10.6	$0.2
Labor	$15.9	$16.0	$0.2
Equipment	$16.8	$16.2	-$0.6
Tooling	$10.9	$10.5	-$0.3
Material	$36.2	$89.8	$53.6
Total	**$100.6**	**$153.7**	**$53.2**

Figure 424: LWV Rear Doors Incremental Costs (Manufacturing & Assembly) Summary

9.6.2.3 Hood

The LWV hood is built from aluminum stampings for the entire structure including brackets and reinforcements. The hinges, latch and striker are carried over from the baseline hood assembly. The LWV hood incremental costs are summarized in Figure 425.

Hood Cost Breakdown	Baseline Costs ($ USD)	LWV Costs ($ USD)	Hood Incremental Costs ($ USD)
Building	$3.1	$3.1	$0.0
Maintenance	$1.7	$1.8	$0.0
Energy	$0.6	$0.7	$0.0
Overhead	$6.1	$6.2	$0.1
Labor	$10.2	$10.5	$0.4
Equipment	$7.8	$5.2	-$2.6
Tooling	$6.2	$6.4	$0.2
Material	$20.1	$43.2	$23.1
Total	**$56.0**	**$77.2**	**$21.3**

Figure 425: LWV Hood Incremental Costs (Manufacturing & Assembly) Summary

9.6.2.4 Deck Lid

The decklid in the LWV are built from aluminum stampings for the entire structure including brackets and reinforcements. The hinges, torsion rods, latch/lock and striker are carried over from the baseline. The LWV decklid incremental costs are summarized in Figure 426.

Decklid Cost Breakdown	Baseline Costs ($ USD)	LWV Costs ($ USD)	Decklid Incremental Costs ($ USD)
Building	$2.0	$2.4	$0.4
Maintenance	$1.3	$1.6	$0.3
Energy	$0.6	$0.4	-$0.2
Overhead	$4.0	$4.6	$0.6
Labor	$6.5	$7.5	$1.0
Equipment	$5.5	$6.1	$0.6
Tooling	$5.0	$5.0	$0.0
Material	$12.0	$26.3	$14.2
Total	**$36.8**	**$53.8**	**$17.0**

Figure 426: LWV Decklid Incremental Costs (Manufacturing & Assembly) Summary

9.6.2.5 Fender

The fenders in the LWV are built from aluminum stampings for the entire structure including brackets and reinforcements. The LWV fenders incremental costs are summarized in Figure 427.

Fenders Cost Breakdown	Baseline Costs ($ USD)	LWV Costs ($ USD)	Fenders Incremental Costs ($ USD)
Building	$0.1	$0.1	$0.0
Maintenance	$0.9	$1.1	$0.3
Energy	$0.7	$0.7	$0.0
Overhead	$1.1	$1.0	-$0.1
Labor	$1.4	$1.5	$0.1
Equipment	$3.1	$2.9	-$0.1
Tooling	$5.3	$5.5	$0.1
Material	$13.5	$25.8	$12.3
Total	**$26.1**	**$38.7**	**$12.6**

Figure 427: LWV Fenders Incremental Costs Summary

9.6.2.6 Closures and Fenders Incremental Costs Summary

The total incremental cost for the LWV closures and fenders is $155 as summarized in Figure 428. The assembly of both the baseline and the LWV fenders are the same and hence the assembly costs are shown as cost neutral.

Closures Sub-System	Baseline Costs			LWV Costs			Closures Incremental Costs
	Baseline Manufacturing	Baseline Assembly	**Baseline Total**	LWV Manufacturing	LWV Assembly	**LWV Total**	
Hood	$29	$27	$56	$52	$26	$77	$21
Front Doors	$72	$39	$111	$122	$39	$160	$50
Rear Doors	$65	$35	$101	$118	$36	$154	$53
Decklid	$20	$17	$37	$33	$21	$54	$17
Fenders	$26	Neutral	$26	$39	Neutral	$39	$13
Total			**$330**			**$484**	**$154**

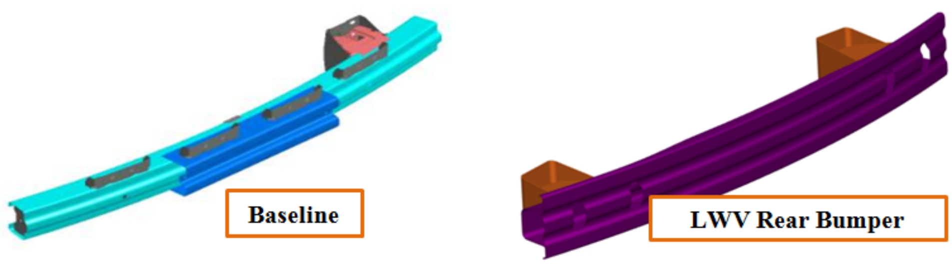
Figure 428: Closures and Fenders Incremental Costs

9.6.3 Bumpers

The bumper system on the baseline 2011 Honda Accord vehicle is fabricated from roll-formed steel with a tensile strength of 590 MPa. The forward surface of the front bumper beam utilizes a center mounted front plate and two crush cans attached to the bumper beam along with mounting brackets for attachment to the front rails. Stiffening gussets are added to the non-impact side of the bumper. The LWV front and rear bumper designs maintain the geometry of the original baseline designs, but substitutes AHSS for the baseline steel, allowing the metal gauges to be reduced. The bumper beam is a hot stamped boron steel design for the LWV front and rear bumpers. Though the price of AHSS is higher than that of the baseline, the amount of material saved with the optimized design is enough to offset it and results in no additional costs for the LWV front bumpers. The incremental cost impact to produce the front bumper is a decrease in costs of $0.9, while that for the rear bumper is an increase $2.1 as summarized in Figure 429 and Figure 430 respectively.

Front Bumper Cost Breakdown	Baseline Costs ($ USD)	LWV Costs ($ USD)	Front Bumper Incremental Costs ($ USD)
Building	$0.9	$1.0	$0.1
Maintenance	$0.6	$0.7	$0.2
Energy	$0.7	$0.8	$0.1
Overhead	$2.3	$2.5	$0.2
Labor	$2.6	$3.3	$0.7
Equipment	$2.8	$3.7	$1.0
Tooling	$2.2	$2.5	$0.3
Material	$12.3	$8.9	-$3.4
Total	**$24.2**	**$23.4**	**-$0.9**

Figure 429: Front Bumpers Incremental Costs



Rear Bumper Costs	Baseline Costs ($ USD)	LWV Costs ($ USD)	Rear Bumper Incremental Costs ($ USD)
Building	$0.9	$0.8	-$0.1
Maintenance	$0.5	$0.6	$0.1
Energy	$0.7	$0.9	$0.2
Overhead	$1.9	$1.9	$0.0
Labor	$2.1	$2.1	$0.0
Equipment	$2.4	$3.7	$1.3
Tooling	$1.6	$1.5	-$0.1
Material	$8.9	$9.6	$0.7
Total	**$19.1**	**$21.2**	**$2.1**

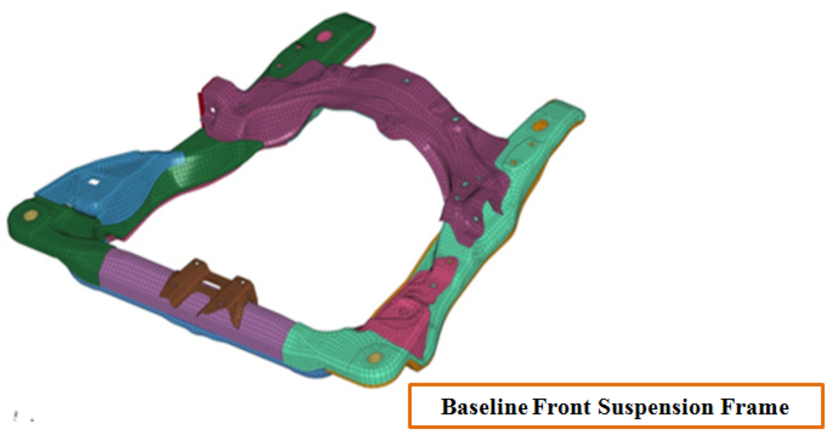
Figure 430: Rear Bumpers Incremental Costs

9.6.4 Front Suspension

9.6.4.1 Baseline Front Suspension

Even though the front and rear suspensions are normally supplied by suppliers, the project team took the effort and designed both the front and rear suspensions to make sure that the parts with new material can meet all the functional objectives of the baseline vehicle and the parts are properly downsized with the light-weighted vehicle design. Also the CAD data for suspensions can be used for following simulations. The cost assessment of the baseline suspension was conducted using the TCM approach similar to the other assemblies in the body structure and closures. The team assumed that the suspension was purchased from a supplier, and therefore had an additional markup applied to the TCM estimated costs as applied by a supplier to the OEM.

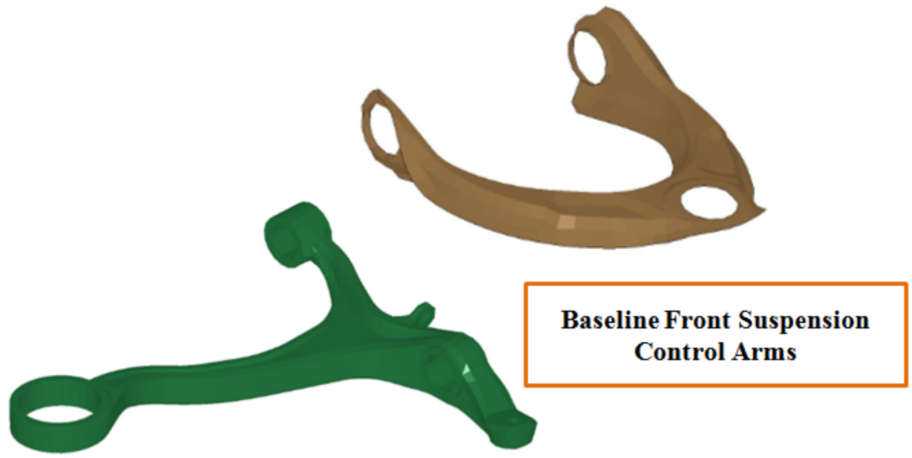
The baseline front suspension is a standard double wishbone design. The assembly includes the K-frame (engine cradle), upper and lower A-arms, steering knuckle, stabilizer bar and other miscellaneous parts with a combined mass of 81.3 kg. The dimensions from the CAD data were used for determining the cost estimation inputs. The team used the teardown analysis to determine the assembly parameters. The baseline front frame is an all steel design with multiple panels welded together. The baseline front frame costs are summarized in Figure 431.



Front Frame Cost Breakdown	Baseline Manufacturing Costs ($ USD)	Baseline Assembly Costs ($ USD)	Front Frame Baseline Costs ($ USD)
Building	$0.2	$1.8	$2.1
Maintenance	$1.1	$0.7	$1.8
Energy	$1.4	$0.6	$1.9
Overhead	$2.0	$3.0	$5.0
Labor	$1.8	$4.4	$6.2
Equipment	$5.1	$3.1	$8.3
Tooling	$5.7	$1.8	$7.5
Material Price	$48.7	$0.3	$49.0
Total	$66.1	$15.8	**$81.8**

Figure 431: Baseline Costs - Front Suspension Frame

In the double wishbone front suspension design there are upper and lower control arms. The front suspension upper control arm (upper triangle) is a conventionally stamped component. Based upon the teardown, the team assessed that the front suspension lower control arm was a cast iron. The baseline control arms costs summary for both upper and lower control arms are shown in Figure 432 and takes into account the costs for machining and corrosion preventive coating.



Control Arm Cost Breakdown	Upper Control Arm Costs ($ USD)	Lower Control Arm Costs ($ USD)	**Baseline Control Arms Costs ($ USD)**
Building	$0.0	$0.8	$0.8
Maintenance	$0.1	$0.6	$0.7
Energy	$0.2	$3.7	$3.9
Overhead	$0.3	$10.2	$10.5
Labor	$0.5	$13.3	$13.7
Equipment	$0.7	$7.1	$7.8
Tooling	$0.7	$3.7	$4.5
Material	$4.3	$22.2	$26.5
Total	$6.8	$61.6	**$68.4**

Figure 432: Baseline Costs – Front Suspension Control Arms

Similar to the lower control arm, the baseline front suspension steering knuckle is also a cast iron design; the estimated costs are shown in Figure 433.

Baseline Front Suspension Steering Knuckle

Steering Knuckle Cost Breakdown	Steering Knuckle Baseline Costs ($ USD)
Building	$0.9
Maintenance	$0.7
Energy	$3.4
Overhead	$14.5
Labor	$19.0
Equipment	$9.5
Tooling	$3.8
Material Price	$17.3
Total	**$69.2**

Figure 433: Baseline Costs –Front Suspension Steering Knuckle

The baseline front suspension stabilizer bar is an advanced high strength steel bent tube. The costs estimated as shown in Figure 434, also takes into account the secondary operations required for bending the tube to the final form.

Stabilizer Bar Cost Breakdown	Stabilizer Bar Baseline Costs ($ USD)
Building	$0.1
Maintenance	$0.0
Energy	$0.1
Overhead	$0.7
Labor	$0.3
Equipment	$0.5
Tooling	$0.0
Material Price	$5.9
Total	**$7.7**

Figure 434: Baseline Costs – Front Suspension Stabilizer Bar

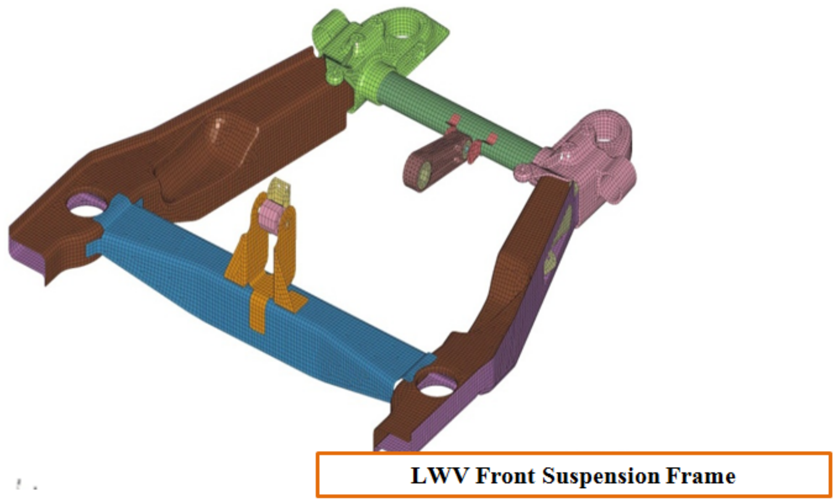
As mentioned earlier, because the suspension was assumed to be purchased from a supplier, the team applied an additional mark-up rate to the component costs to determine the OEM's purchase price. The total baseline front suspension costs including the applied mark-up rates are summarized in Figure 435. It should be noted that the costs shown do not represent the absolute costs of a front suspension; only the redesigned components and sub-systems were analyzed since this study is focussed only on incremental costs.

Front Suspension Components	Baseline Vehicle Costs ($ USD)
Front Frame	$66.1
Upper Arm	$6.8
Lower Arm	$61.6
Steering Knuckle	$69.2
Stabilizer Bar	$7.7
Assembly Cost	$15.8
Total (w/o mark-ups)	$227.1
SG&A	$10.2
Profit	$13.6
Total	$251.0

Figure 435: Baseline Total Costs - Front Suspension

9.6.4.2 LWV Front Suspension

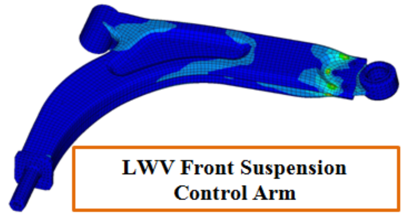
The LWV replaced the baseline double wishbone front suspension with a MacPherson strut similar to that used on the Honda Civic. The steel engine cradle on the baseline vehicle was replaced by an aluminum engine cradle, with equivalent strength and performance to the baseline (validated by CAE simulation). The team examined the design data to determine the necessary inputs to estimate the manufacturing and assembly costs which are summarized in Figure 436.



Front Frame Cost Breakdown	LWV Manufacturing Costs ($ USD)	LWV Assembly Costs ($ USD)	LWV Front Frame Costs ($ USD)
Building	$0.4	$1.8	$2.2
Maintenance	$1.0	$0.7	$1.7
Energy	$2.4	$0.6	$3.0
Overhead	$6.6	$3.0	$9.6
Labor	$6.6	$4.4	$11.0
Equipment	$3.6	$3.1	$6.7
Tooling	$9.1	$1.8	$10.9
Material Price	$61.1	$0.3	$61.5
Total	$90.8	$15.8	**$106.6**

Figure 436: LWV Costs - Front Suspension Frame

In a MacPherson suspension design there is only one control arm for each side. The LWV front suspension control arm is a stamped advanced high strength steel with galvanized zinc coating, designed with an upper and lower shell for each control arm. The two shells are welded together by MIG welding (clamshell design). The LWV control arm manufacturing costs are summarized in Figure 437.



Control Arm Cost Breakdown	LWV Control Arm Costs ($ USD)
Building	$1.3
Maintenance	$1.9
Energy	$1.7
Overhead	$3.6
Labor	$5.1
Equipment	$10.4
Tooling	$7.6
Material	$14.5
Total	**$46.1**

Figure 437: LWV Costs - Front Suspension Control Arm

The LWV steering knuckles are completely re-designed in cast aluminum. The design changes take into account the requirements for integrating the new design into the LWV front suspension assembly. There are fewer assembly steps required for this integration compared to the baseline assembly. The costs associated with this simpler assembly are negligible and are not shown in Figure 438.

Steering Knuckle Cost Breakdown	LWV Steering Knuckle Costs ($ USD)
Building	$0.5
Maintenance	$0.8
Energy	$1.9
Overhead	$11.7
Labor	$15.0
Equipment	$10.9
Tooling	$4.2
Material Price	$12.7
Total	**$57.8**

Figure 438: LWV Costs - Front Suspension Steering Knuckle

The LWV front suspension stabilizer bar design is similar to that of the baseline vehicle, except the fine tuning made to the design to integrate the stabilizer bar within the new assembly structure. The only costs that are different from the baseline are the material costs, as illustrated in Figure 439.

Stabilizer Bar Cost Breakdown	LWV Stabilizer Bar Costs ($ USD)
Building	$0.1
Maintenance	$0.0
Energy	$0.1
Overhead	$0.7
Labor	$0.3
Equipment	$0.5
Tooling	$0.0
Material Price	$4.9
Total	**$6.7**

Figure 439: LWV Costs - Front Suspension Stabilizer Bar

The LWV front suspension total costs are summarized in Figure 440. Since the front suspension assembly is purchased the mark-ups are also accounted for in the cost assessment, as discussed in Section 9.4.3. The costs shown do not represent the absolute costs of a front suspension, only the redesigned components and sub-systems which were analyzed since this study is focused only on incremental costs.

Front Suspension Components	LWV Costs ($ USD)
Front Frame	$90.8
Upper Arm	$0.0
Lower Arm	$46.1
Steering Knuckle	$57.8
Stabilizer Bar	$6.7
Assembly Cost	$15.8
Total (w/o mark-ups)	$217.2
SG&A	$9.8
Profit	$13.0
Total	$240.0

Figure 440: LWV Total Costs - Front Suspension

9.6.4.3 Front Suspension Incremental Costs

The front suspension incremental cost is summarized in Figure 441. The overall cost impact of the LWV front suspension design is a cost savings of $11.0 as shown in the figure. However, the cost savings is mainly due to the adoption of the MacPherson suspension design in the LWV compared to the double wishbone baseline front suspension design; there is some cost savings associated with the clamshell AHSS control arm design. If the lightweighting approach such as using aluminum for the front frame, clamshell AHSS control arm etc. are applied to a vehicle which already has MacPherson front suspension there could be a cost increase as shown in Figure 441. Please note that the cost estimates for the typical MacPherson suspension are only for comparison purposes. Each of the suspension components are designed for a specific vehicle structure, engine configuration and vehicle loads; the component designs and weights vary within the same weight class or same vehicle foot print.

Front Suspension Components	Baseline Double Wishbone Costs ($ USD)	Typical MacPherson Costs ($USD)	LWV Costs ($ USD)	**Incremental Costs to Typical MacPherson ($ USD)**	**Incremental Costs to Baseline Double Wishbone ($ USD)**
Front Frame	$66.1	$64.2	$90.8	$26.6	$24.7
Upper Arm	$6.8	$0.0	$0.0	$0.0	-$6.8
Lower Arm	$61.6	$51.0	$46.1	-$4.9	-$15.5
Steering Knuckle	$69.2	52.82	57.79	$5.0	-$11.4
Stabilizer Bar	$7.7	$7.3	$6.7	-$0.6	-$1.0
Assembly Cost	$15.8	$15.8	$15.8	$0.0	$0.0
Total (w/o mark-ups)	$227.1	$191.1	$217.2	$26.1	-$10.0
SG&A	$10.2	$8.6	$9.8	$1.2	-$0.4
Profit	$13.6	$11.5	$13.0	$1.6	-$0.6
Total	$251.0	$211.2	$240.0	$28.8	-$11.0

Figure 441: Front Suspension Incremental Costs

9.6.5 Rear Suspension

The LWV rear suspension design is the same as baseline vehicle. However, the designers achieved significant mass reduction of the rear suspension by material substitution of the baseline rear K-frame steel components with aluminum. The estimated cost for the LWV rear suspension frame compared to the baseline frame is shown in Figure 442.

Rear Frame Cost Breakdown	Baseline ($ USD)	LWV ($USD)	**Incremental Costs ($ USD)**
Stamping	$53.2	$81.1	$27.9
Stamping -Laser Welded Blanks	$0.0	$0.0	$0.0
Purchased Parts	$2.5	$6.4	$3.9
Hydroforming	$17.6	$29.8	$12.2
Assembly	Neutral (similar design)	Neutral (similar design)	$0.0
Rear Frame Cost	$73.3	$117.3	$44.0

Figure 442: Rear Suspension Frame Incremental Costs

Some cost reduction was also achieved due to the materials savings from the lower weight suspension arms, bearing hub and the stabilizer system, assuming the manufacturing resource requirements are the same for the same geometry. The incremental costs for the LWV rear suspension are summarized in Figure 443.

Rear Suspension Cost Breakdown	Baseline ($ USD)	LWV ($USD)	**Incremental Costs ($ USD)**
Rear Frame Cost	$73.3	$117.3	$44.0
Suspension Arms	$25.3	$22.8	-$2.4
Bearing Hub	$12.3	$11.7	-$0.6
Stabilizer Sys	$6.1	$4.8	-$1.2
SG&A	$5.3	$7.0	$1.8
Profit	$7.0	$9.4	$2.4
Total Costs	$129.2	$173.1	**$43.9**

Figure 443: Rear Suspension Incremental Costs

9.6.6 Wheels

The LWV wheels used AHSS to replace the baseline vehicle's standard steel wheels. The incremental costs were estimated as illustrated in Figure 444**.**

Wheel Cost Breakdown	**Baseline Cost ($ USD)**	**LWV Cost ($ USD)**	**Incremental Cost ($ USD)**
Stamped Parts	**$8.8**	**$9.9**	**$1.0**
Stamping -Laser Welded Blanks	**$0.0**	**$0.0**	**$0.0**
Purchased Parts	**$5.2**	**$5.2**	**$0.0**
Rollformed Parts	**$7.3**	**$8.3**	**$1.0**
Total Manufacturing	**$21.4**	**$23.4**	**$2.0**
Wheel Assembly Cost	**$3.7**	**$3.7**	**$0.0**
Total Wheel	**$25.1**	**$27.1**	**$2.0**
SG&A	**$1.1**	**$1.2**	**$0.1**
Profit	**$1.5**	**$1.6**	**$0.1**
Wheel Cost (single)	**$27.7**	**$29.9**	**$2.2**
Total Wheel Cost (per vehicle)	**$110.9**	**$119.7**	**$8.8**

Figure 444: Wheels Incremental Costs

9.6.7 Brakes

The reduced weight of the LWV allows the brake system (calipers, pads and discs) to be downsized to the same weight as the Honda Civic without degrading vehicle performance. In addition, LWV replaced the steel front and rear calipers with aluminum calipers. Even though there is a potential for cost savings by replacing the baseline mechanical parking brake with an electric parking brake, the costs are assumed to be neutral. The brake components incremental costs are summarized in Figure 445.

Brake Components	Baseline ($ USD)	LWV ($USD)	Incremental Costs ($ USD)
Front Calipers	$48.8	$55.0	$6.3
Rear Calipers	$40.7	$42.9	$2.2
Front Disc	$59.0	$44.1	-$14.9
Rear Disc	$30.1	$23.8	-$6.3
Master Cylinder	Neutral		$0.0
Front Pads	Neutral		$0.0
Rear Pads	Neutral		$0.0
Hand Brake	Neutral		$0.0
ABS System	Neutral		$0.0
Vacuum Pump	Neutral		$0.0
Brake Lines	Neutral		$0.0
Miscellaneous	Neutral		$0.0
SG&A	$8.0	$7.5	-$0.6
Profit	$10.7	$9.9	-$0.8
Total	$197.3	$183.2	**-$14.1**

Figure 445: Brakes Incremental Costs

9.6.8 Seats

The baseline seats costs were estimated by Intellicosting with the supporting design information from EDAG. A teardown analysis was conducted to assess the individual parts and the structure of the front and rear seat assemblies. The teardown analysis results were compared to the available technical cost analysis data of similar seats used in cars in the same segment as the baseline vehicle. The historical data of similar detailed cost study results were used as the basis to develop the costs summarized in Figure 446 and Figure 447.

Baseline Front Seat (LH&RH) Components	Weight	Baseline Costs ($ USD)
Frame and Mechanisms (Steel)	32.06	$377.1
Foam for cushions	5.5	$36.1
Covers	2.74	$57.6
Garnish trim (plastics)	4.12	$5.3
Miscellaneous Parts and	1.38	$2.0
Total	**45.8**	**$478.1**

Figure 446: Baseline Front Seats (Passenger and Driver side) Costs Breakdown

Baseline Rear Seat Components	Weight	Baseline Costs ($ USD)
Frame and Mechanisms (Steel)	7.95	$70.2
Foam for cushions	7.12	$30.2
Covers	1.9	$56.8
Garnish trim (plastics)	0.62	$8.2
Miscellaneous Parts and	3.44	$2.0
Total	**21.03**	**$167.5**

Figure 447: Baseline Rear Seats Costs Breakdown

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 sufficient technical details of the future seat lightweighting technologies, the TCM methodology could not be applied for cost estimation of the LWV seats. The cost of the future light weighting technologies cost increment estimated by the supplier ranges from 10% to 20%, and the team used the average, 15% (the details are shown in Section 5.13.2.8). The LWV seats incremental costs are summarized in Figure 448.

Seat Components	Baseline Costs ($USD)	LWV Costs ($ USD)	Incremental Costs ($ USD)
Rear Seat Assembly	$167.5	$192.6	$25.1
Front Seat (LH & RH) Assembly	$478.1	$549.8	$71.7
Total	$645.5	$742.4	**$96.8**

Figure 448: LWV Seats Incremental Costs

9.6.9 Instrument Panel

The instrument panel of the baseline 2011 Honda Accord is constructed of a tubular steel cross car beam with multiple steel brackets and mounts welded to it beam. Most of the other components, aside from electronics and inflatable restraint system, are various types of plastics; it is replaced in the LWV with a cast magnesium cross-car beam.

The incremental costs of the magnesium cross beam were estimated based on the assumption that all the design parameters required to facilitate the magnesium casting process will be incorporated into the cross car beam. The tooling and equipment costs were estimated by consultation with suppliers and industry experts. The brackets and mounts are welded onto the cross car beam in the baseline vehicle. This additional assembly costs are eliminated in the LWV cross car beam by incorporating the brackets and mounts into the basic casting. The incremental costs are summarized in Figure 449.

IP Beam Cost Breakdown	Baseline ($ USD)	LWV ($ USD)	Incremental Costs ($ USD)
Manufacturing	$43.0	$67.9	$24.9
Assembly	$11.0	$0.0	-$11.0
SG&A	$2.4	$3.1	$0.6
Profit	$3.2	$4.1	$0.8
Total	$59.7	$75.0	**$15.4**

Figure 449: Instrument Panel Beam Incremental Costs

The plastic materials in the instrument panel, electronics and audio which are not Class A surfaces will make use of Trexel's MuCell® hydrogen-filled polymer. This does not add cost as the design process and tooling resources are the same for MuCell® as for the baseline parts. The overall cost increment for the LWV instrument panel is due to the cross car beam.

9.6.10 Engine and Transmission

The LWV powertrain consists of a downsized engine from the original 2.4 L, four cylinder engine in the baseline 2011 Honda Accord to a 1.8 L naturally aspirated engine such as that used in Honda Civic. A detailed engine incremental costs study is not within the scope of this study; the LWV incremental costs based on the material cost estimates are summarized in Figure 450.

Item	Material	Accord LX 2.4l (kg)	Civic LX 1.8l (kg)	Δ Mass (kg)	Δ Cost $ (+/-)
Engine	Al/Steel/Mix				
Engine Block	Aluminum	20.52	19.31	-1.21	-$3.99
Cylinder Head	Aluminum	14.51	11.33	-3.19	-$10.55
Crankshaft	Steel	16.37	13.05	-3.32	-$6.71
Pistons (4x)	Aluminum	1.80	1.35	-0.44	-$1.47
Connecting Rods (4x)	Steel	2.13	1.62	-0.51	-$1.02
Engine Oil	n/a	4.16	3.82	-0.34	$0.00
Other Engine Items	Steel/Mix	59.88	56.13	-3.75	-$7.57
Misc.	N/A	50.53	34.68	-15.84	$0.00
Total		169.90	141.30	-28.60	-$31.31

Figure 450: LWV Engine Incremental Costs[219]

The chosen LWV transmission is a conventional fives speed automatic transmission currently paired in the Honda Civic with the 1.8 liter engine. This change results in a cost savings of $67.3 based on material costs only, as illustrated in Figure 451.

[219] Source: All engine specifications and weights obtained from A2Mac1; incremental costs based on material savings

Item	Material	Accord LX 2.4l (kg)	Civic LX 1.8l (kg)	Δ Mass (kg)	Δ Cost $ (+/-)
Transmission	Al/Steel/Mix				
Gearbox Casing	Aluminum	20.3	10.1	-10.2	-33.8
Clutch Housing	Aluminum	8.1	7.5	-0.6	-2.1
Transaxle Case	Aluminum	1.4	1.9	0.5	1.8
Viscous Coupling	Steel/Mix	11.1	9.2	-2.0	-3.9
Gear Box Oil	n/a	4.4	3.3	-1.2	0.0
Other Transmission Items	Steel/Mix	51.4	36.9	-14.5	-29.2
Total		96.7	68.8	-27.9	-67.3

Figure 451: LWV Transmission Incremental Costs[220]

9.6.11 Other Systems

For all of the following systems, the LWV will use the same technology as the baseline vehicle, but with the components downsized to match those of the Civic.

- Exhaust
- Drive Shafts
- Steering System
- Fuel system
- Fuel, oil and coolant
- Battery
- HVAC & Cooling System

Similar to the engine and transmission incremental costs estimates, the incremental costs of these systems were estimated based on material cost reduction due to downsizing. The incremental costs are summarized in Figure 452. The manufacturing process for the LWV fuel system is unchanged from the baseline and less material is required to fabricate the smaller fuel tank, resulting in material cost savings as shown in Figure 452. The majority of the 8.1 kg mass reduction in fuel, oil and coolant is due to the 2.7 gallon lesser fuel required for the LWV to maintain the same range as the baseline. Fuel cost is a part of dealer costs and is not included in the direct cost. The cost impact from the reduction in oil, coolant (0.7 kg) and battery downsizing (1.1 kg) is minimal.

The cost impacts due to the implementation of the following technologies were assessed as cost neutral based on feedback from respective component supplier:

- MuCell® – Trim and Headlight (housings)
- 3M Thinsulate™ material – Insulation (except under carpet)
- Aluminum wiring - Wiring

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[220] All transmission specifications and weights obtained from A2Mac1; incremental costs based on material savings

LWV System	Baseline Mass (kg)	Technology Implemented	Mass Saving (kg)	Incremental Costs ($ USD)
Exhaust	20.7	Downsized to Civic exhaust (same	1.7	-$4.0
Drive Shafts	15.2	Downsized to Civic (same materials)	3.5	-$5.3
Steering System	20.3	Downsized Power Steering to Civic	4.8	-$7.2
Fuel System	12.0	Down Sized from 18.5G tank to	1.8	-4.10
Fuel, oil, coolant	68.7	15.8 Gallons	8.1	0.00
Trim	26.3	Mucell© (Non Class-A)	3.0	0.00
Wiring	21.7	Aluminum/copper	4.3	0.00
Battery	12.4	Downsized to Civic (same materials)	1.1	0.00
Headlights	9.4	Mucell© Housing	2.4	0.00
HVAC & Cooling System	37.9	Downsized to Civic (same materials)	4.5	0.00
Noise Insulation	9.4	3M© Thinsulate™, QuietBlend®	3.2	0.00

Figure 452: LWV Exhaust, Drive Shafts and Steering System Incremental Costs

9.6.12 Capital Expenditure

The tooling costs to build new tools (stamping dies, extrusion dies, holding fixtures, cutting tools etc.) of the different LWV sub-systems were amortized to calculate a cost per system and are summarized in Figure 453. The tooling is typically owned by the OEM and considered as capital expenditure. The tooling costs were also considered for the other vehicle systems for which the mass savings were mainly as a result of material substitution or downsizing for a lighter vehicle. However, the tooling costs for these systems were predominantly cost neutral or there were minimal incremental costs. Hence, the vehicle system's tooling costs are not shown in the Figure 453 for Powertrain (Engine-Transmission, Fuel System, Exhaust), Interior (Seats and Trim), electrical wiring.

Vehicle Sub-System	Baseline Tooling Costs (in million $ USD)	LWV Tooling Costs (in million $ USD)	Incremental Tooling Costs (in million $ USD)
Body Structure	$80.3	$87.3	$7.0
Front Doors	$9.2	$9.6	$0.3
Rear Doors	$8.9	$8.6	-$0.3
Decklid	$4	$4	$0.0
Front Bumper	$1.8	$2.0	$0.3
Fenders	$4.4	$4.5	$0.1
Rear Bumper	$1.3	$1.3	$0.0
Hood	$5.1	$5.3	$0.2
Front Suspension	$12.9	$18.5	$5.6
Rear Suspension	$5.2	$4.8	-$0.4
Wheels	$0.8	$0.9	$0.1
Instrument Panel Beam	$7.0	$8.3	$1.3
Total	$140.9	$155.0	$14.1

Figure 453: LWV Incremental Tooling Costs Summary

The manufacturing equipment (stamping presses, extrusion presses etc.) and the assembly equipment (welding robots, roller-hem etc.) assumptions are the same on both the baseline and LWV cost estimation. The only exception is the laser welding assembly equipment, because it is not used as a joining method on the baseline vehicle. The estimated laser welding equipment cost used for the cost assessment is already included in the incremental cost estimates shown in Figure 454. An OEM converting their process from spot to laser welding would consider this a capital expenditure. However, one laser welder can replace several spot welders on the baseline vehicle, and could actually reduce the actual expenditure.

9.7 Total Vehicle Cost Increment

The cost increment for the different vehicle sub-systems are summarized in Figure 454, and includes the incremental tooling costs shown in Figure 453. The total direct cost increase is $319 per vehicle and increases to $429 per vehicle if the cost reduction for the downsized powertrain is not included in the incremental cost calculation.

Vehicle System	Honda Accord System Mass (kg)	Technology Implemented	Light Weight Vehicle		
			Mass Saving (kg)	Premium ($/kg)	Incremental Direct Costs ($)
Body Structure	328.0	Advanced High Strength Steel	72.8	$2.02	$146.8
Doors Front	32.8	Aluminum Stampings	15.9	$3.12	$49.6
Doors Rear	26.8	Aluminum Stampings	11.9	$4.46	$53.2
Hood	15.2	Aluminum Stampings	7.7	$2.76	$21.3
Decklid	10.0	Aluminum Stampings	5.2	$3.27	$17.0
Fenders	7.3	Aluminum Stampings	3.3	$3.86	$12.6
Bumpers	15.8	AHSS Hot Stamping	7.1	$0.17	$1.2
Front Suspension	81.3	Assembly - various materials	39.9	-$0.28	-$11.0
Rear Suspensions	53.2	Assembly - various materials	13.3	$3.30	$43.9
Seats Front	45.7	Magnesium Base and back frame	13.7	$5.23	$71.7
Seat Rear	21.0	Composite Back	6.3	$3.98	$25.1
Instrument Panel	31.9	Magnesium IP Beam	9.5	$1.63	$15.4
Engine Transmission	266.6	Down Sized from 2.4L to 1.8L, 5Speed Auto	56.5	-$1.74	-$98.6
Fuel System	12.0	Down Sized from 18.5G tank to 15.8G	1.8	-$4.10	-$7.2
Fuel, oil, coolant	68.7	15.8 Gallons	8.1	$0.00	$0.0
Wheels	93.9	AHSS	14.2	$0.62	$8.8
Trim	26.3	Mucell© (Non Class-A)	3.0	$0.00	$0.0
Wiring	21.7	Aluminum/copper	4.3	$0.00	$0.0
Battery	12.4	Downsized to Civic (same materials)	1.1	$0.00	$0.0
Headlights	9.4	Mucell© Housing	2.4	$0.00	$0.0
Exhaust	20.7	Downsized to Civic exhaust (same materials)	1.7	-$2.33	-$4.0
Brakes	59.0	Aluminum Calipers & Civic rotors	15.8	-$0.89	-$14.1
Brake Fliuid	0.5		0.0	$0.00	$0.0
Drive Shafts	15.2	Downsized to Civic (same materials)	3.5	-$1.50	-$5.3
HVAC & Cooling System	37.9	Downsized to Civic (same materials)	4.5	$0.00	$0.0
Ducting- HVAC & Engine Intake	0.0		0.0	$0.00	$0.0
Safety Systems	19.3		0.0	$0.00	$0.0
Steering System	20.3	Downsized Power Steering to Civic	4.8	-$1.50	-$7.2
Front & Rear Fascia	13.5		0.0	$0.00	$0.0
Wiper system	6.0		0.0	$0.00	$0.0
Window Washer Fluid	4.8		0.0	$0.00	$0.0
Paint	12.0		0.0	$0.00	$0.0
Noise Insulation	9.4	3M© Thinsulate™, QuietBlend® under	3.2	$0.00	$0.0
Glass	33.5		0.0	$0.00	$0.0
Latches/fastners/mirrors-Misc	47.8		0.0	$0.00	$0.0
Total - with Powertrain	1,480		332	$0.96	$319
Total - without Powertrain	1,112	Powertrain includes Engine-Transmission, Fuel system, Fuel, Oil, Coolant & Exhaust	264	$1.63	$429

Figure 454: LWV Incremental Costs (Direct) Summary

9.8 LWV Mass Savings Cost Curves

9.8.1 LWV Mass Savings Cost Curves including Powertrain Costs

Some of the LWV design options summarized in Figure 454 can be applied to a vehicle without affecting the design of primary load bearing structures such as body structure, closures, and chassis etc. These vehicle systems, such as seats, lighting, safety systems, interior trim, instrument panel etc. can be broadly classified as non-structural vehicle systems. Such mass reduction design changes to non-structural vehicle systems could be implemented during the mid-cycle face lift of a vehicle. The total incremental cost of such changes is low ($105 per vehicle as shown in Figure 458). More significant changes that can be implemented to a vehicle independent of the remaining vehicle systems are the re-design of the closures (doors, hood, and decklid) and fenders using aluminum as the primary material. Combining the non-structural changes previously mentioned with the implementation of aluminum closures results in a total mass savings of 6.5% and a total incremental cost of $259 per vehicle.

Reducing the mass of any vehicle component may allow additional mass savings on supporting (load bearing) vehicle parts. Such secondary mass savings are possible due to the reduction in the gross vehicle weight (GVW) that allows for resizing the powertrain, chassis or body structure, and is known as mass compounding. However, all these changes are significant and involve detailed design revisions to the vehicle as well as validation. Only when the associated secondary mass savings are taken into consideration, the full potential of the primary mass savings are realized. The secondary mass savings achieved in the LWV were used to estimate mass compounding factors as shown in Figure 455; every 1 kg reduction in GVW leads to an additional 0.71 kg secondary mass savings (0.24 kg from body structure, 0.22 kg from powertrain, and 0.25 kg from chassis). A study by MIT estimated a mean mass compounding factor of 0.95 and a factor of 0.77 when all components are available for redesign[221]. The mass compounding factors estimated in other studies by AutoSteel Partnership and MIT are 1.5[222] and 0.95[223] respectively.

Implementing mass reduction changes on the non-structural components (52.80 kg) and taking advantage of mass compounding by downsizing the powertrain, chassis and body structure, results in an overall mass reduction of 90.18 kg with an incremental cost of $47 per vehicle, compared with $105 if mass compounding is not employed, as shown in Figure 456.

	GVW (kg)	Body (kg)	PT (kg)	Chassis (kg)	Non Structural+ Closures (kg)	Payload (kg)
Baseline Vehicle	1,865	343.8	383.3	287.8	465.0	385.0
LWV	1,533	263.9	311.7	204.5	368.2	385.0
LWV Secondary Mass Savings Factors	1.00	0.24	0.22	0.25	0.29	

Figure 455: LWV Mass Compounding Factors

[221] Source: http://pubs.acs.org/doi/abs/10.1021/es202938m
[222] Source: http://www.a-sp.org/database/custom/mass%20compounding%20-%20final%20report.pdf
[223] Source: http://msl.mit.edu/theses/Bjelkengren_C-thesis.pdf

		Mass Reduction (kg)	Incremental Cost ($ USD)
LWV Non-Structural Masses		52.80	$105
Mass Compounding	Body (0.25)	12.72	-$20
	PT (0.21)	11.40	-$19
	Chassis (0.24)	13.26	-$19
Mass reduction including mass compounding		**90.18**	$47

Figure 456: LWV Non-Structural Masses with Mass compounding

When mass reduction changes are made to the closures and fenders in addition to the non-structural masses, the LWV mass reduction is 96.8 kg. The resultant mass reduction from mass compounding results in an overall mass reduction of 165.38 kg with an incremental cost of $153, compared to $259 without mass compounding, as shown in Figure 457.

		Mass Reduction (kg)	Incremental Cost ($ USD)
LWV Non-Structural Masses +Closures		96.83	$259
Mass Compounding	Body (0.25)	23.33	-$34
	PT (0.21)	20.90	-$36
	Chassis (0.24)	24.32	-$35
Mass reduction including mass compounding		**165.38**	$153

Figure 457: LWV Non-Structural Masses with Closures and Mass compounding

The LWV body structure final engineering solution is entirely AHSS with aluminum closures, aluminum chassis frames, downsized engine (from 2.4L to 1.8L), magnesium instrument panel cross-car beam and magnesium seats frames. The LWV final engineering solution achieves a mass savings of 332 kg (22.4%) with a total incremental cost of $319 as shown in Figure 458. One of the options considered during the initial stages was a vehicle design with an estimated mass savings of 19.2% using AHSS as the prominent material for the body structure, closures, chassis frames and seat frames (Option 1 in Figure 458). The other option was replacing the body structure material of the LWV with aluminum. This aluminum intensive design was estimated to reduce mass by 25.1% (Option 3). The last option considered was a composite body structure with magnesium inner door panels and aluminum outer door panels. This design option (Option 4) was above the initial project constraints to keep the price increase of the LWV below 10% of the baseline MSRP. The cost limit using 10% of baseline MSRP is $1,495[224].

[224] The MSRP price of $21,980 is based on Honda Accord 4DR-LX Window Sticker shown in Figure 3. 10% of the baseline MSRP is $2198. Using RPE of 1.47, the boundary of the manufacturing cost limit is $1,495.

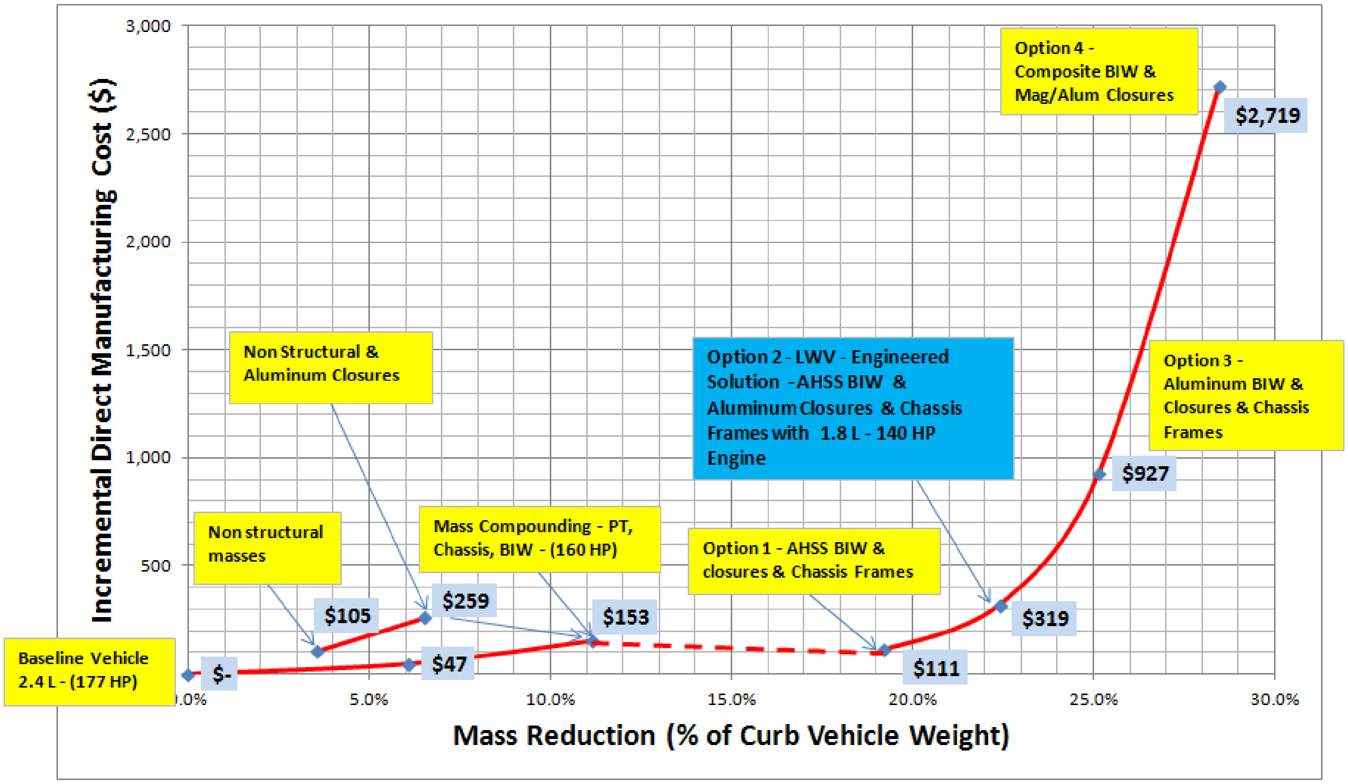


Figure 458: LWV Mass Savings versus Incremental Costs (with Powertrain) Curve

The cost premium for the 332 kg mass savings for the LWV is $0.96 per kg. The cost premium for the different options considered is shown in Figure 459.

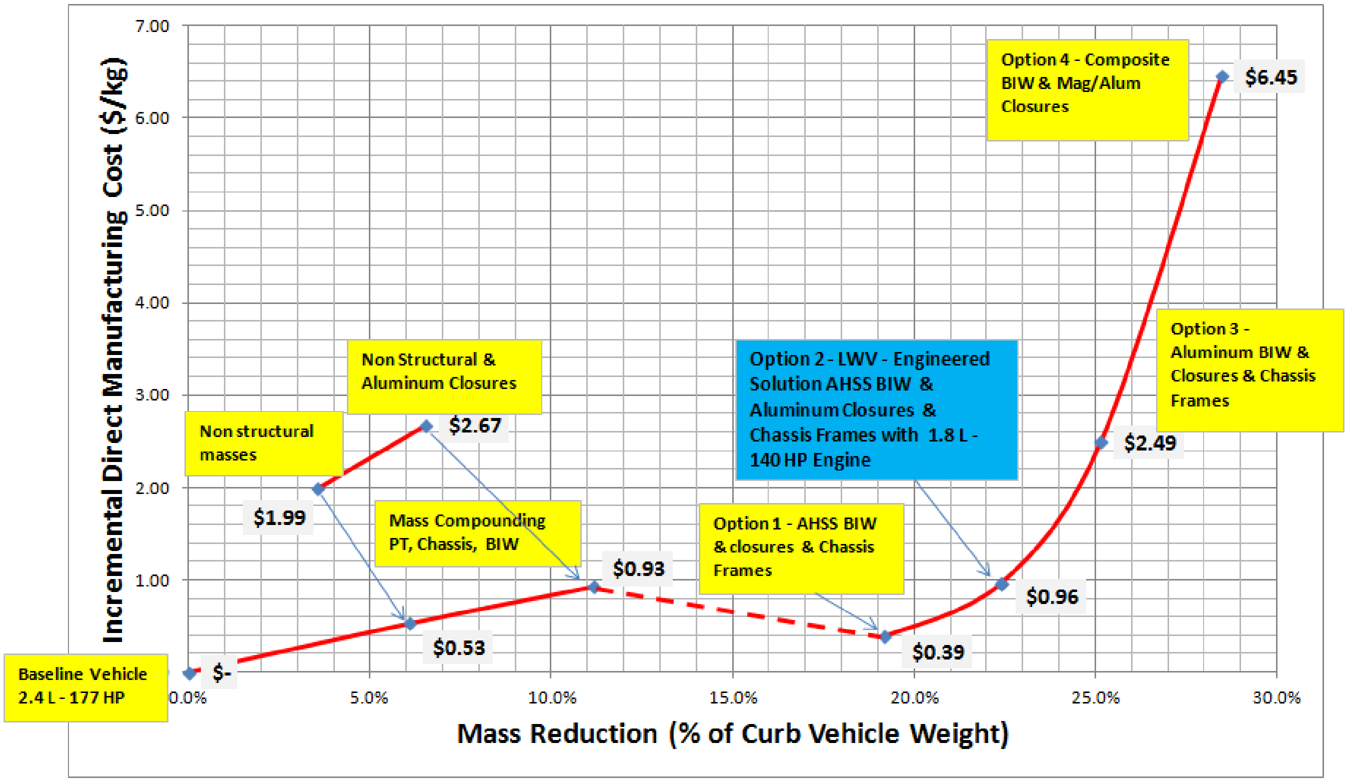


Figure 459: LWV Mass Savings versus Costs Premium (with Powertrain costs) Curve

The mass savings of the LWV and other options without including the savings (both mass and costs) attributed to the powertrain downsizing are compared to the total costs in Figure 460. Similarly, the mass savings without powertrain downsizing are compared to the costs premium in Figure 461.

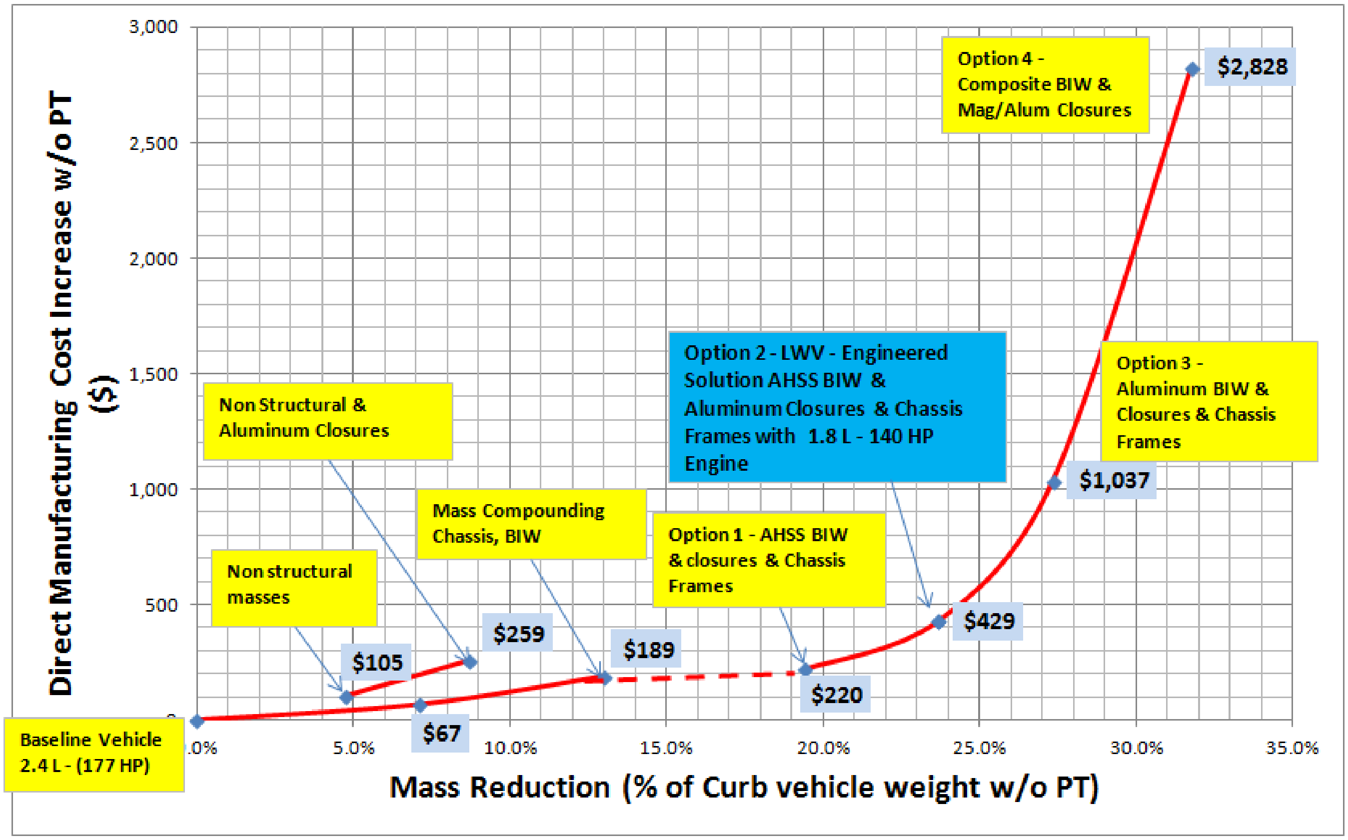


Figure 460: LWV Mass Savings versus Total Costs Curve (without Powertrain costs)

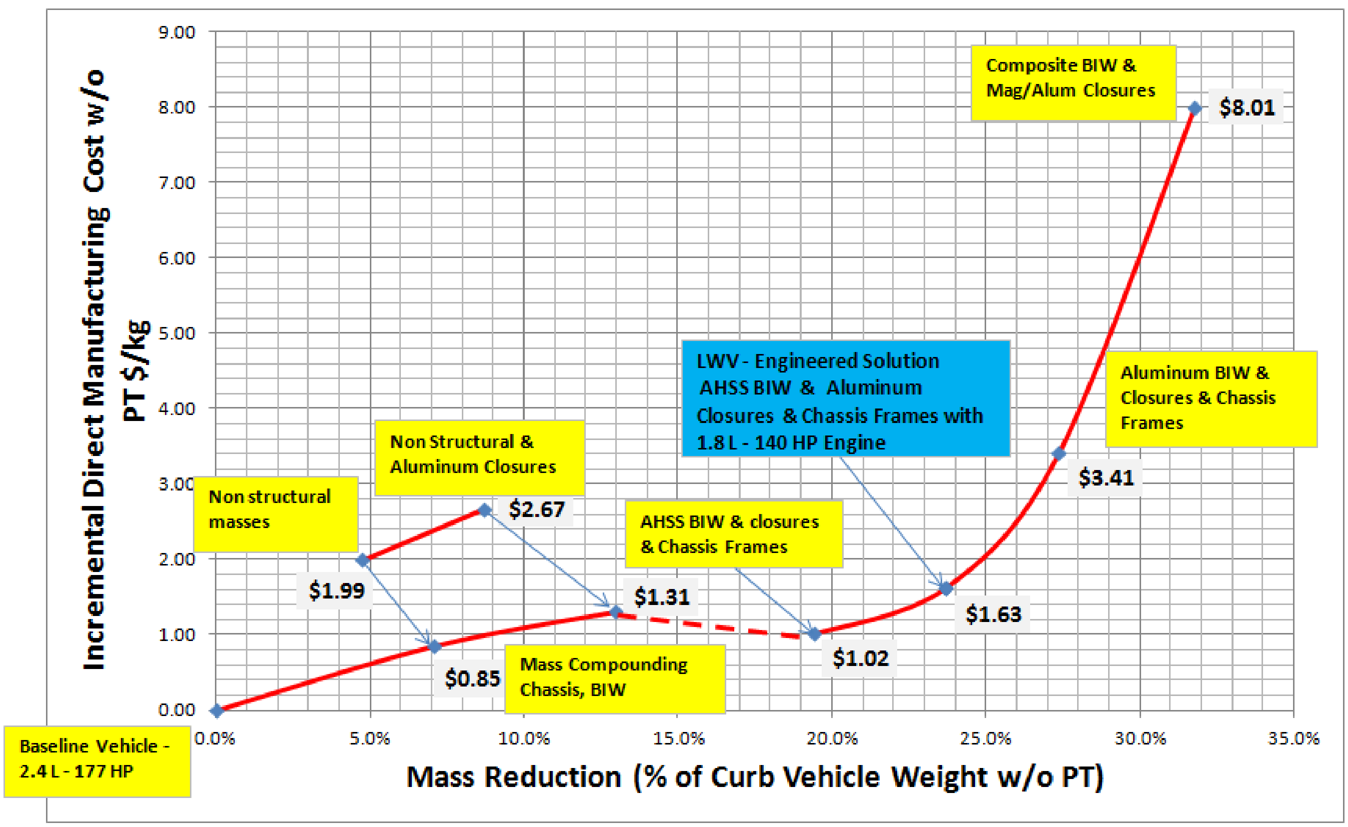


Figure 461: LWV Mass Savings versus Costs Premium Curve (without Powertrain costs)

10 Effect of 'Learning' on Technology Costs (Optional Task 3)

This Optional Task 3 looked at the effect of "learning" on technology costs. Specifically, the team from Electricore, Inc. (prime contractor), EDAG, and George Washington University (GWU) examined the weight and cost differences between spot and laser welding of the vehicle body structure. The purpose of this study is to compare the mass savings and costs associated with converting the assembly of body structure from a resistance spot welding joining process, to laser welding joining process.

Laser beam welding a joining technology for assembling body structures offers a considerable potential for light weighting. The mass of all the flanges required for resistance spot welding on a body structure is approximately 10% of the weight of a vehicle's body structure. So, for the LWV body structure, designed as part of the main task of this project, with a weight of 254 kg, the weight of all of the flanges is of the order 25 kg. There is a potential of a mass savings of 12 to 13 kg by using laser welding technology which requires a smaller flange width. With regards to structural stiffness the laser welded structures generally have improved stiffness when compared to a spot welded structure, which could possibly lead to additional mass saving.

Resistance spot welding is a highly mature body structure joining process which is already being extensively used in the automotive industry for high volume production. Spot welding has already been adapted to sustain the quality and high volume production requirements of the automotive industry.

Laser welding assembly is a process that can be controlled precisely which allows the high speed welding of a seam which is both narrow and uniform. This means that the process can considerably reduce heat generation and distortion within the material. This, in turn, reduces finishing work and means that the seam can be reproduced at a continuous high quality. In spite of the progress made since the inception of the laser welding process, it is not often in the automotive industry due to the costs involved. However, since there is a lot of on-going research on laser welding, progress is being made to make the process more suitable for high volume production and to lower the equipment costs.

This study investigated the following:

1. Mass saving potential of laser welding the body structure
2. The structural performance (torsional and bending stiffness and normal modes of vibration) of laser welded body structure compared with spot welded structure
3. Body structure assembly comparison of laser weld intensive body assembly versus spot weld intensive assembly for the following:
    a. Equipment capital costs
    b. Space requirements
    c. Operational costs (labor, energy, consumables and maintenance)
    d. Cost per unit for 200,000 annual production with equipment write off over 5 and 10 years

Figure 462 shows the process steps followed for comparing the Laser Weld with Spot Weld assembly process.

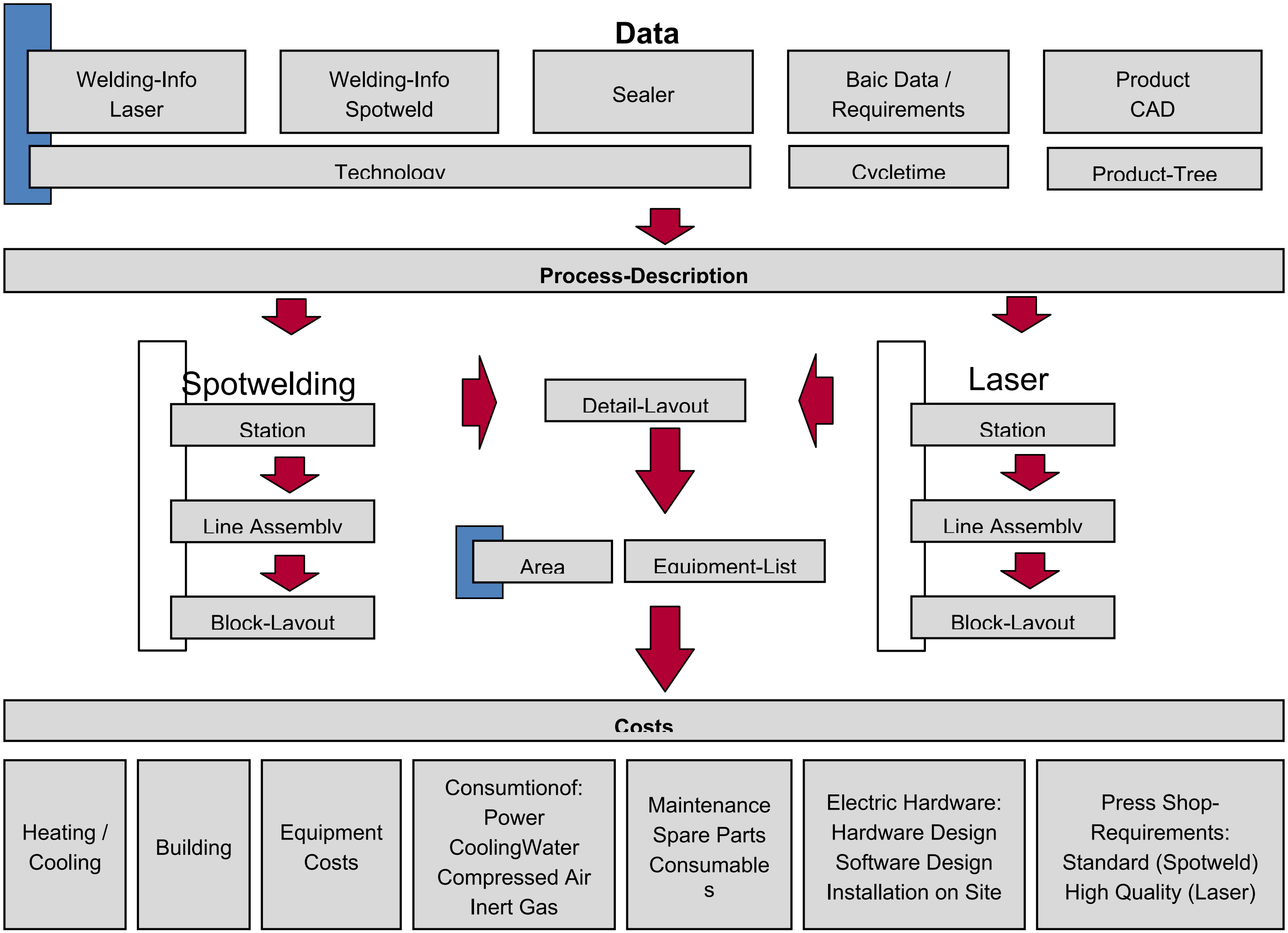


Figure 462: Process for comparing Spot-welding versus Laser-welding LWV Body Structure

10.1 Resistance Spot Welding

Worldwide majority of the vehicle body structures and closures utilize spot welding as the joining method via robot mounted spot welding equipment. Generally speaking when using resistance spot welding as the joining method, the weld flange is the order of 16 mm in width. This allows for the weld tip and clearance between the weld shank and the adjacent part. See Figure 463 for spot weld flange condition.

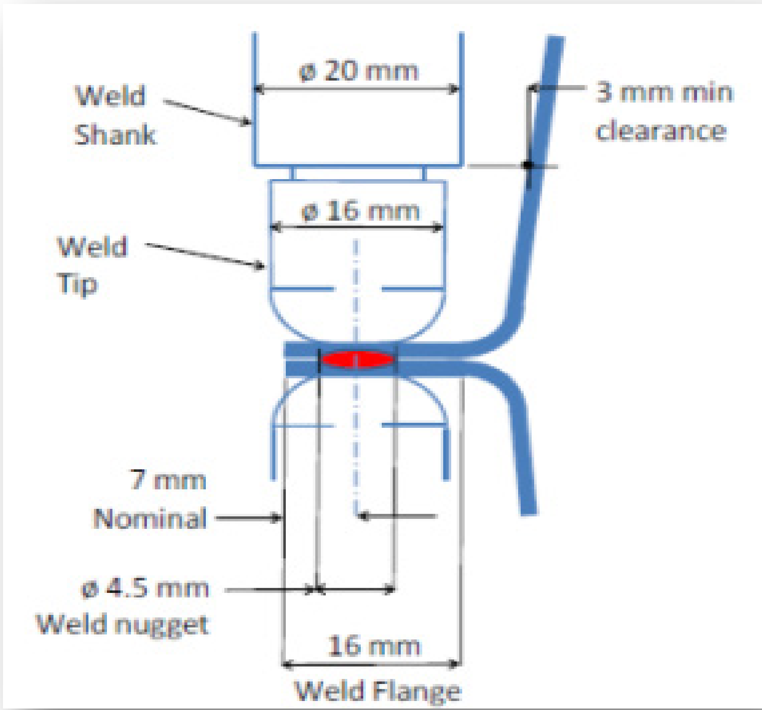


Figure 463: Spot weld flange requirements

Resistance spot welding is a joining technology which establishes a joint between multiple (two or more) sheets of metal by pressing the parts together and sending a current flow through the electrodes and the parts. The contact resistance, which is at highest between the sheets, results in a temperature increase and hence in a local melting zone.The electrodes are made of either an alloy of copper-chromium, zirconium alloy, or dispersion strengthened copper alumina system and have to be exchanged after approximately 6000 weld. A typical Body in White (BIW) structure of a high volume production car nowadays contains approximately 5000 spot welds. The quality of these welds is a key requirement for the structural performance of the vehicle for crash and NVH (Noise, Vibration & Harshness).

Typical characteristics and requirements of Spot Welding technology are:

- Welding guns must have direct access to the parts
- Accessibility from both sides of the parts is required
- Use of stationary or (robot-) guided welding guns
- Flanges in the parts are required, as a an overlapping of the parts is required

- Electrodes are mostly water-cooled, in order to guarantee a low resistance between the sheets and the electrodes
- Various design requirements must also be considered

The pure welding time usually is in the range of 0.1 to 0.4 seconds, whilst the water cooled electrodes apply a welding current of 5 to 25 kA creating a lentoid spot connection[225]. The squeeze time and the hold time are two other important weld parameters. The whole cycle of creating a spot weld is shown in Figure 464. The squeeze phase serves to overcome a poor fitting of the parts due to a rough surface or other reasons and has about the same length for coated and uncoated steels. During the weld phase the actual connection is created, demanding a higher weld current and a longer weld time for zinc-coated steels compared to uncoated steels. Afterwards the electrode force is kept up for a specified hold time to ensure the consolidation of the weld. All this adds up to an approximate welding time of about 3 seconds per spot, depending on the different welding parameters.

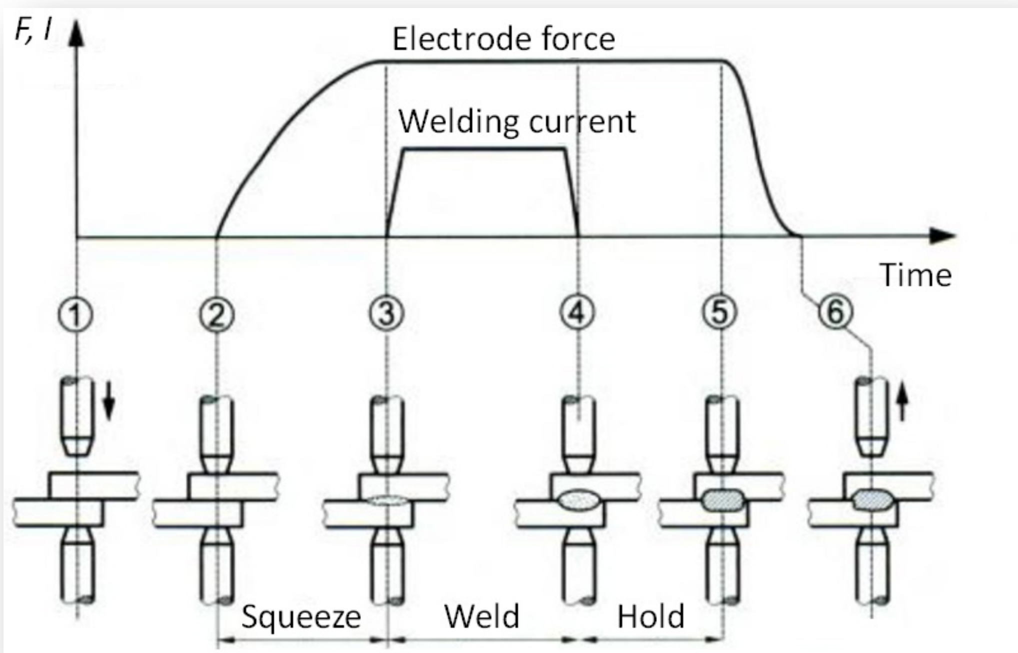


Figure 464: Cycle of resistance spot welding[226]

The spacing between two spot welds (the pitch) is usually 30 to 100 mm. One of the restrictions for the minimum spacing is the quality of the weld nugget. As displayed in Figure 465 with too close positioned spot welds there is a shunt established through the previously created spot weld. This reduces the current flow right between the electrodes so that the heat input decreases. At which distance the risk of a shunt occurs depends on the weld parameters, the sheet's coating and thicknesses. The mentioned upper limit of 100 mm pitch only guarantees sufficient strength in combination with adhesive bonding. In practice the weld pitch averages to about 40 mm for spot welding.

[225]http://www.uni-potsdam.de/u/al/mitarbeiter/zeissler/lehre/vmh/material/schweissen.pdf
[226] Koether & Rau, 2007, p. 205

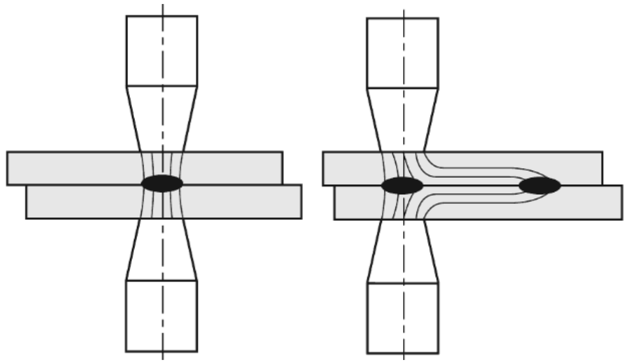


Figure 465: Desired current flow (left) and current flow with shunt (right)[227]

Apart from the differing weld parameters resistance spot welding of zinc-coated sheets mainly is a challenge for the process reliability. While for uncoated sheets over 6,000 spots can be created with one electrode, for zinc-coated steels the limit is usually below 3,000. Good weld quality is essential and depends, to a considerable degree, upon uniformity of the electrode contact surfaces. This is achieved through automatic dressing (milling) the electrode at predetermined number of spot welds (approximately 200) based on the welding conditions.

For advanced high strength steels the process is not much different than for mild steels. Some parameters, such as the weld current, may have to be slightly lower due to the higher electrical resistance caused by the alloying elements in the steel. The electrode force may have to be increased, due to the more pronounced spring back behavior of high strength steels. But all this can be handled quite well by the welding systems in production today, for a high volume production process. Similarly stainless steels can also be spot welded effectively in a high production environment.

10.2 Laser Beam Welding

In 1995 a Japanese study suggested that 25 % of the industrial weld operations could be carried out by laser (Light amplification by stimulated emission of radiation) welding. At that time the laser actually was applied for only 0.5 %[228]. Though this figure certainly has increased since then, there still is a lot of future potential. Tailored blanks (sheet metal blanks with two or more material thickness and/or different steel grades) used for light weight stampings are made by laser welding today.

Laser technology is highly suitable for joining processes. The narrow and uniform geometry of the welding seam is particularly advantageous. Controlled precisely, the joining process can be performed at high speeds. This means that heat generation and, as a result, distortion within the material can be reduced considerably. This in turn reduces finishing work and means that the seam can be reproduced at a continuous high quality. A typical laser welding seam dimensional requirements for stamped parts is shown in Figure 466. Compared with Spot Welding shown in Figure 463, the width of the laser welding flange is 8mm versus 16mm for spot welding. This change of flange size reduction if implemented on all the spot welded flanges on a body structure would lead to approximately 5% mass saving of the structure.

[227] Fertigungstechnik, 2010

[228] Steen, William M. and Mazumder, Jyotirmoy. 2010. Laser Material Processing. London : Springer, 2010.

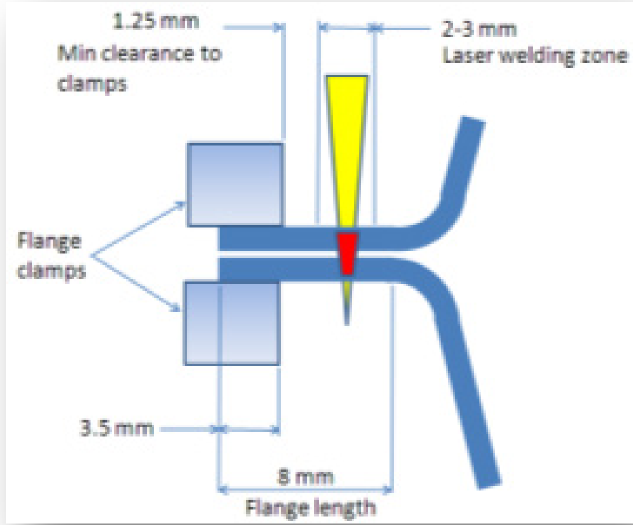


Figure 466: Flange requirements for laser welding

Multitudes of weld seams and joint conditions that can be created using laser welding are shown in Figure 467, Figure 468 and Figure 469.

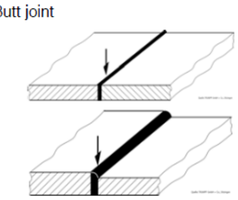
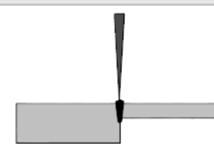
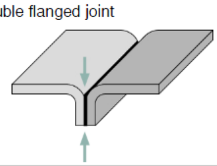
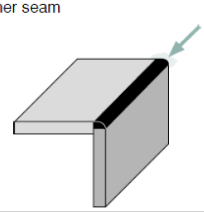
Seam geometry	Description	The most favorable seam geometry
Butt joint 	• Various sheet thicknesses possible. • The most favorable force flow. • Good accessibility. • Expensive preparation. • Characteristic features: The joint gap must be very small.	
Double flanged joint 	• Extremely low preparation costs. • High rigidity. • Unfavorable force flow. • Very good accessibility. • Characteristic features: Higher material cost.	
Corner seam 	• Low plaster cost. • Only 90° angle weldable. • Characteristic features: Solid-state laser in case of this seam geometry advantageous.	

Figure 467: Laser Welded Seams and Joints[229]

[229] Trumpf, Inc.

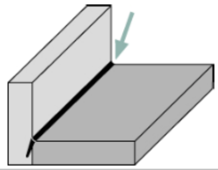
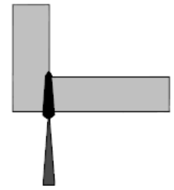
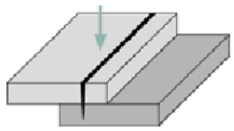
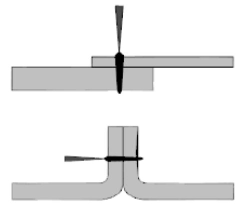
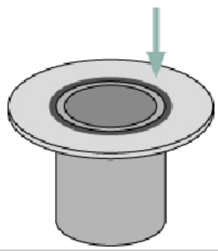
Welding seam	Description	The most favorable seam geometry
Fillet seam 	• Expensive preparation. • Favorable force flow. • Unfavorable accessibility. • Characteristic features: Bends due to the bad accessibility to the lack of fusion.	
Lap seam 	• Low preparation cost. • Good accessibility. • Power transmission over the seam cross-section. • Unfavorable force flow.	
Axial circular weld 	• Corresponds to a butt joint. • Preparation: Tacking or force fit. Reason: The gap on the opposite side is expanded due to diagonal shrinking at the beginning of the seam. • Favorable force flow. • accessibility depends on the geometry of the workpiece.	

Figure 468: Laser Welded Seams and Joints[230]

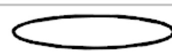
Form	Graphics	Evaluation
Pull-through line		• Quick and easy to manufacture. • The mechanical voltage for load is the highest at the beginning and the end of the seam (voltage peak). • Less welding depth at the beginning and end.
Line made up of single points		• Less heating due to pulsing. • The workpiece cools in the breaks between the pulses.
Stepped line		• Heat input less than that in case of pull-through line. • Less welding depth at the beginning and end of every seam section.
Oval		• High tensile strength during shell loading. • Double welding length. • Higher heat input.
Round-stepped		• Tensile strength during shell loading higher than stepped line. • Higher heat input as well.
Free shapes		• Shape is optimized for loading. • Heat input is optimized.

Figure 469: Laser Welded Seam Forms[231]

Choice of weld seams and joint conditions afforded by the laser welding process leads to additional design freedoms compared with spot welding. These can be applied to achieve additional mass saving.

[230] Trumpf, Inc.
[231] Trumpf, Inc.

The smaller flanges in the body structure for around door openings and around the frames of doors also lead other advantages of easier access and improved visibility.

10.2.1 Laser welding - System components

A laser welding unit consists of a laser beam source, a motion unit and an optical system to guide the laser beam and at its end is a process and focusing unit.

1. Laser source: The most common laser source for laser welding metals are CO_2- and Nd:YAG-Laser.
   - CO_2-Laser: The laser beam emerges in a mixture of CO2 and other gases and has a wavelength of 10.6 µm. CO_2-Laser allows a high process speed combined with a durable high power output (up to ca. 40 KW).
   - Nd:YAG-laser are solid body lasers with a wavelength near the visible light, 1.06 µm. The advantage against CO_2-lasers is that it can be guided by laser light-cables. Nd:YAG-laser can be used in steady-shift system (cw-use, with steady high power) or pulsed.
2. Motion unit: The motion system moves either the laser beam over the work part or the work part under the laser beam. Type of motion sequence setups are:
   - Machine with moving optics
     (e.g. Industrial robot, but also workstations with up to five axis)
   - Machines with moving work parts
   - Hybrid-machines (both work part and optics move)

To apply laser welding, the laser beam is focused and redirected to the weld seam by a lens system containing mirrors, lenses and optical fibers (see Figure 470). The radiation being absorbed by the work piece induces the heat into the part, which then spreads by conduction[232]. Since the beam is highly concentrated very narrow seams can be welded which limits the heat impact into the work piece.

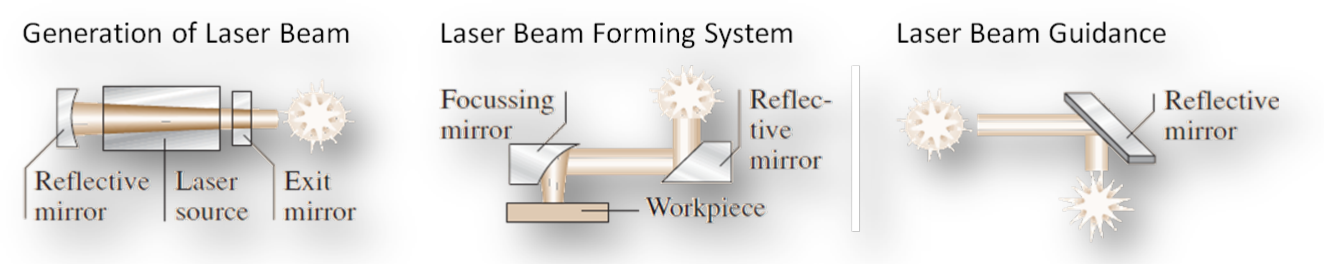


Figure 470: Laser beam creation and direction [233]

A great advantage of laser welding is the possibility to divide a single laser beam for using only one laser resonator to supply a number of welding stations increasing the efficiency. Moreover remote laser welding is able to create a weld seam even if the laser gun is up to 1,000 mm away from the work piece as shown in Figure 471.

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[232] Springer Handbook of Mechanical Engineering
[233] Springer Handbook of Mechanical Engineering

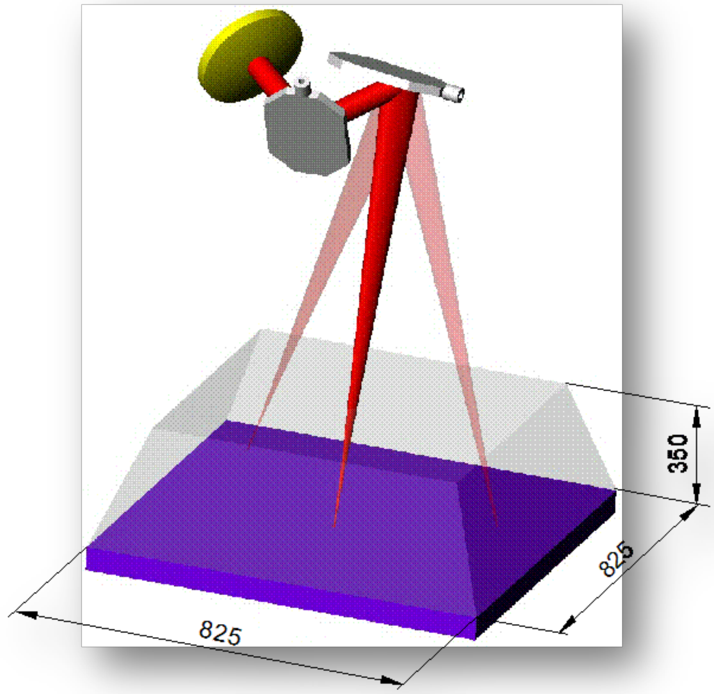

Figure 471: Remote laser optics and work area[234]

As shown in Figure 471, with the remote laser welding the laser beam can cover a large area of the work piece. This leads to a significant increase in productivity with reduction in cycle time by eliminating the intermediate positioning times from one weld to the next when compared with conventional laser welding as illustrated in Figure 472.

[234] Trumpf Inc., 2010

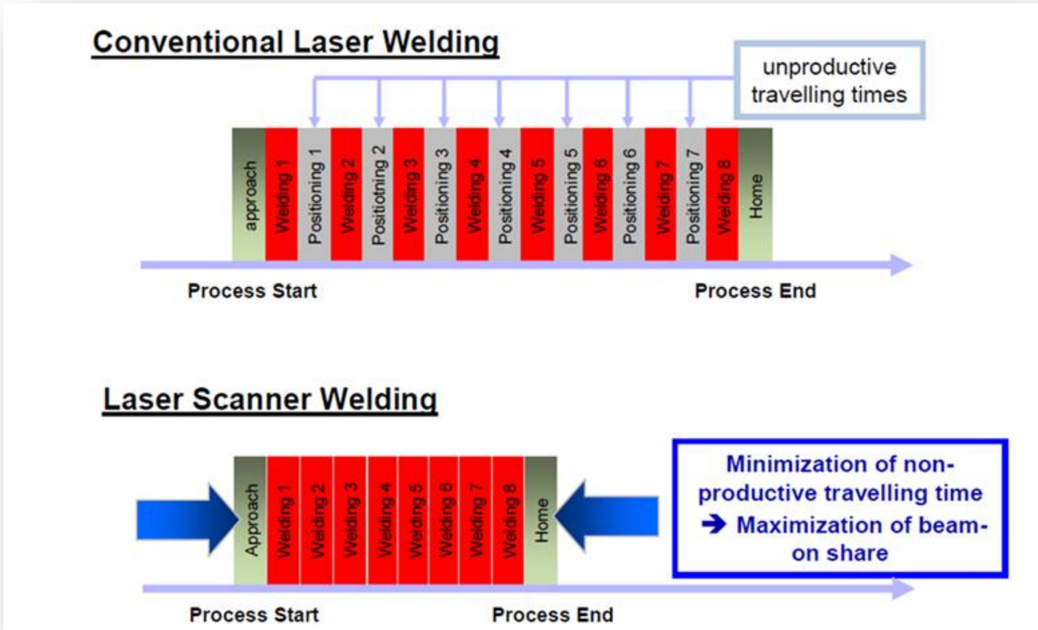

Figure 472: Laser Welding Process Cycle Time Comparison[235]

10.2.2 Laser Welding Three Thicknesses

Since with laser welding one sheet of material is completely molten to reach down to the interface of the two parts there only can be two layers bonded at a time. For linear connections three layers can be bonded by means of a staggered weld pattern. As displayed in Figure 473 the continuous laser weld line is fragmented into sections bonding alternately the lower or the upper sheet to the middle sheet. For a regular pattern the length of a single section t_l could be about 40 mm, while the spacing between the sections t_s accounts to 5 to 10 mm.

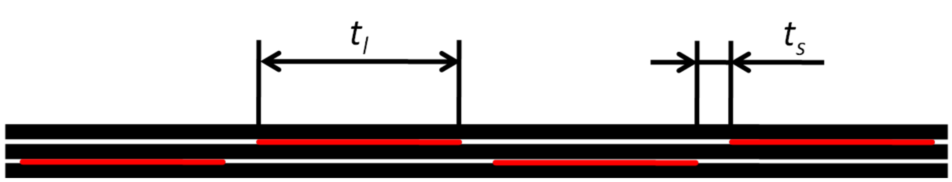

Figure 473: Staggered pattern for 3T laser weld

The welding of three material thicknesses (3T) is a requirement that is often encountered in the design of body structures. Further development work to achieve good quality 3T welds would benefit the laser welding process considerably. This certainly is a future possibility. This is one area of where further learning will lead to more efficient usage of laser welded equipment, leading to a reduction in the equipment cost.

[235] Trumpf Inc., 2010

10.2.3 Laser Welding Limitations

At present one of the main obstacle keeping laser beam welding from a large scale production application in the automotive industry are the restrictions when it comes to welding zinc-coated steels. For a lap joint the vapour created by the two inner zinc layers have to be removed to create the weld as displayed in Figure 474. The vaporizing temperature of zinc is 1180 K below the melting temperature of steel at1811 K. This causes the zinc layers between the sheets to vaporize well before the sheet metal itself is molten. When the top sheet metal is eventually liquidized the zinc vapour blows out through the molten key-hole creating failures in the weld seam. Expulsion of molten metal causes splatter on the surface (see Figure 475) and the remaining vapor can lead to porosity of the weld seam[236].

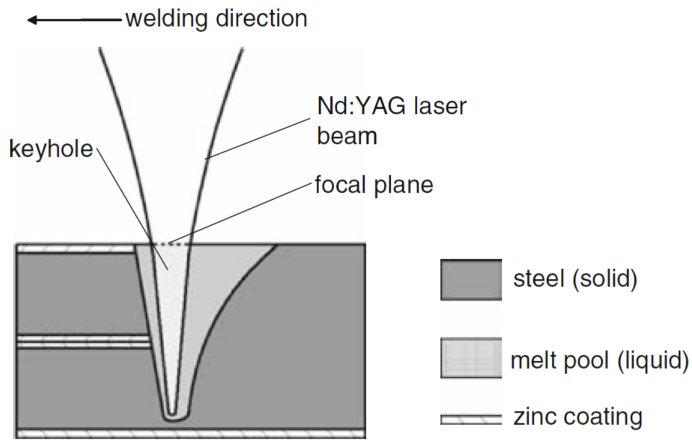

Figure 474: Lap joint laser beam welding of zinc-coated sheets[237]

Figure 475: Splatter on surface caused by Zinc coating vapour blowout – Zero Gap between the welded panels[238]

To avoid the weld issues there usually is a gap introduced between the two sheets for depressurizing the zinc vapour. This gap can be created by surface-fusing certain spots next to the weld bead on one sheet to create small elevations, which are referred to as dimpling. For better efficiency the same laser gun as for the welding itself can be used to create the dimples. Surface dimples created by a laser beam are shown in Figure 476. The height of the dimples can be adjusted from 0.1mm to 0.2mm by laser parameters.

[236]Davies, Geoff. 2003.Materials for Automobile Bodies. Oxford : Butterworth-Heinemann, 2003.
[237] Milberg & Trautmann, 2009, p. 10
[238] Trumpf Inc., 2010

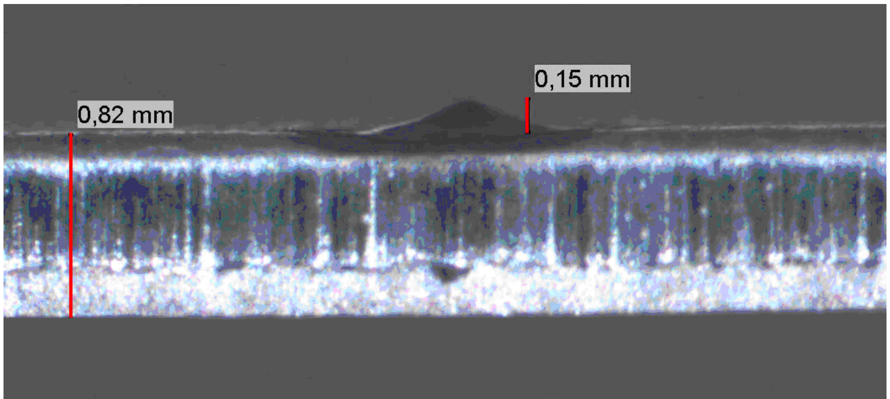

Figure 476: Surface Dimples Created by Laser Beam[239]

Another possibility is to introduce the embossments by a mechanical operation. According to Steen, William M. and Mazumder, Jyotirmoy[240] the required gap can be calculated as follows:

$$g_{min} \geq \frac{2t_{zn}v\rho_s}{\pi\sqrt{2\rho_v\rho_L g t_p}}$$

This indicates that the gap size is dependent on the thickness of the zinc layer t_{zn}, the welding speed v, the densities of the solid ρ_s, the liquid ρ_L and the vapor ρ_v, the gravitational acceleration g and the sheet thickness tp. Figure 477 show laser weld seam of acceptable quality when a 0.20mm gap is introduced in between the zinc coated welded panels.

Figure 477: Weld Seam with 0.20 mm Gap between the zinc coated welded panels[241]

10.2.4 Laser Welding Without Gap

Due to manufacturing efficiency the automotive industry is seeking a method to weld zinc-coated steels without having to provide a precisely defined gap between the panels. One of the approaches is the use of a laser beam with carefully controlled pulsed power and laser speed, whose aim it is to remove the pores generated in one pulse by the next pulse in form a of zone refining. Another possibility is to put alloy element layers between the sheets to tie the zinc[242], which is quite cumbersome. The American Welding Society recommends, removing the zinc-coating from the metal sheets in the interface area if no gap is introduced. Some manufacturers even went back to no zinc-coating on one side of the whole part. Also multi foci and other variations of multiple laser sources have been tried out. The approach of

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[239] Trumpf Inc., 2010
[240] Steen, William M. and Mazumder, Jyotirmoy. 2010. Laser Material Processing. London : Springer, 2010.
[241] Trumpf Inc., 2010
[242] Steen, William M. and Mazumder, Jyotirmoy. 2010. Laser Material Processing. London : Springer, 2010.

Trautmann[243]seems to be quite promising, using bifocal hybrid laser welding with one Nd:YAG and one high power diode laser.[244] But further research concerning the application on high volume production conditions is required. In general porosity remains an issue for hybrid laser welding processes.

This is one area of where further learning will lead to more efficient usage of laser welded equipment, with significant reduction in the equipment cost.

10.3 Welding Technology Summary

Comparing the well-established joining technology of resistance spot welding to the laser beam welding, the former certainly is the process better known. For decades production engineers gained experience with and improved the process of spot welding. This makes it a highly reliable and efficient process. Moreover welding zinc-coated steels already has been introduced years ago and also the welding of three thicknesses is achievable without problems. Spot welding under atmospheric conditions as well as welding of magnetic or reflective materials causes no issues. Compared to laser welding the initial costs of the equipment and the requirements regarding tolerances of the work pieces are lower[245].

The benefits of laser welding are the high static and dynamic stiffness of the created joints in the structure. Single sided accessibility of the welding surfaces leads to greater design flexibility. The single-sided accessibility of the laser gun itself gives more flexibility to the fixture set up and less restrictions to the structure's design. The seam could be visually inspected for quality of the seam. Weight reduction is achieved by smaller flange size and the possibility to improve the structural stiffness by creating continuous joints[246]. The heat affected area around the welded seam is very small, mainly due to the narrower heat affected zone owed to the very high energy density. In addition the weld bead exhibits a visually smoother finish; the application of after treatment operations makes it suitable for exterior class A surfaces. The high costs of the laser equipment can be reduced by using one laser source for up to four laser welding guns[247]. The laser beam from an Nd:YAG-source can easily be transported by fibers and thereby be time-shared as well as divided.

One of the essential advantages for laser welding is, especially for remote laser welding, the much higher welding speed. For spot welding roughly a time of 3 seconds per spot can be assumed, dependant on the weld parameters and configurations. If the gap between two spot welds in now assumed to be 30 mm, the spot weld gun achieves a speed of 10 mm/s along the flange. For laser welding the speed for average applications is around say 50 mm/s, which is highly dependent on the kind of materials, the thicknesses and other parameters. For certain configurations speeds up to 200 mm per second can be achieved.

Mainly due to the much higher speed, the greater flexibility and the lower requirements regarding accessibility laser welding has become a competitive option to spot welding. If the process stability in general was increased and an approach to easily welding zinc-coated sheets proved to be high volume production capable, laser welding could be applied in a large scale. The required progress in these areas is certainly within reach within the next 5 to 10 years.

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[243]Carlson, B.; Kovacevic, R.; Yang, S.
[244]Trautmann, 2009
[245]Steen, William M. and Mazumder, Jyotirmoy. 2010. Laser Material Processing. London : Springer, 2010.
[246] Materials for Automobile Bodies, Davies
[247]Steen, William M. and Mazumder, Jyotirmoy. 2010. Laser Material Processing. London : Springer, 2010.

10.4 Weight Saving Potential and Structural Performance of Laser Welding

10.4.1 Baseline Body Structure

To evaluate the effects of converting from a resistance spot welded body structure to laser beam welded body structure, the mid-term design of the LWV (available as of July 2011) was used to initiate the study. The CAD data and FEA models used in this study represent a design that met the stiffness performance requirement while the crashworthiness requirements were still being refined. However, this should not impact the results of the study. The FEA model of the LWV body is shown in Figure 478.

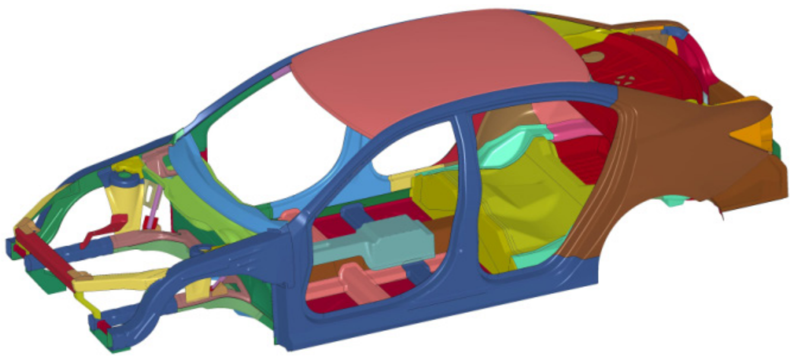


Figure 478: FE model of Body Structure

This model was modified to represent a. predominantly a Spot Welded structure and b. a Laser Welded structure. As shown in Figure 479 the adapted spot welded structure has a mass of 247.7 kg while the laser welded body had a mass of 234.5 kg. This resulted in a mass reduction of 12.2 kg, a 4.96 % saving of the body structure mass.

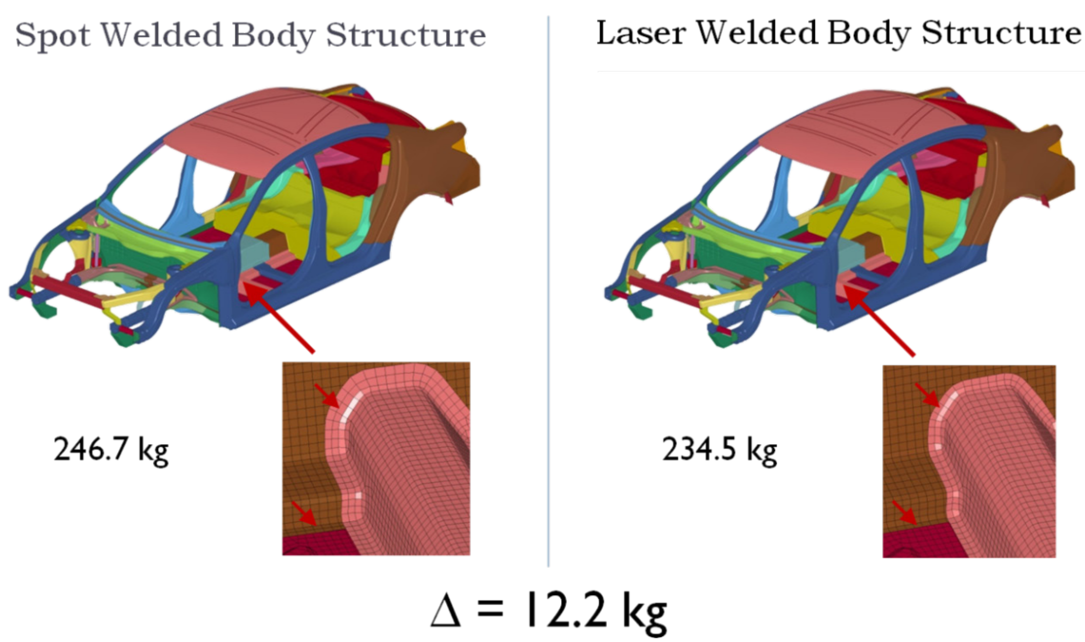


Figure 479: Illustration of weight comparison results

The mass saving for every part was determined and analysed. As shown in Figure 480, the upper structure's contribution was low at 0.316 kg. This was expected, because the extensive application of adhesive bonding in that area left only a few flanges to be trimmed. Significantly larger reductions were gained from the side structure (4.00 kg). The largest mass savings contribution came from the lower structure, at 7.92 kg. Subdividing this part reveals that the middle section does show significant weight reduction. Its savings is comparable to the side structure. The front end has a very large mass savings potential. On passenger vehicles with today's standard layout of front engine and front wheel drive the center of gravity always is shifted undesirably to the front. Mass savings in this area can partly compensate for that. The lower rear also delivers a significant share; in relative terms even the highest.

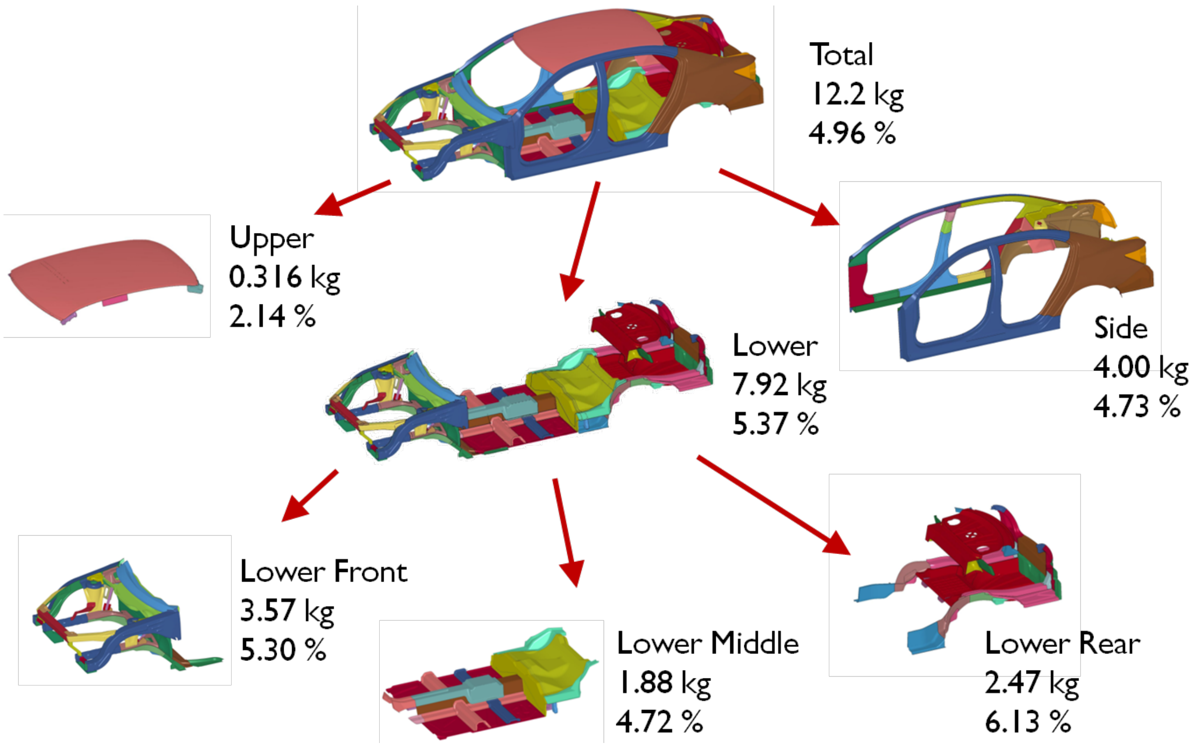


Figure 480: Distribution of obtained mass saving

10.4.2 Structure Design Change - Approach

There is a weight reduction potential from changing the primary assembly process from resistance spot welding to laser beam welding. This can be achieved by the modification of the flanges. While a spot weld connection usually requires a flange width of approximately 16 mm for joining parts. A laser beam weld requires approximately 8 mm of flange width as shown in Figure 481. The actual required flange width depends upon several parameters, such as the thicknesses of the parts to be joined, the number of layers, the materials and the welding parameters.

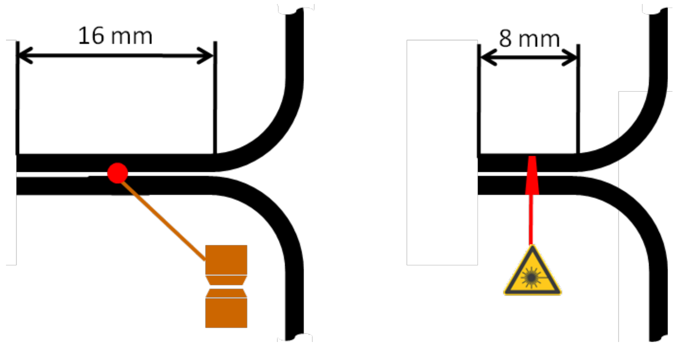


Figure 481: Flange width comparison spot weld (left) and laser beam weld flange

In general all flanges could be trimmed by 8 mm. However there are some exceptions, which have to be treated separately such as 3T joints. If all three parts of a 3T joint connect to the flange from the same side, at least the middle thickness needs a flange width considerably larger than 8 mm. A configuration like this is displayed in Figure 482. Here all components involved in the joint have to be considered to ensure none of the flanges are trimmed excessively.

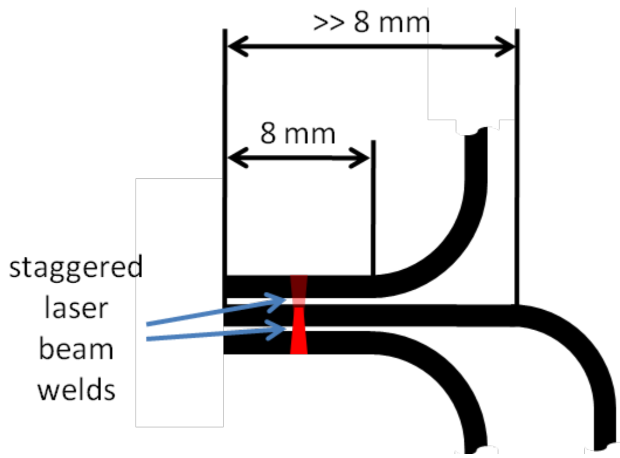


Figure 482: Flange set-up for a 3T laser beam weld

Another aspect which needs to be considered is the distinction between flange joints and lap joints (see Figure 483). In converting the flange joint from spot to laser welding, the flanges of all parts can be trimmed. In a lap joint, only one part can be trimmed to maintain a remaining flange overlap of 8 mm due to the geometrical configuration. This result in larger mass savings when converting a flange joint to a laser beam weld compared with a lap joint.

Figure 483: Schematic representation of a flange weld (left) and a lap joint weld (right)

Considering the large amount of functionalities a body structure must handle, it is also necessary to check whether the flanges to be trimmed serve other purposes. It was determined that trimmed flanges of 8 mm width could be used to carry a door seal or the wind shield. But if the flange fulfilled other structural requirements, it was not trimmed. An example of this is the front rail, where the tip is attached to the rear part of the rail and the end lap thereby needs to be longer than 8 mm during the frontal impact (see Figure 484).

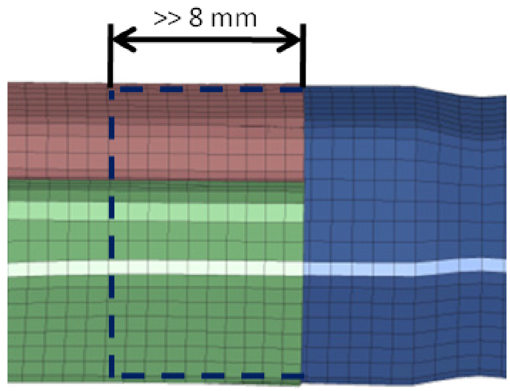


Figure 484: Front rail tip (right end) inserted into rail counterpart with an overlap much larger than 8 mm

Another effect of the conversion is the replacement of the intermittent joining approach of the spot welded body structure with continuous weld line of laser welding. This will generally lead to an increased stiffness of the structure, which must be determined with the help of FE calculation. If a considerable increase in stiffness can be detected, the thickness of parts not subject to crash loads can be decreased to bring the laser welded structure down to the same performance level as the spot welded structure. In this way some additional weight savings is possible.

10.4.3 Evaluation of Structural Performance

The spot welded and the laser welded body structure FEA models were updated to include the following items to evaluate the torsional and bending stiffness and to determine its normal modes of frequencies:

- The front and rear wind screens were attached with representative adhesive bonding
- The front and rear bumpers bolted onto the structure
- Other bolted on parts such as the rear end tunnel cross member and the instrument panel beam were added

The body structure with the above mentioned additions (also known as Body in Prime BIP), for the torsion stiffness setup is shown in Figure 485, and bending stiffness setup is shown in Figure 486. The stiffness performance of the structure was assessed on the basis of the resonance frequencies as well as the static torsion and bending stiffness of the body structure. The analysis computations were carried out by the analysis program MScNASTRAN.

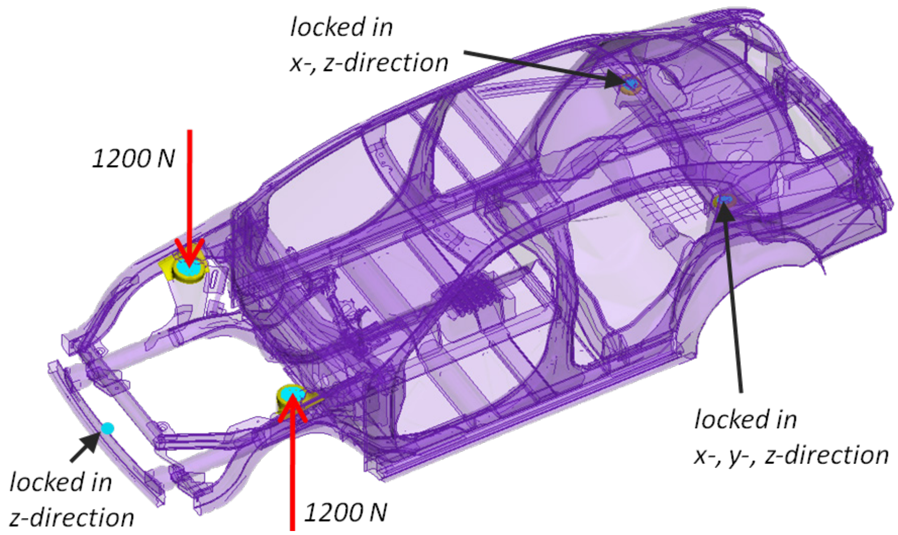


Figure 485: Set up for determination of static torsion stiffness

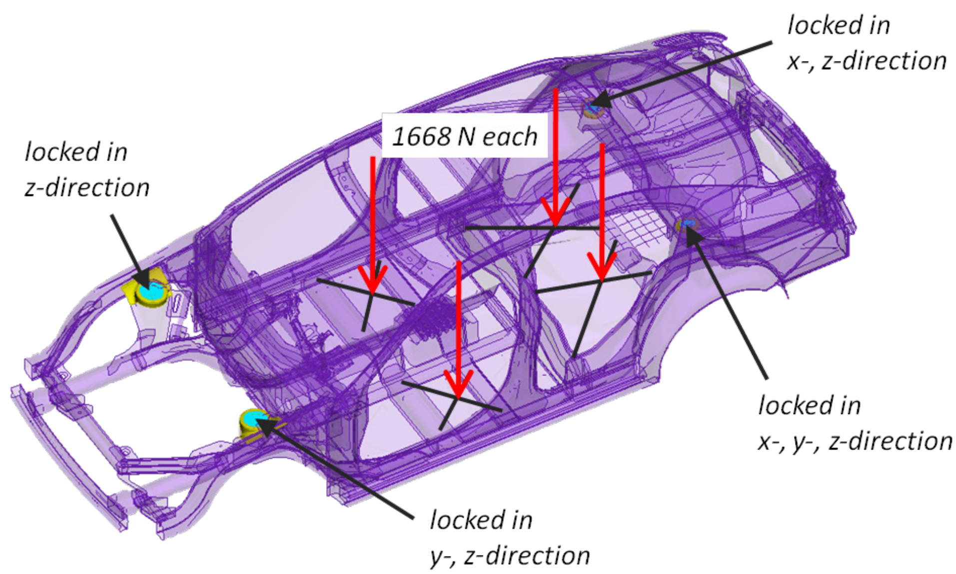


Figure 486: Set up for determination of bending stiffness

For the normal modes resonance frequency analysis the frequency modes in the range from 0 to 80 Hz were identified. Looking at the deformation patterns of the different calculated frequencies the front end lateral mode, the first bending mode and the first torsion mode were identified and compared to the ones of the laser welded model.

10.4.4 Structural Performance Results Comparison

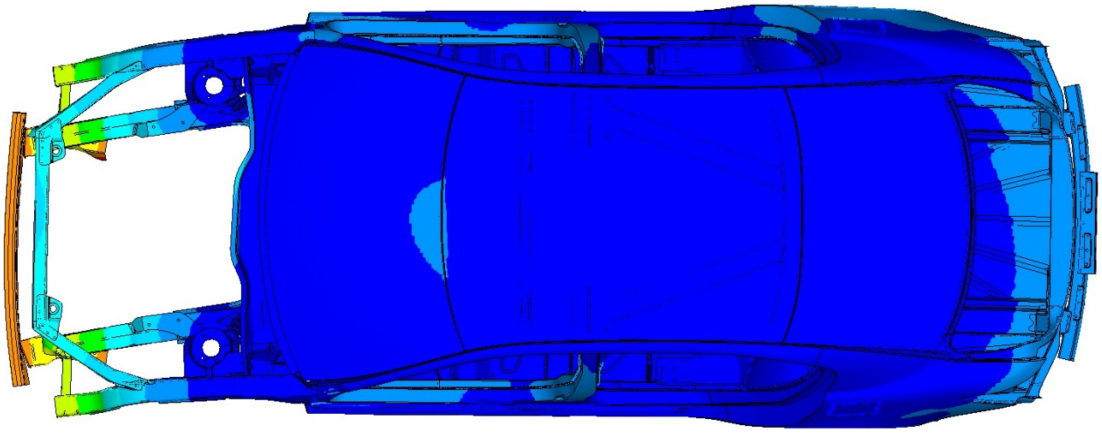
The predicted results for the spot welded and the laser welded structure are shown in Figure 487. As can be seen the laser welded structure is almost 5% lighter with improved structural performance.

	spot welded body structure	laser welded body structure	Δ
weight [kg]	246.7	234.5	-4.95%
modal analysis			
front end lateral [Hz]	34.15	35.75	+4.69%
1st order bending [Hz]	37.15	36.81	-0.92%
1st order torsion [Hz]	47.39	48.22	+1.75%
static analysis			
bending [N/mm]	11957	12186	+1.92%
torsion [Nm/°]	15802	16508	+4.47%

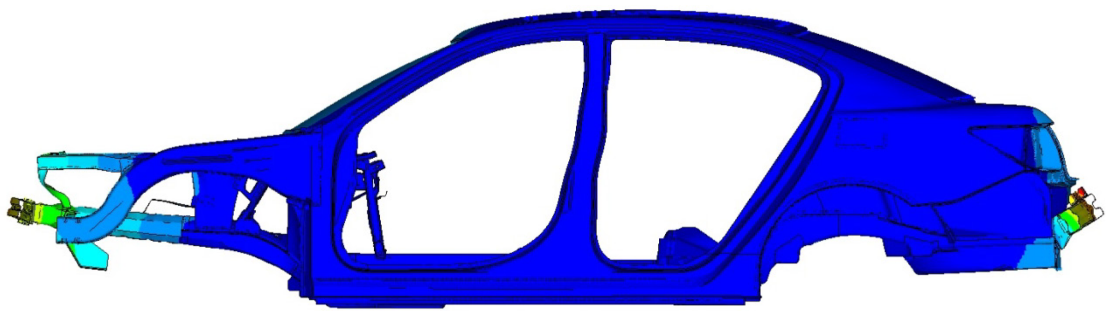
Figure 487: Results of the performance analysis – Spot Weld versus Laser Weld Structures

The torsion stiffness of the laser welded model clearly is better than that of the spot welded model. Both the static and the dynamic torsion stiffness increased considerably. This indicates potential for further mass savings, as initially hoped for. A panel which mainly improves the torsion stiffness could be decreased in thickness, as for example the main dash panel, as long as the degradation of the frontal impact performance could be precluded. Further research would be required to find a proper way to use this increase in stiffness for more weight savings.

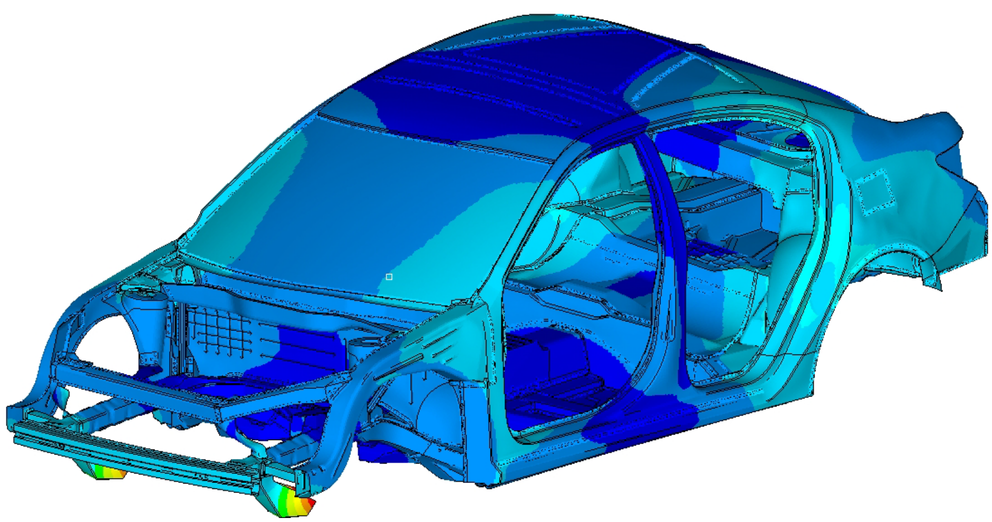
The deformation pattern of the front lateral mode of the laser welded structure is shown in Figure 488. The frequency of the first bending mode did slightly decrease with the conversion to laser welding. On the other hand, the static bending stiffness increased. However, since those deviations are not only oppositional but also quite small, it could be concluded that the bending stiffness remained about the same. Although, the laser welding did not improve the stiffness in that case, it could at least be assumed that the bending performance of the laser welded body structure does not degrade, since the static key figure rises more than the dynamic one decrease.



Front end lateral mode of laser welded structure



First order bending mode of laser welded structure



First order torsion mode of laser welded structure

Figure 488: Normal Mode Shapes of the laser welded structure

10.5 Assembly Layout for Spot Welded and Laser Welded Structure

10.5.1 Overview

A vehicle body structure is typically composed of 300 to 500 sheet metal stamped panels. All these parts in the body structure are designed to be assembled together using predominantly spot welding, adhesive bonding with some laser welding. For high volume production a body structure is produced at a rate of approximately one a minute. A highly automated assembly line is typically equipped with approximately 300 to 500 robots, 40 to 50 direct operators with another 100 to150 supporting staff to accomplish this task.

10.5.2 Assembly Layout for Spot Welded Structure

For this study all the body parts were reviewed at individual part levels to create the respective sub-assembly sequence. Similarly, all the sub-assemblies were reviewed further to generate the assembly sequence. This information is compiled by Design, Engineering and Production team members familiar with all aspects of the design and production equipment. This information is first represented in a very detailed 'Assembly Tree' as shown in Figure 489. The parts are designed in such way that they can come together and can be located accurately relative to each other for the joining operation. The part CAD data in conjunction with the assembly data specified on the 'Assembly Tree' form the bases of the body assembly plant layout, assembly tooling design and automation equipment specification.

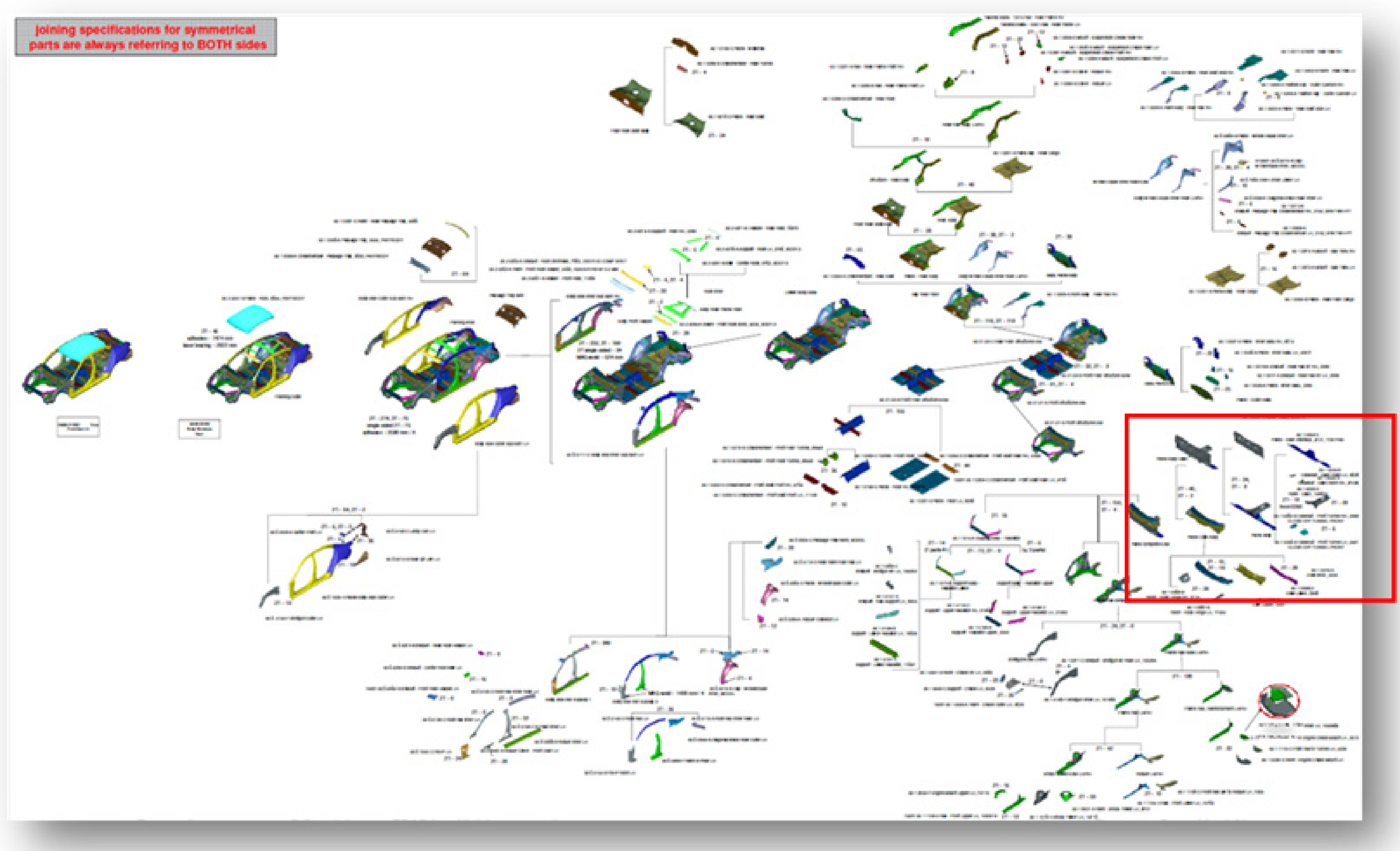


Figure 489: Assembly Tree for the Spot Welded Body Structure

As an example the assembly sequence diagram for the dash panel shown in Figure 489 (in the red rectangle) is also shown below in Figure 490, is further explained on the following pages.

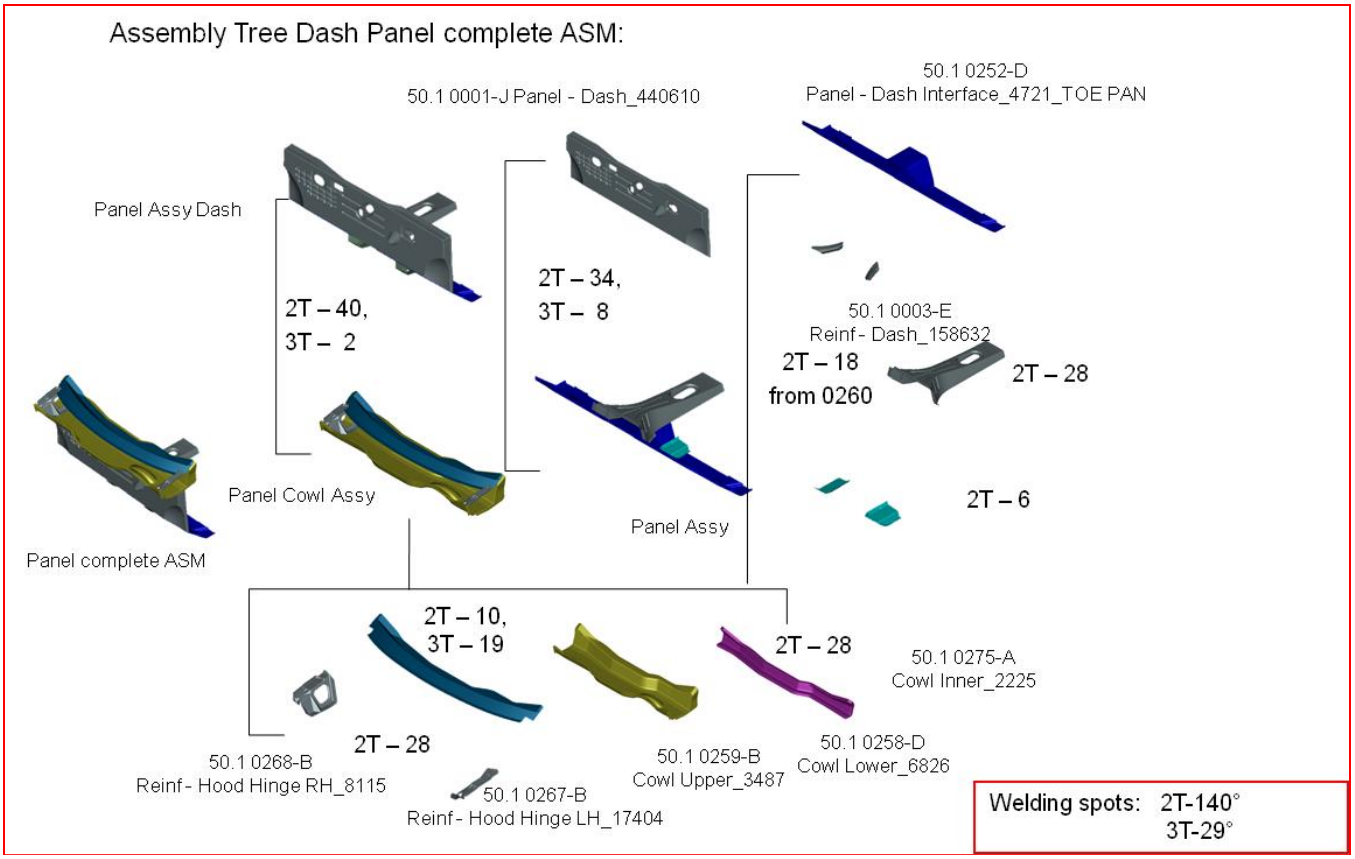


Figure 490: Assembly Tree Dash Panel

10.5.2.1 Dash Panel Reinforcements

The dash panel reinforcement subassembly is shown in Figure 491. After the parts are loaded into the geometry station they are clamped within very close tolerances to make sure the assembly fulfills the required quality criteria. Then a few spot welds are created to maintain that precisely defined position of the parts relative to each other. (22 spot welds for the shown subassembly). The respot sometimes is carried out in separate steps, because the robot may has to change its position holding the part. For the dash reinforcement, there were 30 respots applied within three steps.

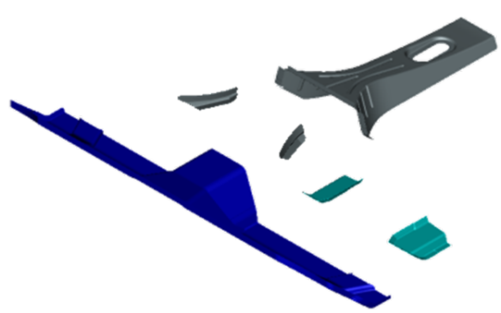


Figure 491: Dash panel reinforcement subassembly

Figure 492 shows the dash subassembly. There are 24 geo welds and 18 respots applied to this subassembly.

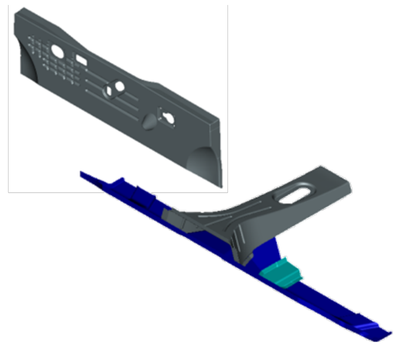


Figure 492: Dash panel subassembly

10.5.2.2 Cowl Sub Assembly

The cowl subassembly shown in Figure 493 is built in two phases. First the upper cowl and the two hood hinges are welded with 22 spots in the geometry station. The respot contains 6 weld spots. Then the lower and inner cowl is welded with 22 geo welding spots and six respots. Eventually the two created built-ups are joined by 21 geo and 8 respot weld points.

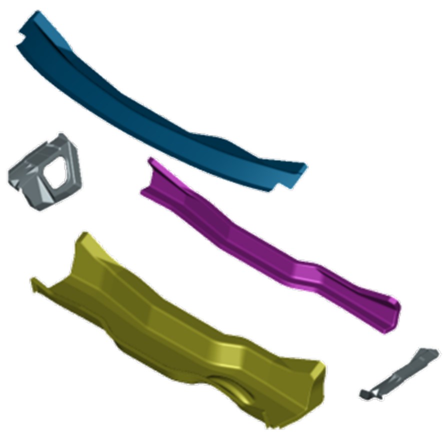


Figure 493: Cowl panel subassembly

Hence the cowl panel and the dash panel subassemblies are joined to the dash subassembly applying 22 geo welds.

10.5.2.3 Front Rail Outer Sub Assembly

The front rail outer subassembly was put together in five stages. First the front rail upper and the upper engine mount (two lower green parts in Figure 494) were welded each with 8 geo spots and respots. Then the shock tower (grey) and the shock tower reinforcement (green) were joined by 8 geo spots and 21 respots. Those two subgroups were connected by again 8 geo spots and 10 respots. The lower section of the front rail outer was created by joining the lower front rail (blue) and the "lower front rail to rocker" (bronze) with only 10 geo welds. Eventually the two groups were assembled using 24 geo welds and 12 respot welds and again 6 respots. In contrast the front rail inner could be joined in one assembly. This was done by 20 geo and 2 respot welds. The outer and inner rails were put together with 22 geo spot welds.

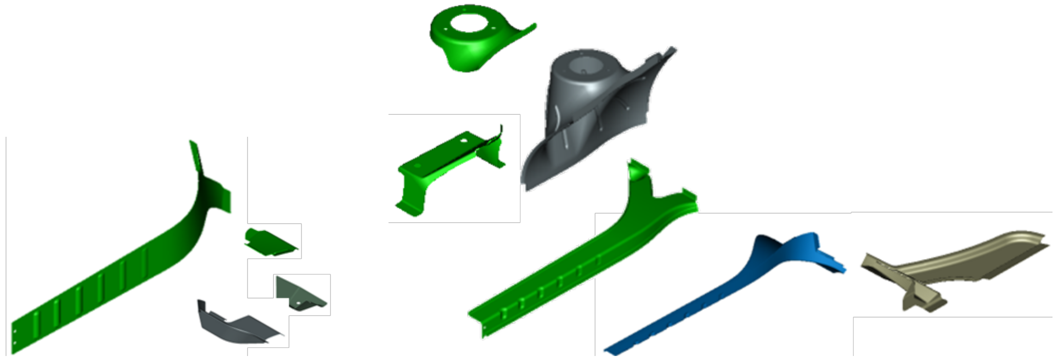


Figure 494: Front rail inner (left) and outer (right) subassembly

10.5.2.4 Shotgun Inner

For the shotgun inner two stages were needed for the assembly. The group shown in Figure 495 on the left was joined by 12 geo welds and 10 respots. The two parts on the right were connected by 12 geo spot welds and 6 respots. The final subassembly was established by 14 geo welds and 6 respots. To join the front rail and the inner shotgun 24 geo welds and 8 respots were needed.

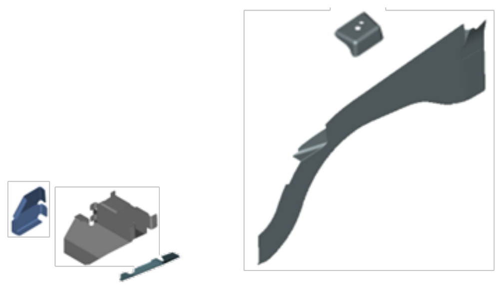


Figure 495: Shot gun inner subassembly

10.5.2.5 Radiator Support Sub Assembly

The radiator support was joined by 2T (92) and 3T (8) spot welds. The lower part, seen in Figure 496, was made with 14 geo welds, while the upper part required only 6. Assembling together was done with 32 geo welds, 48 respots in the first phase and the mentioned 3T welds as respots in the second phase.

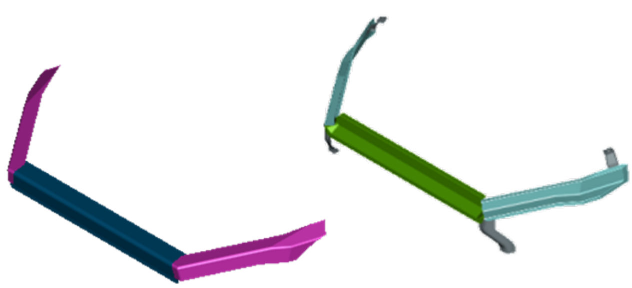


Figure 496: Upper (left) and lower (right) radiator support subassemblies

10.5.2.6 Front End Assembly

At this point the front end of the lower structure could be completely assembled (shown in Figure 497). Therefore 36 geo welds, 96 respots and eventually 41 respots were required, adding up to 169 two layer and 4 three layers spot welds in total.

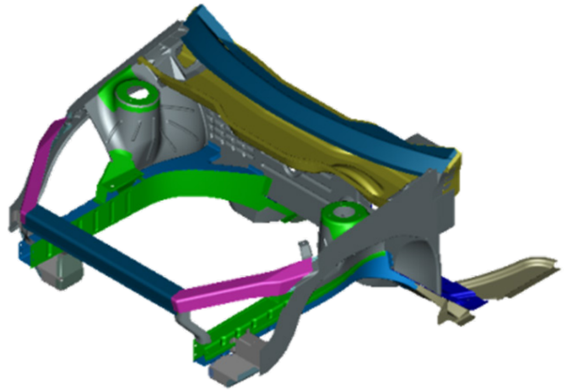


Figure 497: Lower structure front end assembly

10.5.2.7 Front Floor Sub-Assembly

The front floor assembly was created from two subgroups. First the tunnel (dark blue in Figure 498), the seat cross members front (dark brown) and the tunnel cross members (green) were assembled. The geo welding for this contained 16 spot welds, 10 and 30 respot welds. In the next station the other parts were added by applying another 200 spot welds.

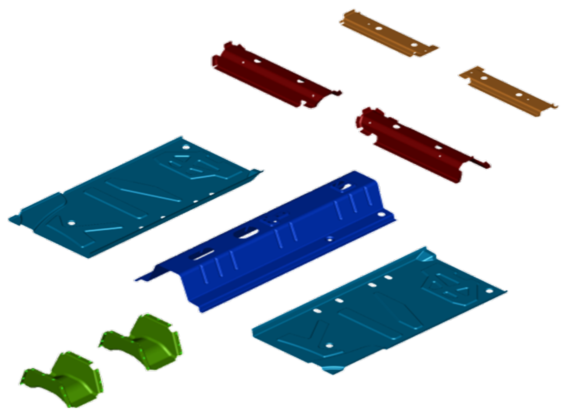


Figure 498: Front floor subassembly

10.5.2.8 Rear Rail Sub-Assembly

To assemble the rear rail first the lower part of it was joined, containing the ten parts displayed in the lower end of Figure 499. This was the main lower rail, its extension to the rocker and the stiffening plate, and the rails suspension cradle mounts. The connection was obtained by 20 geo welds and 7 respots for each rail. The upper rail section containing the grey and the turquoise dyed parts was joined by 8 geo welds and 8 respots each, including one seat cushion support on each side.

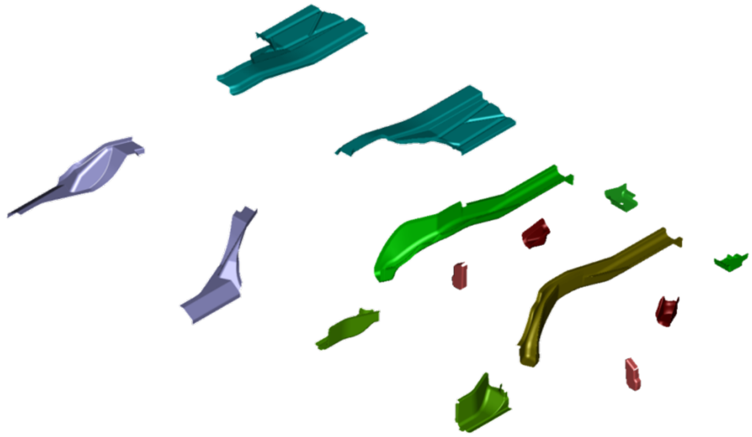


Figure 499: Rear rail subassembly

10.5.2.9 Rear Floor Assembly

The rear cargo floor (bronze colored part in Figure 500) and the gas tank mounts (dark brown) were connected by 8 geo welds and 8 respots. The rear seat panel was joined with the waterfall panel and the rear tunnel cross member with 18 geo welds and 13 respots. Before attaching those floor subassemblies to the rails both lower rails were combined by the cross member with 10 geo welds and 8 respots.

Figure 500: Parts to be assembled to the rear floor

Firstly the cargo floor subassembly was joined with the lower rail assembly making use of 18 geo welds and two times 11 respots in two different clamping configurations. Then the rear seat section came in, being connected by 18 geo welding spots and 10 respots.

The five parts composing the inner wheel house subassembly shown in Figure 501 were connected by eighteen (18) geo welds and three (3) 2T and three (3) 3T respots.

Figure 501: Inner wheel house subassembly

The back panel subassembly is shown in Figure 502. The parts are welded by 10 geo spots and three stages of respotting, with 53 spot welds.

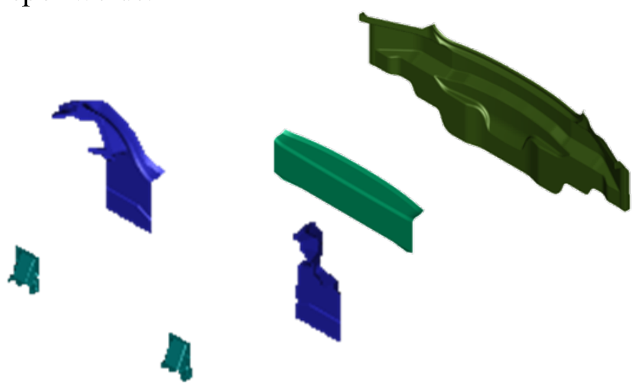


Figure 502: Back panel subassembly

To create the rear floor subassembly shown in Figure 503 first the floor section was joined with the back panel, the inner wheel house and an additional cross member below the rear seat .The geo welding for that operation comprehended 38 two layer and 2 three layer spot welds. Respotting was done in two steps, with 44 and 43 spot welds. Adding the upper part it was eventually possible to apply all the 3T welds with the rear rail. This sequence required 20 spot welds each for the geo welding, 88 each for the first step of respot and 10 each for the second step of respot.

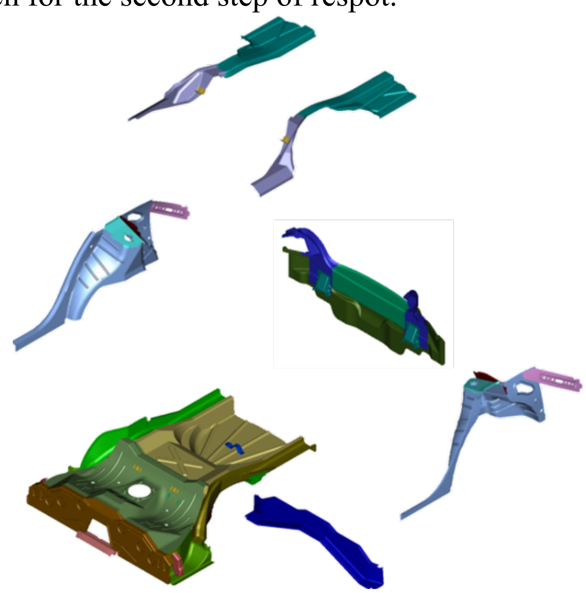


Figure 503: Rear floor subassembly

10.5.2.10 Under-floor Assembly

To complete the lower body the front structure, the front floor and the rear floor had to be assembled (see Figure 504). Geo welding was performed by 20 spot welds before the assembly was transferred to a buffer station. Then two respot stations followed, applying 52 and 53 spot welds. After another buffer a monitoring station checked 20 control points on the assembly before it was transferred to the next framer.

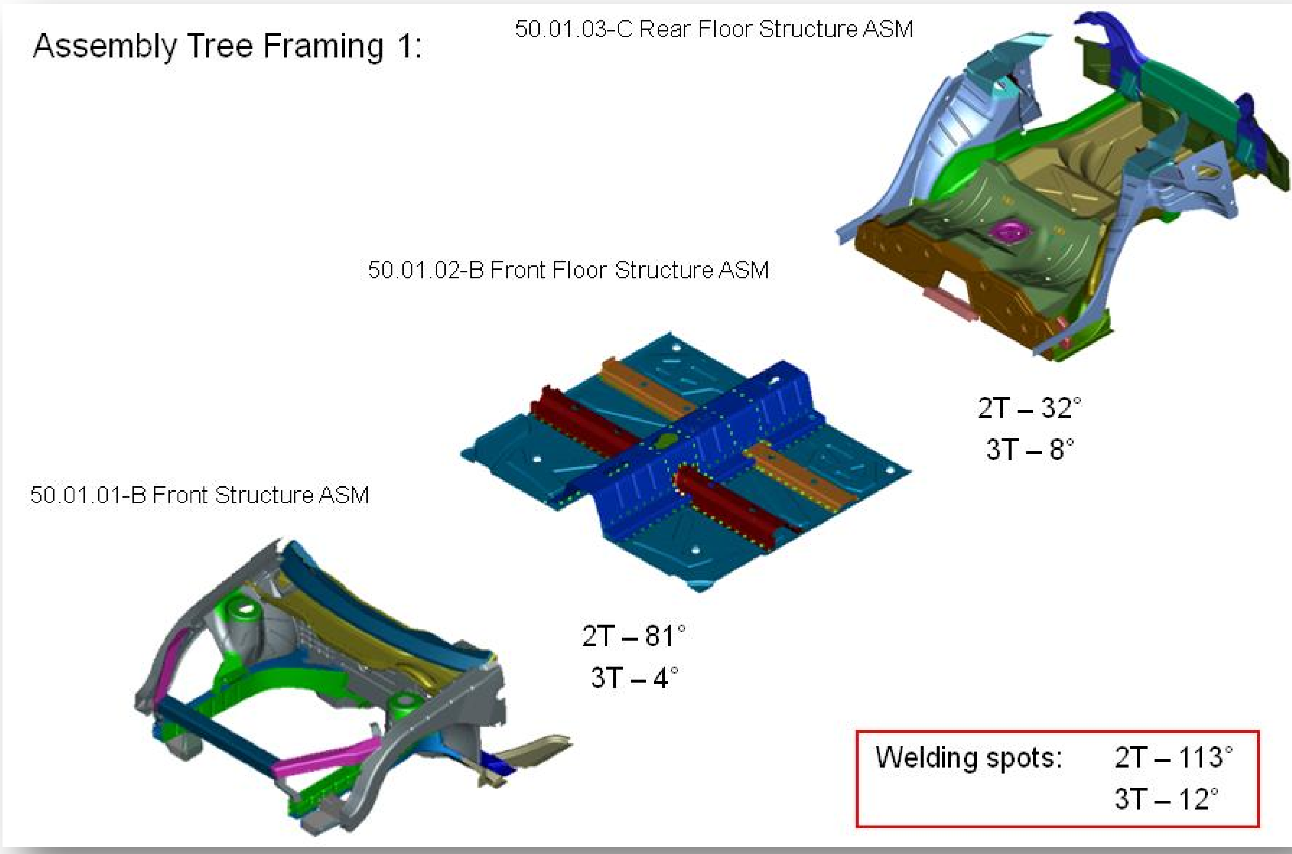


Figure 504: Lower body assembly – Framer 1

10.5.2.11 Remaining Spot Welded Structure Assembly

The approach illustrated in Sections 3.2.2 to 3.2.10 for the Lower body assembly is repeated with similar details for the rest of the body structure. Several other sub-assemblies are created and put together in framing stations 1 to 4 as shown in Figure 504 to Figure 507.

This information defined in the Assembly Tree is utilised to identify the required equipment to accomplish the body structure assembly within the required cycle time.

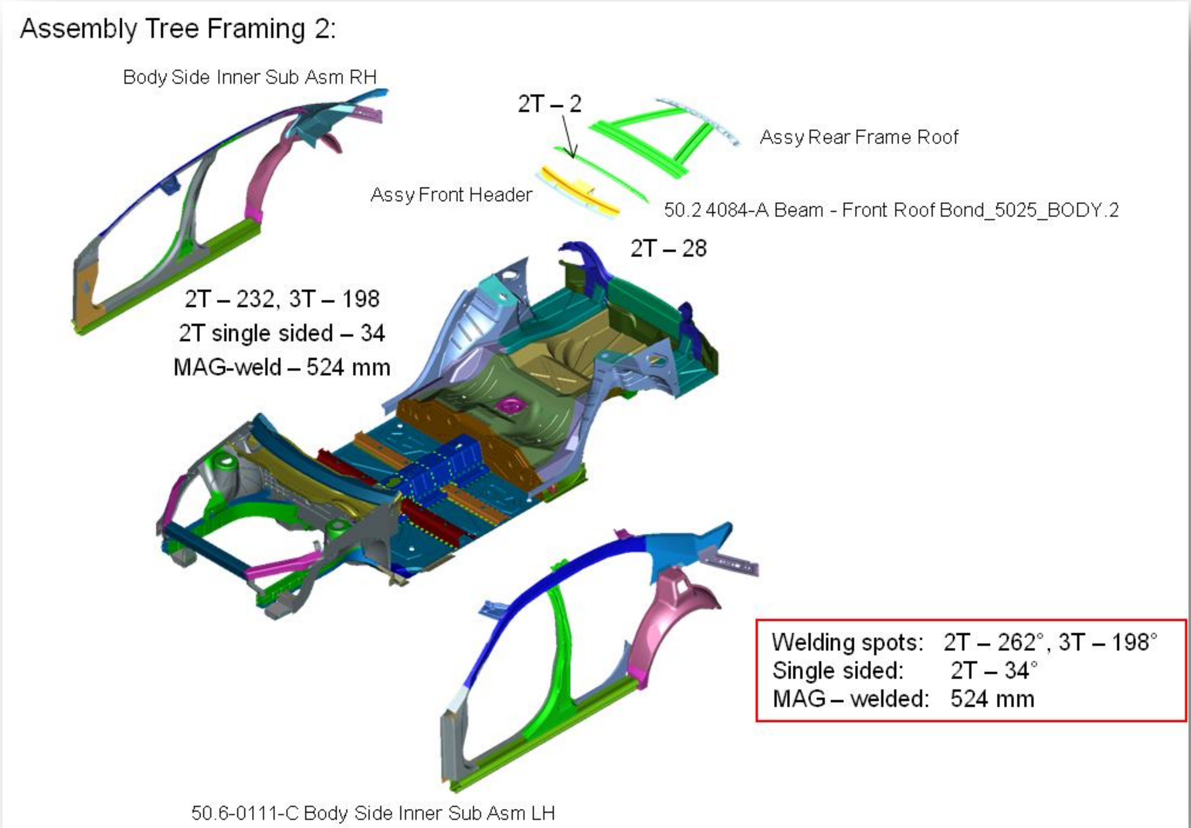


Figure 505: **Spot welded body assembly – Framer 2**

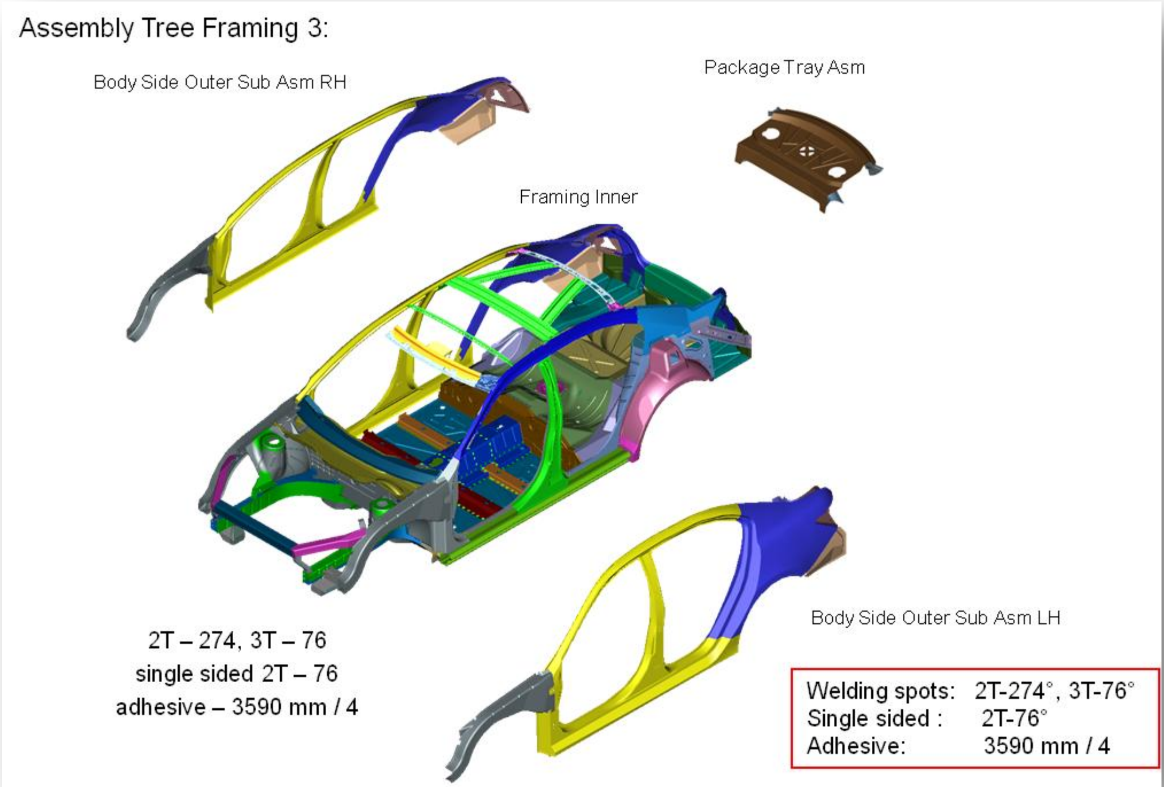


Figure 506: **Spot welded body assembly – Framer 3**

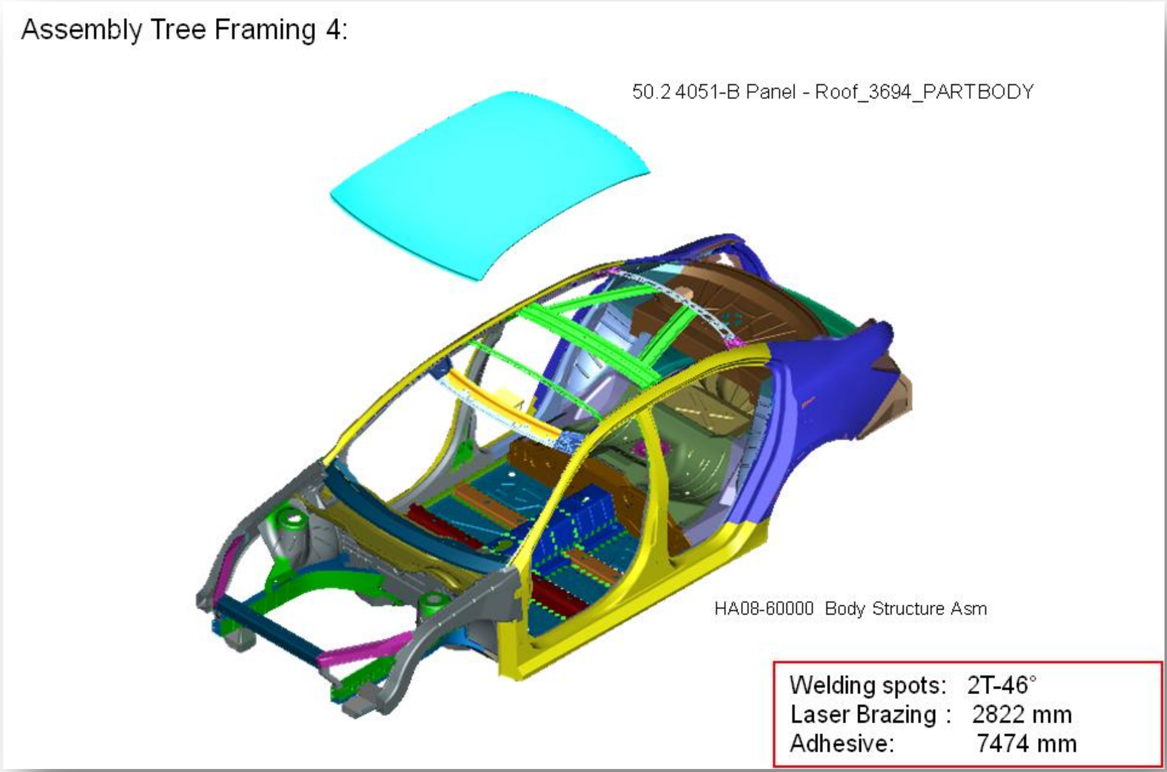


Figure 507: **Spot welded body assembly – Framer 4**

10.5.3 Assembly Layout for Laser Beam Welded Structure

Since the parts were the same for both the spot welded structure and the laser welded structure, the assembly tree structures were also very similar. Only the differences to the spot welded structure regarding assembly structure are highlighted in the following sections.

Similar to the spot welding there are geo welding stations which fastens the parts to each other with very small tolerances and – if applicable – in one of the later stations, where more seams are established to strengthen the connection, referred to as respot laser welding in this report.

Before the welding could be initiated, the parts needed to be dimpled as a requirement for laser welding zinc-coated steels as discussed in Section 1.2.2 of this report. Depending on how many clips are necessary to clamp the parts while welding, the number of dimples was defined. Usually every clip necessitates three dimples. Since the clamping configuration is very important to laser welding, also the number of clips will be specified on the following pages.

As indicated in the previous section, some small flange areas required laser welds shaped like spot welds. Those laser weld circles were just added as additional weld seams and their seam length was assumed to be 10 mm. Also for the laser welded structure assembly the cycle time was set so 55 seconds. The 'Assembly Tree' for laser welded structure is shown in Figure 508 below.

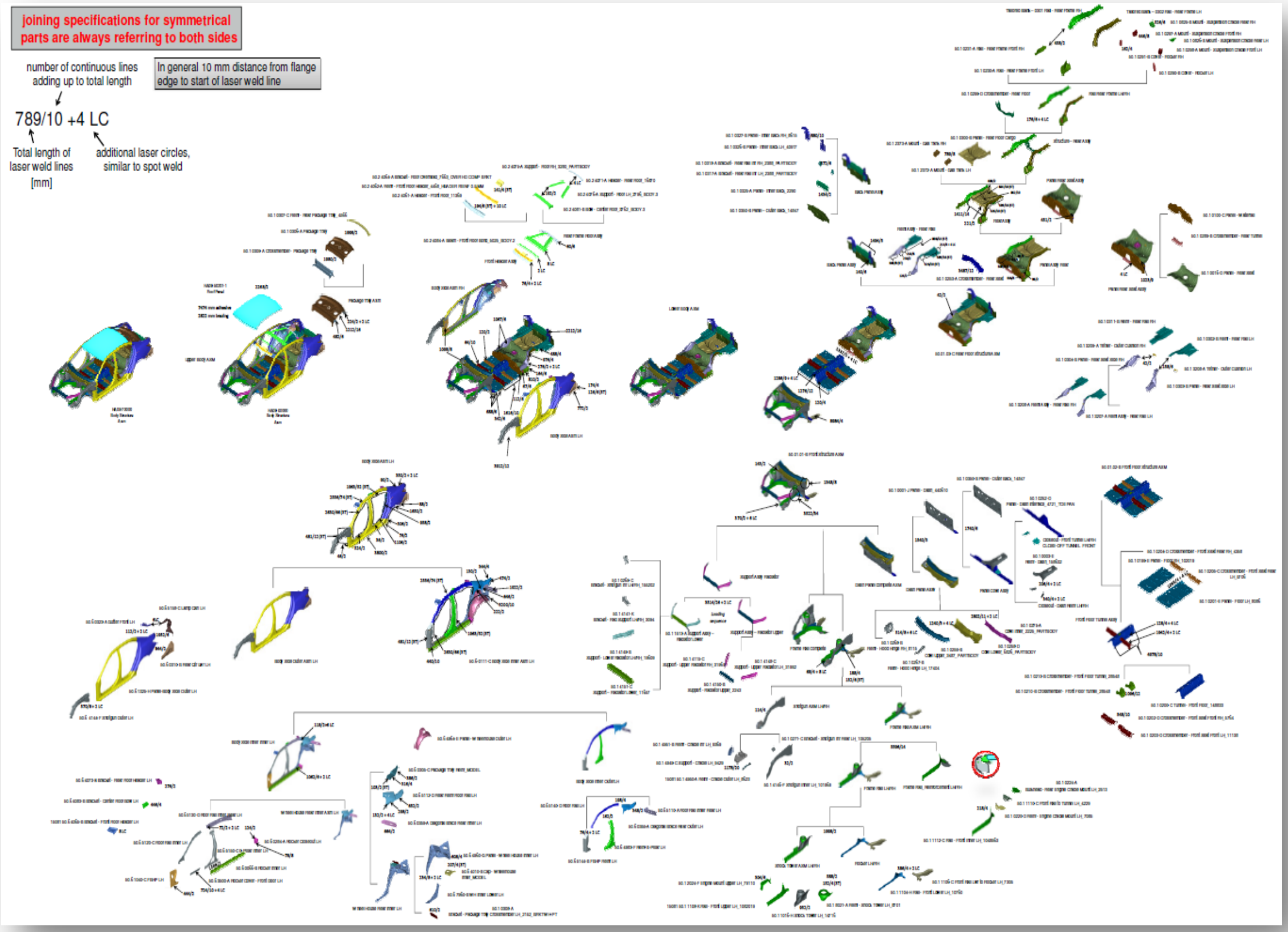


Figure 508: Assembly Tree – Laser Welded Structure

10.5.3.1 Dash Panel Sub-Assembly

For laser welding the dash panel subassembly was joined in one station, not having the reinforcement subassembly set up in a different step as with spot welding. 228 embossments were dimpled into the parts. There was only a geo welding operation, creating 18 laser weld seams with a total length of 2326 mm while the parts were fastened by 76 clips. The cowl panel subassembly required 255 dimples for 85 laser clips. 27 geo welds with a total length of 2639 mm were created by laser. At one repot laser welding station another 10 seams with a total length of 2060 mm were created. To join those two subassemblies 42 laser clips were required necessitating 126 dimples. The 3 geo weld seams applied accumulated to a length of 1540 mm.

10.5.3.2 Upper Front Rail Sub-Assembly

To establish the upper front rail subassembly 32 clips and 96 dimples were applied per side. The geo welding operation created 922 mm of laser weld with 5 seams. Another 2 seams with a total length of 76 mm were created with the 3T pattern. The lower front rail subassembly parts were dimpled 78 times which included the dimples for the next assembly step also. 26 clips fastened those two parts while they were welded to each other and to the upper front rail subassembly with 4 geo weld seams adding up to 1202 mm, creating the outer front rail subassembly. To connect the four parts of the inner front rail subassembly to each other and to the outer front rail and thereby forming the front rail subassembly, 420 dimples for 140 clips were inserted. The connection itself was established by 9 geo laser welds with a total length of 2907 mm on each side's subassembly.

10.5.3.3 Shotgun Inner Sub-Assembly

The shot gun inner subassembly required 60 clips and 180 dimples. The four parts were joined by 662 mm of geo laser welding distributed on 13 welds. To prepare the connection of the front rail and the shotgun inner 32 dimples were applied. Using 16 clips the assembly was created by 168 mm of geo weld seam. Another 76 mm were welded as the other half of the 3T pattern mentioned just above, increasing the number of seams to a total of 11.

10.5.3.4 Radiator Support Sub-Assembly

Creating the radiator support subassembly its ten parts were dimpled exactly 300 times. Correspondingly 100 clips were applied to geo weld 28 seams with a total length of 3534 mm. To finalize the front structure by assembling both wheelhouse subassemblies, the radiator support and the dash subassembly, 519 dimples were introduced. The subassembly was fastened with 173 clips while 3311 mm of geo laser welding on 34 seams was performed. Finally the structure was respot, laser welded at 18 seams with a length of 2132 mm.

10.5.3.5 Front Floor Assembly

Similar to the spot welded assembly, the laser welded front floor was also created starting off with joining the tunnel, the tunnel cross members and the seat cross members front. To prepare the connection, those parts were dimpled 138 times. The tunnel got an additional 300 dimples for subsequent joining operations. Geo welding the mentioned panels fastened by 46 clips at 22 seams established 1644 mm of laser welds. Adding the main floor panels and the seat rear cross members necessitated another 300 dimples. Clamping the parts with 200 clips they were joined by 10 geo laser Mass & Cost Saving Potential of Laser Welding Compared to Spot Welding welds with a total length of 3043 mm. Afterwards there were two respot stations. First there were 6 seams with 2915 mm and then 8 seams with a length of 3047 mm created.

10.5.3.6 Rear Floor Sub-Assembly

The assembly of the rear floor (shown in Figure 509) started with the connection of the two lower rails with the cross member, while the rails itself were assembled in the same way as the spot welded ones were. All this took place in one geo welding station after the parts were dimpled, creating 1808 mm of laser welds within 30 seams. Identical so the spot welded assembly the upper rail was assembled separately first. Joining both panels and the seat cushion supports after dimpling them required 8 seams with a total length of 200 mm. Then the lower rail set up and the gas tank mounts were connected to the rear floor cargo inside a geo welding and a respot station after passing the dimpling station, applying a total of 24 2T and 44 3T seam lines accumulating to a welding length of 3693 mm. In parallel the panel rear seat subassembly was created, connecting those three dimpled parts with 13 laser welds of 1063 mm length in one geo welding and one respot station. Joining this subassembly to the lower rear rail and cargo floor configuration required only one geo welding station, where 42 2T seams and 8 seams with the 3T pattern were applied after the parts have been dimpled, having a total length of 2892 mm. The back panel assembly also was created in the same order as that for spot welding. All 18 seams adding up to 2886 mm were created in one geo welding station.

Figure 509: Rear floor subassembly of the laser welded structure

Hence the rear floor subassembly could be established as it was done for the spot welded structure. The difference was that the inner wheel house was not part of this subassembly, but came along with the side structure, as will be discussed later on. Connecting the three described subgroups and the cross member rear seat required dimpling and then 74 2T and 64 3T geo laser welds with a total length of 8030 mm. The framing one operation for the laser welded structure included a loading and dimpling, a geo welding, a buffer, two respot, again a buffer measuring and finally the lifter station. The front lower, the middle floor and the rear floor subassemblies were joined to the lower structure by 3000 mm geo welding, 7000 mm respot welding and again 3180 mm of respot welding, creating 42 weld lines in total.

10.5.3.7 Body Side Inner Assembly

The parts shown in Figure 510 were first dimpled 63 times and then assembled with the help of 21 clips and of 8 2T and 2 3T laser seams creating a weld length of 840 mm. The rear roof rail parts were added and prepared by 51 dimples. Being fastened with 17 clips the parts were geo welded with 9 2T and 1 3T laser welds adding up to a length of 1295 mm.

In the next step, more parts from the body inner side were attached, see Figure 510. For this operation 264 dimples were required for 88 clips. 23 geo welds with a total length of 1896 mm were applied to assemble the new parts to each other. In another geo welding station the two groups were joined by 8 weld seams of 630 mm length. The body side reinforcement subassembly on the other hand was put together in the exact same configuration as with the spot welded structure. First applying 174 dimples for 58 clips, the parts were geo welded with 7 welds with a total length of 402 mm.

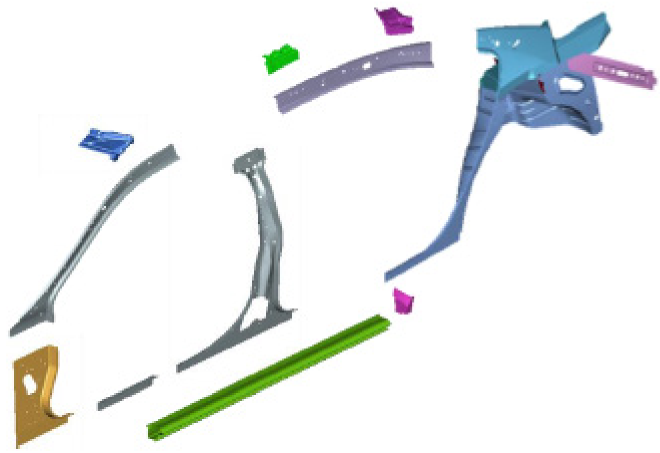


Figure 510: Inner body side inner subassembly of the laser welded structure

The inner wheel house panel was added to the inner body side inner subassembly by 5 geo welds having a length of 1600 mm after the parts were dimpled. Preparing to also add the body side reinforcement to that group the parts were dimpled 514 times. Being clamped with 128 clips welding of the parts was performed in one geo welding and one respot station. In total 17 2T and 102 3T weld seams were created, adding up to 7000 mm geo and 5008 mm respot weld length.

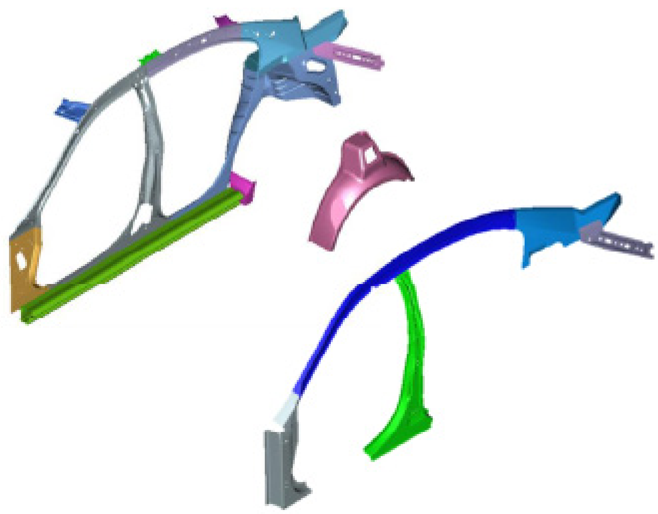


Figure 511: Body side inner subassembly of the laser welded structure

The body side outer subassembly again was put together similar to the spot welded version. Having the parts dimpled at 258 locations, they were clamped together with 86 clips and geo welded with 14 seams1789 mm weld length. After the dimpling operation uniting the body side inner and outer subassemblies required 2500 mm of geo laser welding and 6600 mm of respot welding each in two stations, followed by another 960 mm of respot welding. In total 13 2T and 102 3T laser weld seams were established.

10.5.3.8 Framing

For the inner roof structure the assembly configuration were exactly the same as that for spot welding. The rear group was joined by 6 geo laser welds after dimpling, adding up to a length of 232 mm. The front header assembly required 10 3T and 10 2T geo welds to be created after the dimpling operation was performed and the parts were clamped together. This resulted in a total weld length of 435 mm.

In the framing station two (see Figure 512) the side assemblies and the roof structure were attached to the lower structure. After the required dimples were introduced 7776 mm of adhesive was applied. Then 5440 mm of geo welds were established, followed by first 7000 mm and then 2950 mm of respot welding. In total 136 2T and 6 3T seam lines were welded. After a buffer station the as-assembly was measured for quality monitoring.

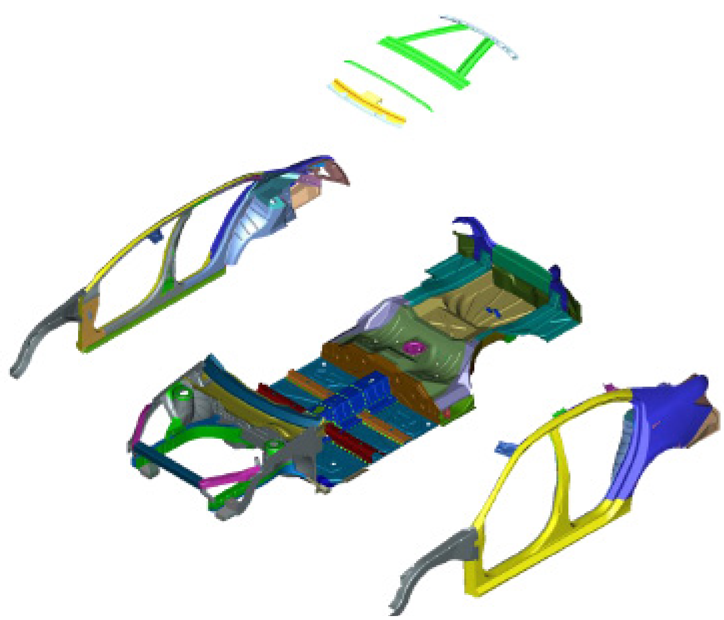


Figure 512: Framing station two for the laser welded structure

To complete the body structure the package tray assembly and the roof panel were added in framing station three, displayed in Figure 513. After dimpling 3000 mm adhesive were applied to the roof panel and another 4474 mm to the preassembled body. After running through a buffer station, 5170 mm of geo laser welding is carried out on the assembly. Then 2000 mm of respot welding is done, resulting in a total of 28 seam lines. In the next station 2822 mm of laser brazing connects the roof panel with the roof rails. Hence a brushing station, another buffer, a seam check station, a third buffer, the measuring station, the grinding and cleaning station and a quality control station are passed.

Like for the spot welded structure the discussed assembly information was used to develop the de-tailed shop layout for the entire body assembly.

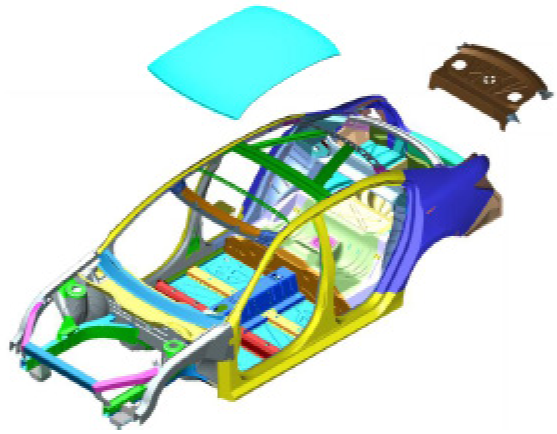


Figure 513: Framing station three for the laser welded structure

10.5.4 Assembly Layout Comparison

The assembly plant layouts developed for the resistance spot welded and the laser beam welded assemblies are displayed in Figure 515 and Figure 516. Both of the layouts show how the subassemblies of the lower structure – the lower structure front, the front floor and the rear floor –are put together. It also illustrates how they are joined in the framing station and how the structure proceeds through the other framers where the side structures, the package tray and the upper structure are attached. These layouts identify all the necessary assembly tooling fixtures, robots, controls and safety equipment that is required for a highly automated auto body assembly plant.

The laser welding assembly requires 1,225 square meters (7%) more space than the spot welding assembly (see Figure 514). Comparison of the number of robots required, shows that the spot welding assembly uses 428robots, while the laser welding assembly require only 315 a reduction of 26%. Both assembly lines require same number of direct operators, 37 each. Other required support personnel and organization are assumed to be the same for both options.

Body Assembly	Number Weld Spots or Seam Length (mm)	Number of Operators	Number of Robots	Floor-Space (m^2)
Spot Welded	3,723	37	428	18,365
Laser Welded	132,684	37	315	19,590
		0%	-26%	7%

Figure 514: Comparison of Spot Welding versus Laser Welding Assembly

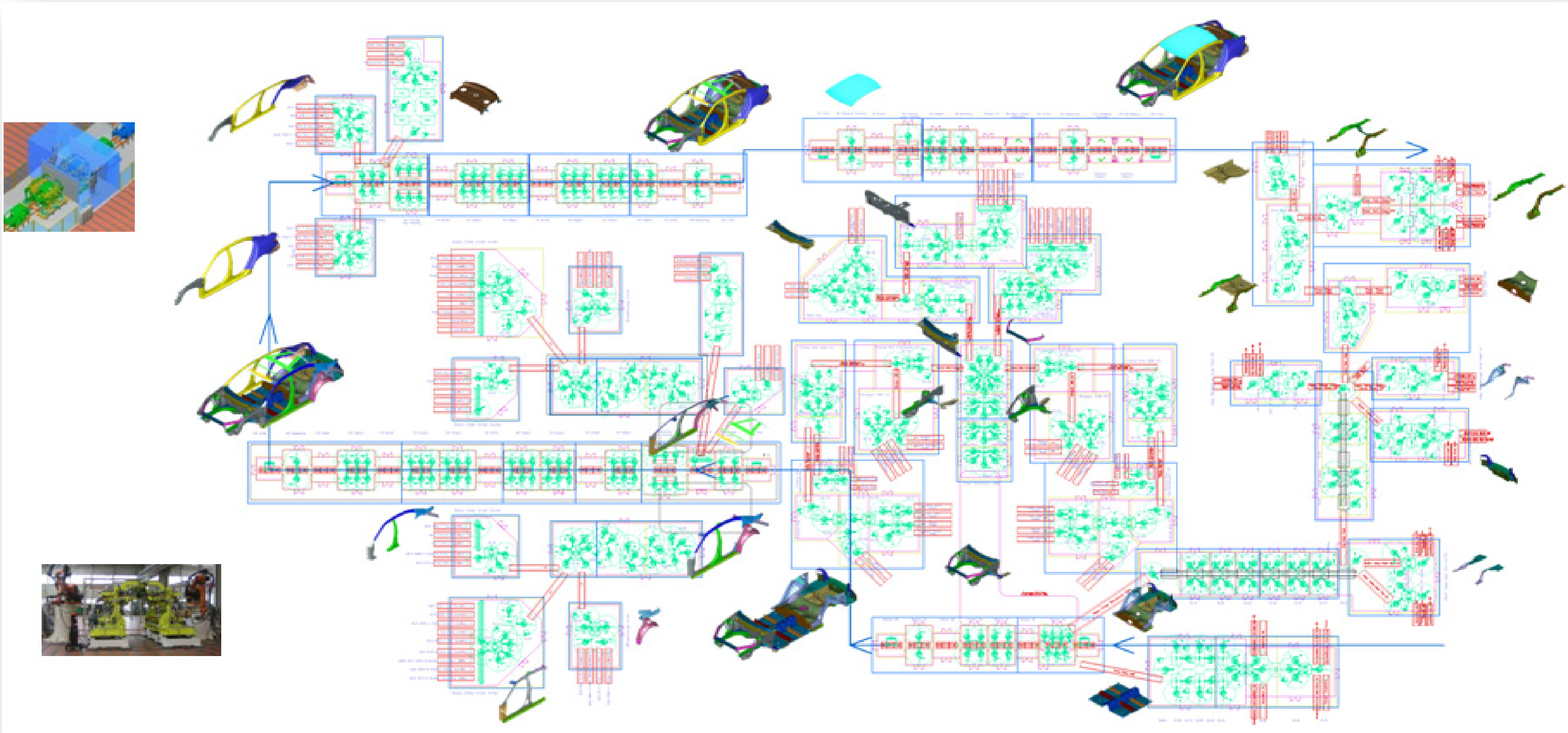


Figure 515: Shop layout for resistance spot welded assembly

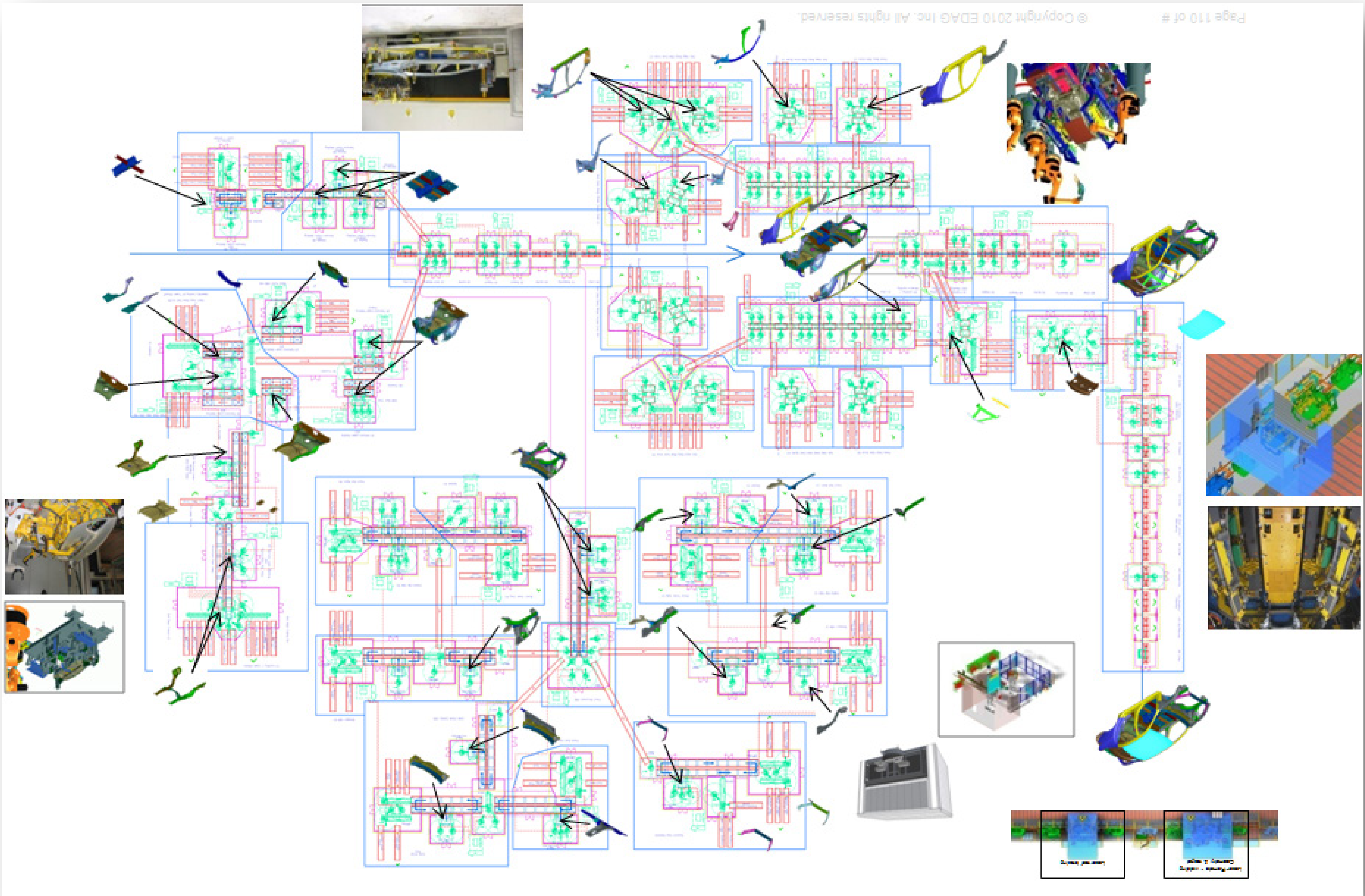


Figure 516: **Shop layout for laser beam welded assembly**

10.5.5 Costs Estimation for Assembly Equipment

From the detailed assembly layout, the cost of all the equipment is calculated. Having the whole shop layout for the spot welded and laser welded assembly planned after setting up the assembly tree, all the required machines and equipment is specified. The quantity as well as the kind of equipment was precisely defined. This included the setup of all stations, such as fences, safety circuits and illumination; the entire power periphery required for the welding guns and the robots, for example switch boards, processing units, control units and monitoring displays; the transportation gear to move the parts and subassemblies, like robots, lifters and belt conveyors; the welding equipment itself. Having cost numbers for all those components available in EDAG Cost Modeling data base, they were added up to generate the total costs of the assembly plants.

10.5.6 Assembly Systems Comparisons

Breakdown of cost and other key parameters for the two assembly methods are tabulated in Figure 517 and Figure 518. The data for each of the subassemblies and main framing stations is shown for detailed comparison of the following parameters:

- Number of direct operators
- Number of Robots
- Floor space in square meters
- Annual energy consumption cost
- Total Investment
- Annual operational cost
- Annual maintenance
- Cost of assembly per vehicle with equipment write off over 5 and 10 years

Body Assembly	Number Weld Spots or Seam Length (mm)	Number of Operators	Number of Robots	Floor-Space (m^2)	Annual Energy Consumption ($)	Total Investment ($)	Annual Operational Cost ($)	Annual Maintenance ($)	Life Time costs per vehicle - 5 years ($)	Life Time costs per unit- 10 years ($)
Spot Welded	3,723	37	428	18,365	4,992,687	72,367,307	14,973,212	4,905,040	171.76	135.57
Laser Welded	132,684	37	315	19,590	924,146	99,482,478	11,277,496	3,181,457	171.78	122.42
		0%	-26%	7%	-81%	37%	-25%	-35%	0%	-10%

1,225

Figure 517: Summary – Comparison between spot welding and laser welding assembly plants

10.5.6.1 Total Investment

The total investment for laser welding $99.5 Million is 37% higher than the investment for spot welding $72.4 Million (see Figure 518). Though the number of robots for laser welding is reduced from 428 to 315, the laser welding assembly equipment is still significantly higher cost than comparable spot welding equipment. The laser beam generators, the transportation of parts and assemblies within the laser welding cell to 'light tight' safe closed areas is more elaborate leading to higher investment costs.

Over the past 10 years the cost of the laser equipment has been reduced by over 40%. With increased usage of the equipment over the next 10 years, due to increased demand and improvements in technology the cost is expected to be reduced further by 20 to 30%.
At present an additional (approximately 15%) laser equipment is installed to create surface dimples on zinc coated panels so these can be welded (see Section 1.2.2 of this report). In the future if a lower cost

solution is found for this problem, this will be equivalent to additional reduction in the investment cost related to laser welding.

10.5.6.2 Annual Operational Cost

The operational cost of running the laser welding body structure assembly cost of $11.3 million is 25% lower than the cost for spot welding of $14.97 million. The annual operational cost is made up annual direct labor, energy consumption, building charges and other consumable items (e.g. weld tips).The laser beam welding equipment is much more efficient in terms of energy usage when compared with spot welding. The annual energy cost for assembly of 200,000 body structures for laser welding $924,000 is almost 80% lower than the energy usage of $4,993,000 for the spot welding operations.

10.5.6.3 Annual Maintenance Cost

The maintenance cost of running the laser welding body structure assembly cost of $3.18 million is 35% lower than the cost for spot welding of $4.91 million. The spot welding operations requires approximately 25% more robots and almost 4 times more weld guns compared with laser welding setup. This increase in equipment requires higher level of maintenance costs, which are made up of maintenance personnel labor cost and spare parts.

10.5.6.4 Per Vehicle Cost

The calculated cost per vehicle for the assembly of a laser welded body structure of $122.42 is 10% lower than the spot welded assembly cost of $135.57 as shown in Figure 518. These numbers are based on the assumption of the equipment useful life period of 10 years. It is interesting to note that the higher initial investment cost for the laser welding equipment is over time offset by the gains in efficiency, 25% operational costs reduction and 35% lower maintenance charges. For a 5 year equipment useful life assumption the body structure assembly cost per vehicle is coincidently the same for both options at $171.80.

The cost results shown in Figure 518 only apply to the Optional Task 3 study. For this task the body structure is based on an early version of the LWV body design (July 2011). For comparison purposes the structures for this task are 100% Spot Welded versus 100% laser welded. The final design of the LWV body structure is approximately 50% spot welded and 50% Laser and adhesive bonded. The cost numbers shown in Figure 512 are not representative of the final design of LWV body structure.

The cost results for the final design of LWV are discussed in Chapter 9.

Sub-Assembly Spot Welded	Number Weld Spots	Number of Operators	Number of Robots	Floor-Space (m^2)	Annual Energy Consumption ($)	Total Investment ($)	Annual Operational Cost ($)	Annual Maintenance ($)	Life Time costs per vehicle - 5 years ($)	Life Time costs per unit- 10 years ($)
Sidepanel inner ASM LH	275	4	32	1,530	364,931	6,284,272	1,422,095	389,382	15.34	12.20
Sidepanel inner ASM RH	275	4	32	1,530	364,931	6,284,272	1,422,095	389,382	15.34	12.20
Sidepanel outer ASM LH	83	1	6	220	56,999	1,207,056	314,395	72,035	3.14	2.54
Sidepanel outer ASM RH	83	1	6	220	56,999	1,207,056	314,395	72,035	3.14	2.54
Framing 1	125	1	17	530	169,695	2,379,062	440,958	141,364	5.29	4.10
Framing 2	492	1	29	1,460	575,152	4,687,909	890,636	275,184	10.52	8.17
Framing 3	426	1	41	1,250	473,675	5,364,319	779,539	366,768	11.10	8.41
Framing 4	46	1	12	900	77,683	4,683,158	375,313	97,089	7.05	4.70
Roof inner ASM	48	2	8	350	85,068	1,844,270	595,526	112,763	5.39	4.46
Front-Floor	246	2	21	930	224,722	3,156,317	762,090	255,555	8.24	6.67
Package Tray	84	1	7	340	83,706	1,286,451	346,670	102,689	3.53	2.89
Rear Floor ASM	686	8	92	4,255	1,161,504	13,993,899	3,325,384	1,074,169	35.99	28.99
Front Structure ASM	854	10	125	4,850	1,297,623	19,989,268	3,984,116	1,556,623	47.69	37.70
Total :	3,723	37	428	18,365	4,992,687	72,367,307	14,973,212	4,905,040	171.76	135.57

Sub-Assembly Laser Welded	Length of Laser Weld (mm)	Number of Operators	Number of Robots	Floor-Space (m^2)	Annual Energy Consumption ($)	Total Investment ($)	Annual Operational Cost ($)	Annual Maintenance ($)	Life Time costs per vehicle - 5 years ($)	Life Time costs per unit- 10 years ($)
Sidepanel complete ASM	22,504	6	55	2,775	140,494	14,339,875	1,781,848	454,023	25.52	18.35
Sidepanel complete ASM	22,504	6	55	2,775	140,494	14,339,875	1,781,848	454,023	25.52	18.35
Framing 1	13,011	1	13	650	36,440	3,514,595	317,474	83,012	5.52	3.76
Framing 2	15,234	1	17	900	49,183	4,629,552	339,967	105,180	6.86	4.54
Framing 3	7,010	1	13	1,200	41,352	5,017,793	343,836	82,775	7.15	4.64
Roof inner ASM	541	2	6	400	18,047	1,821,248	545,015	44,025	4.77	3.86
Front-Floor	10,600	2	15	1,150	52,450	5,947,580	608,668	191,998	9.95	6.98
Package Tray	3,978	1	9	400	28,183	2,188,107	299,467	90,784	4.14	3.05
Rear Floor ASM	20,005	4	34	1,490	103,113	13,206,974	928,275	499,206	20.34	13.74
Front Structure ASM	17,297	13	98	7,850	314,388	34,476,879	3,944,430	1,176,432	60.08	42.84
Additional-costs for laser-							386,667	-	1.93	2.32
Total :	132,684	37	315	19,590	924,146	99,482,478	11,277,496	3,181,457	171.78	122.42

Figure 518: Comparison of Spot Welding versus Laser Welding Assembly Vehicle Body Structure

10.6 Conclusions

The equipment needed to laser weld and assemble an entire body structure is considerably more than that required for spot welding. On the other hand, because laser welding is a relatively newer technology in the automotive industry, there is still the potential for major improvements in the near future. In contrast, no significant enhancements are anticipated for spot welding, being a very mature technology. While lasers are widely used for other applications in the automotive industry (e.g., laser cutting operations, laser welded tailored blanks or laser brazed roof rails), the specific use of lasers for welding, especially remote laser welding on the assembly line is not as common.

EDAG's experience over the past 10 years shows that the cost of the laser equipment has been reduced by over 40%. With increased usage of the equipment over the next 10 years, due to increased demand and improvements in technology, the cost is expected to be reduced further by 20%.

At present an additional (approximately 15%) laser equipment is installed to create surface dimples on zinc coated panels so these can be welded (see Section 10.2.3 of this report). In the future if a lower cost solution is found for this problem, this will be equivalent to additional reduction in the investment cost related to laser welding. There is definite learning potential regarding the development of mass production capabilities for laser welding which will lead to lower costs for the equipment and operations.

The results of this study indicates the 37% higher initial investment cost for the laser welding equipment is offset by a 25% reduction in operational costs and 35% lower maintenance charges. This equates to a 10% lower assembly cost, a saving of $13.15 per vehicle. The cast saving and mass saving of 12.2 kg (5% of the body structure) with increased structural performance achieved through laser welding should warrant further investigation and hopefully eventually broad implementation.

10.6.1 Further Mass Saving Potential of Laser Welding Assembly Process

The mass saving could be improved further by taking advantage of the benefits of the laser beam welding technology. As mentioned previously, the smaller flange width requirements are only one benefit of this joining technology. Another is the reduced accessibility demands. While body structures developed for spot welding must fulfill challenging requirements regarding two-sided accessibility. The reduced requirements regarding accessibility for laser welding would give much more latitude in design. Taking account of laser welding at an early stage of the design of a body structure would certainly improve its performance, mass, and cost. Thus, completely re-designing a spot welded body structure to incorporate laser welding, instead of merely converting it as was done in this project, would result in further mass savings.

Regarding the reduction of the flange size, laser beam welding has further potential. Spot welding creates a laminar connection, and thereby, always needs a lap joint configuration. In contrast, laser welding establishes a linear connection, making it possible to create butt joints which would eliminate flanges from some of the parts. One of the parts to be joined would be equipped with guide notches/slots. The counterpart feature which engages the guide notches of the other part. In this way, the positioning within a specified tolerance can be assured. Laser welds are applied where the parts are inserted into the slots, as displayed on the right in Figure 519.

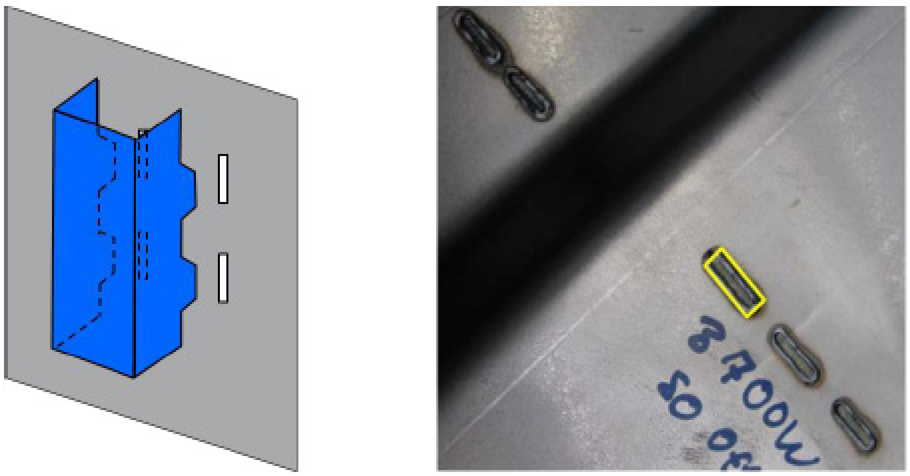


Figure 519: Laser beam welding without flanges: schematic (left) and example of use (right) [248]

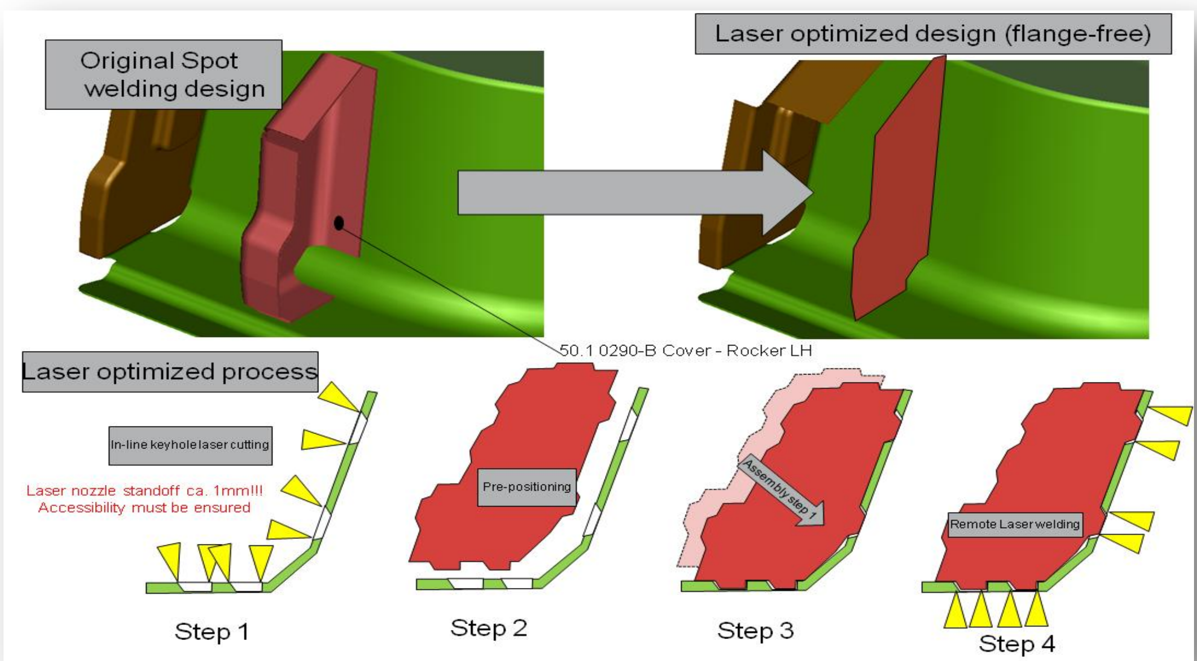


Figure 520: **Design example of laser beam welding without flanges**

[248] Trumpf Inc., 2010

1 Appendix A—Detailed Component Weights

Trunk asm	1	12.474		
Trunk frame	1	9.948	Steel	Stamped
Hinge asm with torque rods	1	2.254	Steel	
Rear garnish panel	1	1.765	Plastic	
Trunk latch	1	0.342	Steel	
Mass	1	0.666	Steel & plastic PP	
Body Structure				
Structure with paint and sealer	1	361.161	Steel & sealer	
Structure with/out paint & sealer (Est)	1	327.786	Steel & sealer	
Windshields - windows		21.375		
Windshield	1	13.938	Glass	
Rear window	1	7.437	Glass	
Fenders		8.052		
Front fenders				
Left fender	1	4.026	Steel	
Right fender	1	4.026	Steel	
Bumpers				
Front bumper				
Bumper Beam	1	7.958	Steel	Roll form & satmping
Front fascia asm	1	5.900	Plastic PP	
Rear bumper				
Bumper Beam	1	7.800	Steel	Roll form & stamping
Rear fascia asm	1	4.540	Plastic PP	
Lighting		9.664		
Head lamp	2	6.858	Plastic & electrics	
Rear light on body	2	2.536	Plastic & electrics	
CHMSL Rear stop light	1	0.125	Plastic & electrics	
Dome light	1	0.057	Plastic & electrics	
License plate light	2	0.088	Plastic & electrics	
Windshield wiper		5.577		
Windshield wiper module				
Wiper asm	1	3.563	Steel & other matls	
Wiper blade asm				
Arm & blade - Driver side	1	0.710	Steel & other matls	
Arm & blade - Passenger side	1	0.692	Steel & other matls	
Washer				
Washer tank asm	1	0.612	Plastic & electrics	
Interior (Sub-system)		67.499		
Instrument panel asm incl beam/cluster/center unit	1	31.933	Pastic/steel/electics mix	
Cross car beam	1	9.379	Steel	
Instrument cluster	1	0.903	Plastic & electrics	
Center unit with audio controls	1	3.183	Plastic & electrics	
Noise insulation		12.670		
Sound insulation engine side (single/main)	1	0.290		
Sound insulation (cockpit side)	1	7.500		
Dash panel insulation	1	2.370		
Trunk area sound insulation system		1.270		
On wheel arch Lh/Rh	1	1.240		
Center console asm	1	5.100	Plastic & steel	
Over head console asm with dome light	1	0.456	Plastic & electrics	
Trims parts		17.340		
Headliner	1	2.408		
Interior components	1			
Sun visors				
Driver side	1	0.565		
Passenger side	1	0.565		
Side upper grab handle				
Front	2	0.200		
Rear	2	0.200		

Panels				
Left & right side				
Door step inner panel front Lh/Rh	2	0.744	Plastic PP	Injection molded
Door step inner panel rear Lh/Rh	2	0.436	Plastic PP	Injection molded
A pillar panel LH/Rh	2	0.486	Plastic PP	Injection molded
B pillar upper panel Lh/Rh	2	0.702	Plastic PP	Injection molded
B pillar lower panel Lh/Rh	2	1.084	Plastic PP	Injection molded
C pillar upper panel Lh.Rh	2	0.604	Plastic PP	Injection molded
Trunk				
Sill panel	2	1.224	Plastic PP	
Side compartment Lh/Rh	2	8.122	Plastic PP	
Mirror system				
Rear view mirror	1	0.283		
Parcel tray system				
Parcel tray	1	2.638		
Floor carpeting				
Interior	1	9.213		
Trunk	1	2.561		
Speakers system				
Rear speaker	2	0.456		
Seats (Sub-system)		64.870		
Front Seat	1	45.360		
Rear seat asm	1	19.510		
Seat 1-3				
Seat Back	1	12.020		
Seat Cushion	1	4.020		
Rear seat trim	1	2.730		
Electrics (Sub-System)		29.751		
Battery	1	12.444		
Wiring				
Harness interior	1	4.223		
Harness engine	1	4.200		
Harness linstrument panel	1	3.500		
Harness front door	2	1.280		
Harness rear door	2	0.600		
Fuse Box				
Engine relay and fuse box	1	0.429		
Control modules				
OBC On board control center	1	2.116		
ECM Engine control module	1	0.959		
Suspension (Sub-System)				
Shocks absorbers				
Front		35.820		
Strut assembly	2	14.800		
Coil spring	2	6.800		
Rear				
Strut assembly	2	10.200		
Coil spring	2	4.020		
Axles				
Front axle		67.021		
K-frame	1	28.811	Steel	Stamping & fabrication
Arm suspension system				
Lower triangle	2	14.200	Steel	Cast
Upper triangle	2	6.800	Steel	Stamping
Stabilizer bar system				
Stabilizer bar	1	3.610		
Steering knuckle				
Steering knuckle	2	13.600	Steel	Casting

Rear axle		48.659		
K frame	1	21.779	steel	Stamping & fabrication
Arm suspension system				
Upper transversal arm	2	6.800	Steel	Stamping
Lower transversal arm	2	2.000	Steel	Steel fabrication
Lower transversal arm secondary	2	2.100	Steel	Steel fabrication
Rear control arm	2	1.600	Steel	Steel fabrication
Casing	2	6.800	Alloy	Cast
Hub	2	5.600	Steel	Machining
Stabilizer bar system				
Stabilizer bar	1	1.980	Steel	
Wheels		79.749		
Wheel				
Front & Rear	4	79.248		
Rim	1	9.287	Steel	
Tire	1	10.024	Rubber	
Hub cover	1	0.501	Plastic	Injection molded
Exhaust (Sub-system)				
Exhaust line system		20.748		
Exhaust	1	14.288	Steel	
Exhaust on engine with catalytic converter	1	5.420	Steel & other matl	
Exhaust shield				
Screens on engine system	1	0.350	Alloy	
Front tunnel shield	1	0.338	Alloy	
Rear tunnel shield	1	0.352	Alloy	
Engine (Sub-system)				
Engine complete	1	142.000		
Transmission (Sub-system)		148.333		
Gear box complete	1	128.900		
Drive shaft		19.433		
Drive shaft left	1	9.200	Steel & Elastomers	
Drive shaft right	1	6.840	Steel & Elastomers	
Gear shift mechanism center console	1	3.393		
Brakes (Sub-system)		40.950		
Front brakes				
Disc	2	16.200	Steel	
Brake caliper	2	10.800	Steel	
Rear brakes				
Disc	2	8.160	Steel	
Brake caliper	2	5.790	Steel	
Air (Sub-system)				
Air filter assembly	1			
Heating (Sub-system)		10.433		
Heater box	1	3.234	Various matls	
Heater duct floor	1	0.708	Plastic PP & steel	
Radiator	1	2.293	Alloy	
Evaporator	1	4.198		
Air conditioning (Sub-system)		13.909		
HVAC unit	1	6.861		
Compressor	1	5.740	Steel alloy & electrics	
AC lines	1	1.308	Alloy & Elastomers	
Steering (Sub-system)		19.679		
Steering column asm incl wheel	1	9.029	Various matls	
Steering rack	1	8.240	Various matls	
Steering rack mounting	1	2.410	Alloy	Cast
Cooling - water (Sub-system)				
Cooling system				
Radiator	1	4.420	Alloy & plastic PA66	
Fan system				
Radiator fan & support asm	1	7.052	Plastic & Electric	Plastic injection molded
Expansion bottle system				
Expansion bottle asm	1	0.342	Plastic	Blow Molded

Safety (Sub-system)			
Airbags		9.423	
Driver airbag	1	1.005	
Passenger airbag	1	2.918	
Curtains Airbag	2	5.500	
Seat belt		7.008	
Seat belt front	2	3.240	
Seat belt adjuster	2	0.870	
Rear seat belt outer	2	1.814	
Rear central seat belt	1	1.084	
Fuel (Sub-system)		12.503	
Fuel tank complete	1	12.023	Plastic & electric
Fuel lid	1	0.480	Steel
Pedals (Sub-system)		3.033	
Brake pedal	1	1.885	Metal & plastic
Accelerator pedal	1	1.148	Metal & plastic
Fluids (Sub-system)		68.720	
Fuel	1	50.890	
Engine Oil	1	3.560	
Gearbox oil	1	1.960	
Engine coolant	1	6.990	
Brake fluid	1	0.490	
Window washer fluid	1	4.830	

Vehical Specification

Vehical Information	
2011 Honda Accord 4DR LX	
VIN: 1HGCP2F3XBA055835	
Engine Number: K24Z2-4018756	
Control Number: 061145	
Exterior Color: Alabaster Silver	
Interior Color: Black	
Engineering	
Engine Type	In-Line 4-Cylinder
Engine Block/Cylinder Head	Aluminum-Alloy
Displacement (cc)	2354
Horsepower @ rpm (SAE net)	177 @ 6500
Torque (lb-ft @ rpm)	161 @ 4300
Redline	6800
Bore and Stroke (mm)	87 x 99
Compression Ratio	10.5 : 1
Valve Train	16-Valve DOHC i-VTEC®
Multi-Point Fuel Injection	
Drive-by-Wire™ Throttle System	
CARB Emissions Rating	ULEV-2/PZEV
Direct Ignition System with Immobilizer	
100K +/- Miles No Scheduled Tune-Ups	
5-Speed Automatic Transmission	
Gear Ratios: 1st: 2.652, 2nd: 1.517, 3rd: 1.037, 4th: 0.738, 5th: 0.537, Reverse: 2.000, Final Drive Ratio: 4.44	
Body/Suspension/Chassis	
Unit-Body Construction	
Double Wish Bone Front Suspension	
Independent Multi-Link Rear Suspension	
Stabilizer Bar (mm, front/rear)	26.5 / 13.0
Variable Gear Ratio (VGR) Power-Assisted Rack-and-Pinion Steering	
Steering Wheel Turns, Lock-to-Lock	2.56
Steering Ratio	13.08
Turning Diameter, Curb-to-Curb (ft)	37.7
Power-Assisted Ventilated Front Disc/Solid Rear Disc Brakes (in)	11.1 / 11.1
Wheels	16" Steel with Full Covers
All-Season Tires	P215/60 R16 94H
Exterior Measurements	
Wheelbase (in)	110.2
Length (in)	194.9
Height (in)	58.1
Width (in)	72.7
Track (in, front/rear)	62.6 / 62.6

Curb Weight (lbs, AT)	3279
Interior Measurements	
Headroom (in, front/rear)	41.4 / 38.5
Legroom (in, front/rear)	42.5 / 37.2
Shoulder Room (in, front/rear)	58.2 / 56.4
Hiproom (in, front/rear)	56.6 / 54.3
Cargo Volume (cu ft)	14.7
Passenger Volume (cu ft)	106
Seating Capacity	5
EPA Mileage Estimates /Capacities	
5-Speed Automatic (City/Highway/Combined)	23 / 34 / 27
Crankcase (qt)	5.6
Coolant System (qt, AT)	8.5
Fuel (gal)	18.5
Required Fuel	Regular Unleaded
Safety	
3-Point Seat Belts at all Seating Positions	
Front 3-Point Seat Belts with Automatic Tensioning System	
Driver's and Front Passenger's Seat Belt Reminder	
Dual-Stage, Multiple-Threshold Front Airbags (SRS)	
Dual-Chamber Front Side Airbags with Passenger-Side Occupant Position Detection System (OPDS)	
Side Curtain Airbags	
Driver's and Front Passenger's Active Head Restraints	
Advanced Compatibility Engineering™ (ACE™) Body Structure	
Vehicle Stability Assist™ (VSA®) with Traction Control	
Anti-Lock Braking System (ABS)	
Electronic Brake Distribution (EBD)	
Brake Assist	
Tire Pressure Monitoring System (TPMS)	
Daytime Running Lights (DRL)	
Side-Impact Door Beams	
Lower Anchors and Tethers for Children (LATCH): Lower Anchors (2nd-Row Outboard), Tether Anchors (2nd-Row All)	
Child-Proof Rear Door Locks	
Emergency Trunk Release	
Exterior Features	
One-Touch Power Moonroof with Tilt Feature	
Integrated Rear Window Antenna	
Remote Entry System with Power Window Control	
Variable Intermittent Windshield Wipers	
Multi-Reflector Halogen Headlights with Auto-off	
Body-Colored Door Handles	
Body-Colored Power Side Mirrors	
Body-Colored Impact-Absorbing Bumpers	
Chrome Exhaust Finisher	
Chrome Window Trim	
Comfort & Convenience	
Air Conditioning with Air-Filtration System	
Power Windows with Auto-Up/Down Driver's Window	

Power Windows with Auto-Up/Down Driver's and Front Passenger's Windows
Illuminated Power Window Switches
Power Door Locks/Programmable Auto-Locking Doors
Cruise Control
Illuminated Steering Wheel-Mounted Audio and Cruise Controls
Tilt and Telescopic Steering Column
Center Console with Sliding Armrest and Storage Compartment
Beverage Holders, Front and Rear
Driver's and Front Passenger's Illuminated Vanity Mirrors
Map Lights
Sunglasses Holder
Coin Box
12-Volt Power Outlets
Lockable Glove Compartment
Driver- and Passenger-Side Seatback Pockets
Remote Fuel Filler Door Release
Remote Trunk Release with Lock
Electronic Remote Trunk Release
Rear Window Defroster
Cargo Area Light
Floor Mats
Side Door Pockets
Seating
Driver's Seat with Manual Height Adjustment
Adjustable Front Seat-Belt Anchors
Fold-Down Rear Seatback
Fold-Down Rear-Seat Center Armrest/Trunk Pass-Through
Audio Systems
160-Watt AM/FM/CD Audio System with 6 Speakers
Radio Data System (RDS)
MP3/Windows Media® Audio (WMA) Playback Capability
MP3/Auxiliary Input Jack
Speed-Sensitive Volume Control (SVC)
Instrumentation
Backlit Gauges
Tachometer
Digital Odometer and Digital Trip Meters
Maintenance Minder™ System
Door-/Trunk-Open Indicator
Fuel and Coolant Temperature Indicators
Low-Oil Pressure and Brake Fluid Indicators
Vehicle Stability Assist (VSA®) Indicator
Passenger-Side Side Airbag-Off Indicator

Source: Honda USA
http://automobiles.honda.com/accord-sedan/specifications.aspx

DEFIANCE
TESTING & ENGINEERING

EDAG Incorporation

2011 Honda Accord BIW Modal Test

Defiance Report No. 106072-000

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March 20, 2011

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Geometry Plots
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EDAG Incorporation

2011 Honda Accord BIW Modal Test

Defiance Report No. 106072-000

1.0 OBJECTIVE

The objective of this modal test was to find the modal properties of a 2011 Honda Accord BIW (with front and rear glasses) within 10 to 100 Hz frequency range.

2.0 SUMMARY

The modal tests were performed at Defiance from March 1 to 4, 2011. The mode description table on page 3 describes the modes that were identified. Geometry and verification plots are provided in Appendix A. Animated mode shapes in AVI file format are provided to customer separately.

3.0 MODAL TESTS

3.1 Mechanical Setup

The Accord BIW was supported with four rubber airbags at four locations to give an approximation of 'free-free' boundary conditions. The air pressure in the airbags was reduced as much as possible to minimize the interference of these supports on the lowest flexible modes of the structure. Refer to Appendix B for test setup photographs.

3.2 Modal Test Setup and Data Acquisition

Tri-axial accelerometers were attached to each of the selected geometry points with hot-melt glue that was sufficiently rigid for the frequency range of interest. The accelerometer fore/aft and lateral axes were placed as close as possible to parallel with the floor resulting in an orthogonal orientation of the vertical axis with the floor. This orientation was achieved with the use of low-mass nylon tapered blocks. When necessary, these blocks were placed between the accelerometer and the body surface. The factory calibration of all the accelerometer axis sensitivities was checked prior to testing.

3.0 MODAL TESTS *(Continued)*

Excitation to the BIW was provided with two electro-dynamic shakers. These shakers were set up with a rigid mounting of the bases to the floor. The positioning of the shakers is shown in the photographs in Appendix B. The front shaker was positioned 15 degrees from vertical in the lateral direction. The rear shaker was positioned 15 degrees from vertical in the fore/aft direction. The combined orientation of these two shakers allowed for effectively exciting the significant modes.

The structure's linearity, test time-invariance, and reciprocity were checked and are shown in Appendix A. An excitation force of 2.7 N_{rms} was selected for these tests.

LMS Test.Lab software and SCADAS MOBILE recorder were used for acquiring the excitations and responses. To observe the quality of the measured excitation and responses, the time domain force input and selected accelerometer responses were monitored in real-time. Additionally, the drive point FRFs, ordinary coherence functions, and the autopower spectrum of the force inputs were also monitored. Data acquisition parameters are listed in the following table:

2011 Honda Accord BIW Modal Test Data Acquisition Parameters:

Sampling Frequency	256 Hz
Useable Frequency Bandwidth	128 Hz
Transform Size	2048
Frequency Resolution	0.125 Hz
Windowing	Uniform/Uniform
Shaker Excitation Profile	Burst Random (40% burst length)
Number of Averages	20
FRF estimation	H_1
Shaker excitation bandwidth	0-128 Hz
Shaker armature mass	< 0.4 lbs
Shaker control method	Current control mode

3.3 Modal Parameter Estimation

PolyMax in Test.Lab was used to curve-fit the acquired experimental data (FRFs) from 10 to 110 Hz. From these results, the frequencies of the modes were determined along with damping values. A graphical animation of the geometries for each of the modes was used to aid in describing the characteristics of the modes. Upper and lower residual mode correction was used for the FRF synthesis. The synthesized FRFs of drive points and summation function along with the measured ones are shown in Appendix A.

Modal parameter estimation table is listed in the following page.

MODAL PARAMETER ESTIMATION DESCRIPTION TABLE

Department: NVH **Project No.:** 106072-000
Date: 03/15/11 **Engineer:** Hong Yin **Technician:** Ken Knight

Project Title: EDAG BIW Modal Testing
Description: Experimental modal testing for a Honda Accord BIW

VIN / ID	Manufacturer	Make	Body Style	Build	Weight	Driveline	Engine	Trans	Tires
	Honda		BIW		796 lbs				

Boundary Condition: Air rides for simulated 'free-free' conditions **Exciter(s):** 2 modal shakers

Exciter Orientation: 1. Left front rail with exciter skewed vertical and 15 degrees lateral
2. Right rear lower corner with exciter skewed vertical and 15 degrees fore/aft

Curve Fitting: LMS PolyMAX

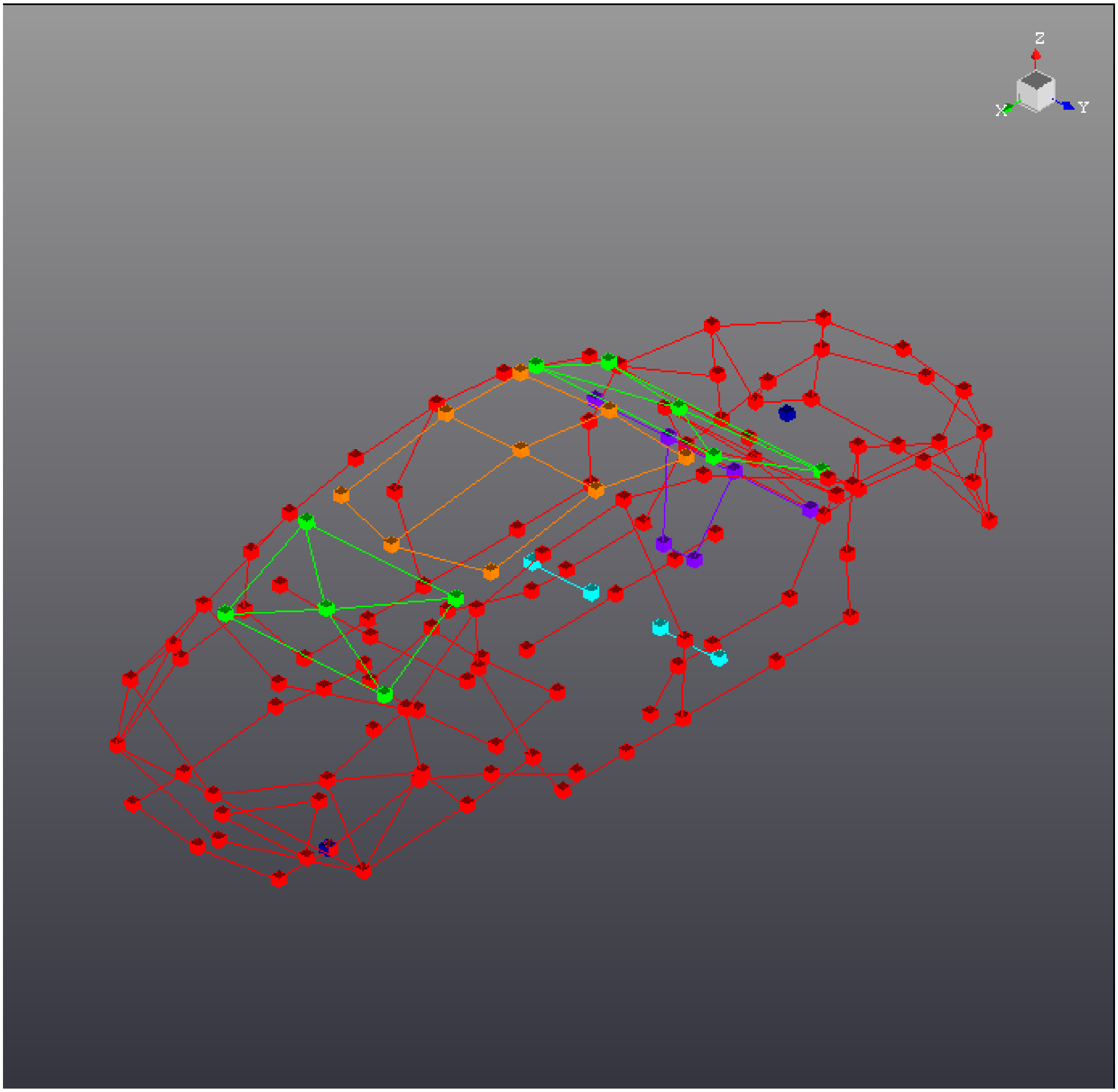
MODAL PARAMETERS

Mode Number	Frequency (Hz)	Damping	Mode Shape Description
Mode 1	35.128 Hz	0.38%	Front Lateral, Roof Vertical
Mode 2	39.301 Hz	0.44%	Vertical Bending Mode(front and rear out-of-phase)
Mode 3	44.205 Hz	0.30%	Vertical Bending Mode(front and rear in-phase)
Mode 4	50.126 Hz	1.04%	Torsion
Mode 5	55.289 Hz	1.18%	Torsion, Rear orsion/Lateral, B-Pillar Lateral (in-phase)
Mode 6	56.639 Hz	0.42%	Vertical Bending (roof and floor out-of-phase), IP,Firewall and Trunk Rear Fore-Aft (in-phase)
Mode 7	61.186 Hz	0.37%	Vertical Bending (floor vertical in two directions), IP Fore-Aft, Front Glass Vertical
Mode 8	68.492 Hz	0.36%	Torsion,
Mode 9	70.117 Hz	0.61%	Front Torsion,IP Fore-Aft,Floor and Spare Wheel Tub Vertical (out-of-phase)
Mode 10	71.454 Hz	0.69%	Front Twist, Rear Lateral, Spare Wheel Tub Vertical
Mode 11	75.568 Hz	0.45%	Vertical Bending, Trunk Rear Fore/Aft
Mode 12	83.284 Hz	0.60%	Vertical Bending (floor vertical in two directions), Roof Rear Vertical
Mode 13	85.100 Hz	0.85%	Trunk Panel Lateral (out-of-phase)
Mode 14	91.198 Hz	0.86%	Vertical Bending, IP and Trunk Rear Fore-Aft (in-phase),
Mode 15	95.567 Hz	0.56%	Torsion, Mid Vertical,IP Fore/Aft
Mode 16	96.935 Hz	0.58%	Vertical Bening, IP and Trunk Rear Fore-Aft (out-of-phase)
Mode 17	98.979 Hz	0.80%	Torsion
Mode 18	102.071 Hz	0.79%	Vertical, IP Vertical/Twist, Trunk Rear Fore-Aft
Mode 19	103.098 Hz	0.65%	Vertical/Torsion, Trunk Rear For-Aft
Mode 20	110.907 Hz	0.45%	Roof Vertical , Trunk Rear Fore-Aft

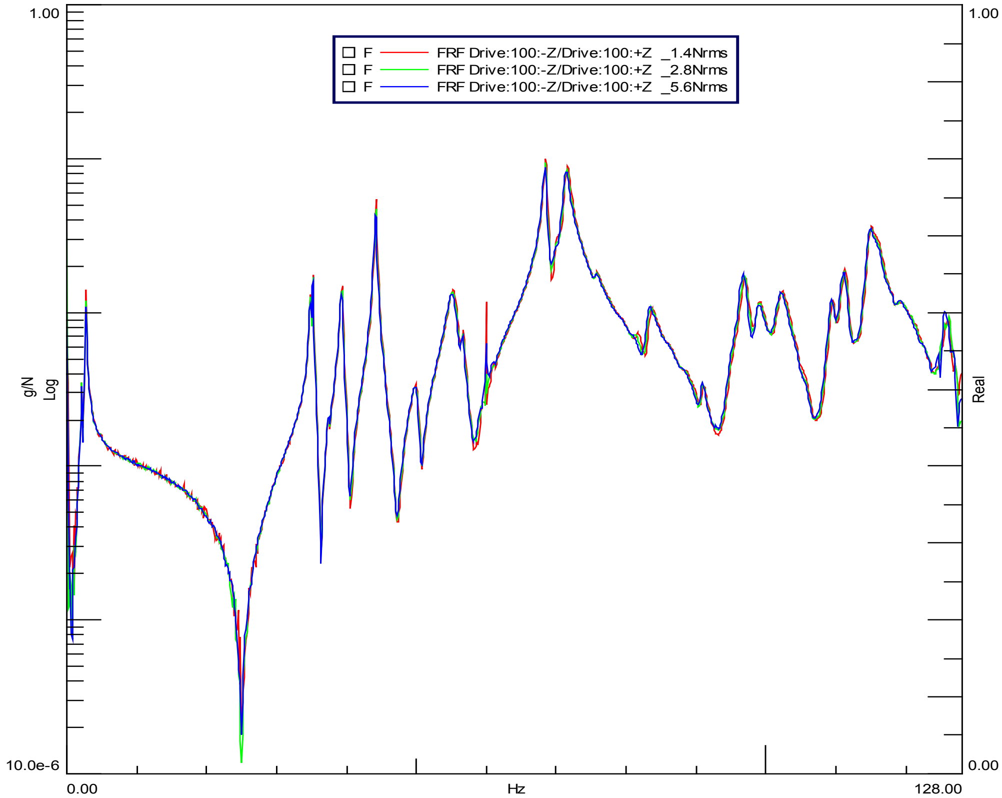
Appendix A

2011 Honda Accord BIW Modal Test Plots

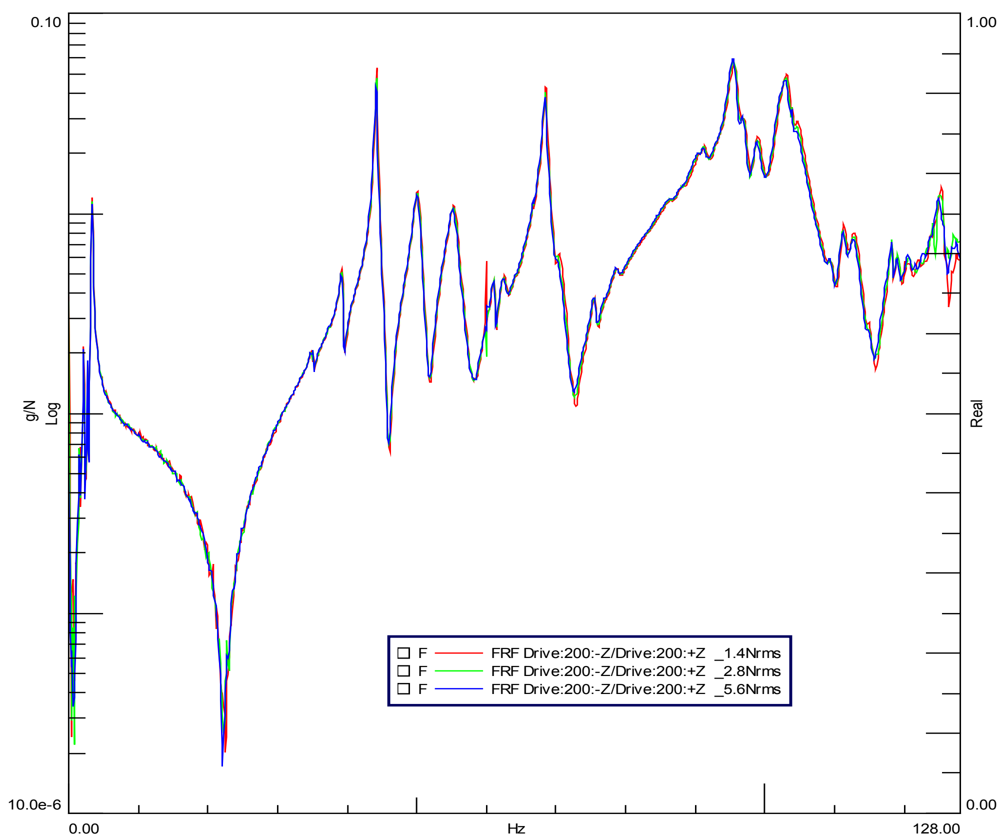
Geometry Plot
Modal Experiment Validation Plots
- Linearity Check
- Reciprocity Check
- Time-invariance Check
- Mode Summation Function (Synthesized vs. Experiment)
- Experimental Mode Summation Function



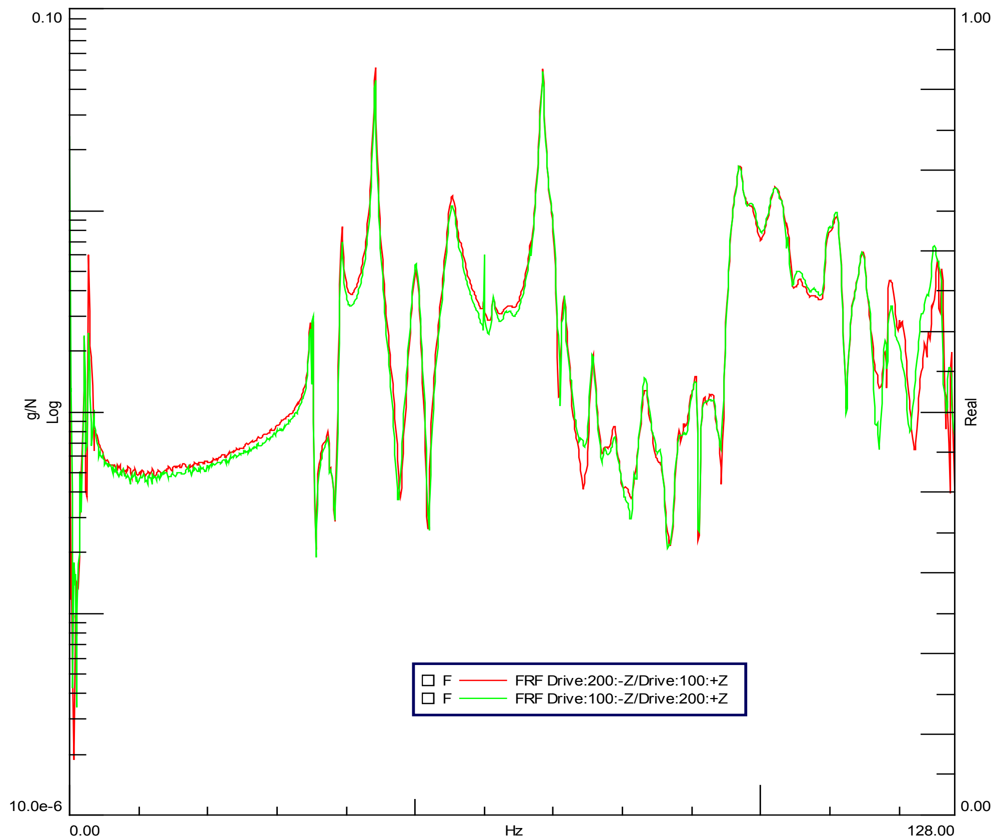
Geometry



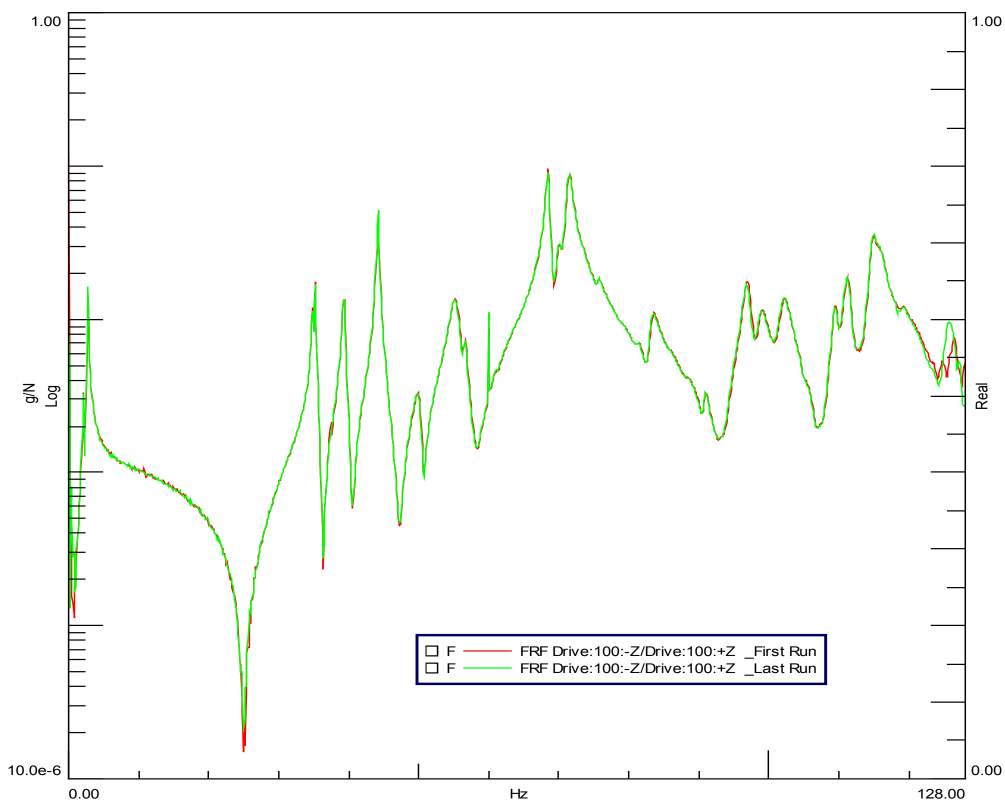
Linearity Check – Front Drive Point



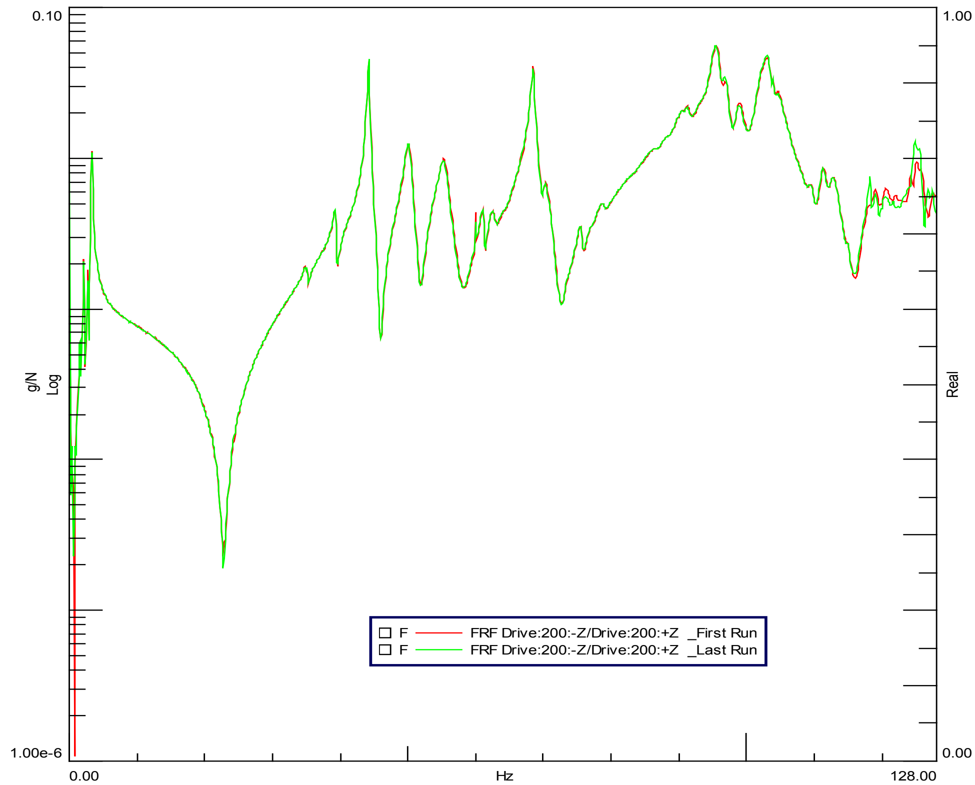
Linearity Check – Rear Drive Point



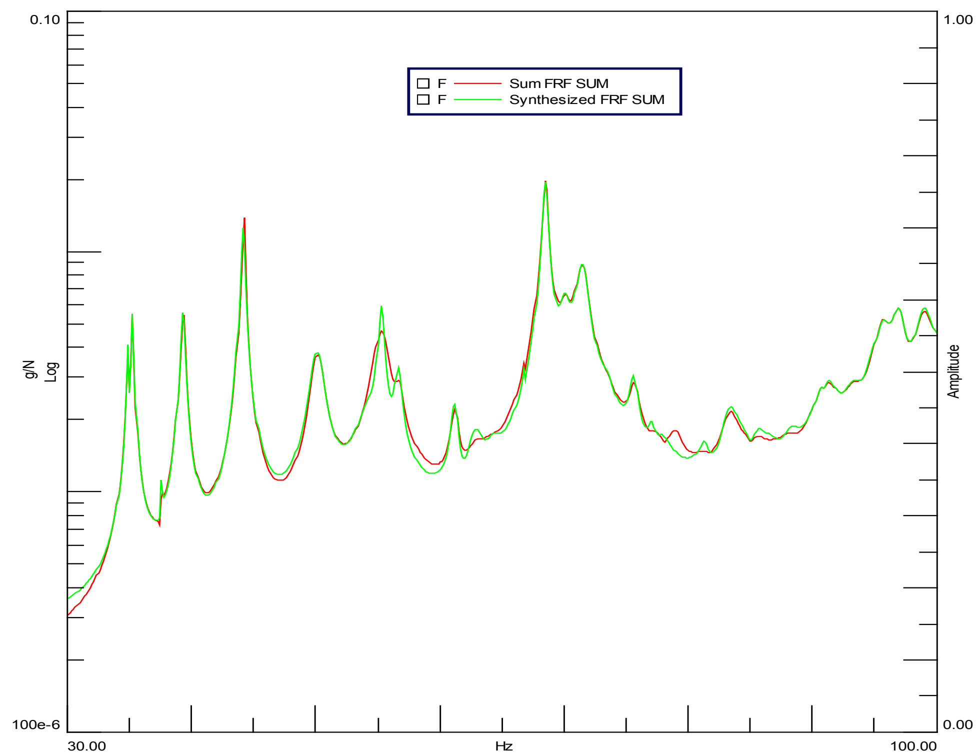
Reciprocity Check



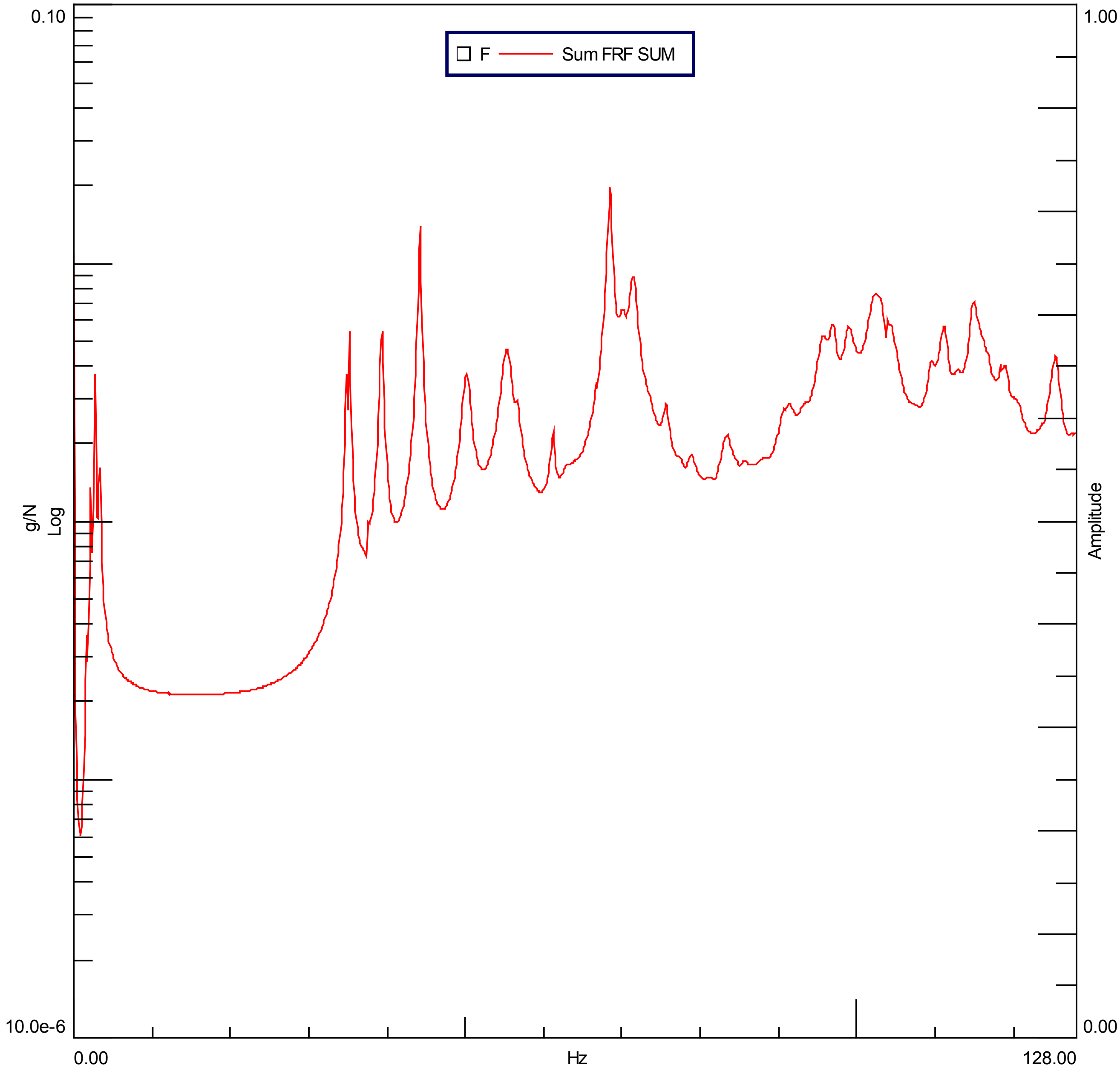
Time-invariance Check – Front Drive Point



Time-invariance Check – Rear Drive Point



Mode Summation Function of FRF – Experimental vs. Synthesized



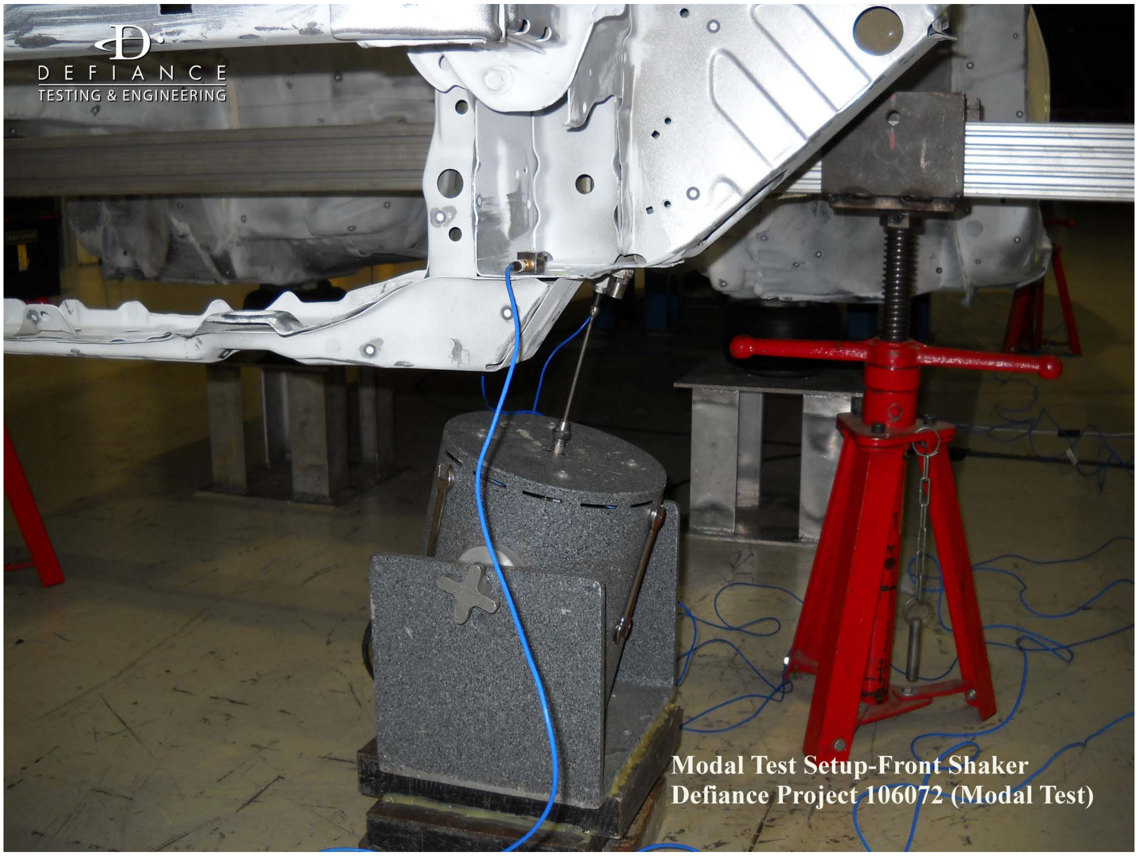
Measured Mode Summation Function of FRF

Appendix B

2011 Honda Accord BIW Modal Test Photographs

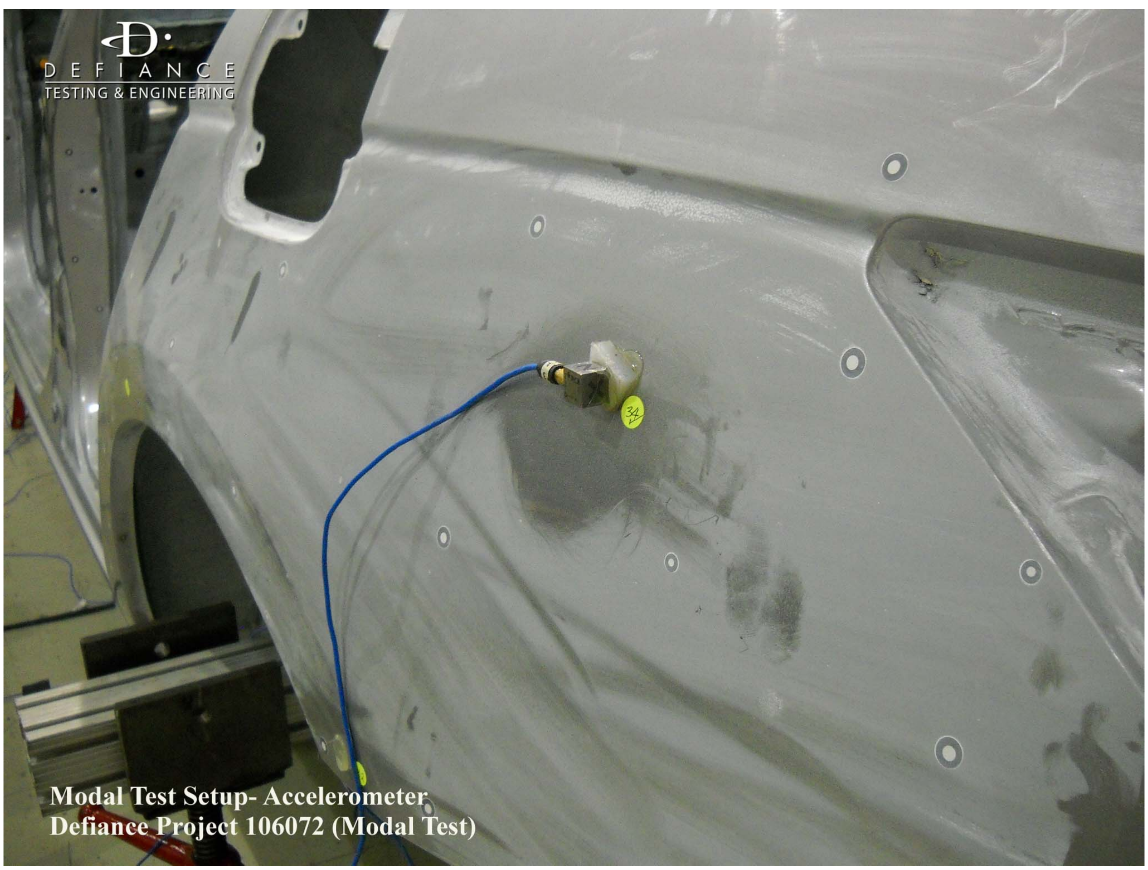
Modal Test Setup
Defiance Project 106072 (Modal Test)

Modal Test Setup
Defiance Project 106072 (Modal Test)


DEFIANCE
TESTING & ENGINEERING
Modal Test Setup-Front Shaker
Defiance Project 106072 (Modal Test)

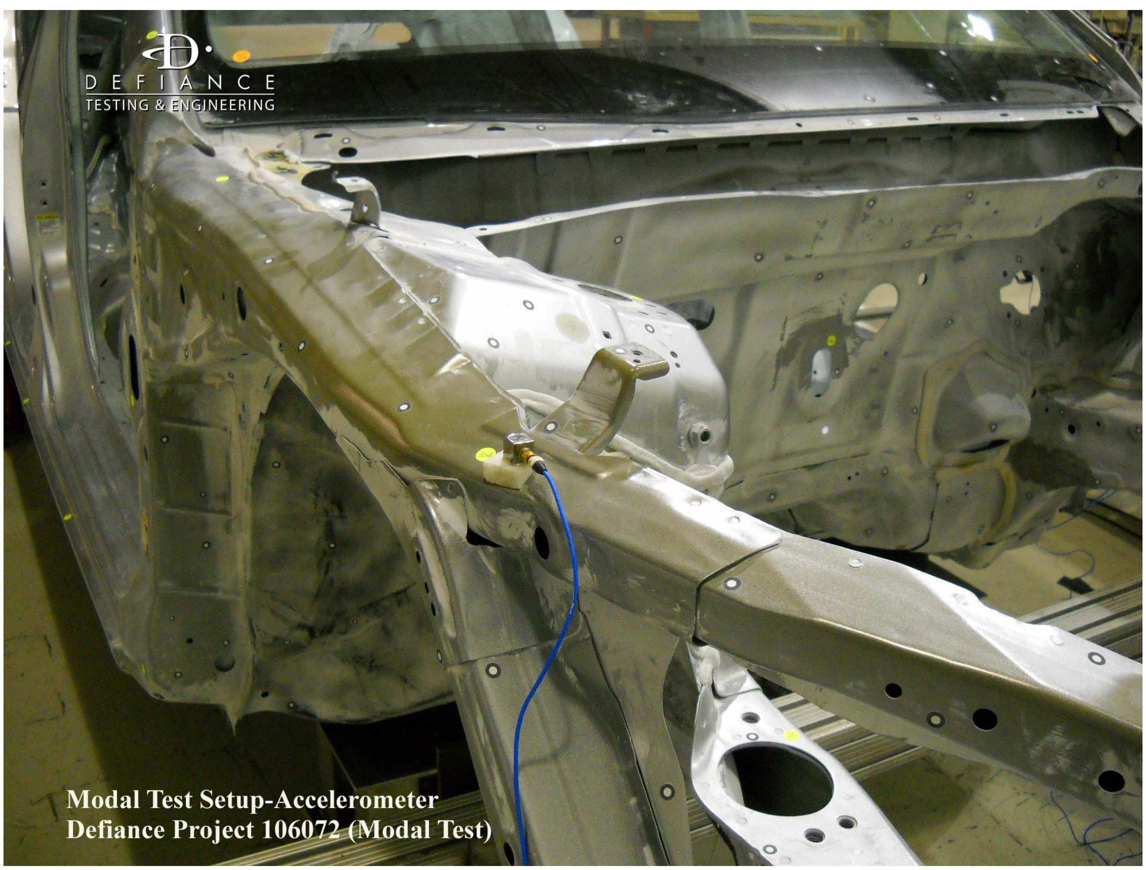

DEFIANCE
TESTING & ENGINEERING
Modal Test Setup-Rear Shaker
Defiance Project 106072 (Modal Test)

Modal Test Setup-Rear Shaker
Defiance Project 106072 (Modal Test)



Modal Test Setup- Accelerometer
Defiance Project 106072 (Modal Test)

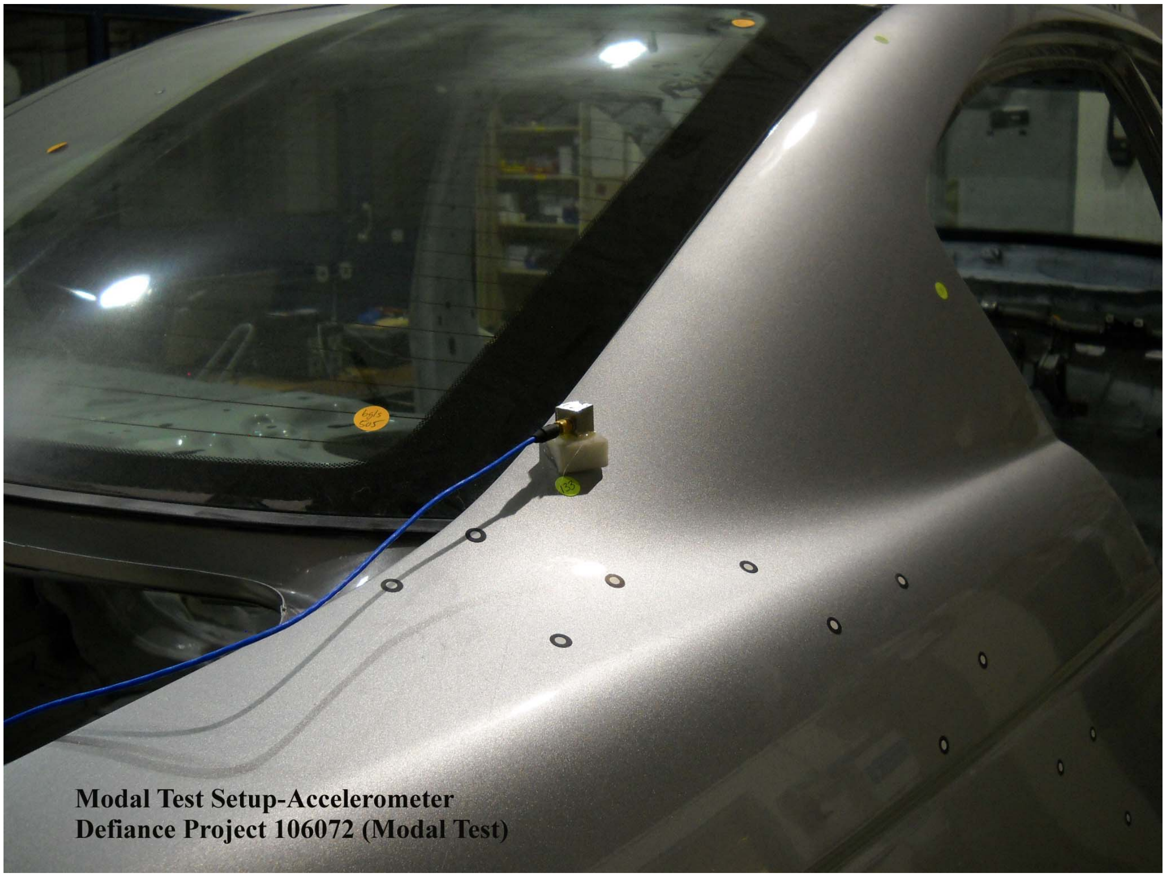
Modal Test Setup- Accelerometer
Defiance Project 106072 (Modal Test)

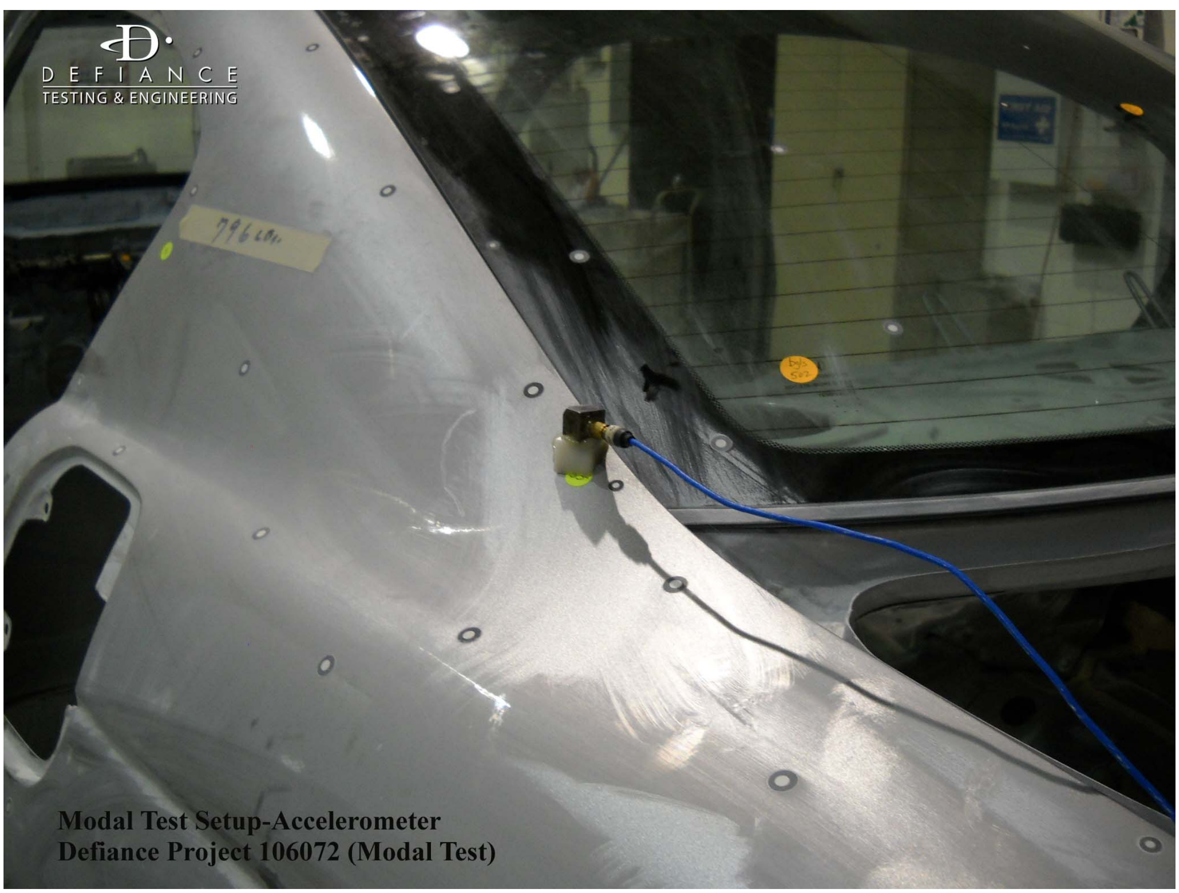


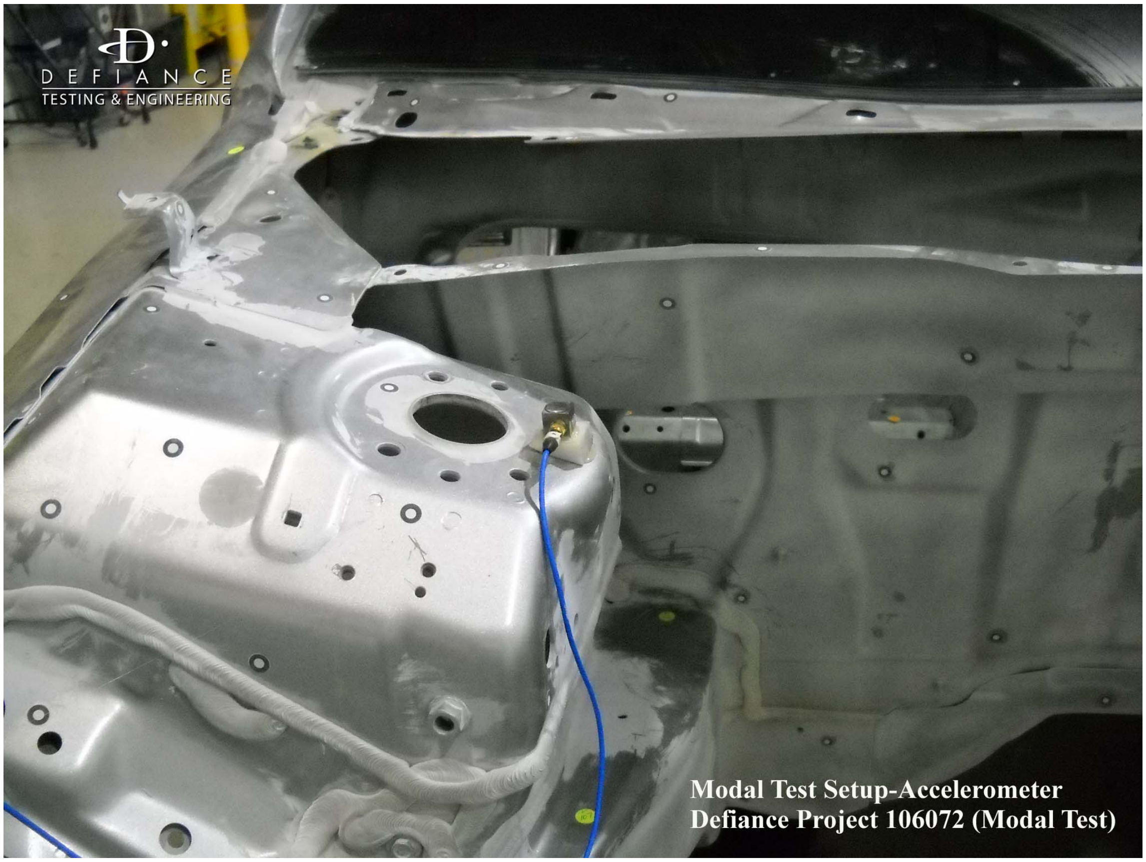
Modal Test Setup-Accelerometer
Defiance Project 106072 (Modal Test)


Modal Test Setup-Accelerometer
Defiance Project 106072 (Modal Test)

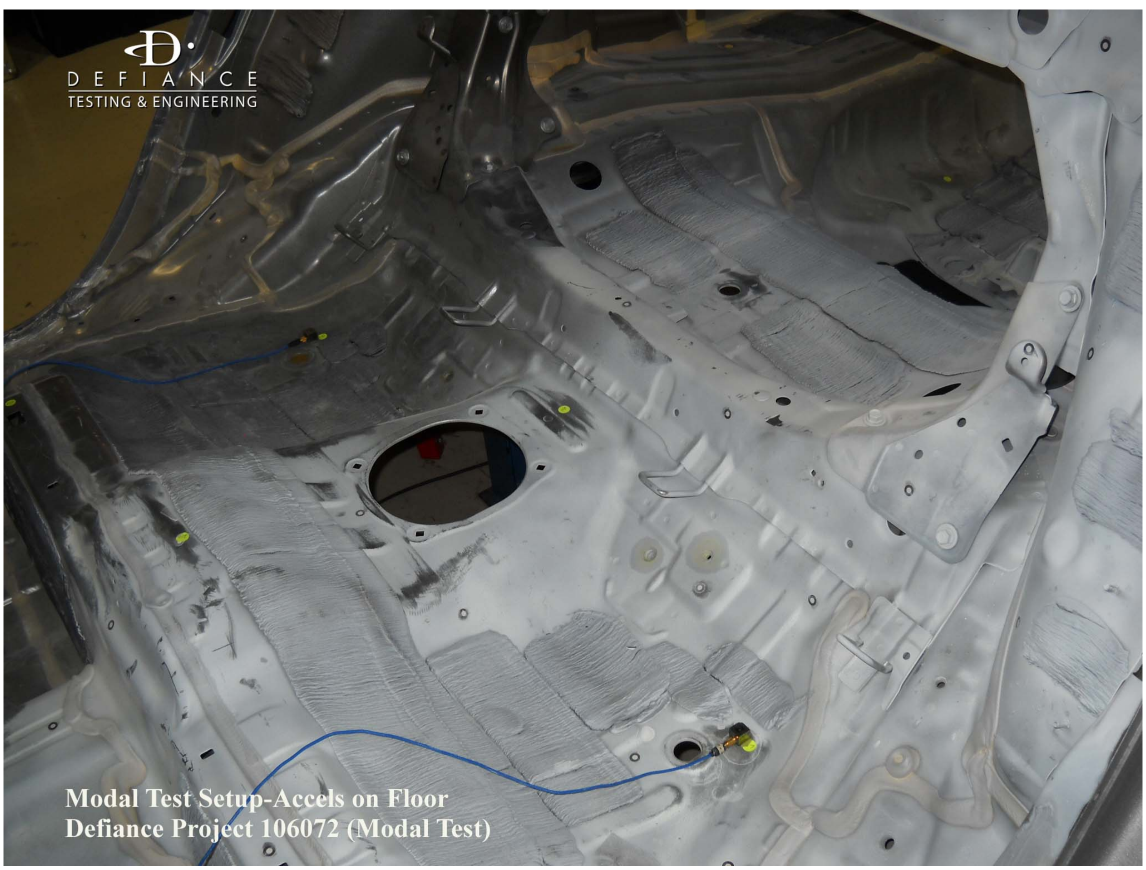

Modal Test Setup-Accelerometer
Defiance Project 106072 (Modal Test)


Modal Test Setup-Accelerometer
Defiance Project 106072 (Modal Test)


DEFIANCE
TESTING & ENGINEERING
Modal Test Setup-Accelerometer
Defiance Project 106072 (Modal Test)



Modal Test Setup-Accelerometer
Defiance Project 106072 (Modal Test)

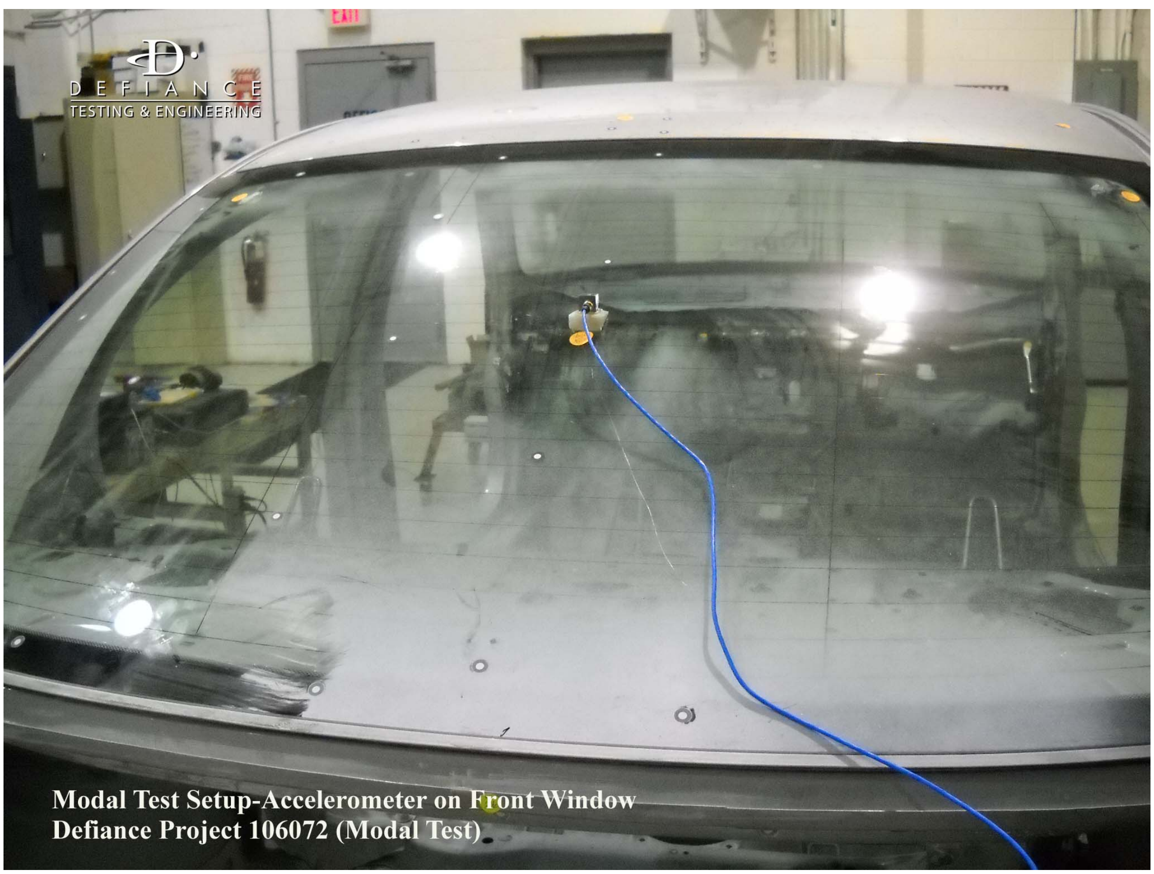


Modal Test Setup-Accels on Floor
Defiance Project 106072 (Modal Test)

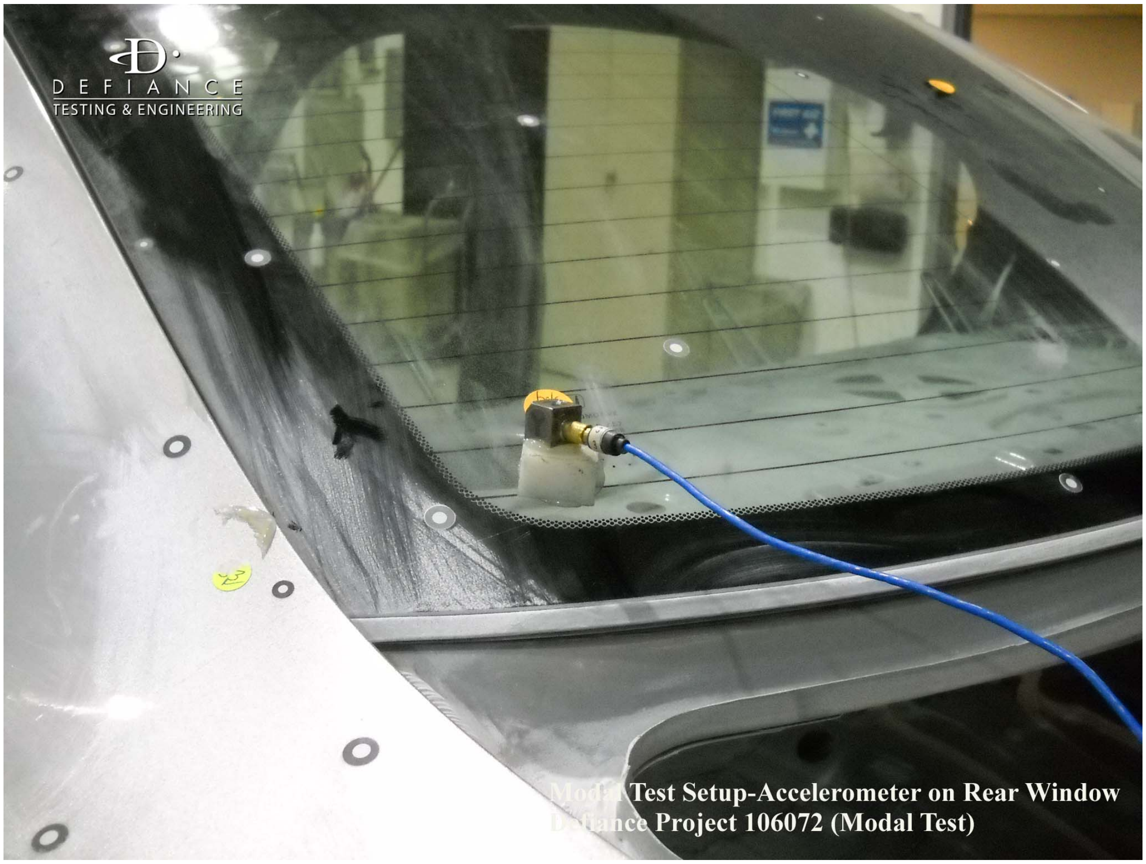
Modal Test Setup-Accels on IP
Defiance Project 106072 (Modal Test)

Modal Test Setup-Accels on Roof
Defiance Project 106072 (Modal Test)

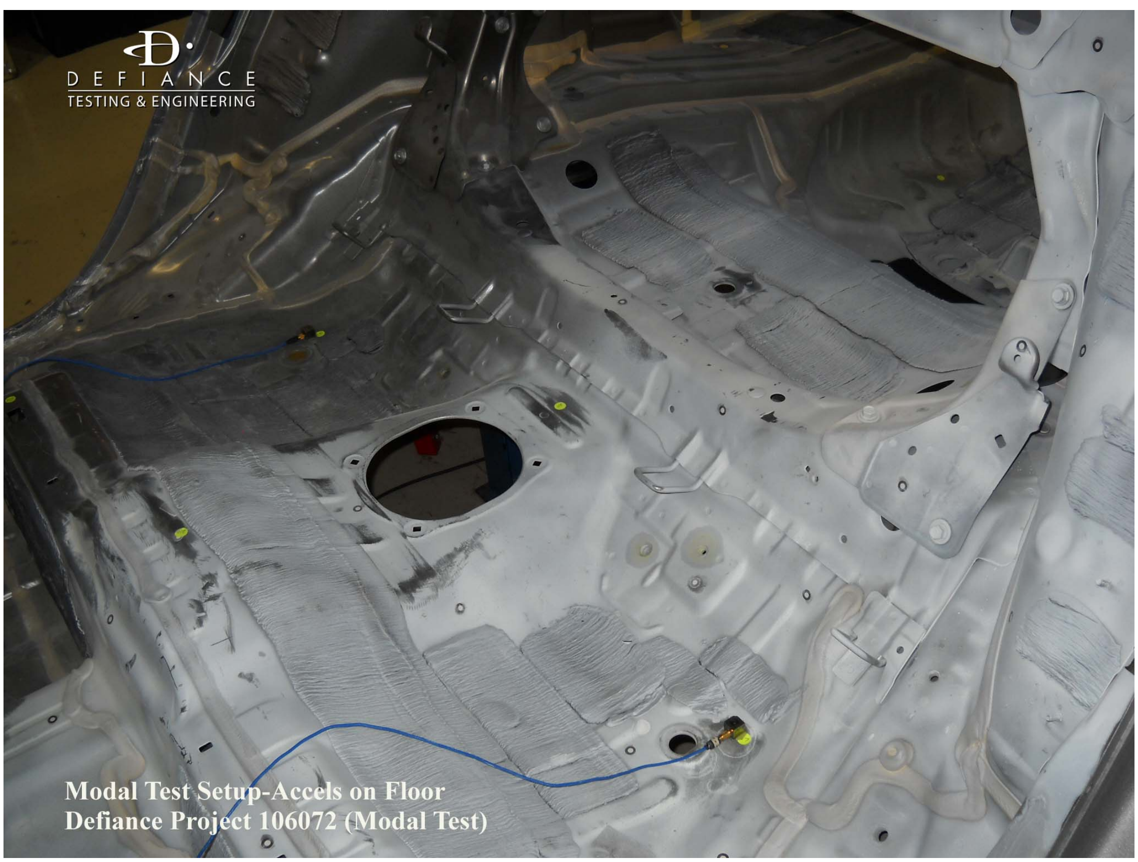
Modal Test Setup-Accelerometer on Front Window
Defiance Project 106072 (Modal Test)



Modal Test Setup-Accelerometer on Front Window
Defiance Project 106072 (Modal Test)



Modal Test Setup-Accelerometer on Rear Window
Defiance Project 106072 (Modal Test)



Modal Test Setup-Accels on Floor
Defiance Project 106072 (Modal Test)

Appendix C

Equipment List

Equipment

Project Number: 106072
Project Name: 2011 Honda Accord BIW Modal Test
Activity Number: 30
Activity Name: 30-Run
Sample: 1
Building: 10

Description	Model Number	Serial Number	Asset	Capacity 1	Capacity 2	Ch.	Ch. Description	Type Of Cal Schedule	Next Cal Date	Reservable
Accelerometer	356A15	17052	0039246	50 g	2-5000 Hz			Scheduled Calibration	7/17/2010	Yes
	356A15	17056	0039237	50 g	2-5000 Hz			Scheduled Calibration	7/16/2010	Yes
	356A15	32602	0041738	50 G's				Scheduled Calibration	7/16/2010	Yes
	356A15	32603	0041739	50 G's				Scheduled Calibration	7/16/2010	Yes
	4371	1187101	0030146	6,000 g	10-2,000 Hz			Scheduled Calibration	7/15/2010	Yes
	4371	1573268	0030161	6,000 g	10-2,000 Hz			Scheduled Calibration	7/15/2010	Yes
Charge Amplifier	2635	1029904	0031033					Scheduled Calibration	8/12/2010	Yes
	2635	1277897	0031077					Scheduled Calibration	7/17/2010	Yes
Electro Dynamic Shaker	MB50A	00176	0031618	50 Lbs						Yes
	MB50A	00177	0031617	50 Lbs						Yes
Electro Dynamic Shaker Amplifier	SS250VCF	218382	0031626							No
	SS250VCF	218390	0031627							No
Hand Held Shaker	394B06	634	0031798	1 g	.08 kHz			Scheduled Calibration	3/9/2011	No
Load Cell (Impulse Hammer)	208B	6847	0032162	10 Lbs				Scheduled Calibration.	7/21/2010	No
	208B01	15039	0032166	10 Lbs				Scheduled Calibration	7/21/2010	No
SCADAS Recorder	SCR 05-16	53092617	0042370	5-Slot						No

EDAG Incorporation

2011 Honda Accord BIW Static Bending and Torsion Tests

Defiance Report No. 106072-000 (Static)

Prepared for:

EDAG Incorporation
275 Rex Boulevard
Auburn Hills, MI 48326

Attn: **Jim Davies**
48-514-7529
James.davies@edag-us.com

Prepared by:

Hong Yin

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Senior Project Engineer
248-458-5900 x 219
hyin@defiancetest.com

March 26, 2011

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3.5 Bending Test Results 3

Appendix A: BIW Static Torsion and Bending Test Deflection Plots A1-A4

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Appendix C: Equipment List....................C1-C2

EDAG Incorporation

2011 Honda Accord BIW Static Bending and Torsion Tests

Defiance Report No. 106072-000 (Static)

1.0 OBJECTIVE

The objective of the static torsion and bending tests was to identify the static torsion stiffness and the static bending stiffness values for a 2011 Honda Accord BIW (with front and rear glasses).

2.0 SUMMARY

All testing was performed at Defiance's Troy facility at 1154 Maplelawn from March 7 to 23, 2011. The static torsion and bending stiffness results are shown in Table 1. Static torsion and bending deflection plots are shown in Appendix A. Test setup photographs and equipment used on this project are shown in Appendix B and C, respectively.

Table 1: Static Torsion and Bending Stiffness Summary

Torsion Stiffness (Nm/Deg)	12,330
Driver Side Bending Stiffness (N/mm)	7,305
Passenger Side Bending Stiffness (N/mm)	8,690

3.0 STATIC TESTS

3.1 Test Setup

The BIW was constrained using a minimum constraint support system with Heim joints. One torsion test and one bending test were conducted. For torsion test, the front supports (the loading point) for the BIW were at the front strut mounts and the rear supports were at the rear spring-seats. For bending test, the front and rear supports were same as the torsion test. Loading point was at the halfway between the front and rear constraints. Refer to the photographs in Appendix B.

Linear Voltage Potentiometers (LVP) were placed along the longitudinal direction of the structure to measure vertical displacements. Measurement locations included constraint points and body points. There were four measurement locations on constraints and twenty on the body portion of the vehicle. The following table contains the coordinates of the measurement points. The original of X is at the very front of the front bumper with positive toward the rear of the vehicle. The Y is the distance between two LVPs at both the driver side and the passenger side for the same x position.

Table 2: Torsion Test LVP Locations

Location Names	Transducer Pair		Coordiatea	
	Driver	Passenger	X (mm)	Y width (mm)
Front most point on frame rail	1	13	0	1034
Body	2	14	570	1045
Torsion load point/ front constraint	3	15	850	1055
Rail @ Dog leg	4	16	1100	1000
Sill @ A-Pillar	5	17	1390	1595
Sill	6	18	1800	1595
Sill / Bending Load	7	19	2145	1595
Sill	8	20	2655	1595
Sill @ C-Pillar	9	21	3125	1595
Rear Constraint	10	22	3570	1040
Rail	11	23	4000	890
End of Rail	12	24	4430	890

Table 3: Bending Test LVP Locations

Location Names	Transducer Pair		Coordinates	
	Driver	Passenger	X (mm)	Y width (mm)
Front most point on frame rail	1	13	0	1034
Body	2	14	570	1045
Front constraint	3	15	790	1055
Rail @ Dog leg	4	16	1100	1000
Sill @ A-Pillar	5	17	1390	1595
Sill	6	18	1800	1595
Sill / Bending Load	7	19	2145	1595
Sill	8	20	2655	1595
Sill @ C-Pillar	9	21	3125	1595
Rear Constraint	10	22	3570	1040
Rail	11	23	4000	890
End of Rail	12	24	4430	890
Bending Plate	25	26	2145	1550

3.2 Torsion Tests

A hydraulic actuator was attached to the twist beam to apply the necessary torque to the structure. Following three warm up cycles, torsion loads were applied at the front constraints to achieve the required torque value of 3433 Nm (2780 N with 1.235 m between two front constrain points). The moment arm for the torsion test was 1.405 m (55.3 inches). The designed load of 2,443 N (550 lb) was applied on the loading point of the front loading arm. For this test a counterclockwise motion (CCW, left twist) was defined as having the left side of the loading structure moving down and the right side moving up, as viewed from the front of the body (loading at front and fixed at rear of the body). Similarly, a clockwise motion (CW, right twist) was defined as the left side moving up and the right side moving down, as viewed from the front of the body. The loading sequence was as follows:
0, $^1/_3$ CW, $^2/_3$ CW, CW, $^2/_3$ CW, $^1/_3$ CW, 0, $^1/_3$ CCW, $^2/_3$ CCW, CCW, $^2/_3$ CCW, $^1/_3$ CCW, 0

Three runs were performed at each test.

ACCREDITED

3.3 Bending Test

For the bending test, steel brackets were welded to the underside of the body. Refer to the photographs in Appendix B. These brackets were attached halfway between the front and rear constrains. A steel beam was then placed into the brackets to act as the loading bar for the input of the force to the body. A cable attached to the center of the beam applied a vertical pull through the pulley system that attached to an actuator. A load cell was used to measure a maximum load of 2000 lbs (8896 N) applied to the BIW in nine increments as one full cycle. The loading sequence was as follows:

0, $^1/_4$ MAX, $^1/_2$ MAX, $^3/_4$ MAX, MAX, $^3/_4$ MAX, $^1/_2$ MAX, $^1/_4$ MAX, 0

Three run were performed for this bending test.

3.4 Torsion Test Results

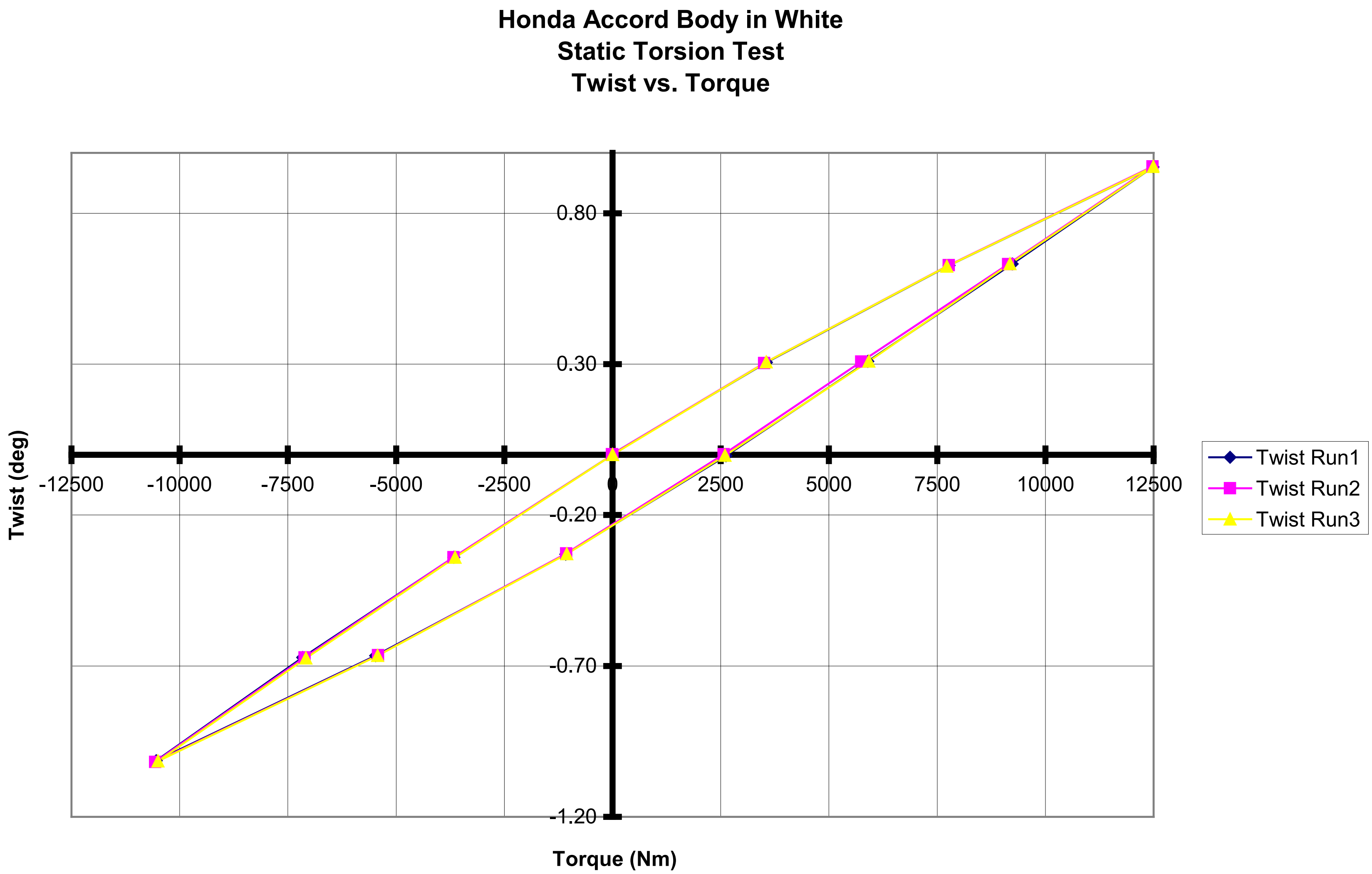
The calculated twist angles versus distance along the body (in the X-direction) were plotted. The twist angles at the front constraints (loading points) were used to calculate the torsion stiffness values. A linear regression analysis was performed for the twist angle results over all thirteen acquired load increments. The slope of the linear regression line was used to calculate the stiffness values shown in Table 1.

3.5 Bending Test Results

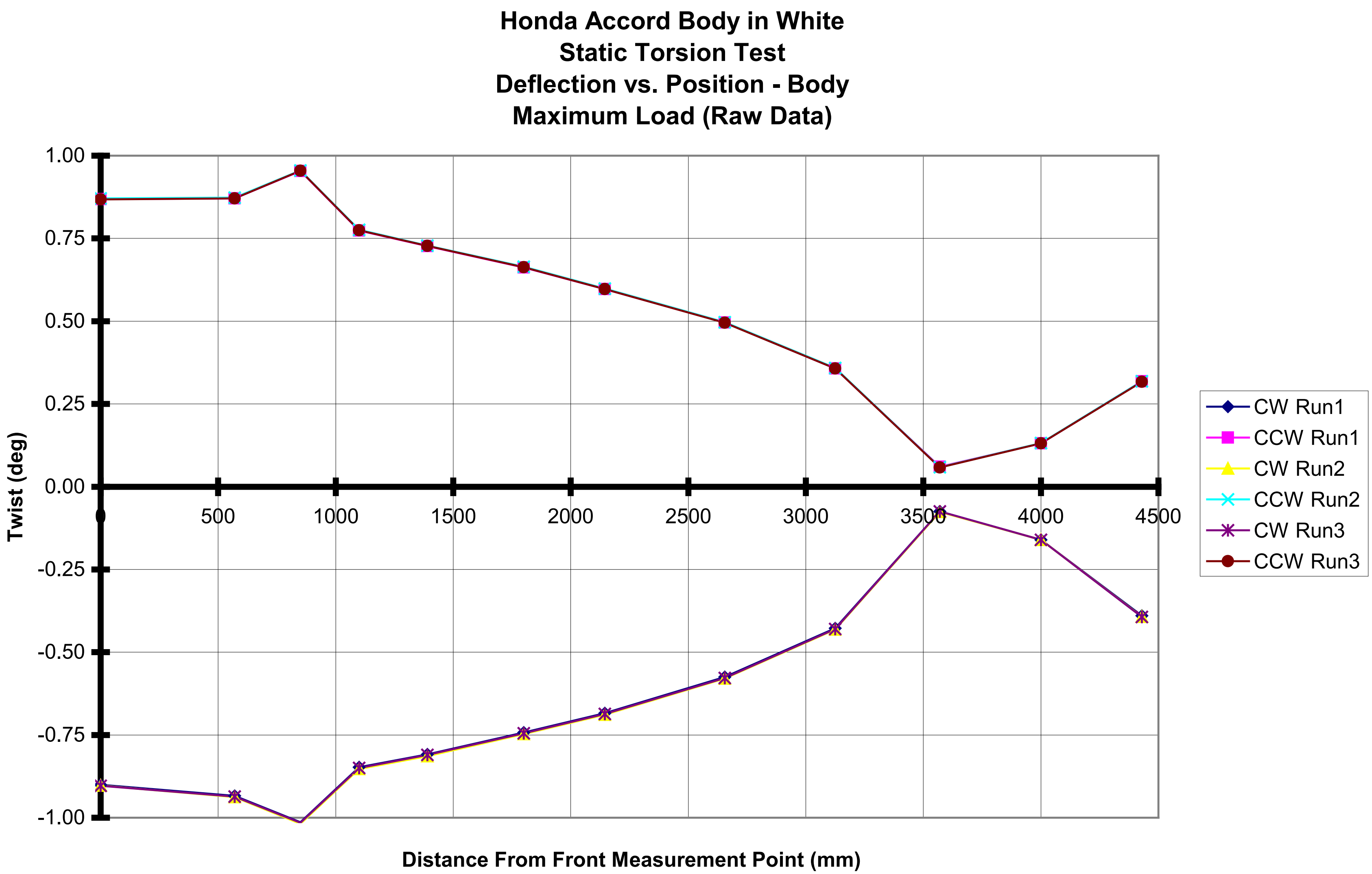
The deflections versus distance along the body (in the X-direction) were plotted. The deflections at the loading points were used to calculate the bending stiffness values. A linear regression analysis was performed for the deflection results over the nine load increments. The slope of the linear regression line was used to calculate the stiffness values shown in Table 1.

Appendix A

BIW Static Torsion and Bending Test Deflection Plots

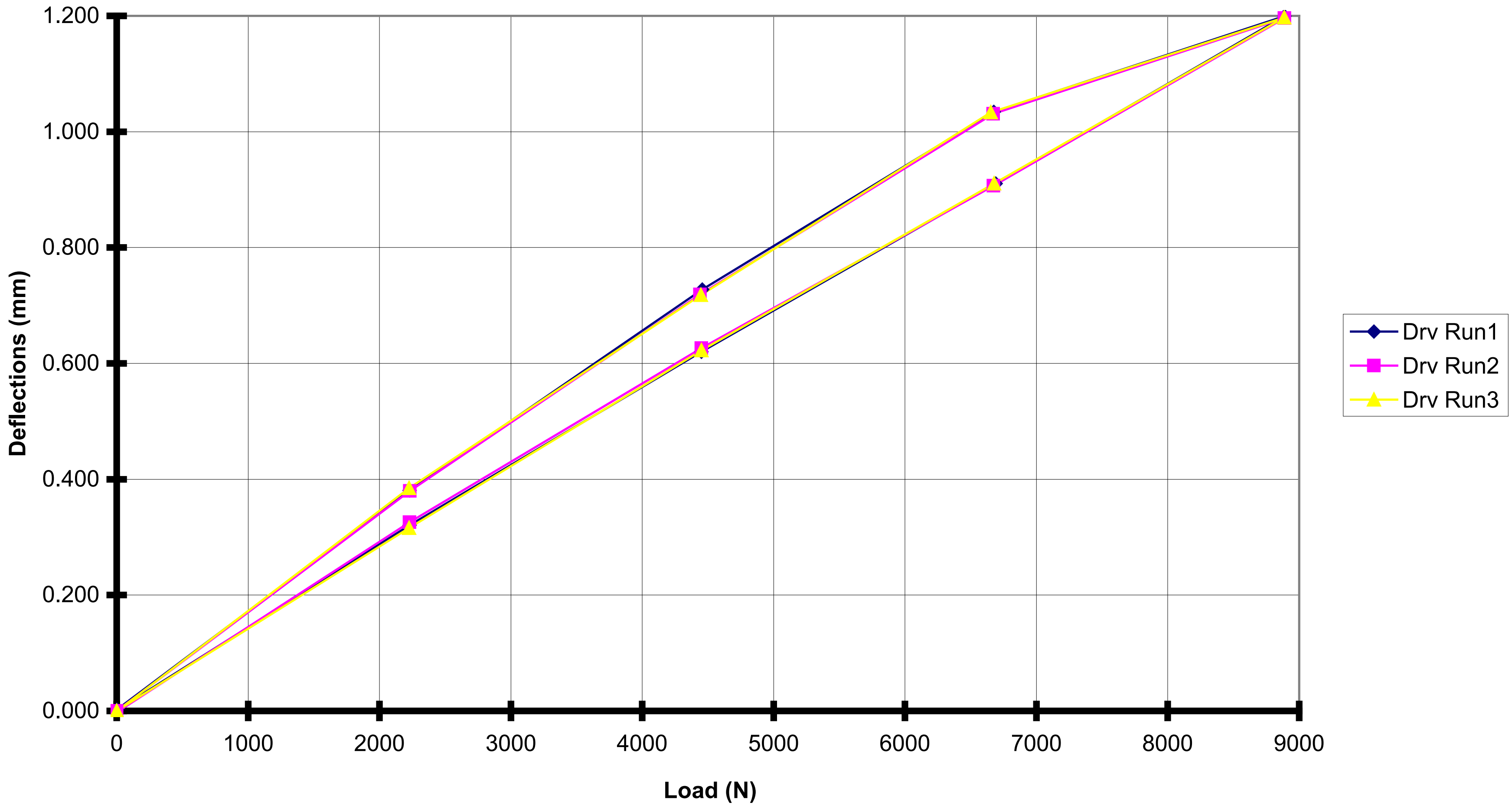


Uncorrected Stiffness = 11480 Nm/deg
Corrected Stiffness = 12330 Nm/deg

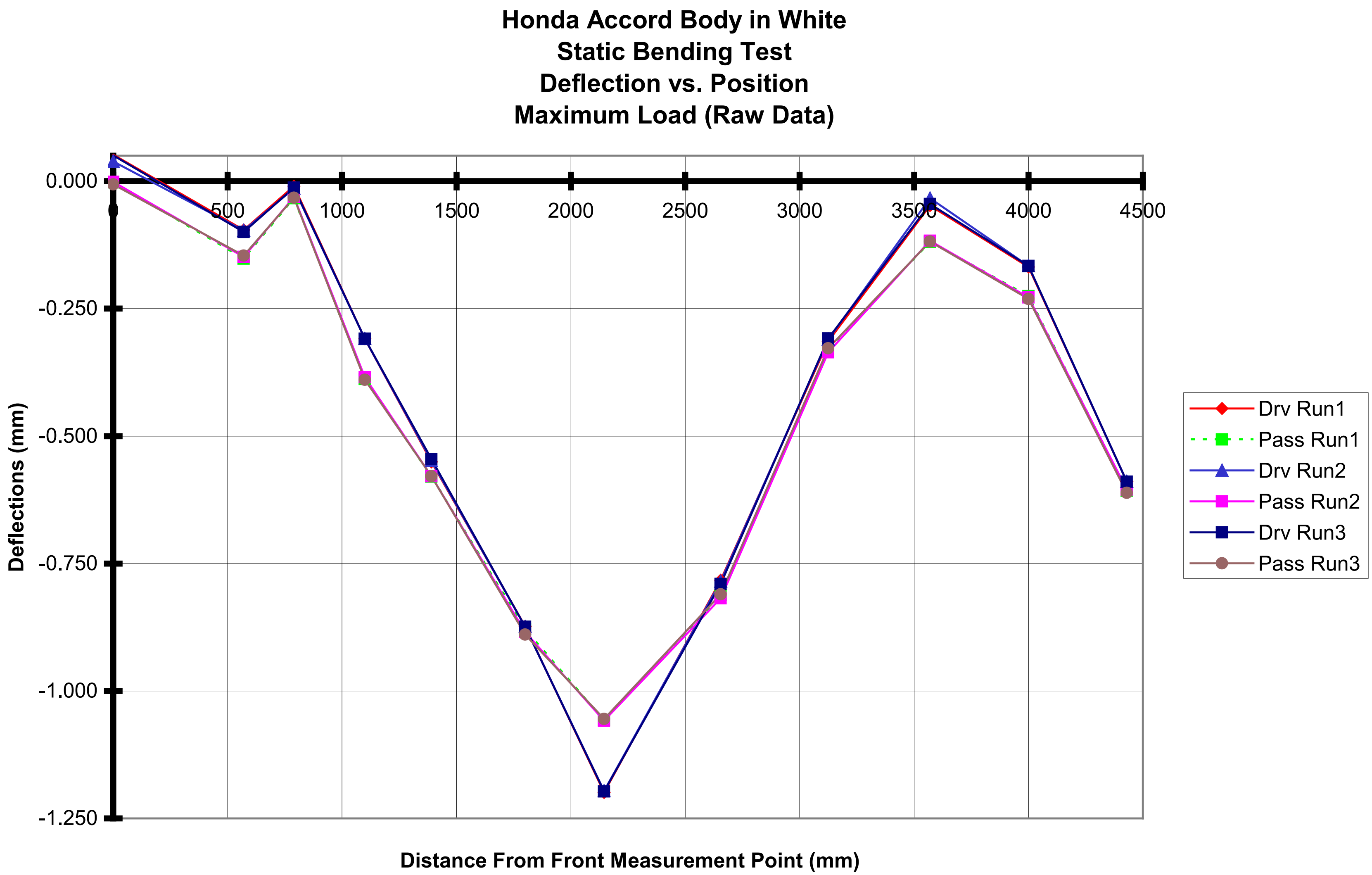


Uncorrected Stiffness = 11480 Nm/deg
Corrected Stiffness = 12330 Nm/deg

Honda Accord Body in White
Static Bending Test
Deflection vs. Load



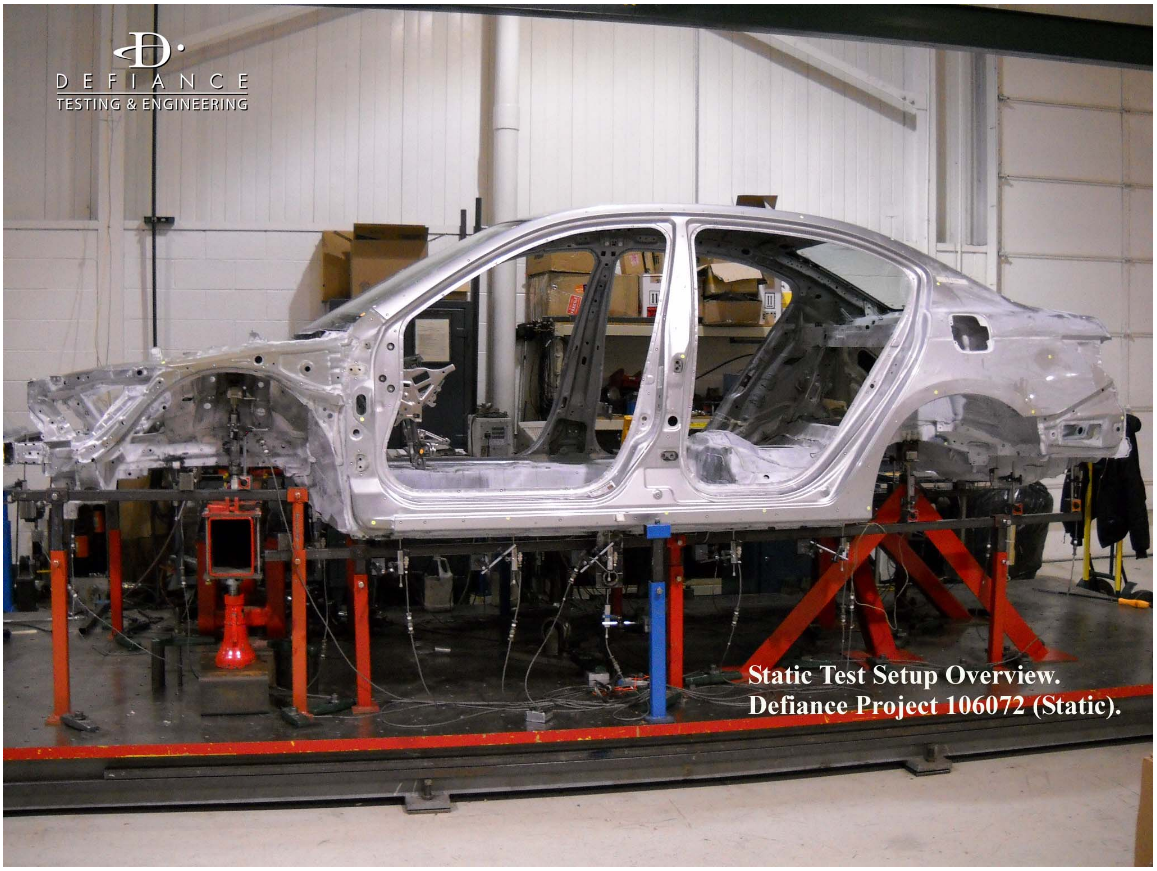
Corrected Driver Stiffness = 7305 N/mm
Corrected Passenger Stiffness = 8690 N/mm



Corrected Driver Stiffness = 7305 N/mm
Corrected Passenger Stiffness = 8690 N/mm

Appendix B

BIW Static Torsion and Bending Test Setup Photographs


DEFIANCE
TESTING & ENGINEERING
Static Test Setup Overview.
Defiance Project 106072 (Static).


DEFIANCE
TESTING & ENGINEERING
Static Test Setup Overview.
Defiance Project 106072 (Static).

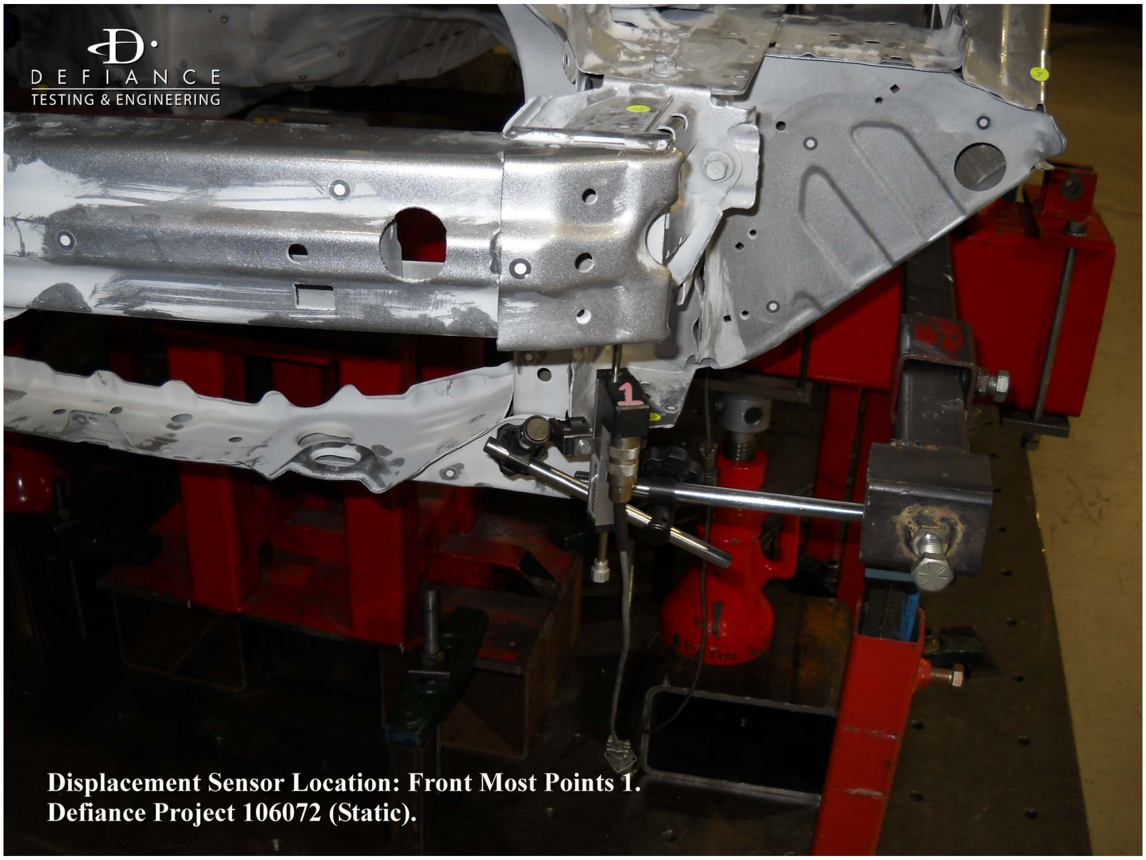
Static Test Setup
Left Rear View.
Defiance Project 106072 (Static).

Static Test Setup
Right Rear View.
Defiance Project 106072 (Static).

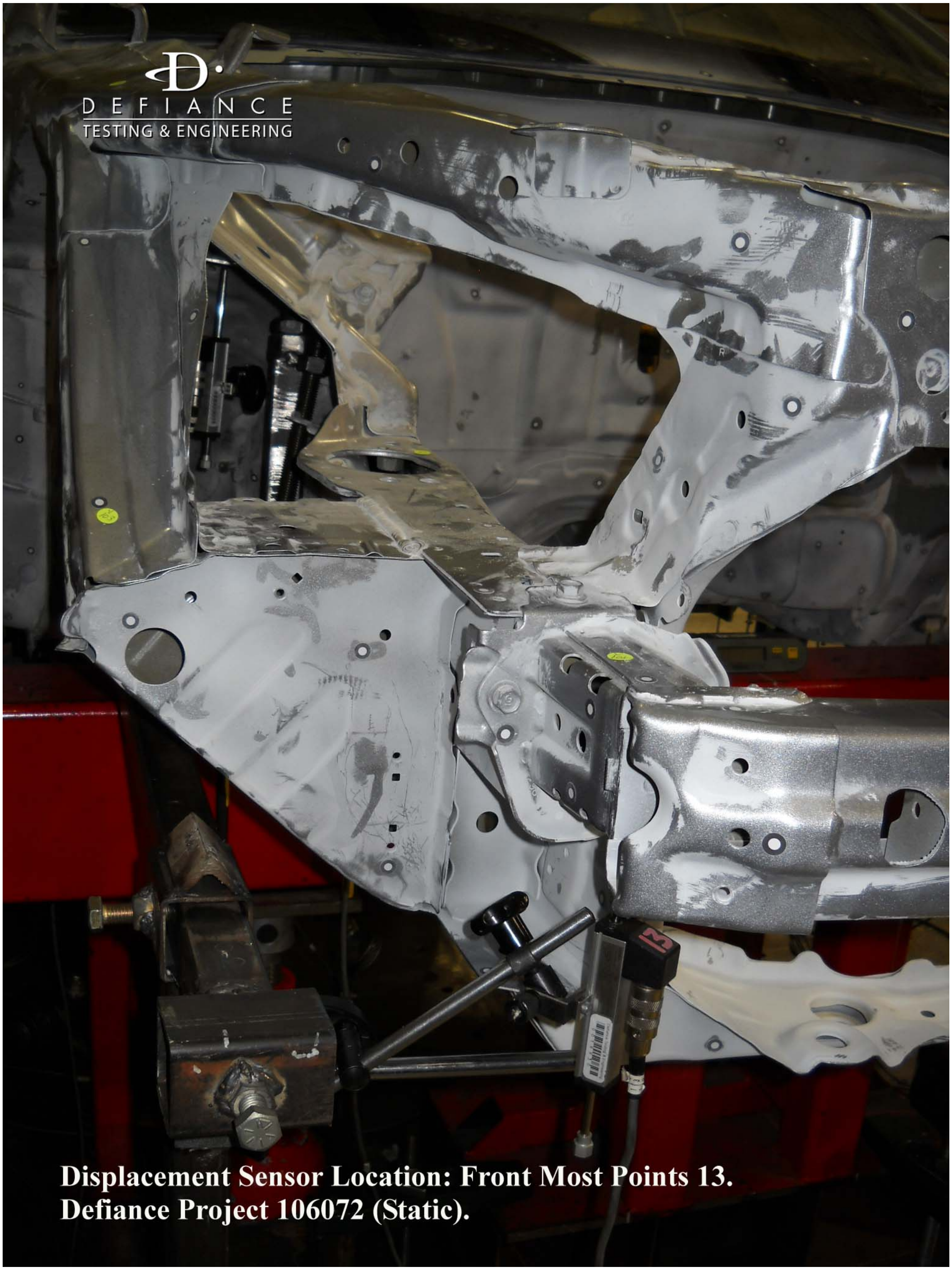
Static Torsion Setup
Loading Point
Defiance Project 106072 (Static).

Bending Setup
Loading Mechanism
Defiance Project 106072 (Static).


DEFIANCE
TESTING & ENGINEERING
Bending Setup
Loading Mechanism
Defiance Project 106072 (Static).


DEFIANCE
TESTING & ENGINEERING
Displacement Sensor Location: Front Most Points 1.
Defiance Project 106072 (Static).


DEFIANCE
TESTING & ENGINEERING
Displacement Sensor Positions 5,6 and 7.
Defiance Project 106072 (Static).

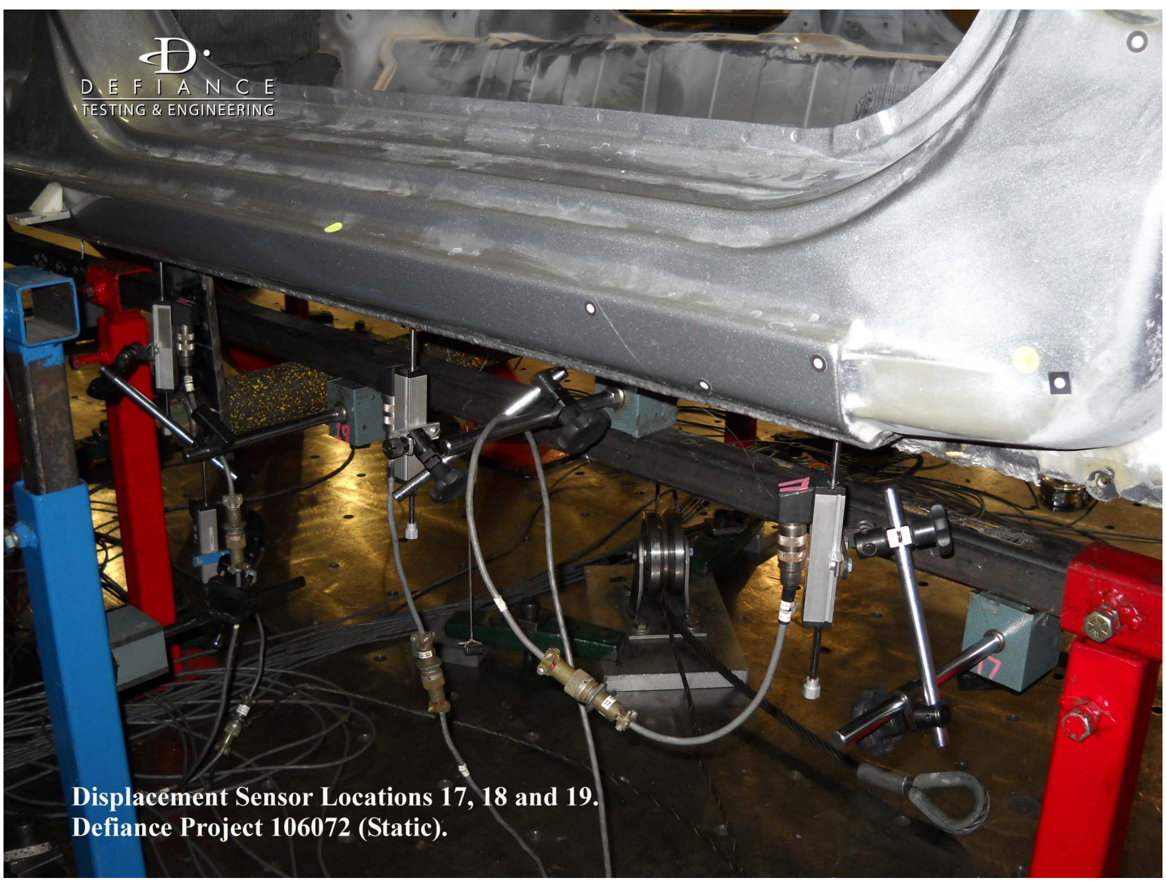


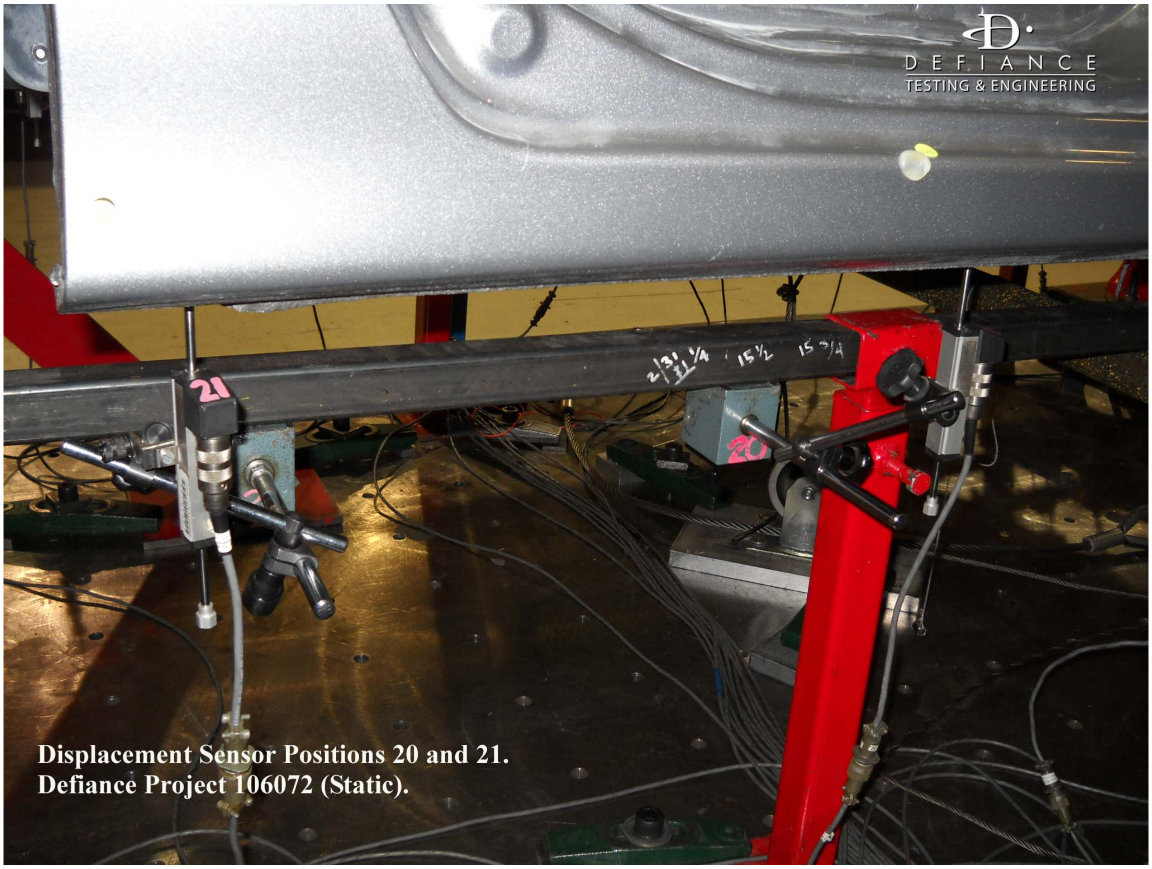
Displacement Sensor Location: Front Most Points 13.
Defiance Project 106072 (Static).


DEFIANCE
TESTING & ENGINEERING
Displacement Sensor Positions 6 and 7.
Defiance Project 106072 (Static).


DEFIANCE
TESTING & ENGINEERING
Displacement Sensor Positions 8 and 9.
Defiance Project 106072 (Static).

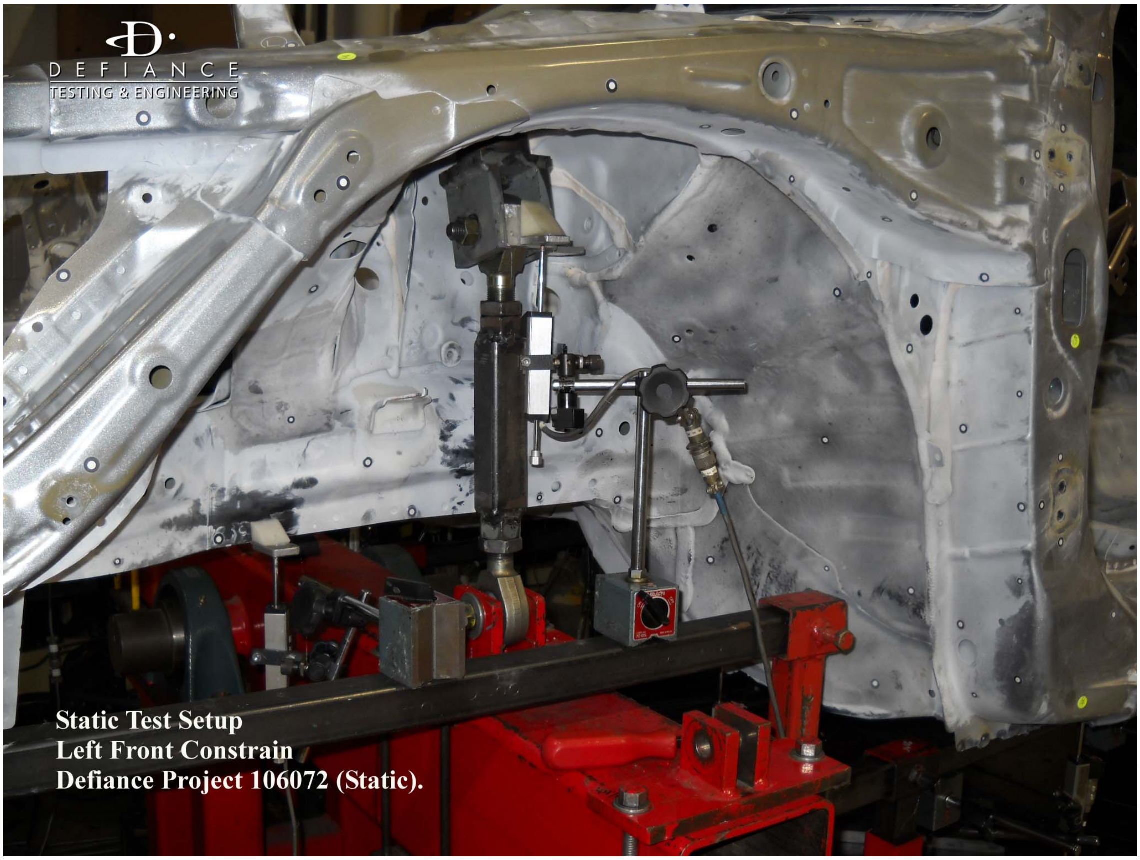

DEFIANCE
TESTING & ENGINEERING
Displacement Sensor Positions 10,11 and 12.
Defiance Project 106072 (Static).


DEFIANCE
TESTING & ENGINEERING
Displacement Sensor Locations 17, 18 and 19.
Defiance Project 106072 (Static).

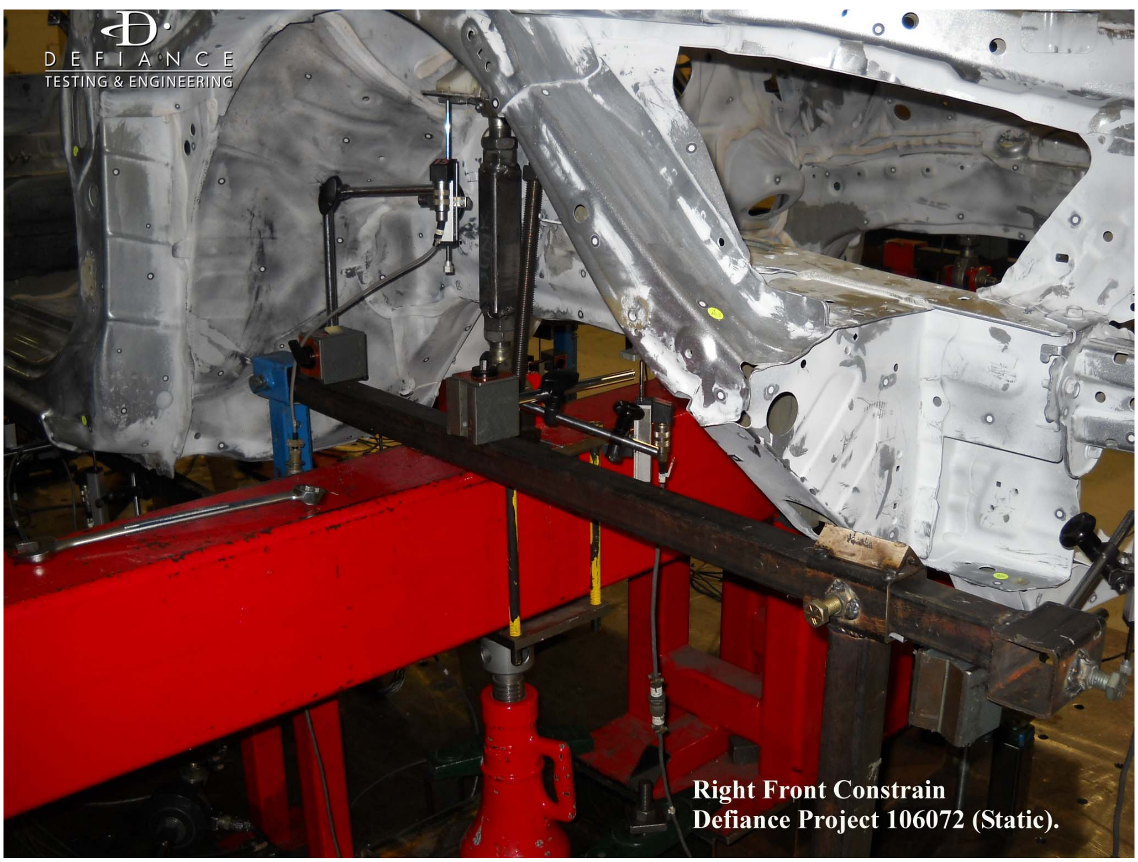


Displacement Sensor Positions 20 and 21.
Defiance Project 106072 (Static).

Displacement Sensor Positions 22,23 and 24.
Defiance Project 106072 (Static).



Static Test Setup
Left Front Constrain
Defiance Project 106072 (Static).



Right Front Constrain
Defiance Project 106072 (Static).

Appendix C

Equipment List

Equipment

Project Number: 105604 **Project Name:** Vehma VVC BIW Bending &Torsion **Building:** 10

Activity Number: 30 **Activity Name: Static Stiffness** **Sample:** 1

Description	Model Number	Serial Number	Asset	Capacity 1	Capacity 2	Ch.	Ch. Description	Type Of Cal Schedule	Next Cal Date	Reservable
AC Controller	406.11(AC)	4671	0031179	AC						No
Control Unit	436.11(FG)	959	0031261							No
E Series Multifunction DAQ Board	PCI-6031E	0xB627AD	0039200	64 In/2 Out	100k/ 16 Bit			Scheduled Calibration	4/6/2011	No
Load Cell	3173-3K	1879	0032096	3,000 Lbs				Scheduled Calibration	3/30/2011	No
LVP	TRS50	000608	0019911	2 In				Scheduled Calibration	10/7/2011	No
	TRS50	000621	0019927	2 In				Scheduled Calibration	10/7/2011	No
	TRS50	000632	0019918	2 In				Scheduled Calibration	10/7/2011	No
	TRS50	000637	0036316	2 In				Scheduled Calibration	10/7/2011	No
	TRS50	003083	0019928	2 In				Scheduled Calibration	10/7/2011	No
	TRS50	003103	0019914	2 In				Scheduled Calibration	10/7/2011	No
	TRS50	003171	0019913	2 In				Scheduled Calibration	10/7/2011	No
	TRS50	003194	0019915	2 In				Scheduled Calibration	10/7/2011	No
	TRS50	003219	0035971	2 In				Scheduled Calibration	10/7/2011	No
	TRS50	046436	0041361	2 in.				Scheduled Calibration	10/7/2011	No
	TRS50	0609	0019932	2 In				Scheduled Calibration	10/7/2011	No
	TRS50	0622	0019934	2 In				Scheduled Calibration	10/7/2011	No
	TRS50	0634	0019935	2 In				Scheduled Calibration	10/7/2011	No
	TRS50	0639	0019936	2 In				Scheduled Calibration	10/7/2011	No
	TRS50	0660	0019930	2 In				Scheduled Calibration	10/7/2011	No
	TRS50	16566G	0019912	2 In				Scheduled Calibration	10/7/2011	No
	TRS50	3093	0019931	2 In				Scheduled Calibration	10/7/2011	No
	TRS50	3173	0019937	2 In				Scheduled Calibration	10/7/2011	No
	TRS50	3174	0019938	2 In				Scheduled Calibration	10/7/2011	No
	TRS50	3192	0019929	2 In				Scheduled Calibration	10/7/2011	No
	TRS50	607	0035608	2 In				Scheduled Calibration	10/7/2011	No
	TRS50	655	0035609	2 In				Scheduled Calibration	10/7/2011	No
	TRS50	86032G	0040585	2 In				Scheduled Calibration	10/7/2011	No
	TRS50	86034G	0039143	2 In				Scheduled Calibration	10/7/2011	No

Description	Model Number	Serial Number	Asset	Capacity 1	Capacity 2	Ch.	Ch. Description	Type Of Cal Schedule	Next Cal Date	Reservable
LVP	TRS50	Red # 18	0036304	2 In				Scheduled Calibration	10/7/2011	No
Panel Meter	DVM24/2000B	0035807	0035807	0-20 Volts				Scheduled Calibration	4/29/2011	No
Power Supply	XTS20-3	22296	0034420	20 Volts	3 Amp					No
Servovalve	760-779A	101	0033161	2.5 GPM						No
Temperature/RH Probe	RHDP	11318	0002693	2 Channel						No

1 Appendix E—Detailed Component Costs

1.1 Closure Components Cost Breakdown

Front Doors (RH & LH) Cost Breakdown	Baseline Manufacturing Costs	LWV Manufacturing Costs	Baseline Assembly Costs	LWV Assembly Costs	Baseline Costs ($ USD)	LWV Costs ($ USD)	Front Doors Incremental Costs ($ USD)
Building	$0.4	$0.5	$4.0	$4.0	$4.4	$4.5	$0.1
Maintenance	$1.7	$2.2	$1.7	$1.6	$3.4	$3.9	$0.5
Energy	$2.5	$1.7	$0.9	$0.8	$3.4	$2.5	-$0.9
Overhead	$4.2	$3.7	$7.2	$7.2	$11.4	$10.9	-$0.5
Labor	$5.2	$4.1	$12.5	$12.5	$17.7	$16.6	-$1.0
Equipment	$8.9	$7.9	$9.0	$8.8	$17.9	$16.7	-$1.2
Tooling	$7.7	$8.1	$3.6	$3.6	$11.3	$11.7	$0.4
Material	$41.2	$93.4	$0.0	$0.0	$41.2	$93.4	$52.2
Total	$71.8	$121.6	$39.0	$38.7	$110.7	$160.4	**$49.6**

Figure 1: Front Doors Incremental Costs

Rear Doors (RH & LH) Cost Breakdown	Baseline Manufacturing Costs	LWV Manufacturing Costs	Baseline Assembly Costs	LWV Assembly Costs	Baseline Costs ($ USD)	LWV Costs ($ USD)	Rear Doors Incremental Costs ($ USD)
Building	$0.4	$0.5	$3.6	$3.6	$4.0	$4.2	$0.1
Maintenance	$1.7	$2.2	$1.5	$1.5	$3.2	$3.7	$0.5
Energy	$2.5	$2.0	$0.9	$0.8	$3.4	$2.8	-$0.6
Overhead	$3.8	$3.9	$6.5	$6.7	$10.3	$10.6	$0.2
Labor	$4.6	$4.1	$11.3	$11.9	$15.9	$16.0	$0.2
Equipment	$8.7	$8.2	$8.1	$7.9	$16.8	$16.2	-$0.6
Tooling	$7.5	$7.3	$3.3	$3.3	$10.9	$10.5	-$0.3
Material	$36.2	$89.8	$0.0	$0.0	$36.2	$89.8	$53.6
Total	$65.3	$118.1	$35.3	$35.6	$100.6	$153.7	**$53.2**

Figure 2: Rear Doors Incremental Costs

Decklid Cost Breakdown	Baseline Manufacturing Costs	LWV Manufacturing Costs	Baseline Assembly Costs	LWV Assembly Costs	Baseline Costs ($ USD)	LWV Costs ($ USD)	Decklid Incremental Costs ($ USD)
Building	$0.1	$0.1	$1.9	$2.3	$2.0	$2.4	$0.4
Maintenance	$0.6	$0.7	$0.7	$0.9	$1.3	$1.6	$0.3
Energy	$0.4	$0.3	$0.2	$0.1	$0.6	$0.4	-$0.2
Overhead	$0.7	$0.4	$3.3	$4.1	$4.0	$4.6	$0.6
Labor	$1.0	$0.5	$5.5	$7.0	$6.5	$7.5	$1.0
Equipment	$1.9	$1.5	$3.6	$4.6	$5.5	$6.1	$0.6
Tooling	$3.5	$3.1	$1.5	$1.8	$5.0	$5.0	-$0.1
Material	$12.0	$26.3	$0.0	$0.0	$12.0	$26.3	$14.3
Total	$20.1	$32.9	$16.6	$20.9	$36.8	$53.8	**$17.0**

Figure 3: Decklid Incremental Costs

Hood Cost Breakdown	Baseline Manufacturing Costs ($ USD)	LWV Manufacturing Costs ($ USD)	Baseline Assembly Costs ($ USD)	LWV Assembly Costs ($ USD)	Baseline Costs ($ USD)	LWV Costs ($ USD)	Hood Incremental Costs ($ USD)
Building	$0.1	$0.1	$3.0	$3.0	$3.1	$3.1	$0.0
Maintenance	$0.6	$0.9	$1.1	$0.9	$1.7	$1.8	$0.0
Energy	$0.4	$0.4	$0.2	$0.3	$0.6	$0.7	$0.0
Overhead	$0.7	$0.7	$5.4	$5.5	$6.1	$6.2	$0.1
Labor	$1.0	$0.9	$9.2	$9.6	$10.2	$10.5	$0.4
Equipment	$1.9	$1.6	$5.9	$3.7	$7.8	$5.2	-$2.6
Tooling	$3.8	$3.9	$2.4	$2.6	$6.2	$6.4	$0.2
Material	$20.1	$43.2	$0.0	$0.0	$20.1	$43.2	$23.1
Total	$28.7	$51.7	$27.3	$25.6	$56.0	$77.2	**$21.3**

Figure 4: Hood Incremental Costs

1.2 Bumpers and Fenders

The bumpers and fenders costs breakdown are shown below

Rear Bumper Costs	Baseline Manufacturing Costs ($ USD)	LWV Manufacturing Costs ($ USD)	Baseline Assembly Costs ($ USD)	LWV Assembly Costs ($ USD)	Baseline Costs ($ USD)	LWV Costs ($ USD)	Rear Bumper Incremental Costs ($ USD)
Building	$0.0	$0.2	$0.8	$0.6	$0.9	$0.8	-$0.1
Maintenance	$0.1	$0.3	$0.4	$0.3	$0.5	$0.6	$0.1
Energy	$0.2	$0.3	$0.5	$0.6	$0.7	$0.9	$0.2
Overhead	$0.6	$1.0	$1.3	$0.9	$1.9	$1.9	$0.0
Labor	$0.4	$0.8	$1.8	$1.3	$2.1	$2.1	$0.0
Equipment	$0.4	$2.1	$2.0	$1.6	$2.4	$3.7	$1.3
Tooling	$0.6	$0.7	$1.0	$0.8	$1.6	$1.5	-$0.1
Material	$8.7	$9.4	$0.2	$0.2	$8.9	$9.6	$0.7
Total	$11.1	$14.9	$8.0	$6.3	$19.1	$21.2	**$2.1**

Figure 5: Rear Bumper Incremental Costs

Front Bumper Cost Breakdown	Baseline Manufacturing Costs ($ USD)	LWV Manufacturing Costs ($ USD)	Baseline Assembly Costs ($ USD)	LWV Assembly Costs ($ USD)	Baseline Costs ($ USD)	LWV Costs ($ USD)	Front Bumper Incremental Costs ($ USD)
Building	$0.0	$0.2	$0.8	$0.8	$0.9	$1.0	$0.1
Maintenance	$0.2	$0.4	$0.4	$0.3	$0.6	$0.7	$0.2
Energy	$0.3	$0.3	$0.3	$0.5	$0.7	$0.8	$0.1
Overhead	$1.0	$1.1	$1.3	$1.4	$2.3	$2.5	$0.2
Labor	$0.8	$1.0	$1.8	$2.2	$2.6	$3.3	$0.7
Equipment	$1.0	$2.1	$1.8	$1.7	$2.8	$3.7	$1.0
Tooling	$1.2	$1.6	$1.0	$0.8	$2.2	$2.5	$0.3
Material	$12.1	$8.8	$0.2	$0.1	$12.3	$8.9	-$3.4
Total	$16.6	$15.6	$7.6	$7.8	$24.2	$23.4	**-$0.9**

Figure 6: Front Bumper Incremental Costs

1.3 Front Suspension Costs Breakdown

1.3.1 Front Frame Costs

Front Frame Cost Breakdown	Baseline Manufacturing Costs ($ USD)	LWV Manufacturing Costs ($ USD)	Baseline Assembly Costs ($ USD)	LWV Assembly Costs ($ USD)	Front Frame Baseline Costs ($ USD)	LWV Front Frame Costs ($ USD)	Front Frame Incremental Costs ($ USD)
Building	$0.2	$0.4	$1.8	$1.8	$2.1	$2.2	$0.2
Maintenance	$1.1	$1.0	$0.7	$0.7	$1.8	$1.7	-$0.1
Energy	$1.4	$2.4	$0.6	$0.6	$1.9	$3.0	$1.0
Overhead	$2.0	$6.6	$3.0	$3.0	$5.0	$9.6	$4.6
Labor	$1.8	$6.6	$4.4	$4.4	$6.2	$11.0	$4.8
Equipment	$5.1	$3.6	$3.1	$3.1	$8.3	$6.7	-$1.5
Tooling	$5.7	$9.1	$1.8	$1.8	$7.5	$10.9	$3.4
Material Price	$48.7	$61.1	$0.3	$0.3	$49.0	$61.5	$12.5
Total	$66.1	$90.8	$15.8	$15.8	**$81.8**	**$106.6**	**$24.7**

Figure 7: Front Frame Incremental Costs

Upper Control Arm Cost Breakdown	Baseline Manufacturing Costs ($ USD)	LWV Manufacturing Costs ($ USD)	LWV Assembly Costs ($ USD)	Upper Control Arm Baseline Costs ($ USD)	LWV Costs ($ USD)	Upper Control Arm Incremental Costs ($ USD)
Building	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Maintenance	$0.1	$0.0	$0.0	$0.1	$0.0	-$0.1
Energy	$0.2	$0.0	$0.0	$0.2	$0.0	-$0.2
Overhead	$0.3	$0.0	$0.0	$0.3	$0.0	-$0.3
Labor	$0.5	$0.0	$0.0	$0.5	$0.0	-$0.5
Equipment	$0.7	$0.0	$0.0	$0.7	$0.0	-$0.7
Tooling	$0.7	$0.0	$0.0	$0.7	$0.0	-$0.7
Material	$4.3	$0.0	$0.0	$4.3	$0.0	-$4.3
Total	$6.8	$0.0	$0.0	**$6.8**	**$0.0**	**-$6.8**

Figure 8: Upper Control Arm Incremental Costs

Lower Control Arm Cost Breakdown	Baseline Manufacturing Costs ($ USD)	LWV Manufacturing Costs ($ USD)	LWV Assembly Costs ($ USD)	Baseline Costs ($ USD)	LWV Costs ($ USD)	Lower Control Arm Incremental Costs ($ USD)
Building	$0.8	$0.1	$1.2	$0.8	$1.3	$0.5
Maintenance	$0.6	$1.3	$0.6	$0.6	$1.9	$1.4
Energy	$3.7	$1.3	$0.3	$3.7	$1.7	-$2.0
Overhead	$10.2	$1.9	$1.7	$10.2	$3.6	-$6.6
Labor	$13.3	$3.7	$1.5	$13.3	$5.1	-$8.1
Equipment	$7.1	$8.3	$2.1	$7.1	$10.4	$3.3
Tooling	$3.7	$4.5	$3.1	$3.7	$7.6	$3.8
Material	$22.2	$11.3	$3.2	$22.2	$14.5	-$7.7
Total	$61.6	$32.5	$13.6	**$61.6**	**$46.1**	**-$15.5**

Figure 9: Lower Control Arm Incremental Costs

Steering Knuckle Cost Breakdown	Baseline Manufacturing Costs ($ USD)	LWV Manufacturing Costs ($ USD)	Steering Knuckle Baseline Costs ($ USD)	LWV Steering Knuckle Costs ($ USD)	Steering Knuckle Incremental Costs ($ USD)
Building	$0.9	$0.5	$0.9	$0.5	-$0.3
Maintenance	$0.7	$0.8	$0.7	$0.8	$0.1
Energy	$3.4	$1.9	$3.4	$1.9	-$1.5
Overhead	$14.5	$11.7	$14.5	$11.7	-$2.9
Labor	$19.0	$15.0	$19.0	$15.0	-$4.0
Equipment	$9.5	$10.9	$9.5	$10.9	$1.4
Tooling	$3.8	$4.2	$3.8	$4.2	$0.4
Material Price	$17.3	$12.7	$17.3	$12.7	-$4.7
Total	$69.2	$57.8	**$69.2**	**$57.8**	**-$11.4**

Figure 10: Steering Knuckle Incremental Costs

Stabilizer Bar Cost Breakdown	Baseline Manufacturing Costs ($ USD)	LWV Manufacturing Costs ($ USD)	Stabilizer Bar Baseline Costs ($ USD)	LWV Stabilizer Bar Costs ($ USD)	Stabilizer Bar Incremental Costs ($ USD)
Building	$0.1	$0.1	$0.1	$0.1	$0.0
Maintenance	$0.0	$0.0	$0.0	$0.0	$0.0
Energy	$0.1	$0.1	$0.1	$0.1	$0.0
Overhead	$0.7	$0.7	$0.7	$0.7	$0.0
Labor	$0.3	$0.3	$0.3	$0.3	$0.0
Equipment	$0.5	$0.5	$0.5	$0.5	$0.0
Tooling	$0.0	$0.0	$0.0	$0.0	$0.0
Material Price	$5.9	$4.9	$5.9	$4.9	-$1.0
Total	$7.7	$6.7	**$7.7**	**$6.7**	**-$1.0**

Figure 11: Stabilizer Bar Incremental Costs

1.4 Wheel Incremental Costs

Wheel Costs Breakdown	Baseline Costs ($ USD)	LWV Costs ($ USD)	Wheels Costs ($ USD)
Building	$0.19	$0.20	$0.0
Maintenance	$0.5	$0.5	$0.0
Energy	$0.8	$0.9	$0.1
Overhead	$1.0	$1.1	$0.1
Labor	$1.8	$1.9	$0.2
Equipment	$1.7	$1.8	$0.2
Tooling	$3.8	$4.2	$0.4
Material Price	$54.7	$61.7	$7.0
Total Costs	$64.5	$72.5	**$8.0**
Total with SG&A, Profit			**$8.8**

Figure 12: Wheel Incremental Costs

1.5 LWV Manufacturing Cost Inputs Extract

Stamping Part Inputs						Blank 1					Stamping				Equipment/Tooling Investment							
Part Name	Part Number	Final Part Weight	Exposed	Visible	Number per vehicle	Blank 1 Material	Blank 1 Input Material Price	Blank1 Input Coil Width	Blank 1 Input Coil Progression	Blank 1 Input Blank Thickness	Cycle Time (hits/hr)	Number of hits	Stamping Reject Rate	Stamping Workers per line	Blank Tonnage	Welding Equipment Investment	Blank Heating Equipment (NA)	Trimming Equipment (included in Stamping)	Triming Tooling Investment	Stamping Equipment Investment	Stamping Tooling Investment	Lubricant
Panel Dash	K15081 50.1 0001	3.2	Yes	No	1	DP 500/800	1.34	590	1687	0.6	400	5	0.10%	3	1000	$0	$0	$0	$0	Transfer1-1400	$1,000,000	PLAIN CARBON LUBE
Reinf - Engine Cradle Mount RH	K15081 50.1 0222	0.9	Yes	No	2	DP 500/800	1.34	406	451	1.5	540	4	0.10%	3	1000	$0	$0	$0	$0	Tandem1-350	$163,264	PLAIN CARBON LUBE
Bulkhead - Rear Engine Cradle Mount LH	K15081 50.1 0224	0.1	No	No	2	DP 700/1000	1.31	241	237	1.0	1200	3	0.10%	1		$0	$0	$0	$0	Progressive1-350	$90,163	PLAIN CARBON LUBE
Panel - Dash Interface	K15081 50.1 0252	6.9	No	No	1	DP 700/1000	1.31	550	1765	1.3	750	4	0.10%	3	1000	$0	$0	$0	$0	Transfer1-1400	$750,000	PLAIN CARBON LUBE
B Closeout - Front Tunnel LH	K15081 50.1 0256	0.2	No	No	2	DP 500/800	1.24	224	234	1.5	1200	3	0.10%	1		$0	$0	$0	$0	Progressive1-150	$92,114	PLAIN CARBON LUBE
Reinf - Hood Hinge LH	K15081 50.1 0267	0.5	Yes	No	2	HSLA 350/450	1.15	415	343	1.2	1200	3	0.10%	3		$0	$0	$0	$0	Progressive1-350	$120,588	PLAIN CARBON LUBE
Bracket - Shotgun Inr LH	K15081 50.1 0269	0.03	Yes	No	2	Cold Rolled Reference -Mild 140/270	0.99	231	153	1.0	1200	3	0.10%	1		$0	$0	$0	$0	Progressive1-150	$88,155	PLAIN CARBON LUBE
Bracket - Shotgun Inr Rear LH	K15081 50.1 0271	0.10	Yes	No	2	Cold Rolled Reference -Mild 140/270	0.99	150	155	0.8	1200	3	0.10%	1		$0	$0	$0	$0	Progressive1-150	$88,191	PLAIN CARBON LUBE
Cowl Inner	K15081 50.1 0275	1.3	No	No	1	BH 280/400	1.00	322	1505	0.7	750	4	0.10%	3	1000	$0	$0	$0	$0	Transfer1-1400	$584,842	PLAIN CARBON LUBE
Front Rail Lwr to Rocker RH	K15081 50.1 1105	1.7	Yes	No	2	DP 500/800	1.34	465	780	1.3	510	4	0.10%	3	1000	$0	$0	$0	$0	Tandem3-600	$557,553	PLAIN CARBON LUBE
C Front Rail to Tunnel RH	K15081 50.1 1109	0.2	Yes	No	2	DP 500/800	1.34	266	350	1.0	1200	3	0.10%	1		$0	$0	$0	$0	Progressive1-350	$91,918	PLAIN CARBON LUBE
Engine Mount Upper RH	K15081 50.1 2022	0.6	Yes	No	2	DP 500/800	1.34	343	336	2.0	460	4	0.10%	3	1000	$0	$0	$0	$0	Tandem3-600	$673,965	PLAIN CARBON LUBE
Closeout - Dash Reinf RH	K15081 50.1 4044	0.1	Yes	No	2	DP 700/1000	1.41	147	235	0.8	1200	5	0.10%	1		$0	$0	$0	$0	Progressive1-150	$91,508	PLAIN CARBON LUBE
Bracket - Rad Support RH	K15081 50.1 4142	0.1	Yes	No	2	DP 700/1000	1.41	177	321	0.8	1200	5	0.10%	1		$0	$0	$0	$0	Progressive1-350	$97,500	PLAIN CARBON LUBE
Shotgun Outer LH	K15081 50.1 4145	2.4	Yes	No	1	DP 500/800	1.34	578	1226	0.8	500	3	0.10%	3	1000	$0	$0	$0	$0	Transfer1-1400	$725,369	PLAIN CARBON LUBE
Support - Upper Radiator LH	K15081 50.1 4148	0.4	Yes	No	2	DP 700/1000	1.41	250	900	0.7	1200	3	0.10%	1		$0	$0	$0	$0	Progressive1-150	$91,480	PLAIN CARBON LUBE
Support - Lower Radiator LH	K15081 50.1 4149	0.4	Yes	No	2	DP 700/1000	1.41	230	704	0.7	1200	3	0.10%	1		$0	$0	$0	$0	Progressive1-350	$94,819	PLAIN CARBON LUBE
Support - Radiator Upper	K15081 50.1 4150	0.8	Yes	No	1	DP 700/1000	1.41	250	961	0.8	600	2	0.10%	3	600	$0	$0	$0	$0	Tandem3-600	$374,172	PLAIN CARBON LUBE
Support - Lower Radiator	K15081 50.1 4151	0.7	Yes	No	1	DP 700/1000	1.41	231	1031	0.8	600	2	0.10%	3	600	$0	$0	$0	$0	Tandem3-600	$463,492	PLAIN CARBON LUBE
Reinf - Cradle Outer RH	K15081 50.1 4947	0.3	Yes	No	2	HSLA 350/450	1.15	335	277	1.5	510	3	0.10%	2	600	$0	$0	$0	$0	Tandem1-350	$319,377	PLAIN CARBON LUBE
Reinf - Cradle Inner RH	K15081 50.1 4948	0.3	Yes	No	2	HSLA 350/450	1.15	342	280	1.5	1100	3	0.10%	1		$0	$0	$0	$0	Progressive1-350	$119,923	PLAIN CARBON LUBE
Reinf - Shock Tower RH	K15081 50.1 8020	0.5	No	No	2	TWIP 500/980	2.13	345	380	1.4	560	3	0.10%	3	600	$0	$0	$0	$0	Tandem1-350	$268,788	PLAIN CARBON LUBE
Shotgun Inner LH	K15081 50.1 4146	1.3	Yes	No	1	DP 500/800	1.34	432	1066	0.8	900	4	0.10%	3	600	$0	$0	$0	$0	Transfer1-1400	$481,583	PLAIN CARBON LUBE
Support - Cradle RH.igs	K15081 50.1 4946	1.3	Yes	No	2	HSLA 350/450	1.15	370	791	1.7	510	3	0.10%	3	1000	$0	$0	$0	$0	Tandem1-350	$132,166	PLAIN CARBON LUBE
Panel - Rear Seat - B-Surface	K15081 50.1 0016	4.1	No	No	1	DP 350/600	1.19	915	1485	0.6	400	5	0.10%	3	1000	$0	$0	$0	$0	Transfer2-2400	$841,064	PLAIN CARBON LUBE
Cover - Gas Tank Access - B-Surface	K15081 50.1 0017	0.2	Yes	Yes	1	Cold Rolled Reference -Mild 140/270	1.04	309	309	0.6	1150	3	0.10%	1		$0	$0	$0	$0	Progressive1-150	$105,405	PLAIN CARBON LUBE
Panel - Waterfall	K15081 50.1 0100	2.2	Yes	No	1	DP 350/600	1.29	451	1653	0.6	400	5	0.10%	3	600	$0	$0	$0	$0	Transfer1-1400	$828,598	PLAIN CARBON LUBE
Rail - Rear Frame Front LH	K15081 50.1 0230	2.4	Yes	No	2	DP 700/1000	1.41	495	653	1.8	510	4	0.10%	3	1000	$0	$0	$0	$0	Tandem3-600	$374,060	PLAIN CARBON LUBE
Bracket - Spare Tire	K15081 50.1 0240	0.2	Yes	No	1	HSLA 350/450	1.15	323	160	2.0	1200	3	0.10%	1		$0	$0	$0	$0	Progressive1-150	$92,187	PLAIN CARBON LUBE
Crossmember - Rear Seat	K15081 50.1 0253	2.5	No	No	2	DP 500/800	1.24	375	1537	1.0	500	3	0.10%	3	1000	$0	$0	$0	$0	Transfer1-1400	$564,622	PLAIN CARBON LUBE
Cover - Rocker LH	K15081 50.1 0290	0.2	Yes	No	2	DP 500/800	1.34	243	343	1.0	1150	3	0.10%	1		$0	$0	$0	$0	Progressive1-350	$107,734	PLAIN CARBON LUBE
Mount - Suspension Cradle Front LH	K15081 50.1 0298	0.4	Yes	No	2	DP 300/500	1.23	313	275	1.5	1150	3	0.10%	1		$0	$0	$0	$0	Progressive1-150	$108,758	PLAIN CARBON LUBE
Crossmember - Rear Floor	K15081 50.1 0299	2.1	No	No	1	DP 700/1000	1.31	489	947	1.2	750	4	0.10%	3	1000	$0	$0	$0	$0	Transfer1-1400	$633,968	PLAIN CARBON LUBE
Panel - Rear Floor Cargo	K15081 50.1 0300	5.6	Yes	No	1	DP 350/600	1.29	1381	1168	0.8	400	4	0.10%	3	1000	$0	$0	$0	$0	Transfer1-1400	$888,477	PLAIN CARBON LUBE
Rear Rail Inr Brkt LH	K15081 50.1 0317	0.2	No	No	2	BH 280/400	1.00	268	322	1.0	1150	3	0.10%	1		$0	$0	$0	$0	Progressive1-350	$113,894	PLAIN CARBON LUBE
Mount - Suspension Cradle Rear LH	K15081 50.1 0826	0.4	Yes	No	2	DP 500/800	1.34	322	295	1.5	1200	3	0.10%	2		$0	$0	$0	$0	Progressive1-350	$99,387	PLAIN CARBON LUBE
Bracket - Seat Cushion Teather Outer LH -	K15081 50.1 0843	0.0	No	No	3	Cold Rolled Reference -Mild 140/270	0.93	141	182	1.0	1200	3	0.10%	1		$0	$0	$0	$0	Progressive1-150	$87,993	PLAIN CARBON LUBE
Bracket - Fuel Tank Support RH	K15081 50.1 0853	0.2	No	No	2	Cold Rolled Reference -Mild 140/270	0.93	200	283	1.0	1200	3	0.10%	1		$0	$0	$0	$0	Progressive1-150	$91,662	PLAIN CARBON LUBE
Rear Rail Upper Reinf LH	K15081 50.1 1302	0.4	Yes	No	2	DP 500/800	1.34	380	267	1.2	1200	3	0.10%	1		$0	$0	$0	$0	Progressive1-350	$93,808	PLAIN CARBON LUBE
Mount - Gas Tank LH	K15081 50.1 2372	0.3	Yes	No	2	BH 210/340	1.04	312	296	1.0	1200	3	0.10%	1		$0	$0	$0	$0	Progressive1-350	$91,671	PLAIN CARBON LUBE
Crossmember - Rear Tunnel	K15081 50.1 0289	0.6	Yes	No	1	DP 700/1000	1.41	316	493	2.0	600	3	0.10%	3	600	$0	$0	$0	$0	Tandem1-350	$434,926	PLAIN CARBON LUBE
Rear Toe Hook - B-Surface.igs	K15081 50.1 0316	0.0	No	No	1	DP 700/1000	1.31	40	40	3.0	560	4	0.10%	2		$0	$0	$0	$0	Tandem1-350	$323,875	PLAIN CARBON LUBE
Teather - Seat Cushion Outer LH - B-	K15081 50.1 0842	0.0	No	No	2	HSLA 350/450	1.05	50	50	2.0	1200	3	0.10%	1		$0	$0	$0	$0	Progressive1-150	$20,000	PLAIN CARBON LUBE
Teather - Seat Cushion	K15081 50.1 0846	0.0	No	No	2	HSLA 350/450	1.05	50	50	2.0	1150	3	0.10%	1		$0	$0	$0	$0	Progressive1-150	$10,000	PLAIN CARBON LUBE
Rocker Closeout LH	K15081 50.6 0284	0.3	Yes	No	2	BH 280/400	1.06	381	430	0.7	510	3	0.10%	2	400	$0	$0	$0	$0	Tandem1-350	$296,351	PLAIN CARBON LUBE
Package Tray Reinf	K15081 50.6 0305	0.5	No	No	1	BH 280/400	1.00	320	678	0.7	600	3	0.10%	2	400	$0	$0	$0	$0	Tandem1-350	$402,790	PLAIN CARBON LUBE
Rear Qtr Lwr LH	K15081 50.6 0310	0.8	Yes	No	2	BH 280/400	1.06	458	608	0.7	560	3	0.10%	3	400	$0	$0	$0	$0	Tandem1-350	$386,895	PLAIN CARBON LUBE
A Gutter Front LH	K15081 50.6 0323	0.1	No	No	2	BH 280/400	1.00	232	352	0.7	1150	3	0.10%	1		$0	$0	$0	$0	Progressive1-150	$125,499	PLAIN CARBON LUBE
Diagonal Brace Rear Outer LH	K15081 50.6 0355	0.5	Yes	No	2	DP 700/1000	1.41	308	682	0.9	530	5	0.10%	3	600	$0	$0	$0	$0	Tandem3-600	$643,076	PLAIN CARBON LUBE
Diagonal Brace Rear Inner LH	K15081 50.6 0359	0.5	Yes	No	2	DP 700/1000	1.41	210	825	0.9	560	3	0.10%	3	600	$0	$0	$0	$0	Tandem3-600	$393,810	PLAIN CARBON LUBE
FBHP LH	K15081 50.6 1040	1.4	Yes	No	2	DP 500/800	1.34	676	450	1.2	600	3	0.10%	3	1000	$0	$0	$0	$0	Tandem3-600	$377,967	PLAIN CARBON LUBE
Panel-Body Side Outer LH	K15081 50.6 1325	12.1	Yes	Yes	2	DP 300/500	1.33	3556	1565	0.7	400	5	0.10%	4	1000	$0	$0	$0	$0	Transfer2-2400	$3,650,000	PLAIN CARBON LUBE
Panel-Body Side Outer H	K15081 50.6 1325	12.1	Yes	Yes		DP 300/500	1.33	3556	1565	0.7	400	5	0.10%	4	1000	$0	$0	$0	$0	Transfer2-2400	$3,650,000	PLAIN CARBON LUBE
Cap - Wheelhouse Inner	K15081 50.6 4010	1.1	Yes	No	1	DP 350/600	1.29	426	330	2.4	600	3	0.10%	2	400	$0	$0	$0	$0	Tandem1-350	$258,986	PLAIN CARBON LUBE
Panel - Wheel House Inner LH	K15081 50.6 4960	3.2	Yes	No	1	BH 280/400	1.06	1430	1389	0.7	400	5	0.10%	3	1000	$0	$0	$0	$0	Transfer1-1400	$863,073	PLAIN CARBON LUBE
Panel - Wheelhouse Outer LH	K15081 50.6 4964	2.0	Yes	Yes	1	BH 280/400	1.16	552	1384	0.7	500	5	0.10%	3	1000	$0	$0	$0	$0	Transfer1-1400	$736,246	PLAIN CARBON LUBE
			No	No			0.00				500	5	0.10%	3	1000	$0	$0	$0	$0	Transfer1-1400	$758,235	PLAIN CARBON LUBE
Roof Rail Inner Rear LH	K15081 50.6 5110	1.2	No	No	1	DP 700/1000	1.31	442	1121	0.8	900	4	0.10%	3	1000	$0	$0	$0	$0	Transfer1-1400	$500,546	PLAIN CARBON LUBE
Roof Rail Inner Rear RH	K15081 50.6 5111	1.2	No	No	1	DP 500/800	1.24	442	1121	0.8	900	4	0.10%	3	1000	$0	$0	$0	$0	Transfer1-1400	$500,546	PLAIN CARBON LUBE
FBHP Reinf LH	K15081 50.6 5144	1.5	No	No	2	DP 500/800	1.24	478	951	0.8	540	4	0.10%	3	1000	$0	$0	$0	$0	Tandem3-600	$600,000	PLAIN CARBON LUBE
Lamp Can LH	K15081 50.6 5158	0.9	No	No	1	DP 300/500	1.13	776	1100	0.7	490	4	0.10%	3	1000	$0	$0	$0	$0	Tandem3-600	$627,162	PLAIN CARBON LUBE
WH inner Lower LH	K15081 50.6 7960	1.0	Yes	No	2	DP 500/800	1.34	700	430	1.0	450	4	0.10%	3	600	$0	$0	$0	$0	Tandem3-600	$662,224	PLAIN CARBON LUBE
Panel - Inner Back	K15081 50.1 0325	1.2	No	No	1	DP 500/800	1.24	402	872	0.7	600	3	0.10%	3	600	$0	$0	$0	$0	Tandem3-600	$372,994	PLAIN CARBON LUBE
Panel - Inner Back LH	K15081 50.1 0326	0.7	No	No	2	DP 300/500	1.13	368	776	0.7	460	4	0.10%	3	600	$0	$0	$0	$0	Tandem2-400	$433,744	PLAIN CARBON LUBE
Panel - Outer Back	K15081 50.1 0350	3.5	Yes	Yes	1	DP 350/600	1.39	556	1792	0.7	500	4	0.10%	3	1000	$0	$0	$0	$0	Transfer2-2400	$820,000	PLAIN CARBON LUBE
Panel - Roof	K15081 50.2 4051	8.8	Yes	Yes	1	DP 300/500	1.33	1334	1772	0.6	400	4	0.10%	3	1000	$0	$0	$0	$0	Transfer2-2400	$1,187,500	PLAIN CARBON LUBE
Header - Front Roof	K15081 50.2 4061	0.7	No	No	1	BH 280/400	1.00	244	1046	0.7	400	4	0.10%	3	600	$0	$0	$0	$0	Transfer1-1400	$633,860	PLAIN CARBON LUBE
Reinf - Front Roof Header	K15081 50.2 4062	0.4	No	No	1	BH 280/400	1.00	200	1017	0.6	900	3	0.10%	3	600	$0	$0	$0	$0	Transfer1-1400	$375,362	PLAIN CARBON LUBE
Bracket - Roof Overhead	K15081 50.2 4064	0.2	No	No	1	BH 280/400	1.00	266	372	0.7	1200	3	0.10%	1		$0	$0	$0	$0	Progressive1-350	$122,394	PLAIN CARBON LUBE
Bracket - Front Roof Header LH	K15081 50.2 4065	0.3	No	No	2	BH 280/400	1.00	328	300	1.2	1000	3	0.10%	1		$0	$0	$0	$0	Progressive1-350	$161,447	PLAIN CARBON LUBE
Header - Rear Roof	K15081 50.2 4071	0.7	No	No	1	BH 280/400	1.00	232	1059	0.9	400	4	0.10%	3	600	$0	$0	$0	$0	Transfer1-1400	$629,319	PLAIN CARBON LUBE
Bracket - Rear Roof Header LH	K15081 50.2 4073	0.2	No	No	2	BH 280/400	1.00	272	276	1.0	1100	3	0.10%	1		$0	$0	$0	$0	Progressive1-150	$122,030	PLAIN CARBON LUBE
Support - Roof RH	K15081 50.2 4075	0.3	No	No	2	BH 280/400	1.00	243	775	0.6	600	3	0.10%	3	600	$0	$0	$0	$0	Tandem3-600	$373,949	PLAIN CARBON LUBE
Bracket - Center Roof Bow RH	K15081 50.2 4082	0.2	No	No	2	DP 300/500	1.13	218	309	1.0	1100	3	0.10%	1		$0	$0	$0	$0	Progressive1-150	$119,318	PLAIN CARBON LUBE
Package Tray	K15081 50.1 0306	3.8	No	No	1	BH 280/400	1.00	934	1174	0.6	500	3	0.10%	3	1000	$0	$0	$0	$0	Transfer1-1400	$800,000	PLAIN CARBON LUBE
Reinf - Rear Package Tray	K15081 50.1 0307	1.1	No	No	1	DP 500/800	1.24	300	1355	0.6	900	3	0.10%	3	1000	$0	$0	$0	$0	Transfer1-1400	$391,911	PLAIN CARBON LUBE
Bracket - Package Tray Crossmember LH	K15081 50.1 0308	0.2	No	No	2	BH 280/400	1.00	250	390	0.7	600	4	0.10%	2	400	$0	$0	$0	$0	Tandem1-350	$185,873	PLAIN CARBON LUBE
Crossmember - Package Tray	K15081 50.1 0309	1.6	No	No	1	DP 350/600	1.19	458	1177	0.7	500	4	0.10%	3	1000	$0	$0	$0	$0	Transfer1-1400	$610,853	PLAIN CARBON LUBE
Tunnel Crossmember	K15081 50.1 0210	0.6	Yes	No	2	DP 700/1000	1.41	463	385	0.8	1100	3	0.10%	1		$0	$0	$0	$0	Progressive1-350	$149,500	PLAIN CARBON LUBE
Shotgun Outer LH	K15081 50.1 4145	2.4	Yes	No	1	DP 500/800	1.34	578	1226	0.8	500	3	0.10%	2	1000	$0	$0	$0	$0	Transfer1-1400	$725,369	PLAIN CARBON LUBE
Shotgun Inner LH	K15081 50.1 4146	1.3	Yes	No	1	DP 500/800	1.34	432	1066	0.8	900	4	0.10%	2	600	$0	$0	$0	$0	Transfer1-1400	$481,583	PLAIN CARBON LUBE
Lamp Can LH	K15081 50.6 5158	0.9	No	No	1	DP 300/500	1.13	776	1100	0.7	490	4	0.10%	3	1000	$0	$0	$0	$0	Tandem3-600	$627,162	PLAIN CARBON LUBE
Panel - Wheel House Inner LH	K15081 50.6 4960	3.2	Yes	No	1	BH 280/400	1.06	1430	1389	0.7	400	4	0.10%	2	1000	$0	$0	$0	$0	Transfer1-1400	$863,073	PLAIN CARBON LUBE
Panel - Wheelhouse Outer LH	K15081 50.6 4964	2.2	Yes	Yes	1	BH 280/400	1.16	552	1384	0.7	500	4	0.10%	2	1000	$0	$0	$0	$0	Transfer1-1400	$736,246	PLAIN CARBON LUBE

Figure 13: Manufacturing Cost Model Inputs Extract

1.6 Assembly Cost Model Inputs

Assembly Name	Sub-Assembly Number	Assembly Number	Parts	Number of discrete parts	Assembly Process	Number of Welds or Length of Weld/Hem (mm)
Dash Panel Sub-Asm	50.1 0001-1	50.1 3000	50.1 0001, 50.1 0252	2	8-RSW (Large)	27
Cowl Upper Sub-Asm	50.1 0259-1	50.1 3000	50.1 0258, 50.1 0259, 50.1 02767, 50.1 0268	4	8-RSW (Large)	130
Dash Reinf Sub-Asm	50.1 0003-1	50.1 3000	50.1 0003, 50.1 4044, 50.1 4045	3	6-RSW	5
Dash Panel Sub-Asm	50.1 0001-2	50.1 3000	50.1 0001-1, 50.1 0259-1, 50.1 0003-1, 50.1 4044, 50.1 4045	5	8-RSW (Large)	63
Front Rail Rh Sub-Asm	50.1 1007-1	50.1 3000	50.1 1103, 50.1 1111, 50.1 1007, 50.1 1005, 50.1 0226, 50.1 2022,50.1 0022	6	8-RSW (Large)	42
Support Cradle Lh Sub-Asm	50.1 4949-1	50.1 3000	50.1 4950, 50.1 4950, 50.1 4949	3	7-RSW (Medium)	23
Front Rail Lh Sub-Asm	50.1 1008-1	50.1 3000	50.1 2024, 50.1 0224, 50.1 0006, 50.1 1008, 50.1 1004, 50.1 1112, 50.1 0220	6	8-RSW (Large)	42
Support Cradle Rh Sub-Asm	50.1 4946-1	50.1 3000	50.1 4946, 50.1 4947, 50.1 4948	3	7-RSW (Medium)	23
Radiator Support Sub- Asm	50.1 4151-1	50.1 3000	50.1 0269, 50.1 0270, 50.1 4141, 50.1 4142, 50.1 4151, 50.1 4154, 50.1 4149	7	7-RSW (Medium)	15
Front Structure Sub-Asm	50.1 3000-1	50.1 3000	50.1 1008-1, 50.1 1007-1, 50.1 0001-2	3	8-RSW (Large)	143
Front Structure Sub-Asm	50.1 3000-2	50.1 3000	50.1 1016, 50.1 1017, 50.1 4946-1, 50.1 4949-1, 50.1 4146, 50.1 4153, 50.1 3000-1	7	8-RSW (Large)	119
Radiator Support Sub-Asm	50.1 4151-2	50.1 3000	50.1 4148, 50.1 4150, 50.1 4155, 50.1 4151	4	8-RSW (Large)	96
Front Structure Sub-Asm	50.1 3000-3	50.1 3000	50.1 4151-2, 50.1 3000-2, 50.1 3000-1	3	8-RSW (Large)	22
Front Structure Asm	50.1 3000	50.1 3000	50.1 109, 50.1 110, 50.1 3000-3	3	8-RSW (Large)	23
Back Panel Inner Lh Asm	50.1 5520	50.1 5500	50.1 0317, 50.1 0326	2	7-RSW (Medium)	6
Back Panel Inner Rh Asm	50.1 5510	50.1 5500	50.1 0318, 50.1 0327	2	7-RSW (Medium)	6
Back Panel Asm	50.1 5500	50.1 5500	50.1 0325, 50.1 0350, 50.1 5510, 50.1 5520	4	8-RSW (Large)	47
Package Tray CrossMember Sub-Asm	50.1 0309-1	50.1 5100	50.1 0308, 50.1 0309, 50.1 0312	3	7-RSW (Medium)	8
Package Tray Asm	50.1 5100	50.1 5100	50.1 0306, 50.1 0307, 50.1 0309-1	3	8-RSW (Large)	86
Wheel House Inner Sub-Asm Lh	50.6 4060-1	50.6 1000	50.6 4010, 50.6 4060	2	7-RSW (Medium)	6
Body Side Inner Sub-Asm Lh	50.6 5150-1	50.6 1000	50.6 5112, 50.2 4065, 50.2 4083, 50.2 4073, 50.6 0305	5	7-RSW (Medium)	20
Body Side Inner Sub-Asm Lh	50.6 5150-1.1	50.6 1000	50.6 3500, 50.6 5150, 50.6 5120, 50.6 7960, 50.6 1040	5	7-RSW (Medium)	20
Body Side Inner Sub-Asm Lh	50.6 5150-1	50.6 1000	50.6 4060-1, 50.6 5150-1.1	2	7-RSW (Medium)	13
Body Side Inner Sub-Asm Lh	50.6 5150-2	50.6 1000	50.6 0066, 50.6 5150-1	2	4-Laser - Robotic (Large)	8474.28
Body Side Inner Sub-Asm Lh	50.6 5150-2	50.6 1000	50.6 5110, 50.6 5144, 50.6 4983, 50.6 5140	5	7-RSW (Medium)	10
Body Side Inner Sub-Asm Lh	50.6 5150-2	50.6 1000	50.6 0284, 50.6 4964	3	7-RSW (Medium)	7
Body Side Outer Sub-Asm	50.6 5150-2	50.6 1000	50.6 1325, 50.6 5150-2	2	4-Laser - Robotic (Large)	7194.38
Body Side Inner Sub-Asm Lh	50.6 5150-2	50.6 1000	50.6 1325, 50.6 5150-2	2	4-Laser - Robotic (Large)	879
B-Pillar Inner	50.6 1000-1	50.6 1000	50.6 5150,50.6 0066	1.5	3-Laser - Robotic	450.8
WheelHouseOuter	50.6 1000-1	50.6 1000	50.6 4960, 50.6 1325	2	4-Laser - Robotic (Large)	1590.05
Body Side Asm Lh	50.6 1000	50.6 1000	50.6 1325, 50.6 5150-2	2	8-RSW (Large)	20
Body Side Outer Sub-Asm	50.6 1325	50.6 1000	50.6 1325, 50.6 1323, 50.65158, 50.6 0310	4	7-RSW (Medium)	23
Floor Front Sub-Asm	50.1.0200-1	50.1.3100	50.1.0199, 50.1.0200, 50.1.0204	3	8-RSW (Large)	98
Floor Front Sub-Asm	50.1.0200-1	50.1.3100	50.1.0199, 50.1.0200, 50.1.0204	3	1-Adhesive	3956
Floor Front Sub-Asm	50.1.0200-2	50.1.3100	50.1.0200-1, 50.1.0210, 50.1.0210	3	8-RSW (Large)	36
Floor Front Sub-Asm	50.1.0000	50.1.3100	50.1.0200-2, 50.1.0202, 50.1.0203, 50.1.0204, 50.1.0205	5	8-RSW (Large)	118
Floor Front Sub-Asm	50.1.0000	50.1.3100	50.1.0200-2, 50.1.0202, 50.1.0203, 50.1.0204, 50.1.0205	5	1-Adhesive	3340
Floor Front Sub-Asm	50.1.0000	50.1.3100	Exhaust Hangers	4	7-RSW (Medium)	6
Seat Pan Rear Sub-Asm	50.1 0016-1	50.1 5000	50.1 0100, 50.1 0016, 50.1 0253, 50.1 0253, 50.1 0852, 50.1 0853	6	8-RSW (Large)	91
Rear Floor Sub-Asm	50.1 0300-2	50.1 5000	50.1 0846, 50.1 0847, 50.1 0847-1, 50.1 0847-1, 50.1 0016-1, 50.1 0300-1	6	8-RSW (Large)	40
Cargo FloorSub-Asm	50.1 0300-1	50.1 5000	50.1 2372, 50.1 2373, 50.1 0240, 50.1 0300	4	7-RSW (Medium)	16
Rear Rail Lh Sub-Asm	50.1 0301-1	50.1 5000	50.1 0301, 50.1 0290, 50.1 0298, 50.1 0230	4	7-RSW (Medium)	20
Rear Rail Rh Sub-Asm	50.1 0301-2	50.1 5000	50.1 0301, 50.1 0290, 50.1 0298, 50.1 0230-R	4	7-RSW (Medium)	20
Rear FloorSub-Asm	50.1 0300-2	50.1 5000	Exhaust hanger x 4	4	7-RSW (Medium)	8
Rear FloorSub-Asm	50.1 0300-2	50.1 5000	50.1 0301-2, 50.1 0301-1	3	7-RSW (Medium)	20
Rear RailReinf Lh Sub-Asm	50.1 0302-1	50.1 5000	50.1 0302, 50.1 0303, 50.1 0843-1	3	7-RSW (Medium)	8
Child Restraint Wire Otr Sub-Asm	50.1 0843-1	50.1 5000	50.1 0842, 50.1 0843	2	6-RSW	4
Child Restraint Wire Otr Sub-Asm	50.1 0845-1	50.1 5000	50.1 0845, 50.1 0844	2	6-RSW	4
Rear RailReinf Rh Sub-Asm	50.1 0302-2	50.1 5000	50.1 0845-1, 50.1 0302-R, 50.1 0303-R	3	7-RSW (Medium)	16
Rear Floor Sub-Asm	50.1 0300-3	50.1 5000	50.1 0300-2, 50.1 0302-1, 50.1 0302-2	3	8-RSW (Large)	128
Rear Floor Asm	50.1 5000	50.1 5000	50.1 0300-3, 50.1 0299, Crossmember x 2	4	8-RSW (Large)	62
Underbody Asm -1	50.1 -1	50.1	50.1 5500, 50.1 5000, 50.1 0000, 50.1 3000	4	F0-RSW (Framer)	187
Upper Structure	50.2	50.1	50.2 4061, 50.2 4062, 50.2 4064	3	7-RSW (Medium)	18
Body Side L	50.1 -2	50.1	50.1 1000, 50.1 1000-L	3	F0-RSW (Framer)	143
Body Side R	50.1 -2	50.1	50.1 1000, 50.1 1000-R	6	F0-RSW (Framer)	143
Roof Supports	50.1 -2	50.1	50.2 4071, 50.2 4075, 50.2 4076, 50.2 4085	2	7-RSW (Medium)	18
Package Tray Asm	50.1 -2	50.1	50.1 5100, 50.1 -2	4	F0-RSW (Framer)	80
Underbody Asm -1	50.1 -2	50.1	50.2, 50.1 -2	4	F0-RSW (Framer)	310
Underbody Asm -1	50.1 4145-1	50.1	50.1 0271, 50.1 4145,	2	7-RSW (Medium)	27.5
Underbody Asm -1	50.1 4152-1	50.1	50.1 0272, 50.1 4152	2	7-RSW (Medium)	27.5
Underbody Asm -1	50.1	50.1	50.1 4145-1	2	3-Laser - Robotic	1799.13
Underbody Asm -1	50.1	50.1	50.1 4152-1	2	3-Laser - Robotic	1799.13
Upper Structure	50.1	50.1	50.2 4051, 50.6 1325	2	F1-Laser (Framer)	2958.1
Upper Structure	50.1	50.1	50.2 4051, 50.6 1325	2	F1-Laser (Framer)	2958.1
Upper Structure	50.1 -2	50.1	50.2 4081, 50.1 -1	2	3-Laser - Robotic	1150.5
Upper Structure	50.1 -2	50.1	50.2 4082, 50.1 -1	2	3-Laser - Robotic	1150.5
Front Strucutre Sub-Asm	50.1 3000-3	50.1 3000		2	3-Laser - Robotic	672.2
Rear Structure Sub-Asm	50.1 0016-1	50.1 5000		2	3-Laser - Robotic	1089.94

Figure 14: Assembly Cost Model Inputs

1 Appendix F—Crash Testing Details

The purpose of this appendix is to explain how the light weight vehicle design functioned in the crash tests, i.e., explain how and when the separate parts of the structure behaved to control impact forces to the light weight vehicle. The scope is to describe how the vehicle performed within a reasonable number of pages for the general reader. Six crash tests will be explained, one after the other. It is assumed that automotive design engineers—seeking detailed, in-depth technical information—will want to download the LS-DYNA model of the light weight vehicle and run the model themselves.

1.1 Frontal NCAP Test

The frontal impact test of the New Car Assessment Program (NCAP), undertaken by the National Highway Traffic Safety Administration (NHTSA), is a full frontal barrier test at a vehicle speed of 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 light weight vehicle model used in the US NCAP analysis has a test weight of 1325 kg, which includes curb weight of vehicle as1150 kg, 80 kg weight of Hybrid III 50th percentile male driver, 50 kg Hybrid III 5th percentile female front passenger weight, and 45 kg cargo weight for the instrumentation.

The frontal NCAP test determines the crashworthiness of a vehicle based on the injury-based data (HIC, Nij, chest compression, & femur forces) obtained from the dummies. The scope of work of this study did not encompass simulation of dummy occupants in the FEM of the crash. Therefore, the light weight vehicle is evaluated based on structural-based safely parameters (crash pulse and occupant compartment intrusion) and compared with the safety rating of the Honda Accord 2011.

The US-NCAP Frontal Crash crush for the light weight vehicle and the Honda Accord 2011 are presented in Figure 19.1-1 and Figure 19.1-2.

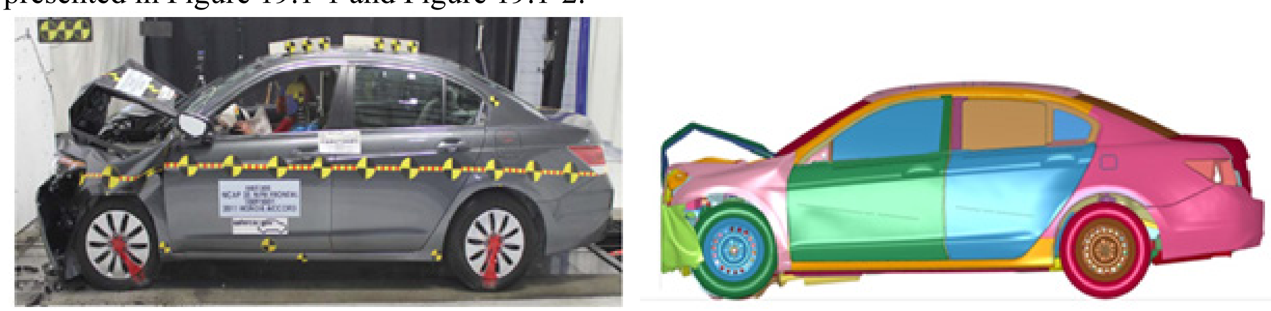


Figure 19.1- 1: Left side view after NCAP frontal crash

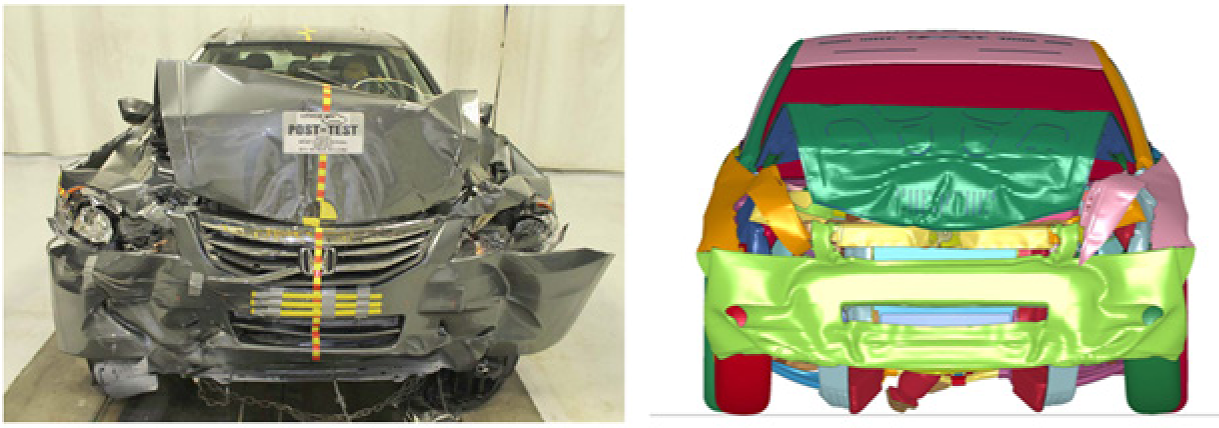


Figure 19.1- 2: Full frontal view after NCAP frontal crash

During the crash, a significant amount of energy is absorbed by the front rails, engine cradle, bumper beam, crush cans and shotgun as shown below in Figure 19.1-3.

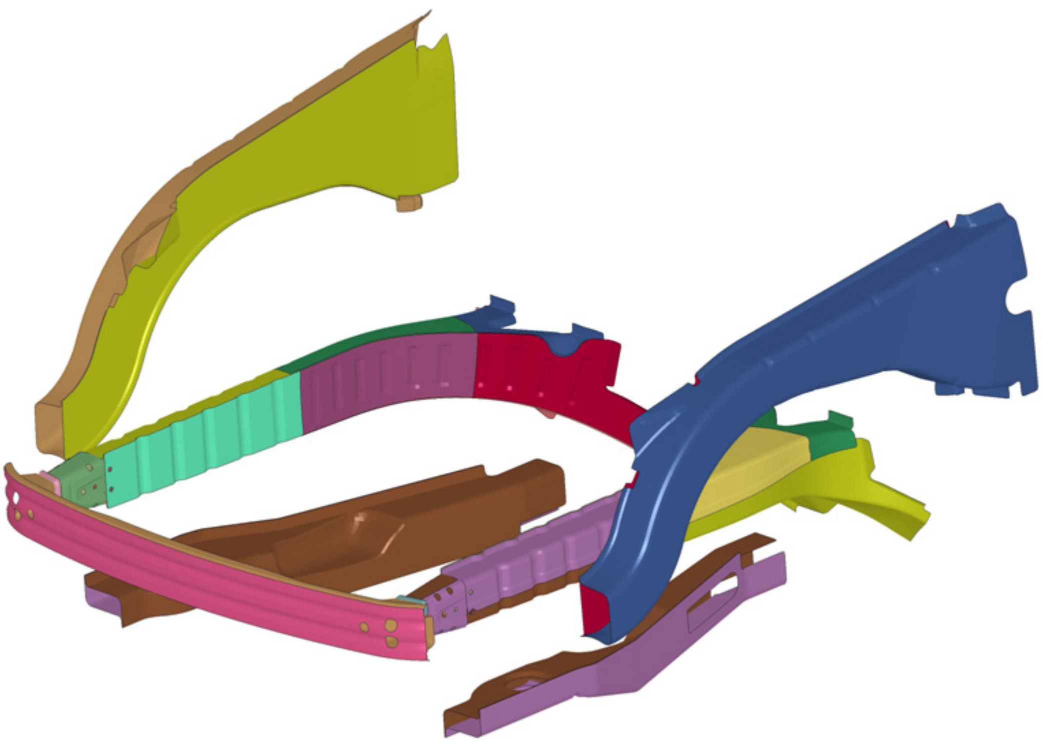


Figure 19.1- 3: Key energy-absorbing structure for NCAP frontal crash

Five parts of the light weight vehicle will be followed through the crash. The five parts are (1) bumper, (2) two longitudinal rails, and (3) two sub-frame rails. Figure 19.1-4shows the outline of the vehicle parts, with the five structural parts in color for clarity. In Figure 19.1-5, the crush of the five key structural parts—over the time of the crash—are presented. Figure 19.1-6 is a graph that follows the energy absorbed by the five structural parts over the period of the NCAP frontal test.

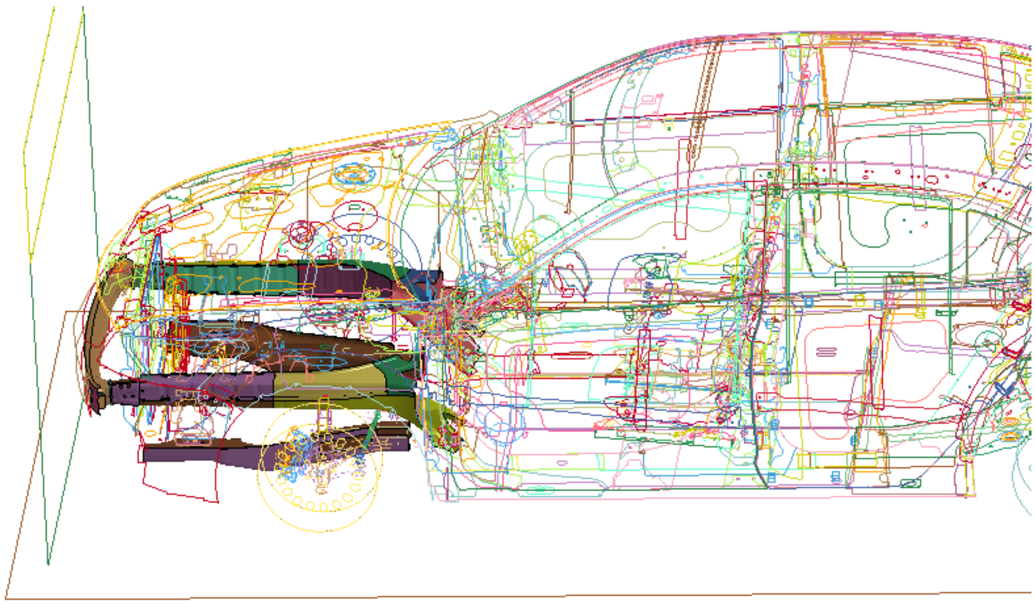


Figure 19.1- 4: Schematic of light weight vehicle showing five key structural parts in color for NCAP frontal test

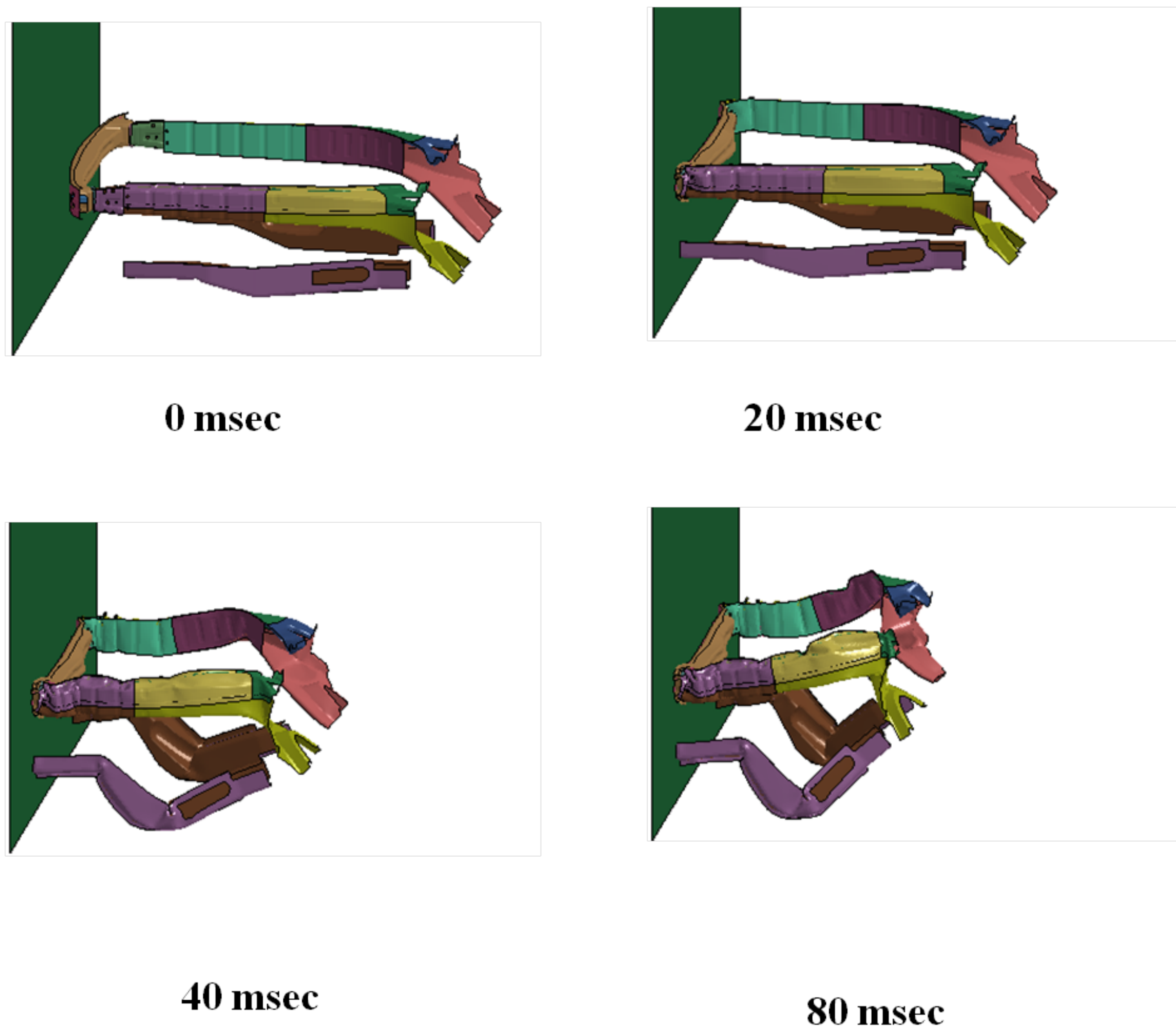


Figure 19.1- 5: Crush of five key structural parts over the time of the NCAP frontal test

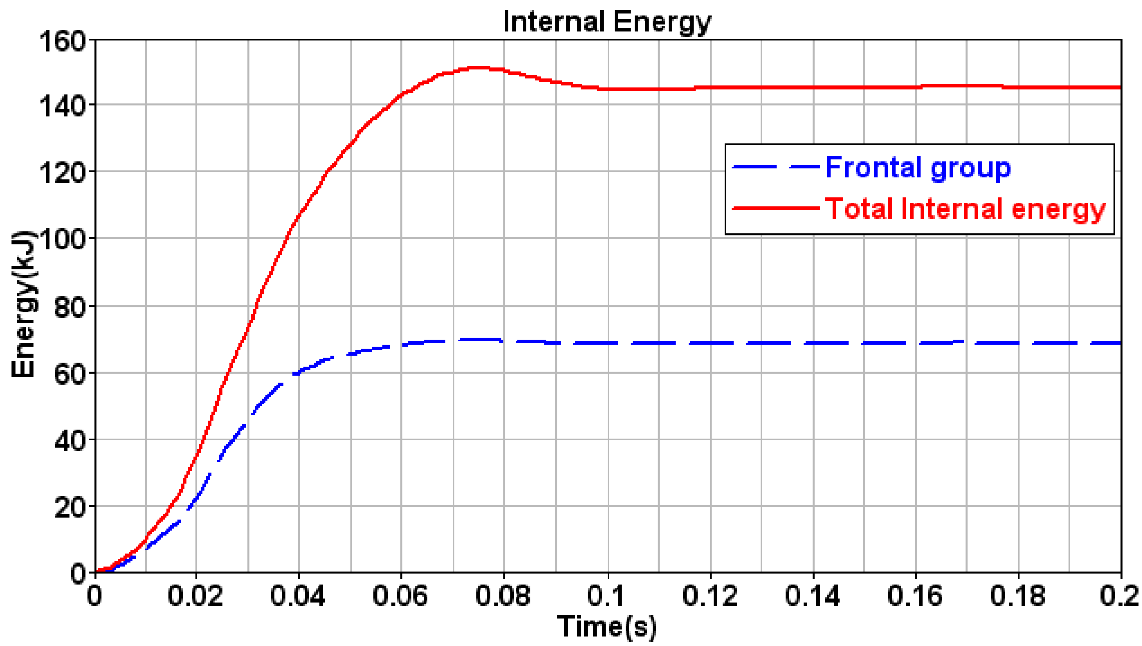


Figure 19.1- 6: Energy absorbed by the five key structural parts during the NCAP frontal test

After the crash, the fuel tank should remain physically intact so as not to allow leakage of gas from the tank. Figure 19.1-7 and Figure 19.1-8below show that there is no damage to the fuel tank, and one could expect that there would be no leakage of gas from the tank.

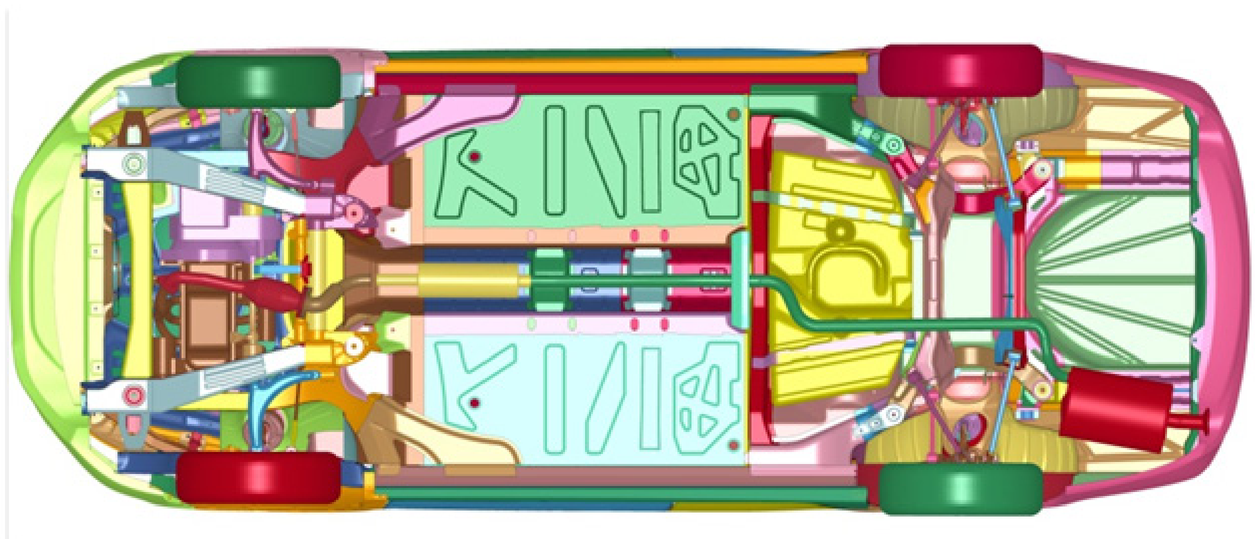


Figure 19.1- 7: Bottom view of light weight vehicle before NCAP frontal crash test

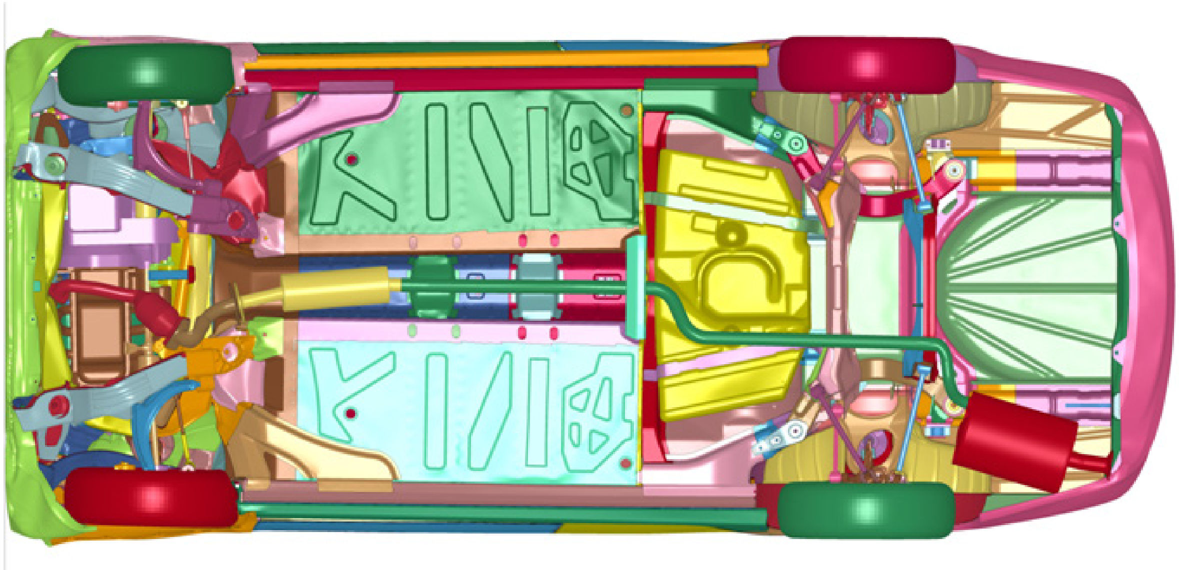
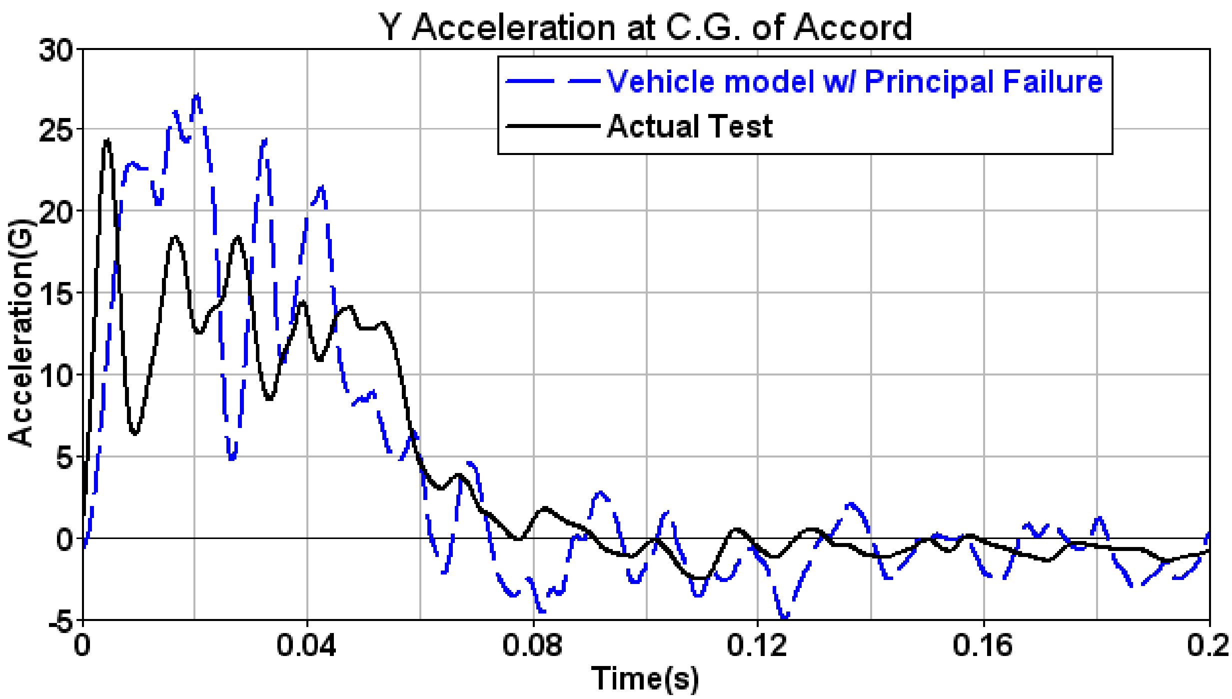


Figure 19.1- 8: Bottom view of light weight vehicle after NCAP frontal crash test

1.2 Lateral NCAP Moving Deformable Barrier Test

In this crash test, a moveable deformable barrier (MDB), with a mass of 1370 kg impacts the light weight vehicle on the driver's side with velocity of 61 km/h, as shown in Figure 19.2-1. The FEM model accounts for a 50th percentile male dummy with weight of 80 kg on the driver seat and a 5th percentile female dummy with weight of 50 kg on the passenger seat just behind the driver seat with 45 kg cargo weight in the rear. A side-by-side, post-test comparison of the light weight vehicle and Honda Accord 2011 is shown in Figure 19.2-2. Figure 19.2-3 shows a graph of the lateral acceleration at the center of gravity for the light weight vehicle and the Honda Accord 2011. Figure 19.2-4 shows a plot of the lateral velocity at the center of gravity for the light weight vehicle and the Honda Accord 2011.



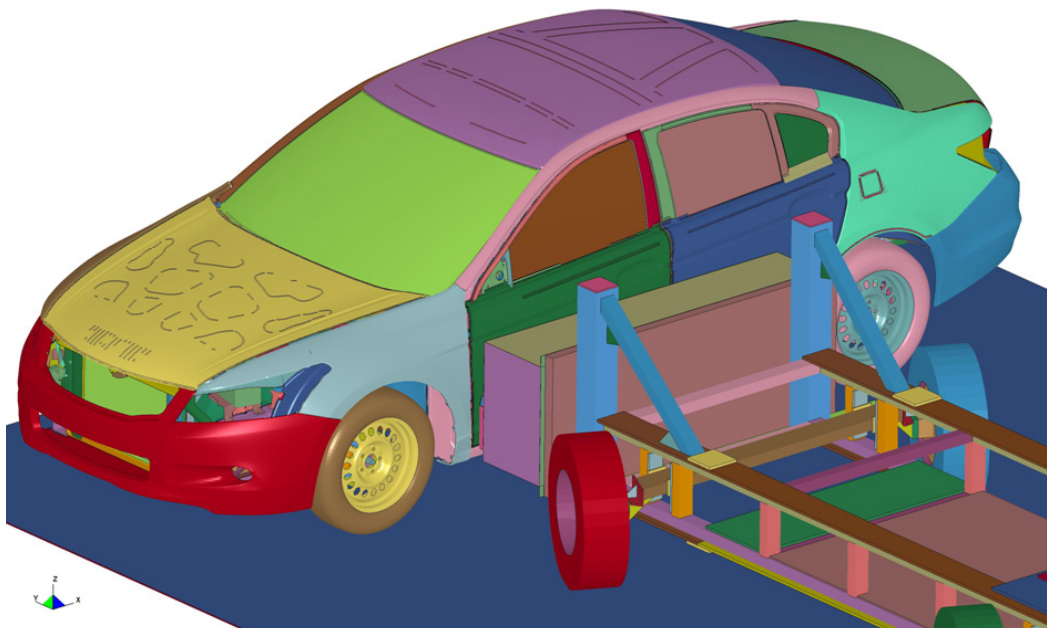


Figure 19.2- 1: Test set up for the NCAP side barrier test

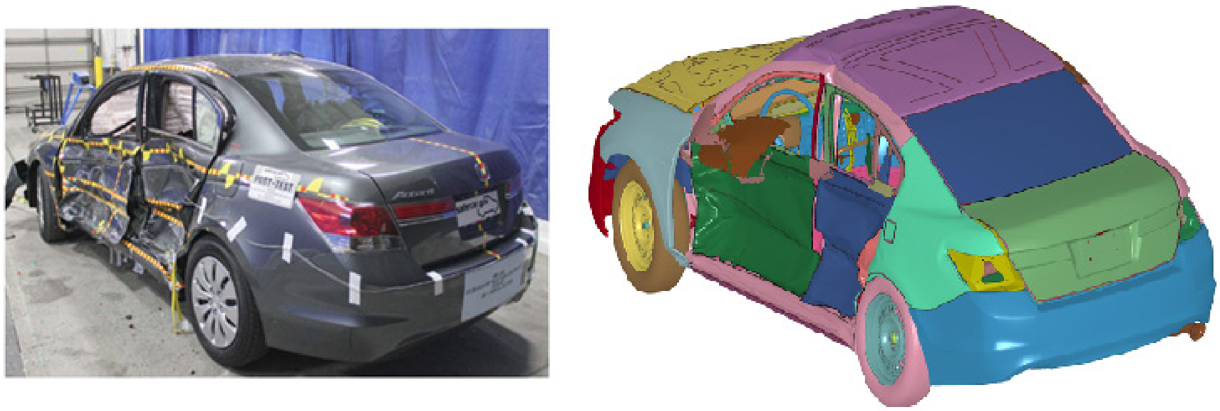


Figure 19.2- 2: Post-crash views of Honda Accord 2011 and light weight vehicle after NCAP side barrier test

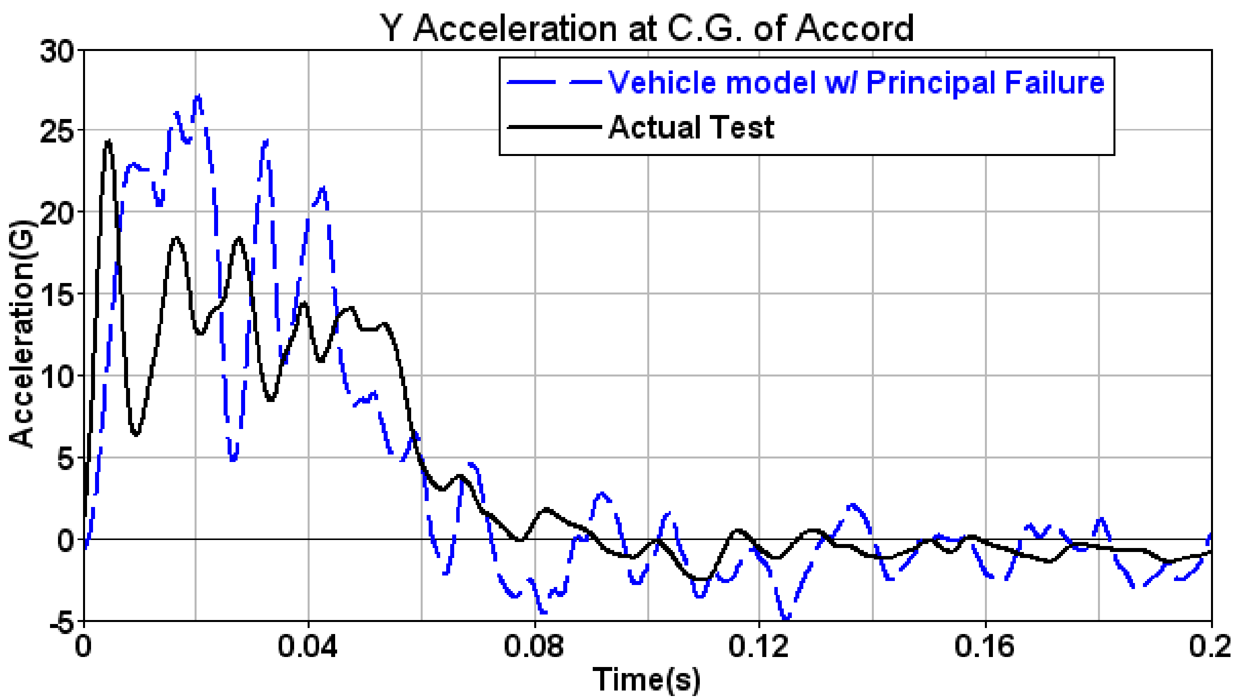


Figure 19.2- 3: Lateral acceleration at the center of gravity of light weight vehicle and Honda Accord 2011 in NCAP side barrier test

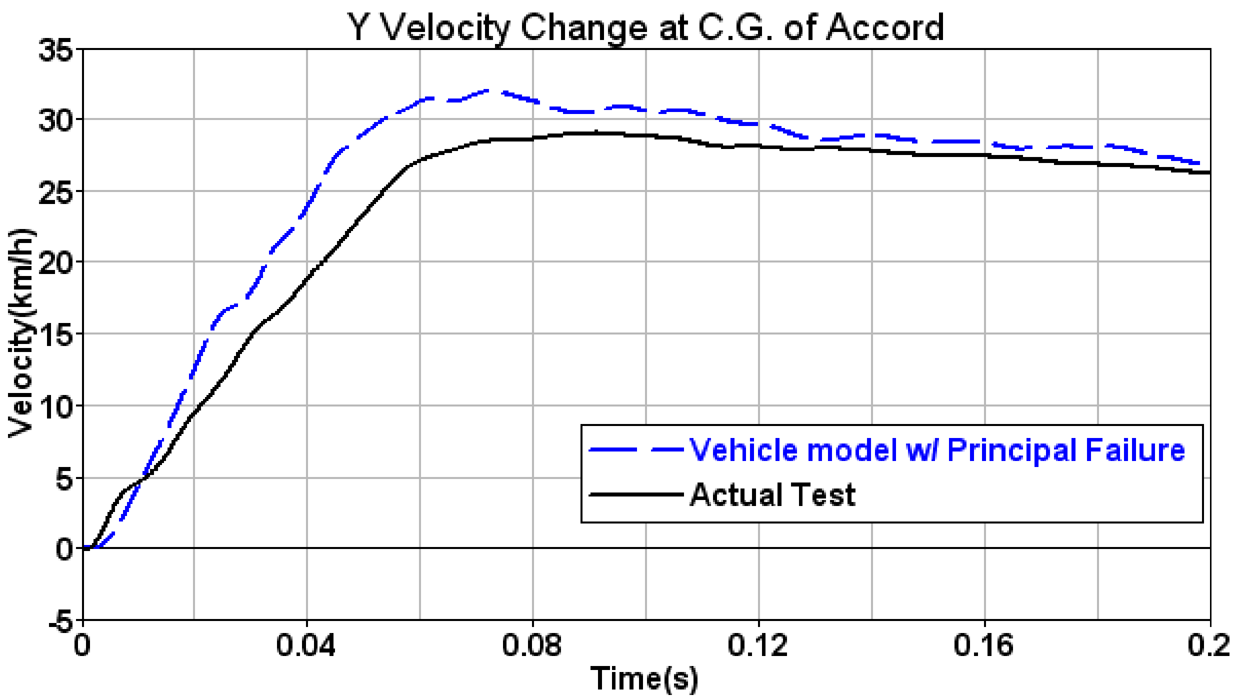


Figure 19.2- 4: Lateral velocity at the center of gravity of light weight vehicle and Honda Accord 2011 in NCAP side barrier test

Five parts of the light weight vehicle will be followed through the crash. This side group includes (1) outer and inner panel of left front and left rear doors, (2) rocker sill, (3) reinforcement beams, (4) B-pillar, and (5) roof sill. Figure 19.2-5 shows the outline of the vehicle parts, with the five structural parts in color for clarity. In Figure 19.2-6, the crush of the five key structural parts—over the time of the crash—are presented. Figure 19.2-7 is a graph that follows the energy absorbed by the five structural parts over the period of the NCAP side barrier test.

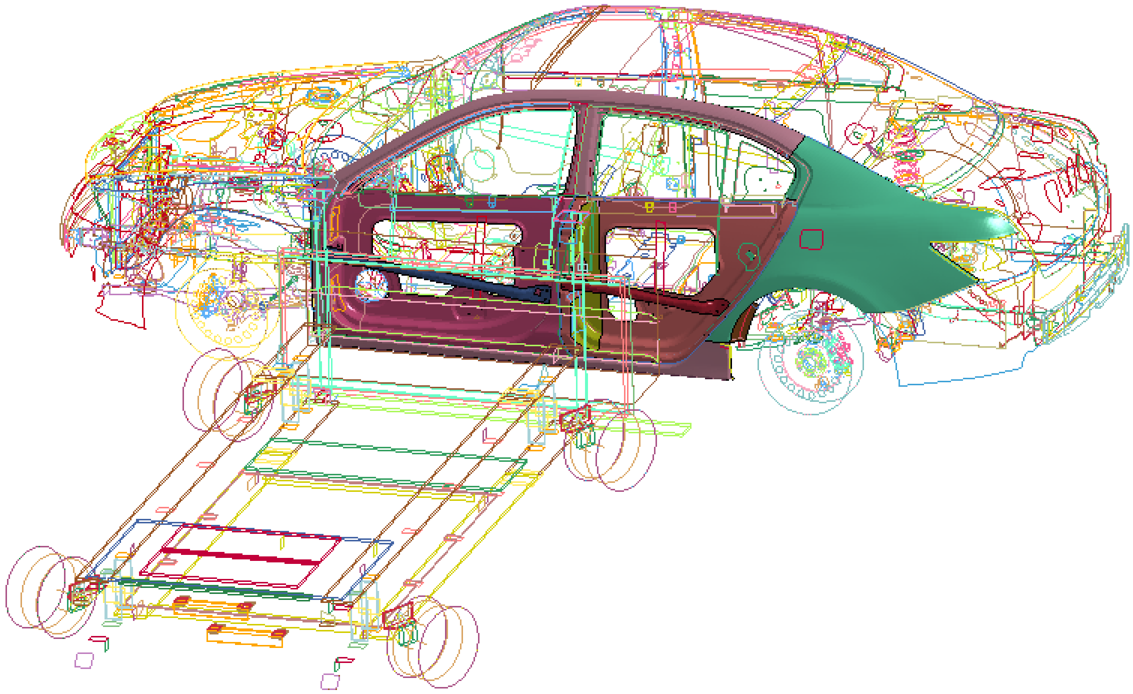


Figure 19.2- 5: Schematic of light weight vehicle showing five key structural parts in color for NCAP side barrier test

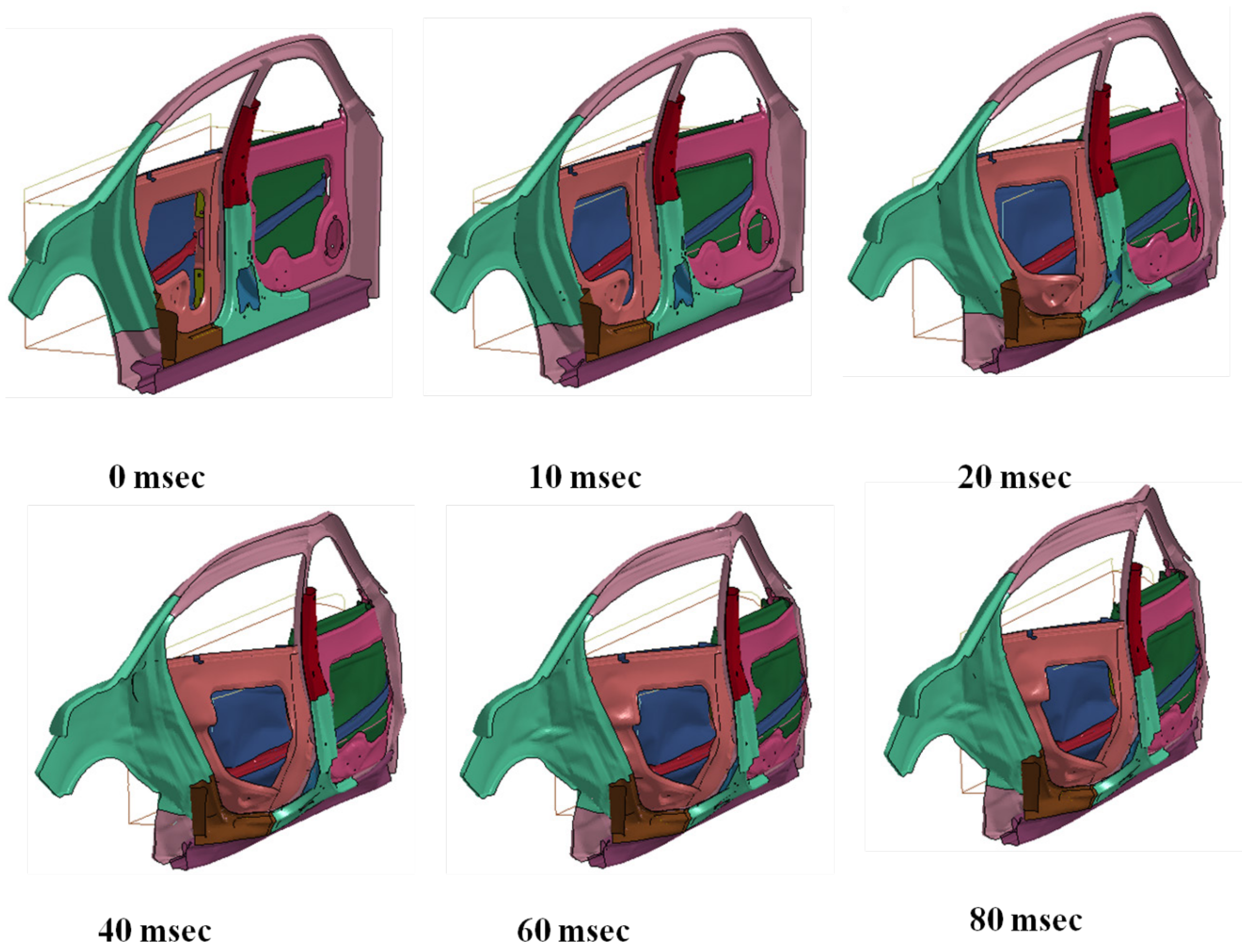


Figure 19.2- 6: Crush of five key structural parts over the time of the NCAP side barrier test

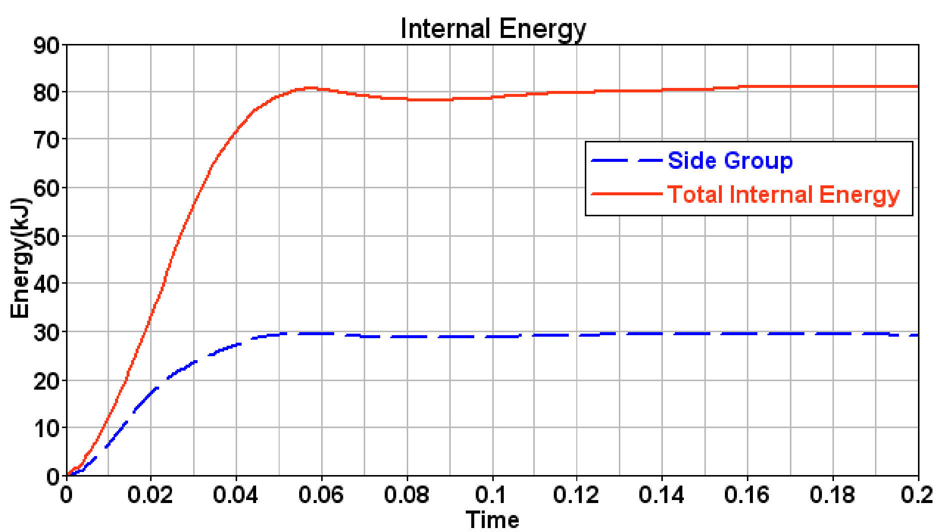


Figure 19.2- 7: Energy absorbed by the five key structural parts during the NCAP side barrier test

Figures 19.2-8 and 19.2-9 below show that there is no damage to the fuel tank, and one could expect that there would be no leakage of gas from the tank after the NCAP side barrier test.

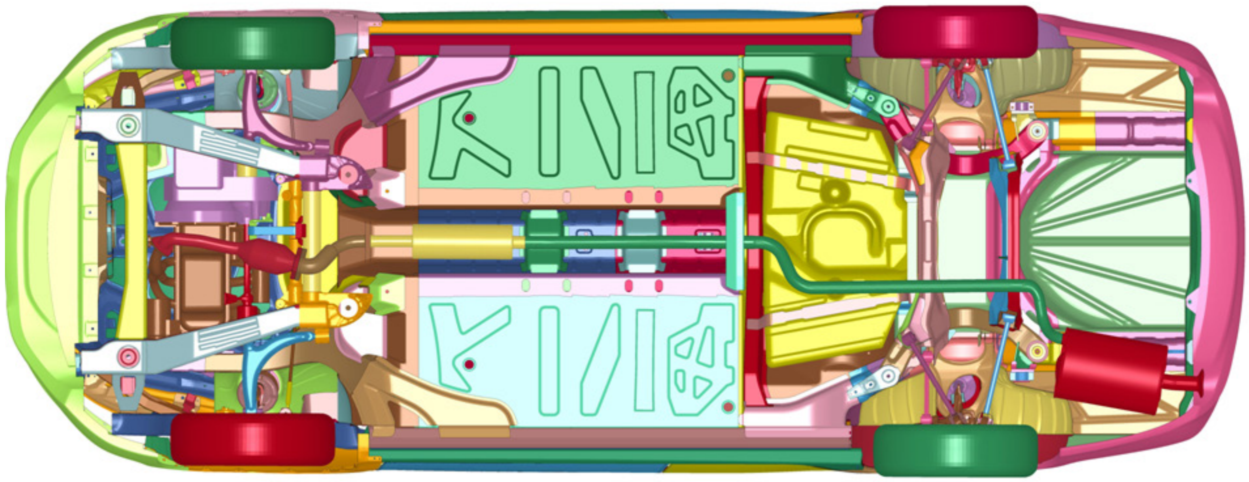


Figure 19.2- 8: Bottom view of light weight vehicle before NCAP side barrier test

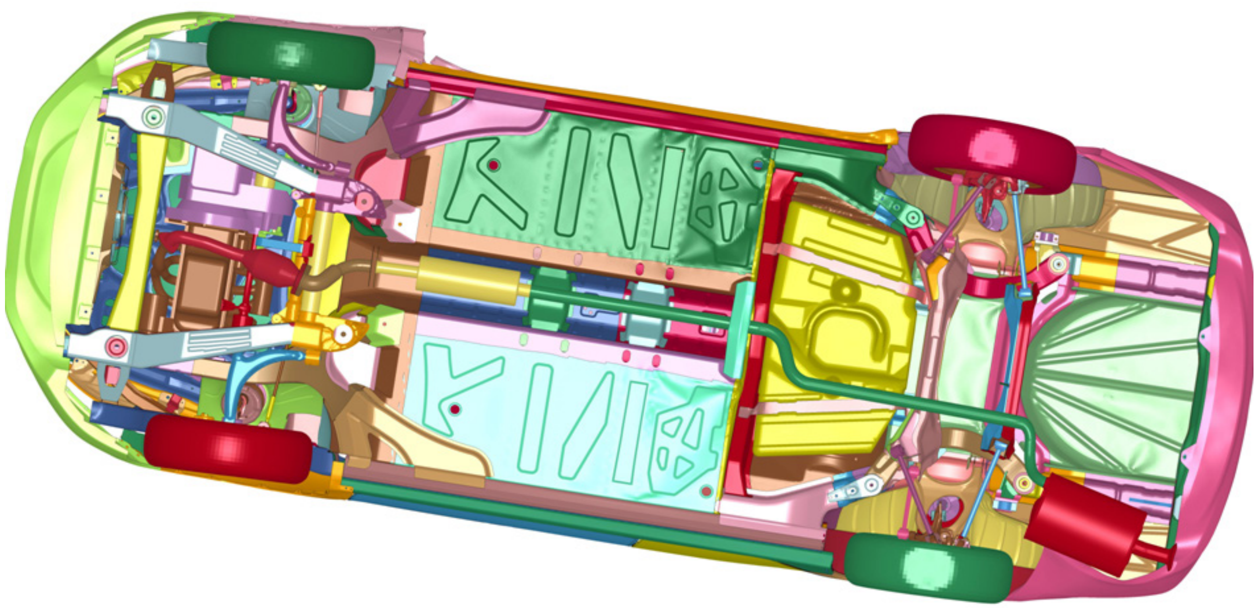


Figure 19.2- 9: Bottom view of light weight vehicle after NCAP frontal crash test

1.3 Lateral NCAP Pole Test

In this test the light weight vehicle impacts the rigid pole laterally at a speed of 31 km/h such that its line of forward motion forms an angle of 75 degrees with the vehicle's longitudinal axis, simulating a real-world crash in which the vehicle hits a tree while sliding on the road.
The rigid pole is a vertically oriented metal structure with (1) a diameter of 254 mm, (2) beginning no more than 102 mm above the lowest point of the tires on the struck side of the fully

loaded test vehicle, and (3) extending at least 150 mm above the highest point of the roof of the test vehicle. This impact set up is shown in Figure 19.3-1. A side-by-side, post-test comparison of the light weight vehicle and Honda Accord 2011 is shown in Figure 19.3-2.

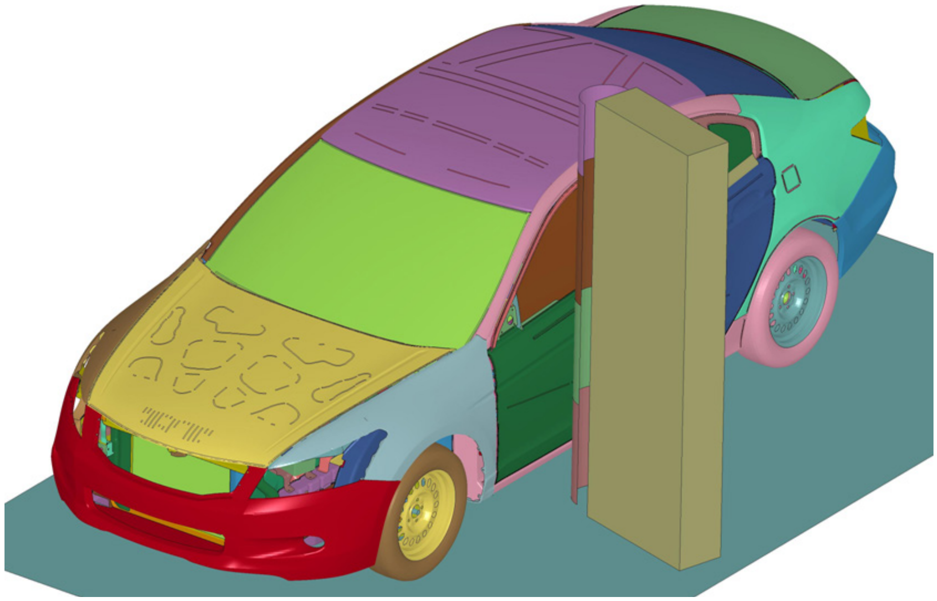


Figure 19.3- 1: Test set up for the NCAP side pole test

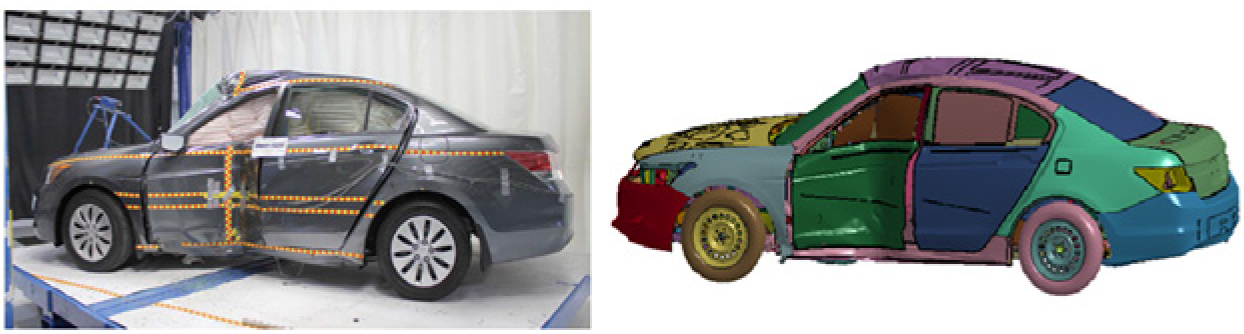


Figure 19.3- 2: Post-crash views of Honda Accord 2011 and light weight vehicle after NCAP side pole test

In a pole impact, parts that absorb much of the crash energy are (1) left-front door, (2) rocker sill, (3) door reinforcement beam, (4) lower B-pillar, (5) roof, and (6) floor structure. Figure 18 shows the outline of the vehicle parts, with the five structural parts in color for clarity. In Figure 19, the crush of the six key structural parts—over the time of the crash—are presented. Figure 20 is a graph that follows the energy absorbed by the five structural parts over the period of the NCAP side pole test.

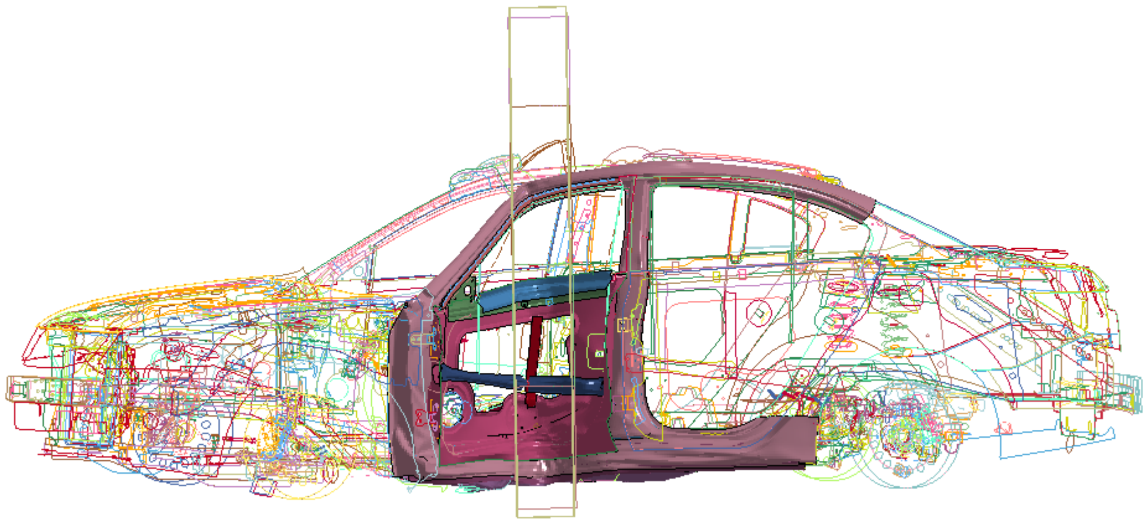


Figure 19.3- 3: Schematic of light weight vehicle showing six key structural parts in color for NCAP side pole test

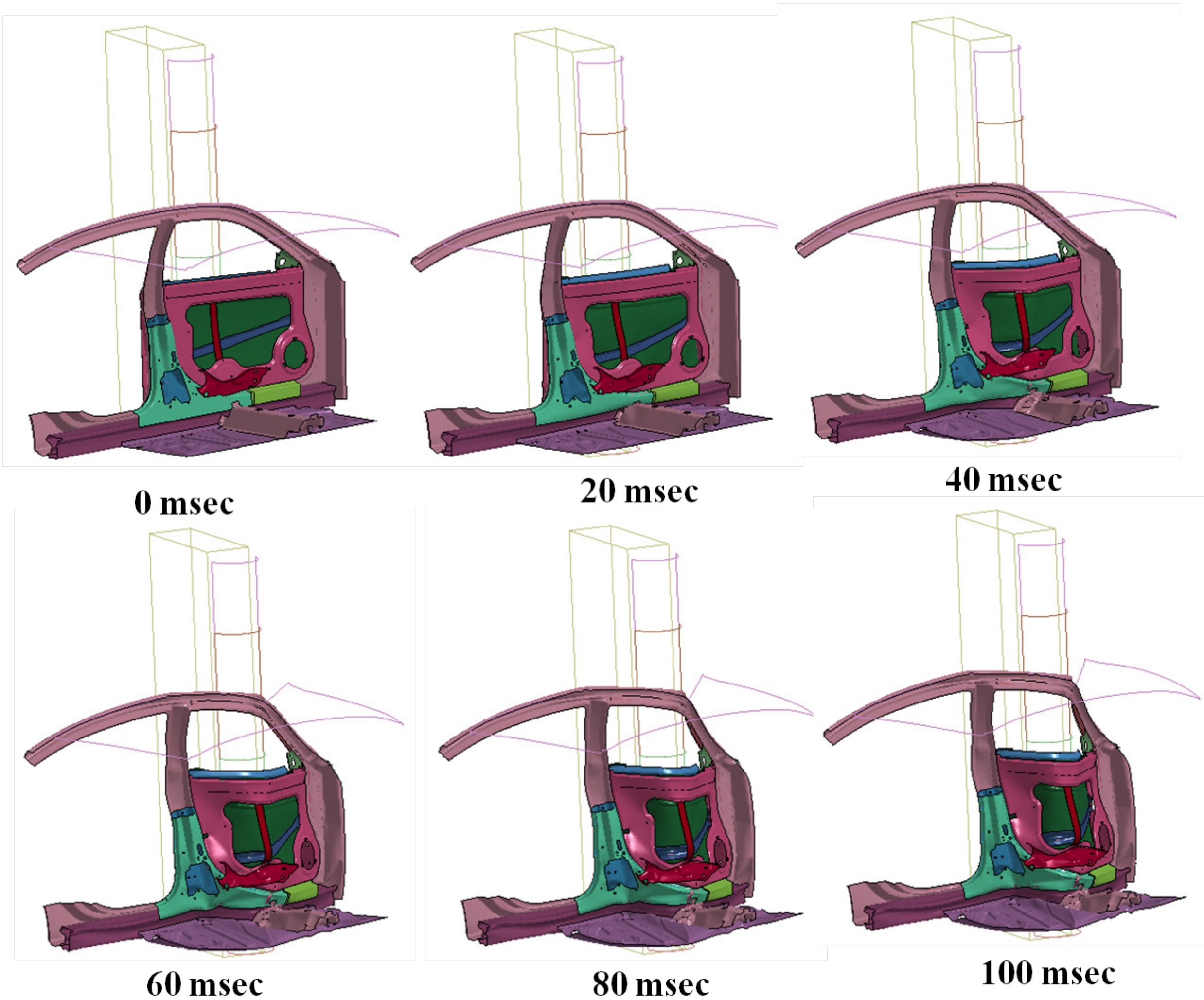


Figure 19.3- 4: Crush of six key structural parts over the time of the NCAP side pole test

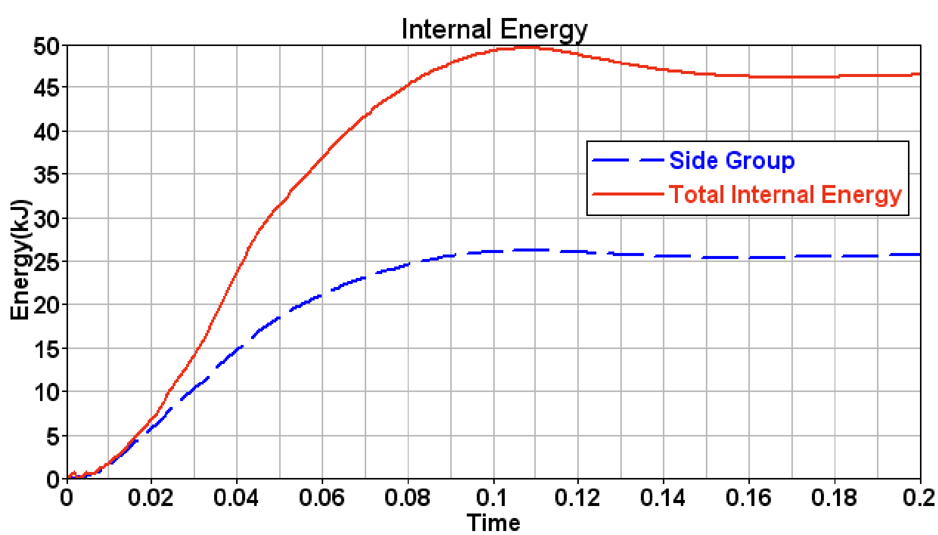


Figure 19.3- 5: Energy absorbed by the six key structural parts during the NCAP side pole test

1.4 IIHS Roof Crush Test

The IIHS roof crush test is used to evaluate the crashworthiness of the vehicle structure in rollover crashes. The roof structure of the vehicle is crushed against a rigid plate (platen), and 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. The light weight vehicle is held rigidly with clamps about the rocker section. The Federal Motor Vehicle Safety Standard No. 216 specifies that roof structure should sustain a load three times the vehicle curb weight. The IIHS roof crush rating stipulates that the roof structure must sustain loading of four times the curb weight for a *good* ratings. The light weight vehicle falls into the *good* rating zone. The IIHS roof crush deformation of the light weight vehicle and the Honda Accord is shown in Figure 19.4-1.

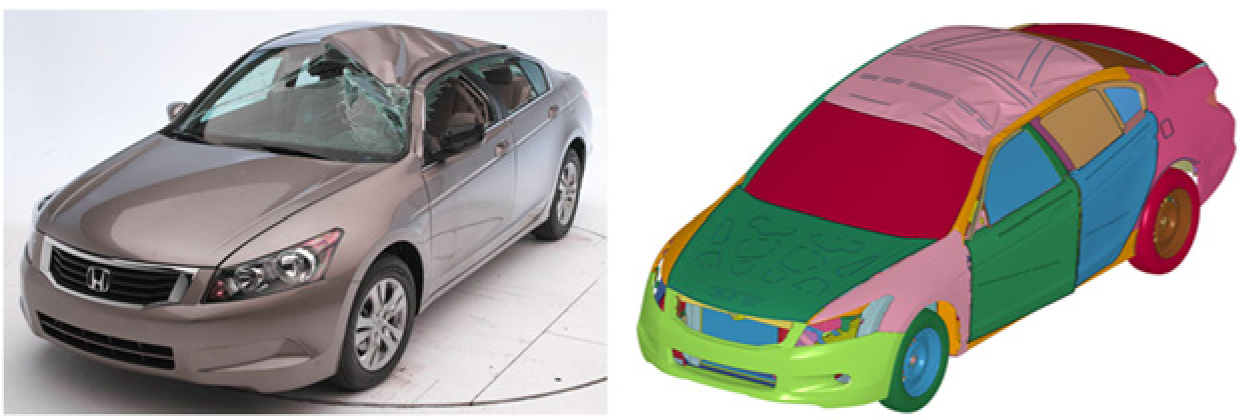


Figure 19.4- 1: Post-crash views of Honda Accord 2011 and light weight vehicle after IIHS roof crush test

In the IIHS roof crush test, parts that absorb much of the crash energy are (1) upper B-pillar, (2) roof, (3) roof sill, and (4) four constraint parts. Figure 19.4-2 shows the outline of the vehicle parts, with the four structural parts in color for clarity. In Figure 19.4-3, the crush of the four key structural parts—over the time of the crash—are presented. Figure 19.4-4 is a graph that follows the energy absorbed by the four structural parts over the period of the IIHS roof crush test.

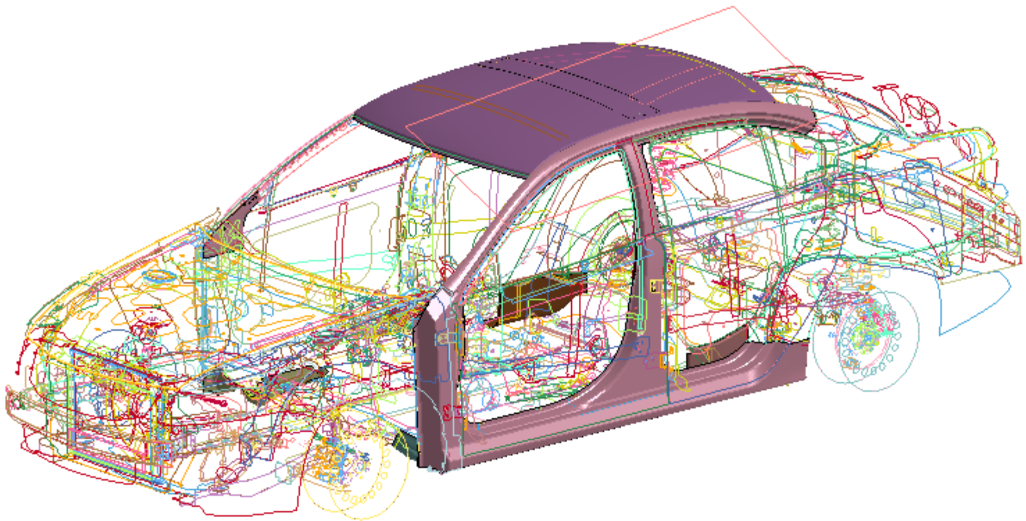


Figure 19.4- 2: Schematic of light weight vehicle showing four key structural parts in color for IIHS roof crush test

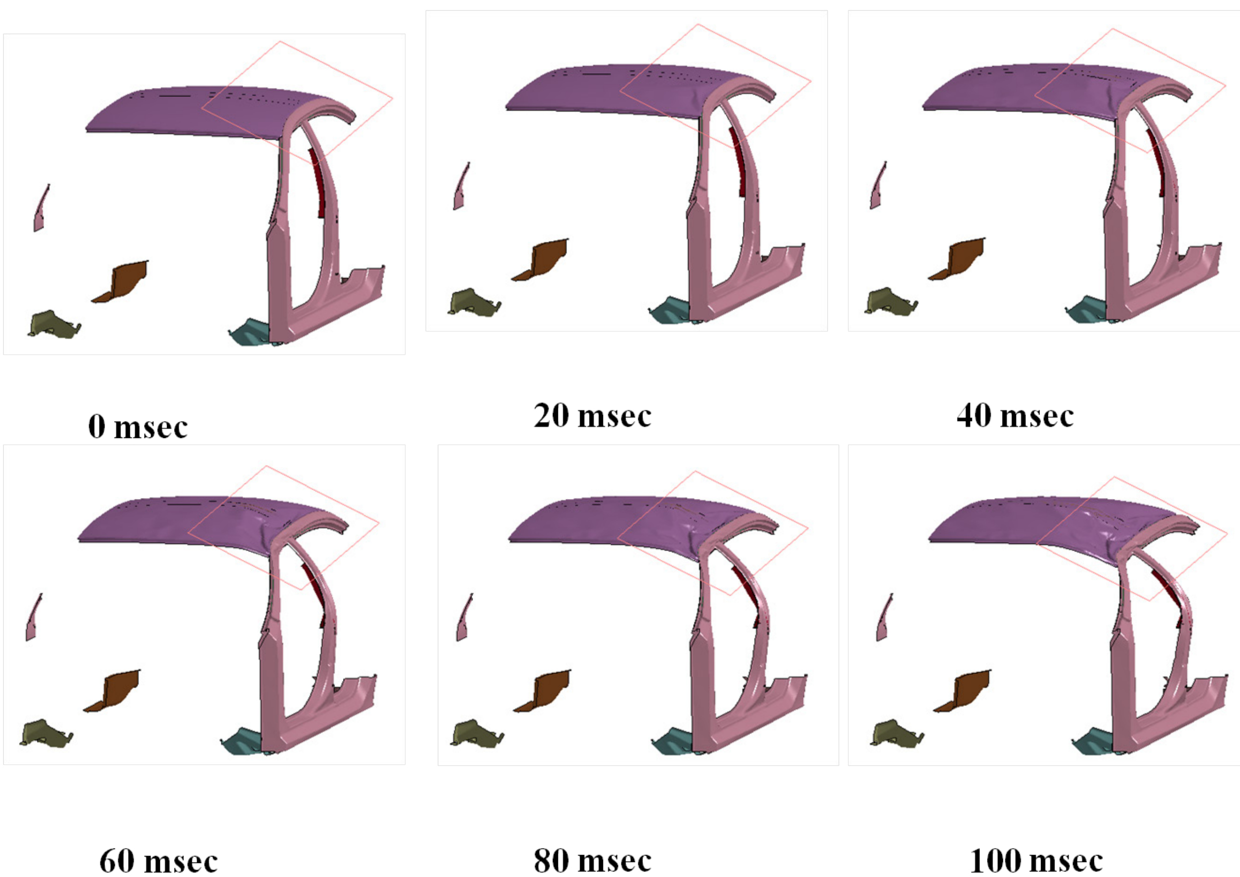


Figure 19.4- 3: Crush of four key structural parts over the time of the IIHS roof crush test

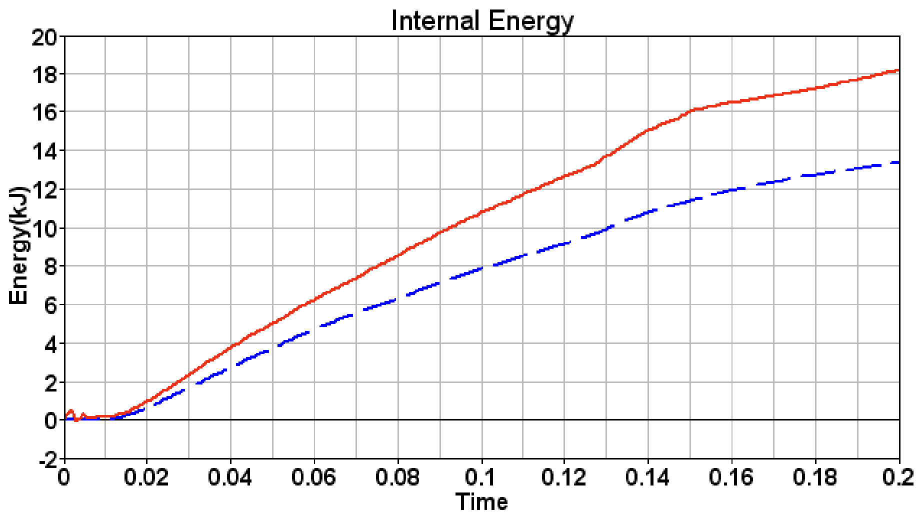


Figure 19.4- 4: Energy absorbed by the four key structural parts during the IIHS roof crush test

1.5 IIHS Lateral Moving Deformable Barrier Test

In the IIHS side barrier test, the front end of the moveable deformable barrier (MDB) represents the front end of an SUV, with a test weight of 1500 kg. The MDB impacts the light weight vehicle on the driver's side with a velocity of 50 km/h as shown in Figure 19.5-1. The light weight vehicle carries the weight of two 5th percentile test dummies (45 kg each), one in the driver's seat and the other in the rear passenger seat directly behind the driver dummy. The vehicle also carries 32 kg of weight in the cargo area and 59 kg (instrumentation and camera) of weight on the non-struck front and rear side doors. The post-crash light weight vehicle and Honda Accord 2011 are shown in Figure 19.5-2.

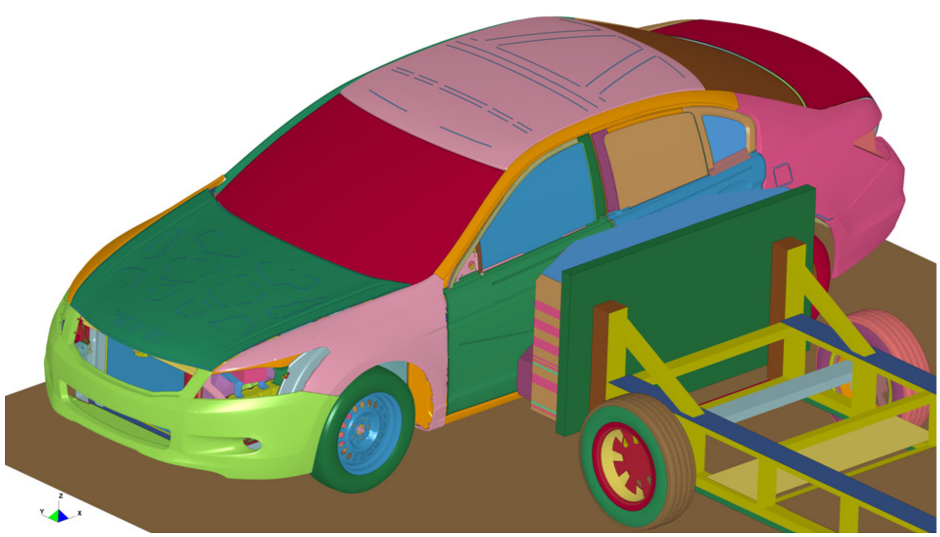


Figure 19.5- 1: Test set up for the IIHS side barrier test

Figure 19.5- 2: Post-crash views of Honda Accord 2011 and light weight vehicle after IIHS side barrier test

In the IIHS side barrier test, parts that absorb much of the crash energy are (1) outer and inner panel of left front and left rear doors, (2) rocker sill, (3) door reinforcement beams, (4) B-pillar, and (5) roof sill. Figure 19.5-3 shows the outline of the vehicle parts, with the five structural parts in color for clarity. In Figure 19.5-4, the crush of the five key structural parts—over the time of the crash—are presented. Figure 19.5-5 is a graph that follows the energy absorbed by the five structural parts over the period of the IIHS side barrier test.

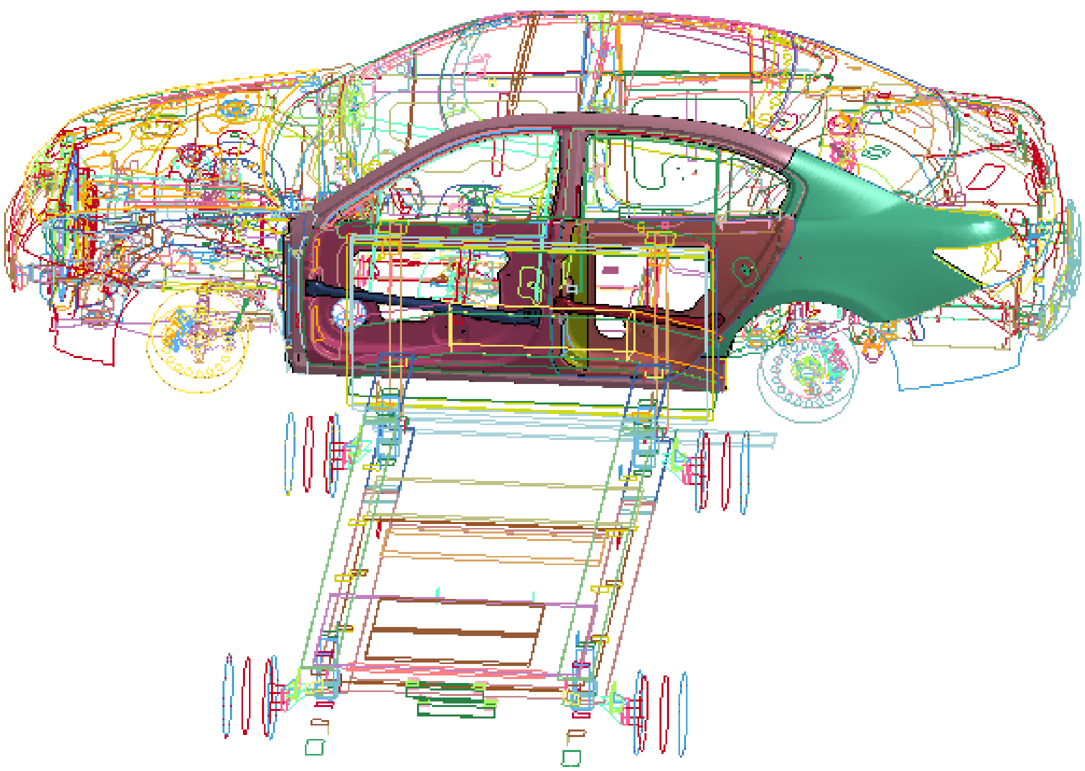


Figure 19.5- 3: Schematic of light weight vehicle showing five key structural parts in color for IIHS side barrier test

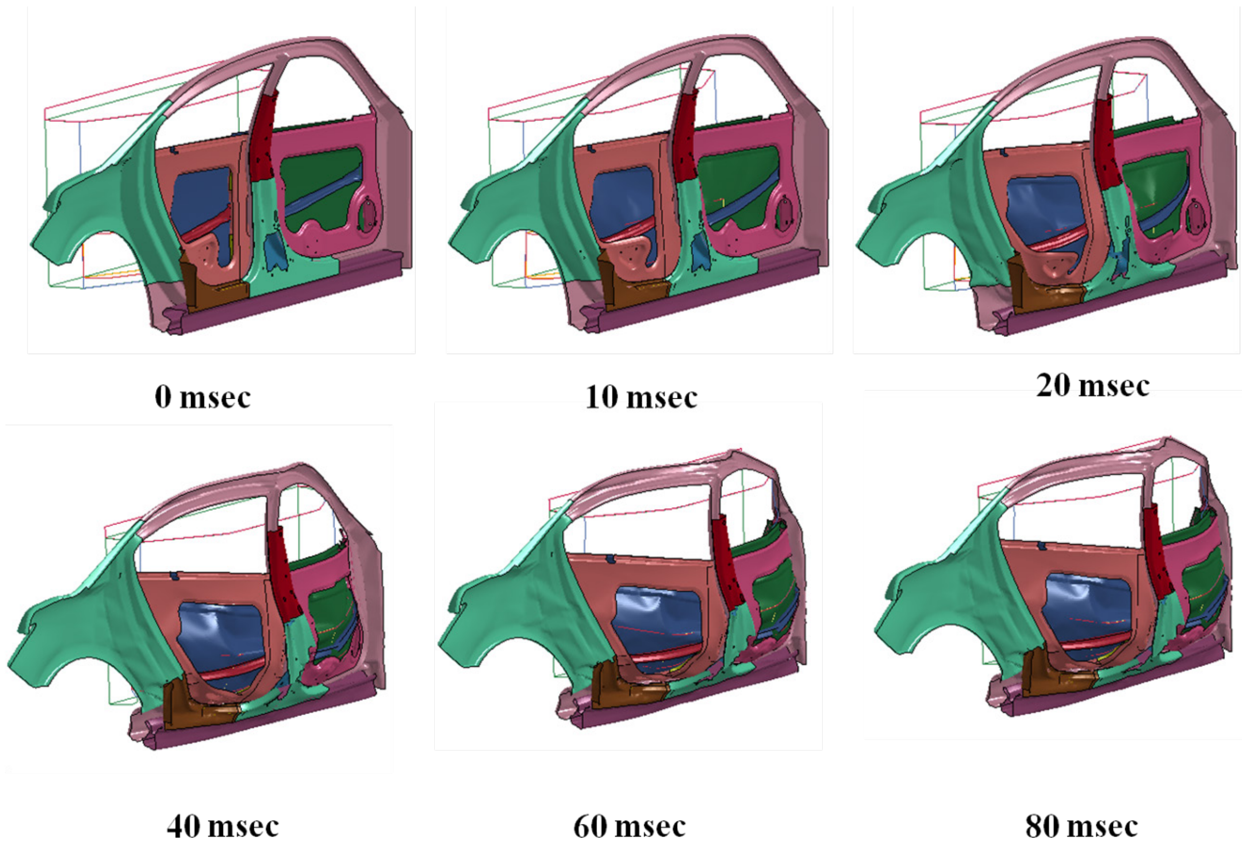


Figure 19.5- 4: Crush of five key structural parts over the time of the IIHS side barrier test

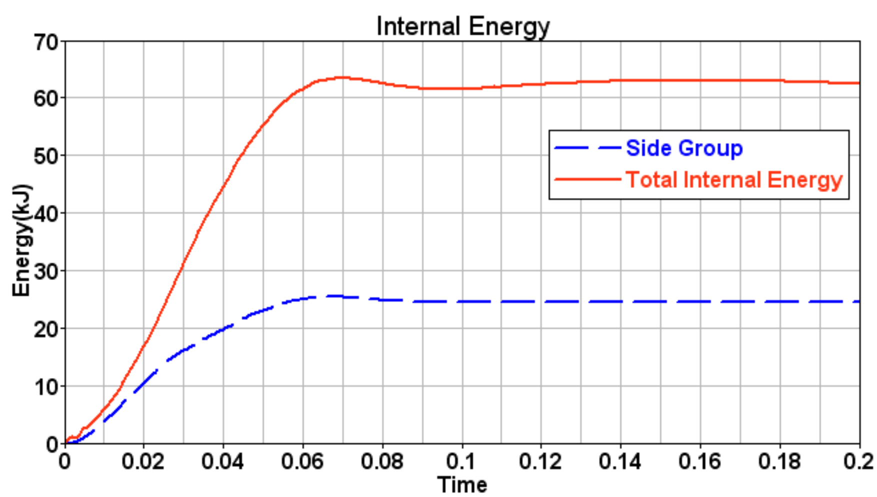


Figure 19.5- 5: Energy absorbed by the five key structural parts during the IIHS side barrier test

Figure 19.5-6 and Figure 19.5-7 below show that there is no damage to the fuel tank, and one could expect that there would be no leakage of gas from the tank after the IIHS side barrier test.

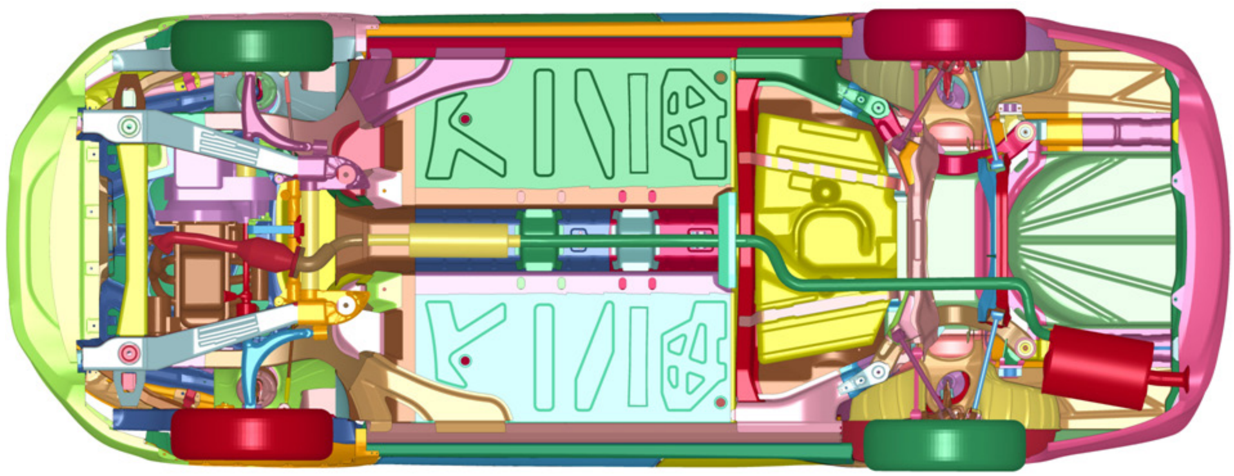


Figure 19.5- 6: Bottom view of light weight vehicle before IIHS side barrier test

Figure 19.5- 7: Bottom view of light weight vehicle after IIHS side barrier test

1.6 IIHS Frontal Offset Test

For this test, the light weight vehicle hits the deformable aluminum honeycomb barrier at a velocity of 64 km/h (40 mp)h. Forty percent of the total width of the vehicle strikes the barrier on the driver's side. A Hybrid III dummy representing an average-size (50th percentile) man is positioned in the driver seat. At the time of this report, IIHS had not performed the frontal offset barrier test on the Honda Accord 2011. For comparison purposes, the Honda Accord Crosstour safety rating results are used. The Honda Accord Crosstour has a frontal body structure similar to the Honda Accord 2011 vehicle. For the IIHS offset frontal test, the post-crash vehicles, both the light weight vehicle and Honda Accord Crosstour are shown in Figure 19.6-1 and 19.6-2.

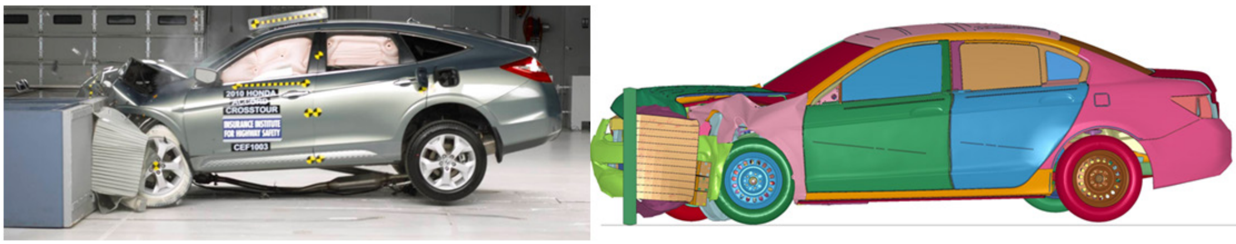


Figure 19.6- 1: Post-crash, left-side view after IIHS frontal offset test

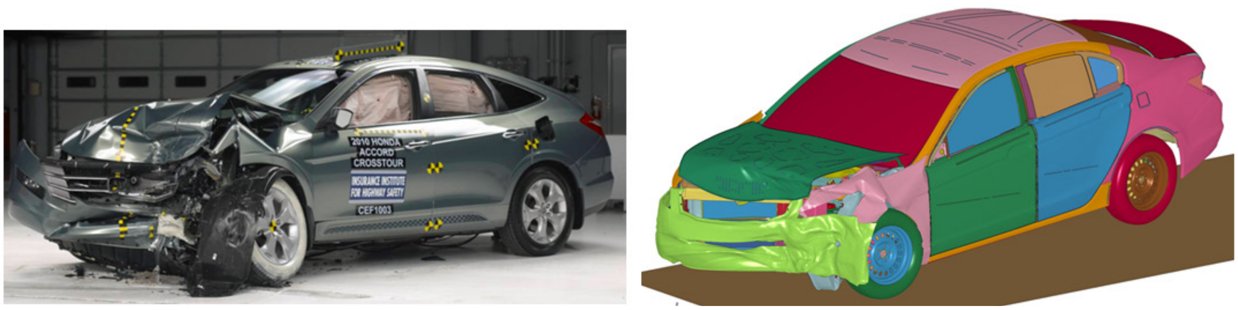


Figure 19.6- 2: Post-crash, isometric view after IIHS frontal offset test

In the IIHS frontal offset barrier test, parts that absorb much of the crash energy are (1) front bumper, (2) left longitudinal rail, (3) left sub-frame rail, (4) left shotgun, and (5) toe pan. Figure 19.6-3 shows the outline of the vehicle parts, with the five structural parts in color for clarity. In Figure 19.6-4, the crush of the five key structural parts—over the time of the crash—are presented. Figure 19.6-5 is a graph that follows the energy absorbed by the five structural parts over the period of the IIHS frontal offset barrier test.

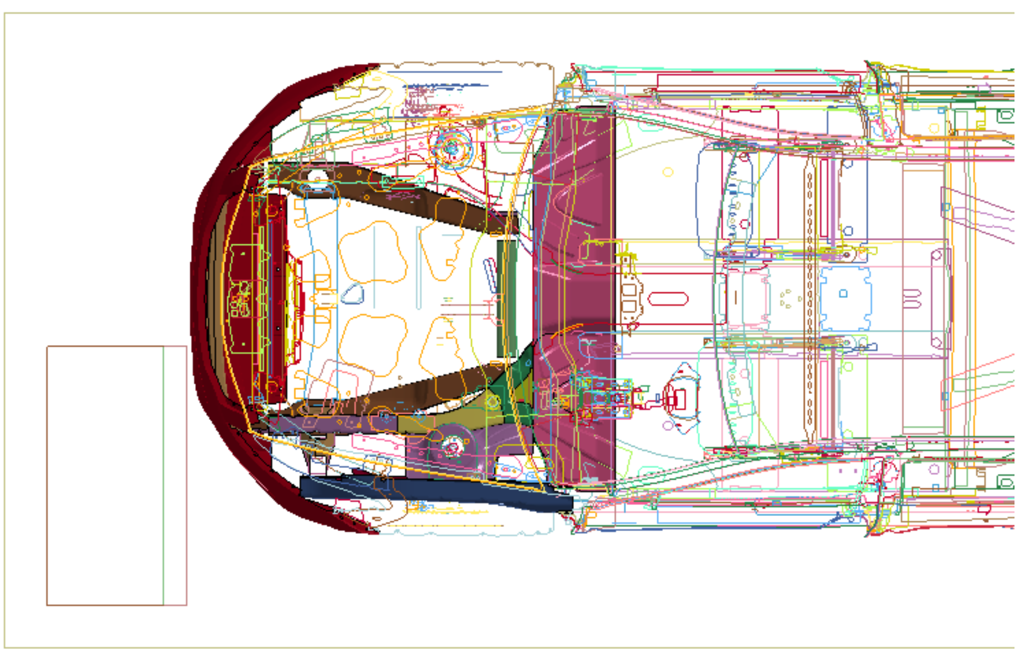


Figure 19.6- 3: Schematic of light weight vehicle showing five key structural parts in color for IIHS frontal offset test

Figure 19.6- 4: Crush of five key structural parts over the time of the IIHS frontal offset test

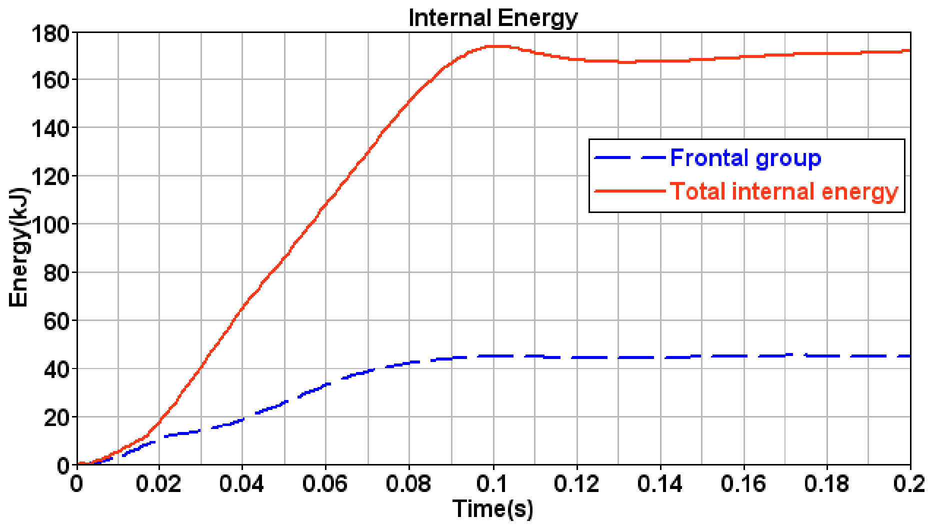


Figure 19.6- 5: Energy absorbed by the five key structural parts during the IIHS frontal offset test

A bottom view of the light weight vehicle is shown in Figure 16.6-6 and 19.6-7. These two figures indicate there is no visible support of damage to the fuel tank after the crash test.

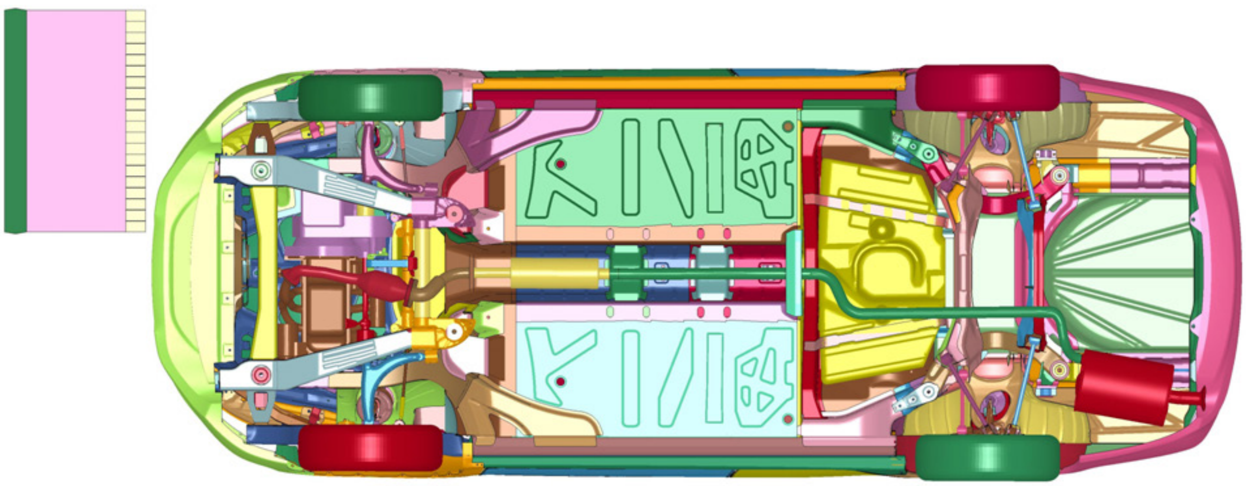


Figure 19.6- 6: Bottom view of light weight vehicle before IIHS frontal offset test

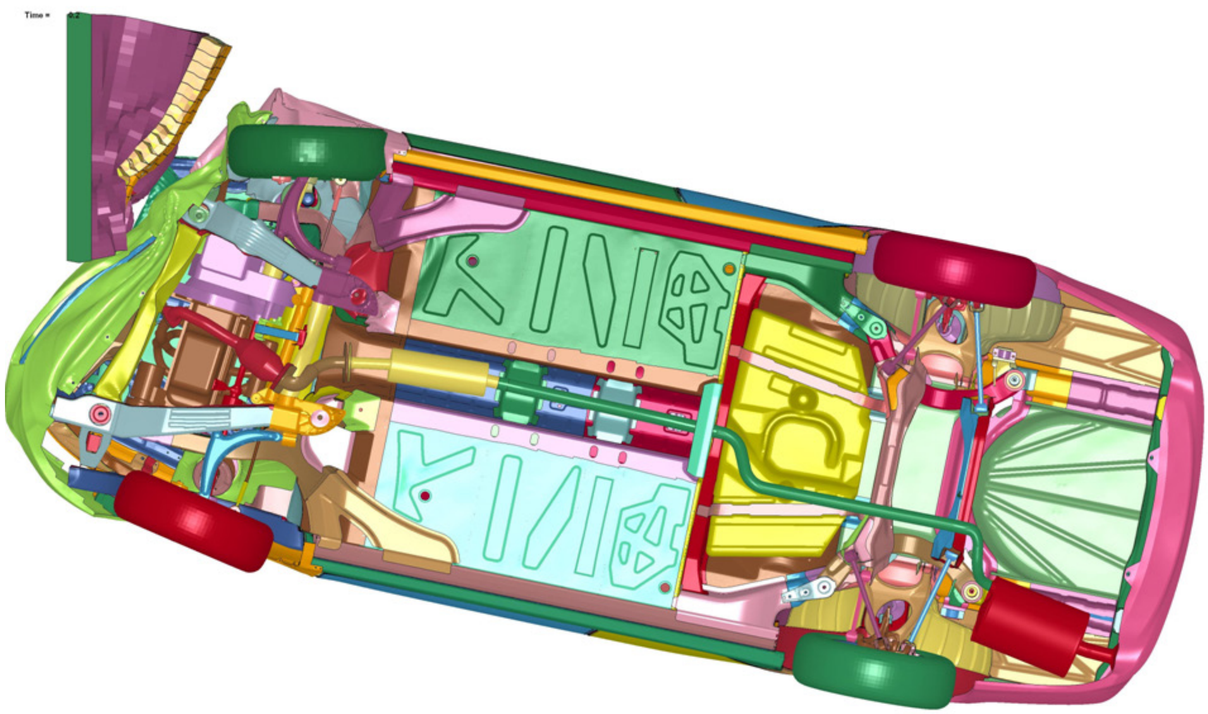


Figure 19.6- 7: Bottom view of light weight vehicle after IIHS frontal offset test

1.7 FMVSS No. 301 Rear Impact Test

For due diligence, an additional rear-impact test was simulated with the light weight vehicle. This supplementary test is not among the six consumer information tests that are analyzed throughout this report. Federal Motor Vehicle Safety Standard (FMVSS) No. 301 specifies a rear-impact. The rear-impact test is designed to promote the crashworthiness of the body structure and fuel tank. 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% as shown in Figure 19.7-1. The MDB used in the rear-impact test weighs 1380 kg.

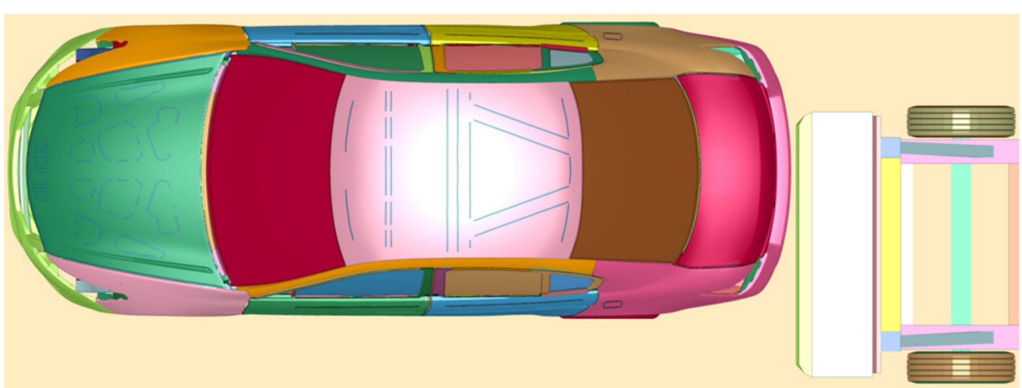


Figure 19.7- 1: Test set up for FMVSS No. 301

The pre-test view of the back of the light weight vehicle is shown in Figure 19.7-2. Post-test views of the vehicle are presented in Figure 19.7-3 and 19.7-4. These two figures indicate there is no visible support for damage to the fuel tank after the rear-impact crash test.

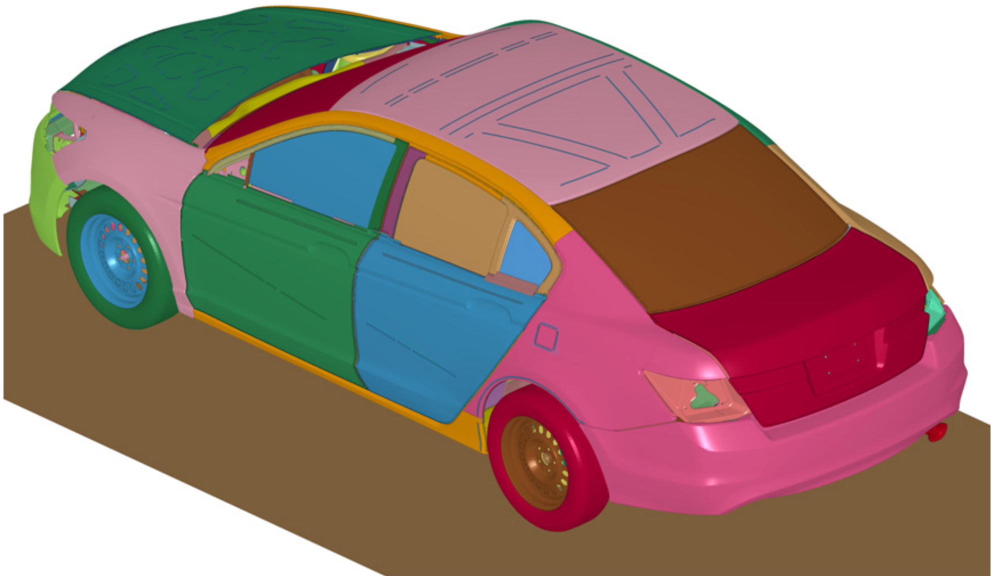


Figure 19.7- 2: Pre-test view of rear of light weight vehicle

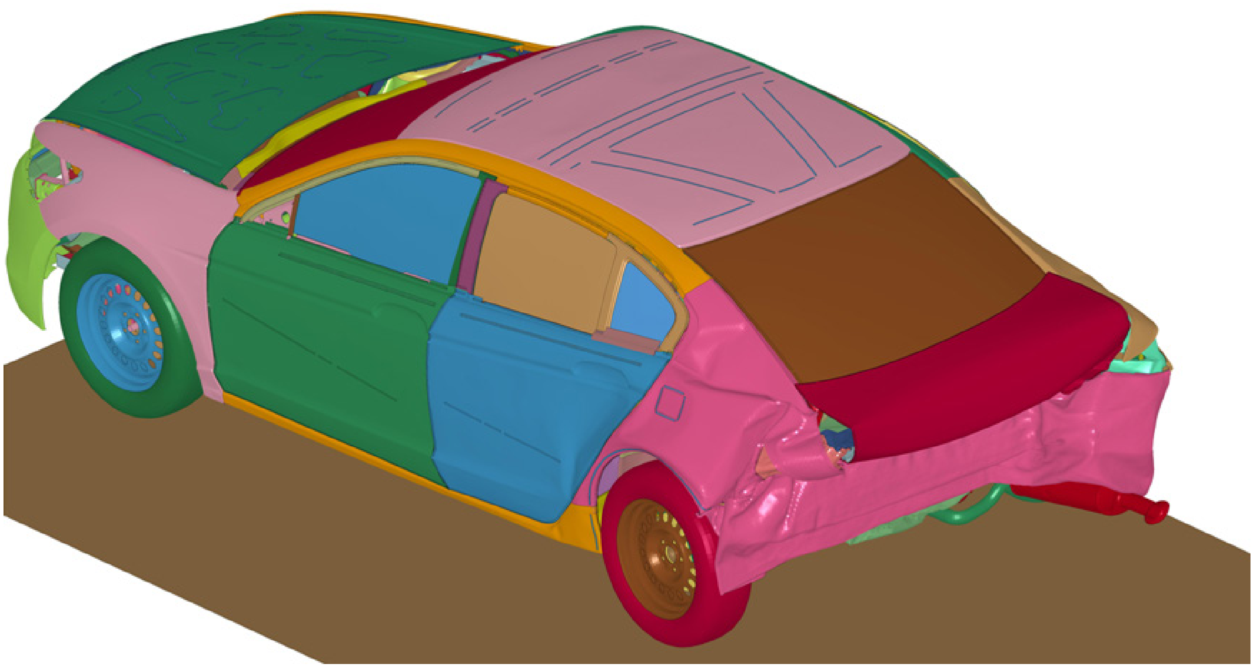


Figure 19.7- 3: Isometric view of rear of light weight vehicle after FMVSS No. 301 test

Figure 19.7- 4: Bottom view of light weight vehicle after FMVSS No. 301 test

Appendix G. Peer Review Comments Log

Verma 4-22-12

Review Comment Number	Reviewer	Page in Individual Peer Review Report	Comment / Suggestion	Commented Section	LWV Team Response	Location of Response
1	Verma	2	Assumptions and Data Sources: The provided report documents a cost-constrained, reduced-weight redesign of a mid-size vehicle, along with performance evaluations, finite element-based structural analysis, extensive manufacturing data and cost estimates for 2017-2025 timeframe. The main findings appear to be based on sound economic and engineering principles. The methodology of 'Technical Cost Modeling' is applied to estimate the incremental manufacturing costs and sufficiently detailed design data and manufacturing steps are used in calculations. Although there are some concerns regarding the design (some suggestions are made in this review) the overall study is valuable and a valid step in answering questions related to lightweight vehicle designs. As compared to other published studies, the material selection is more conservative due to the cost constraint.			No change required
2	Verma	2	Assumptions and Data Sources: 1-The report does not contain sufficient details of the LWV design and of its comparison with the base Accord, making it difficult to assess the extent of changes and to evaluate whether non-structural criteria such as manufacturing constraints were fully included. Later discussions with NHTSA clarified that the LWV design is a 'clean sheet approach' and not 'parts substitution'. This makes it more important that the design and the optimization input/output be detailed to enable full review.		For this project a 'clean sheet design approach' was applied. The vehicle body structure, closures (hood, doors, decklid and fenders) and major suspension components were a complete new design. All new structures were fully assessed for manufacturing and assembly feasibility.	

3	Verma	2	2- Composites are not among the selected materials for the LWV with the stated reason of unsuitability for large volume production for cars in this price range. This should be re-examined since composite panels have been in production for large-volume cars for almost two decades. In addition, all major manufacturers have had ongoing studies for composite-intensive structure for mass production.	Section 5.10	Composites with carbon fiber were considered for possible applications on the LWV, but were not used due higher costs and unsuitability of the manufacturing process for high volume production (200,000 Annual). Composites with glass fiber and/or glass powder generally are not as mass efficient when compared with stamped aluminum for components such as hoods, fenders and door outers.	
4	Verma	2	3- In the incremental cost projections, some account needs to be taken of factors such as moving production off-shore (cheaper sources of labor) and of the effect on the material prices due to rising car production in other countries..	Section 9.2	The study focuses on incremental costs. So change of any variables would affect both the baseline and LWV by similar amount. For an example, outsourcing to low cost country will affect both baseline and LWV and the net incremental cost reduction might be zero.	
5	Verma	2	4- Crashworthiness equivalence of the LWV proposal to the Accord is not fully established in the report and more analysis needs to done. Later discussions with NHTSA indicate that side impact-related concern can be addressed by the LWV analysis and will be included in the report. However, there remain other issues, described later in this review, that need to be addressed.	Section 6	Additional discussion about the timely deployment of airbags in frontal impacts is included in the report. The side impact performance was also further investigated and structural changes recommended in order to achieve 'crashworthiness equivalence' between the baseline vehicle and the LWV.	Section 6.4 Section 6.5
6	Verma	3	Vehicle Design and Optimization Methodology and its Rigorousness: The proposed LWV uses various grades of high strength steel for the body and aluminum for exterior panels, along with a few magnesium components. There is no utilization of composites for LWV body which makes this study more conservative than other studies in terms of material selection. The LWV appears to be also dimensionally similar to the base Accord except for a smaller engine and a different suspension. This approach of a future vehicle close to an existing vehicle in dimensions and in materials increases the practicability and affordability. However, it is recommended that the use of composites be re-examined since composite use is more prevalent than is stated here.	3.3 5.10	See response to comment #3 for considerations given to application of composites.	

7	Verma	3	Vehicle Design and Optimization Methodology and its Rigorousness: The LWV design is stated as based on mathematical optimization programs but the report does not specify the complete set of inputs, such as objective functions, constraints and feasible domain specifications. Since the design was clarified as a 'clean sheet approach', the details mentioned above are necessary in order to fully evaluate the completeness and rigor of the study. Generally, mathematical optimizations may indicate trends but by themselves, do not always lead to actual mass reductions in vehicles because they do not account for many non-structural criteria and constraints which are essential to large-volume manufacturing and assembly. In order to assure the viability of optimization studies, it is essential that quality, durability & manufacturing engineers be part of the optimization input. It is also critical that the output of optimization programs be re-analyzed for conditions that cannot be fully specified in the optimization, such as crashworthiness and durability requirements and several assembly considerations.	3.3 5.2.3 5.2.4	- The 'topology optimization' is conducted to identify load paths without the engineers preconceptions. Engineers' preconceptions/experience is not always correct; it is like driving forward by looking in the rear view mirror. The 'topology optimization' identifies load paths that are purely based on mathematics. - 3 G(geometry, gauge and grade of material) sectional optimization - produce non-intuitive: mass efficient designs. The results from the optimization steps are used as guideline to lead the design. All such designs used on the LWV are fully reviewed by engineers for suitability of the designs for manufacturability (forming and assembly). All designs are further assessed for structural performance (stiffness, vibration, durability and crash) using the industry accepted analysis methods.	
8	Verma	3	Vehicle Design and Optimization Methodology and its Rigorousness: There are several other published studies for lightweight vehicle design in the 2017-2025 timeframe. However, those are not based on the consideration of limited cost increase (10%). Thus, the findings in those studies appear to have more 'reach' in material selection and significant use of composites is on such 'reach'. But not all studies are as detailed in terms of design, performance evaluation and manufacturing steps. However, it is still useful to compare all studies on lightweight future vehicles to establish the corridors of 'maximum possible weight reduction' and 'likely cost increase' for the 2017-2025 vehicles.	3.3	These are all literature research type of studies - not based on "design and engineering". There is very limited amount of information which we can use from these studies	

9	Verma	4	Vehicle Functionalities and Crashworthiness Testing Methodological Rigor: The provided report contains evaluation of the significant functional aspects of the LWV, with some exceptions. For example, the durability criteria do not seem to include corrosion resistance which can affect vehicle design. Also, the report shows that the LWV retains several features which add to its mass and cost but are unrelated to the specific safety or performance targets (e.g. wheel size, front structure). These are discussed later in this review.	4.9.2	Report updated to include corrosion consideration.	Section 4.9.2
10	Verma	4	Vehicle Functionalities and Crashworthiness Testing Methodological Rigor: It is known that mathematical optimization programs can generate reduced-mass designs to meet structural stiffness and strength goals (such as vehicle frequencies) but do not usually comprehend all the criteria for achieving crash safety goals, making it necessary to augment optimization results by additional analyses. This report has several deficiencies in crash safety analyses of the LWV. These were discussed with NHTSA in a meeting. Additional data shown by NHTSA successfully address side impact tests. Other concerns remain and these are discussed later.	6.4 6.5	Additional work was conducted based on Dr. Verma's recommendations. The front end crash results were re-evaluated and assessed for timely air-bag deployment. Report was updated to include additional information. For side impact: 1. Additional measurements were taken from the test vehicle for the interior B-Pillar surfaces 2. The measured results were compared with the LWV predictions 3. The LWV body side structure was modified to achieve comparable intrusion values. The latest results are shown in the Report Section 6	Section 6.4 Figure 251 Section 6.5
11	Verma	4	Vehicle Functionalities and Crashworthiness Testing Methodological Rigor: The crash simulation technology of using LS-DYNA is well established and the models used in the study have sufficient detail in the geometry and the materials for the purposes of this study. However, all the requirements for crash test performance are not comprehended and more work needs to be done to evaluate additional parameters to establish the LWV equivalence. One of the important deficiencies in the report is that it ignores a basic requirement in meeting safety goals that the structure enable appropriate sensing for the restraint system deployment. In current NCAP test regimen, vehicle scores are based on measurements on ATDs and it is not possible to compensate for late deployment of airbags and get 5 stars, as explained later in this review.	4.8.2 6.4 6.5	See response to Comment #10	

12	Verma	4	Vehicle Functionalities and Crashworthiness Testing Methodological Rigor: The LS-DYNA models for the vehicle have adequate level of detail for the purpose of this study and the front NCAP and the IIHS ODB simulations executed successfully on a workstation. The results from the simulations appear to correctly represent the crash dynamics of the vehicle.		Positive comment	
13	Verma	5	Vehicle Manufacturing Cost Methodology and its Rigorousness: The cost figures presented in the report are the incremental direct costs for manufacturing and were obtained by (a) 'technical cost modeling' process for parts fabricated by the vehicle manufacturer and (b) by interviewing supplier companies for parts that are purchased by the vehicle manufacturer. The package provided for review by NHTSA contains a set of spreadsheets with comprehensive list of parts and components for the vehicle. The manufacturing steps for LWV are generally evolutions of existing processes for enabling large volume production with higher strength steel, aluminum and magnesium. This is a valid approach for cost approximation since it is based on detailed list of parts and of manufacturing processes and does not require 'inventions' of new processes for manufacturing the LWV. The use of incremental cost is also preferable to other measures (e.g. unit cost) for the parameters of this study.	9	Positive comment	
14	Verma	5	Vehicle Manufacturing Cost Methodology and its Rigorousness: The technical cost modeling process for evaluating new products is one of the well-accepted methods and it provides useful information when the input to the model contains detailed list of parts (complete Bill of Materials) of the product and of the manufacturing process (complete Bill of Process). The quality of the cost projection also depends on the validity of the input data (e.g. raw materials, labor rates, etc.) for the projected future time-frame. In the present report, it appears that both the product and the manufacturing + assembly processes are described in sufficient detail and the unit cost inputs obtained from various publications represent current estimates. These values are projected into the 2017-2025 timeframe by accounting for changes due to volume, learning etc. In general, these projections are conservative and underestimate the potential cost reductions due to volume (LWV is one of the highest selling segment), technology and labor rates internationally.	9	The LWV studied in this project is MY2020 vehicle using 2010 material price in 2010 dollar. The project has considered the volume effect of this high selling segment when selecting technologies. As stated in the response to comment #4, any input data change will have minimum impact on the incremental costs because it will affect baseline and LWV similarly.	Section 9.1

15	Verma	5	Vehicle Manufacturing Cost Methodology and its Rigorousness: There exist several other methods for estimating the cost of new technology and future products, such as 'ownership cost', 'landed cost', 'total energy cost', etc. However, the present approach of incremental cost estimation is preferable, in my opinion for assessing the affordability in the 2017-2025 timeframe. It may perhaps be enhanced by adding other manufacturing considerations, e.g. tool life reductions when used in forming with HSS. The light weight parts may also require less energy in assembly operations and in transportation.	9.2	These parameters are already included in the cost model	
16	Verma	6	Conclusions and Findings: Overall, the study is an important step towards evaluating engineering (design, manufacturing) feasibility, functionality implications and economic viability (incremental cost of manufacturing) of reduced-weight automobiles. The study is based on extensive amount of product design, manufacturing analysis and detailed cost estimation and the conclusions correctly project the LWV cost and performance. However, the documentation in the provided report needs several revisions and additions s in order to fully assess all the findings. Also, additional analyses of crash safety need to be completed and any resulting design revisions included in the estimate and in the documentation.	6.4 6.5	See response to Comment #10	
17	Verma	6	Conclusions and Findings: The study is based on an existing vehicle and its reduced mass redesign for the 2017-2025 timeframe. Its main conclusions regarding design, functionalities and manufacturing cost are based on correct principles and are generally credible, except for the needed revisions and additions as suggested elsewhere in this review. It is especially important that the work needed for crash safety be completed and documented prior to release, since this (equivalence in safety performance) has been mentioned by some in the past as a matter of concern. The mass reduction estimates in the report should be considered as 'conservative' since they appear to be based on part by part redesign of an existing vehicle and not on 'completely new design based on future manufacturing technology'. It is likely, as seen from other studies, that larger weight reductions can be achieved by using such future technologies in designing the next Accord. However, the study's approach of utilizing relatively near-term projections in manufacturing technology and cost input also increases its acceptability.	3.3 6.4 6.5	See response to Comment #10	

18	Verma	7	Other Potential Areas for Comment: The exact methodology used for estimating mass reduction in other LDV classes is not clear from the report. It is stated on p.306 that the approach was to "apply appropriate light weighting technology…discussed in Chapter 5 to each representative vehicle to calculate vehicle mass reduction", but such calculations are not presented for the other LDV classes. Instead, for example, it is stated on p. 326 for compact passenger cars that "a 22% mass reduction….is assumed". This needs to be clarified. In the absence of any other logic, it would be acceptable in my experience to apply the percentage mass reduction from LWV study to across other size & mass categories as well but this should be clearly stated.	8.2	Suitable choice of materials and manufacturing technologies based on the lessons learned from the LWV program were applied to each class of vehicles. It must be noted that the amount of percentage mass reductions determined for the LWV are not applied exactly 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 for the LWV an iron/steel part is replaced with an aluminum part, the percentage mass reduction is likely to be significantly high and this high value cannot be applied to the vehicle system if it is already made from aluminum. **Each sub-system was reviewed by the team and a suitable mass reduction was determined and applied to each system. The applied percentage reduction took into account the year of manufacture, the manufacturing technology & material, the percentage reduction achieved for the LWV and EDAG Engineering team experience.**	Section 8.2
19	Verma	7	Other Potential Areas for Comment: Three revisions are suggested prior to the report's finalization –(a) more details need to be provided of the LWV design process, including the optimization parameters, objective functions, specified constraints, etc., so as to assure that the design comprehended all the important aspects and is not likely to be changed as it goes into manufacturing, (b) detailed comparisons need to be presented between the Accord dimensions and the LWV dimensions, (c) necessary analysis and design changes in the LWV for crash safety performance should be completed and documented in the report.	5.2	(a) The design process applied to the LWV is shown in Figure 83 & 84 (b) Dimensionally and functionally (ground clearance, front and rear occupant leg-rooms, luggage carrying capacity, wheel base, vehicle width and height) the LWV is same as the Honda Accord. (c) See response to comment #10.	Section 5.2.1

20	Verma	7	Other Potential Areas for Comment: Much of the work on lightweight vehicle designs by automobile companies and parts manufacturers is not available publicly. Those studies may perhaps lead to more mass reduction (e.g. low mass/ low cost composite seats, composite structure, etc.) along with other technologies (higher inflation pressure 'intelligent' tires, electrical wire reduction by increased multiplexing, etc.). However, the past practice for achieving mass reduction has been 'incremental steps' - to reduce the mass of the components and parts, and to make changes in vehicles dimensions by efficient packaging. The present study is a valid approach for achieving slightly accelerated mass reduction the 2017-2025 vehicles.		Positive comment	
21	Verma	7	Other Potential Areas for Comment: The detailed cost models provided in this study comprehend the product and the manufacturing details and the estimated incremental manufacturing cost of LWV is a credible basis for assessing affordability, provided the design-related concerns are addressed. In my opinion, it is likely that the actual incremental costs for LWV in the 2017-2025 will be slightly lower than those estimated here because a. manufacturers can shift production to other countries (cheaper labor), and b. the raw material cost differential will decrease for aluminum and magnesium.	General	This study is focused on incremental costs, so change of any variables would affect both the baseline and LWV equally, making no difference to the incremental costs. Similarly outsourcing of components would affect both the baseline and LWV equally. Material prices are affected by market forces that affect both the baseline and LWV equally.	
22	Verma	9	I have reviewed the cost spreadsheets and find them to be sufficiently detailed. While it is possible to change some of the input numbers (such as labor rates) on the sheets and achieve slightly different results, the overall conclusions regarding incremental costs of LWV remain largely unchanged. However, several comments are made about the specifics of the study.	General	No response required.	
23	Verma	9	1. For many of the non-structural components, the incremental cost estimates are higher than expected as generated by parts manufacturers based on current US rates. In projecting future costs, one needs to take into account the business practice of searching for the lowest possible costs (raw materials, labor, energy, etc.) on a worldwide basis.		See response to comment #21.	

24	Verma	9	2. In view of the possibility of increased automobile production outside US and especially in the developing economies, it is likely that the demand for steel and prices will increase, resulting in reduced cost differential for other materials used in the LWV.		See response to Comment # 21.	
25	Verma	10	3. The estimated mass-reduction estimates for the seats (pp. 211-219) in the 2017+ are lower than expected since they are based on magnesium structure. It is known that seat frames made of composite materials are of lower mass and also require less steps in their manufacture.		Our numbers for seating technology for lightweighting are based on inputs from the largest seat supplier in the world.	
26	Verma	10	Some of the relevant studies (besides the Lotus Engineering report peer reviewed by EPA) are the following: - Lutsey presented a summary of all findings ("Assessment of Light-Duty Vehicle Mass reduction cost", February 2012); - Cheah's thesis from MIT ("Cars on a Diet: The Material and Energy Impacts of Passenger Vehicle Weight Reduction in the U.S.", MIT, 2010); - Carruth's study ("Design Optimization Case Study: Car Structures", U. of Cambridge, 2010)	General	These are all Literature research type of studies - not based on "design and engineering". There is very limited amount of information which we can use from these studies.	
27	Verma	10	1. The proposed LWV is based on various grades of high strength steel, aluminum and magnesium. The authors concluded that any significant use of composites would violate the cost constraint of 'no more than 10% increase'. However, there may be other data based on composite panels for GM's Saturn vehicles as well as on more recent automobiles with large-scale use of composites that should be considered (see *Fuchs et al., "Strategic materials selection in the automobile body: Economic opportunities for polymer composite design", Composites Science and Technology, vol. 68, 2008*).		See response to Comment #3	
28	Verma	10	2. In section 4.9.2 (p. 96), the definition of 'Durability' is not completely in accord with the testing done by most automakers. The authors have only considered stress- and fatigue-related durability (p.122) and ignored other aspects such corrosion due to weather, salt sprays, etc. Car manufacturers generally conduct series of tests with identified durations such as "100,000 miles durability schedule". It is recommended that appropriate discussions of corrosion-related aspects be included in the report and design implications (e.g. minimum panel thickness to prevent rust-through) be included in the report.	4.9.2	See response to Comment #9	

29	Verma	10	3. In section 4.9.3, (p. 97), it should be mentioned that most manufacturers and ratings agencies such as 'Consumers Reports' use a well-defined set of metrics to quantify drivability and 'Ride & Handling' and these include both acceleration and braking tests. The parameters shown in figure 37 (p. 64) are a good representation of such a metric. However, the report shows that the LWV has been evaluated (p. 110) only for acceleration performance and not for braking. This evaluation for braking is important for the following reason.	4.9.3	The braking distances for the LWV should be comparable to the baseline Honda Accord because the sizes of front and rear brake components are based on the Honda Civic which is heavier than LWV.	
30	Verma	10	4. In the absence of specific calculations showing otherwise, it can be expected that the LWV (23% lighter mass) will provide the same braking performance with 16" wheels-and-tires combination as base Accord does with 17" wheels-and-tires combination. In addition, the difference between the tires for these two wheel sizes does not affect most of driving. The 16" wheels available on the base Accord should be included in LWV due to their lighter mass and lower cost. The authors state (p. 68) that they decided to retain the 17" wheels since, in their opinion this will maintain handling and braking performance. This needs to be verified through simulated testing and documented in detail.	4.5.4.3	The LWV body structure is designed so it can accommodate both 17" and 16" wheels. The wheel flops/clearance is suitable for both sizes of wheels. But the LWV uses 16" similar to the Honda Accord Baseline Vehicle.	Section 4.5.4.3
31	Verma	11	5. The description of the LWV design approach in section 5.2.3 (Topology Optimization) is unclear as to the specific inputs to the optimization program. I am familiar with the various optimization methodologies and would like to recommend that the authors specify the parameters (such as peak loads, time integral, etc) used in defining the objective functions quantitatively (a statement such as 'IIHS Side' is vague) and also state the design parameters and the search domain.	5.2.3	Optistruct, the software used for the topology optimization, is licensed from Altair Engineering, Inc. The parameters used in the analysis are load determination for each load case and the method of combining several load cases. This is EDAG proprietary information.	
32	Verma	11	6. Details should be presented on the LWV design and its comparison to the Accord in the important dimensions.		Dimensionally and functionally (ground clearance, front and rear occupant leg-rooms, luggage carrying capacity, wheel base, vehicle width and height) the LWV is same as the Honda Accord.	Section 5.2.1

33	Verma	11	7. Since the LWV uses a smaller engine, there is more free space in the front end (as stated on p.103) which can be used to improve the crash performance of the structure (more crush space can be translated into lower levels of effective average acceleration) or to reduce the length of the vehicle and thus gain more mass reduction. However, neither of these seems to have been done in the design and the statement in section 5.2.2 (p.104) that the additional space was used to make the vehicle 'more efficient in managing the loads' is not supported by the presented results for front crash of LWV (figure 250). It is recommended that this be re-evaluated and the front structure design be appropriately modified to utilize this space efficiently.	5.2.2	The report Section 5.2.2 states "*Because the LWV can take a smaller powertrain unit without sacrificing performance, some front end space is freed up that can be utilized for more efficient structural load paths. The additional packaging space allows for front rails with larger stable sections. The larger sections are generally more efficient in managing the loads*." The body in white structure of the LWV is 23% lighter than the baseline vehicle, using AHSS. This magnitude of mass reduction is achieved partly due to efficient space utilization. Also the LWV is kept at the same dimension as the baseline Honda Accord so that the design can be shared with other powertrain configurations or other vehicles on the same platform.	5.2.2
34	Verma	12	1. Since the LWV uses a smaller engine than the Accord, there is more available crush space in LWV than in the Accord. However, the analysis results on p.243 of the report show significantly smaller dynamic crush (dynamic crush = area under the Velocity-Time curve) in the LWV. An explanation should be provided as to whether this extra available space was otherwise utilized for mass reduction by reducing vehicle length.	6.4	See response to comment #33.	
35	Verma	12	2. An important function of the front structure is to generate sufficient deceleration levels to enable proper deployment of airbags and seatbelt pretensioners. This has become critically important in the current NCAP regimen due to the fact that measurements on the ATDs' neck are a major part of the star rating system (see *Verma, "Trends in Automobile Safety: Analysis of Recent Front NCAP Crash Tests ", http://www.mpholcomb.com/pdf/articles/markedArticle_1.pdf*)	6.4	Additional discussion added to report concerning timely airbag deployment.	Section 6.4 Figure 251

36	Verma	12	3. The LWV shows much lower deceleration levels than the base Accord in the 3-18 millisecond range (figures 249-252). Since this is the time period during which airbag deployment decision and initiation take place, this may indicate delay in deployment of the airbag and cause likely difficulty in achieving the goal of 5 star rating. Possible modifications to the front structure design should be explored to assure proper deployment timing for airbag. It is clear from using the provided LS-DYNA models that small modifications in the LWV design can achieve the above-stated goals of timely restraint system deployment.	6.4	Additional discussion added to report concerning timely airbag deployment	Section 6.4 Figure 251
37	Verma	12	4. The statements regarding the equivalence of occupant protection as measured in IIHS ODB test (pp 93-94) are unclear and the report does not show a comparison of decelerations, leading to possible concern that this study does not comprehend all the aspects of occupant safety in these tests.	4.8.6	The LWV show similar deceleration pulse and delta velocity comparing to the baseline Accord. Therefore it is expected that the airbag in LWV can be deployed in a timely/similar manner to the baseline vehicle. Additional discussion added to report concerning timely airbag deployment	Section 6.4
38	Verma	13	5. It is noted from the report that the LWV retains the Accord's ACE structure for the front end. This raises several concerns.	4.8.1	The LWV front end design is not ACE even though it has similarities to ACE. The shotgun structure is integrated with radiator support structure. The engine cradle was redesigned to be more active in frontal crash early on. The front-end crash pulse can be fine-tuned better with the three front end load paths - 1. front end crash rails 2. Extended shotgun 3. Engine cradle	
39	Verma	13	6. Several comments are made (pp. 76 -77 and other places) about the performance of Accord's ACE structure but no data are presented to show the relationship, if any, between the selected configuration and the specific crash safety goals for the LWV.	4.8.1	See Comment - above	
40	Verma	13	7. Since LWV's primary purpose is mass reduction without degradation in performance and safety, other non-ACE structures for front end should be evaluated in detail. These configurations are widely used and can achieve the specified targets in all NCAP and IIHS tests.	4.8.1	Data on such designs is not available for proper engineering analysis; there are no comparative studies to our knowledge which compare structural attributes from various OEMs' structures. EDAG team experience supplemented with optimization techniques was utilized to determine what we feel is the most appropriate choice of design for the LWV.	

41	Verma	13	8. The results shown for MDB side impact test on the LWV in the provided report (section 6.5) are lacking several parameters (such as door velocity relative to vehicle CG, etc.) that determine the Side NCAP star rating. As mentioned before, these results were shown by NHTSA in a later meeting and establish that the LWV is capable of meeting the 5-star goal for this test.	6.5	See response to comment #10.	Section 6.5
42	Verma	13	9. There are several vague and possibly incorrect statements regarding the logic used in evaluating measured or simulated vehicle response in crashes. The following revisions are recommended. - Revise section 4.8.2 regarding the role of the vehicle structure in NCAP performance. The stated criteria for NCAP frontal and IIHS frontal should be changed from "acceleration and pulse time width" to "peak acceleration, effective average acceleration, delta-v in first 15 msec". - Revise sec. 4.8.7 similarly. Specifically the three qualitative statements on p. 94 ("a longer crash pulse in frontal impact is better than ……….") should be re-written into 'proper deceleration for restraint deployment, peak deceleration levels, measured intrusion values,..). -Revise sec. 4.8.8 for 'NCAP Side with MDB' for dynamic criteria as shown later since B-pillar data on Honda Accord is available; - Statement about roof crush test (p.267) should be revised to reflect that this test is not related to absorption of crash energy and that indeed, the energy in this quasi-static test is very small.	4.8.2 4.8.7 4.8.8	Section 4.8.8 - Our analysis suggests that the B-pillar signal (NCAP side barrier laboratory test of Honda Accord) is flawed: (1) it does not rise to approach the velocity of the impacting MDB, (2) it does not wind up at the final velocity of the struck vehicle, (3) it drops to an impossibly-low velocity of about 1.5 m/sec, and (4) the velocity-versus-time diagram of the Honda Accord is unlike any of the velocity-versus-time diagrams of any other vehicle that we examined. As the B-Pillar data on the baseline vehicle was not available. The B-Pillar velocity of the LWV was compared with 3 other similar sized vehicle test result: LWV 10.3 m/s, Kia Optima 10.6 m/s, Chevrolet Malibu 9.5 m/s, and Toyota Camry 9.3 m/s. Report revised Section 6.5 Figures 271 and 272 added Report revised.	Sections 4.8 & 4.8.2 Section 4.8.7 Section 4.8.8 Section 6.5 Section 6.7
43	Verma	13	Typos and Unnecessary statements- - The report states (p.75) that the mass of the Accord BIW increased by 39% from 1994 to 2008 and speculates on the reason for such increase. It should be stated that the main reason for this is increased in car size and move to higher market segment.	4.8.1	Report updated	Section 4.8.1

44	Verma	14	APPENDIX - Following an initial meeting with NHTSA team members, I provided a set of recommendations to NHTSA for completing some of the crash safety analysis. This is included below as a matter of record. The results presented by NHTSA in a later meeting show that the LWV can achieve 5 star rating in the side impact MDB tests.	6.4 6.5	See response to comment #10.	Section 6.4 Section 6.5

Appendix G. Peer Review Comments Log

Srdjan

Review Comment Number	Reviewer	Page in Individual Peer Review Report	Comment / Suggestion	Commented Section	LWV Team Response	Location of Response
1	Srdjan	9	It can be seen that the engine cradle develops two deep folds and that it contacts the ground… 'I expect that the above deformation mode would create very forces in the cradle and its rear support. These forces may rupture the supports or fracture the cradle".	6.4	The researchers of this project believe hitting the ground is not significant given the entire structure hitting rigid wall at high speed. Similar behavior is observed on Chevrolet Malibu which achieved a 5-star rating (NHTSA test number 6268). The engine cradle failure mode of Malibu is similar to LWV.	
2	Srdjan	10	Joining technologies are described in Subsection 7.2.2 and Section 10. However, the description is entirely on the manufacturing processes. For example, the weld (spotweld, laser weld) mechanical properties with respect to joining different AHSSs are not described in the LWV report. I think this is an important aspect of the design that must be included in the report.	7.2.2 10	The determination of mechanical properties of joints using spot-welds and laser welds is outside the scope of work for this project. However most of the proposed grades of AHSS and the recommended joining methods are already used in high volume automotive production applications.	
	Srdjan	14	The material modes should use plastic strain rate instead of the total strain rate for the strain rate effect calculations. In conjunction with the strain rate sensitivity, this approach regularizes the localization effect that otherwise lead to strong mesh dependency. This option (VP = 1) was not used in the LWV model although it is recommended in practice.		The researchers for this project did not expect any difference by using parameters suggested by the peer reviewer. The researchers did a simulation to test this out. The results are shown in comment #9 under Srdjan.	
3	Srdjan	23	A minimum of 5 through-thickness integration points is currently recommended practice for the crash simulations.	6.2	We believe researchers use three points routinely. See results below in Comment 9.	
4	Srdjan	24	Another commonly overlooked formulation aspect for the shell elements is the through thickness shear factor. Recommended value is 0.833. Changing the factor to 0.833 is recommended.	6.2	See results in comment 9 below for the NCAP frontal test with this change. There is no significant change in the results.	

5	Srdjan	25	The results of the LWV simulations show significantly larger side intrusions compared to the baseline vehicle test (figures 262 and 263). The crash image sequence (Figure 30) shows that the baseline vehicle roof deforms much less than the roof of the LWV model which is shown in Figure 31.	6.5	In response to this comment and other general concerns raised by other peer reviewer regarding body side structure, the side structure has been strengthened. See response to comment #10 under Verma.	Section 6.5 Figures 264, 267, 268, 271 and 272
6	Srdjan	26	Increased side crush due to bending/fracture of inner side of B-pillar.	6.5	See response to comment #5 under Srdjan.	
7	Srdjan	27	The result of bending failure means rocker is less able to pick up the forces of the side impact. . . B-pillar bending means rocker cannot participate in impact at that point.	6.5	See response to comment #5 under Srdjan.	
8	Srdjan	32	Same comments about B-pillar in IIHS side test as NCAP side barrier test.	6.5	See response to comment #5 under Srdjan.	
9			The LWV - CAE model was updated with suggestion made by the reviewer and re-run. The results below show no significant difference when compared with the LWV results. The changes to model do however increase the computer computation time 30%. Therefore the team kept the original parameters; 1. 3 integration points across element thickness, 2. Original failure criterion.			

Accord Light Weighted Model Reviewer Recommended Updates

May 6th 2012

The National Crash Analysis Center
The George Washington University

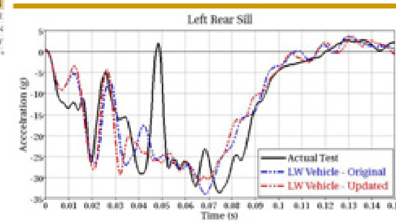
Implemented Reviewer Updates

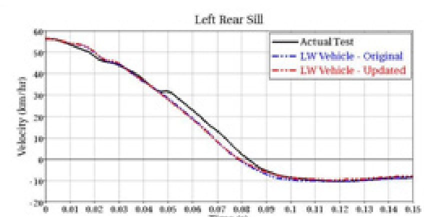
- Incorporated failure for DP 500-800 steel, AA6451 aluminum, and all other materials with yield strength of 500 MPa or higher (failure incorporated for only materials with yield strength of 700 MPa or higher in original model)
- Viscoplastic formulation (VP=1) was used for strain rate effects for all materials (default VP=0 was used in original model)
- Used five integration points across element thickness for all shell components (3 integration points used in original model)
- Updated shear factor to 0.833 for all shell components (default value of 1.0 was used in original model)
- Fixed minor discrepancies in material curves
- Lowed yield strength of welds to 550 MPa (1550 MPa yield was used in original model)

Simulation Setup

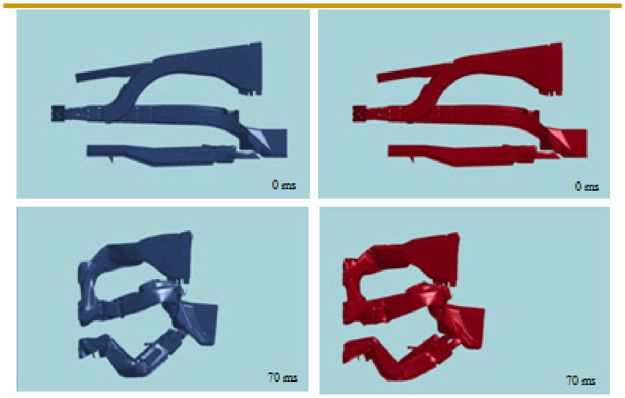
- The updated model was run for the Front NCAP Case (56 km/hr into a rigid wall)
- Two simulations were conducted on the same machine with the same number of processors and using the same version of LS-DYNA. One with original model and one with updated model

Simulation Comparisons



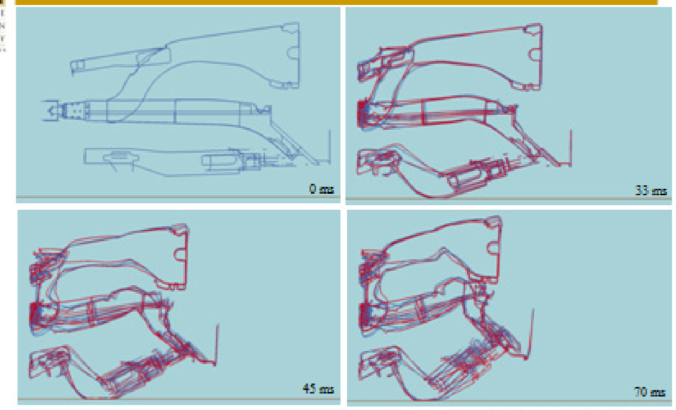


Simulation Comparisons



Original LW Model   Updated LW Model

Simulation Comparisons



Original LW Model
Updated LW Model

THE GEORGE WASHINGTON UNIVERSITY

Computation Time Comparisons

```
LS-DYNA Version     : mpp971sR4.2.1
LS-DYNA Revision    : 53450
Platform            : Intel MPI 3.1 Xeon64
OS Level            : Linux Red Hat 4 upd 4
Compiler            : Intel Fortran Compiler 10.1
Precision           : Single precision (I4R4)
MPP execution with  : 24 procs

Original LW Model:
 Problem time       =    2.0000E-01
 Problem cycle      =    317481
 Total CPU time     =     35473 seconds (   9 hours 51 minutes 13 seconds)

Updated LW Model:
 Problem time       =    2.0000E-01
 Problem cycle      =    317481
 Total CPU time     =     46498 seconds (  12 hours 54 minutes 58 seconds)
```

30% increase in total CPU time

Appendix G. Peer Review Comments Log

Sujit Das

Review Comment Number	Reviewer	Page in Individual Peer Review Report	Comment /Suggestion	Commented Section	LWV Team Response	Location of Response
1	Sujit Das	2	Appendix I.1 ASSUMPTIONS AND DATA SOURCES: Data sources and assumptions used for the component cost estimation using the TCM approach seem to be valid. For other component, a better documentation of methodology and data sources would have been useful. For example, Platts data source used for the initial design analysis as mentioned in the document is incorrect since the data from this data source is limited to the material cost and does not include component manufacturing cost. Mass savings potential estimates for aluminum body closures and fenders seem to be overly optimistic since most studies to date have indicated a mass savings potential around 40%.	Chapter 5	Report Figure 138 updated to better describe the methodology. The mass savings identified for the LWV is for the actual door design in aluminum with hot stamped steel side door intrusion beam and compared with the Honda Accord baseline doors in steel. These designs meet the functional requirements in crash performance.	Figure 138
2	Sujit Das	2	Appendix I.1 ASSUMPTIONS AND DATA SOURCES: Issues with data sources and assumptions have been discussed by specific page no as outlined below. Latest data on secondary mass savings impacts by Alonso et al. (2012) could be considered in order to estimate the overall vehicle/system cost premium impacts.	Chapter 9	Report updated citing the work from Alonso et al. The result from Alonso study is very close to the result of this study.	Section 9.8.1

3	Sujit Das	2	Appendix I.4 VEHICLE MANUFACTURING COST METHODOLOGY AND ITS RIGOROUSNESS: A combination of TCM and Supplier Assessments approaches used for the incremental cost analysis seems to be reasonable. However, the initial cost estimation procedure of each design was not systematic and the methodology used varied by specific component under consideration. Sufficient level of documentation regarding the methodology and data sources used would have been useful.	Chapter 5	The initial design cost estimates were used only for directional purposes. Due to the lack of detail design/manufacturing parameters specific to each design, the cost estimation for the first phase of the program had to be based on certain generic assumptions. Such cost estimation procedure is a common practice during the initial stages of any project, the cost estimates are fine-tuned as design evolves. Report is updated to better describe the process.	Section 5.8
4	Sujit Das	2	Appendix I.4 VEHICLE MANUFACTURING COST METHODOLOGY AND ITS RIGOROUSNESS: TCM approach used for the entire body structure, closures, bumpers, fenders, front suspension, and rear suspension etc. has demonstrated the strong technical rigor in the cost analysis. It is appropriate that the detailed methodology such as TCM has been used for those components having the data readily available for relatively mature manufacturing technologies. Mass reduction methodology used was somewhat of an arbitrary bottom-up approach, without knowing at the outset about the final total vehicle mass reduction goal and also any yardstick at the component level cost reduction goal to achieve the final cost reduction goal as different component level lightweight designs were being evaluated.	Overall methodology	The team believes that a systematic approach is used for this study. The mass reduction goal was clear "the maximum mass reduction possible within the 10% cost constraint, without any reduction in the vehicle functionalities". The different alternatives considered are discussed for each vehicle sub-system/system. The final LWV design achieved the most "cost effective mass reduction". In other words, mass reduction beyond that point is not value added from a cost perspective; money could be spend on other more fuel efficient technologies, such as powertrain technologies, instead.	No change.

5	Sujit Das	3	Appendix I.5 CONCLUSION AND FINDINGS: Overall, it is a fairly well-written report. The study's conclusions are fairly backed up by the methods and analytical rigor of the study. The screening analysis of initial designs of components lacked the use of consistent methodology and data sources. The final cost target of ±10% baseline vehicle MSRP was not systematically considered explicitly in the component final design selection. Although the final target is based on MSRP, but comparisons including final results are presented in terms of cost and not price by using the appropriate indirect cost multiplier factor as discussed in the report. The mass compounding effect which has a strong influence on the study's conclusions has been considered only to a limited extent indirectly in the case of body structures at the end of cost analysis in Sect. 9.8. It doesn't consider explicitly the effect of mass compounding on the body structure since its lightweighting affects non-powertrain component masses. The interdependency between primary and secondary mass savings should have been considered at the each component level for the final design including during the evaluation of initial component designs. A good discussion on the effect of learning on technology costs of the welding of body structure was provided but was not included in the analysis. It'd have been appropriate to consider for all major vehicle components since the lightweighitng technology implementation timeframe in this study is in the range of 5-13 years out in the future.		Report updated with the 10% MSRP cost target numbers in Executive Summary and as foot note in several points of the report. The mass compounding effect is used to calculate the additional points on the cost curve. Mass compounding is tool/method for estimating component mass in absence of doing detailed design. The final design of the LWV is an 'engineered/designed' solution, so the components have already been properly sized in consideration of the final LWV mass reduction. Mass compounding effect has been taken into account in the design. Again all major structures/components for the LWV are designed/engineered to fulfill the desired functional requirements. Learning is applied to LWV assembly costs.	Various Footnote 9.6.1.7

6	Sujit Das	3	Appendix I.4 VEHICLE MANUFACTURING COST METHODOLOGY AND ITS RIGOROUSNESS: Using the TCM approach for other non-body vehicle systems particularly powertrain costs instead of based on mass difference would improve the study contribution.	9.6.10	The TCM approach was also used for the other non-body systems such as suspension components, wheels etc. that were new designs in the LWV. Weight reduction for systems such as seats and brakes were estimated based on supplier inputs and were not based on detailed designs. The rigorous TCM approach could not be conducted for those systems due to the lack of design details. Detailed powertrain costs were not in the scope of this is study.	9.6.10
7	Sujit Das	4	Appendix I.5 CONCLUSION AND FINDINGS: The estimated incremental cost increase of $320 or $0.96/kg at the complete vehicle level mass savings of 23% seems to be overly optimistic based on the recent estimates. For example, the 2011 National Research Council study indicates an avg. cost premium of $1650 for a 20% vehicle mass reduction. However, consistent with the conservative Lotus Engineering High Development estimate of $500/vehicle for a 33% vehicle mass reduction. Most component level cost premium estimates seem to be optimistic in addition to the few components such as engine transmission, exhaust, and brakes etc. which were not based on using the TCM approach. In the cost analysis of initial component designs, particularly for body closures and fender components, no general trend of increasing cost premium with higher component mass savings potential was found.		The mass reduction of the LWV design is achieved using AHSS for the body structure and aluminum for the closures. The use of these comparatively low cost materials and the applied high production volume manufacturing technologies keep the incremental cost at the low calculated value. The 20% mass reduction assumed by NRC study is achieved by use of premium higher cost materials, such as aluminum and composite intensive body structure. The cost premium for the LWV using these kinds of premium materials is $2719, also very high (NRC's value at $1650).	
8	Sujit Das	4	Appendix I.5 CONCLUSION AND FINDINGS: Lotus Phase II Study and the 2011 National Research Council Study on "Assessment of Fuel Economy Technologies for Light-Duty Vehicles".	General	These reports were reviewed by the team in the research activity.	No change required

9	Sujit Das	4	Appendix I.6 OTHER POTENTIAL AREAS FOR COMMENT: Cost from the study particularly based on the detailed TCM cost models developed for the entire body structure, closures, bumpers, fenders, front suspension, rear suspension, and their corresponding assembly process seem to be reasonable. Not sure whether estimated components costs refer to the same manufacturing technology year (i.e., 2020) for both cost approaches used for the study and in what specific year cost dollars component cost estimates are based on since material prices as noted on p. 357 are in 2010 dollars? Cost premium estimates in terms of $/kg seem to be reasonable, however overly optimistic in terms of absolute values.	General	The estimated component costs refer to the same manufacturing technology year at 2020 and are also using 2010 dollars, consistent with the material costs. This is clarified in the report. The cost premium $/kg comment is addressed in response to comment #7 above under Sujit Das.	Section 9.1 See response to comment #7 above under Sujit Das.
10	Sujit Das	6	CHAPTER 3: p. 35 Although one of the major boundary conditions for this project is set to be maintaining the retail price parity (±10% variation) with the baseline vehicle, but no explicit mention of what the retail price of the baseline vehicle is. Also there seems to be confusion between the retail price and production cost throughout the report. For example, Sect. 3.4.2 (p. 37) talks about the target vehicle design based on maintaining the cost parity, defined as the maximum feasible amount of mass reduction that could be accomplished with ±10 percent variation in production cost and not retail price. Actual cost reduction goal should have been indicated here and it was mentioned only one place in the entire document, i.e., on page 394.	Chapter 3	Report updated with the 10% MSRP cost target numbers in Executive Summary and as foot note in several points of the report. Retail price is only used for setting cost boundary as specified in the statement of work of this contract. It is not used anywhere else.	See response to comment #5 above under Sujit Das.
11	Sujit Das	6	CHAPTER 3: p. 37 Sect. 3.4.4 It is mentioned that the Electricore Team provided an incremental mass and cost difference between the powertrain chosen and the baseline powertrain without a full scaled powertrain study. Assumptions and source of information for powertrain have not been clearly documented in the report since its results have a significant impact on the overall results.	Section 3.4.4	Powertrain was chosen based on a PSAT analysis. Details about the PSAT simulation and assumptions can be found in section 4.5	Section 3.4.4 Section 4.5

12	Sujit Das	6	SECTION 5.8: p.142 The initial cost estimation procedure of each design option was not systematic and may be too broad in nature based on multiple information sources used in each case. How were the final design selections were made using the 4 major factors listed in Figure 139 for a select few materials is not clear. Glass fiber reinforced polymer composites design option should have been considered in some component cases, since it is particularly cost-effective in near net-shape components such as body structures compared to aluminum as shown in the case of material cost with manufacturing for fiber glass to be lower than aluminum cast.	Section 5.8	The initial design cost estimates were used only for directional purposes. Due to the lack of detail design/manufacturing parameters specific to each design, the cost estimation for the first phase of the program had to be based on certain generic assumptions. Such cost estimation procedure is a common practice during the initial stages of any project, the cost estimates are fine-tuned as design evolves. -We have considered Glass fiber reinforced composites but not chosen due to issues mentioned in Section 5.9.5 -High volume implementation is a major concern to be addressed before considering glass fiber for automotive applications, as stated in the report.	Section 5.8 Section 5.9.5 Figure 139 updated.
13	Sujit Das	6	SECTION 5.8: It is unclear at what annual production volume are manufacturing process factors based on although a constant production volume of 200,000 was assumed in the case of final component cost estimates using the TCM approach. Also, are the material costs with manufacturing factors based on part manufacturing? Not sure whether Platts provided the part manufacturing cost as listed in the cases of aluminum sheet, aluminum cast, and magnesium cast. For example, magnesium cast for IP beam was estimated to be about $10.44/kg, compared to $6.57/kg shown in Figure 139. In some cases such as Vinyl ester compound, glass fiber, and carbon fiber without any mention of reinforcement assumption it is hard to evaluate the part manufacturing cost. The assumption of very similar manufacturing cost for both steel (up to 590 MPa avg. strength) and aluminum sheet around $0.34/kg seems to be inaccurate. It should be significantly higher in the latter case.	Section 5.8	The annual production volume are manufacturing process factor based for a typical high volume of 200,000 Figure 138 and report revised The manufacturing cost assumptions in the study are based on the most current data the project team gathered and the team believes it is accurate.	Section 5.8.1, Figure 138 Section 5.8.1, Figure 138

14	Sujit Das	6	SECTION 5.8: The manufacturing process scrap assumptions shown in Figure 139 are inaccurate. A significant lower scrap rate of 3% in the case of aluminum cast and magnesium cast is incorrect. Similarly, 20% for carbon fiber is an overly underestimate. It is an important parameter in estimating the competitiveness of initial design options and so would be good to revisit the analysis with the appropriate assumptions. Consideration of the manufacturing scrap in the initial component design analyses needs to be documented.	Section 5.8	The team believes that 3% scrap rate for aluminum cast and magnesium cast is not an overly underestimate and is correct. According to the experience of the team, the scrap rate for aluminum cast and magnesium cast could be even as low as 1% known as "dross-loss or melt loss". Most other scrap is added to the melt for recasting. The manufacturing scrap is explained in Section 5.8.1.	No change required for scrap rate for aluminum cast. Section 5.8.1 is updated to further explain scrap rate.
15	Sujit Das	7	SECTION 5.8: p. 155 No consideration was given to the ULSAC effort by American Iron and Steel Institute. Also, long-term option of carbon hoods and fenders option was discussed instead of near-term cost-effective glass-fiber reinforced polymer composites.	Section 5.8	The ULSAC study by American Iron and Steel Institute was reviewed and its input was used appropriately by the LWV team to establish the mass saving potential of Advanced High Strength Steel solutions for the closures. The glass-fiber reinforced polymer composites were also considered but were found not as mass efficient when compared with stamped aluminum for components such as hoods, fenders and door outers. The glass-fiber reinforced polymer composites generally offer a good cost effective solution for Mid-Volume production applications (up 60,000 annual production volume).	
16	Sujit Das	7	SECTION 5.8: p. 160 Sect. 5.10.2.4 Aluminum stamped front door mass savings potential of 48% seems to be high, 40% value is well-accepted by the industry based on the latest Aachen study. For magnesium casting front door, same mass savings potential of 48% has been estimated which should have somewhat higher than the case of aluminum. In addition, unsure about the lower mass savings potential of 45% in the case of aluminum stamping rear door as discussed on p. 168 under Sect. 5.10.3.4.	Section 5.8	The mass savings identified for the LWV is for the actual door design in aluminum with hot stamped steel side door intrusion beam and compared with the Honda Accord baseline doors in steel. These designs meet the functional requirements in crash performance.	No change required, as explained in the report these are based on detailed designs; not approximations

17	Sujit Das	7	SECTION 5.8: p. 156 Energy consumption of composite processing is not a major drawback for the potential automotive use, but rather embodied energy of the material and life cycle energy consumption should be the criteria used for this material selection. Cycle time and raw material cost are the major drawbacks towards the economy viability of composites today.	Section 5.8	The 'embodied energy of the material' or the total energy required to make the material and the Life Cycle Assessment (LCA) during the use phase and material re-cycling - is outside the scope of this report. This is a very good subject for a future study.	
18	Sujit Das	7	SECTION 5.8: p. 164 Potential mass savings potential using polycarbonate could have been considered for the rear windows due to less susceptibility to abrasion.	Section 5.8	Addressed in Report 5.17.1	Section 5.17.1
19	Sujit Das	7	SECTION 5.8: p. 145 Seems like incremental cost calculations for LWV body structure for Option 1 were not based on using values of material cost with manufacturing ($/kg) shown in Figure 139, i.e., (2.08*252.4-328*1.46) = $46/kg and not $147/kg as indicated on this page. It was found to be the case for all other design option calculations and a discussion of the methodology used would be useful.	Figure 142	Report updated	Section 5.9.2.1
20	Sujit Das	7	SECTION 5.8: p.148 Use of the word "plastic" in the case of some large non-structural body panels is unscientific. Instead "glass fiber reinforced polymer composites" should be used by identifying the specific reinforcement and resin matrix material type.	Figure 144	Report updated at various location	
21	Sujit Das	7	SECTION 5.8: p. 154 Sect. 5.10 Total mass of closures and fenders is listed as 95 kg but Fig. 232 indicates a mass of 92.1 kg. The difference appears to be in the mass estimates for fenders.	Section 5.10	Correction made and report updated	Section 5.10 Figure 158
22	Sujit Das	7	SECTION 5.8: p. 156 Sect. 5.10.1 The procedure for initial cost of each design option for the closure assemblies refers to the use of manufacturing process sectors, but unsure whether and how the values shown in Figure 139 have been used in the estimation procedure.	Sect. 5.10.1	Report updated for better explanation.	Sect. 5.10.1
23	Sujit Das	7	SECTION 5.8: p. 169 Sect. 5.10.3.5, third paragraph, last line: Instead of $44.88 per kg cost increase premium should be $4.88 per kg cost increase premium.	5.10.3.5	Report updated	5.10.3.5

24	Sujit Das	8	SECTION 5.8: Estimated cost premium per kg of savings using aluminum stampings in the initial design of closure assemblies in the range of $2.76-$4.46/kg appears to be close to the reported value of $4.40/kg by the Aluminum Association. The cost premium was the most in the case of least 45% mass savings potential for doors rears, i.e., $4.46/kg compared to $2.76/kg in the case of 51% mass savings potential of hood. But the cost premium increases to $3.27/kg for an assumed 52% mass savings potential in the case of aluminum stamping decklid, which should have been closer to the value obtained for hood. No general trend of cost premium vs. % mass savings was found due to aluminum lightweighting.	Section 5.8	The costs for the closures were estimated individually for each detailed design. So, the estimated costs vary based on the design, manufacturing processes, tooling costs, cycle times, material scrap etc. We do not expect a general trend across different parts or assemblies.	No change required.
25	Sujit Das	8	SECTION 5.8: Estimated mass savings potential of 51% in the case of aluminum stamping hood appears to be overly optimistic. Similarly, 52% mass savings potential in the case of aluminum stamping decklid.	Section 5.8	Mass savings are based on detailed designs of the baseline vehicle and the LWV which meets similar functional requirements.	No change.
26	Sujit Das	8	SECTION 5.8: p. 188 In the case of composite bumper, glass fiber reinforced polymer composites bumper should have been considered as one of the viable options.	Section 5.8	Composite bumper was considered as one of the viable option, but was not chosen because of the higher cost. The details are discussed in section 5.10.7.6.	Section 5.10.7.6
27	Sujit Das	8	SECTION 5.8: p. 191 Some cases for lightweighting they consider a lower vehicle model, for example, for front suspension Honda Insight and Civic are considered for determining masses. The final LWV curb weight goal is around 1232 kg and 1252 kg (p. 191) and some parts particularly suspension have been selected based on them, contrary to the final estimated LWV design mass of 1146 kg.	Section 5.8	As stated in Section 5.11.1.2, Honda Insight and Civic were used only as benchmarks based on anticipated weight of the LWV and their use of McPherson strut design. The suspension part mass is based on 1. Vehicle Mass (Gross Front Axle Weight) 2. Package space for design. The Honda Insight front suspension parts mass is Tabulated in Figure 199. The LWV front suspension mass is shown in Figure 203. As can be the LWV numbers are different and are based LWV suspension design.	Section 5.11.1.2
28	Sujit Das	8	SECTION 5.8: Why is the AHSS cost premium of $1.25/kg for the same mass savings potential of 15% as assumed in the cases of doors, hood, and decklid is lower? The estimated value in the latter cases has	Sect. 5.10.6.3	Figure 166 is for the front door frame only - $2.08/kg premium. Figure 169 for Front Doors total the premium is $3.12/kg saving. Figure 174 rear door frame massing	

			been $2.08/kg.		premium $2.08/kg, Figure 177 for rear doors total it is $4.46 per kg mass saving. Similar figures for hood and decklid. For the left and right hand fender assemblies the premium is calculated at $1.25 per kg.	
29	Sujit Das	8	SECTION 5.8: p. 184 Sect. 5.10.6.5 : SMC should be considered as glass fiber reinforced composite instead of plastic (which is quite generic and a low valued product) as mentioned in the report	Sect. 5.10.6.5	Report updated	Sect. 5.10.6.5
30	Sujit Das	8	SECTION 5.8: p. 188 Sect. 5.10.7.3 First paragraph, last sentence – something wrong in the reported cost increase premium of $17 per /kg for the Option 1 AHSS bumper. Should be $0.17/kg as noted on the next page.	5.10.7.3	Correction made in the report	5.10.7.3
31	Sujit Das	8	SECTION 5.8: p. 188 In the case of aluminum stamping bumper, cost premium is estimated to be $6.27/kg for an assumed mass savings potential of 35%, the least mass savings potential but the highest cost premium among the closure components. Only in this case high raw material aluminum price was mentioned, hopefully the same assumption was also made in other cases of closure components.	5.10.7.6	Yes, the material assumptions are stated in the report and applied to the complete cost assessment. The mass saving for bumpers in aluminum is significantly lower than the closures (see comment 25). Hence the mass saving premium is higher.	
32	Sujit Das	8	SECTION 5.8: p. 195 Estimated mass savings for various LWV front suspension components seem to be reasonable if lightweight material substitution is based on a reduced initial component mass suitable for the LWV.	Section 5.8	Yes, the mass estimated is based on a design suitable for LWV	No change required
33	Sujit Das	9	SECTION 5.8: p. 222 Sect. 5.15 It is likely that HVAC system will also be downsized in the LWV which has not been considered in the analysis.	Section 5.15	The HVAC systems are sized for (1)The volume of the occupant compartment (2)The defrosting requirements of the windscreen. Since the LWV has the same requirements as the baseline vehicle, it was not down sized in capacity to maintain the same functionality. This logical reasoning for not resizing the HVAC is also stated in the report.	Section 5.15

34	Sujit Das	9	SECTION 5.8: p. 197 Since for most rear suspension components, they were downsized only without any lightweighting; cost savings should have been taken into consideration to reflect reduced component masses.	Section 9.6.5	Report updated to reflect savings for rear suspension components as suggested by the reviewer.	Figure 437
35	Sujit Das	9	SECTION 5.8: p. 205 If baseline an LWV curb weights are assumed to be 1480 kg and 1277 kg, respectively and assuming every 10% vehicle curb mass reduction results in 6-8% fuel economy improvement, in that case average fuel economy should have been at least around 40 mpg and not 32 mpg as indicated.	Section 5.8	PSAT analysis results shown in Figure 97, combined cycle fuel economy for LWV is 31.6 mpg. This can also be confirmed with the following calculation. Baseline Accord has a 27 mpg fuel economy. The vehicle has a mass reduction of 22.4%. Therefore the improvement of fuel economy is 6.5%*22%/10% = 15%. Therefore the final fuel economy for the LWV is 27 x (1+0.15) = 31 mpg.	No change required, the calculation is accurate
36	Sujit Das	9	SECTION 5.8: p. 218 Figure 227 was not referenced in the document. In this Figure, the baseline vehicle seating mass is estimated to be 65.84 kg, compared to 67 kg used in the mass savings analysis. It is unlikely that nano generation and natural materials will be used in Generation 3, 2018-2020 timeframe seats.	Figure 227 (now Figure 228	Figure 228 is now referenced in the report. The recommended technologies are based on the seat suppliers.	Section 5.13.2.8 Figure 228
37	Sujit Das	9	SECTION 5.8: p. 199 For wheels, cost analysis of the Al option should have been considered.	Section 5.8	We considered AL but decided to go with Steel wheel because of the mass/cost effectiveness	5.11.3.2
38	Sujit Das	9	SECTION 5.8: p. 201 Sect. 5.12.1 It'd be useful to document the information source for engine and transmission costs.	Section 5.12	Report updated	5.12, 9.6.10
39	Sujit Das	9	SECTION 5.8: p. 219 Cost increase premium estimates shown in Figure 228 are inaccurate for Generation 1 & 2 – showing to be the same as Generation 3.	SECTION 5.8	The numbers shown are correct, based on Seat Supplier Feedback	No change required
40	Sujit Das	9	SECTION 5.8: p. 225 Sect. 5.17.1 Polycarbonate glass option should have been considered as one of the fixed glass options at least in the case rear window since abrasion is less of an issue in that case.	Section 5.17.1	Report 5.17.1 states the reason for not considering this option which is due to the uncertainty for high volume production readiness of this technology.	Section 5.17.1

41	Sujit Das	9	Chapter 9: p. 347 Two cost assessment methods used for the incremental cost analysis on mid-size vehicle were found to be reasonable. Not enough documentation available on the methodology used for the evaluation of alternative design options for components. Although cost analysis of wheels was based on supplier assessments, but it has been mentioned as one of the components where TCM approach was used. Since Supplier Assessments are based on the estimated cost to the OEM for the year 2020, for which specific year and what extent anticipated technology improvements for component costs that were evaluated using the TCM approach were considered?	Section 9.1	MY2020 ready technologies were evaluated in the study and the cost estimated were estimated for that year with cost of money of 2010$. Report is updated with more details.	Section 9.1
42	Sujit Das	9	SECTION 5.8: p. 201 As mentioned earlier in the case of rear suspension components, cost credits should have been considered in the case of some of the reduced brake component masses. Appropriate documentation would be useful why the mass savings in the LWV brake design, front calipers is about twice that of rear calipers.	Section 5.8	Report updated – cost credit applied	Figure 437, no change required because rear calipers are lighter (lesser potential for mass reduction)
43	Sujit Das	9	SECTION 5.8: p. 226 & 229: Unclear about the reasoning behind the selection of LWV case of 22.6% mass savings potential and also difficult to identify the differences in underlying assumptions for four scenarios listed in Figure 233. Relative cost estimates for four different scenarios should have been evaluated in order to justify the specific LWV case meeting the cost target of ±10% of the baseline vehicle.	Now Figure 234.	The four scenarios in Figure 234 are: 1. An all Advanced Strength Steel (AHSS) design 19.2% mass saving; 2. Design with AHSS body structure and Aluminum Closures; 3. An all-aluminum solution; 4. An advanced Carbon Fiber and Multi-material Solution The chosen option 2 for the LWV design achieves in our opinion a good balance of mass saving at an acceptable level of cost premium.	Section 5.18 updated
44	Sujit Das	10	Chapter 9: p. 350 Sect. 9.2.3 The listing of various major cost elements considered in TCM for fabrication and assembly costs should be clearly mentioned as the sum of material, direct labor, energy, equipment, overhead labor.	Sect. 9.2.2	Report updated to reflect reviewer's recommendation.	Sect. 9.2.2
45	Sujit Das	10	Chapter 9: p. 351 Sect. 9.3.1 Since parts are assumed to be manufactured in a Greenfield facility, shouldn't then uniform facility cost assumption (i.e., $/ft2) be included in this table? Unclear about the definition of annual paid time, 8 x2 shifts/day x 240 days/yr = 3840 hrs but listed as 3600 hrs in Fig. 395. 3840 hours value was used in the TCM models.	Section 9.3.1	Yes, there is a facility assumption. Report updated.	Section 9.5.7 (after Figure 399)

46	Sujit Das	10	Chapter 9: p. 352 Tooling investment should be based on the tool life, i.e., in terms of no. of parts per tool manufactured.	Section 9.3.2	The tooling estimates are based on the tool required for the specified production volume including re-machining if necessary. Report shows the amortization schedule and the production volume.	Section 9.3.2
47	Sujit Das	10	Chapter 9: p. 356 Sect. 9.4.3.1 The mark-up rate was mentioned to be 4% but actually used in the suspension cost models as 4.5%.	Sect. 9.4.3.1	Correction made and Report updated.	Sect. 9.4.3.1 & Suspension Cost Model
48	Sujit Das	10	Chapter 9: p. 364 Indirect labor markup of 25% for the indirect labor seems to be low. It should be more in the range of around 40% and should also supervisory personnel under this category. But in the case of TCM cost models, actual indirect labor value and not a fixed percentage was used. Was the consistent methodology used across all components and if so which one?	General	In this study a markup factor of 25% was used consistently for all the components including the TCM models for both the baseline and the LWV. This mark-up will be different for different manufacturers. 25% was used a typical number.	No change required
49	Sujit Das	10	Chapter 9: p. 366 Figure 409 Where is the material loss percent for the stamping process included since it is mentioned as NA in this Figure?	Figure 409 (now Figure 413)	Report updated.	Figure 413
50	Sujit Das	10	Chapter 9: p. 367 How is the material cost share of total component cost is calculated? Does it take into account the scrap rate of each unit operations in component manufacturing?	Section 9.5.7	Report updated.	Section 9.5.7
51	Sujit Das	10	Chapter 9: p. 371 Figure 415 Does the overhead in cost breakdown indicate indirect labor? If so, it may be worthwhile to combine them into one category, i.e., labor. It is quite surprising that overhead and labor costs are quite similar for the baseline vehicle body structure.	Now Figure 419	This cost is for the overhead labor in manufacturing plant, (i.e. indirect labor directly connected to the manufacturing and assembly process).	No change required
52	Sujit Das	10	Chapter 9: p. 373 Comparing the overhead and labor costs of body structure between baseline and LWV, it is quite counter intuitive that in the former case overhead cost is higher but lower in the case of labor cost.	Section 9.6.1.7	Cost estimates are based on individual design, cannot predict a generic trend or pattern. Report updated.	Section 9.6.1.7

53	Sujit Das	10	Chapter 9: p. 374 - p.375 Not clear why does the incremental cost of tooling increase in the case of front doors, but it decreases in the case of rear doors although same material and manufacturing technologies have been used. Similarly, only in the case of decklids among closures and fenders the incremental cost is positive.	Section 9.6.2.2	These numbers are based on the tooling cost estimates for each part in each assembly. Because different design are used for different parts, no a particular trend should be expected,	Section 9.6.2.2
54	Sujit Das	11	Chapter 9: p. 392 Figure 449: Incremental direct costs seem to be quite optimistic, since in most cases less than $50 particularly in the case of aluminum. If incremental costs were that low, we would have seen more aluminum penetration in today's vehicles.		Over 40% of hoods are already mass produced in aluminum in Europe. Approximately $100 increase in manufacturing cost for the aluminum front and rear doors is a significant cost increase for approximately 30kg mass saving for high volume base vehicles like the Honda accord.	No change required
55	Sujit Das	11	Chapter 9: p. 393 Sect. 9.8.1 What's the source of 0.7 secondary mass savings factor used in the analysis? LWV mass savings cost curves analyses seem to be reasonable but the cost optimization has been shown entirely based on alternative body structures. For the example shown, out of 0.7 secondary mass savings, 0.25 is from the body. But the present analysis of body components is based on the savings due to lightweighting, which should have been separated between savings between lightweighting and mass compounding. This type of analysis should have been done when the component level initial designs were evaluated. This analysis seems to have been done after the fact in order to check whether the cost target has been achieved. Since mass compounding analyses shown on Figures 450 thru 452 are not based on the baseline vehicle under consideration in the report, the significance of its discussion in the report is unclear. The actual mass compounding analysis should have been based on similar type of analysis from the beginning part-by-part analysis instead of looking at the impacts at the end.	Sect. 9.8.1	The bases of 0.7 kg secondary mass saving for each kg of primary mass saving is explained in the report. See response to comment #5 above for Sujit Das.	Sect. 9.8.1
56	Sujit Das	11	Chapter 9: p. 378 Sect. 9.6.3 Although it is mentioned in the text that there is no increase in material cost in the LWV case due to mass savings, but material cost increase has been shown in Figure	Section 9.6.3	Report Updated (9.6.3). That statement is only for the front bumper as noted in the report.	Section 9.6.3

			426 in the case of rear bumpers.			
57	Sujit Das	11	Chapter 9: p. 389 onwards Other systems and powertrain costs were estimated based on the difference in component masses and material prices. Better documentation of data sources would be useful.	Chapter 9	Report Updated - the estimates are only based on material savings	Section 9.6.9, 9.6.10, 9.6.11
58	Sujit Das	11	Chapter 9: p. 379 Sect. 9.6.4 Although in the first paragraph, it has been mentioned that the suspension was assumed to be purchased from a supplier and so an additional markup was applied, but the rest of this section discusses the detailed cost results using the TCM approach based on CAD data. Which approach was finally used? Was there any difference in TCM cost analysis assumptions between the body structure and suspension, since in the latter case the markup was used but not in the former case?	Section 9.6.4	The difference here is that body structure is normally manufactured by OEM and suspension parts are normally supplied by parts suppliers. For supplier supplied parts, a markup is applied to reflect the indirect cost from the supplier. Suspensions are redesigned by EDAG. So EDAG estimated the direct manufacturing cost based on the CAD design. After the direct manufacturing cost is estimated, a multiplier is applied to reflect the indirect manufacturing cost from the supplier.	Section 9.1, Section 9.6.4
59	Sujit Das	11	Chapter 9: p. 388 Sect. 9.6.5 It is surprising that baseline front seat is more than 2X heavier than the rear seat?	Sect. 9.6.5	The rear seat was predominantly foam on a light wireframe. It is a fixed rear seat unlike the heavy mechanisms on the front seat. The baseline vehicle seat components are weighed during the benchmarking. The weights in the report are accurate.	No change required
60	Sujit Das	11	Chapter 9: p. 389 Sect. 9.6.6 It looks like SG&A and Profit factors used to estimate the final IP beam cost is different than those used earlier for other component cases.	Sect. 9.6.6 (now 9.6.9)	No, they are supposed to be the same. The correction has been made in the report.	Section. 9.6.9
61	Sujit Das	11	Chapter 9: p. 395 Figure 453. It appears that there has been confusion between cost and price. So far, all incremental cost discussion has been based on cost, since the factor 1.47 was never used to convert to the retail price equivalent. Since the price increase target for the LWV is below 10% of the baseline MSRP, all mass compounding effect comparisons should have been based on MSRP.	9.8.1	Footnote added to define Retail Price value and 10% value. Please also see response to comment #10 above for Sujit Das.	Section 9.8.1

62	Sujit Das	12	Chapter 10: 1. A very detailed analysis of the effect of 'Learning' on resistance spot welding vs. laser beam welding has been provided but without incorporating any of its results in the final cost analysis. The analysis should have been extended to other components particularly aluminum body closures which would have significant impacts on the final results of the study.	Chapter 10	Addressed in Report (9.6.1.7)	Section 9.6.1.7
63	Sujit Das	12	Chapter 10: p. 438 Figure 513. Estimated sub assembly cost of spot welded body structure does not match the estimates shown on Figure 414 or Figure 416.	10.5.6.4	The observation of the reviewer is correct. The costs in Chapter 10 are based on a separate study. Then the results from Chapter 10 are applied to the light-weighted Accord. The report has been updated to take into consideration the results from Chapter 10 (Effects of Learning)	10.5.6.4, 9.6.1.7
64	Sujit Das	12	Appendix C & F: Although incremental cost estimates for various components in these two appendices appear to be the same, but the absolute costs of Baseline and LWV are different.	Appendix C, Appendix F	Report Updated. Appendix C was outdated and removed. Appendix F is now Appendix E	Appendix E
65	Sujit Das	12	Excel Cost Model Files: Energy calculations should be considered under "Process" and not "Plant".	Cost Model	The calculations are based on the cycle time of the process; however the costs are part of the plant energy consumption.	No change required
66	Sujit Das	12	Excel Cost Model Files: BIW cost models seem to be reasonable and calculations at the specific component level have been captured really well. Cost models are well designed by including five distinct tabs to capture different types of part data and calculations. The models are not currently designed for user-friendliness in order to do the sensitivity analysis which is essentially to examine the robustness of model results.	Cost Model	There is a tab in the model to do a sensitivity of the costs with respect to material prices. All the assumptions for volatile costs such as energy, labor, facilities etc. are clearly shown in the model. Sensitivity can be done if needed. These models were created to estimate the costs and show the results in a very transparent intuitive manner.	No change required
67	Sujit Das	12	Excel Cost Model Files: It'd be useful if sequential manufacturing process steps used for each part manufacturing under each cost model are explicitly mentioned in one of the worksheets (may be under Introduction worksheet as shown by Process Planning Sheets as an example which has not been updated in any component cases). It'd have then demonstrated the actual implementation of the TCM approach used in the cost estimation. Since in most cases same GenericProcessInputs worksheet is used, the specific inputs for a given component is	Cost Model	The sequential manufacturing process is explicitly shown in the report. The Introduction Worksheet explains the overall methodology; it is the same approach for all the processes. It was intentional to use the same "GenericProcessInputs" for all the cost models to show that cost methodology was consistent for all the parts in the study.	No change required

			not intuitive/explicit.			
68	Sujit Das	12	Excel Cost Model Files: Assembly models are quite impressive and results seem to be reasonable. Models appear to be quite similar to the ones developed by EDAG for WorldSteel last year.	Cost Model	Same team as the WorldAutoSteel Program worked on this project; hence the similar models were developed and used for this study.	No change required
69	Sujit Das	12	Excel Cost Model Files: What is "BIW" sub-assembly in baseline BIW assembly model but not indicated in the LWV model?	Cost Model	The names are generic in the Cost Model. Refer to the Assembly Details or Numbers for the specific sub-assembly details. Assembly layouts for both the baseline and LWV are shown in the report (Appendix)	No change required
70	Sujit Das	12	Excel Cost Model Files: LWV Cost model – Al material inputs hyperlinks are provided at the beginning of the worksheet "PartManufacturing Results" although no aluminum option was considered for the final LWV design.	Cost Model	Some of the options were considered earlier and hence shown in the cost model. The results clearly show the options used	Cost Model
71	Sujit Das	13	Excel Cost Model Files: Since assembly costs of mainly body components have been considered, what about assembly costs related to non-body components, i.e., chassis, powertrain, interior, electrical etc.	Cost Model	As stated in the report Section 9.2.3 the cost models are only for the incremental costs; only the modified sub-assemblies/assemblies were assessed for costs	Section 9.4.2, Footnote 180
72	Sujit Das	13	Excel Cost Model Files: Factors used for Tool Investment, Line Rate, and Reject Rate under the Materials List for aluminum seem to be quite optimistic, particularly in the case of reject rates of various unit operations in the case of magnesium IP casting. These factors have a tremendous effect on the final results and documentation of the information source would be useful.	Cost Model	These factors are based on research and discussions with industry experts as stated in the report. The reject rate of magnesium IP casting was discussed with manufacturer and casting reject rates are normally low.	No change required because these assumptions are part design related, not generic assumptions.
73	Sujit Das	13	Excel Cost Model Files: Rear_Frame: Value missing in profit estimation cell component	Rear Frame Cost Model	Value is added to cost model.	Rear Frame Cost Model
74	Sujit Das	13	Excel Cost Model Files: Front_Suspension Components Model: Not sure how LWV Lower Arm costs have been estimated. Part of the cost is estimated based on similar component cost estimate of $8.13 four times in this spreadsheet. It is likely that assembly costs between the baseline and LWV designs would be different, since it also includes assembly of dissimilar metals such as AHSS and aluminum.	Cost Model	The LWV uses a McPherson strut front suspension. The lower control arm is AHSS stamped assembly with ball-joint to an aluminum knuckle connection. The baseline vehicle uses Double wish-bone front suspension, with cast iron lower control arm with ball-joint connection to a cast/forged iron knuckle. It is assumed that this type of assembly takes similar	No change needed.

					equipment and labor to accomplish. The use of dissimilar metals on the LWV does not lead to any special (additional steps) for assembly. Total assembly cost for both suspensions is calculated to $15.80.	

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