

Steel E-Motive Engineering Report

Development of a new vehicle and body structure for a fully autonomous, Mobility as a Service vehicle, featuring the latest advanced high-strength steel material grades and manufacturing processes



IN PARTNERSHIP WITH



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1.0 Preface

This report documents the results of the Steel E-Motive engineering programme. The Steel E-Motive programme is the most recent addition to WorldAutoSteel's series of initiatives demonstrating steel solutions that help address the affordable, sustainable and safe mobility challenges that are facing automakers, governments and policy makers around the world.

This programme follows the Ultra-Light Steel Auto Body (ULSAB) 1998, the Ultra-light Steel Auto Closures (ULSAC) 2000, Ultra-light Steel Auto Suspension (ULSAS), ULSAB-AVC (Advanced Steel Concepts) 2021 and Future Steel Vehicle (FSV) 2013.

WorldAutoSteel has commissioned Ricardo (<https://www.ricardo.com/en>), to conduct the engineering development of 2 vehicle design concepts, codenamed SEM1 and SEM2, which are fully autonomous battery electric vehicles for use in Mobility as a Service (MaaS) operations. With its engineering partner ARRK, the vehicle designs were developed from "clean sheet", with the specific focus on the body structure, demonstrating how the latest Advanced High-Strength Steels (AHSS) can be applied to address the requirements and challenges for this next generation of personal transportation vehicle.

1.1 WorldAutoSteel member companies

- ANSTEEL
- ArcelorMittal
- Baowu
- CSC
- Erdemir
- HBIS Group
- Hyundai Steel
- JFE
- JSW
- Kobelco
- Nippon Steel
- Nucor
- POSCO
- Tata Steel
- Ternium
- Usiminas
- U.S. Steel
- Voestalpine

1.2 Steel E-Motive programme engineering service providers

- Ricardo (lead)
- ARRK (support)

1.3 Steel E-Motive lead project team members

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Hyundai, Jongmin Lee
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Harry Jones

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2.0 Executive Summary

2.1 Introduction & motivation for the Steel E-Motive programme

Privately owned passenger cars have long been the go-to transportation mode for personal, land-based mobility. A number of influencing factors are now contributing to a significant shift in personal transportation modes. Climate change threatens the health, safety and wellbeing of everyone on the planet, with a significant reduction in Greenhouse Gas emissions identified as the primary solution to global warming. The transition from fossil fuelled internal combustion engines to hybrid and electric propulsion systems should help address climate change to some extent, but the impact of this will also be dependant on the ability to decarbonise vehicle manufacture and electricity used to charge vehicle batteries.

Population growth and societal changes such as the growth of mega-cities, continued urbanisation trends, personal expenditure and vehicle ownership & running costs will also change the demands on personal transportation. Despite advances in vehicle safety technologies, car design and the introduction of vehicle safety tests, requirements and legislation, fatalities, and serious injuries as a result of road traffic accidents are still excessive. Future mobility solutions must continue the path of for improved road safety.

The continuous development and implementation of new technologies into passenger cars and clean energy will help to address the challenges and accelerate the shifts in transportation modes. The first generation of Battery Electric Vehicles (BEV) technologies are already well established. The continued growth in BEV sales and shifts to clean energy electricity sources are expected to result in an overall reduction in GHG emissions from passenger cars in the coming years. Subsequent generations of BEVs will feature improvements in battery technology and charging, offering higher capacity at lower costs and production carbon intensity.

Autonomous vehicle technologies continue to develop and become more accessible. Vehicles featuring SAE levels 1 to 3, with semi-autonomous functions such as hands-free driving are starting to become mainstream. A number of fully autonomous vehicles (SAE level 5) are currently in pilot and demonstration phases, with mainstream rollout expected in the 2030 to 2035 period. Fully autonomous vehicles will enable freedoms and potential not experienced with human operated vehicles so far. Passenger convenience can be enhanced from the leisure or work time gained from not operating (driving) the vehicle. Disabled and physically impaired persons could have more readily available access to transportation with fully autonomous vehicles. The connectivity required from autonomous vehicle to vehicle (V2V) and vehicle to infrastructure (V2X) will enable traffic flows to be better controlled and regulated, resulting in improved journey times, and reduced traffic congestion. With proper regulation, autonomous vehicles should result in fewer traffic collisions, with deaths and serious injuries reduced. With excessive speed, appropriate use of safety restraint systems (seatbelts) and drug and alcohol misuse cited as the primary cause of road traffic deaths and injuries, autonomous vehicles should prohibit such violations in operation. Cost of ownership benefits could also be realised with reduced labour costs for vehicle operation and shared mobility (increased vehicle occupancy) lowering journey costs for users.

The Steel E-Motive programme encapsulates the emerging trends in shared mobility and vehicle technologies and has delivered new vehicle concept designs that demonstrate how Advanced High Strength Steels can help to deliver a cost effective, sustainable and safe transportation solution of the future.

2.2 Key Results From The Steel E-Motive Programme

The Steel E-Motive programme has engineered 2 vehicle design concepts, with specific focus on the AHSS body structures. SEM1 is a compact, 4 passenger vehicle intended for city type journeys, such as home to office, home to school, shopping and leisure activities. It has a 75kWh battery electric propulsion system with a front axle, single speed electric motor. SEM2 is a larger derivate of SEM1, seating up to 6 passengers and is intended for longer, higher capacity journeys such as city to city and city to airport type journeys. SEM2 features a larger 96kWh battery and front and rear electric motors. Both vehicles are specifically engineered to have full (SAE level 5) autonomy operating 100% of the time. Both SEM1 and SEM2 have 4-wheel steering, enabling a smaller turning radius which enhances vehicle manoeuvrability in confined spaces such as parking lots and hotel forecourts.

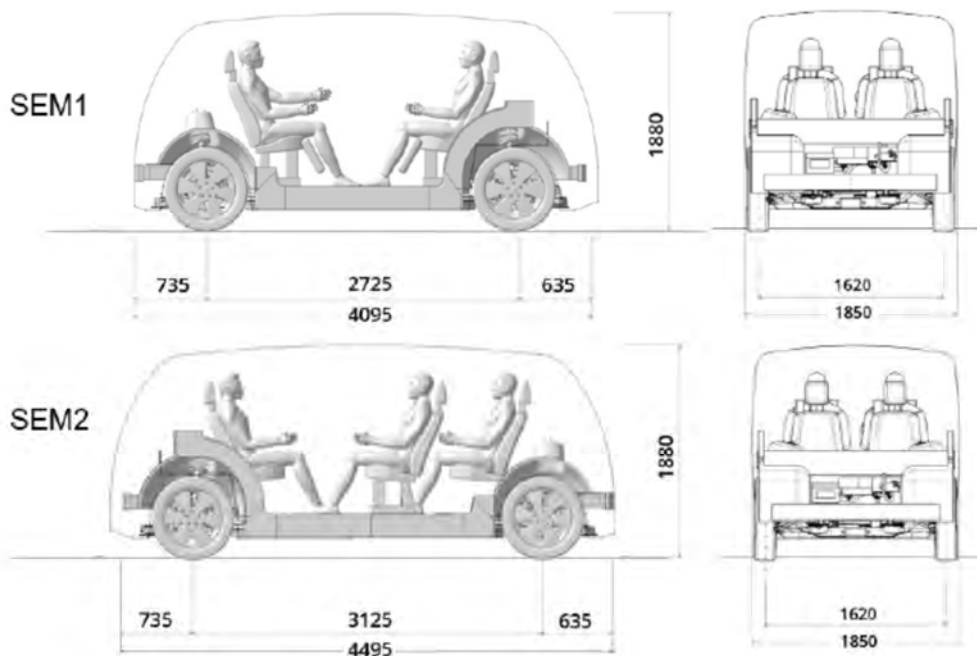


Figure 2.2.1 SEM1 and SEM2 overall vehicle dimensions

The vehicle curb and gross weights of SEM1 and SEM2 are summarised below.

| | SEM1 | SEM2 |
|---------------------------|-------------|-------------|
| Vehicle curb weight (kg) | 1512 | 1873 |
| Vehicle gross weight (kg) | 2012 | 2548 |

A styling exercise was undertaken to develop a brand identify for the Steel E-Motive vehicles and an exterior styling A surface developed. A complete vehicle 3D packaging and layout study was undertaken, sizing and positioning the occupants and major vehicle systems such as powertrain, chassis, electrical, safety. This coupled with the exterior styling A surface provided a “workable” volume, from which the AHSS body structure could be engineered. Computer Aided Engineering (CAE) optimisation tools were used to help determine the main

loadpaths through the body structure. These were then interpreted and developed into the preliminary body structure concept. The body structure main section profiles and joint designs were then optimised and AHSS grades and fabrication methods selected for the primary concept. CAE structural analyses were then used to guide the design and AHSS grade and gauge assignment.

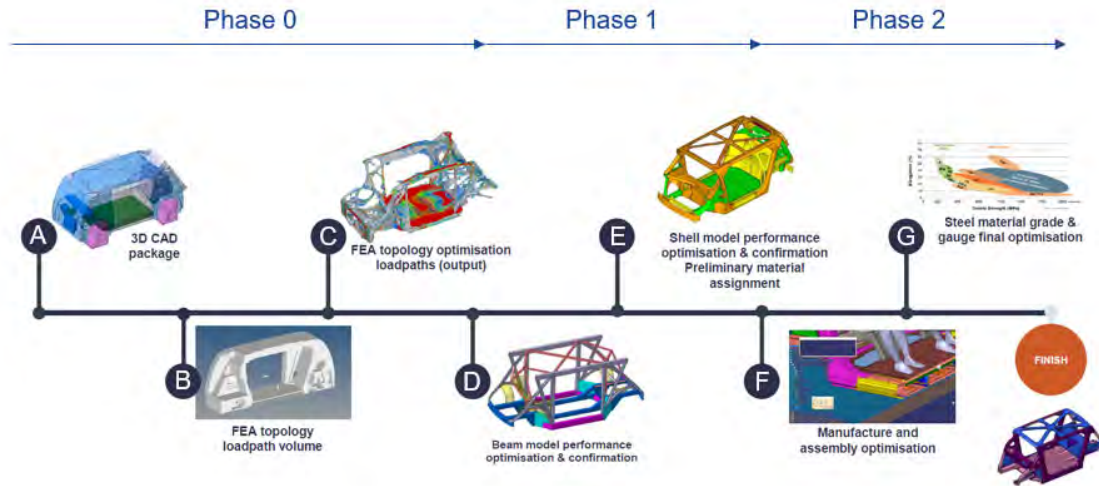


Figure 2.2.3 Approach for the development of Steel E-Motive body structure

Figure 2.2.4 shows the final SEM1 body structure and body in white designs and AHSS grade utilisation.

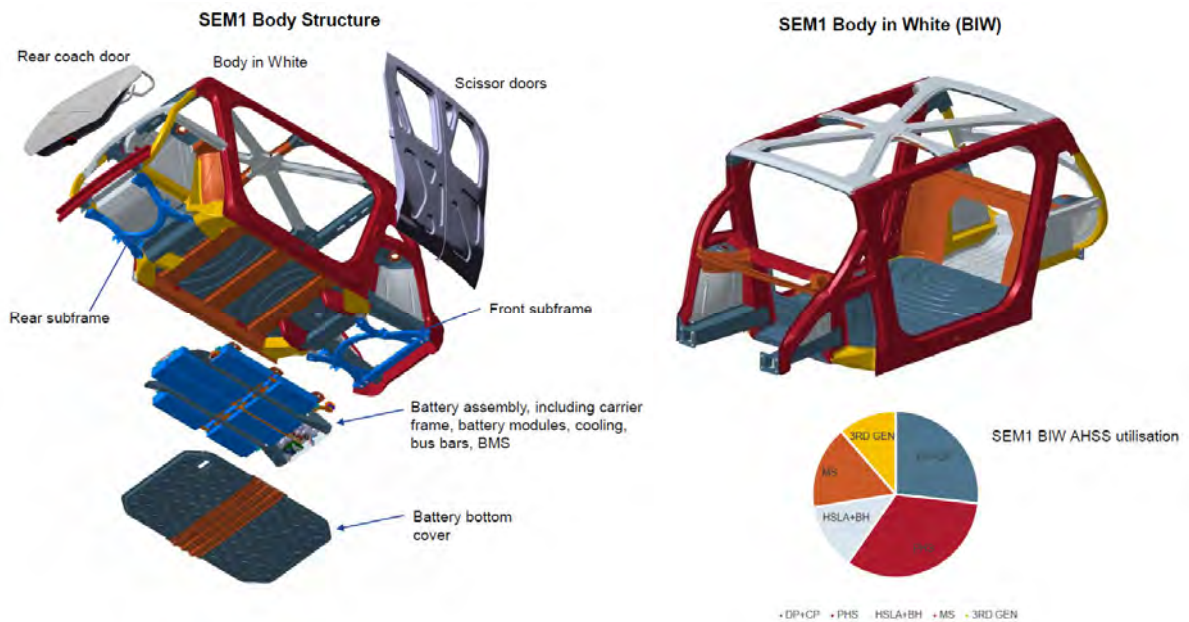


Figure 2.2.4 SEM1 body structure, body in white and AHSS grade utilisation

The SEM1 vehicle and body structure achieved the following performance attributes:

Vehicle performance and range: maximum vehicle speed = 130kph, up to 500km range on a single charge (WLTC cycle), vehicle turning circle radius of 7.4m, achieved by using 4-wheel steering.

Cabin comfort and ergonomics: Comfortable ingress and egress (entry and departure) from the vehicle is ensured by 1) a low step in height 2) wide (>1.0m) door aperture/opening width 3) flat floor interior (enabled by electric powertrain and unique battery frame concept (see below)). 4 occupants are seated in an inward facing configuration

Weight: Vehicle curb weight = 1512kg. This is 27% lighter than a typical current production battery electric vehicle of comparable size to SEM1. This was achieved by removing the driver interface systems (such as steering wheel, pedals, instrument cluster), applying expected weight savings as a result of battery technology improvements, AHSS body in white weight optimisation savings and secondary savings achieved from a complete vehicle weight optimisation study. The final body in white achieved a weight of 282kg. This is calculated to be 25% lighter than an expect/benchmark weight for a vehicle of comparable size and proportions. This was achieved using a combination of AHSS grades and properties, using gauges as low as 0.7mm in thickness, coupled with appropriate design and body construction methods.

Lifecycle greenhouse gas emissions: A complete vehicle lifecycle assessment and optimisation study was performed, concluding that a reduction of up to 86% CO₂ equivalent greenhouse gas emissions could be achieved comparing a current (2022) battery electric vehicle and SEM1 in full operation in Europe in 2035. This reduction was achieved considering a number of factors and measures, including, efforts to decarbonise vehicle production such as “green steel” and reduced carbon batteries, optimising vehicle design, minimising weight and scrap, considering future electricity grid decarbonisation using renewable sources such as wind and solar power, considering the operational efficiency improvements of autonomous vehicles, extending the lifetime of the vehicle and batteries and assuming increased passenger occupancy in order to reduce the number of specific vehicle journeys per passenger-kilometer.

Safety: SEM1 is engineered to the latest high speed crashworthiness tests and requirements. Computer Aided Engineering crash simulations were used to evaluate and optimise the vehicle design:

- USNCAP 56kph frontal rigid barrier (FFB). Maximum deceleration pulse of 33.1g and maximum intrusion of 1.8mm. These are expected to provide good levels of occupant protection.
- IIHS 64kph front offset deformable barrier (ODB). Maximum deceleration pulse of 20.5g and maximum intrusion value of 5.2mm. These are expected to enable SEM1 vehicle to achieve the IIHS “good” rating (highest) for this test.
- IIHS 64kph front small overlap rigid barrier (SORB) test. Maximum deceleration pulse of 19.9g and maximum intrusion value 74mm. These are expected to enable SEM1 vehicle to achieve the IIHS “good” rating (highest) for this test.
- IIHS 60kph side moveable deformable barrier. Minimum intrusion clearance from seat centreline calculated at 296mm versus >180mm target. These are expected to enable SEM1 vehicle to achieve the IIHS “good” rating (highest) for this test.
- USNCAP 32kph side pole (4 locations assessed). IIHS side crash intrusion targets were used to assess occupant protection performance in this loadcase. Performance

indicated that IIHS “good” rating to be achieved. This loadcase is particularly challenging for protection of propulsion battery. Results showed that there is no risk of contact between battery housing structure and modules. This means that there is minimal risk to rupture and damage to the battery which may lead to thermal runaway and fire incidents.

- FMVSS305 EV Rear 80kph 70% overlap moving deformable barrier. Maximum acceleration pulse of 22g and 30mm intrusion. Results suggest minimum risk of injury to occupants.
- IIHS roof crush. Achieved roof strength load to vehicle weight ratio (SWR) of 9.58, exceeding the requirement of >4.00 for attaining IIHS “good” rating.
- Additionally, SEM1 was assessed for the EuroNCAP 50kph 50% overlap moving progressive deformable barrier (MPDB) and NHTSA 90kph oblique deformable barrier front loadcases. In both cases the predicted deceleration pulses and intrusion levels demonstrated good levels of performance.
- For all crashworthiness loadcases, the body structure maintained it’s integrity around the passenger compartment and battery housing.
- One of the most significant engineering challenges in the Steel E-Motive programme was achieving the IIHS “good” rating for the 64kph front SORB test and the low pulse and intrusion levels in the 56kph FFB test. These crash loadcases have conflicting requirements on the body structure. The SORB test requires a very strong front corner structure such that the vehicle can react the barrier crash loads enabling the vehicle to “glance” off the barrier. This results in lower crash pulse and intrusion levels. The front FFB loadcase requires a structure that will crush and collapse progressively in a controlled manor, to fully decelerate the vehicle and minimise pulse and intrusion. The balance was achieved through careful design of the front crash structure and selection and tuning of the AHSS grades and gauges.
- The Steel E-Motive vehicles will also benefit from the advanced safety features and functionality that fully autonomous vehicles bring, such as collision avoidance and autonomous emergency braking. With these system, the likelihood of an accident should be significantly reduced. Should a collision occur, the occupants and battery are sufficiently protected by the AHSS body structure. Whilst the development and engineering of the autonomous vehicle systems was not specifically addressed in the Steel E-Motive programme, the body structure design does account for the positioning, packaging and mounting of the autonomous sensors and processors.

Stiffness and strength: SEM1 body structure achieves static torsional stiffness of 63,285Nm/degree versus a target of 25,000Nm/degree. This means that the risk of issues such as “squeak and rattle” of body and trim parts would be minimised. The static vertical bending stiffness was calculated at 13,438N/mm versus a target of 9,000N/mm.

The body structure was assessed for fatigue and durability using quasi-static loads and non-linear stress FEA. The results showed no areas of concern. The predicted peak stresses in the body structure were well below the infinite life fatigue strengths for the AHSS grades selected.

Noise Vibration & Harshness (NVH): First body structural mode at 32Hz and first battery mode at 35Hz. These attain sufficient decoupling from other vehicle system modes such as powertrain and suspension. The attachment dynamic stiffness (driving point inertance) at key chassis interfaces are at least 5 to 10 times the local bushing stiffness. This ensures that the Steel E-Motive vehicle achieves competitive interior noise and vibration levels

Manufacture and assembly: The SEM1 BIW is divided into 3 main zones – the front mid and rear. Each zone is then subdivided into primary assemblies and sub-assemblies. The definition of the zones, assemblies and sub-assemblies follows a conventional high-volume passenger car with a stamped steel body structure. This means that existing vehicle manufacture and assembly facilities could be used for the mass production of SEM1 (and SEM2). This reduces investment and capital expenditure costs for the vehicle. Production volumes of >250,000 vehicles per year would be possible with such manufacturing methods.

Vehicle Cost and Total Cost of Ownership: Both Steel E-Motive vehicles feature stamped steel body structures, using high volume manufacturing methods which deliver low unit costs. The body structure uses fabrication methods that help to deliver high material utilisation and low scrap rates, reducing the overall quantity of steel required and contributing to lower overall cost. SEM1 and SEM2 are based on a common platform principle. SEM2 features 68% carry over/common parts from SEM1. Vehicle operator running costs and passenger journey costs are expected to be competitive with alternative personal transport modes due to the autonomous driving characteristics and fleet volumes assumed in operation.

2.3 Key Innovations

Using the newest steel grades and fabrication processes, Steel E-Motive's portfolio enables tailoring vehicle properties that achieve significant safety, cost, and comfort advantages with eight key innovations only possible using steel:

1. **Autonomous vehicle AHSS body structure**, specifically engineered to accommodate fully autonomous vehicle operating conditions and requirements. The front occupants are positioned rear facing towards the front of the vehicle and the BIW B pillars are housed within the door structure. The passenger side doors have a “scissor” type motion (sliding). The seating position and door configuration enable a more open, spacious feeling interior compared to a conventional passenger car. A wide door aperture provides improved occupant ingress and egress to and from the vehicle. The body in white achieves competitive weight and stiffness performance as a result of structural loadpath optimisation, section size and joint design optimisation and the stiffness and strength properties of AHSS.
2. **AHSS Passenger Protection Zone** provides excellent crashworthiness protection for the rear-facing front passengers in the event of a frontal or side collision.
3. **Short Front Crash Zone** structure meets the most stringent global crash requirements. Dual Phase (DP) Tailor Welded Blanks enable efficient design.
4. **Small Overlap Front Crash Glance Beam**, a specific module of the front crash structure that guides (“glances”) the vehicle along the IIHS 64kph small overlap impact barrier. This results in reduced crash intrusion and deceleration pulse values. The glance beam allows the front crash structure to deform in front crash loadcases with greater offsets, such as IIHS moderate overlap and frontal rigid barrier.
5. **(Rocker) Hex beam energy absorbers**, made of roll-formed DP steel, are low cost, compact, and weight efficient devices providing side crash energy absorption, providing protection for the occupants and propulsion battery.

6. **Hydroformed in-door B-Pillars**, featuring a compact cross section profile providing greater glazed area for better passenger visibility. The side doors provide coverage for most of the body structure side area, therefore the conventional body side outer A surface panels have been deleted, providing cost and weight savings.

7. **Integrated Battery Carrier Frame**. The battery is integrated into the body in white lower structure, resulting in the conventional “generation 2” battery housing side and upper/cover parts to be deleted. The battery modules, cooling system and electrical connectors are mounted to an AHSS carrier frame. The frame is then inserted and bolted into the BIW housing cavity. The BIW floor acts as the battery top cover and the BIW rocker provides side crash protection. The installed frame enables a compact package, resulting in low floor height and flat floor which gives improved occupant ergonomics. A 3-sheet bottom cover provides protection from underneath. The integrated carrier frame results in significant cost and weight saving without compromising battery safety, durability. The battery modules are easily accessible, meaning that the individual damaged or expired modules could be easily replaced instead of replacing the complete battery pack.

8. **Semi-glazed lattice roof structure**. A large, glazed area enhances the open & spacious feel to the cab, whilst the structural members provide the stiffness and strength required

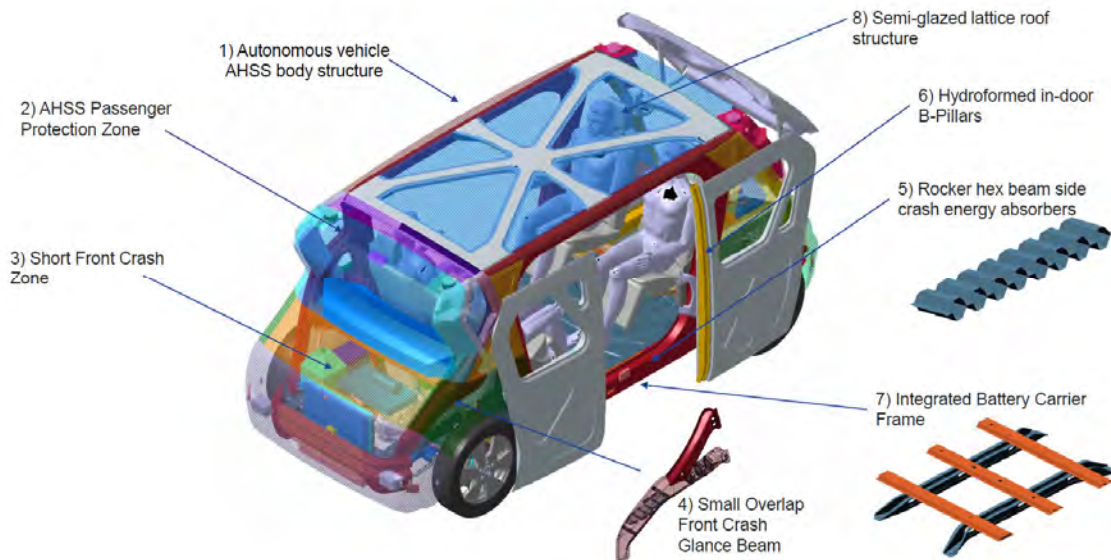


Figure 2.3.1 Steel E-Motive key innovations (shown on SEM1)

2.4 Development of SEM2 variant

The larger SEM2 vehicle variant was engineered during the concept definition Phase 0 where the base layout, package and specifications were determined. Detailed engineering of the body structure was undertaken during Phase 2, concurrently with the development of SEM1. The target was to maximise part commonality between SEM1 and SEM2 such that costs and manufacturing complexity could be minimised. The additional size and space of SEM2 was achieved by increasing the vehicle wheelbase and overall length by 400mm, with the mid zone effectively extended at a point rearwards of the midpoint. This enabled the front

and rear zones to be largely carry over/common with SEM1. The scissor doors are largely carryover as an additional C pillar was incorporated to maintain a common body side door aperture profile. Commonality in the SEM1/SEM2 roof structures was achieved by creating an add-on roof portion at the rear of SEM2. Figure 2.4.1 shows SEM1 and SEM2 at vehicle level and Figure 2.4.2a shows a comparison of the body structures.

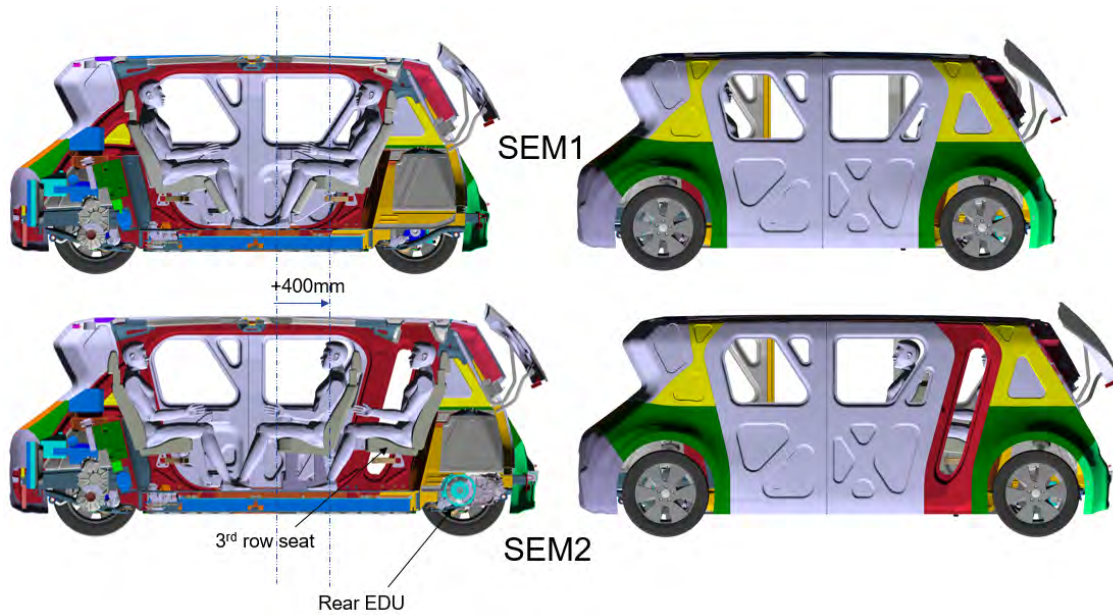


Figure 2.4.1 Comparison of SEM1 and SEM2 vehicles

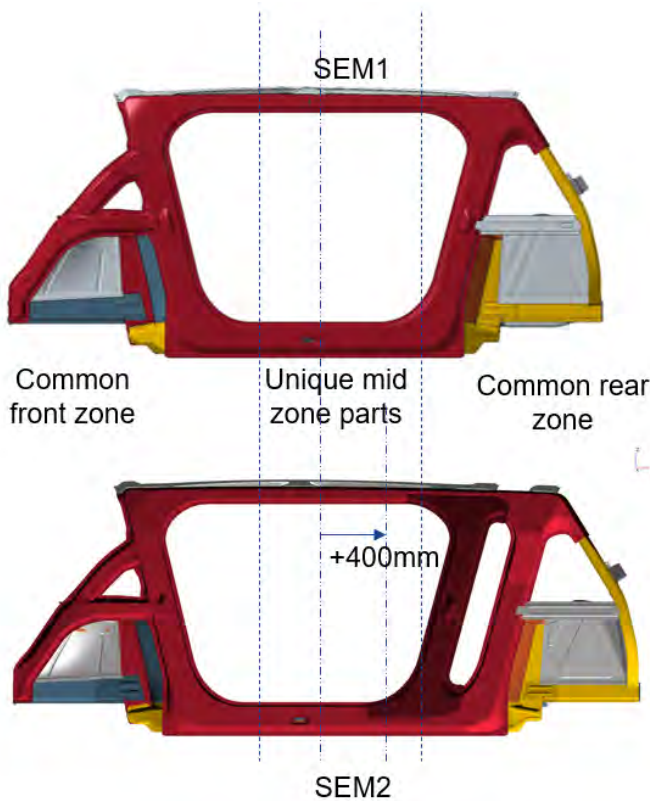
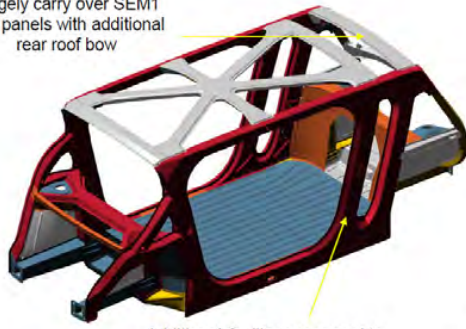


Figure 2.4.2a SEM1 and SEM2 Body in White

Largely carry over SEM1 roof panels with additional rear roof bow



Additional C pillar over-panel to provide occupant side crash protection
Larger TWB PHS door ring

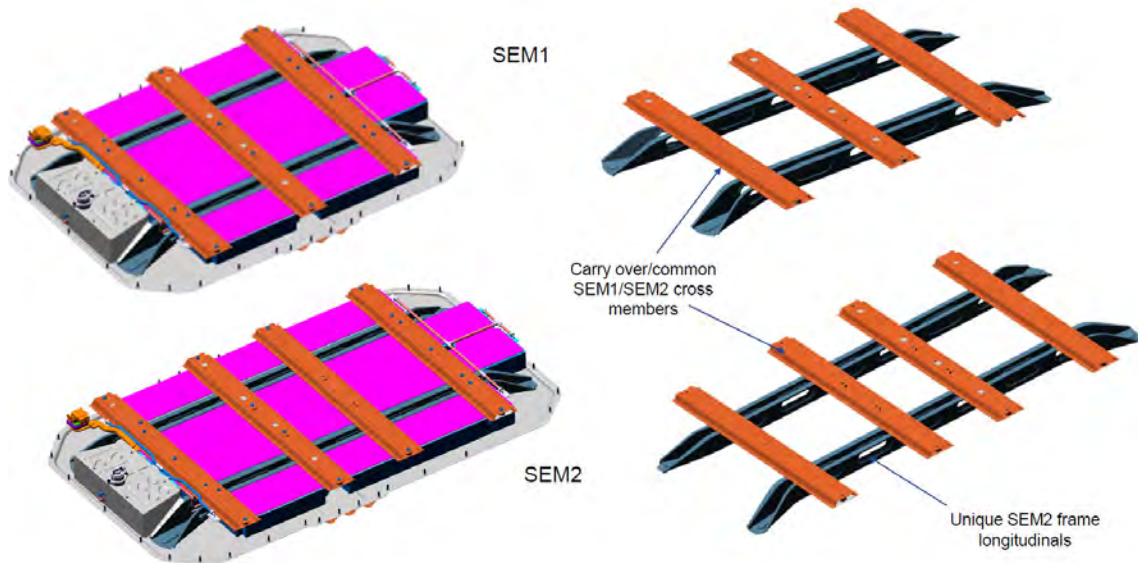


Additional "Three A bar" (duplicate SEM1 Three bar)
Provide side pole barrier protection

Figure 2.4.2b SEM2 Body in White

By adopting a platform approach, 156 out of a total of the 229 BIW parts (68%) are common between SEM1 and SEM2. 53 unique BIW parts are required for SEM2 and 20 parts are common geometry but will require material grade change. The SEM2 BIW weight achieved 323kg versus a target of 361.9kg.

The battery capacity of SEM2 was increased to 96kWh, ensuring the vehicle performance and range in line with the targets. The same carrier frame concept was used for the SEM2 battery pack. Part commonality was assured using SEM1 design of carrier frame cross members. Unique SEM2 frame longitudinals and battery bottom covers were required due to the increased length and wheelbase.



2.5 Additional SEM1 and SEM2 engineering studies conducted by academic institutions

Throughout the Steel E-Motive programme, a number of supporting studies and projects were undertaken by academic institutions. This enabled undergraduate and research students to apply and develop their engineering skills on an advanced vehicle technology programme, whilst the Steel E-Motive programme benefited from the external perspectives and expansion of the Steel E-Motive vehicle concepts beyond their original brief.

- 1) Development of hydrogen fuel cell powered variant of SEM1. Loughborough University (UK), MEng student final year engineering project. The study successfully demonstrated a SEM1 vehicle concept design with the powertrain converted to an hydrogen fuel cell. Performance simulations were used to validate the vehicle range and support the fuel cell specification. A 3D CAD design study packaged the main powertrain systems and components (shown in Figure 2.5.1)

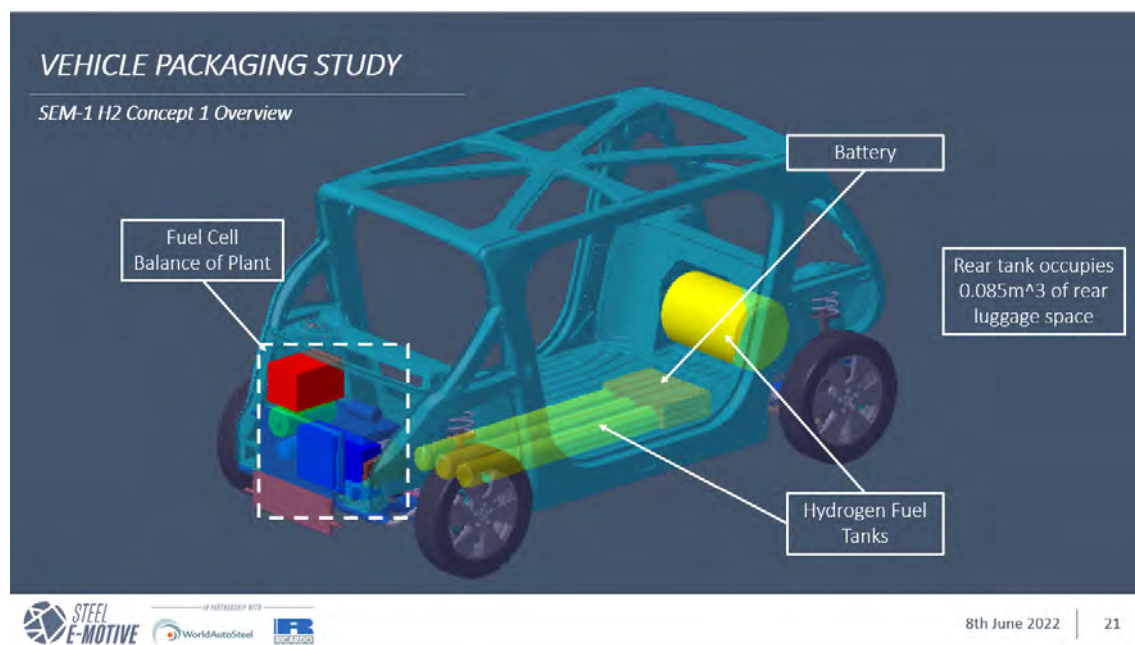


Figure 2.5.1 Loughborough University (UK) MEng final year engineering project to develop fuel cell powertrain variant concept of SEM1

- 2) Michigan Tech University (MTU) – Senior Capstone Project #1: Steel E-Motive Side Door Functionality, Door Hinge Assessment

The MTU Senior Capstone Design Team, sponsored by WorldAutoSteel and the Auto/Steel Partnership, were challenged to develop an improved door and hinge for the Steel E-Motive side closure mechanism. MTU's design solution uses a four-bar linkage hinge design to keep the door parallel to the body of the vehicle to avoid damage to either the door or the body. The team used a 4:1 gear ratio for the drive motor to open the door. Finally, one of the pins in the secondary arm linkage is accessible by passengers and removable, allowing users to manually push the door open in the event of an emergency.

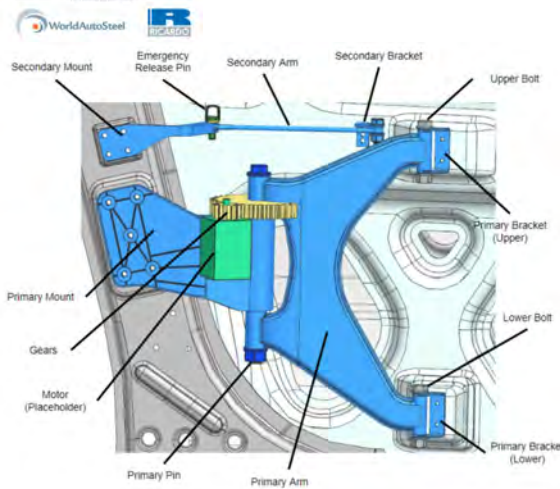


Figure 2.5.2 MTU Capstone project to enhance the design of SEM1 scissor door hinge and drive mechanism

- 3) The Ohio State University undertook a Senior Capstone Project to confirm the viability of a complex Resistance Spot Weld (RSW) joint comprising of 5 individual sheet layers for SEM1 BIW. This 5-layer stack-up weld project demonstrated technical capability that allow manufacturers to leverage current manufacturing infrastructure, lowering investment costs and improving sustainability.

The welded joint under consideration was the front extended passenger protection zone of the car, specifically the vertical dash brace and upper glance beam reaction area. The various material grades include MS1200, PHS2000, and MS2000 with gauges of 1 to 2 mm and coatings of EG and AS150 (for the PHS grades). The conclusions of the study were as follows:

1. A five-layer stack-up spot weld can be successfully created with advanced high strength steels using a range in number of pulses, currents, forces, and times, indicating sufficient process robustness.
2. Simufact Welding successfully models weld nugget development and final weld size, that allows parameter selection avoiding costly trial and error practices.
3. Using a pulsation current schedule with descending current pulses was just as successful in creating welds as using the same current level pulses. This was perhaps assisted by joint symmetry.

A single spot weld for a five-layer stack-up has greater time and cost efficiency than welding a two-layer and a three-layer stack-up into a combined five layers

- 4) Michigan Technological University (MTU) undertook a Senior Capstone Project to develop a solution for expanding the application of SEM2 vehicle from passenger carrying to goods carrying vehicle. A rapid conversion system was engineered, allowing the vehicle to be transformed from passenger transportation by day to goods carrying by night. This would enable the vehicle to achieve a higher operational time, increasing revenue and profit for operators.

Figure 2.5.3 shows the design concept for the rapid interior configuration system. This design showcases two pairs of T-shaped rails placed in the fore-aft direction of the vehicle. These T-Rails are compatible with a slider system that connects to the bottom of each seat leg. The rails allow adjustment of the interior seats and rapid removal by the use of a depot-based pallet jack accessory

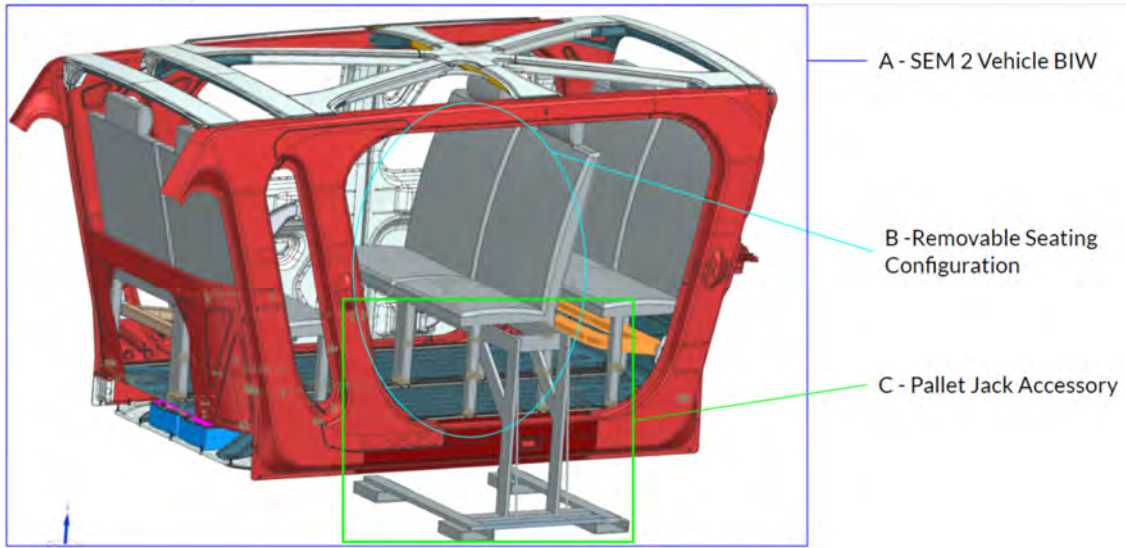


Figure 2.5.3: System level concept – rapid adaptation of SEM2 to autonomous delivery services

3.0 Motivation for Steel E-Motive project: Addressing future transportation challenges

3.1 Introduction

The future of mobility is changing. The mass transportation challenges faced by cities and heavily populated areas can be addressed by automotive technologies and innovations that are forecast to be implementable within the next decade. The fully autonomous vehicle concepts Steel E-Motive, operating in a ride hailing, Mobility as a Service (MaaS) role has the potential to offer a safer, convenient, comfortable, and cost-effective transportation mode. By reducing the net number of vehicles on the road, the impacts of traffic congestion can be alleviated. The Steel E-Motive vehicle concepts are powered by a battery electric powertrain, resulting in zero tailpipe emissions. Vehicle lifetime greenhouse gas (GHG) vehicle emissions can be reduced by considering that electricity supply (for charging the Steel E-Motive batteries) will come from an increasingly renewable (or “green”) source such as wind or solar energy. Vehicle manufacturers and their suppliers, including the steel producers are implementing new production approaches and facilities enabling significant reductions in greenhouse gas emissions. With the combined effects of lower carbon intensive production methods, renewable energy sources, vehicle efficiency built into the design and operation and increasing passenger occupancy rates through ride hailing, it is estimated that lifecycle greenhouse gas emissions could be reduced by up to 86% compared to current day battery electric vehicles operating as personalised taxis. Additionally, the Steel E-Motive MaaS vehicle concept will enable improved mobility access for the underserved population, such as disabled or physically impaired and those living in remote regions with limited or reduced access to public transport.

3.2 Future Transportation Challenges, PESTEL Analysis

The urban transportation challenges of the future are well documented and understood. A PESTEL analysis (Political, Economic, Social, Technology, Environmental and Liability) enables a comprehensive, holistic evaluation of the challenges and is a solid precursor for defining the solutions and the subsequent requirements and specifications of vehicles such as Steel E-Motive. Figure 3.2 shows a PESTEL analysis undertaken for Steel E-Motive.

| Political | Economic | Social | Technological | Environmental | Legal |
|---|---|--|---|---|---|
| - Global trade policies and tariffs | - Access to credit and credit costs | - Consumer behaviour changes (rent/lease vs outright ownership, on-demand, leisure time utilisation, convenience, lifestyle, flexible working) | - Digital and communications growth (connectivity, processing, radar, lidar, computation, artificial intelligence, big data, GPS & mapping) | - Global and local climate change agreements and policies | - Liability and insurance (WRT autonomous vehicles) |
| - Global trade policies and tariffs | - Impact of high inflation | - Ageing population | - Infrastructure improvements (road, rail, sea) | - Local air quality policies and directives | - Product warranty and recall |
| - Global energy security | - Economic growth | - Access to healthcare and improving living standards | - Vehicle propulsion system technologies (battery electric, hydrogen, charging) | - Towards complete life cycle evaluation, policies and regulation | - Data protection and data security |
| - Global stability, (conflict) | - Cost of living (housing, food, clothing, leisure) | - Serving the underserved (impaired, disabled) | - Innovations in materials and manufacturing | - Land, river and sea pollution | - Labour laws and regulation |
| - Urbanisation, housing, health and living standards | - Global and local transportation costs | - Cost of living and wage growth | - Green energy supply and innovations | - Recycling, reuse disposal policies | - Intellectual property management |
| - Population growth | - Raw material costs (iron, steel, precious metal) | - Environmental awareness and responsibility | | - Scarce resources availability and impacts | |
| - Taxation policies (e.g. environment related) | - Cost of environmental impacts (floods, heatwave) | | | - Noise pollution | |
| - Reduced road traffic injuries and towards zero fatalities | | | | | |

Figure 3.2.1 PESTEL analysis

The PESTEL analysis highlights societal trends, such as changes in consumer habits and behaviour, disposable income challenges, health and living standard changes and an increasing awareness and concern by the general population of environmental challenges and impacts. The environmental impacts of transportation and industrialisation are being addressed by global and regional leaders in the form of legislation and targets on greenhouse gas emissions, pollutants and recycling. This is driving developments in low carbon technologies for all types of transportation (land, sea, air) as well as clean & green energy sources such as wind and solar power. Digital and connectivity technologies continue to expand and develop and are being embraced by the automotive industry, enabling features such as autonomous and active safety to be deployed. The PESTEL analysis provides a good foundation for determining future trends which may impact vehicle development and technology.

3.4 Autonomous Vehicle Technology Roadmap

A roadmap analysis (Figure 3.4.1) of future autonomous and Mobility as a Service vehicles was constructed to confirm the validity and expected implementation timing for Steel E-Motive. The top half of the roadmap describes the *enabling factors* which are expected to develop, mature or be implemented within the next 30 years, which will empower the growth of autonomous and MaaS. The lower half describes the expected *outcomes* as a result of the enablers.

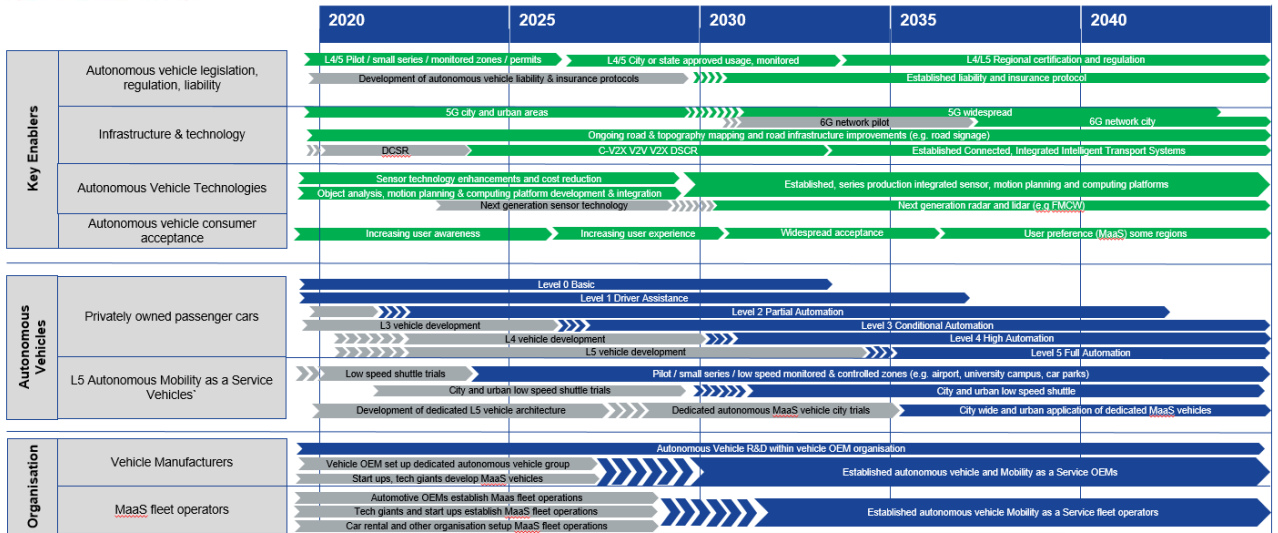


Figure 3.4.1 Autonomous vehicle and Mobility as a Service roadmap (see enlarged version in Appendix 4)

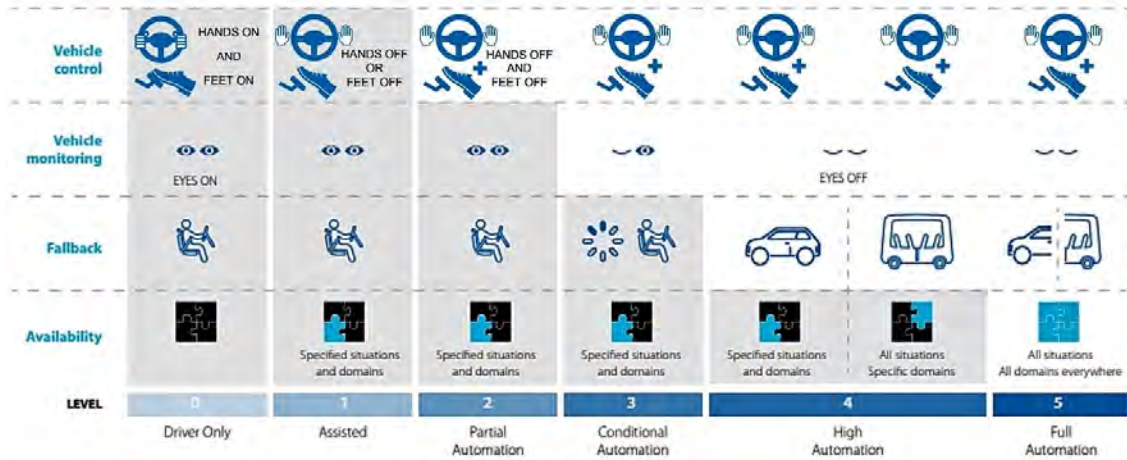


Figure 3.4.2 SAE definitions of autonomous vehicles + explanation

One significant challenge for autonomous vehicles is establishing the liability and insurance responsibilities. In present-day privately-owned vehicles, the operator (driver) is primarily responsible for accidents and damage to vehicles, where the cause can be specifically attributed. Vehicle manufacturers and infrastructure providers can also be liable depending on the nature and cause of accidents. With fully autonomous vehicles, there is no human in-vehicle operator. The users' input to the vehicle or service will be to define a journey start and end point. The calculation of the vehicle route, the control of the vehicles' speed and direction and the decisions it makes will be managed by an on-board computer and will be based on the information it receives from sensors and the pre-programmed algorithms. In the event of an accident or collision involving a fully autonomous vehicle, the liability will then shift from the vehicle operator (driver) to the organisation responsible or liable for governing the actions of the vehicle. This could be the vehicle OEM, the technology supplier or fleet operator. This significant shift in responsibility and liability requires collaboration and agreement between government authorities, vehicle OEMs and lawyers to determine protocols and policies for autonomous vehicles. Additionally, governments and policy makers will be required to develop and implement new legislation, ensuring the safe

operation of autonomous vehicles on public highways. During the timeframe of the Steel E-Motive project, several autonomous vehicle pilot trials were taking place on public highways, where temporary permits or licenses were granted by national or regional authorities. Examples of draft legislation being reviewed at the time of Steel E-Motive project include Article 11 of EU Regulation No. 2019/2144, permitting European Small Series Type Approval (EUSSTA) of fully automated M and N category vehicles, with manufacturers permitted to register up to 1500 vehicles per year. [<https://www.interregs.com/articles/spotlight/draft-eu-regulations-on-the-type-approval-of-fully-automated-vehicles-published-000241>]. Many of the current autonomous vehicle trials require a capable driver to be present. By 2030, the permits to operate are expected to be expanded to larger city-wide fleet trials without trained drivers. By 2035, it is expected that suitable legislation and liability protocols will be established, enabling the operation of fully autonomous vehicles on existing public highways.

The continued development and growth in motion sensing, computational, infrastructure and communication technologies are a key enablers to fully autonomous vehicles. Radar and lidar sensor technologies are currently mature enough to enable fully autonomous vehicle operation. Future development will focus on performance enhancements, size, cost, and safety improvements. Motion detection, calculation and computation technologies will also undergo continued development, enabling greater capacity, cost reduction and safety. Steel E-Motive vehicles are intended to be operated on existing highways therefore offsetting requirements for purpose built, dedicated road networks for autonomous vehicles (i.e., geofenced). Existing highways may require some developments and enhancements to cater for fully autonomous vehicles. The detection of vehicles, objects and road signs requires a clear and unobstructed view from the vehicle, therefore minor improvements to road traffic junctions, roundabouts, traffic signage and signals may be required. Autonomous vehicles are reliant on constant, uninterrupted communication between other vehicles ("V2V") and stationary objects such as traffic signals and monitoring stations ("V2X"). Existing V2V and V2X protocols are already established, such as DCSR (Dedicated Short-Range Communications). Wider communications systems such as 4G and 5G networks are also required for autonomous vehicles. These are currently widespread in urban areas and network coverage is increasing. Where 4G and 5G networks are not available then autonomous vehicles may have restricted operation by geofencing. In the future, higher capacity, faster and more reliable networks such as 6G and satellite communications are likely to be introduced, with the higher bandwidth enabling enhanced journey reliability and infotainment. Autonomous vehicles also require detailed topological data of the road networks. In many cases, present day mappings largely meet the requirements for autonomous vehicles.

3.5 Addressing the requirements of Smart Cities

Smart Cities are a response to an increasing world of connectivity, where data and information gathered from sensors to manage assets and is processed and to manage resources and services efficiently. Data can be collected from citizens, devices, buildings, and assets that is processed and analysed to monitor and manage traffic and transportation systems, power plants, utilities, water supply networks, waste, crime detection, information systems, schools, libraries, hospitals, and other community services. Fully autonomous Mobility as a Service vehicles such as the Steel E-Motive concepts will play an important role in Smart Cities of the future.

Combining the autonomy, connectivity and efficiency aspects of future vehicles will assist Smart Cities to improve the transportation of passengers and goods, easing congestion, reducing pollution and improving safety.

4.0 Steel E-Motive Vehicle Targets and Requirements

4.1 Introduction – approach and considerations for the derivation of Steel E-Motive targets and requirements

The requirements for a fully autonomous vehicle are in many instances quite different to a conventional human operated passenger car. The use cases, mode of operation and interaction with the vehicle users is quite different. Additionally, there is little if any reference data available for existing autonomous vehicles such that the Steel E-Motive targets and requirements could be verified. The approach for deriving targets and requirements for Steel E-Motive was therefore based on an evaluation of the vehicle user (occupant) and the vehicle fleet operator or owners' requirements and expectations, coupled with knowledge and experience from conventional passenger cars. Vehicles also have regulatory requirements such as the protection of occupants and the high voltage battery in the event of collisions. Prior to deriving the vehicle targets, the key user and operator expectations for the Steel E-Motive vehicle were collaboratively defined within the project team. These key expectations were then used to derive numerical targets for the vehicle and cascaded to the vehicle systems and subsystems.

Passenger comfort and convenience: Fully autonomous MaaS vehicles represent a modal shift in urban transportation. They will also need to compete with privately owned and human driven vehicles for several years to come. In order to initiate a demand and a shift to MaaS operations, a high degree of passenger comfort and convenience is required. The term “comfort” can be interpreted as alleviation from disturbances and annoyances that vehicle users are subjected to throughout the complete journey. Examples of disturbances and annoyances that users can be subjected to include vibrations and motion sensations as a result of road inputs and vehicle manoeuvres, noises, and harmonics as a result of the vehicle operation, such as road (tyre noise), bump noises, wind noise, electric machine noises, squeaks and rattles and temperature & humidity differences and expectations. The vehicle interior, spaciousness and ergonomics also contributes to passenger comfort. Convenience describes the *ease of use* of the service. The Steel E-Motive project did not specifically consider the ride hailing and connectivity aspects of MaaS operations, but users would expect a rapid and reliable on-demand response, seamlessly interfacing with existing transportation methods such as rail, bus and ferry services. The vehicle would be expected to operate effectively and reliably in a diverse number of locations, from enclosed city and urban areas to more remote locations. Vehicles also need to be designed with a range of users in mind. This includes babies and small children, through to the elderly, disabled and visually impaired. The design should also consider the fact that the autonomous nature of the vehicle, assistance for disabled or persons with special needs would be reduced as there is effectively no vehicle driver.

Safety: Autonomous vehicles feature enhanced active and pre-emptive safety systems that should reduce or minimise the likelihood of a vehicle to vehicle or vehicle to object collision by automatic control of the vehicle speed and direction. The Steel E-Motive vehicle is designed to operate in a mixed traffic mode where autonomous and human operated vehicles operate on the same highway. The likelihood of a low or high-speed collision can therefore not be completely eliminated. For this reason, high speed crash and safety regulations and requirements have been applied for the Steel E-Motive design. This is to ensure that risk of serious injuries and fatalities are minimised in the event of a collision. The Steel E-Motive design also features a battery electric propulsion system, where the high voltage batteries are vulnerable and susceptible to damage in the event of a collision. This can lead to increased risk of fires and injuries if the battery is not sufficiently protected. New

users of autonomous vehicles may also be wary and sceptical of their safety given the removal of human driver. It is therefore important to alleviate such fears or opinions by demonstrating a reassuring level of vehicle safety performance. This can be communicated to users in advance via brand awareness and marketing.

Total cost of ownership: Total cost of ownership is relevant to both the vehicle user and the operator or owner. From the users' perspective, there will be an expectation of journey price competitiveness, with respect to private vehicle ownership and human operated taxis. The MaaS operators will be seeking to maximise operating profits, minimising investment costs, minimising the return-on-investment duration and minimising financial risks associated with the operations.

Environment and sustainability: The contribution of passenger cars and vehicle emissions to the climate change challenges is well understood and actions such as global climate agreements and local emissions and pollution regulations are in place to address the issues. The pace of transition to more sustainable modes of transportation is reliant on governments, regulators and now the vehicle users. There is now a common awareness and acceptance that mobility users' choice of transportation mode can significantly impact climate change. One of the key objectives from the Steel E-Motive project is to demonstrate that the use of the latest steel material grades and manufacturing processes, coupled with efficient design and optimisation a ride sharing vehicle can enable significant greenhouse gas (GHG) emissions.

Once the key attribute requirements for the Steel E-Motive vehicle were defined, a thorough target setting activity was undertaken. The following sections describe the derivation and justification of the numerical targets in more detail.

4.2 Vehicle Requirements and Targets

4.2.1 SEM1 Vehicle performance targets and overall dimensions

| Target | Value | Comment |
|---|--------------|---|
| Overall vehicle length (mm) | 4100 | Overall vehicle dimensions describe a compact vehicle, fitting between European B-C segment sized passenger car |
| Overall vehicle width (mm) | 1850 | |
| Overall vehicle height (mm) | 1850 | |
| Wheelbase (mm) | 2725 | |
| Track, front and rear (mm) | 1620 | |
| Vehicle turning circle (metres) | <7.6 | To align with common city taxi regulations such as London Condition of Fitness. Enabling high degree of vehicle manoeuvrability |
| Autonomy level (SAE) | 5 | Fully autonomous 100% of time in all conditions and highways. No direct human control interfaces (i.e., steering wheel, pedals, turn indicators) |
| Vehicle curb weight (kg) | <1640 | |
| Vehicle Gross Vehicle Weight GVM, (kg) | <2140 | Based on 4 passengers + 150kg payload No towing requirement No roof carrying requirement (e.g., roofbox) |
| Vehicle acceleration 0-102km/h (sec) | <9 | |
| Maximum vehicle speed km/h | 130 | |
| Towing requirements | | (vehicle not required to perform towing operation) |
| Range on 1 full battery charge(km) | >500 | Based on a WLTC drive cycle |
| Battery charging Time (minutes) | <20 | From 10% to 90% State of Charge (See 6.2.2 for battery requirement & specifications) Assume fixed charging location (no inductive charging requirement) Standard charger interface. Vehicle side location for charge socket |
| Expected vehicle life (km) | >500,000 | Based on expectation for taxi vehicle. Subject to revision depending on LCA impact |
| Sustainability and Life Cycle performance | | Steel E-Motive should demonstrate the benefits that steel can offer as a sustainable material. The project should demonstrate the maximum potential for reduction in greenhouse gas emission and outline the sensitivities in the approach and calculation of greenhouse gas emissions |
| Body manufacturability and vehicle assembly | | To use conventional sheet steel fabrication processes for the body structure (for example, but not limited to; hot and cold stamping, roll forming, roll stamping, hydroforming). Body assembly to use Resistance Spot Welding (RSW), laser welding, brazing, structural adhesives, mechanical fasteners Utilise a conventional high volume vehicle assembly processes and approaches The design to be suitable for production in global locations and facilities |
| Anticipated production volumes (per year) | 250,000 | |
| Anticipated Start of Production (SOP) date | 2030 to 2035 | |
| Luggage volume capacity (litres) | 400 | To have separate, lockable luggage compartment. Luggage volume based on available volume in passenger and luggage compartment |

| | | |
|------------------------------|--|--|
| Passenger ergonomics | | <p>To have a minimum side door aperture opening width >1.0m</p> <p>To be compliant with disabled user requirements (e.g., wheelchair, ramp access)</p> <p>To seat 4 passengers comfortably, assuming 95% ile mannequin</p> <p>To accommodate breadth of potential users (e.g., babies, children, elderly)</p> |
| Vehicle servicing and repair | | <p>Steel E-Motive design to ensure that minor service points (such as coolant, screen wash, brake fluid reservoir) to be readily accessible without the requirement for hand tools.</p> <p>Ensure major servicing of parts such as brake pads & discs, tyres can be completed within industry standard timelines and efforts</p> <p>Major repair parts such as high voltage battery can be undertaken in competitive timelines</p> |

4.2.2 Body in White (BIW) targets

| Target | Value | Comment |
|---|--------------------------------|--|
| Body in white weight (kg) | <309 | Target BIW weight derived from statistical regression analysis of reference vehicles (see Figure 4.4.2.1 below) |
| BIW cost (\$) | | The design should demonstrate the lowest cost feasibly possible whilst achieving structural performance targets |
| Static torsional stiffness (Nm/deg) | >25,0000 | Fully trimmed BIW. BIW + battery + subframes, + bumper beams + closures + glazing |
| Static vertical bending stiffness (N/mm) | >9,000 | |
| 1 st body modal frequency | >28Hz | |
| 1 st battery modal frequency | >35Hz | |
| Chassis attachment point dynamic stiffness (N/mm) | > 5x dynamic bushing stiffness | |
| Panel resonances | >50Hz | |
| BIW Durability | | <p>Predicted linear stresses to be within expected fatigue or proof stress limits. Loadcases considered:</p> <p>Fatigue loadcases:</p> <ul style="list-style-type: none"> • Braking fatigue • Acceleration fatigue • Cornering fatigue LH • Vertical 30degree positive fatigue • Settling at GVW • Maximum rebound • Limit forwards braking • Limit cornering LH <p>Abuse loadcases:</p> <ul style="list-style-type: none"> • Maximum bump load • Maximum bump and braking load • Pothole braking |



A vehicle's body in white (BIW) is one of the largest and heaviest parts of a vehicle, significantly contributing to the vehicle kerb weight. Lower vehicle weight results in reduced powertrain size (battery and motor). Additionally, "weight spiral" effects mean that a lighter vehicle can itself be reduced in weight as components such as suspension parts are required to take lower static and dynamic loads. With a significant contribution to vehicle weight, the BIW also has a significant impact on overall vehicle Greenhouse Gas (GHG) emissions. Reducing the material content in the body results in lower GHG emissions in the vehicle production stage and a lower weight results in lower energy consumption during the vehicle use phase also. Using less material also results in lower overall cost of the product. In order to define a weight target for the BIW, a benchmarking statistical approach was applied. A data sample from comparable vehicles was assembled and the statistical relationship between key vehicle and system dimensions (such as overall length, width and height, weight) was calculated and evaluated. With Steel E-Motive being one of the first full design of battery electric fully autonomous vehicles there are no matching vehicles or datasets to compare against. Instead, vehicles of comparable architectures, such as vans and people carriers were used for the analysis. Figure 4.2.2.1 shows the statistical evaluation of "vehicle box size" versus BIW weight. Vehicle box size is defined as the effective surface area of a hypothetical box placed around the extremities of the vehicle. This parameter was selected as the Steel E-Motive concepts features a "one box" type architecture, with the weight of the "box" effectively influenced by the surface area.

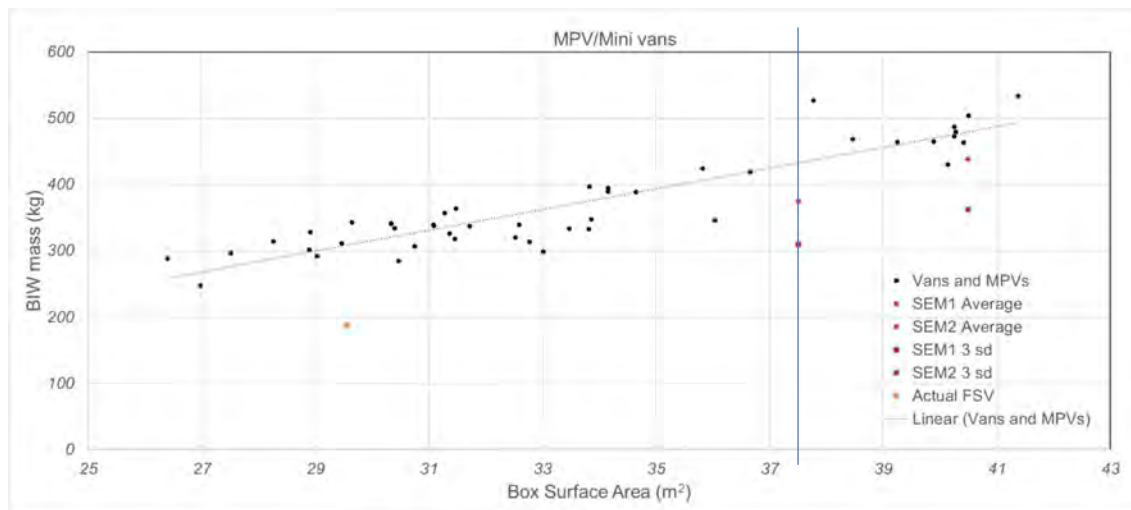


Figure 4.2.2.1 Statistical regression analysis of MPV & Minivan BIW weight versus Box Surface Area. Analysis courtesy of Donald E Malen, University of Michigan. Data source from a2mac1

The statistical analysis shows that there is a consistent relationship between the weight of the BIW in the reference vehicle data sample and the box surface area. The regression r^2 coefficient = 0.83, confirms the level of correlation (where 1.0 represents a direct correlation between the two data parameters). With the relationship between BIW weight and box surface area established, the expected weight of the Steel E-Motive BIW could be estimated given the overall vehicle dimensions (obtained from vehicle dimension targets). With vehicle length = 4095mm, width = 1850mm and height = 1880mm, an overall box surface area for SEM 1 vehicle is calculated at 37.5m. Using the mathematical relationship between BIW

weight and box area, the “expected” BIW weight for SEM1 is calculated as 374kg. This would be the expected weight for a current production vehicle, such as an MPV or minivan with the given dimensions. For the Steel E-Motive project, a certain degree of innovation and technology would expect to yield a more lightweight BIW. In order to account for this, a factor of 3 times the standard deviation of the statistical dataset is applied. This results in the BIW weight target of 309kg. This value is the effective BIW weight target applied for SEM1. The BIW is defined as the steel body structure and excludes the high voltage battery and structure, front and rear subframe, doors, seats, glazing, front, and rear bumper beams.

4.2.3 Vehicle safety and crashworthiness targets

Steel E-Motive SEM1 and SEM2 vehicles are intended for operation in mixed mode traffic (both autonomous and human operated). To ensure absolute protection of the occupants and other road users, the Steel E-Motive concepts were engineered to meet high speed crash test regulations and requirements. A summary of the tests, requirements and targets is shown in Figure 4.2.3.1. The crash tests and requirements were selected to ensure the design is compliant and compatible with vehicle global safety standards. The Steel E-Motive SEM1 crash performance was evaluated and developed using Finite Element Analysis (FEA) simulation. The FEA models were setup to replicate the real-world crash events, and according to standard simulation approach and methodologies. In order to simplify the calculation process, crash test dummies and air bags were omitted from the models and calculations. The crashworthiness evaluations were determined from acceleration pulse and occupant compartment intrusion levels.

Table 4.2.3.1 Summary of Vehicle Crash Test Loadcases and Targets

| | Test | Vehicle Speed | Barrier Type | Target | Additional Info |
|------------|--|--|---|--|---|
| Front | USNCAP full frontal rigid barrier (“FFB”) | 56kph | Rigid, 100% | Vehicle acceleration pulse <35g Front bulkhead intrusions <40mm No damage to battery | Acceleration to be measured at B pillar location or equivalent. Acceleration pulse processed using sliding mean approach |
| | Insurance Institute Of Highway Safety (IIHS) front Offset Deformable Barrier (ODB) | 64kph | 40% overlap, deformable | Vehicle acceleration pulse <35g Occupant compartment intrusion levels below values as described in Table 4.4.3.3. Values to demonstrate “good” rating No damage to battery | Where possible, pulse and intrusion levels should achieve lowest value. Targets are maximum permitted values |
| | Insurance Institute Of Highway Safety (IIHS) Small Offset Rigid Barrier (SORB) | 64kph | 25% overlap, rigid barrier | Vehicle acceleration pulse <35g Occupant compartment intrusion levels below values as described in Table 4.4.3.4 Values to demonstrate “good” rating No damage to battery | |
| Side | USNCAP rigid pole | 32kph (note, moving barrier/pole) | Rigid pole, 254mm diameter, 15degrees to perpendicular. In line with front occupant head location | Occupant compartment intrusion levels below values described in Figure 4.4.3.5 (IIHS targets). For battery intrusion test locations, >30mm of intrusion clearance between battery | USNCAP requirement describes occupant (dummy) injury levels. IIHS intrusion levels applied for this test (see below). 3 additional test locations evaluated |
| | IIHS side barrier | 60kph | IIHS deformable barrier, 1900kg, design ii | Occupant compartment intrusion levels below values described in Figure 4.4.3.5 Values to demonstrate “good” rating No damage to battery | |
| Rear | FMVSS305 EV | 80kph (moving barrier) | Deformable barrier (FMVSS301). 70% overlap | <35g pulse <40mm occupant compartment intrusion No damage to battery | |
| Roof crush | FMVSS216a/IIHS | Quasi-static loading, 127mm fixed displacement | Rigid plenum | Measured force to exceed 4 x Strength To Weight Ration (SWR), based on vehicle gross weight | |

Front crash loadcases

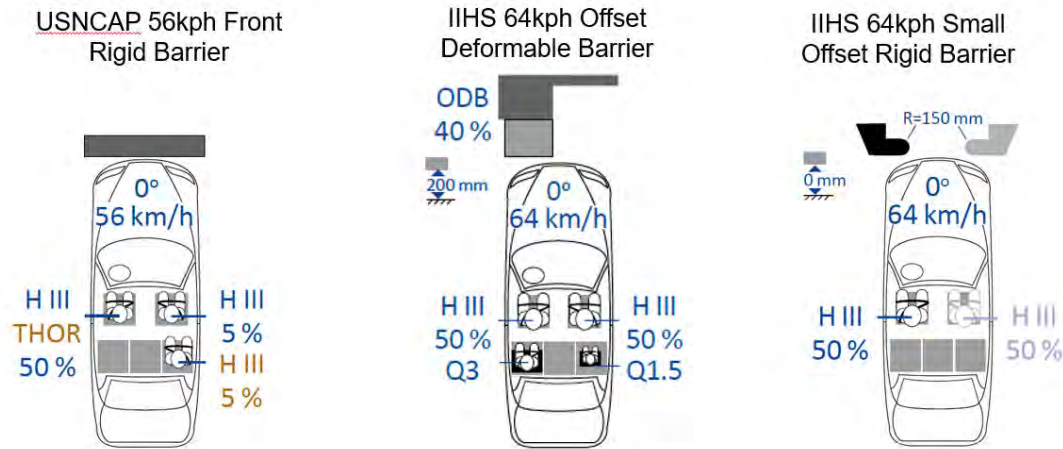


Figure 4.2.3.2 Front Crash Test Configurations

The objective of the USNCAP 56kph rigid barrier test is to ensure the vehicle is able to absorb sufficient crush energy in the event of a frontal impact, such that the occupants' injuries are minimised. The rigid test barrier results in the vehicle's moving kinetic energy is mainly converted to crush energy in the structure. A front crash structure is therefore required to decelerate the vehicle progressively without the occupant compartment being compromised by high intrusion. This challenge is particularly compounded with smaller vehicles, where the available front crush length is lower.

The IIHS 64kph ODB or moderate overlap test aims to simulate a high-speed vehicle to vehicle impact. The deformable crash barrier results in some of the vehicle kinetic energy being absorbed by crush in the barrier. One of the main challenges and objectives of this test is minimising injury as a result of intrusion into the occupant compartment. The high velocity and energy levels involved further make this more challenging.

The IIHS 64kph small overlap rigid barrier test (SORB) replicates a high-speed vehicle impact into a rigid stationary object. The lateral overlap between barrier and front of the vehicle is 25%. The combined effect of the high impact velocity, the rigid barrier, and the small overlap results in a considerable challenge for the management of the crash loads and protection of the occupants. The real-world test is applied to both the driver and passenger sides. With the symmetrical left to right design of Steel E-Motive (and the lack of "driver"), the loadcase was applied to the left side of the vehicle only.

The IIHS test protocols are primarily intended to inform the consumer (general public) on the safety performance of new vehicles and assist purchasing decisions. Vehicles are independently tested, and a rating system applied to advise on the relative safety performance. Vehicles are awarded "good", "acceptable", "marginal" and "poor" depending on the measured intrusion values, occupant (dummy) injuries and level and performance of active safety systems. As dummies and air bags were not considered in Steel E-Motive crash simulations, the ratings were based on structural intrusion levels alone. The acceleration pulses were noted as a reference. Acceleration pulses >35g were deemed unacceptable. The intrusion measurement locations are defined in the IIHS test protocol [https://www.iihs.org/media/ec54a7ea-1a1d-4fb2-8fc3-b2e018db2082/1A5oYw/Ratings/Protocols/current/small_overlap_test_protocol.pdf] and

shown in Figure 4.2.3.4 below. The locations are defined for a conventional human operated vehicle, where risk of injury can occur from protruding objects such as the steering wheel and brake pedal. The fully autonomous Steel E-Motive vehicle features no such direct vehicle control interfaces, and a decision was made during the programme to position the front occupant in a rear facing configuration. To account for this, modifications to the front crash intrusions measurement locations were made on the Steel E-Motive vehicle. The steering wheel, brake pedal, parking brake pedal locations were deleted. To account for the rear facing forward position of the front occupants and the proximity of the head to structure and glazing, two additional measurement locations were added at the upper front hinge pillar. An additional measurement location was added to the upper dash panel to ensure no intrusion occurred to the front seat back. The front intrusion measurement locations for Steel E-Motive as shown in Figure 4.2.3.5

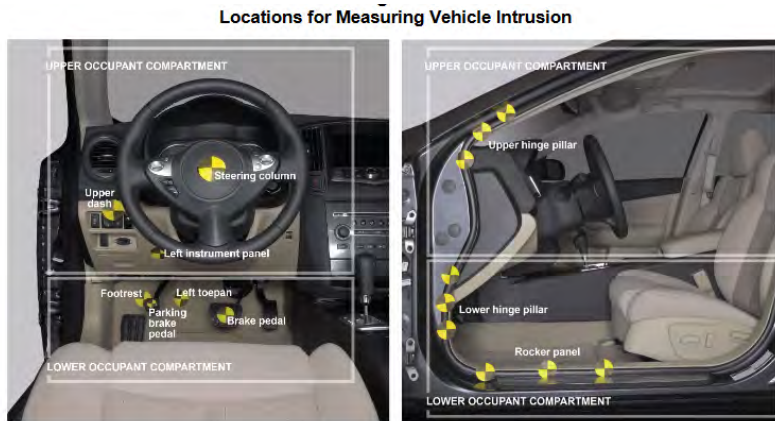


Figure 4.2.3.4 IIHS front crash intrusion measurement locations for conventional vehicle

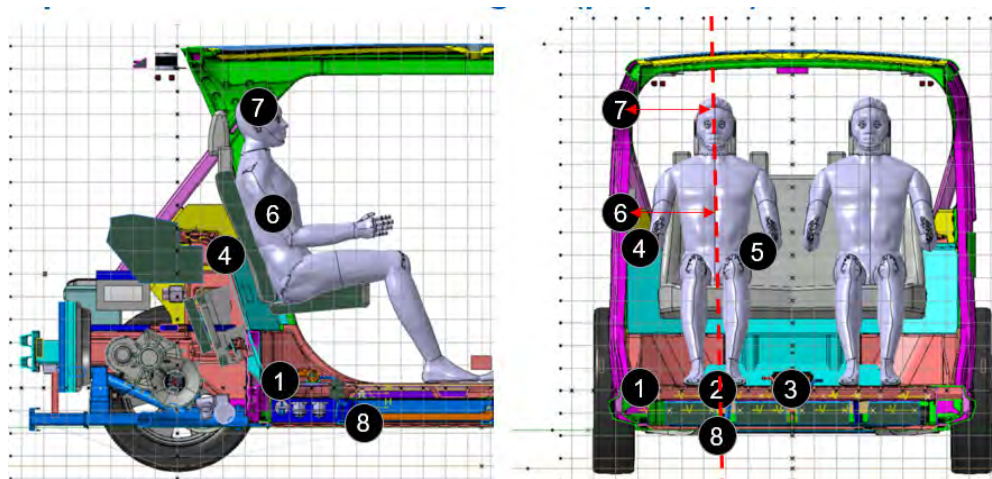


Figure 4.2.3.5 Steel E-Motive front crash intrusion measurement locations

The front crash target intrusion target values were based on IIHS values that achieve a “good” safety rating. The targets values are summarised in Figure 4.2.3.6 below.

| Measurement Location | IIHS 64kph 40% offset deformable barrier | IIHS 64kph 25% small overlap rigid barrier |
|----------------------|--|--|
| 1,2,3 | < 150mm | <150mm |
| 4, 5 | <50mm | <75mm |
| 6,7 | >180mm clearance between intrusion point and seat centreline | |
| 8 | No contact between battery module and structure | |

Figure 4.2.3.6 IIHS front crash intrusion targets for Steel E-Motive vehicles

Side crashworthiness loadcases

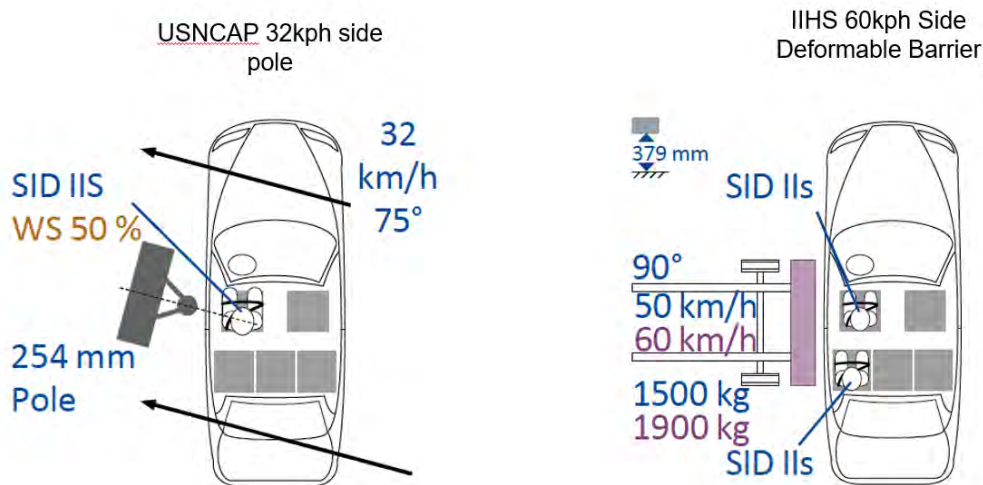


Figure 4.2.3.7 Side crash test configurations

The USNCAP side pole test considers a crash event where the vehicle strikes a static object such as a lamppost or road sign from the side, hence a test pole diameter of 254mm. The vehicle impact velocity is 32kph, at an angle of 75degrees. The pole and impact position is aligned to the driver's head. The primary objective of the test is to ensure the occupants are sufficiently protected from the impact resulting in reduced injury risk. Given the proximity of the high voltage batteries to the extremities of the vehicle, there is also a considerable risk of damage to the cells in this test. Damage to the battery cells can lead to leakage of the electrolytes and a thermal runaway event (fire). An additional intrusion clearance criteria of >30mm was therefore added for this to test in order to ensure the batteries remain undamaged. This means that there should be a minimum distance of 30mm between the outside of the battery module case and the body structure/battery housing. The USNCAP test protocol calls for the pole test in one location (in line with the drivers' head). To ensure a robust design and enhanced level of safety and protection for the occupants the Steel E-Motive project considered and engineered for 3 additional pole test locations as shown in

Figure 4.2.3.8. Position 1) is the required test location, in line with the drivers' head. Position 2) is located at the X coordinate centreline of the vehicle and poses challenges due to distance from supporting vertical structures in the body such as A and C pillars. Test position 3) is aligned with the rear occupants' head, ensuring sufficient protection is offered for rear passengers. Position 4) is located at a midpoint between the vehicle centreline (position 2) and the rear vertical "C" pillar. As per position 2) this location was selected as a potentially vulnerable position for the high voltage battery. Positions 1) and 3) are primarily intended to ensure protection of the occupants and positions 2) and 4) are primarily to ensure protection of the high voltage battery. The targets for the USNCAP side pole (real world) tests are based on measured occupant (or crash test dummy) injury loads and criteria. As the Steel E-Motive FEA simulations did not include dummies or air bags, an alternative approach using the IIHS side barrier targets was employed. The level of occupant protection was determined by the post-crash intrusion clearance to a virtual line in the centre of the occupant seat. The IIHS side barrier test requires >180mm of clearance post-crash in order to achieve a "good" rating. The same target was applied for the USNCAP side pole test.

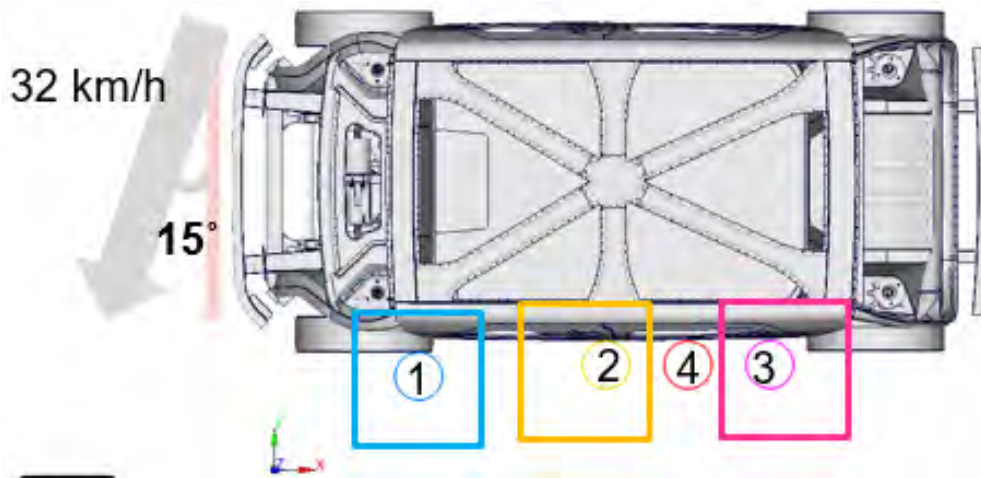


Figure 4.2.3.12 USNCAP side pole test locations

One of the main challenges for any side pole tests is the small contact area of the pole versus the vehicle. This results in very high concentrated loads applied to the body structure during the crash event. Also, there is a much smaller region in the vehicle structure to manage the crash event and loads when compared to front or rear crash tests. With the vehicle occupants and batteries located relatively closer the barrier impact location the crash loads and subsequent intrusions need to be carefully managed, primarily through design of the body and side closure structure and safety restraint systems (e.g., air bags).

The IIHS side barrier test simulates a collision between two vehicles with one vehicle impacting the test vehicle perpendicular to the direction of travel. This scenario is typical of a collision at a traffic T junction. In 2020, the test protocol was updated to consider a more challenging condition, with the impact velocity increased from 50kph to 60kph and the test barrier weight increased from 1500kg to 1900kg. The profile of the barrier was also modified to take into consideration recent changes in vehicle front end design and profile (figure 4.2.3.13)

Note 1: All dimensions and tolerances are for honeycomb only.

Note 2: All honeycomb elements have the same ribbon orientation.

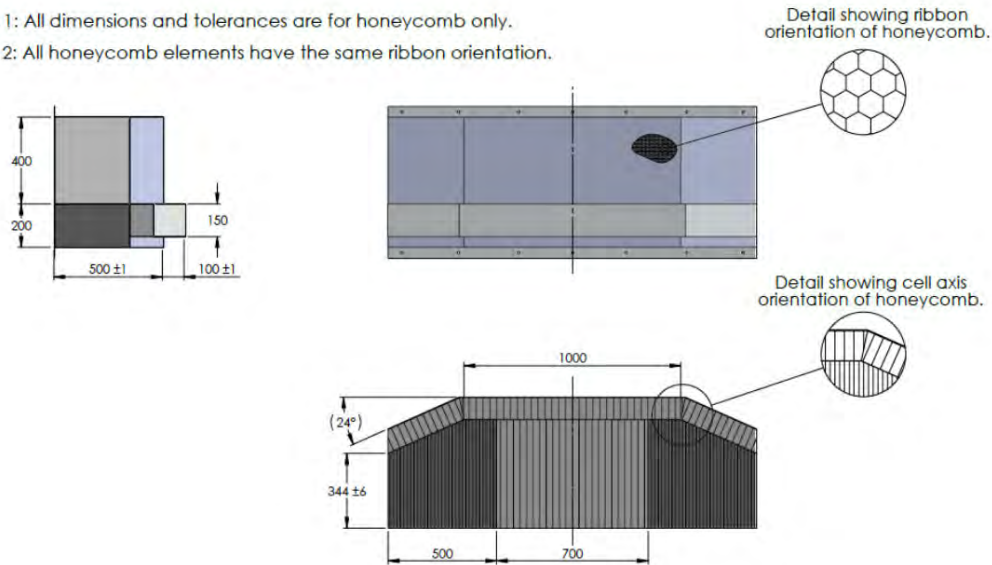


Figure 4.2.3.13 IHS side barrier (2) dimensions https://www.iihs.org/media/b76a49b5-88db-4535-b08f-c269d59f4934/lanIHw/Ratings/Protocols/current/side_barrier_spec-2.0.pdf

For the Steel E-Motive SEM1 concept, the centre of the test barrier is aligned to a position 156.05cm rearwards of the front wheel centreline as shown in Figure 4.2.3.14

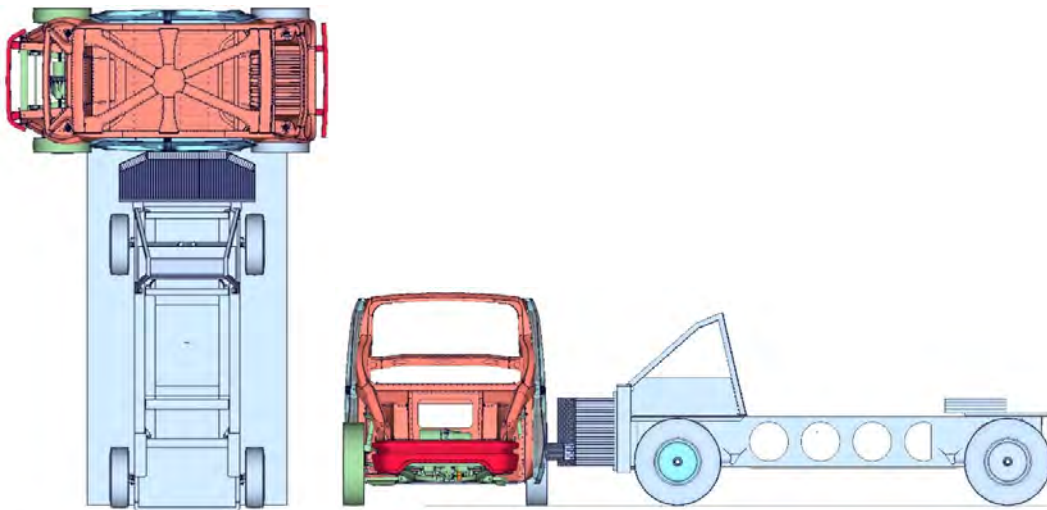


Figure 4.2.3.14 alignment of IHS side barrier (version 2.0) to Steel E-Motive SEM1 vehicle

One of the main challenges and considerations with the IHS side barrier test is that the barrier vertical position is above the general floor height. A lower floor height is desired in order to enable better ingress and egress to and from the vehicle, especially for a ride hailing vehicle. This means that the barrier does not initially impact with the outer structure of the body (e.g., the rocker) and there is a limited lateral loadpath across the vehicle. The structure in the vehicle side closures and B-pillar (if any) are the primary contact points and interfaces to the barrier. As per the IHS front crash protocols, a rating system is applied to the side barrier test based on measured intrusion and dummy injuries. The goal for Steel E-

Motive was to achieve a “good” rating in side crash. The IIHS protocol requires the B pillar intrusion values to be >180mm from the centreline of the seat.

[https://www.iihs.org/media/3fe4c863-2726-4823-b924-06b079222929/KktnZQ/Ratings/Protocols/current/side_impact_2.0_ratings_guidelines.pdf]

For the SEM1 vehicle, a decision was taken during the design stage to position the front occupants in a rear facing configuration. The assessment protocol for Steel E-Motive was there modified to ensure that the maximum intrusion at any location is >180mm from the seat centreline. Figure 4.4.3.15 describes the IIHS side crash intrusion target applied for Steel E-Motive. The same target was applied for the USNCAP side pole test.

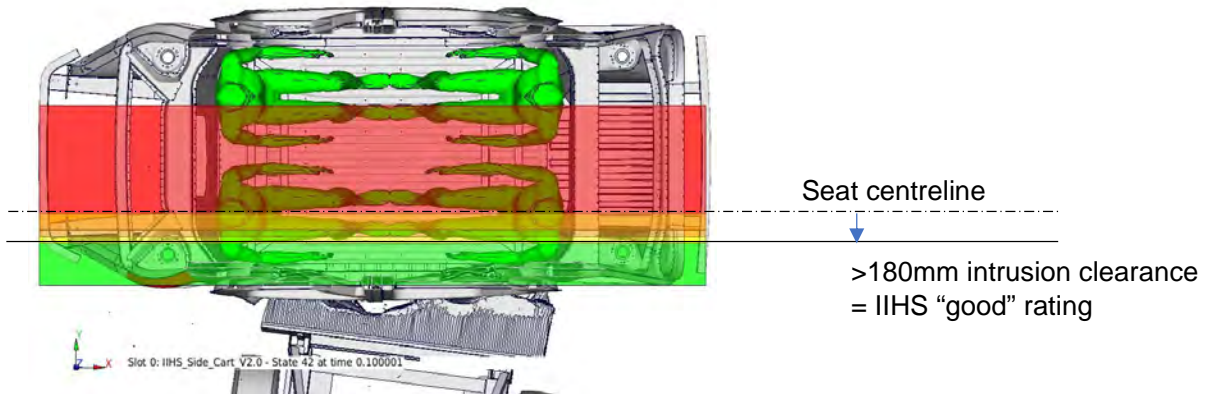


Figure 4.2.3.15 IIHS side crash intrusion targets applied for Steel E-Motive

Rear crashworthiness loadcase

The FMVSS 305 EV (incorporating FMVSS 301) loadcase considers a moving vehicle impacting a stationary vehicle, replicating a collision event in waiting traffic. A deformable barrier with a weight of 1368kg impacts the test vehicle at a speed of 80kph with a 70% overlap. The primary objective of the FMVSS 305 (EV) is to maintain the integrity of the high voltage electrical systems, namely, to prevent damage to the high voltage battery and cables and minimise occupant injury risks. A target of <40mm rear bulkhead intrusion and <35g was applied to ensure a reduced risk of occupant injury. The design approach and philosophy for rear crash load management is similar to the front, where the impact crush energy needs to be carefully managed using crushable body structure elements whilst ensuring the structural intrusions to the occupant compartment and battery are minimised.

FMVSS 305 EV (incorporating FMVSS 301)

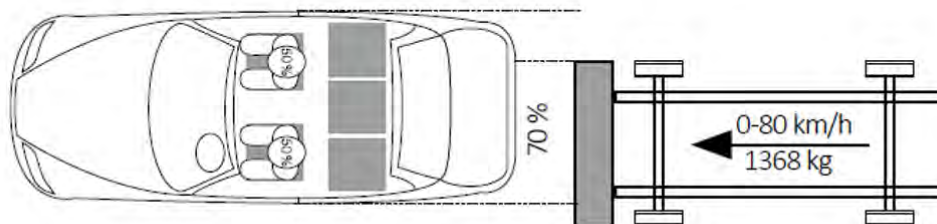


Figure 4.2.3.16 FMVSS 305 EV rear crash test configuration

Roof Crush

The objective of the IIHS roof crush is to ensure the vehicle occupants remain protected in a dynamic vehicle roll over event. The vehicle is maintained in a static upright position with a loading cell position as per the specification shown in Figure 4.4.3.16. A quasi-static load is applied to the vehicle roof structure, up to a point where the load cell displacement reaches 127mm. The peak force in the load cell is measured at this point and the *strength to weight* ratio (SWR) is calculated. The SWR is derived from the peak load force at 127mm divided by the vehicle curb weight (in Newtons). The target for Steel E-Motive was to achieve IIHS “good” rating, where the peak force at 127mm displacement is at least 4 times greater than curb weight. Achieving the required roof crush load relies on high strength roof members and suitable loadpath and member strength from the upper to the lower body structure (such as A pillar).

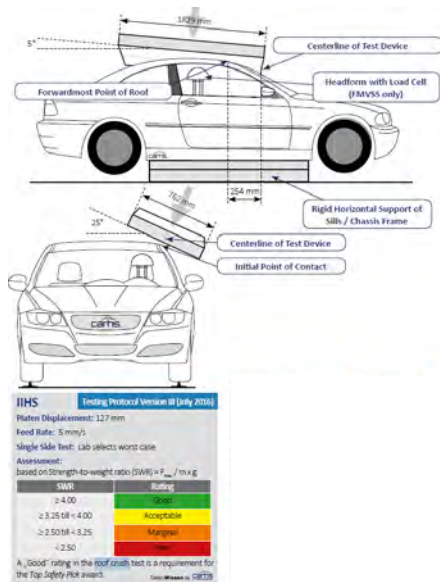


Figure 4.2.3.16 IIHS roof crush test and rating

4.2.4 Vehicle crash reference loadcases

The loadcases and targets outlined in section 4.2.3 were considered as “core” targets, meaning that the Steel E-Motive design was engineered to meet the performance requirements defined. Additionally, two *reference* crash loadcases were considered to periodically assess the design and quantify the crash performance.

EuroNCAP Moving Progressive Deformable Barrier (MPDB) replicates a car-to-car frontal impact and is designed to improve the crash compatibility between vehicles. The test vehicle impacts at 50kph into a moving deformable barrier, with weight 1400kg, travelling at 50kph, with a frontal impact offset of 50%. The deformable barrier design is engineered to replicate the crush performance of a modern European passenger car. The EuroNCAP assessment of occupant dummy injuries (forces and moments on limbs and joints), intrusion levels and deformation of the impact barrier. For Steel E-Motive, the vehicle acceleration pulse and intrusion values were observed and compared to the front IIHS and USNCAP FFB values. The main challenge for this test is management of the high crush loads as the effective impact velocity is 100kph, whilst ensuring both the test vehicle and barrier collapse progressively, minimising injury risks to the occupants.

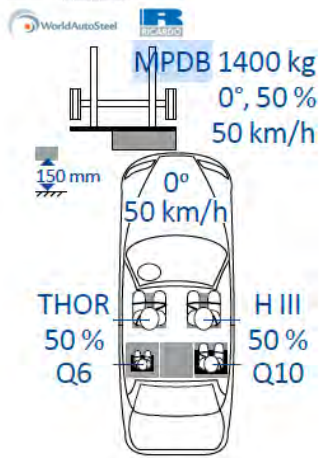
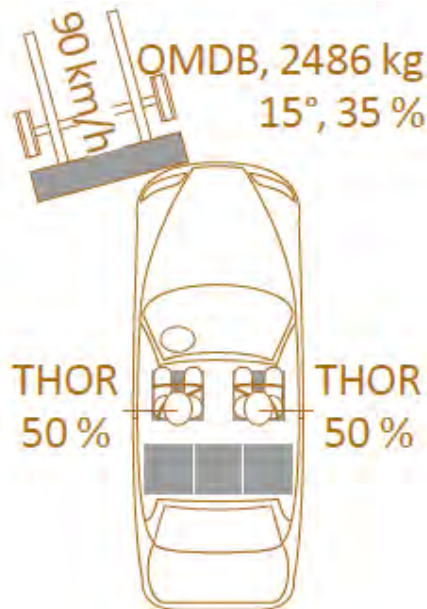


Figure 4.2.4.1 EuroNCAP Moving Progressive Deformable Barrier (MPDB) test protocol

At the time of undertaking the Steel E-Motive programme, the NHTSA front 90kph, 35% overlap, 15degrees oblique test was not officially mandated as a requirement or test for production vehicles but was cited as a potential test to be introduced at some point in the future. This loadcase was also considered as a *reference* crash loadcase for the Steel E-Motive programme. A moving deformable barrier of weight 2486kg is impacted into the stationary test vehicle at 90kph, the barrier being at 15degrees to the direction of travel and impacting with a 35% offset to the front. The resultant acceleration pulse and intrusion levels were compared to the core loadcase targets.



4.2.6 Propulsion Battery Targets

Given the size and weight of high voltage batteries in electric vehicles, the requirements and specifications of the battery can influence the overall vehicle design and architecture.

Figure 4.2.6.1 summarises the requirements and targets for the of the Steel E-Motive high voltage battery

| Requirement/Specification/Test | Target | Comment |
|---|--------|---|
| Battery type and chemistry | - | “agnostic” (see comment below) |
| Battery capacity (kWh) and voltage | - | To be determined, such that the vehicle can operate effectively within a typical ride hailing/taxi type drive cycle |
| Overall battery pack weight (kg) | | Not specified but should be competitive with market trends and enables fulfilment of vehicle targets (e.g., range, curb weight) |
| | | |
| China requirement GB 38031-2020, incorporating 100kN crush load | | Battery pack integrity to be maintained. No rupture or electrolyte leakage. Strength of the pack to be determined by the design and strength properties of the material |
| ISO 12405-2 PSD Random Vibration Fatigue | | Battery pack integrity to be maintained. No rupture or electrolyte leakage. Strength of the pack to be determined by the design and strength properties of the material |
| | | |
| Debris and jacking intrusion prevention | | Battery design to withstand high velocity road debris impact from underneath the vehicle Battery design to withstand a jacking load from underneath the vehicle. Detailed in 4.4.6.2 |
| 1 st battery modal frequency | >35Hz | System level target (and FEA modelling approach) to ensure full vehicle modal target is achieved |

4.2.5.1 Battery chemistry and cell type

The battery cell and chemistry technologies in electric vehicles will continue to evolve considerably in the coming years. Car makers are faced with many options of battery technologies and approaches for integrating them into the vehicle. The intended Start of Production (SOP) date for Steel E-Motive concepts is in the 2030 to 2035 timeframe. By that time, it is anticipated that the battery technology will have evolved even further. Given that the primary focus of the Steel E-Motive project was the design of the body structure, a decision was taken to engineer the vehicle for an “agnostic” battery chemistry type and cell, meaning that the vehicle and body design should enable the freedom for a variety of battery cell types (e.g., pouch, prismatic, cylindrical) and cell technologies (e.g., lithium ion, solid state) to be considered in future designs. To assist the engineering of the body structure, some subsequent assumptions were made on battery type and technologies, such that the module package sizes, and weight could be determined and considered in the overall vehicle design. These specifications are outlined in Section 6.

4.2.5.2 Battery strength and durability requirements

Damage or rupture to high voltage batteries can result in significant hazards to the vehicle occupants and other road users. If the battery cell integrity is compromised, the electrolytes can leak and mix, resulting in very temperatures, thermal runaway (an uncontrollable thermal temperature risk as a result of exothermic chain reaction of secondary cell). Subsequent combustion and fires can release toxic and noxious fumes and must be extinguished using specific methods. In addition to the vehicle safety requirements several battery system

standards and requirements are mandated to ensure the battery is not damaged or ruptured as a result of everyday use or occasional accidental abuse or misuse events.

China standard GB 38031-2020 and GB/T 31467.3-2015 incorporates several requirements for battery electric vehicle batteries including a 100kN crush load applied to the pack. A quasi-static load of magnitude 100kN is applied to the battery pack extremities in the primary vehicle crash loading directions (X and Y), with a cylindrical impactor of diameter 150mm. The load application positions are not prescribed, hence the worst-case locations are typically accounted for, as shown in Figure 4.2.5.2.1 below

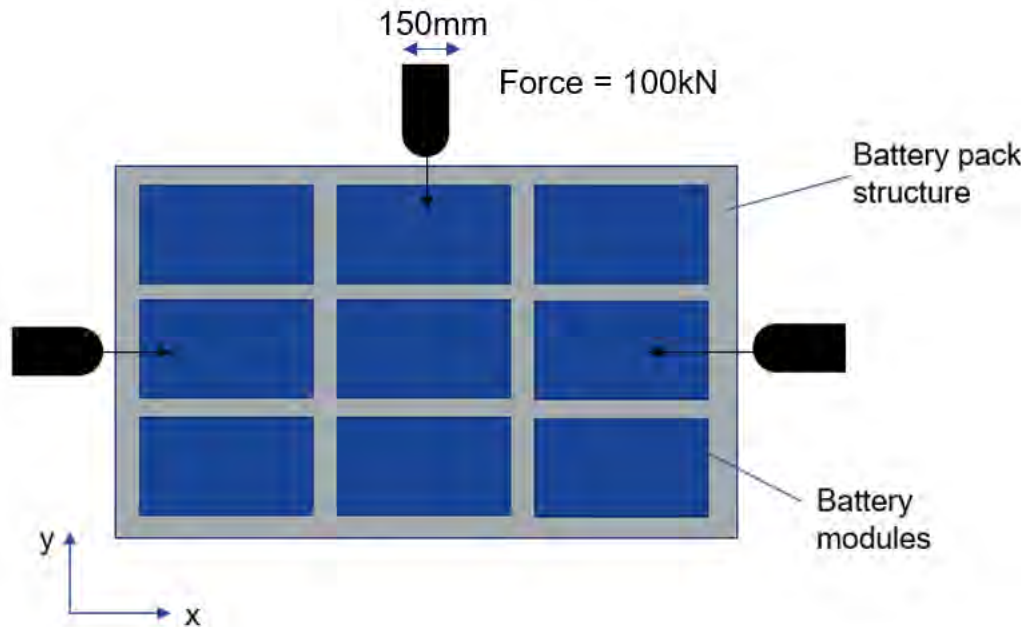


Figure 4.2.5.2.1 Standard GB 38031-2020 incorporating 100kN quasi-static crush load

The standard requires the battery pack to maintain its overall integrity, with no evidence of electrolyte leakage, damage, or rupture to the cells. The battery overall resistance and voltage must remain within prescribed limits. The test can be performed at pack level (for example on a sealed and contained battery pack assembly) or as installed in the vehicle.

To account for potential misuse of the vehicle or battery, the Steel E-Motive design considers a 25G shock test loadcase is applied. Separate loadcases are applied in the X, Y and Z directions according to the profile shown in Figure 4.2.5.2.2. The battery structure integrity must be maintained with no permanent damage to the pack or modules. The material plastic strain limits were used to determine permanent damage to the pack and modules.

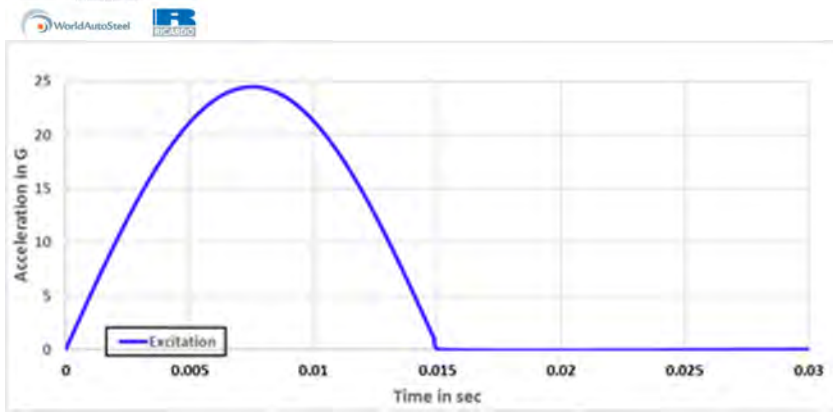


Figure 4.2.5.2.3 25g battery shock test load profile

Battery packs in electric vehicles are typically located in the lower portion of the vehicle, primarily due to package requirements and to achieve a lower overall centre of gravity. This location puts the battery in a vulnerable location. There are risks from road debris and large objects impacting the underside of the vehicle whilst the vehicle is moving, which could rupture the battery modules. The batteries are also located close to designated jacking or lift zones, where the vehicle is raised for service or repair. In some cases, users or technicians can place the vehicle jacking or lifting devices in the incorrect location, such as the battery cover. With these parts of the structure not specifically designed to withstand the lifting load of the vehicle, excessive deformation of the battery cover may lead to contact and high loads acting on the modules, resulting in damage to the cells and subsequent issues with thermal runaway and fires. A similar scenario may occur if the vehicle parked or stopped accidentally or by malfunction in the vicinity of an automatic/remotely operated traffic bollard. To account for these misuse situations, 6 battery cover or undertray loading points were identified as potential points of greatest weakness and vulnerability. A load equivalent to half of the vehicle gross weight was applied at each location (independent tests) over a cylindrical impactor of 50mm diameter. The requirements of the test are that no physical contact should occur between the cover and the battery modules. Figure 4.4.6.4 shows the locations for the applied loads and Figure 4.2.5.2.4 shows the loading profile or time history

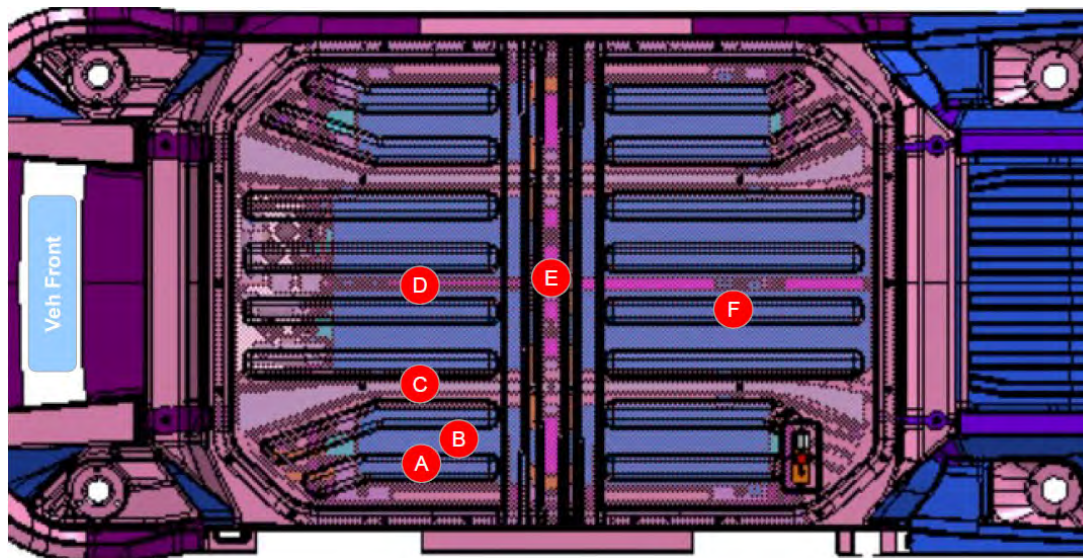


Figure 4.2.5.2.4 Vehicle lifting and jacking misuse loadcase. Locations for misuse vehicle jacking, lifting or debris impact

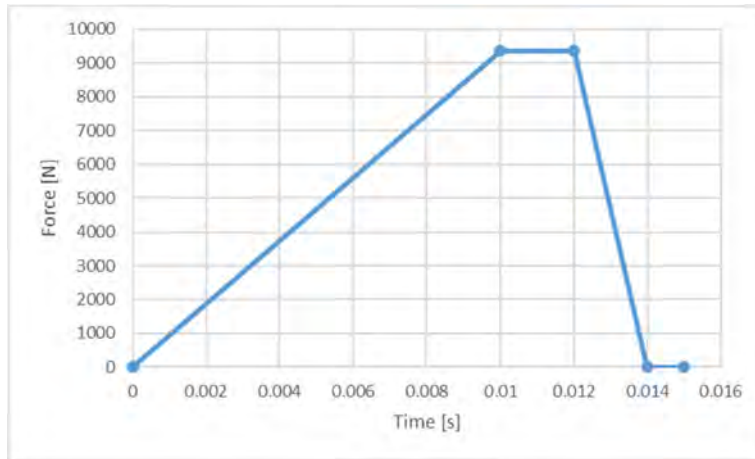


Figure 4.2.5.2.5 Vehicle lifting and jacking misuse loadcase. Force-time profile

During the life of the vehicle, the battery is also subjected to vibration loading as a result of road induced loads and vehicle manoeuvring. The repetitive cycling loading can cause fatigue failure of the battery structure and its components. To ensure fatigue failures don't occur, an ISO 12405-2 Power Spectral Density (PSD) fatigue loading requirement was applied. Figure 4.2.5.2.6 shows the FEA model approach and PSD loading profile. Acceptance of the performance was based on the predicted stresses in the battery and structure being within the material grade fatigue limits.

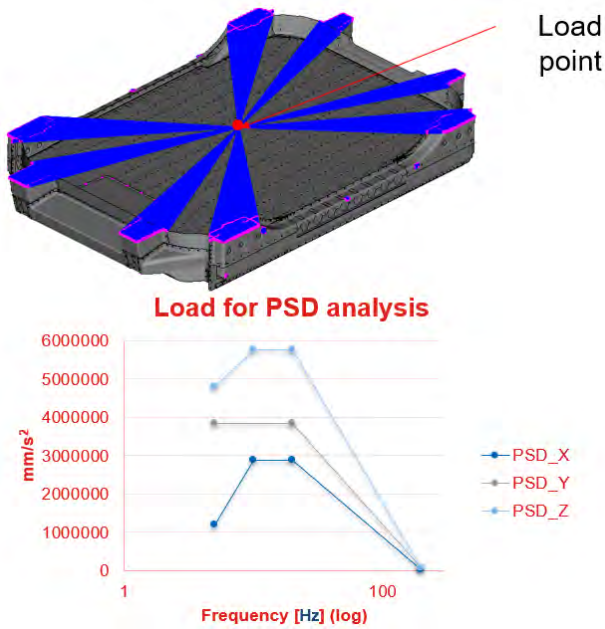


Figure 4.2.5.2.6 Battery PSD fatigue analysis approach and loading

5.0 Steel Grades, Joining Methods and Fabrication Technologies

This section describes the different steel grades and fabrication processes considered in the design and development of Steel E-Motive.

5.1 Steel Grades and Selection Criteria

Automotive steels are commonly classified by a metallurgical designation and strength level. Common designations include low-strength steels (interstitial-free and mild steels); conventional High-Strength Steels (HSS) (carbon-manganese, bake hardenable, high-strength interstitial-free, and high-strength, low-alloy steels); and Advanced High-Strength Steels (AHSS) (dual phase, transformation-induced plasticity, ferritic-bainite, complex phase, martensitic, twinning-induced plasticity, press-hardened and 3rd Generation steels).

The different grades have distinctly different microstructures and deformation characteristics. The results are different performance levels for part formability, crash, and energy management. The Global Formability Diagram compares strength and total elongation (a steel property related to formability) for different types of steel and is shown in Figure 1.

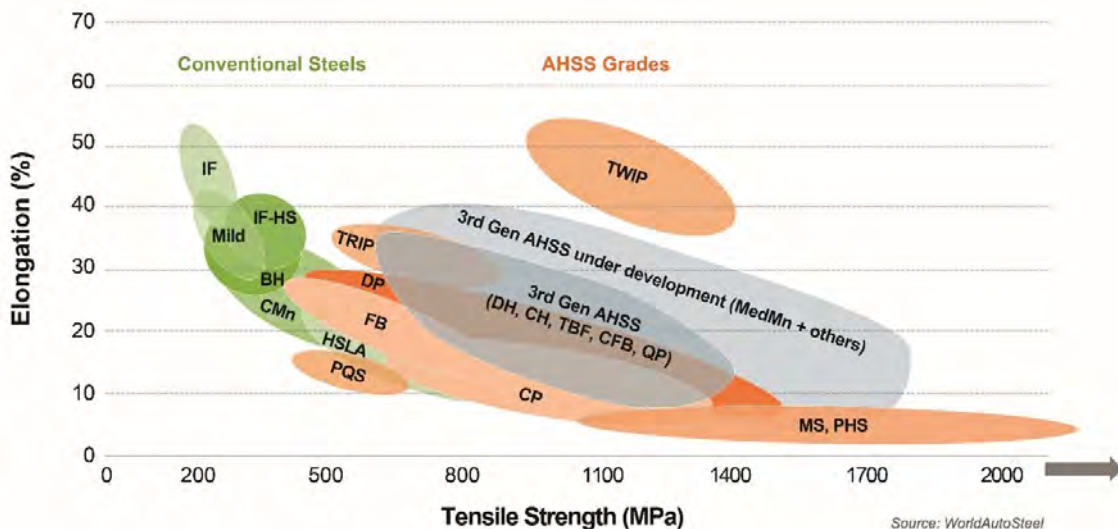


Figure 5.1: Steel Global Formability Diagram

The Steel E-Motive Materials Portfolio is a compilation of steel grades considered in the vehicle's design. All are commercially available from our member companies, today or in the near future. These members contributed over 65 grades of AHSS, ranging from the very common dual phase steels to the more complex press-hardened and 3rd Gen steels. The intensive innovation within the auto industry fueled the development of this broad range of materials, where minimum tensile strengths among portfolio grades range from 450 MPa to 2000 MPa. In comparison, and to emphasize the achievement in the automotive steel industry's product development, FutureSteelVehicle, (WorldAutoSteel's previous vehicle concept program) showcased 27 AHSS grades in 2010, with a maximum tensile strength of 1500 MPa. The complete AHSS Materials Portfolio is presented in Table 5.1.

Newer steel grades prosper from improved ductility as well, where steels with strength levels



of 1200 MPa can now achieve 20% elongation, enabling cold forming solutions for more challenging geometries.

The combination of new design technologies, emerging steel grades and advanced steel fabrication processes enabled optimal vehicle lightweighting and safety performance, with significant reductions in Greenhouse Gas (GHG) emissions over the entire vehicle life cycle.

5.1.1 Steel Selection Criterion

The following information list is important when determining the suitability (and availability) of a steel type and grade for component design and functionality requirements:

- Hot-rolled, cold-rolled, and coating availability.
- Thickness and width capabilities.
- Mechanical properties and ranges.
- Joining and assembly requirements.
- Manufacturing process specifications.

AHSS grade development has been driven by the need to balance better performance in ever-more challenging crash regulations, while reducing weight to achieve emissions targets. Third Generation (3rd Gen) AHSS address the automotive industry's need for steels with both higher strength and enhanced formability, allowing more complex geometries to be produced with cold forming, and for some applications, providing an alternative option to press hardening. Even newer versions of the Dual phase (DP), Complex Phase (CP) and Transformation Induced Plasticity (TRIP) steels have been updated to provide additional formability within the same strength range, compared to conventional High Strength Low Alloy (HSLA) steels.

Detailed information about AHSS grades is available at the WorldAutoSteel AHSS Application Guidelines website, at www.assinsights.org.

To complement the product portfolio, WorldAutoSteel contributed several advanced fabrication technologies that helped achieve manufacturing feasibility, while also reducing the material production emissions due to higher material utilization or conversion yields. This is a key objective in the project, evidenced by reduced thickness and high-yield fabrication processes selected for many of the vehicle components.

5.1.2 AHSS Grade Development Sequence

The Second Generation (2nd Gen) AHSS grades have essentially a fully austenitic microstructure and rely on a twinning deformation mechanism for strength and ductility. Austenitic stainless steels have similar characteristics, so they are sometimes grouped in this category as well. Second Gen AHSS grades are typically higher-cost grades due to the complex mill processing to produce them as well as being highly alloyed, the latter of which leads to welding challenges.

Third Gen AHSS grades were developed in collaboration with global contributions from research institutes, universities, steel producers and auto makers. Individual automakers may have proprietary definitions of 3rd Gen AHSS grades containing minimum levels of strength and ductility, or specific balances of microstructural components, but no globally accepted standards exist. Starting around 2010, several international consortia formed with the hopes of achieving the next-level properties associated with 3rd Gen steels in a production environment.

Third Gen steels have improved ductility in cold forming operations compared to other steels at the same strength level. As such, they may offer a cold forming alternative to press hardening steels in some applications. Also, while 3rd Gen steels are intended for cold forming, some are appropriate for the hot stamping process.

Like all steel products, 3rd Gen properties are a function of the chemistry and mill processing conditions. There is no one unique way to reach the properties associated with 3rd Gen steels. Steelmakers use their available production equipment with different characteristics, constraints, and control capabilities. Even when attempting to meet the same OEM

specification, steelmakers will take different routes to achieve those requirements. This may lead to each approved supplier having properties which fall into different portions of the allowable range. Manufacturers should use caution when switching between suppliers, since dies and processes tuned for one set of properties may not behave the same when switching to another set, even when both meet the OEM specification.

There are three general types of 3rd Gen steels currently available or in development. All rely on the TRIP effect. Applying the quenching and partitioning (QP) process to the other grades below may create additional high-performance grades.

TRIP-Assisted Bainitic Ferrite (TBF) and Carbide-Free Bainite (CFB)

- TRIP-Assisted Bainitic Ferrite (TBF) and Carbide-Free Bainite (CFB) are descriptions of essentially the same grade. Some organizations group Dual Phase – High Ductility (DP-HD, or DH) in with these. Their production approach leads to an ultra-fine bainitic ferrite grain size, resulting in higher strength. The austenite in the microstructure allows for a transformation induced plasticity effect leading to enhanced ductility.

Quenched and Partitioned Grades, Q&P or simply QP

- Quenching and Partitioning (QP) describes the processing route resulting in a structure containing martensite as well as significant amounts of retained austenite. The quenching temperature helps define the relative percentages of martensite and austenite while the partitioning temperature promotes an increased percentage of austenite stable room temperature after cooling.

Medium Manganese Steels, Medium-Mn, or Med-Mn

- Medium Manganese steels have a Mn content of approximately 3% to 12%, along with silicon, aluminium, and microalloying additions. This alloying approach allows for austenite to be stable at room temperature, leading to the TRIP effect for enhanced ductility during stamping. These grades are not yet widely commercialized.

5.2 Definition of Steel Types Found in the Steel E-Motive Materials Portfolio

Since the terminology used to classify steel products varies considerably throughout the world, the Steel E-Motive materials portfolio uses a combination of methods to define the steels. Each steel grade is identified by metallurgical type, yield strength and sequenced by minimum ultimate tensile strength (in MPa). To illustrate, DP 500/800 means a Dual Phase steel type with 500 MPa minimum yield strength (YS) and 800 MPa minimum ultimate tensile strength (TS).

5.2.1 Mild (conventional) Steels

Mild steels are the conventional steels historically used in automotive applications and are characterized by low strength and good formability. Drawing Quality (DQ) and Aluminum Killed (AKDQ) steels are examples and often serve as a reference base because of their widespread application and production volume.

5.2.2 Interstitial-Free (IF) Steels (Low strength and high strength)

IF steels have ultra-low carbon levels which reduce their yield strengths, while achieving high work hardening rates. This results in steels with excellent formability as compared to mild

steels. The higher strength grades of IF steel are widely used for structural applications requiring complex geometries and closure applications with more features compared to an aluminum product.

5.2.3 Bake Hardenable (BH) Steels

Bake Hardenable (BH) steels grades are conventional High Strength Steels that exhibit a bake hardening effect. BH steels exhibit an increase in yield strength after room-temperature stamping followed by processing through a thermal cycle comparable to the time-temperature profile used in paint curing (or baking) – approximately 170 °C for 20 minutes. Bake hardenability is characterized by determining the Bake Hardening Index.

BH steel grades have yield strength at shipment from the steel mills of 180 MPa to 300 MPa (approximately 25 ksi to 45 ksi). The grades at the lower strength levels are capable of being produced with a Class A surface finish and are used in applications where dent resistance is desired in thin sheet steel. Applications for the higher strength BH steels include structural parts where Class A surface is not required. The higher strength after forming and baking is the reason automakers might use these in body structure applications, potentially contributing to vehicle lightweighting efforts.

These grades work harden approximately 30 MPa when 2% strain is introduced, either from stamping or during a tensile test, which is similar to dent resistant IF-HS. In contrast to IF-HS, the paint-bake cycle after forming results in an additional yield strength increase. The minimum strength increase from baking is specified by some automakers as 20 MPa to 35 MPa, measured after applying a defined level of strain.

Higher yield strength directly improves the dent performance. Even though BH grades and their non bake hardening counterpart IF-HS grades may have similar yield strength and thickness after forming, BH steels will show superior dent resistance due to the increase in yield strength from the paint baking operation.

Ferrite is the main microstructural phase of BH steels. The strengthening from the paint bake cycle is due to the controlled amount of carbon remaining in solid solution (on the order of 25 ppm) when the steel leaves the production mill. At the baking temperatures after the part is formed, the dissolved carbon migrates to pin any free dislocations created from stamping. This increases the yield strength of the formed part for increased dent resistance. Formability does not suffer since the strength increase occurs after stamping.

5.2.4 High-Strength Low-Alloy (HSLA) Steels

High-strength low-alloy (HSLA) steels were developed as an alternative to alloyed steel, where higher strength was achieved with a much lower alloy content. Lower carbon content and lower alloying content leads to increased ductility, toughness, and weldability compared with grades achieving their strength from only solid solution strengthening such as C-Mn steels. Lower alloying and elimination of post-forming heat treatment makes HSLA steels an economical approach for many applications.

HSLA steels have a microstructure that is mostly precipitation-strengthened ferrite, with the amount of other constituents like pearlite and bainite being a function of the targeted strength level. This steelmaking approach allows the production of sheet steels with yield strength levels now approaching 800 MPa. HSLA steels increase strength primarily by micro-alloying elements contributing to fine carbide precipitation, substitutional and interstitial strengthening, and grain-size refinement. Carbide precipitation and grain-size refinement is achieved with only 0.05% to 0.10% of titanium, vanadium, and niobium, added alone or in combination with each other.

HSLA steels are found in many body-in-white and underbody structural applications where strength is needed for increased in-service loads.

5.2.5 Dual Phase (DP) Steels

DP steels consist of multiple microstructural phases (one a soft phase “Ferrite”, the other a hard phase “Martensite”). The soft ferrite phase is generally continuous, giving these steels excellent ductility. When these steels deform, strain is concentrated in the lower-strength ferrite phase surrounding the islands of martensite, creating the unique high initial work-hardening rate (n-value) exhibited by these steels. Here, the forming process actually increases the strength level of the part, compared to the initial strength level of the steel.

Higher strength DP steels are typically achieved by increasing the martensite volume fraction. Depending on the composition and process route, steels requiring enhanced capability to resist cracking on a stretched edge (as typically measured by hole expansion capacity) can have a microstructure containing significant quantities of bainite.

The work hardening rate plus excellent elongation creates DP steels with much higher ultimate tensile strengths than conventional steels of similar yield strength. For example, DP steels exhibit higher initial work hardening rate, higher ultimate tensile strength, and lower YS/TS ratio than an HSLA with comparable yield strength.

5.2.6 Transformation-Induced Plasticity (TRIP) Steels

Another multi-phase steel with complex metallurgy and production processing, TRIP steels use higher quantities of carbon and other alloying elements than DP steels to achieve uncommon micro-structural phases at or below ambient temperature. TRIP steels contain metastable Austenite, that transforms to the hard phase Martensite during plastic strain of metal forming or crash. During deformation, the TRIP steel microstructure results in higher work hardening rates at higher strain levels, beyond that of DP steels, providing a slight advantage over DP in the most severe stretch forming applications. TRIP steels therefore can be engineered or tailored to provide excellent formability for the manufacturing of complex part shapes and exhibit high work hardening during crash deformation for excellent crash energy absorption. The additional alloying requirements of TRIP steels degrade their resistance spot-welding behavior.

5.2.7 Ferritic-Bainitic (FB) Steels (including Stretch Flangeable - SF)

FB steels have a very fine dual-phase microstructure, achieved from additional alloying and steel processing requirements. These steels are sometimes utilized to meet specific customer application requirements defining Stretch Flangeable (SF) or High Hole Expansion (HHE) capabilities for improved edge stretch capability. They are very formable and are available as hot-rolled products.

The primary advantage of FB steels over HSLA and DP steels is the improved stretchability of sheared edges as measured by the hole expansion test (λ). Compared to HSLA steels with the same level of strength, FB steels also have a higher strain hardening exponent (n) and increased total elongation. Because of their good weldability, FB steels are good candidates for tailored blank applications. These steels also are characterized by both good crash performances and good fatigue properties.

5.2.8 Complex Phase (CP) Steels

CP steels typify the transition to advanced metallurgical complexity to achieve very high ultimate tensile strengths while maintaining reasonably good ductility. The microstructure of CP steels typically contain small amounts of martensite, retained austenite and pearlite within a ferrite/bainite matrix. A thermal cycle that retards recrystallization and promotes the formation of carbo-nitrides precipitation results in extreme grain refinement. DP and TRIP steels do not rely on precipitation hardening for strengthening, and thus the ferrite in these steels is relatively soft and ductile. In CP steels, carbo-nitride precipitation increases the ferrite strength. For this reason, CP steels show significantly higher yield strengths than DP steels at equal tensile strengths of 800 MPa and greater.

Minimizing retained austenite helps improve local formability, since forming steels with retained austenite induces the TRIP effect producing hard martensite. CP steels are characterized by high energy absorption and high residual deformation capacity, excellent features for crash structures including frame rails, pillar reinforcements, fender and bumper beams.

5.2.9 Martensitic (MS) Steel

Martensitic steels are characterized by a microstructure that is mostly all martensite, but possibly also containing small amounts of ferrite and/or bainite. Steels with a fully martensitic microstructure are associated with the highest tensile strength – grades with a tensile strength of 2000 MPa are commercially available, and higher strength levels are under development. Within the group of multiphase steels, MS steels show the highest tensile strength levels.

To create MS steels, the austenite that exists during hot-rolling or annealing is transformed almost entirely to martensite during quenching on the run-out table or in the cooling section of the continuous annealing line. Adding carbon to MS steels increases hardenability and strengthens the martensite. Manganese, silicon, chromium, molybdenum, boron, vanadium, and nickel are also used in various combinations to increase hardenability. This martensite structure can also be developed with post-forming heat treatment. MS steels are often subjected to post-quench tempering (re-heating) to improve ductility, so that extremely high strength levels can be achieved along with adequate ductility for certain forming processes like Roll Forming.

5.2.10 Twinning-Induced Plasticity (TWIP) Steel

TWIP steels have a high manganese content (17-24%) that causes the steel to be fully austenitic at room temperatures. A large amount of deformation is driven by the formation of de-formation twins. This deformation mode leads to the naming of this steel class. The twinning causes a high value of the instantaneous hardening rate (n value) as the microstructure becomes finer and finer. The resultant twin boundaries act like grain boundaries and strengthen the steel. TWIP steels combine extremely high strength with extremely high stretchability. The n value increases to a value of 0.4 at an approximate engineering strain of 30% and then remains constant until both uniform and total elongation reach 50%. The tensile strength is higher than 1000 MPa.

5.2.11 Press-Hardened (Hot Formed) Steel (PHS)

Press hardening steels are typically carbon-manganese-boron alloyed steels. They are also commonly known as Press Hardening Steels (PHS) or hot-stamped steels and are characterized by boron levels between 0.002% and 0.005%. They have been in use since the 1990s in to solve the need for very high strength intrusion resistant crash members,

although Hot Stamping as we know it today was developed in 1970s in Sweden. The most used steel since then has been 22MnB5 with slight modifications. The name 22MnB5 means approximately 0.22 wt-% C, approximately $(5/4) = 1.25\%$ wt-% Mn, and B alloying, which is why they are often referred to as Boron steels.

For 22MnB5 to reach its high strength after quenching, it must be austenitized first, which means heated above the austenite transformation temperature. During heating, ferrite begins to transform to austenite, and then the Austenite transforms to martensite or other microstructures as the steel is cooled. The microstructures produced from this transformation depends on the cooling rate; achieving the “fully hardened” condition in PHS grades requires an almost fully martensitic microstructure, which means a rapid “quench” or “critical cooling rate”. Rapid cooling results also results in parts that retain critical dimensional characteristics, while achieving extremely high strength levels. For energy absorbing applications, there are also tailored parts with “soft zones”, where areas on a component will be intentionally developed with other microstructures to ensure higher energy absorption. This is another example of steel’s ultimate tunability, a feature that cannot be replicated with other materials.

There are two types of press-hardening or hot forming applications, that will be described in more detail in the Steel E-Motive Manufacturing Processes Section:

- Direct Hot-Forming: the part is formed at very high temperatures (above 850°C), followed by quenching (rapid cooling) to ambient temperature.
- Indirect Hot-Forming: pre-forms the part at room temperature to a high percentage of the final part shape followed by additional high temperature forming and quenching. The press hardened steels for this process must begin with better cold forming properties than is necessary in direct hot forming

5.3 Steel E-Motive Manufacturing Processes

Steel E-Motive targets Mobility as a Service (MaaS) providers, whose primary interest is achieving a profitable business model premised on lowest Total Cost of Ownership (TCO). One of the enablers of low TCO is the ability to utilize the existing automotive manufacturing infrastructure to minimize investment costs and utilize already paid-for assets. The ability to utilize these assets also eliminates the need to produce new equipment that can be energy-intensive and hence unfriendly to the environment. Steel E-Motive can be a catalyst towards achieving Net Zero emissions in 2050, and hence manufacturing process selection is critical to that ambition.

In the automotive industry, conventional stamping processes are commonly used to produce parts in the vehicle body structure. But these processes are also characterized by significant levels of engineered scrap, which translate into greater steel production and emissions associated with these parts. Therefore, there is urgency to form parts via fabrication processes that utilize material production more efficiently. Alternatives to stamping include press hardening, roll forming, roll stamping, hydroforming, and others. Various grades of sheet steel material for these processes are available in the form of coils, and each coil can represent a single material sheet (thickness and grade), laser welded coils, or tailor rolled coils.

Below are brief descriptions of each the various material production processes that were considered for various Steel E-Motive components.

5.3.1 Laser Welded Blanks

A laser welded blank is two or more sheets of steel butt seam-welded together into a single blank which is then stamped into a part. As a result of laser welding technology, a single blank can contain different steel grades, different steel thicknesses, or both. Laser welded blank technology allows for the placement of various steel grades and thicknesses within a specific part, placing steel's attributes where they are most needed and removing weight that does not contribute to part performance. For large parts such as a door ring, individual blanks are joined together prior to stamping. The smaller blanks typically achieve the geometry of the final part much more efficiently, compared to blanking the entire door ring from one blank, and then trimming the center of the ring, creating excessive engineered scrap.

Figure 5.2 shows a laser welded door ring with multiple grades and thicknesses. This technology allowed for a reduction in panel thickness in non-critical areas, thus contributing to an overall weight reduction of the part. The lower strength product in the bottom section of the B-Pillar helps dissipate the crash energy in the event of a side impact, playing a key role in crash energy management.

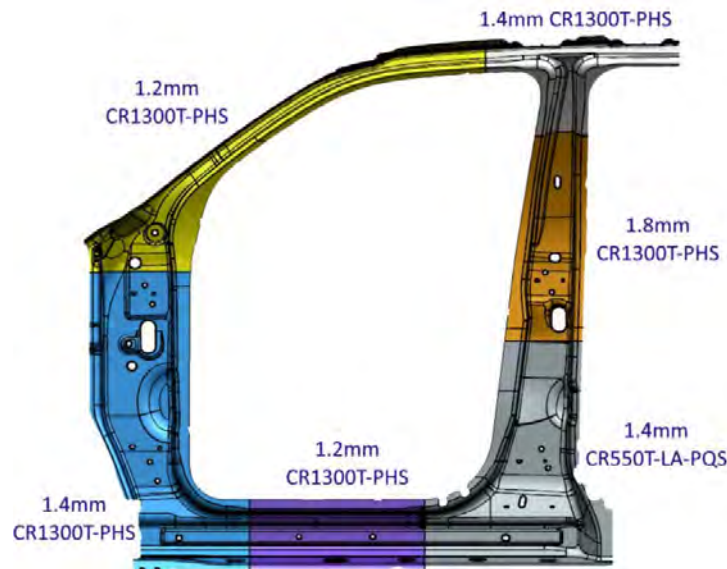


Figure 5.2: Example of a laser weld blank used for a body side door ring.

5.3.2 Laser Welded Coil

Laser welded coil is a process of producing a continuous coil of steel from individual separate coils of varying thickness and grades. The basic process takes separate coils prepares the edges, and laser welds these together and re-coils the strip ready for other blanking or to be used as a continuous feed in a transfer press line. See Figure 5.3.

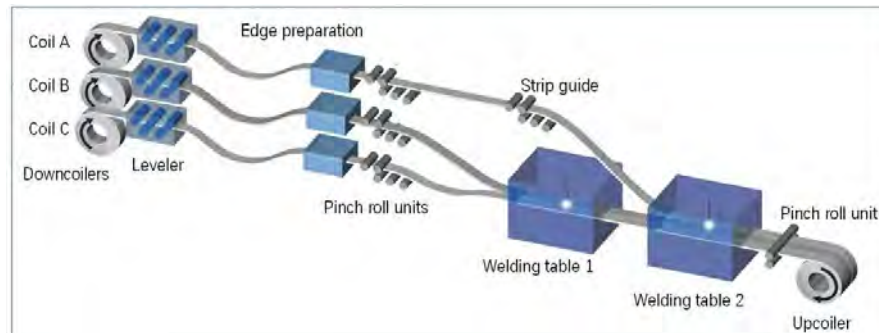


Figure 5.3: Laser welded coils production process.

5.3.3 Tailor Rolled Coil

This is a manufacturing process of flexible cold strip rolling by varying the gap between two rolls which allows for different strip thicknesses in the direction of rolling (Figure 5.4). The accurate measuring and controlling technology ensures that strip thickness tolerances are achieved.

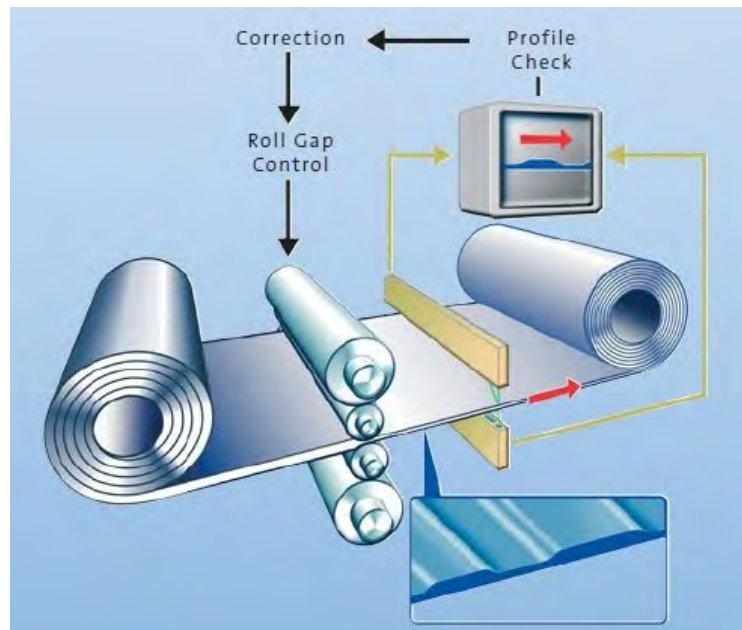


Figure 5.4: The principle of producing a Tailor Rolled Coil.

A tailor rolled coil can be either used for blanking operations (for stamping or tubular blanks) or can be directly fed into a roll forming line.

5.3.4 Conventional Electric-Resistance-Welded (ERW) Tube

ERW tubes are produced specifically for hydroforming. The process can utilize either a standard single thickness and grade coil, a laser welded coil or a tailor rolled coil, as shown in Figure 5.5.

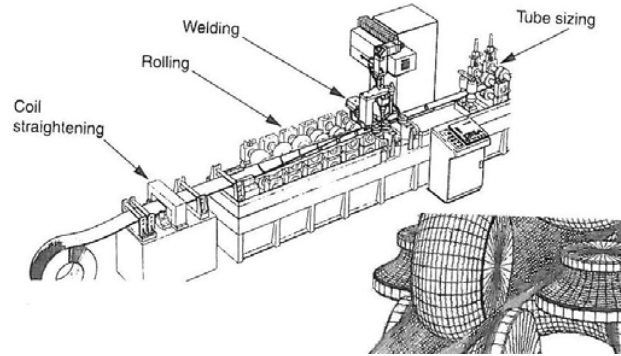


Figure 5.5: Typical roll form layout for making ERW tubes

5.3.5 Tubular Blanks (Laser-Welded)

Laser welded tubes used in the hydroforming process are made from individual blanks. This blank is then formed into a tube of constant diameter or a tapered tube. Manufacturing precision welded tubes typically involves continuous roll forming followed by a longitudinal weld created by laser welding.

The bending behaviour of tube depends on both the tubular material and the bending technique. The weld seam is also an area of non-uniformity in the tubular cross section, and therefore influences the forming behaviour of welded tubes. The recommended procedure is to locate the weld area in a neutral position during the bending operation.

Tubular components can be a cost-effective way to reduce vehicle weight and improve safety. Closed sections are more rigid, resulting in improved structural stiffness. Automotive applications include seat structures, cross members, side impact beams, bumpers, engine subframes, suspension arms, and twist beams. All AHSS grades can be roll formed and welded into tubes with large D/t ratios (tube diameter / wall thickness); tubes having 100:1 D/t with a 1mm wall thickness are available for Dual Phase and TRIP grades (example shown in Figure 5.6).

Due to the cold working generated during tube forming, the formability of the tube is reduced compared to the as-received sheet. The work hardening during tube forming increases the yield strength and the tensile strength, thereby allowing the tube to be a structural member. Successful bending requires aligning the targeted radii with the available elongation of the selected steel grade. Subsequent operations like flaring, flattening, expansion, reduction, die forming, bending and hydroforming must consider the tube properties rather than the properties of the incoming flat sheet.

AHSS tubes provide excellent engineering properties suitable for structures, offering competitive advantage through high-energy absorption, high strength, low weight, and cost-efficient manufacturing.



Figure 5.6: DP 590 formed into a tube w/45 degree bend, then laser welded.

5.3.6 Roll Forming

Roll forming is a continuous forming process which converts a flat steel strip into an engineered shape using consecutive sets of mated rolls. Each roll makes only an incremental change in the form, but the sum of these small steps can be a fairly complex profile. Two common methods are closed roll forming and open roll forming, which describe the way the metal engages each die section. The typical process consists of a steel uncoiler, a hydraulic hole and notch punch, the roll forming machine with several roll stands, a straightener, an automatic cutting station and the final product unload station.

In the forming process, a coil or long individual strips are fed through a roll forming line which converts the flat sheet to a contoured cross-sectional profile. The unique aspect of this approach is the use of consecutive forming stations, each of which nudges the metal towards the desired shape (Figure 5.7). Based on the targeted profile, a computer calculates the optimal placing and shape of the rollers for maximum efficiency and designs the track. The more advanced the desired shape, the more rollers the material goes through. The roll forming line can bend metal, form metal into tubes, create metal maze-like structures, and punch the metal with holes during the process.

For comparison, in conventional stamping the entire part is formed all at the same time, in one press stroke. The part shape – and especially how complex it can be, is limited when the strains from forming exceed what the metal is capable of achieving before splitting. Conversely, in roll formed parts, only a small amount of forming strain is put into the part during each station and even here, only a small section is bent at any given time. Because of this, more complex shapes can be achieved with an appropriately designed roll forming process.

The rollers are precision-contoured metal dies that shape the incoming sheet metal. In most cases, they are also the powered drive rolls that pull the strip through the roll forming unit. These rollers can be as simple as the cylindrical rollers used to roll luggage through airport scanners, or they can take on more intricate shapes. After the final forming station, the strip is sheared to the ordered product length. Typically, no additional work is needed before shipment, since the final form has been achieved.

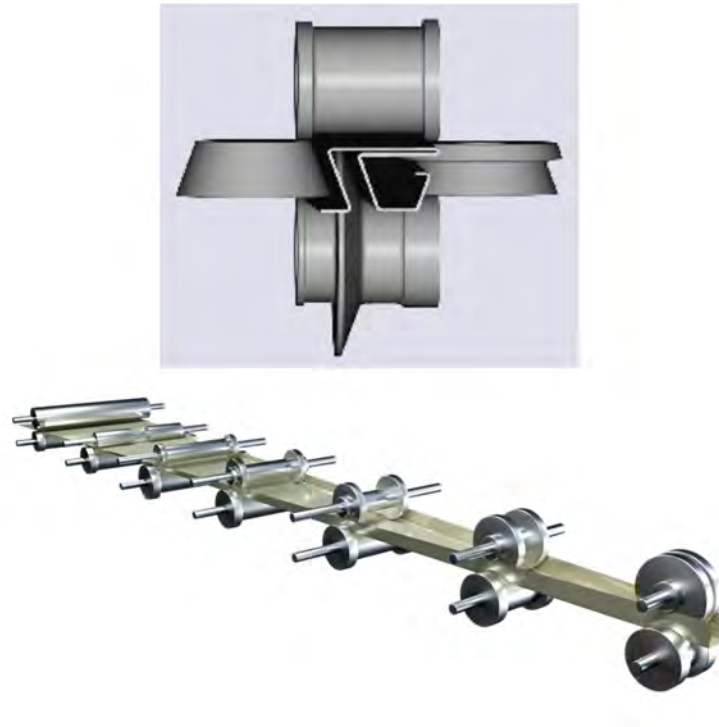


Figure 5.7: Roll forming rolls and line layout, showing incremental changes in part shape.

Advantages of the Roll Forming Process

There are a variety of advantages to roll forming. Because of the “assembly line” efficiency of roll forming, long lengths of metal can be produced and cut in large quantities, which reduces cost. Secondary processes such as punching or even welding can be integrated into a single production line. The profiles that can be produced using roll formed sheet steel utilize the material very efficiently, meaning less waste and lower overall steel production emissions, since engineering scrap (waste) is commonly less than 10%.

The roll forming process makes creating lighter-weight steel parts easier compared to other shaping processes, since the wall thickness can be targeted based on the structural needs of the component. Parts can be rolled even if a finish or paint has been applied. While hot forming can produce similarly complex profiles, roll forming is a room temperature process. As such, it avoids the distortion risk associated with hot forming, while being more energy efficient at the same time.

5.3.7 Roll Stamping

Traditional roll forming creates products with essentially uniform cross sections. A newer technique called Roll Stamping enhances the ability to create shapes and features which are not in the rolling axis.

Using a patented process, forming rolls with the part shape along the circumferential direction create the desired form, as shown below in Figure 5.8.

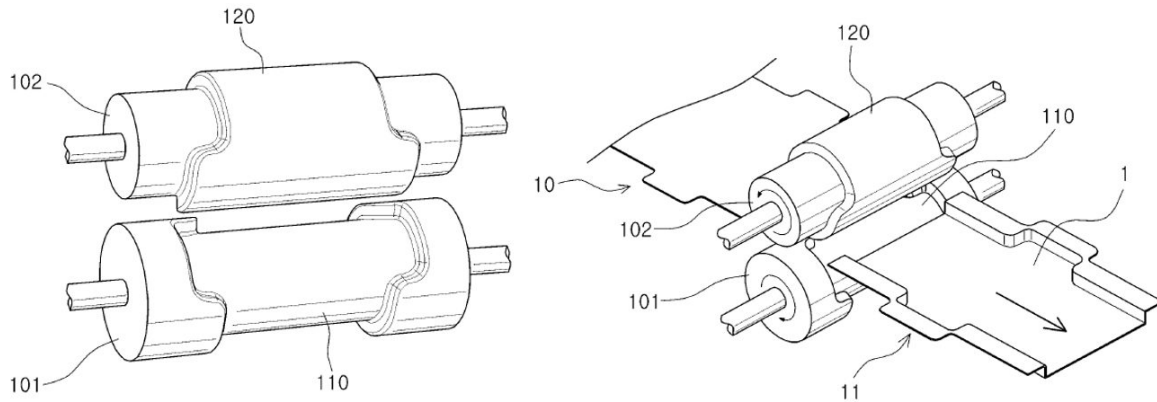


Figure 5.8: *Roll Stamping creates additional shapes and features beyond capabilities of traditional roll forming.*

This approach can be applied to a conventional roll forming line. In the example of an automotive door impact beam, the W-shaped profile in the central section and the flat section which attaches to the door inner panel are formed at the same time, without the need for brackets or internal spot welds (Figure 5.9). Sharp corner curvatures are possible due to the incremental bending deformation inherent in the process.



Figure 5.9: *A roll stamped door part formed on a conventional roll forming line eliminates the need for welding brackets at the edges.*

5.3.8 Stress Reverse Forming™

When HSS sheet is press formed, the “springback” phenomenon, in which the sheet tends to return to its original shape after press forming, must be compensated for to maintain accurate part shape. The amount of springback increases with increasing strength levels, and the corresponding tool shape must be designed more precisely to ensure the accurate part shape, which leads to increased time and cost to develop the appropriate tool shape. Corresponding to the need for a cold press forming method that minimizes spring back, the “Stress Reverse Forming™” was developed by a WorldAutoSteel member company. Generally, a small stress is induced into the steel at the bottom dead point (bottom of the press-stroke) during press forming, which leads to the smaller amount of springback and stabilizing part shape. Stress Reverse Forming™ reduces this induced stress by utilizing the Bauschinger effect of steel, which lowers deformation stress after the deformation direction is reversed (Refer to schematic in Figure 5.10.).

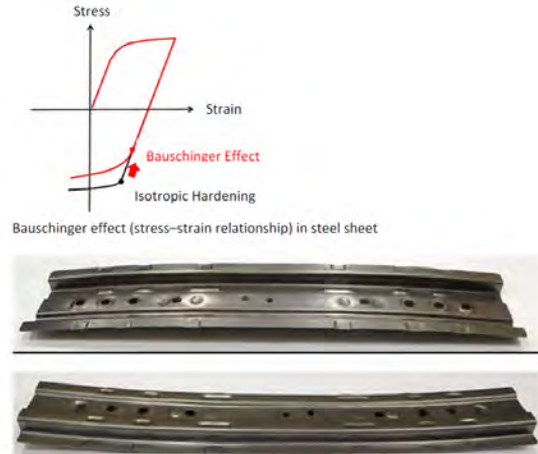


Figure 5.10: Center roof reinforcement adopted with use of 1470MPa grade cold-rolled UHSS by “Stress Reverse Forming.”

5.3.9 Hydroforming (Tube)

Tube hydroforming creates complex shapes by using internal pressure to expand a tube against a die cavity. Frame rails, engine cradles, roof rails and bows, instrument panel beams, cross members, pillars, and seat frames are among the parts created using hydroforming. Benefits of this approach can include part consolidation, weight reduction, improved stiffness and strength, tighter dimensional tolerances, fewer secondary operations, and reduced cost compared with conventional stamping and welding approaches.

These benefits are highlighted in a truck front end structure shown in Figure 5.11, where hydroforming allowed for consolidation of 31 parts into 18 and resulted in a 31% weight reduction.

Automotive body structures have incorporated hydroformed parts for several years, with recent vehicles using AHSS grades to improve crash energy management and impact performance. Figure 5.11 shows the Nissan Titan hydroformed roof rail:



Figure 5.11: 2016 Nissan Titan XD: Door-To-Roof Support.

The hydroforming process for tubes usually involves expanding the tube diameter from 3% to 30% depending on the design, materials selected and pressures available for forming.

Tube production commonly utilizes one of three basic methods of hydroforming tubes, categorized by the internal pressure used for the expansion.

In high-pressure tube hydroforming, the tube is placed in the die and the die is closed. Pressurizing the tube now causes the metal to stretch as the circumference increases to conform to the inner circumference of the die – often with tight radii in corners and product features. Higher strength steels may be unable to expand sufficiently to fill the die geometry or create small radii without failure. Furthermore, high pressure could be necessary to obtain the correct geometry with minimum springback or fewer wrinkles compared to low-pressure hydroforming.

Low-pressure tube hydroforming begins with a tube whose circumference is slightly less than the final circumference of the finished geometry. Tube pressurization occurs after placing the tube in an open die, prior to closing. As the die closes, the circumference of the tube changes shape to conform to the closing die. The internal pressure is sufficient to prevent the tube from buckling during the shape change. A small circumference increase combined with a uniform wall thickness means that high strength and lower-formability metals can achieve tighter radii without failure. This low-pressure process is suitable for tubes made from AHSS. This approach results in a change of the shape of the tube cross-section, rather than tube expansion.

5.3.10 Stamping (cold)

In the stamping process, sheet metal is transformed into complex parts using highly specialized computer-aided drafting and manufacturing programs. Sheet metal stamping produces high quality parts quickly and efficiently and is ideal for most large volume production (+ 100,000 parts or vehicles) because conventional presses can produce large stampings at rates up to 15 parts per minute.

The metal is fed into a press, either in blank or coil form, where the stamping tool, also known as a die, creates the desired shape. The die is pressed into or through the metal with tremendous force, and this force is based on the size and strength of the metal being formed (the force used is measured in tons). With a series of operations, the metal can be altered from a relatively simple shape into a complex geometry. Stretch forming is ideal for shallow parts, in that the blank or coil is held tight by binder pressure or beads, and then stretched into the part shape; the stretching adds strength to the final part and typically allowing the smallest of blank sizes. This translates to lower metal waste and production emissions, ever-increasingly important.

Drawing is a more complicated operation and is how vessels or deep depressions are formed. Tension is used to carefully draw the material into a cavity to change its shape. Though the material might stretch while it's drawn, technicians try to avoid stretching as much as possible to keep the material intact. Vehicle oil pans are an example of an automotive part made with drawing.

As the name implies, cold stamping doesn't use heat; instead, the forming and subsequent operations are performed at ambient temperature. Even though no heat is used, final parts come out of the press warm or hot because of the friction that's created between the metal and the die from the force of the press.

When producing parts using a conventional cold stamping process there are various die set-ups that can be considered depending on the final part geometry. Types of dies used are progressive, transfer, compound, and combination. For the Steel E-Motive stamping processes, only a transfer die configuration was considered (Figure 5.12). This process is used for high volume production where several dies are mounted of a common base plate. Material

is fed into the press in blank or coil form and is generally transferred from die to die automatically with robots or carrier arms. When using a single material thickness and grade, a steel coil will be delivered to the stamping plant and blanking operation completed prior to feeding the blank into the transfer press. This can be completed either as part of the transfer press or off-line in a separate operation. When using either a laser welded or tailor rolled blank the blanking operation will normally be completed by the steel service provider and the blank delivered to the stamping plant. The transfer line presses would normally complete the following stamping operations: blank, form, trim, pierce and flange. To keep tooling cost to a minimum the number of stamping dies in a transfer press are kept to the minimum necessary to produce the part. Traditionally the maximum number of stations in a transfer press is six, but through part and die design improvements most OEM's have limited the number of stations to four.

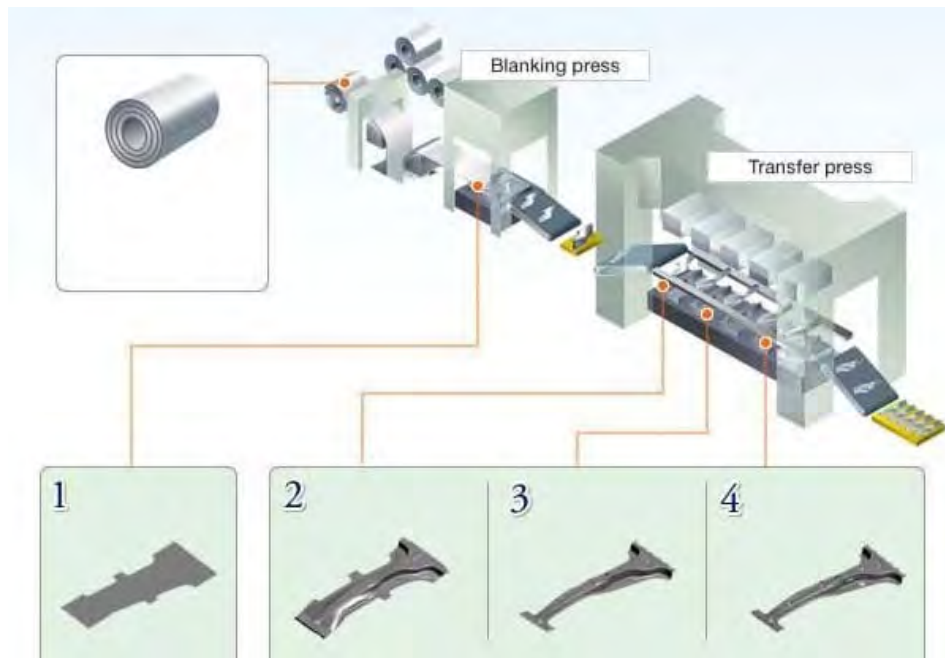


Figure 5.12: Schematic of a typical transfer press layout

5.3.11 Press Hardening

Press hardening (hot stamping) uses a base material, 22MnB5, ferritic-pearlitic structure, with a tensile strength of approximately of 500 - 650MPa. After the hot stamping, the part develops a martensitic structure and increased strength up to 300% of its original value.

The Direct hot stamping process, shown in Figure 5.13, uses blanks heated in a continuous feed furnace to temperatures between 900 and 950 C°. During this heating process an austenitic structure is formed.

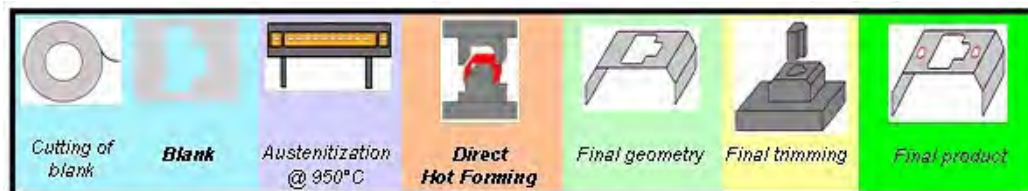


Figure 5.13: Typical direct hot stamping line

Blanks are then transferred to a stamping die to form the correct geometry. The die is built with cooling lines, to allow rapid cooling of the die and part. This quenching takes place after the forming process has been completed and allows a transformation from the austenitic structure to a martensitic microstructure with a tensile strength of up to 1500 MPa (Figure 5.14).

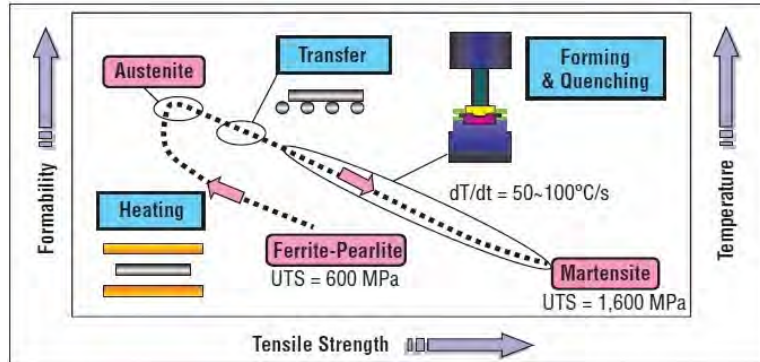


Figure 5.14: Part transformations during the hot stamping process.

The preparation of the blank for hot stamping is similar to that for a cold stamped part, this applies to both direct and in-direct hot stamping. The difference in the stamping operation comes when the decision is made if the part is to be produced using a direct or indirect stamping process. The indirect process differs from the direct process in that the part can be formed up to 100% of its required geometry prior the transfer of the part to a continuously feed furnace (Figure 5.15). This can be achieved in a similar process as used for cold stamping using a transfer press process. The part is placed in a continuous feed furnace then transferred to the hot stamping die. At this stage there is minimal geometry changes to the part in the die. This process gives minimal post forming trimming operations.

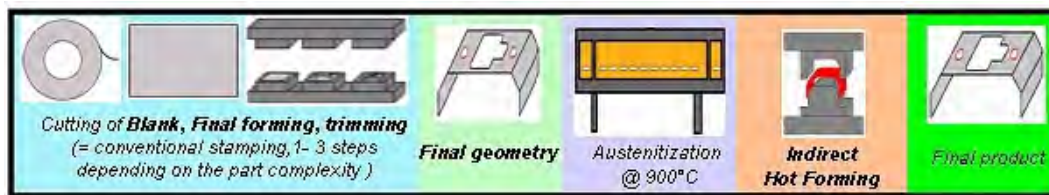
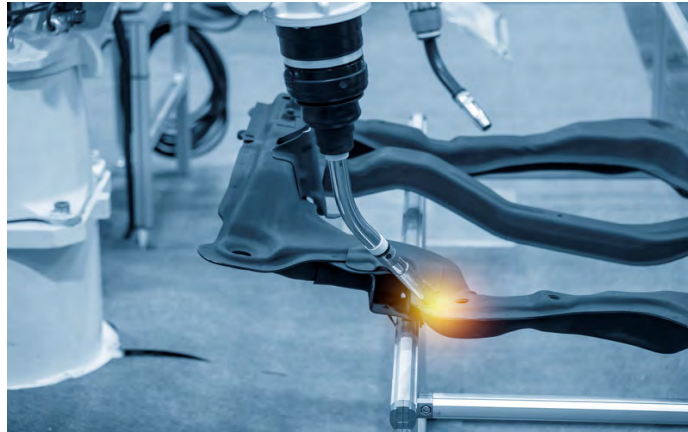


Figure 5.15: In-direct hot stamping process

This is in contrast to a direct process where no pre-forming of the part is done prior to the hot stamping operation. As minimal stamping operations other than forming can be completed in the direct hot stamping die there is a greater use of post stamping laser trimming operations. In both processes, oxidation of the part due to exposure to the ambient atmosphere may occur a de-scaling operation may be necessary. Due to the extreme hardness of the scale and movement of the blank in the die during the stamping operation, high die wear may result. To address the scale formation in hot stamping operations, steel products are provided that include an Aluminized, Galvanealed, or other barrier coating that prevents oxidation of the surface and formation to address die wear issues and post-process scale removal.

5.4 Various Joining Methods Considered for AHSS and Steel E-Motive

Steel E-Motive concepts can be assembled in an existing automotive manufacturing plant with conventional joining equipment. Aside from the Laser Welding Blank process described in Fabrication Processes, the vehicle components are joined with various processes including resistance spot welding, laser welding, and adhesive bonding. These are briefly described here.



2T and 3T stackups of very high-strength press hardened steels are joined successfully with resistance spot welding in current model production. 2T to 3T stackups have also been joined with little difficulty. The Ohio State University in Columbus, Ohio is presently evaluating the potential for a 5T stackup. Simulated stackups have been achieved with the correct model parameters.

5.4.1 Resistance Spot Welding

Advance High-Strength Steels (AHSS) have been successfully resistance welded in automotive assembly lines for several years. Higher clamping forces are required due to the extreme high strengths of these materials, so these tools must be updated especially in Tier 1 and older assembly shops. Typical weld parameters apply to these materials, but must be more closely controlled, as process variation may impact joint strength and functional performance.

The high strength and hardness associated with AHSS can affect spot weld failure modes during the typical peel testing and chisel testing performed for weld quality evaluation; these “test” failures may occur even though the weld strengths are acceptable for the intended application, so experience is required to interpret these results correctly. With AHSS, full button pulls are less likely due to the high Carbon Equivalent that are likely to produce hard weld nuggets. This fact is compounded by the higher yield strengths of the material that will tend to produce greater stresses concentrating at the edge of the nugget during a peel or chisel tests. Therefore, the conventional modes of testing such as peel and chisel testing may be more likely to initiate interfacial or partial interfacial failure modes.

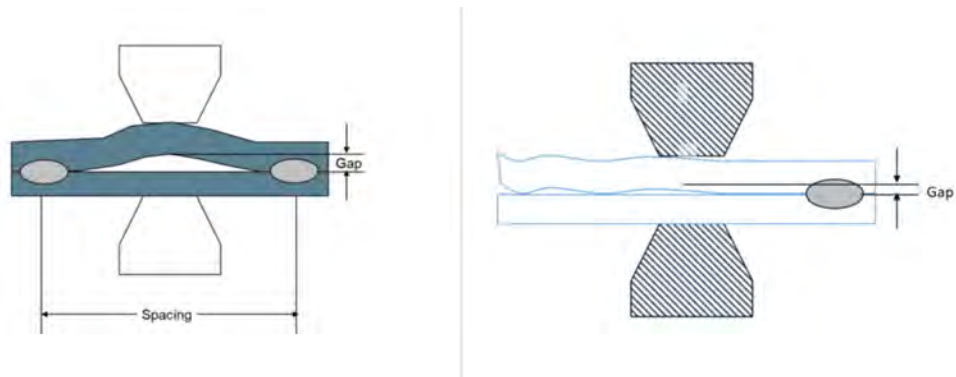
With AHSS, even full interfacial failures may exhibit high strength, although it may sometimes be challenging to differentiate between an interfacial failure and a “stuck” weld condition (which refers to an unfused bond of unacceptable strength). To improve nugget failure modes with AHSS, the hard martensite must be softened. A simple and effective approach to accomplishing this is to add a temper cycle at the end of the weld, something that can easily be added at the end of the spot-welding cycle.

A sufficient amount of quench time must be included prior to tempering to allow the complete transformation to martensite, and the amount of tempering time and current will dictate how much softening occurs. Of course, the quench time adds cycle time to each weld, so production requirements mandate that this time be kept as short as possible. Depending on how hardenable the steel being welded is, other approaches that slow cooling rates may be helpful. These approaches include current pulsing, current sloping, longer weld times, and short hold times.

The unique physical characteristics of Advanced High Strength Steels (AHSS) present some challenges to welding and bonding processes. AHSS differ from mild steels by chemical composition and microstructure. For high-volume production, it's important to note that these microstructural differences will require different welding parameters for successful joining. Assuming you chose the appropriate welding parameters that allow for a large process window, manufacturing variability will strongly affect the RSW weld quality and performance, and thus additional attention to process control is required.

Material fit-up

One of the great advantages of the RSW process is the action of clamping the material together via the electrode force applied during the process. This fit-up issue, as shown in Figure 5.16, can be very significant especially in welding an AHSS product. In this case the effective required force specified during the process setup is significantly reduced and can



result in an unacceptable weld, over-heating, and severe metal expulsion.

Figure 5.16: *Examples of Pre-Welding Condition/Processing Fit-Up Issues.*

For welding AHSS, higher forces are generally required as a large part of the force is being used to force the parts together in addition to the force required for welding. Also, welding parameters may be set for pre-heating with lower current pulses or current up-slope to soften the material for easier clamping to close the joint gap.

Electrodes Misalignment

In many production applications, electrode misalignment is a common problem during machine set up, and this must be carefully avoided to achieve appropriate nugget shape and strength.

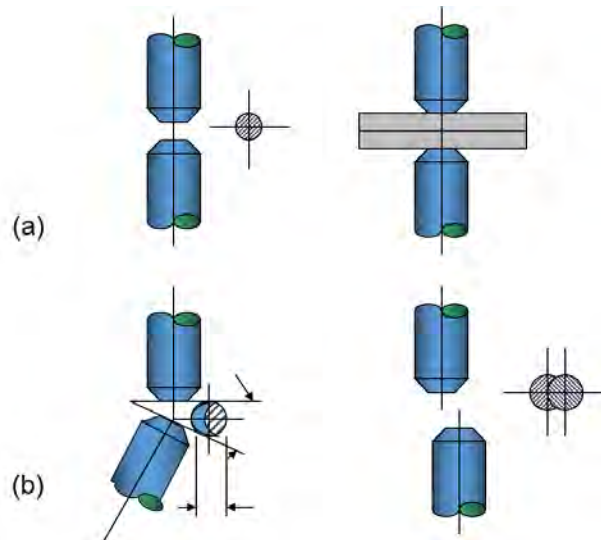


Figure 5.17: *Alignment vs. Misalignment of Electrodes, AHSS and Electrode Geometry*

In these cases, the intended contact between the electrodes is not achieved and thus the current density and the force density (pressure) required for producing an acceptable weld cannot be achieved. With such conditions, overheating, expulsion, sub-size welds and extensive electrode wear will result. Electrode cooling rates are another example of a process variable that must be carefully controlled for AHSS applications; in general, higher cooling rates are necessary to extend electrode life and ensure high joint strength.

Squeeze Time

The squeeze time is the time required for the force to reach the level needed for the specific application. Welding current should be applied only after reaching this force. RSW controllers enable the easy control of squeeze time, just as with the weld time, for example. In many production operations, a squeeze time is used that is too low due to lack of understanding of its function. If squeeze time is too low, high variability in weld quality in addition to severe expulsion will be the result.

The squeeze time required for an application depends on the machine type and characteristics (not an actual welding parameter such as weld time or welding current for example). Some of the more modern force gauges have the capability to produce the curve shown in the Figure so adequate squeeze time will be used. If you do not know what the required squeeze time for your machine/application is, it is recommended to use a longer time.

5.4.2 Laser Welding

Laser welding is growing in more vehicle applications due to inherent weld strength, adaptability to complex weld geometries, and lower part distortion. Automotive applications use a variety of welding joint designs for laser welding in both lap joint and seam butt joint configurations as shown in Figure 5.18. For example, laser butt-welding is used for welding tubes in roll-forming production lines as an alternative method for high frequency induction welding. Seam welds on butt joints need less power from the machine than lap joints due to the smaller weld fusion area, producing less distortion and a smaller heat affected zone (HAZ). Butt joint configurations are more cost efficient, however, the fit up for seam welds can be more difficult to obtain than those of lap joints.

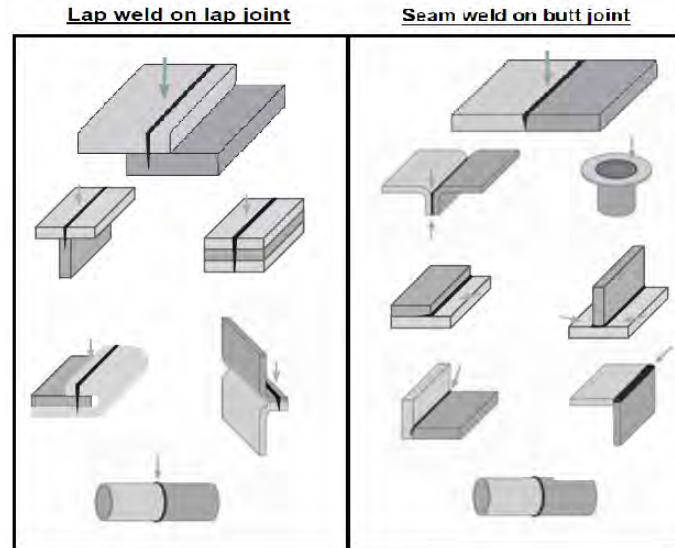


Figure 5.18: Common seam and joint types for laser welding of automotive applications.

When seam welding butt joint configurations, a general guideline for fit-up requirements include a gap of 3-10% the thickness of the thinnest sheet being welded, and an offset of 5-12% thickness of the thinnest sheet. Conversely, lap joints can require a gap of 5-10% the thickness of the top sheet being welded.

Laser welding is often used for AHSS lap (overlap) joints, but of course use different parameters compared to seam butt joint configurations. This type of weld is either a conventional weld with approximately 50% penetration in the bottom sheet or an edge weld. Welding is performed in the same way as for mild steels, but the clamping forces needed for a good joint fit-up are higher with AHSS than for mild steels. Lap joints tend to provide a larger process window, which can compensate for some of the manufacturing difficulties with AHSS, including springback and part distortion. To achieve good laser-welded overlap joints for Zn-coated AHSS, a small intermittent gap (0.1-0.2 mm) between the sheets is recommended, which is identical to Zn-coated mild steels. In this way, the Zn does not get trapped in the melt, avoiding pores and other imperfections. An excessive gap can create an undesirable underfill on the topside of the weld.

Studies have shown laser welding Zn-coated steels can be done without using a gap between the overlapped sheets. This is accomplished using dual laser beams. While the first beam is used to heat and evaporate the Zn coating, the second beam performs the welding. The dual laser beam configuration combines two laser-focusing heads using custom-designed fixtures.

AHSS grades can be laser butt-welded and are used in production of tailored products (tailor-welded blanks and tubes). The requirements for edge preparation of AHSS are similar to mild steels – in both cases, a good quality edge and a good fit-up are critical to achieve good quality welds.

If a tailor-welded product is intended for use in a forming operation, a general stretchability test such as the Erichsen Olsen cup test can be used for assessment of the formability of the laser weld. AHSS with tensile strengths up to 800 MPa show good Erichsen test values (Figure 5.19).

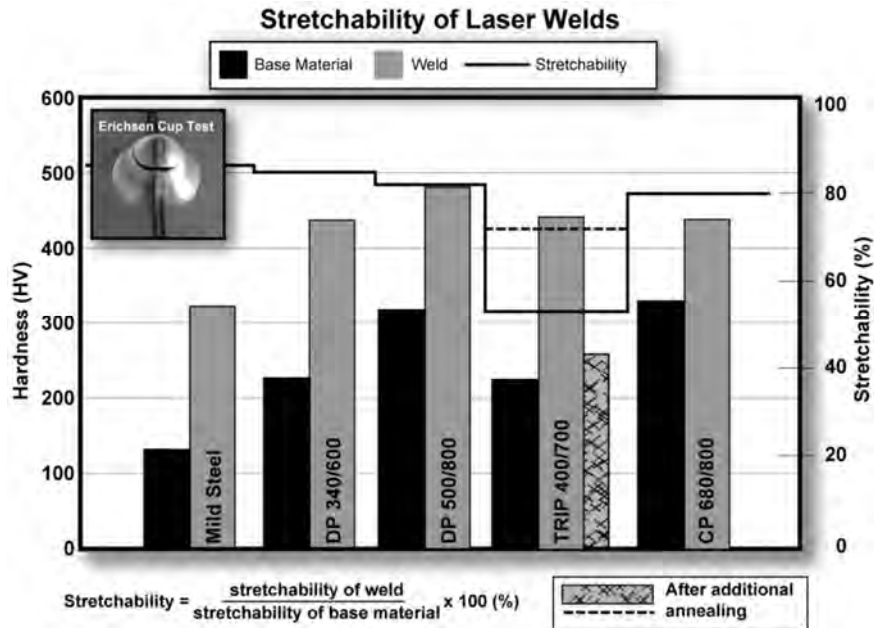


Figure 5.19: Hardness and stretchability of laser butt welds with two AHSS sheets of the same thickness (Erichsen test values describe the stretchability.)

The hardness of the laser welds for AHSS is higher than for mild steels. However, good stretchability ratios in the Erichsen test can still be achieved when the difference in hardness between weld metal and base metal is only slightly higher for AHSS compared to mild steels. If the hardness of the weld is too high, a post-annealing treatment (using HF-equipment or a second laser scan) may be used to reduce the hardness and improve the stretchability of the weld.

5.4.3 Adhesive Joining

Adhesive bonding is a joining process for metals and non-metals that uses an adhesive or glue, typically in the form of a liquid or a paste. It offers the major advantage of being able to join a wide array of materials but is limited by joint strength and applicable service conditions. Many of the fundamentals are similar to brazing and soldering, in particular the need for wetting and capillary action, and overlapping joint designs that rely on joint area for strength. Adhesives are categorized as thermosetting or thermoplastic. Thermosetting adhesives require a chemical reaction to cure and cannot be remelted once cured. They are the most common adhesives for structural applications and are recommended for AHSS.

Adhesives may be applied a variety of ways, including caulking and spray guns, dipping, rollers, and brushes. Curing may be accelerated by heating or some other energy source. Joining of AHSS with adhesive bonding is a good method to improve stiffness and fatigue strength in comparison to other joining methods (spot welding, mechanical joining, arc welding, and laser welding). If higher joint strengths are needed, the overlapped area may be enlarged. Due to the larger bonding area with adhesive bonding, the local stresses can be reduced and therefore the fatigue strength is increased. These improvements in stiffness and fatigue strength are important factors to consider at the design stage, especially in those cases when AHSS is used to decrease the weight of a component.

In general, the use of AHSS with high-strength structural adhesives will result in higher bond strength than for mild steel if the same sheet thickness is applied. Reduction of sheet thickness will decrease the strength because more peel load will occur.

5.4.4 Non-destructive Evaluation (NDE)

Several non-destructive testing processes have been evaluated for their ability to detect good weld nugget formation, incomplete nugget formation and cracking from LME or hydrogen embrittlement. Laboratory results have been quite repeatable, with UTS phased array showing the most promise. However, trials to conduct similar high-quality evaluations in series production have shown mixed results. Attaching sensors to robot heads interferes little with production, however the in-plant vibration, temperature fluctuations and dirt result in poor reproducibility. When welded components are removed and tested off-line (but still in the production plant), the results are improved and more stable; again phased array shows great promise in this application.

Steel industry partners have modelled LME susceptibility and held production application trials of various NDE methods with the hope of achieving a preferred methodology for automotive OEM's and Tier suppliers. As the technology and application understanding mature, we'll communicate recommendations via the website <https://ahssinsights.org/>

6.0 Technical Approach

6.1 Overall engineering approach, timing, and organisation

The Steel E-Motive engineering programme was completed within 24 calendar months. The programme was divided into 3 engineering phases with interim review gateways throughout. (Figure 6.1.1). Phase 0 was a 3-month pre-concept study, confirming and validating the vehicle targets, performing vehicle layout and package studies to define the available space for the body structure, develop a preliminary exterior styling theme and collate the engineering tools and data inputs which would be used throughout the programme. A 3D FEA topology optimisation was undertaken to determine the key loadpaths for the body structure. A desktop benchmarking study was also conducted to identify autonomous MaaS vehicles currently in development and their basic performance and characteristics. Phase 1 focussed on exploring the vehicle and body concepts based on the outputs from Phase 0. Development was done at complete body level as well as subsystems and modules such as the rocker and longitudinal crush rails. A limited number of steel grades was purposefully considered within Phase 1 to simplify the concept development process. On completion of Phase 1, the body concept designs, and performance were evaluated, validated, and down selected as a primary concept for development in Phase 2. Phase 2 focussed on optimising, refining, and validating the vehicle and body design and performance. The complete steel grade portfolio and fabrication process as detailed in Section 5.0 was applied and considered in Phase 2. The first 12 months of the project were largely undertaken with local and global Covid-19 pandemic restrictions in place. The engineering teams worked remotely (mainly home based), relying on web meetings and email communication. Face-to-face meetings between the WorldAutoSteel members did not occur until Month 14 of the project. In order to keep consortia members regularly informed and updated on technical progress, Engineering Working Groups were established, covering Design, CAE, Target Setting and Life Cycle Assessment. Periodic Working Group meetings were held throughout the Steel E-Motive engineering phases, approximately on a 3 monthly basis. The Working Groups provided an opportunity to brief the consortium members on technical progress as well as enabling members to provide their feedback, thoughts, and suggestions to the engineering teams.

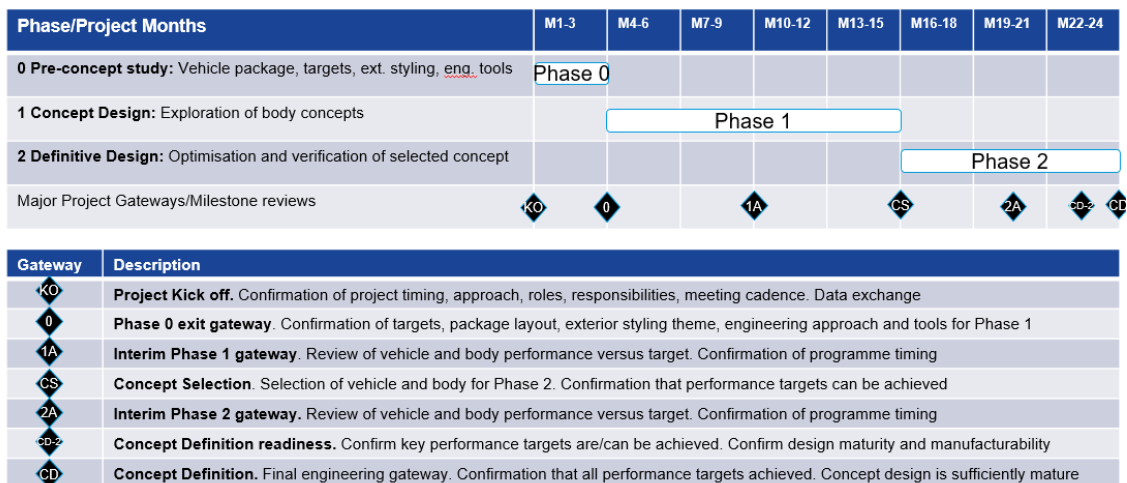


Figure 6.1.1 Steel E-Motive engineering programme timing, phases, and gateways

Figure 6.1.2 shows the Steel E-Motive design and engineering maturation steps, from “clean sheet” to completed vehicle and body structure. Firstly, a 3D CAD package study (step A) determined the overall layout of the vehicle, the positioning of the occupants and the main vehicle systems such as battery, chassis, electrical, interior and closures. This defined a “workable” design volume or space for the body structure. This volume was converted to an FEA model (step B). A series of static loadcases (forces) were defined that approximated the loads that the vehicle and body may experience and should therefore be designed for. These include static twist (torsion) and bending, wheel input (e.g., bump,) crashworthiness loads representing front, side, rear, and roof crush. A 3D CAE topology optimisation was performed, where the optimiser software determines the contribution and sensitivity of each element of the design volume based on the applied loads. With the element contribution and sensitivities combined, the main structural loadpaths through the body were defined (step C). The engineering team then interpreted the recommended body structure loadpaths and converted them to a beam model representation (step D). A 3D Finite Element (FE) model of the beam representation was constructed, and simulations performed to verify the structural performance. Finite Element simulations for static stiffness, NVH (modal) and crashworthiness (front, side, rear, and roof crush) confirmed the structural performance, and the model was iterated, varying the main section profiles and joint stiffnesses until a satisfactory level of performance was achieved. The beam model was then converted to shell model, where the design started to resemble a conventional stamped steel body structure (step E). At this stage, design details such as the flanges, panel breaks, manufacturability and assembly were not considered in detail. The objective was to demonstrate that the design concept could achieve the structural performance and weight targets. In parallel with this activity, concepts for body subsystems such as the rocker, battery, longitudinal crush rails were developed using 3D CAD and FEA tools. The subsystem concepts were incorporated into the complete body structure models throughout the development. Once a satisfactory level of structural performance was achieved (end Phase 1), the engineering activities were then focussed on maturing and refining the vehicle and body design to consider the manufacture and assembly and expanding the steel grades and fabrication processes considered to the complete portfolio. A collaborative, 3-day face-to-face workshop event was held to review the body concept design and subsystems to consider the specific steel grades and fabrication processes that would be suitable and enable optimum performance of the structure whilst satisfying the manufacture requirements. (step G). The material recommendations from the workshop were then incorporated into the Steel E-Motive concept design and further FEA simulations were performed, focused on more refined steel grade and gauge adjustments to optimise the design until all the performance targets were achieved.

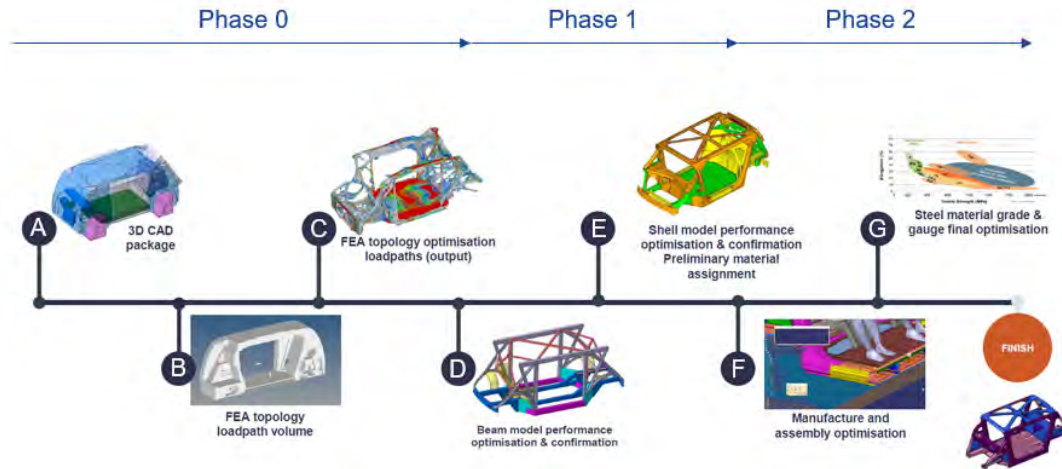


Figure 6.1.2 Engineering approach and maturity of vehicle and body structure concept

6.2 Technical Approach, Phase 0

The objectives of Phase 0 were to establish the basis (or “foundations”) for the subsequent body structure design activities in Phases 1 and 2. Design, analysis and engineering activities were undertaken to determine the size, position, and specification of the main vehicle systems such that the body structure could be developed. To assist some of the decision making and the selection of key vehicle system a “MoSCoW” prioritization approach was applied. For each system or topic under consideration, an evaluation was made as to whether the feature or approach was a “must have”, “should have”, “could have” or “will not have”

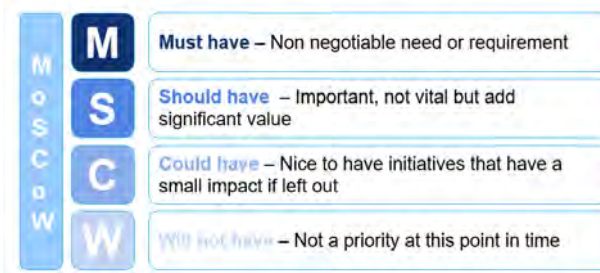


Figure 6.2.1 MoSCoW prioritisation approach.

6.2.1 Powertrain sizing and specification study

The powertrain of battery electric vehicles is typically much larger (by weight and volume) than a typical internal combustion engine. A sizing activity was undertaken to determine the specifications (and therefore size) of the high voltage battery and electric drive unit (EDU). 1D vehicle simulations were performed to determine the EDU and battery specifications that would enable the overall vehicle performance targets (such as range, acceleration, and maximum speed) to be achieved. The e-machine and battery targets were compared to benchmark and reference data and the following powertrain specifications were established.

| Requirement | Specification | Comment |
|--------------------------------|--|--------------------|
| Electric drive unit power (kW) | 115 (peak) | (230kW continuous) |
| Electric drive unit driveline | Single speed, fixed ratio, front axle position | |
| Propulsion battery energy | 75kWh | |

| | | |
|--|--|---|
| Propulsion battery energy density (volume) | 622 Wh/l for battery module 280 Wh/l for battery pack | Based on market expectation for 2030-2035 |
| Propulsion battery energy density (mass) | 377Wh/kg for battery module 266Wh/kg for battery pack | |
| Propulsion battery voltage | 800V | |
| Number of battery modules | | |
| Battery pack weight target | <360kg | |

Figure 6.2.1.1 SEM1 powertrain specification

Electric Drive Units can feature either a fixed single speed gearbox speed or multi-speed. A MoSCoW evaluation suggested single speed EDU for SEM1 would be best suited due to the additional cost, complexity and NVH concerns of multi-speed units.

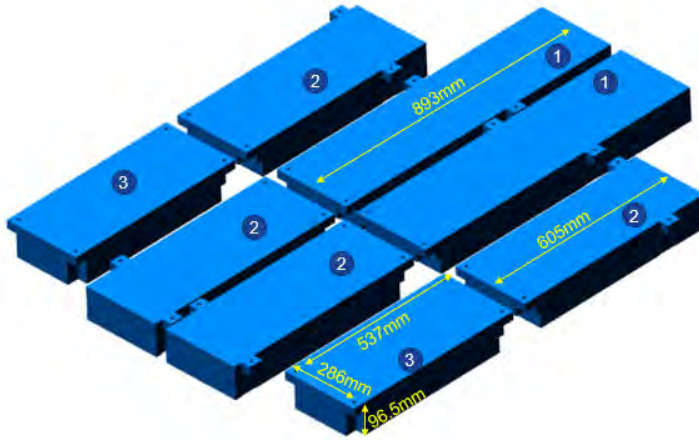
| | | Single Speed | Multi Speed |
|---|------------------------------|---------------|----------------------------------|
| M | Meets requirement | ● | ● |
| | Not recommended | ● | ● |
| S | | | |
| C | | | |
| W | | | |
| M | Performance | SEM1 OK ● | SEM2 OK ● |
| M | NVH | ● | Gear whine ● |
| S | Volume/space claimed In Assy | ● | Overall Sub-Transmission ● |
| M | Efficiency | Single gear ● | ● |
| M | Reliability | ● | More components ● |
| C | Maintenance | ● | Additional thermal performance ● |
| M | Weight | ● | ● |
| Conclusion for Steel E-Motive application | | OK SEM1 ● | OK SEM2 ● |

Figure 6.2.1.2 MoSCoW analysis for SEM1 EDU

The EDU can be positioned to provide traction to the front or rear or both axle of a vehicle. A decision was made to position the single speed EDU to the front axle of SEM1. The primary drivers for this decision being improved package – a rear axle EDU requires more package space with the potential to reduce the available boot volume by 34%. Also, a front axle EDU enables a greater amount of braking energy recovery compared to rear EDU. The vehicle dynamics of a forward braking event result in a dynamic weight shift from the rear to the front axle. This results in a higher braking load and moment on the front axle. With a battery electric vehicle enabling energy recovering to the battery through regenerative braking, a front axle EDU enables a greater proportion of the braking energy to be recovered.

Battery sizing and package considerations

An agnostic approach was taken for the Steel E-Motive battery specification, with no specific cell type of chemistry considered for the battery design. This was intentional, given the rapid pace of battery technology development and the intended, hypothetical production date of 2030-2035 timeframe. The battery was engineered such that different types of battery cells and chemistries could be used within the battery design concept. However, to enable the package, design and structural analysis of the battery, the sizes and specifications as shown in Figure 6.2.1.3 were assumed.



SEM nominal battery capacity: 75kWh
 Total module volume: 111.3litres
 Module specific power: 674Wh/litre
 Module specific weight: 1.78kg/litre
 Total module weight = 111.3 x 1.78 = 198.8kg

Figure 6.2.1.3 SEM1 battery module sizing and specifications

6.2.2 Chassis system selection and sizing

The chassis system of a vehicle plays an important role of connecting the wheels and tyres to the body structure and incorporates the steering, suspension, wheels, tyres, brakes subsystems. The chassis design influences several key vehicle attributes, namely, ride comfort, handling and steering feel, noise, vibration & harshness, manoeuvrability, cost, and weight. The chassis also has a secondary contribution to the crashworthiness of a vehicle. Three front suspension types were considered for the Steel E-Motive concept. A multi-link system provides improved wheel control, ride and NVH performance at the expense of higher weight and cost. A Chapman Strut suspension is a relatively simple concept, with low weight and cost with some compromise to wheel compliance and ride. A MoSCoW analysis confirmed that McPherson strut offers the best compromise between cost, ride, NVH and mechanical package. McPherson strut was selected for the front suspension.

| | Meets requirement ● | | Multi Link e.g. Double W/bone High Arm | McPherson Strut/L Arm | Chapman Strut |
|--|--|---------------------------------------|--|--|--|
| M | Meets requirement ● Not recommended ● | | | | |
| S | | | | | |
| C | | | | | |
| W | | | | | |
| M | Ride / friction | ● | ● | ● Strut friction | ● ARB vs Tension Link |
| M | Longitudinal compliance and Wheel bump recession | ● | ● | ● | ● ARB tension Link tuning |
| C | BOM Cost | ● | ● Higher component count | ● Lower part count | ● |
| S | Environment and Durability | ● | ● Higher component count | ● Strut seals | ● ARB Bushes |
| M | NVH | ● | ● | ● Strut Friction Top mount Softness | ● Longitudinal Compliance in subframes |
| M | Steering - AWS to meet <7.6m Turning Circle | ● | ● Baranca arms | ● Baranca Arms | ● ARB Tension Link |
| M | Mechanical integration / package | ● | ● Upper w/bone BW | ● No upper Arm/strut | ● |
| Conclusion for Steel E-Motive application | | | ● | ● | ● |

Figure 6.2.2.1 MoSCoW evaluation of front suspension types, confirming selection of MacPherson strut

The wheel and tyre size for SEM1 was specified at 19 inches, with an option for 20". This is a larger size than would typically be considered for a vehicle size of SEM1. The reasons for increasing the wheel size were:

- "tall and narrow" profile provides enhanced efficiency, rolling resistance and reduction in frontal area, improving aerodynamics
- balance the overall vehicle style and dimensional proportions, LxWxH

The tyre size was selected as 175/60/R19

Following the selection of suspension type and wheel size, the wheel package envelopes were calculated using 3D CAD. The wheel package envelopes are the volumes that wheels and tyres occupy because of the suspension travel and steering turn envelopes. The volumes must be protected and not encroached by other parts of the vehicle to allow the wheels and tyres to operate unobstructed.

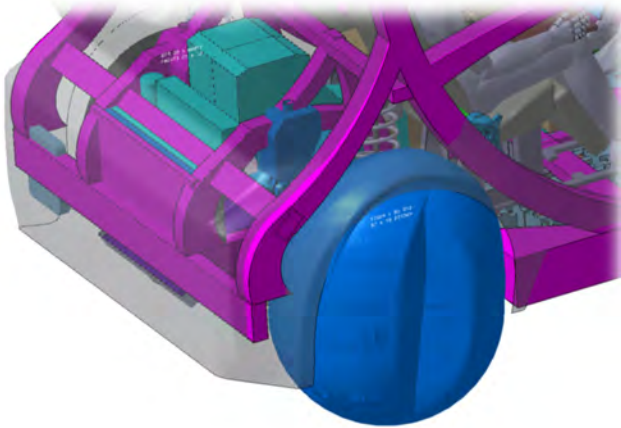


Figure 6.2.2.2 Front wheel and tyre envelopes

| Specification | Value | Comment |
|---|-------------------------|---|
| Front suspension type | McPherson Strut | See MoSCoW analysis |
| Wheel Bump Stroke (mm) | 80 | |
| Wheel Rebound Stroke (mm) | 100 | |
| Wheel Rate (inc parasitic/ex tyre - N/mm) | 28 | |
| Anti-rollbar type | Passive | |
| Anti-rollbar dia (mm) | 35 | |
| Wheel hub bolt pattern | 5 stud | |
| Wheel Bearing type | Gen 3 | |
| Damper type | Passive, twin tube | |
| Subframe (fixed/Isolated and fixings) | 4 point rigidly mounted | Assume rigidly mounted to contribute to body structure stiffness and strength |
| Braking System | CAT A | Disc and calliper |
| Front tyre size | 175/60 R19 | |
| Steering System | Rack and Pinion | EPAS Level 5, no steering wheel or column |

Figure 6.2.2.2 Front suspension specifications

As per the front suspension, the rear suspension options were evaluated using MoSCoW analysis. One importance consideration for the rear suspension was the requirement for <7.6m turning circle. Given the SEM1 vehicle dimensions, calculations showed that steering of the rear axle was required to meet the vehicle turning circle requirements. The alternative rear suspension options of multi-link, Chapman strut and semi-trailing link have challenges in achieving wheel lock angles. The McPherson strut type was selected for the rear suspension primarily for this reason.

| | | Multi Link e.g. 5 link | McPherson Strut | Chapman Strut | Semi Trailing Link |
|--|--|---|---|--|------------------------------------|
| M | Meets requirement | Green | Green | Green | Green |
| S | | Yellow | Yellow | Yellow | Yellow |
| C | | Yellow | Yellow | Yellow | Yellow |
| W | Not recommended | Red | Red | Red | Red |
| M | Ride / friction | Bush vs Ball Bush (Green) | Strut friction (Yellow) | ARB vs Tension Link (Yellow) | Pt1 and 2 stiffness (Green) |
| M | Longitudinal compliance and Wheel bump recession | Tuning Challenge, HP Stiffness (Yellow) | (Green) | ARB tension Link tuning (Yellow) | Tuning Arm / Subframe (Yellow) |
| C | BOM Cost | Component count (Yellow) | Low part count (Green) | Low part count (Green) | Low part count (Green) |
| S | Environment and Durability | (Yellow) | Strut seals (Yellow) | ARB Bushes (Red) | Pt1 and Pt2 stiffness (Yellow) |
| M | NVH | (Green) | Strut Friction Top mount Stiffness (Yellow) | Longitudinal Compliance In subframe (Yellow) | Tuning Hydro Frame bushes (Yellow) |
| M | Steering - AWS to meet <7.6m Turning Circle | Lock angle challenge (Red) | Banana Arm (Green) | ARB Tension Link (Yellow) | Lock angle challenge (Red) |
| M | Mechanical integration / package | Upper Control Arm/BiW (Yellow) | No upper arm (Green) | (Green) | Low z height (Green) |
| Conclusion for Steel E-Motive application | | Yellow | Green | Yellow | Yellow |

Figure 6.2.2.3 Rear suspension MoSCoW analysis, confirming selection of McPherson strut

Confirmation of achieving the 7.6m turning circle was confirmed by the vehicle steering and suspension geometrical analysis as shown in Figure 6.2.2.4

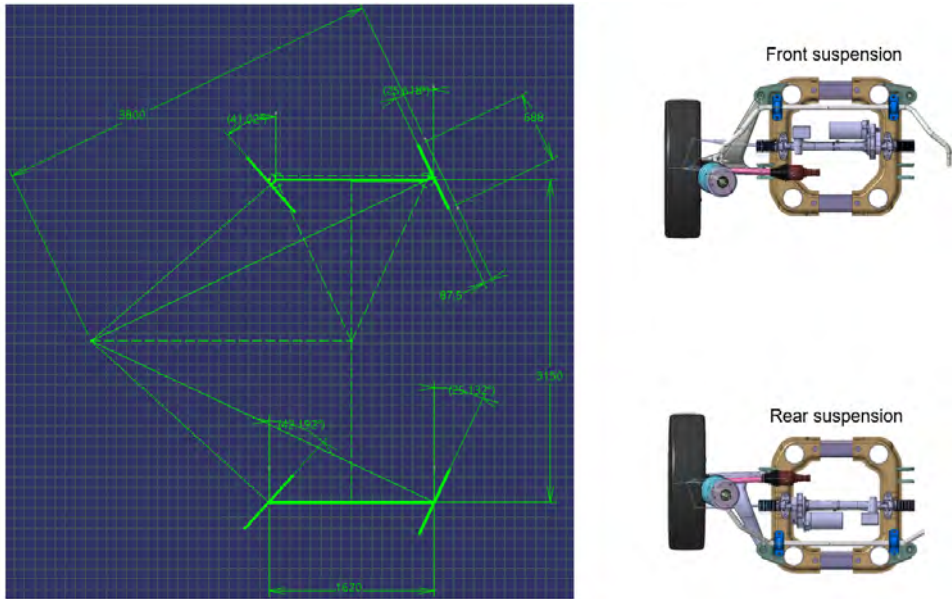


Figure 6.2.2.4 Steering geometry analysis confirming requirement for rear wheel steering (note, this calculation performed for the worst case, long wheelbase variant SEM2)

Figure 6.2.2.5 summarises the overall rear suspension specification for SEM1

| Specification | Value | Notes |
|---|--------------------------|---|
| Geometry | McPherson Strut | See MoScOw analysis |
| Wheel Bump Stroke (mm) | 80 | |
| Wheel Rebound Stroke (mm) | 100 | |
| Wheel Rate (inc parasitic/ex tyre - N/mm) | 29 | |
| Anti-rollbar type | Passive | |
| Anti-rollbar dia (mm) | 28 | |
| Wheel hub bolt pattern | 5 stud | |
| Wheel Bearing type | Gen 3 | |
| Damper type | Passive, twin tube | |
| Subframe (fixed/Isolated and fixings) | Rigidly mounted, 4 point | To contribute to body stiffness, NVH and crash performance |
| Braking System | CAT A | |
| Steering System | Rack and Pinion | EPAS Level 5, required for <7.6m turning circle requirement |

Figure 6.2.2.2 Rear suspension specifications

6.2.3 Vehicle package study

With the SEM1 powertrain and chassis specifications confirmed, 3D CAD package density studies defined the overall layout and space claim for the major vehicle systems and occupants. Figure 6.2.3.1 shows the overall approach for the Phase 0 vehicle package and integration studies.

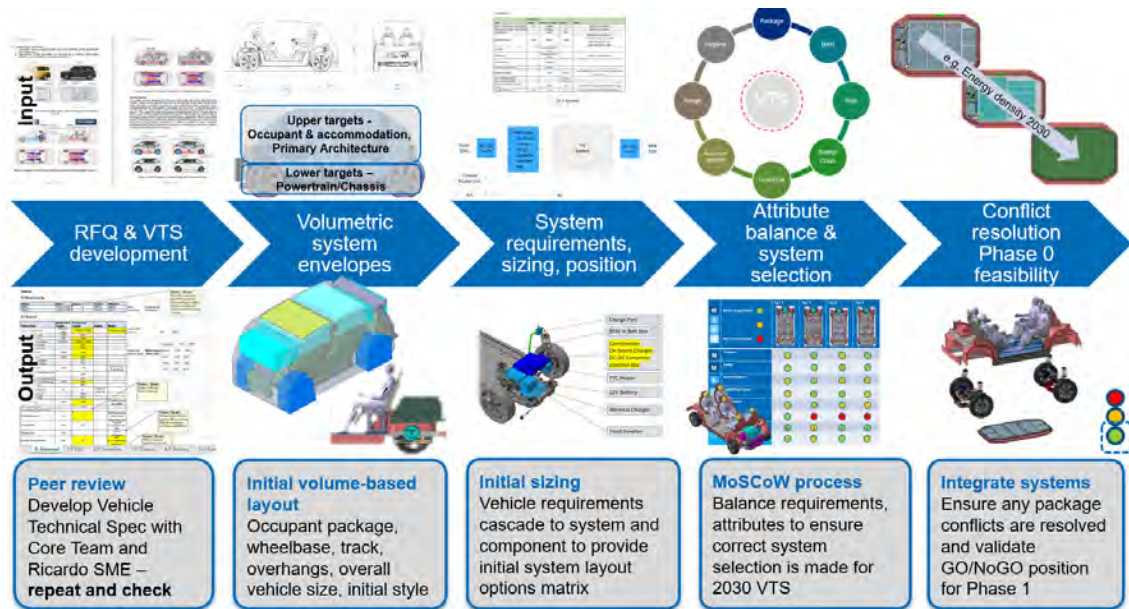


Figure 6.2.3.1 Phase 0 vehicle package and integration studies

Figure 6.2.3.2 shows the overall vehicle size and proportions for the SEM1 vehicle. Note that the front overhang length (735mm) and overall vehicle length (4095mm) were increased from the initial specifications of 635mm and 3095mm respectively in engineering Phase 1. This was to address issues with available crush length and frontal crash performance.

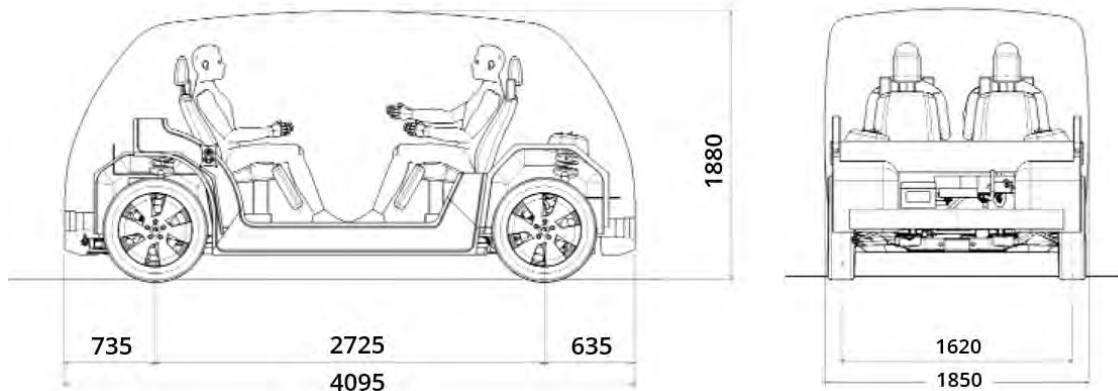


Figure 6.2.3.2 SEM1 overall vehicle dimensions (final design)

Fully autonomous vehicles enable significant freedoms in the positioning of the occupants. With no direct driver interfaces and no requirements for vision and visibility, the occupants can be positioned in unconventional positions and orientations, enabling improved ergonomics, comfort, and interface with devices (e.g., digital screens) and other users.

Occupants are still however subject to requirements of safety and comfort, therefore fixed or allocated seating locations should be defined, such that safety restraint systems can be positioned and engineered for. A study was therefore undertaken to explore the potential occupant seating locations for the Steel E-Motive concepts. The main considerations for the selection of occupant seating locations were comfort, safety, ingress/egress (getting in and out of the vehicle), socialising space, compatibility with SAE level 4 (as a potential future option or consideration), available space for working ability to accommodate the required number of passengers comfortably (4 passengers in SEM1, up to 6 passengers in SEM2). Additional, considerations such package and overall space utilisation, accounting for disabled users, enabling a flat floor and ability to meet the luggage space requirements were also accounted for. A MoSCoW priority analysis was used to assess several different seating options as shown in Figure 6.2.3.3

| | | Ver. 1 | Ver. 2 | Ver. 3 | Ver. 4 | Ver. 5 | Ver. 6 | Ver. 7 | Ver. 8 |
|---|--------------------|--------|--------|--------|--------|--------|--------|--------|--------|
| M S C W | Meets requirement | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | Not recommended | | | | | | | | |
| M | Comfort | | | | | | | | |
| M | Safety | | | | | | | | |
| S | Ingress/Egress | | | | | | | | |
| C | Socializing space | | | | | | | | |
| C | Work space | | | | | | | | |
| C | Level 4 compatible | | | | | | | | |
| M | Passengers number | 4 | 6 | 4 | 6 | 6 | 4 | 4 | 5 |
| Conclusion for Steel E-Motive application | | | | | | | | | |

Figure 6.2.3.3 SEM1 Occupant seating position MoSCoW analysis

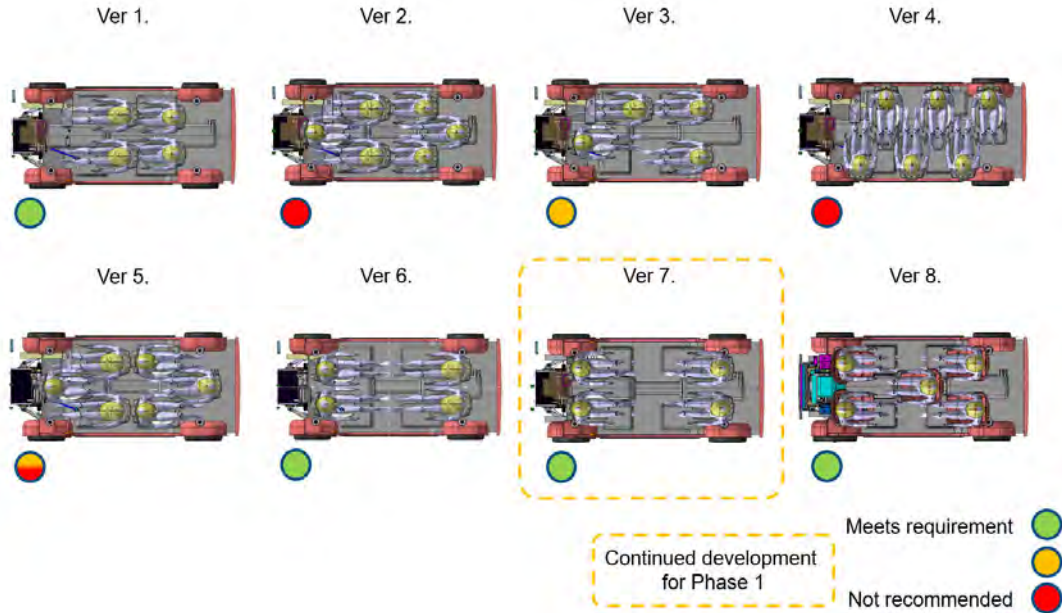
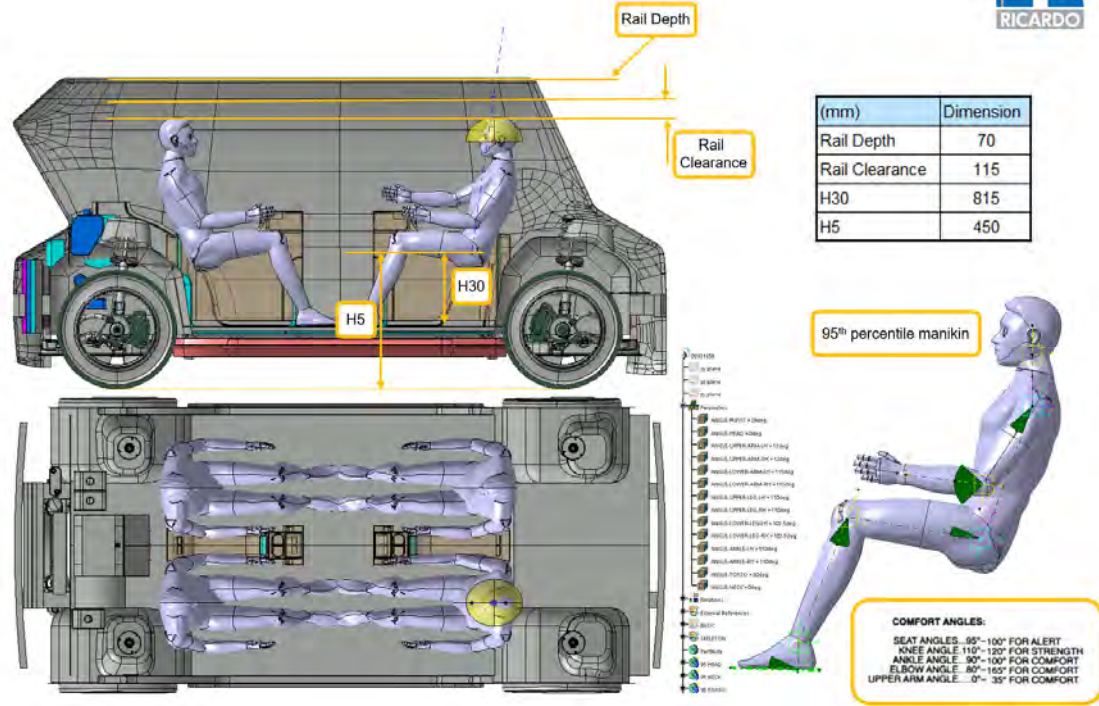


Figure 6.2.3.4 SEM1 occupant position overall evaluation and recommendation

An evaluation of previous research studies and technical papers on the subject of occupant seating positions in autonomous vehicles was conducted. A study by Sofia Jorlöv, Katarina Bohman, Annika Larsson titled “Seating Positions and Activities in Highly Automated Cars – A Qualitative Study of Future Automated Driving Scenarios”, identified preferred seating configurations and activities in fully autonomous vehicles. A sample of occupants were placed in 5 different static seating configurations and polled to determine their preference and feedback. (<http://www.ircobi.org/wordpress/downloads/irc17/pdf-files/11.pdf>) The study concluded that for longer journeys, a “living room” (inward facing) configuration was preferred. This concurs with the recommendation from the MoSCoW evaluation (version 7). This inward facing configuration was therefore selected as the primary direction for seating in SEM1. The rear facing front occupants would require careful design and engineering of the vehicle structure to account for crash protection, as outlined in subsequent sections of this report.

Further 3D CAD studies were undertaken to determine the optimum positioning of the occupants in the inward (“living room”) seating configuration. Industry guidelines for passenger vehicle seating positions were reviewed and applied (H-Point: The Fundamentals of Car Design & Packaging, Stewart Macey and Geoff Wardle). Dimensions such as seat back angle, head and arm clearance, H point height, heel point height were applied for the occupant positions.

Figure 6.2.3.5 shows the occupant positions in the SEM1 vehicle at the conclusion of Phase 0. The seating positions would be subject to some further adjustment in Phase 1 and 2 of the project to enhance the safety and protection of occupants in frontal impacts.



The occupant experience and comfort in a vehicle is also heavily influence by the type and design of the seat. Whilst the specific detail design of the seats was not considered within the Steel E-Motive project, an overall concept for the seat construction was required. The options considered were bench seats, pillar or pilot seats and reversible/swing seats. Given the ride hailing and short to medium journey expectations of SEM1, a bench seat configuration was selected as the primary consideration. This would offer a simpler and lower cost solution than a single pillar seat. It was expected that lack or limited adjustability in a bench seat would be acceptable to vehicle users over shorter durations. The seating configuration for SEM2 is discussed in Section 11. Figure 6.2.3.6 shows the seating configuration for SEM1.

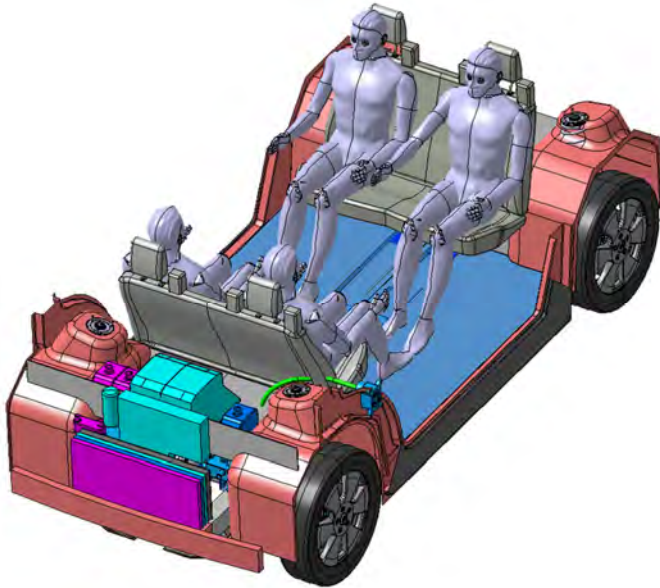
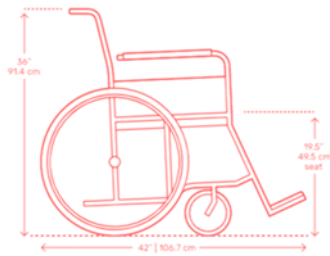


Figure 6.2.3.6 SEM1 bench seating configuration

Consideration for disabled users: Fully autonomous vehicles offer the potential to provide an enhanced quality of life for persons with disabilities. With lower predicted journey costs compared to current private taxi transport and a potentially wider fleet and network of vehicles, MaaS operations should enable disabled users' greater mobility across urban and extra-urban regions. The vehicle design requires adjustment and consideration for disabled users – this was considered in Phase 0. Firstly, standards and requirements for the carriage of disabled passengers were consulted, including The Transport For London (TFL) “Construction and licensing of motor taxis, for use in London – Condition of Fitness” (<https://content.tfl.gov.uk/taxi-conditions-of-fitness-update-2019.pdf>). A standard for wheelchair dimensions was obtained and incorporated into the 3D CAD study (Figure 6.2.3.7)



Wheelchairs are chairs with wheels designed to serve users that are unable to, or have difficulty with, walking due to injury, illness, or disability. Standardized dimensions and related clearances for wheelchairs directly impact the built environment by establishing required widths and turning radii mandated in an effort to make public buildings accessible for all people. Wheelchairs come in a variety of types based on technology, methods of propulsion, and specific uses that leads us to a range of chairs that include everyday manual chairs, sport chairs, custom chairs for challenging terrains, standing position chairs, and motorized chairs.

A typical wheelchair has a length of 42" (106.7 cm), a height of 36" (91.4 cm), seat heights around 19.5" (49.5 cm), and a width of 20" (50.8 cm).

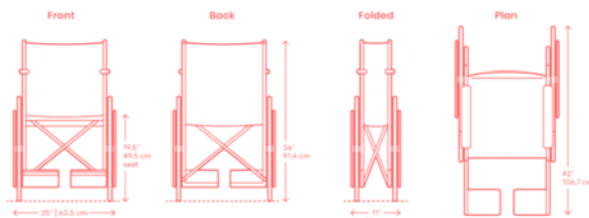


Figure 6.2.3.7 Wheelchair dimensions considered in Steel E-Motive package study

(Source <https://www.dimensions.com/element/wheelchairs>)

Using this and other references, the following disabled access requirements were defined for Steel E-Motive vehicles:

- Minimum door aperture width when open > 0.75m
- Minimum door angle when opened (swing door) 90 degrees
- Facilitate ramp access from kerb side to vehicle. Vehicle may be fitted with air springs and operate a kerbside “crouch” or “kneel” function in order reduce kerb to vehicle floor height. Target is for maximum ramp angle < 4.0 degrees
- Vehicle interior to have “flat floor”. Wheelchair should be able to manoeuvre freely in the vehicle by manual operation
- Designated fixing points to secure wheelchair during transit
- Provision for grab handles, door opening operation

Luggage capacity, stowage and security is an important requirement for taxi vehicles. The luggage capacity target for SEM1 is 450 litres. Design package studies were undertaken to determine the space claim requirements to achieve the 450litre target.

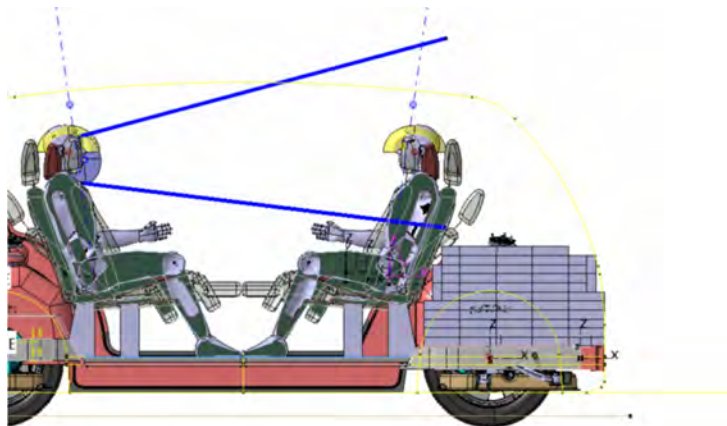


Figure 6.2.3.8 Package space claim study to confirm 450litre luggage capacity

In addition to the propulsion battery and motor, electric vehicles require several additional high voltage components and systems to facilitate the charging and operation. The sizing of these components was based on benchmarking and library data for similar vehicles. The space package positioning for the high voltage components is shown in Figure 6.2.3.9

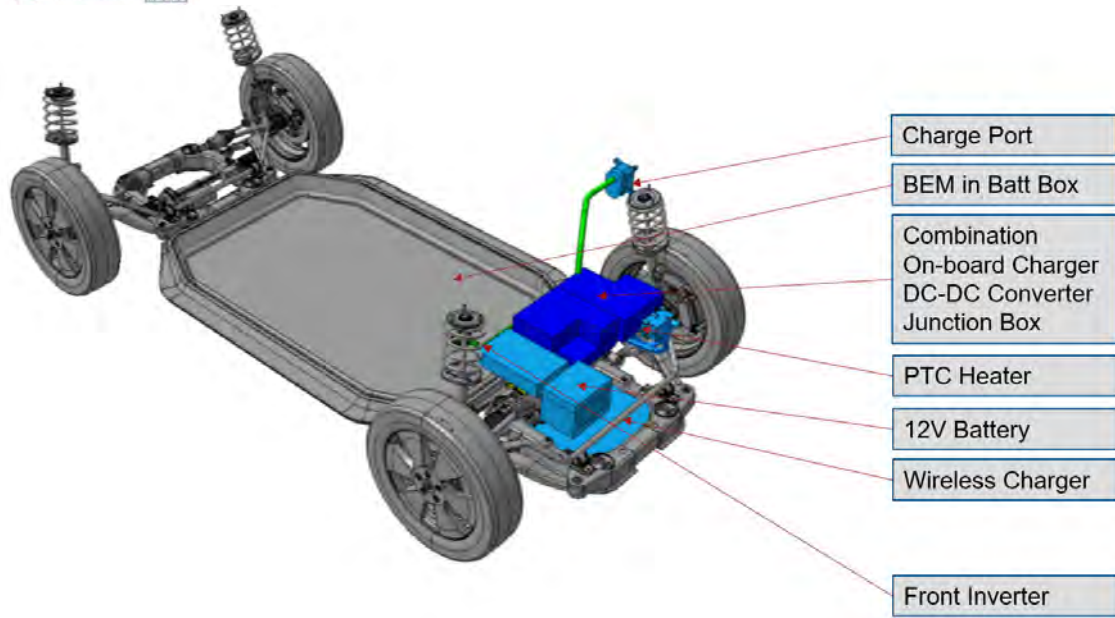


Figure 6.2.3.9 High Voltage system sizing package layout

The vehicle cooling, heating, ventilation, and air conditioning (HVAC) system ensures an appropriate operating temperature for the battery and EDU and conditions the passenger compartment climate to the desired temperature and humidity. The demands on HVAC system for an urban ride hailing vehicle are anticipated to be higher than a conventional passenger car, due the increased frequency of door opening (journey pick-ups and drop offs), the requirement for a large door opening aperture (greater heat loss to/from the vehicle) and the desire to have a spacious feeling interior, which may result in a higher glazed surface area hence greater solar loading into the vehicle.

A schematic layout of the Steel E-Motive thermal system (SEM2 vehicle) is shown in Figure 6.2.3.10. The EDU(s) have a dedicated low temperature cooler circuit, incorporating header tank and heat exchanger(s). The battery pack has a separate cooling circuit with a front mounted chiller pack. The HVAC system comprises of a heat pump, air conditioning compressor, accumulator, and front mounted condenser. HVAC system also requires blower, air vents, ducts, and mixer/valve unit for controlling temperature and humidity via a recirculation valve. The sizing and scaling of the vehicle thermal system and components was based on benchmark and reference data for similar sized vehicles to Steel E-Motive, with adjustments made for the specific ride hailing expectations as described above.

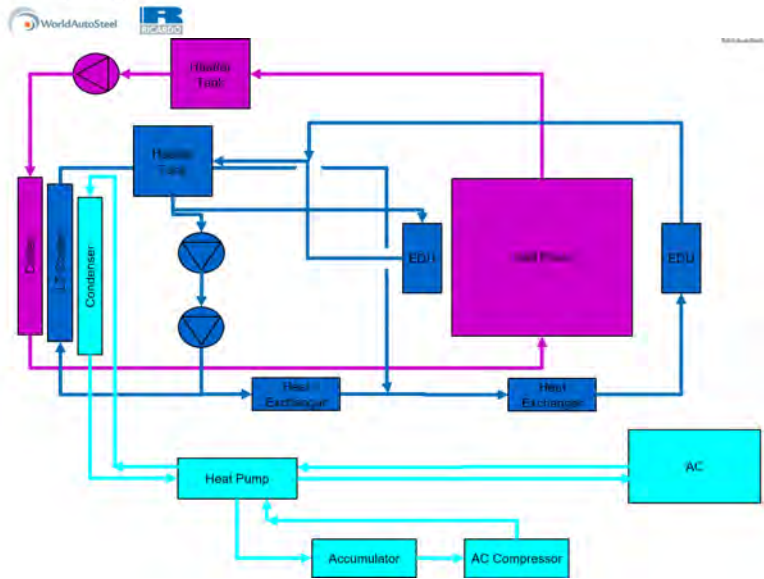


Figure 6.2.3.10 Vehicle thermal system schematic (for SEM2 vehicle featuring a rear EDU)

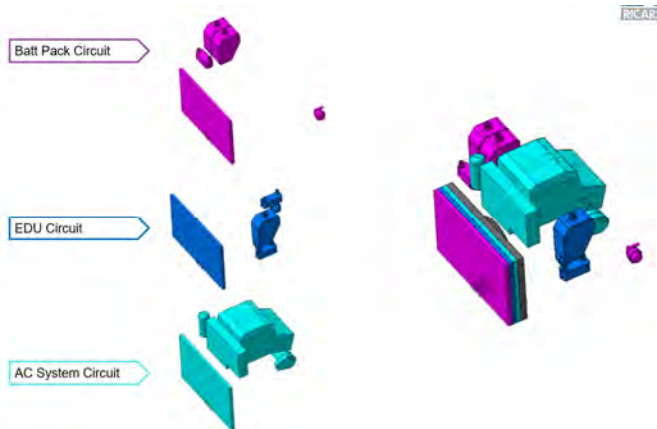


Figure 6.2.3.11 Package volumes for the main thermal system components

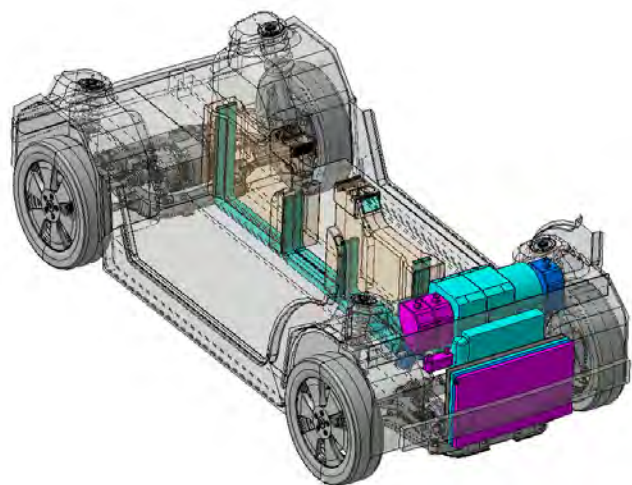


Figure 6.2.3.12 Vehicle thermal systems as packaged (SEM2 vehicle shown)

Autonomous vehicles require systems and components in order to sense the nearby objects and vehicles, recognise and develop a virtual image of the object then make computations to determine the response of the vehicle. The packaging and integration of these systems is not insignificant and required consideration in the development of the Steel E-Motive body structure. The autonomous sensors and controller sizes were positioned as per Figure

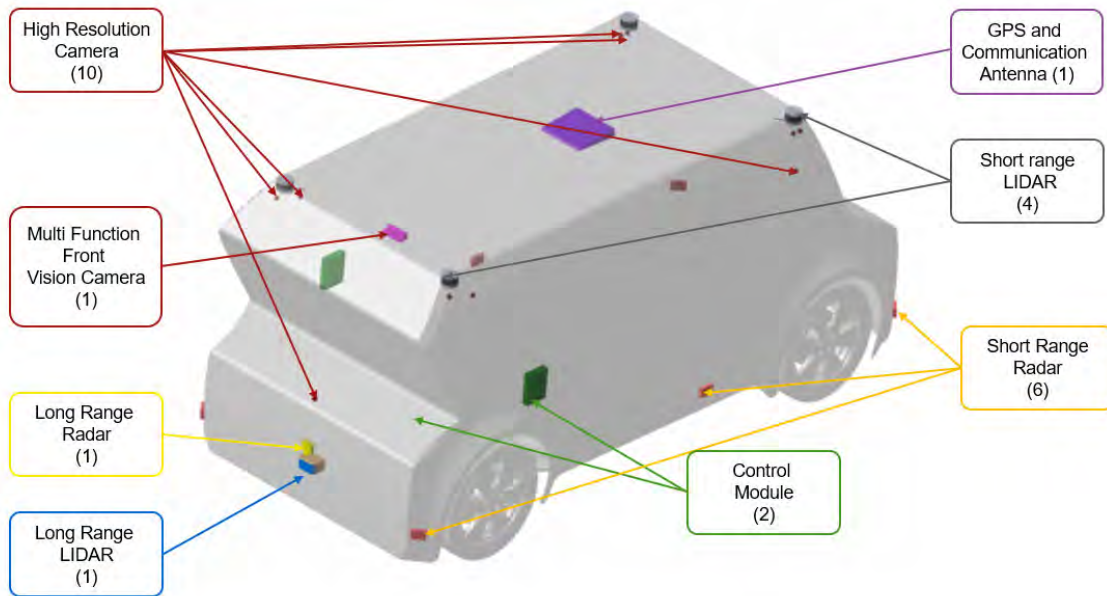


Figure 6.2.3.13 Positioning of level 5 autonomous vehicle sensors

The full level of vehicle autonomy in the Steel E-Motive concepts enabled deletion of the following conventional driver interface components; steering wheel, steering column and adjuster, accelerator pedal and cable, brake pedals, parking brake pedal or parking switch, gear shift controller, turn indicators, rear view & wing mirrors. The main driver information panel would be replaced by a much simpler tablet/screen-based interface. The main interfaces to the occupants are envisaged to be via mobile telephone app, with the vehicle based digital interface primarily for providing journey information, a backup in case of mobile phone/app failure and for fleet operator vehicle service and diagnostics.

The glazing and door openings of a vehicle have a significant impact on the body, it's structural performance and aesthetics. Despite the glazing and doors undergoing detailed design consideration in Phase 1 and 2, a preliminary Phase 0 study was undertaken to define some initial requirements, specifications and sizing of the glazed zones and closures. Firstly, the passenger ergonomics and requirements were considered. Ensuring that users of the Steel E-Motive vehicles can easily enter and exit the vehicle is an important factor in establishing a comfortable and convenient journey experience. With the seating positions already defined where the front occupants are located in a rear facing configuration, the possibility to diverge from a conventional front and rear swing door configuration is made possible. Door concepts including sliding doors, rear hinged swing doors ("suicide doors"), gullwing (roof mounted hinge) and combinations of these were considered and evaluated in a MoSCoW evaluation, as shown in Figure 6.2.3.14. The key requirements and considerations for the vehicle doors were defined as; ease of ingress & egress for the passengers, impact and contribution to overall body stiffness, encroachment/additional vehicle height and width with the doors opened, the package space (cost and weight) for the

mechanism such as sliding rails, contribution, and impact to safety & crashworthiness, potential or restrictions on glazed areas and overall vehicle style impact.

| | Meets requirement ● | Tesla Model X P90D 2016 | Icona Nucleus Concept | MG Vision-I | 2019 Lincoln Continental | Saturn Ion | Kia Sedona SX 3.3 2015 |
|--|--|---------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|
| M | Meets requirement ● | | | | | | |
| S | Not recommended ● | Gullwing rear door | Gullwing single door | Opposed sliding doors | Rear "suicide" door | Rear gullwing no B pillar | Front swing, rear sliding |
| M | Ingress/Egress | ● | ● | ● | ● | ● | ● |
| M | Body Stiffness/NVH | ● | ● | ● | ● | ● | ● |
| S | Opened door space (garage/underground) | ● | ● | ● | ● | ● | ● |
| S | Mechanism Package | ● | ● | ● | ● | ● | ● |
| M | Safety | ● | ● | ● | ● | ● | ● |
| C | Glazing | ● | ● | ● | ● | ● | ● |
| C | Style (option H compatibility) | ● | ● | ● | ● | ● | ● |
| Conclusion for Steel E-Motive application | | ● | ● | ● | ● | ● | ● |

Figure 6.2.3.14 Preliminary MoSCoW evaluation of door concepts

The MoSCoW analysis concluded that a side sliding door configuration would provide the best solution for Steel E-Motive. With this preliminary selection of door concept, 3D CAD studies were performed to evaluate the ingress/egress performance and ensure the occupant seating position were compatible. Figures 6.2.3.15 shows the ergonomic evaluation for a 95th percentile male entering/exiting the Steel E-Motive concept. The study shows that with a door aperture of 0.75m, occupants can comfortably enter and leave the vehicle. The door aperture was subsequently be increased to enable improved access and accommodate disabled users' requirements.

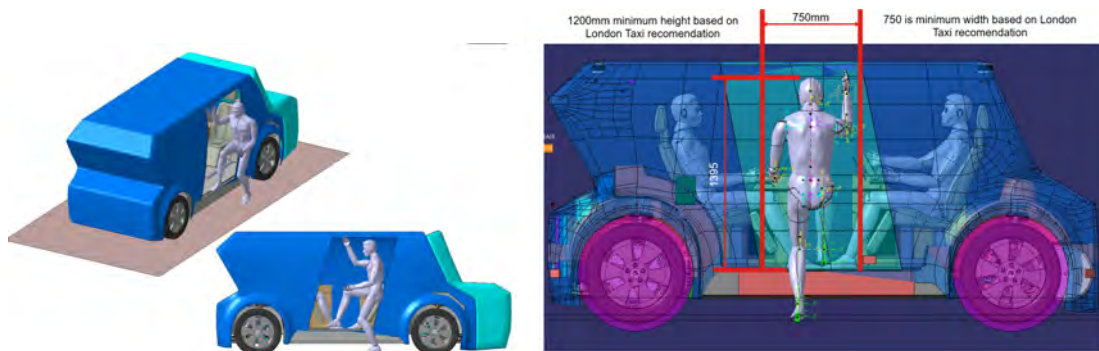


Figure 6.2.3.15 Vehicle ingress/egress study using 95th percentile mannequin

Figure 6.2.3.16 shows the conclusion of a 3D CAD package study of the occupant seating position and sliding door concept. Sliding doors typically have larger section requirements in the y direction, due to the rail and track mechanisms. This can encroach on the occupants seating area and position, especially in a compact sized vehicle such as Steel E-Motive. The

study showed that with a 150mm sliding door overall width (worst case), sufficient clearance to the seated occupant could be maintained.

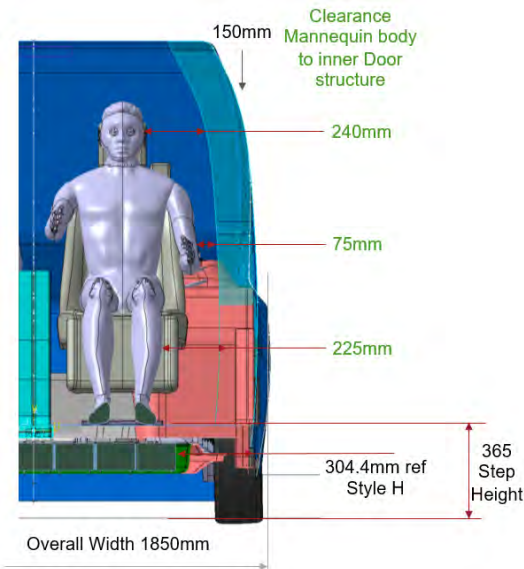


Figure 6.2.3.16 Sliding door to seated occupant package study

The approach and considerations for the detailed development of the side closure concept is described in Section 6.3 and 6.4. The final solution is presented in Section 7.0.

With autonomous vehicles not subjected to direct driver vision and obscuration legislation, the requirements for the glazed surfaces are quite different. Vehicle designers are therefore presented with significant freedoms in the design and location of glazing in autonomous vehicles. Elements of the body structure and other vehicle components can be positioned in locations that would previously be prohibited by the direct driver vision regulations, such as the front windscreen. However, the requirements of the occupants or passengers in autonomous vehicles must also be considered. The ability to have a clear view of the outside from the seated position enhances the occupant’s situational awareness in a journey and can help alleviate motion sickness issues. A 3D CAD study identified the potential glazed surfaces in the Steel E-Motive vehicle package (Figure 6.2.3.17). The would be subject to review and alteration during the detail stages in Phase 1 and 2.

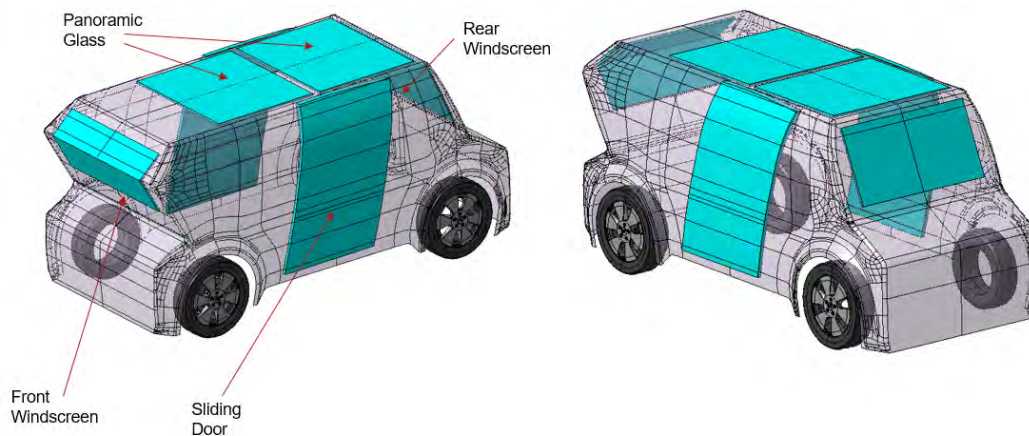


Figure 6.2.3.17 Preliminary glazed surfaces study

Autonomous vehicles are expected to meet the same exterior lighting requirements and regulations which conventional human operated vehicles are subjected to. Exterior lighting is an important aspect of vehicle safety and collision avoidance. Users of autonomous vehicle may also expect the road to be illuminated to provide a sense of security and safety during their journeys. With modern day safety standards, the lighting requirements for passenger cars are significant and require consideration in the vehicle and body design. Front and rear lighting that would meet current legislative requirements was provisioned for in both the 3D CAD package model and the preliminary vehicle styling as shown in Figure 6.2.3.18.

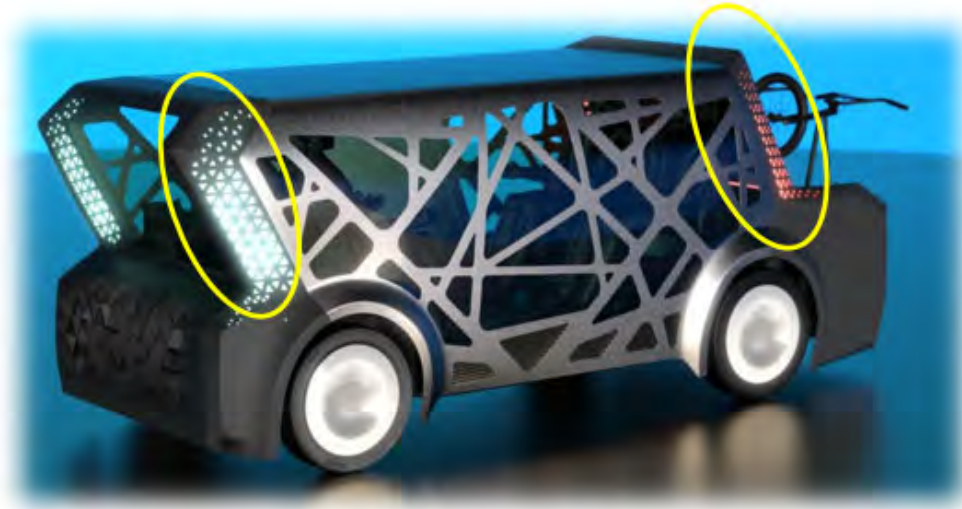


Figure 6.2.3.18 Provision for front and rear exterior lighting in preliminary styling rendering

Combining all the vehicle system requirements, specifications, occupant position considerations and space claims, an overall package model for the Steel E-Motive concept was realised (Figure 6.2.3.19). This essentially defined the volume and position of the major vehicle systems and enabled the development of the body structure in the subsequent phases of the project

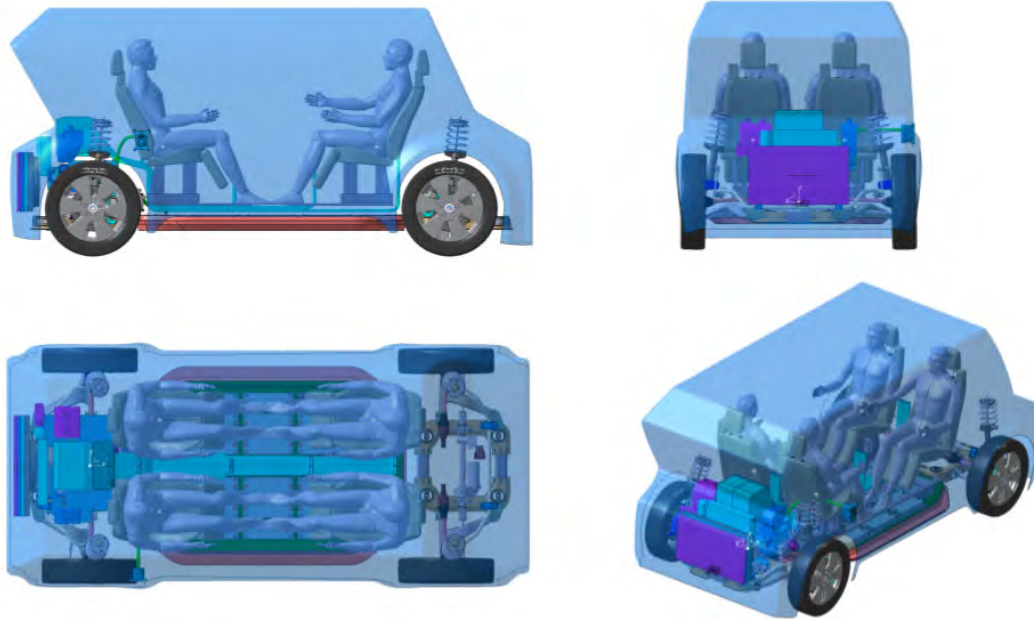


Figure 6.2.3.19 SEM1 Overall vehicle package, Phase 0 (note, the provisional exterior styling theme is applied. See section 6.2.5)

6.2.4 Topology Loadpath Optimisation Simulation

To provide a starting point for the development of the body structure in Phase 1, a 3D topology loadpath optimisation analysis was performed in Phase 0. The objective of the analysis was to define the major structural loadpaths in the body given a set of loads that represent the typical conditions that the vehicle may experience during its lifetime, including crashworthiness loads. The optimisation also supports the development of a weight efficient structure, guiding the design to use structure in appropriate places. The first step of the optimisation is to create a Finite Element model of the available body structure. This was derived from the overall 3D CAD vehicle package study as described in Section 6.2.3 and shown in Figure 6.2.4.1. The interior occupant volume was removed from the overall design volume.

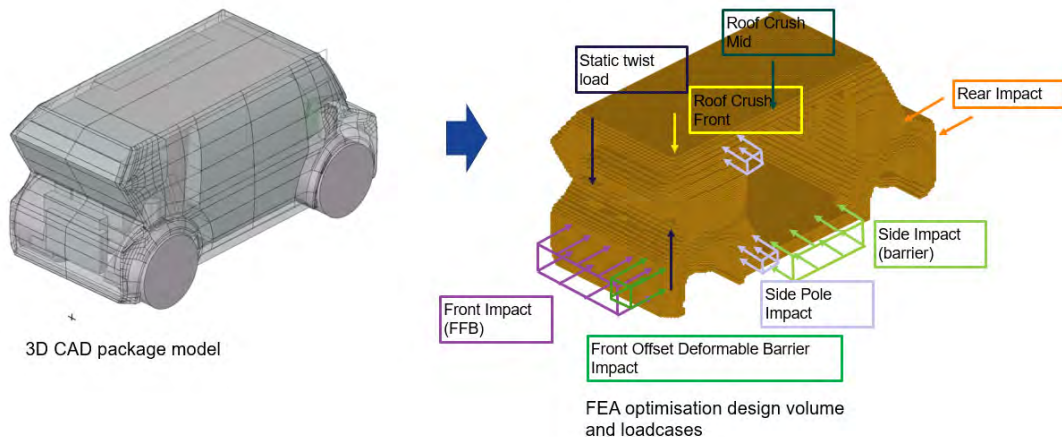


Figure 6.2.4.1 Creation of 3D FEA design volume for topology loadpath optimisation

A set of representative loads (forces) were applied to the FEA mesh volume. The loads applied considered; front crash (FFB), front crash (SORB), side crash (barrier), roof crush (front and mid load), torsion/twisting and vertical bend. The FE optimisation analysis is linear static and the loadpaths in the design volume are calculated based on the element sensitivity. The magnitude of the input loads were therefore normalised to 1.0N, applied as individual loadcase and combined. This enabled the structural loadpaths for specific loadcases to be identified as well as their contribution to the combined loadpaths.

The optimisation software Optistruct was used for the calculation. The software outputs 3D shape data for the loadpaths identified within the design volume. The loadpaths for the combined loadcases is shown in Figure 6.2.4.2

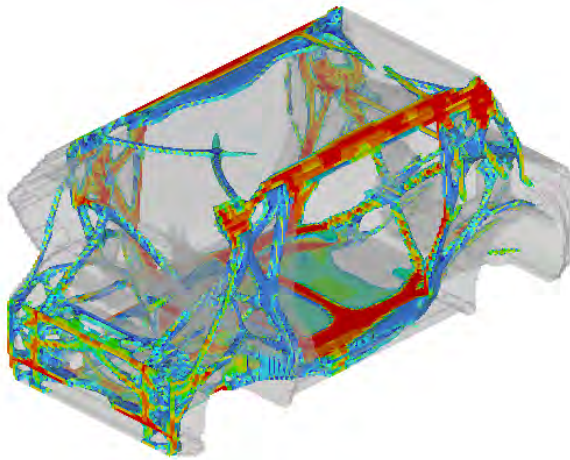


Figure 6.2.4.3 Topology loadpath optimisation considering all (combined) loadcases

The loadpaths considering only the stiffness loadcases (torsion/twist) and vertical bending only loadcases are shown in Figure 6.2.4.4. Should the body structure require improvement or enhancement in static stiffness performance in the subsequent stages of these loadpaths could be referred to and the design enhanced by placing more structure (or section size) in the regions identified.

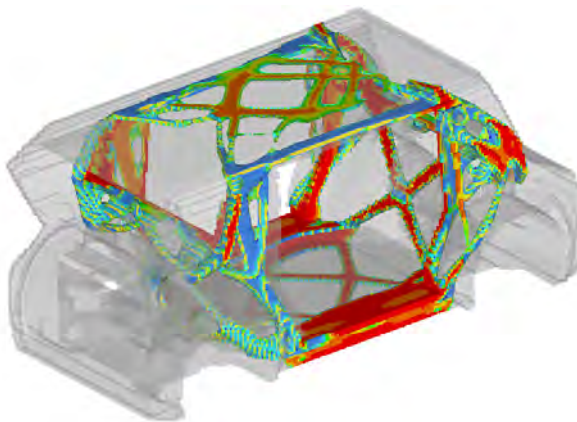


Figure 6.2.4.4 Topology loadpath optimisation considering static torsion and bending loadcases only.

Similarly, the loadpaths for the crash loadcases only could be identified and used to influence the design at later stages as per Figure 6.2.4.5

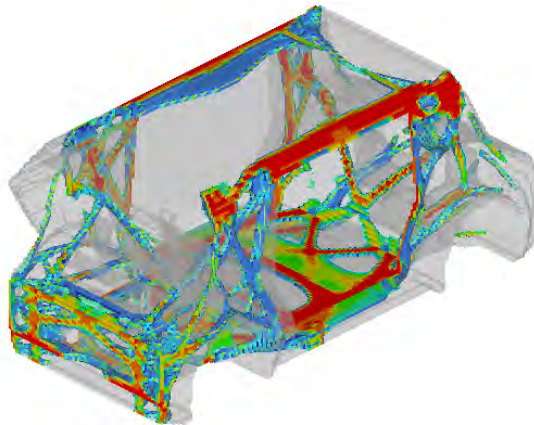


Figure 6.2.4.5 Topology loadpath optimisation considering crash loadcases only

The vehicle closures can contribute to the overall stiffness and strength of a body structure. The door structures cover a significant surface area of side of the vehicle resulting in significant interface with the side crash and pole barriers. Structural reinforcements inside the door offer significant strength and load management in side crash. The side doors create a significant shear panel contributing to the static torsion, bending and NVH modal stiffness of the overall body structure. The topology analyses as described above included no representation of the side closure structures, representing a “worst case”, no contribution scenario. Additional analyses were performed to understand the potential loadpaths and contributions assuming some structural contribution from the side closures. The FEA design volume was modified to include a representation of side closures. Two scenarios were considered: 1) side closure on one side of the vehicle only, the other side being enclosed by the BIW 2) side closures on both sides of the vehicle. The side closure volume was connected to the parent body structure completely around the perimeter, the objective being to try to determine the optimum location for door locks and latches to the body. Figure 6.2.4.6 shows the FEA design volumes for the baseline, no side closures (results as above), single closure on the left side of the vehicle and side closures on both sides of the vehicle

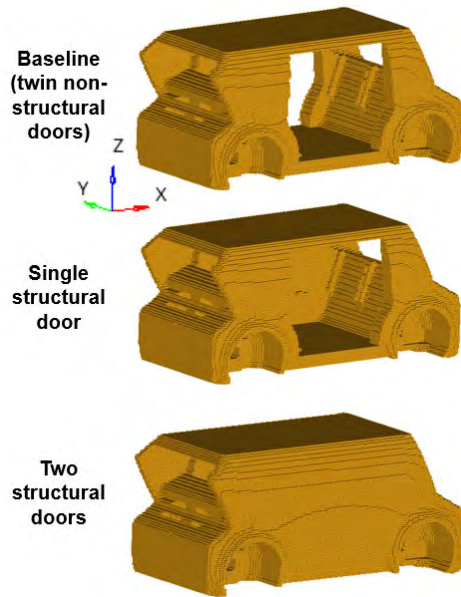
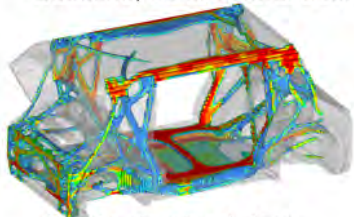


Figure 6.2.4.6 FEA design volumes with different configurations of side closures

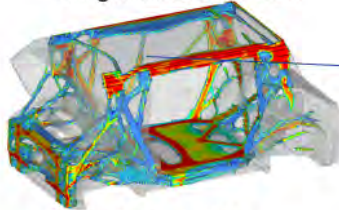
The FEA design volumes were subject to the same loadcases and design constraints. The comparative loadpath results from the topology optimisation analyses are shown in Figure 6.2.4.7. The results show that with the single, left side door structure included, an additional vertical loadpath is recommended. With doors considered on both sides of the vehicle, the optimisation recommends vertical and diagonal loadpaths through the doors. The loadpaths in both doors also introduce additional loadpaths into the roof zone, with double diagonal braces intersecting and connecting with the door loadpaths.

The topology loadpath optimisations are intended to be for guidance purpose only and not to prescriptively define the exact layout and loadpaths for the BIW. Engineering interpretation of the 3D loadpaths was assisted using Virtual Reality (VR) tools. The 3D topology loadpath results were translated into VR format. Engineers were then able to review the loadpaths from a full-scale, real-world view collaboratively. The VR tools enabled the engineers to overlay preliminary structural members onto the recommended loadpaths to develop the primary BIW and door structures. The development of the body structure concept was undertaken within Phase 1 of the project and is described in Section 6.3. An example of the 3D topology results as reviewed in the VR application is shown in Figure 6.2.4.8.

Baseline, no structural doors

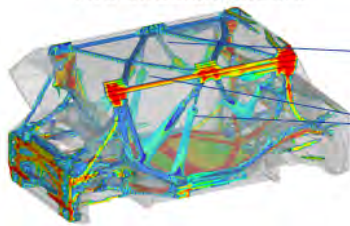


Single structural door



Vertical
loadpath in
side right
side door

Two structural doors



Roof lattice
structure

Diagonal
loadpaths in
both doors

Figure 6.2.4.7 topology loadpath optimisation results with different configurations for the side closures (doors)

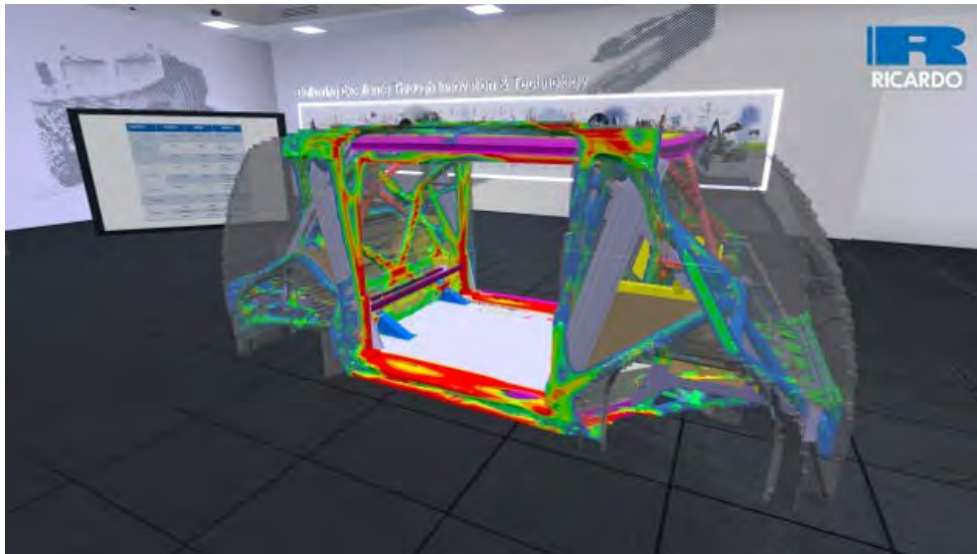


Figure 6.2.4.8 Example of topology loadpath optimisation results using Virtual Reality software

6.2.5 Competitor Vehicle Benchmarking

Competitor vehicle benchmarking is usually undertaken at the start of a new vehicle programme to ensure market competitiveness and appropriate positioning of the vehicle being developed. Benchmark vehicles usually undergo testing and evaluation to establish the key features, specifications, performance attributes and design approach to verify the targets and expectations of the new vehicle. With fully autonomous, MaaS vehicles not expected to enter widespread operation until 2030 at least, the available data for benchmark vehicles was extremely limited. Autonomous MaaS vehicles that were under development were at concept development or prototype stage, hence no physical/hardware testing was possible. Evaluations were therefore limited to “desktop” (literature) based. The desktop benchmarking study aimed to determine the overall vehicle dimensions, seating configurations, door configuration and size, powertrain and autonomous vehicle features of similar vehicle concepts to Steel E-Motive. Figure 6.2.4.1 summarises the high-level features and data that was publicly available at the time of the study.



Figure 6.2.4.1 High level specifications and features of comparable vehicles to Steel E-Motive. (Data sources: <https://www.canoo.com/> <https://www.nevs.com/en/pons/> <https://getcruise.com/> <https://zoox.com/vehicle/>) Information believed to be correct at the time of writing.

A comparison of the benchmark vehicle exterior silhouette and dimensions is shown in figure 6.2.4.2. The specific dimensions were estimated and scaled from technical journals and articles and are therefore approximate and subject to errors. The study does show a similarity in the overall vehicle sizes and proportions. Two exterior silhouettes and profiles are shown as these were under consideration at the time of the benchmarking study.

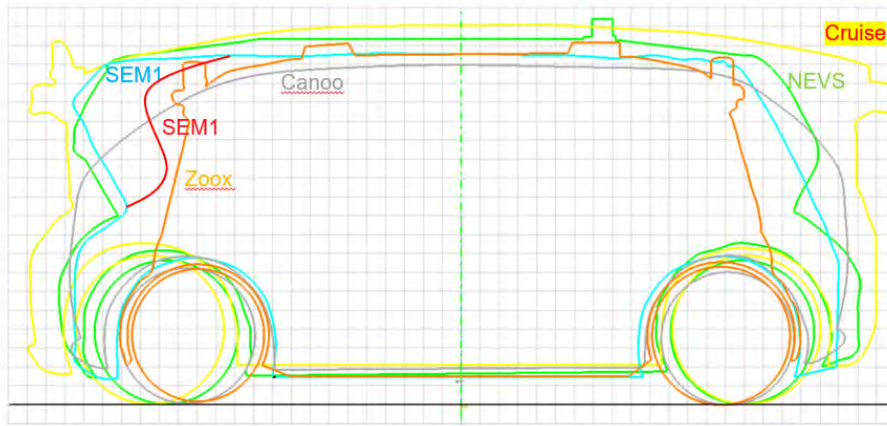


Figure 6.2.4.2 Benchmark vehicle overall size and proportion comparison (note, based on estimated/scaled data from technical journals and articles)

Similarly, the door aperture dimensions were estimated and compared to SEM1. The SEM1 design concluded with an overall door aperture width of 1.07m.

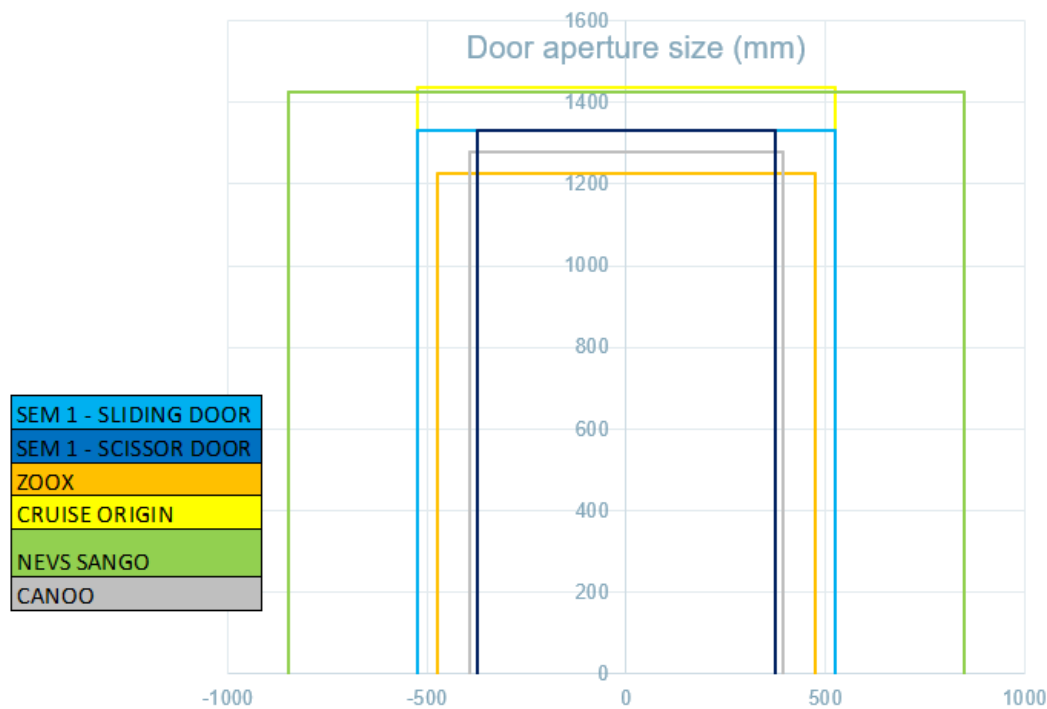


Figure 6.2.4.3 Benchmark vehicle door aperture profiles (note, based on estimated/scaled data from technical journals and articles)

The benchmark evaluation concluded that the GM Cruise vehicle was most aligned to the Steel E-Motive concept, operating at high speed (>40kph), level 5 autonomy, has high volume production intent and is dedicated vehicle design considering the freedoms enabled by full vehicle autonomy. Canoo, NEVS and Zoox were identified as offering lower levels of autonomy or intended to operate at lower maximum speeds than Steel E-Motive and may be intended for low speed off-highway shuttle type transportation. These may have been early

prototype/demonstration vehicles with maximum speed limited for safety. In this case, it is possible that these vehicles may not be compliant with high-speed crash standards and legislation (as in the case of Steel E-Motive). The vehicle structures of these vehicles may differ considerable to vehicles that are compliant with high-speed crash requirements. The vehicles may also be early development vehicles where high speed crash requirements may be considered later in the vehicle development cycle. The vehicles offering level 5 autonomy (NEVS, Cruise, Zoox) all feature interiors with inward (“living room”) seating configuration with double side opening doors on the left and right sides of the vehicle, as shown in Figure 6.2.4.4. Bench type seats feature on the Zoox and Cruise concepts and configurable pilot seats feature in the NEVS concept.

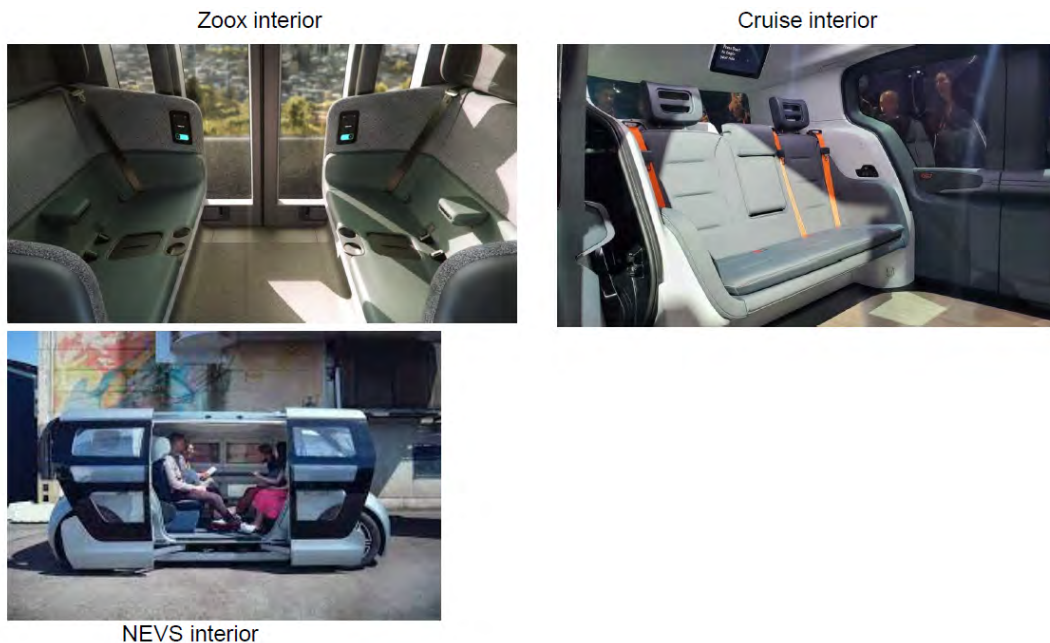


Figure 6.2.4.4 Interior and seating styles of the Zoox, Cruise and NEVS concept vehicles (image source Zoox, Cruise, NEVS)

The desktop benchmarking concluded that Steel E-Motive high-level specifications were aligned to the reference vehicles that were undergoing development at the time. Given the

limited information available, the Steel E-Motive concept would expect to be competitive in the marketplace if it were to enter production in the intended timeframe.

6.2.5 Exterior Styling Study

The primary focus and objectives of the Steel E-Motive project were to develop a fully autonomous vehicle and body concept, demonstrating the suitability of the latest steel grades and manufacturing processes for future vehicles. The styling and exterior aesthetic appearance of the vehicle is also important as it demonstrates and represents the brand (for steel), conveys messages about what the vehicle (and project represents) and the exterior styling and shape also has the potential to influence and impact the definition of the body structure. An exterior styling activity was therefore undertaken within Phase 0 of the project. The styling activity was divided into three stages 1) generation of exterior style themes and concepts 2) review and selection of one exterior styling theme 3) creation of 3D digital (CAD) data of the selected theme and creation of rendering images showing the vehicle style. The exterior styling activity was undertaken by Ricardo's inhouse vehicle design team.

6.2.5.1 Exterior style theme

To provide guidance to the exterior vehicle design group, a “creative design” poll survey was undertaken. The objective of this was to capture the thoughts and ideas of the Steel E-Motive project team of what messages the Steel E-Motive design would expect to represent. A multiple-choice questionnaire presented questions regarding the association of everyday objects, creatures and brands and emotions to the Steel E-Motive project and style. The collective conclusions from the survey would then inform and guide the styling team to create a design that represents and defines the Steel E-Motive concept. A sample of the creative design poll questions and responses are shown in Figure 6.2.5.1.1. The overall poll survey results are shown in Figure 6.2.5.1.2

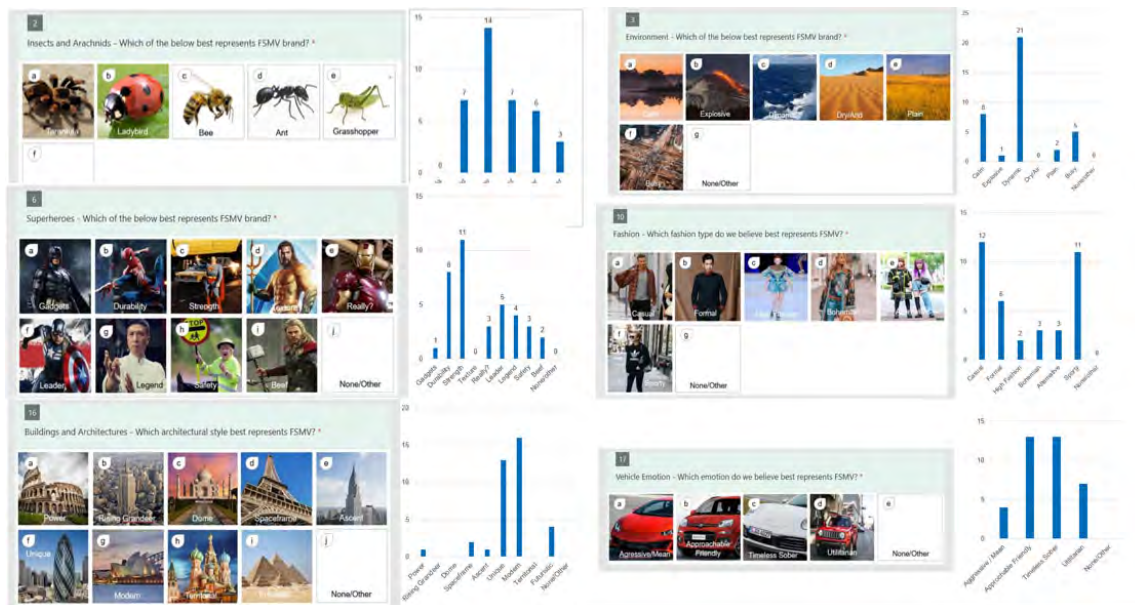


Figure 6.2.5.1.1 Extracts from creative design poll questions and response (see Appendix 4 for larger image)

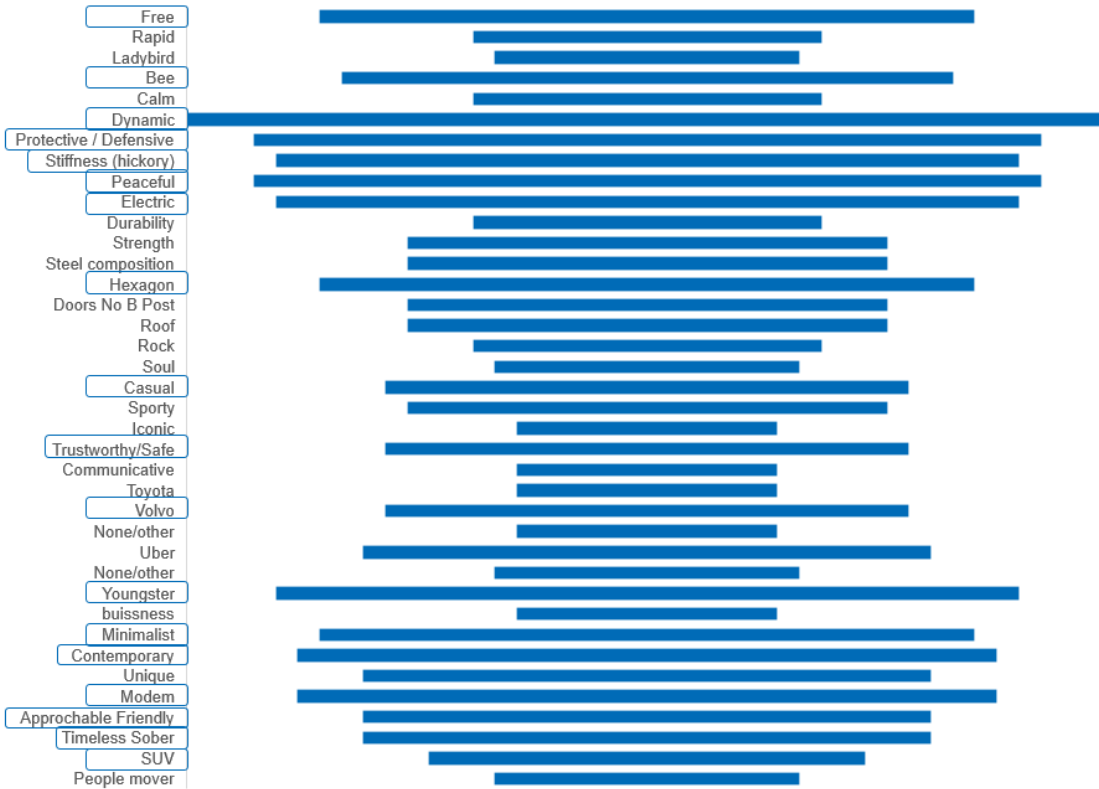


Figure 6.2.5.1.2 Creative design poll overall results, with key “design emotions” highlighted

The results from the creative design poll were reviewed and interpreted by the design team and a vehicle design “styling vision” was created. This was a brief or snapshot of the styling theme and vision and intended to as a reference point and guide for the designers as they created the concept themes.



Figure 6.2.5.1.3 Steel E-Motive styling vision

Several vehicle styling concepts were then generated using freehand sketches, examples of which are shown in Figure 6.2.5.1.4 and 3D design software. Figure 6.2.5.5 shows all the digital renderings of concept themes generated.

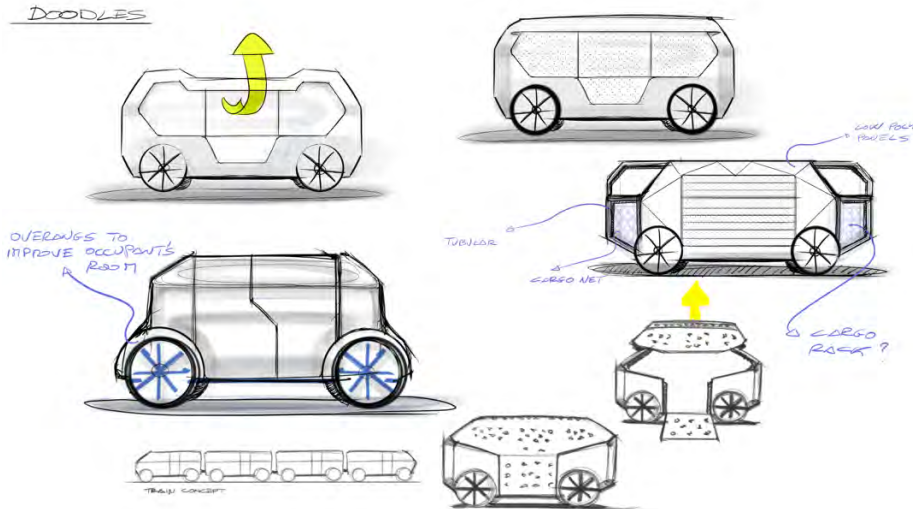


Figure 6.2.5.1.4 Styling concept creation using freehand sketch

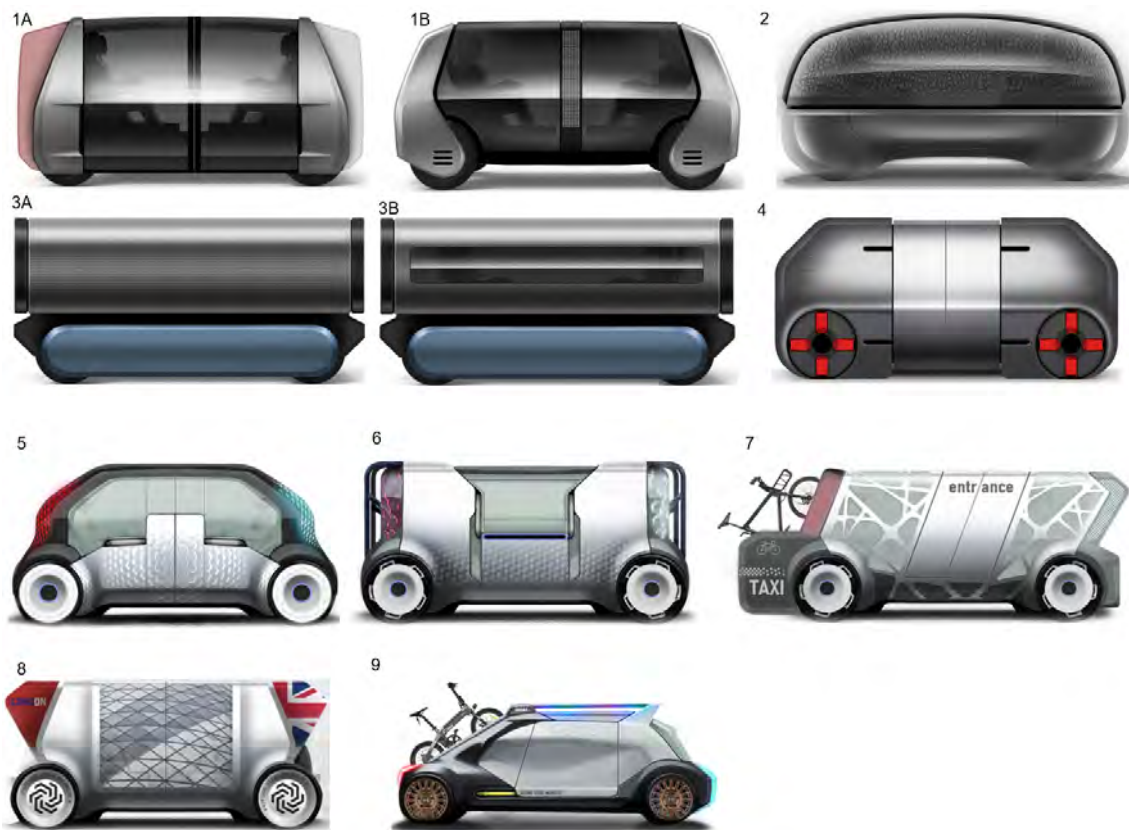


Figure 6.2.5.1.5 Digital renderings of the Steel E-Motive exterior style concept designs

The concept themes were down-selected to 3 concepts using a polling and voting approach within the Steel E-Motive project team. The 3 concepts then underwent an engineering appraisal, to identify issues or benefits that each concept may pose or offer. Figure 6.2.5.1.6 shows the results from the engineering appraisal of the concepts and the results of the concept selection pole. The conclusion from the engineering evaluation was that Concept 7 offered advantages with crashworthiness performance, mechanical package, weight, and cost. Additionally, the exoskeleton concept was viewed as demonstrating a uniqueness and “wow factor”. Concept 7 was therefore selected as the primary concept theme for the Steel E-Motive project. Figures 6.2.5.1.7 and 8 shows the final Phase 0 digital renderings for the selected. The styling theme provided a basis for the engineering teams to work with for the subsequent body engineering activities. The exterior “A” surface provides a boundary where the body design should work to where feasible and possible.

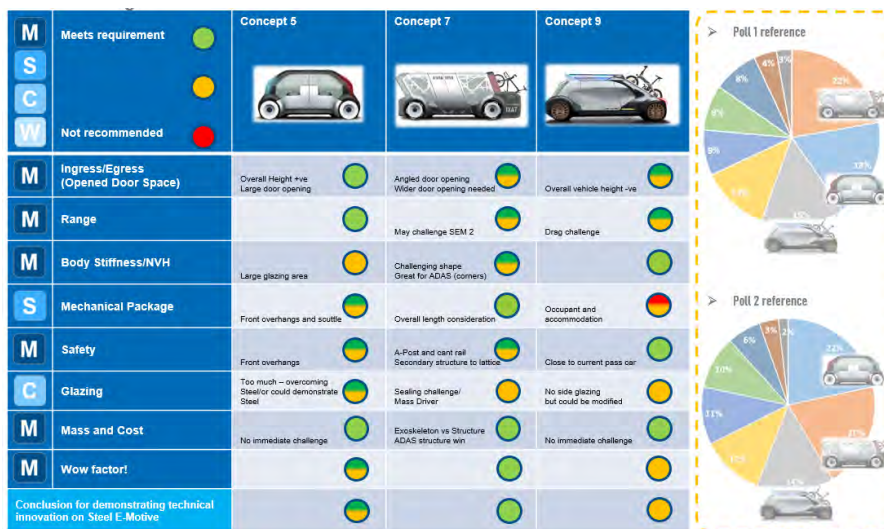


Figure 6.2.5.1.6 Engineering appraisal of 3 selected concepts (see Appendix 4 for larger image)



Figure 6.2.5.1.7 and 8 Digital renderings of Steel E-Motive selected



6.2.7 Vehicle curb weight verification and system weight budget allocation

The curb weight target value for the SEM1 vehicle was defined at 1640kg. An exercise was undertaken to verify this value and allocate the vehicle system weight “budgets” that result in the curb weight value. This would also provide input for Phase 1 activities such as full vehicle crash simulation, where the vehicle weight and weight distribution are required as inputs to the model. The system weight budgets were defined from benchmark data, primarily using a2mac1. (<https://www.a2mac1.com/> a2mac1 is a subscription-based service, where current production vehicles undergo teardown to determine system and component weights and dimensions). For some systems, a weight regression analysis was performed, where the weight-dimension trends were calculated for a sample of vehicles and the expected SEM1 weight estimated based on the weight-dimension regression formula and the SEM1 specific dimensions. The data sample used consisted of battery electric vehicles of similar size and specification to SEM1. Figure 6.2.7.1 shows the SEM1 system weight evaluation and estimation. Based on the evaluation, the curb weight of SEM1 was estimated to be 1512kg versus the target value of 1640kg, a difference of 128kg. This overall weight saving would enable benefits to be realised in the vehicle design stage, such as lower crash loads, lower propulsion energy requirements lower durability loads. This may result in secondary or “weight spiral” effects, where the body, chassis and powertrain systems can be downsized because of the inherent weight savings. For the purpose of calculation and simulations in the subsequent development of the SEM1 vehicle, the curb weight was assumed to be 1512kg

| System | Budget | Description |
|---------------------------|-------------|--|
| | SEM 1 | |
| Body non-structure | 169 | exterior trim panels, interior trim, seating, interior and exterior lighting, dash/controls interface |
| Body Structure | 309 | body in white only, target value based on regression analysis |
| Front sub-frame | 18 | |
| Battery case (structure) | 70 | |
| Rear sub-frame | 18 | |
| Front suspension | 115 | springs, damper, knuckle, control arm, anti-roll bar, bushes, brake discs and caliper |
| Rear suspension | 115 | springs, damper, knuckle, control arm, anti-roll bar, bushes, brake discs and caliper |
| Braking | 10 | booster and master cylinder, ABS and brake lines |
| Steering | 12 | EPAS, steering rack and track rods |
| Tires and wheels | 86 | |
| Motor Trans Front | 80 | |
| Motor Trans Rear | | |
| Battery system less case | 250 | fluids, busbars, cooling plate, modules and PDU |
| Propulsion controls | 60 | charging port, DC:DC inverter, |
| Electrical-non propulsion | 36 | wiring harness, 12v battery, fuse box, radar, lidar, cameras, autonomous control unit, switches and sensors |
| Cooling and heating | 30 | front cooling pack, header tanks, thermostat valves, cooling hoses, HVAC blower, ducting and vents, air conditioning compressor, heat pump |
| Closures | 100 | side doors, tailgate, locks, actuators, hinges, glazing, |
| Bumpers | 34 | bumper beams, crush cans, low speed energy absorbers, exterior panels |
| Estimated Curb Mass | 1512 | kg |

Figure 6.2.7.1 SEM1 curb weight verification and system weight budget allocation

6.3 Technical Approach, Phase 1

6.3.1 Introduction and approach

The primary objectives of Phase 1 of the Steel E-Motive project were to develop body structure concepts based on the preliminary sizing and scoping activities undertaken in Phase 0. The conclusion of Phase 1 would see one body structure selected as the primary route and focus for development and verification in Phase 2. With the high voltage propulsion battery being of significant size, weight and structural contribution to the overall body and vehicle performance, the exploration and development of battery concepts was undertaken in parallel with the development of the body structure. Concepts for some of the body subsystems, such as the front and rear crash structures and the rocker were also undertaken in parallel. An interim project Gateway was held midway through Phase 1, where the key design and performance metrics were assessed against the project targets. The body architecture, battery concepts and subsystems were combined and integrated into a single design and evaluated at the Concept Selection <CS> gateway at the end of Phase 1. To simplify the Phase 1 design and analysis activities, the engineering development in Phase 1 purposefully considered a limited, sample of steel material grades. Manufacturing and assembly feasibility was primarily experience and engineering judgement based – detailed evaluation and development was undertaken in Phase 2. Figure 6.3.1.1 shows the timing and interaction of the Phase 1 engineering activities and Figure 6.3.1.2 shows the approach for the development of the body structure.



Figure 6.3.1.1 Phase 1 engineering activities

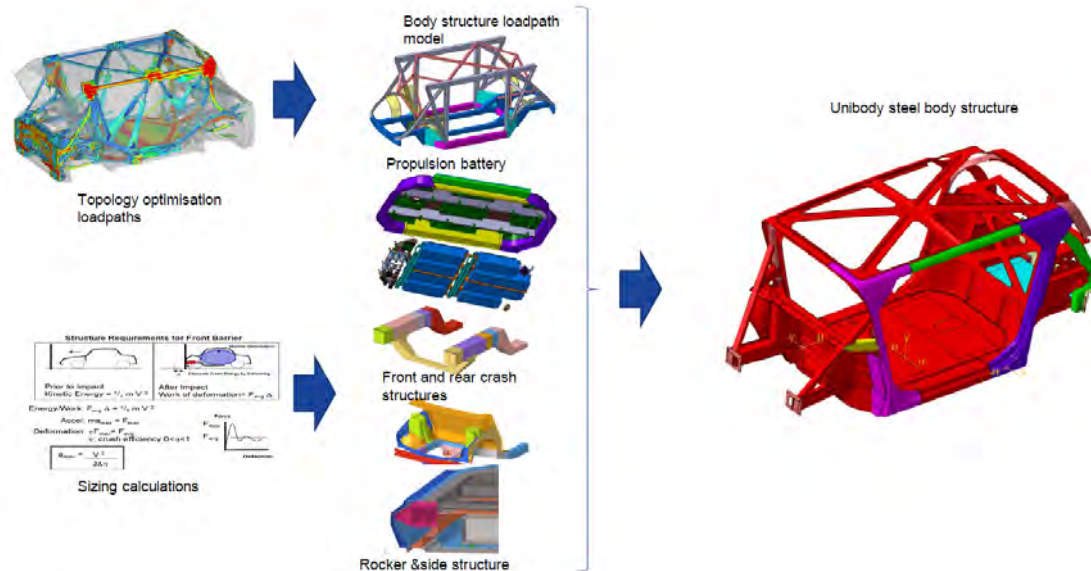


Figure 6.3.1.2 Approach for the development of Phase 1 body structure concept

The first stages of Phase 1 focussed on developing the overall architecture of the body, the layout and sizing of the key structural elements and ensuring the structural performance targets were achievable. In parallel, different concepts for the propulsion battery were developed. This was initially done “standalone” (without considering the native body structure). Once the body architecture was established mid-way through Phase 1, the development of the propulsion battery considered a fully integrated approach with the body structure. Preliminary calculations and concept studies were performed for the front and rear crash structure and subsystems such as the rocker. Similarly, this development was initially done at subsystem level, before the concepts were integrated into the body architecture level mid-way through Phase 1. The Concept Selection <CS> gateway confirmed that the SEM1 targets were achievable given the timing and resources available for the remained of the programme. Some concessions were enabled on the performance targets at this stage, as 100% compliance for all targets would not be expected at this stage of the programme.

6.3.2 Concept Development of Body Architecture

The structural loadpath optimisation undertaken in Phase 0 provided the basis for the development of the overall vehicle and body architecture. At this stage, several different body structure construction types and approaches were considered for the Steel E-Motive concept. A “body on frame” architecture consist of a rolling chassis, with the suspension,

steering and powertrain systems mounted to a ladder frame. A separate, unibody body structure is then mounted to the rolling chassis, usually via isolating rubber mounts. This architecture is suited for vehicles with high payload and towing requirements such as pickup trucks. This high load capacity comes at the penalty of poor overall weight efficiency. A more common architecture for small vehicles and passenger cars is a unibody construction. The load carrying aspects of the chassis are integrated into the body structure. The body structure essentially acts as a “bracket” for all the major systems to attach to. Unibody constructions are more weight and cost efficient than body on frame but lack the load carrying and towing capacity of body on frame design. The growth and development of battery electric vehicles has led to the evolution of “skateboard” concepts. The skateboard chassis contains a base structure or platform, the propulsion battery, power electronics. The suspension, steering and braking systems are also mounted from the platform. An upper body containing the passenger compartment and interior is then mounted to the skateboard. A true skateboard architecture is less weight efficient than a unibody due to the horizontal split between the skateboard and upper body which creates inefficiencies in the loadpaths. The reality is that many battery electric vehicles feature a unibody construction with elements of skateboard features, such as a protective crash structure around the battery, flat floor, and integration of the power electronic systems. Given the targets and requirements for the Steel E-Motive vehicle, the decision was made to use a stamped steel unibody construction. This would enable a weight efficient structure, that could incorporate a flat floor, offer high levels of comfort and crash protection for the occupants and battery and would be suitable for production volumes of greater than 250,000 per year, using existing and conventional manufacturing approaches.

Development of the Steel E-Motive body structure concept started with the loadpath results from the Phase 0 topology optimisation study. The suggested loadpaths were reviewed and interpreted by the design team using 3D CAD and Virtual Reality tools. Figure 6.3.2.1 shows an example of the interpretation of the topology loadpath results resulting in the preliminary beam concept body structure model.

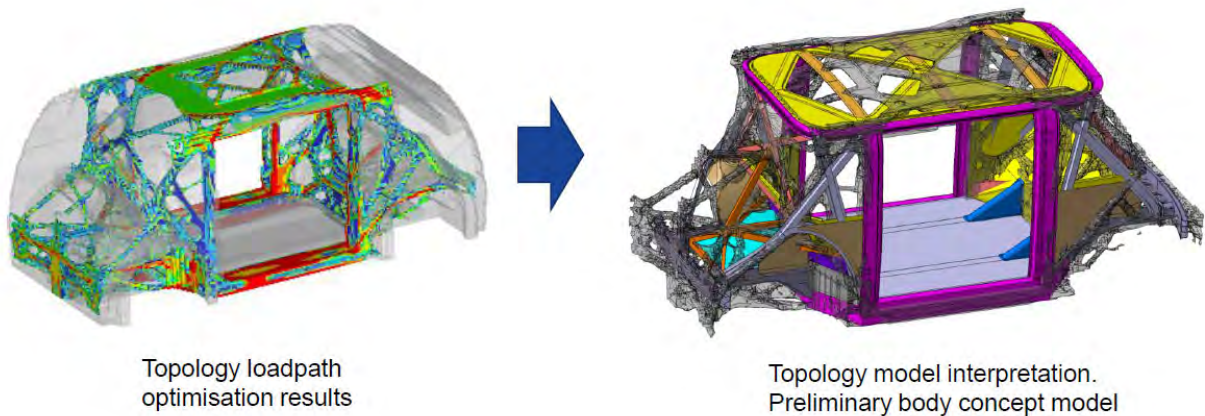


Figure 6.3.2.1 Interpretation of topology loadpath optimisation results into preliminary body structure concept model

The beam concept model featured first approximations for the main section profiles and properties. A Finite Element model of the beam structure body model was created. Front and

rear crash structures were integrated from the body subsystem studies as described in 6.3.3, which were run in parallel to the complete body structure development. Structural analyses were undertaken to evaluate the complete vehicle crashworthiness, static stiffness and NVH modal performance. Analysis iterations were performed, adjusting the beam section profiles and dimensions until satisfactory levels of performance were achieved.

6.3.3 Development of body subsystem and module concepts

Preliminary sizing and development of some of the body subsystems was undertaken at the start of Phase 1 and in parallel to the body architecture study described in 6.3.2. In order to manage crash loads in a frontal impact, a front crash structure is required. The function of the front crash structure is to manage the front impact event by decelerating the vehicle from the impact speed to standstill in a controlled and progressive way, such that the resulting loads on the occupants are not excessive. High levels of vehicle deceleration (or “pulse”) can cause injuries to the head, neck, and internal organs. The crash structure also needs to work with the safety restraint system such as seat belts and airbags can protect the occupants from high pulse levels. Occupant injuries can also occur as a result of the body structure deforming significantly and impacting the occupant. This can cause injuries to more exposed body parts such as legs, feet, arms, and feet. High levels of structural deformation into the occupant compartment are referred to as “intrusion levels”. To achieve satisfactory levels of deceleration pulse and intrusion, a crash structure consisting of collapsible members are engineered to fail and crush in a controlled and predictable manner on impact. Typically, these are longitudinal box sections extending forward from the bulkhead to the front bumper and impact zone. The crush characteristics of regular metallic box sections can be estimated by simple formula. Calculation tools such as MS Excel were used to determine the required crush length for Steel E-Motive. With a pulse target of 35g for the 56kph frontal rigid barrier and an assumed vehicle crash test weight of 1620kg (curb weight +100kg of test equipment), an available crush length of 720mm was required, as shown in Figure 6.3.3.1. These calculations, along with the results from the topology optimisation enabled the creation of front crash structure concept models, as shown in Figure 6.3.3.3. With the guidance of the loadpath optimisation results, a conventional approach of managing the main (primary) crash loads through a longitudinal crush rail, a secondary loadpath through the front subframe and a third or tertiary loadpath through the shotgun was employed. With the unique positioning of the occupants and very short front overhang, the shotgun was oriented more vertically than a conventional passenger car.

- USNCAP FFB, Vehicle Mass=1620kg

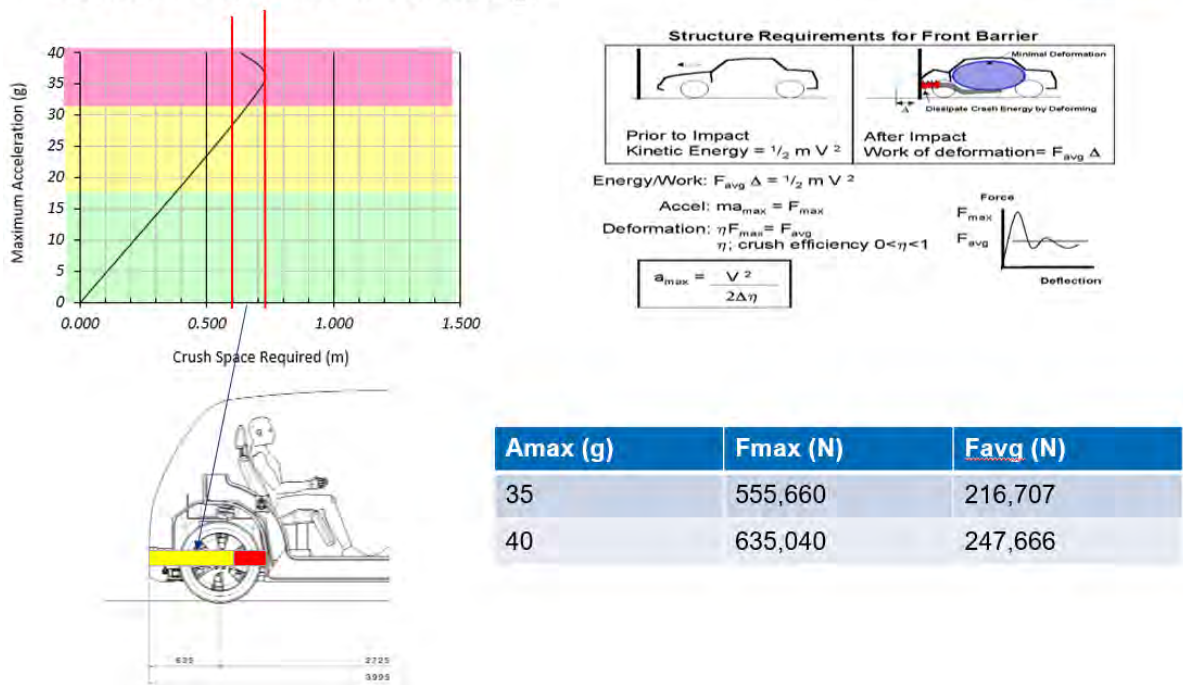


Figure 6.3.3.1 Estimation of required front crush length using formula and MS Excel (calculation tool provided courtesy of Donald E. Malen, Fundamentals of Automobile Body Structure Design, SAE International, 2020, Reference Section 6.2)

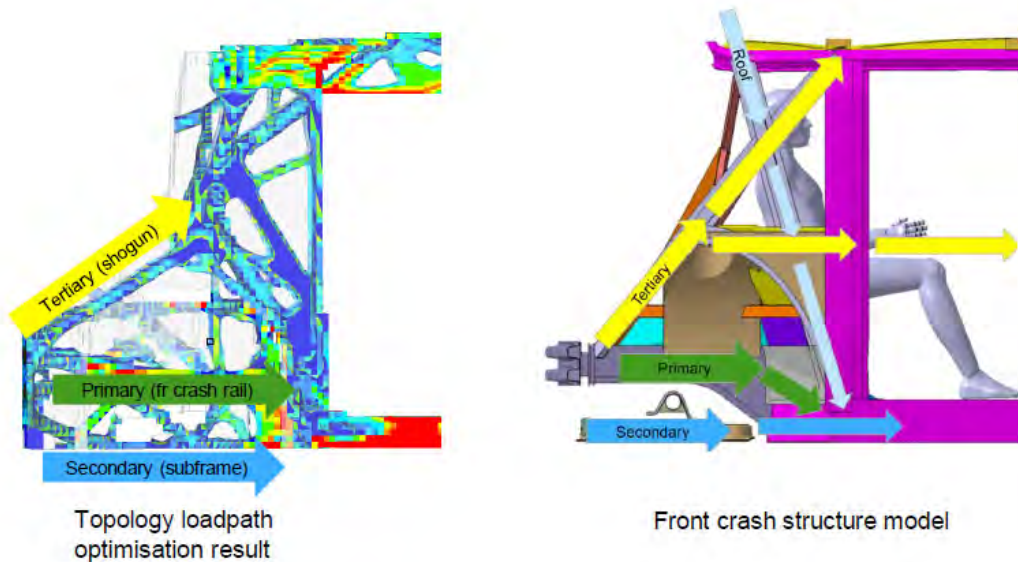


Figure 6.3.3.2 Development of front crash structure concept design using topology loadpath optimisation results. Also shown are the main crash loadpaths

FEA based design studies were performed to understand the sensitivity of the front crash structure design and the contribution of the front subframe and crash rail configuration. A summary of the study is shown in Figure 6.3.3.3. The study concluded that the best crash performance was achieved with an extended (longer) front subframe coupled with tailor

welded crush rail, with steel grades tuned to provide progressive crush and minimise intrusion (Concept 1). The study also showed the sensitivity of the positioning and motion of the EDU in front crash event. The EDU is comparably stiffer and stronger than the front crash structure. The EDU should be engineered to moved downward, towards the ground in a front impact. This should prevent the EDU being pushed rearwards in the front bulkhead which may result in high crash intrusion. The EDU should effectively be moved out of the way to allow the crash structure to work effectively. Based on the front crash studies and results, Concept 1 (shown in Figure 6.3.3.4) was selected as the primary design and incorporated into the complete body structure as described in Section 6.3.2. This concept would undergo further design and material grade refinement throughout the rest of the engineering phases of the project.

| | | Concept 1 | Concept 3a | Concept 3b | Concept 3c | |
|--------------------------------------|------------------------|-----------|------------|------------|---------------|-----|
| Front Longitudinal Crush Rail Design | | | | | | |
| Chassis/subframe design | | | | | (no subframe) | |
| Metric | CAE Target (interim) | | | | | |
| FFB | Acceleration | <48G | 43 | 51 | 56 | 54 |
| | Intrusion | - [mm] | 363 | 398 | 375 | 400 |
| | Max longitudinal force | <350kN | 265 | 261 | 334 | 256 |
| ODB | Acceleration | <40G | 39 | 36 | X | 37 |
| | Intrusion | - [mm] | 893 | 820 | X | 777 |
| | Max longitudinal force | <350kN | 293 | 253 | X | 268 |
| Mass - longitudinal | - [kg] | 13.6 | 10.2 | 13.6 | 12 | |
| Mass - subframe | - [kg] | 15.6 | 14 | 7.2 | X | |
| Overall performance status | | | | | | |

Figure 6.3.3.3 Front crash structure FEA concept design studies evaluating longitudinal crush rail and front subframe configurations (see Appendix 4 for larger image)

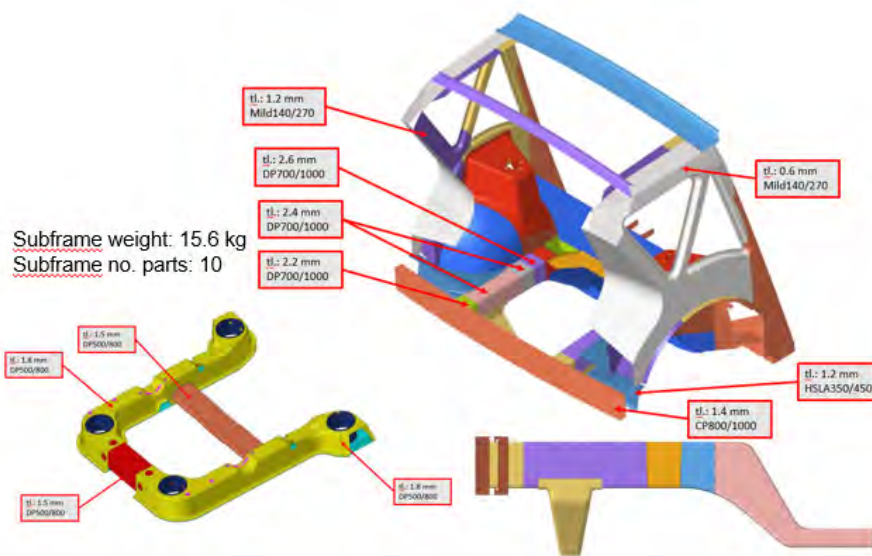


Figure 6.3.3.4 Front crash zone preliminary concept (#1)

Similar concept level studies were performed for the rear crash structure. Here, the objective is to manage the crash loads from a deformable crash barrier only and ensure there is no damage to the propulsion battery. There are also targets for the crash intrusion levels to the occupant compartment. Figure 6.3.3.5 summarises the results from rear crash structure FEA design studies. Concept 1a was selected as the primary rear crash structure concept despite other concepts showing lower battery contact forces. Concept 1a was deemed to have better fabrication and assembly characteristics than the other concepts.

| | | Concept 1a | Concept 1b | Concept 2 | Concept 3a | Concept 3b |
|----------------------------|---------------------------------|------------|------------|-----------|------------|------------|
| Body structure design | | | | | | |
| Rear subframe design | | | | | | |
| Metric | CAE Target (subsystem/ interim) | | | | | |
| Accelerations | <20G | 30G | 42G | 30G | 41G | 49G |
| Battery Forces | <70kN | 88kN | 103kN | 79kN | 85kN | 147kN |
| Door Intrusion | <40mm | 127mm | 69mm | 48mm | 79mm | 15mm |
| Longitudinal Efficiency | - | 37% | 36% | 51% | 36% | 44% |
| Body Mass | - | 148kg | 161kg | 132kg | 148kg | 129kg |
| Subframe Mass | - | 18.4kg | 18.4kg | 18.4kg | 21.1kg | 21.1kg |
| Overall performance status | | | | | | |

Figure 6.3.3.5 Rear crash structure FEA concept design studies (see Appendix 4 for larger image)

Subsystem development of the rocker and side crash structure was also undertaken. The side crash structure was developed for two crash loadcases: the USNCAP 32kph side pole and the IIHS 60kph side barrier. The side pole test impacts the body structure over a relatively small contact area, primarily loading the rocker, with secondary contribution from the side closures and cantrail in the roof. The IIHS side barrier test primarily loads the side closure's structure. The height of the barrier results in the rocker section missing the impact zone. In both tests, the objective is to ensure the occupants remain protected from intrusion of the body structure and the propulsion batteries remain undamaged. The main challenge with side crash is the relatively small space to manage the crash event compared to front and rear zones.

For the rocker, a strategy was adopted, where the outer part of the rocker featured a crush zone, the objective being to absorb the maximum amount of impact energy and the inner section engineered to be a protection zone, where the intrusion to the propulsion battery and occupant compartment would be minimised. (Figure 6.3.3.6). This is a similar concept as applied to the front and rear crash zones but confined to a much smaller area.

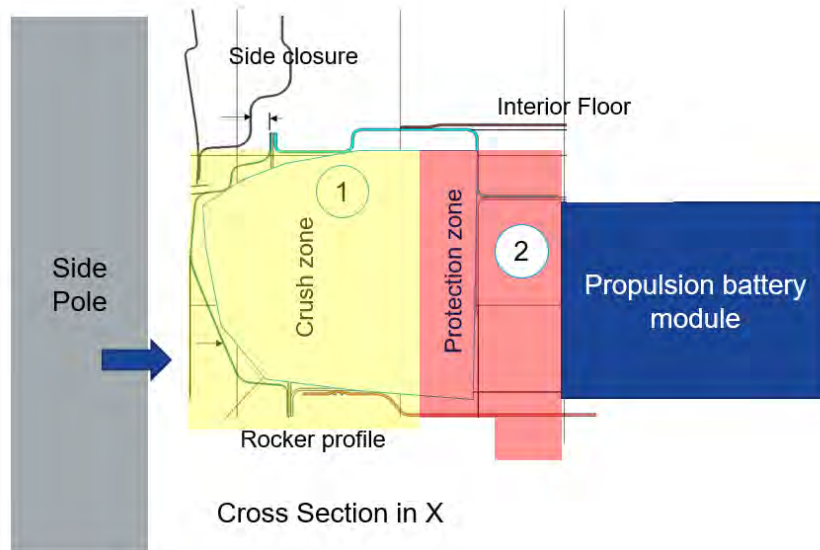


Figure 6.3.3.6 Cross section through rocker and floor showing strategy for outer crushable zone and inner protection zone.

Preliminary FEA studies were performed using a rocker and floor structure subsystem model (Figure 6.3.3.7), to evaluate several different rocker concept designs, adopting the strategy of crush and protection zones.

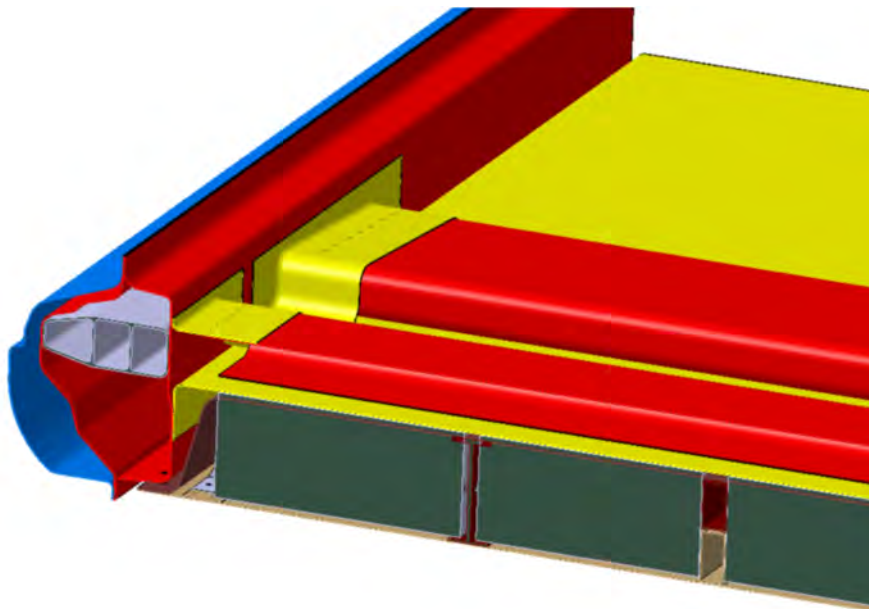


Figure 6.3.3.7 Rocker and floor FEA subsystem model

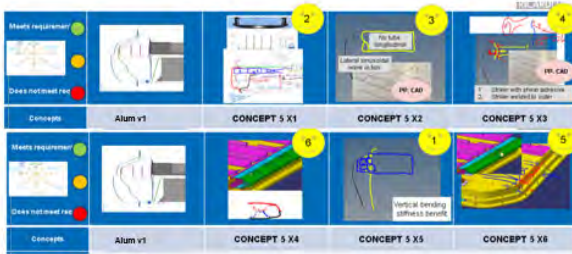
| | | (Benchmark study) | Concept 2 | Concept 5 | Concept 7.3.2 |
|---|------------------------------|---|---|--|---|
| Mid-Zone Design (cross section profile) | | | | | |
| Design concept | | Extruded aluminium crush element. AHSS protection | Fabricated Advanced High Strength Steel crush element | Coverless battery pack. Body floor & crossmembers provide top cover. | Sliding door concept. Re-profiled reinforcement sections, with stabilisers. Swages added to crossmembers. Sill inner increased thickness. |
| Metric | CAE Target (subsystem model) | | | | |
| Rebound | - | 35ms | 43ms | 33ms | 29ms |
| Pole Force | - | 625kN | 560kN | 552kN | 544kN |
| Floor crush | <25mm | 15mm | 80mm | 11mm | 40mm |
| Rocker energy | >80% | 82% | 53% | 95% | 77% |
| Rocker Mass | <18kg/m | 19.8kg/m | 14.9kg/m | - | 21.9kg/m |

Figure 6.3.3.8 Preliminary rocker concept FEA studies, including aluminium extrusion benchmark (See Appendix 4 for larger image)

Firstly, a benchmark evaluation was performed considering an extruded aluminium crushable element. This determined some reference results that subsequent steel designs could be compared to. The subsystem FEA was not able to fully represent a complete side crash event, therefore metrics such as floor crush intrusion, rocker energy and weight per length were used as subsystem evaluation targets. The study concluded that a fabricated steel crushable element was able to match or outperform the aluminium extrusion.

The side closures were undergoing concept design at the same time as the rocker study. One concept under consideration was a sliding side door design, featuring body side rails and tracks along the length of the cantrail and rocker to guide the door during opening and closing. For the door to operate effectively, the lower track of the sliding door concept encroached significantly into the rocker structure. This design was assessed using the FEA subsystem model to understand the potential impact on side crashworthiness performance. The study concluded that the impingement of the closure rails into the rocker compromised the structural performance significantly and the crashworthiness of the rocker could not be recovered to the required levels. This result supported part of the decision not to proceed with sliding doors with body side tracks and rails.

Following the preliminary side crash FEA analyses, further rocker concepts were developed. Design brainstorming meetings were held, and several new concept ideas were generated and subsequently engineered and assessed in the FEA model. Figure 6.3.3.9 shows the concepts generated and the conclusions from the FEA evaluation.



| Base 4 | Concept-5 X1 | Concept-5 X2 | Concept-5 X3 | Concept-5 X4 | Concept-5 X5 | Concept-5 X7 |
|-------------------------------------|--|----------------------------------|--------------------------|---|--|---|
| | | | | | | |
| Base model 3-part pusher Model 5444 | D50mm Crashcans & stiff armature | Sine beam crush | Plunge & crush mechanism | Clamshell 2-Part pusher | D25mm crush tubes | Crush planes |
| Developed for Concept-5 mid-zone | Difficult to make work between crossmembers Armature heavy | Works well & very mass efficient | (Not evaluated) | Works well, comparable with base 3-part M5444 | Tubes need to be joined to container & upper/lower surfaces along length | Stable crush of planes difficult to achieve |
| 9.2kg/m | 11kg to 14kg estimate | 5.7kg/m | | 7.9kg/m | 8.0kg/m | 9.0kg/m |
| MS1700 | Cans DP1180 Armature: MS1700 | DP1180 | | MS1700 | MS1700 | DP1180 |

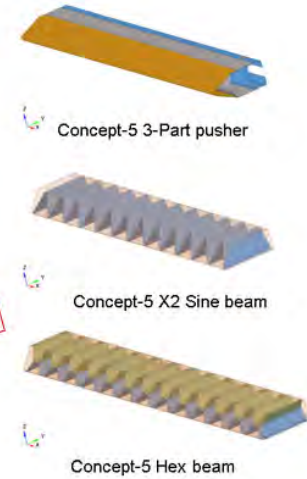


Figure 6.3.3.9 Development and assessment of rocker crush element designs (See Appendix 4 for larger image)

The study showed that concept “5x2” gave good crush performance and weight efficiency. The part could either be stamped or roll formed and having a significant number of edge corners in the contact and crush direction resulted in large amounts of material work hardening and energy absorption. The “sine beam” concept evolved into a 2 part “hex” beam, offering greater energy absorption. A Dual Phase steel grade was selected for the hex beam due to its high elongation and energy absorbing qualities. This concept (Figure 6.3.3.10) was selected and incorporated into the complete body structure model for further development.

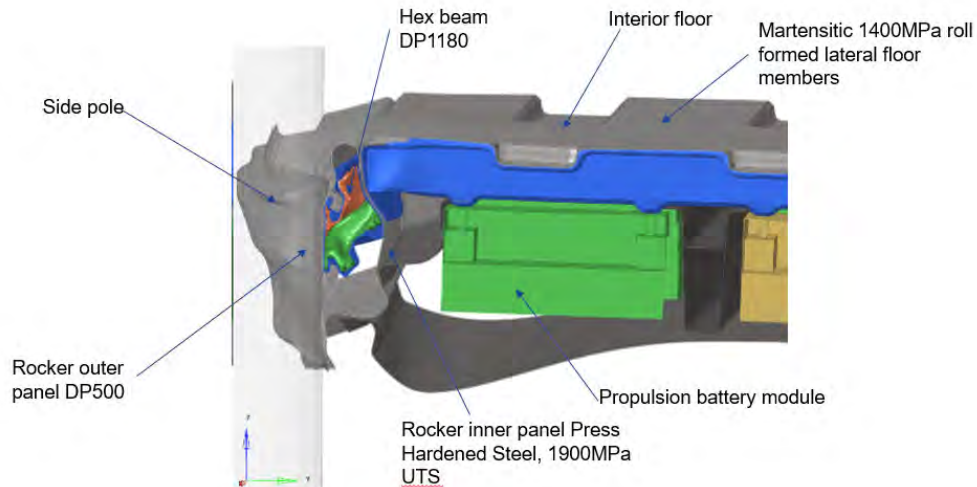


Figure 6.3.3.10 Rocker and floor concept, side pole subsystem FEA model showing the concept design selected for inclusion into the complete body model

6.3.4 Development of Propulsion Battery Concepts

The propulsion battery and supporting structure occupies a significant volume and has a significant contribution to the overall body and vehicle structural performance. Its weight is significant, (up to 1/4 of the vehicle curb weight) and also has the potential to contribute significantly to life cycle greenhouse gas emissions. Being a safety critical component, the battery must be able to withstand low and high-speed crash events as well as the fatigue and abuse loading from regular operation. A concept design study for the battery structure aimed to develop a lightweight design, featuring a low-cost design, achieving low life cycle greenhouse gas emissions, and meeting the structural performance targets. A total of six unique battery concepts were developed and explored.

The first battery concept to be developed was based around a “conventional” sealed pack unit. These are often referred to as “Generation 2” battery pack designs. The battery modules, cooling plates, bus bars and power distribution unit (PDU) are mounted to a stamped steel base plate, which also serves as the bottom protection cover on the underside of vehicle. A steel top cover encapsulates the modules and seals to the base plate, resulting in a fully enclosed battery unit. The pack is mounted to the body structure through fixings on the rockers. Figure 6.3.4.1 shows this concept applied to Steel E-Motive (“Concept 7”). The advantages of this design are improved (or robust) sealing solution, the pack can be manufactured and shipped off-site from the final vehicle assembly and the fully enclosed pack may better stiffness and strength performance. Concept #7 can also be easily integrated to the body and vehicle during assembly. The disadvantages of this design are higher weight and cost, as the top cover function is effectively duplicated by the floor of the BIW, low frequency modal resonance due to the battery modules mounted to a skin plate and potential damage to the modules from debris due to their proximity to the underside of the vehicle.

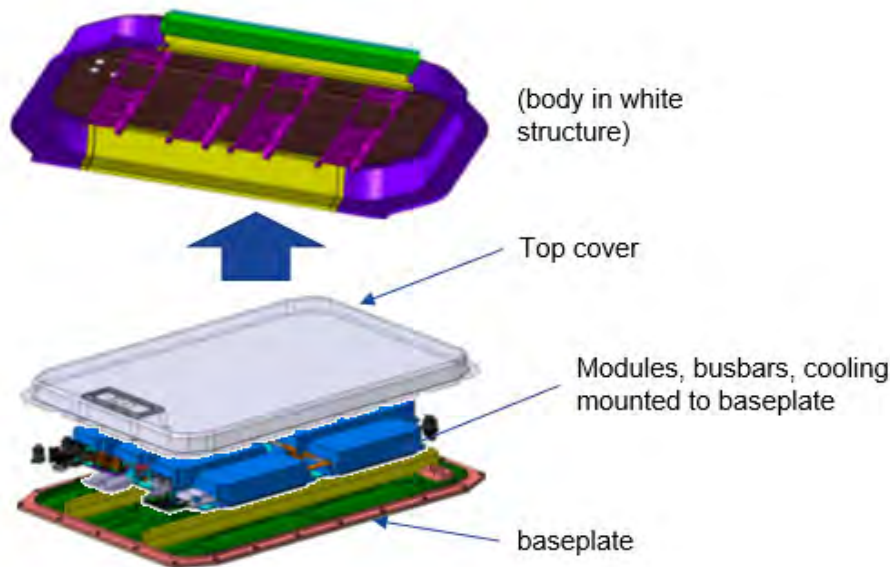


Figure 6.3.4.1 Battery Concept #7, “conventional” sealed battery pack

Battery concept #5 (Figure 6.3.4.2) was an evolution of concept #7, where a weight and cost saving were achieved by deletion of the top cover. The BIW floor design and sealing between the baseplate and rocker underwent design improvements to ensure the pack maintained the required sealing performance.

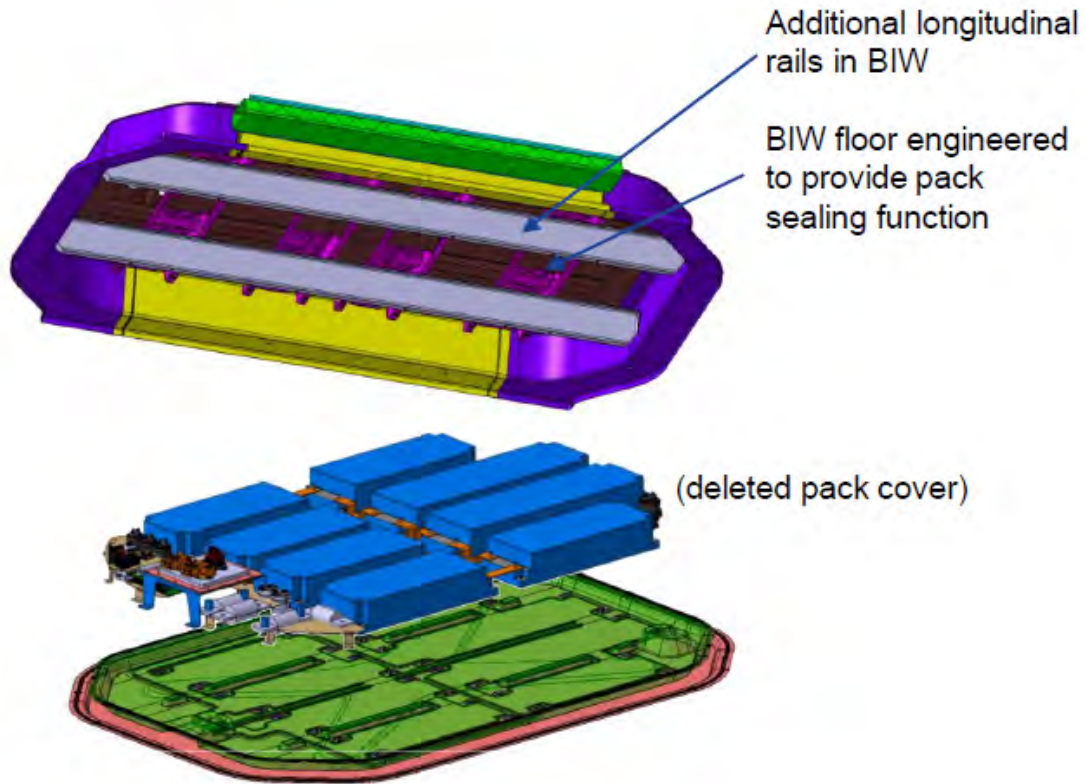


Figure 6.3.4.2 Concept #5, “coverless” pack concept

Battery concept #8 (Figure 6.3.4.3) featured a more radical design with the battery modules mounted (bolted) directly to the body in white, instead of bolting to the battery baseplate. The BIW maintained the sealing function to the floor with the top cover deleted. By attaching the battery modules to the BIW (longitudinal) directly provides improved support and stiffness than mounting to the baseplate. The module locations are also slightly higher than concepts 5 and 7, resulting in a greater clearance between the bottom of the module and the protective baseplate cover. The results in a lower risk of damage as a result of debris impact or incorrect vehicle jacking or lifting from underneath the vehicle. The consequence of this approach is that assembly of the modules to the body is more complex and potentially longer due to increased number of fixings and assembly processes.

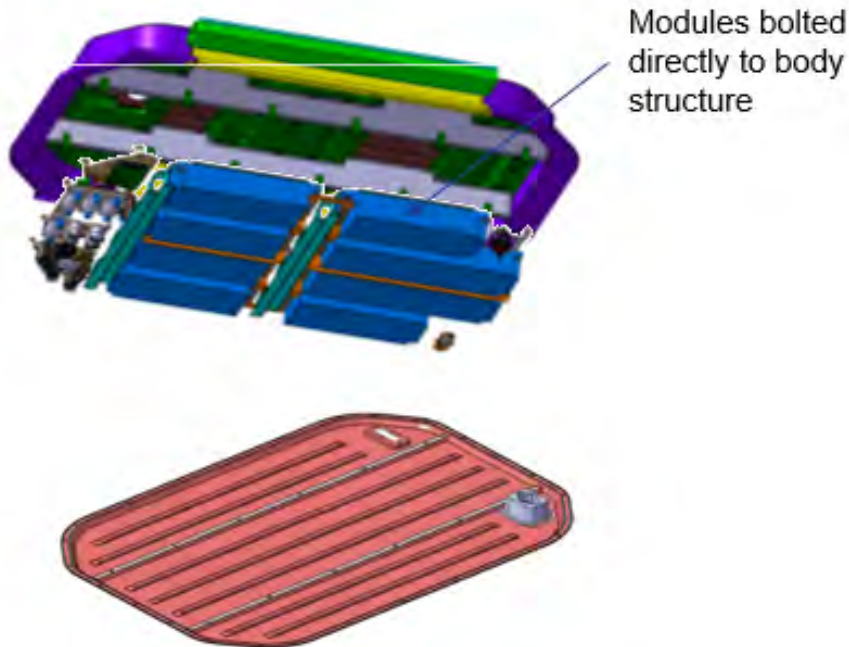


Figure 6.3.4.3 Concept #8, modules to body

The assembly risks and concerns were investigated by undertaking comparative evaluation of the manufacturing steps of concepts 5,7 and 8. The pack sub-assembly, pack and vehicle assembly processes were mapped as shown in Figure 6.3.4.4.

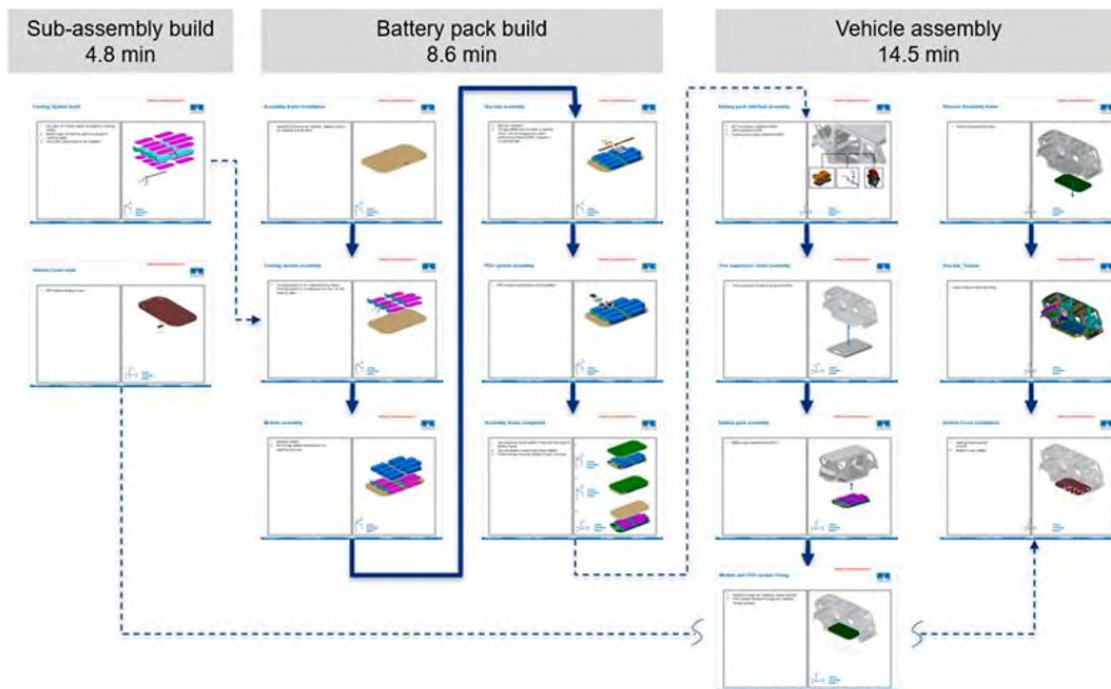


Figure 6.3.4.4 Battery concept #8 assembly process (battery into vehicle only) (See Appendix 4 for larger image)

The manufacturing evaluation concluded that the battery and vehicle assembly “TAKT” time was increased by 15% when compared to concept 7 (Figure 6.3.4.5). Installation of concept 8 battery modules directly to the body structure was identified as particularly challenging. This would require an additional, bespoke vehicle assembly station, where the vehicle would be inverted (upside down), enabling the battery modules to be inserted from above. Concept 8 would also require an additional assembly jig or platen for the modules to be pre-assembled and aligned to prior to the marriage to the body structure.

| Concept variant | Assembly time (est seconds – considers series assy) | | | |
|-----------------|---|------------------------|--------------------|---------------|
| | Total time | Battery Sub-assy Build | Battery Pack Build | Vehicle Build |
| 7 | 1450 (100%) | 460 | 730 | 260 |
| 5 | 1100 (-24%) | 0 | 570 | 530 |
| 8 | 1665 (+15%) | 290 | 515 | 860 |

Figure 6.3.4.5 Comparison of battery and vehicle assembly times for concepts 7, 5 and 8

Battery concept #9 investigated the potential for extreme levels of integration between the body structure and battery pack, with the pack structure containing the floor element of the BIW (Figure 6.3.4.6)

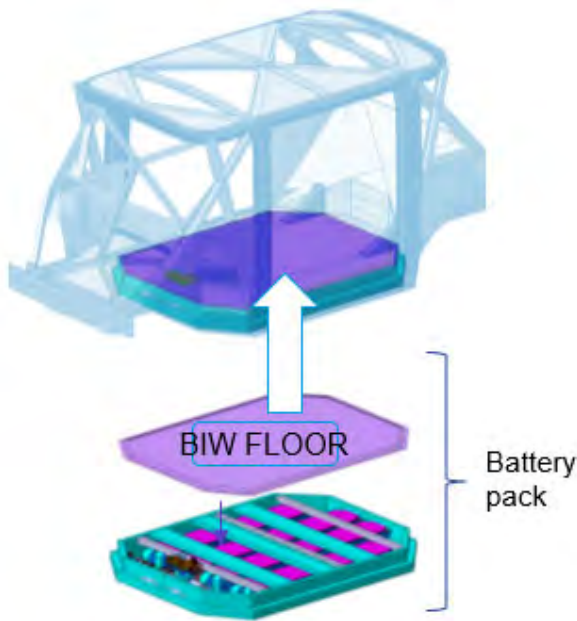


Figure 6.3.4.6 Concept #9, battery pack containing BIW floor structure



The BIW is engineered to feature a void where the conventional floor structure would reside. The battery pack top cover is engineered to be the floor structure of the BIW and assumes its role when the battery and BIW are married on the vehicle assembly line. The battery top cover is a single panel but dual purpose, enabling weight and cost savings. With this concept, the main challenges are the sealing between the occupant compartment and the battery and ensuring overall structural performance of the body system with the separated floor structure. The design and analysis studies showed that these challenges could be largely overcome.

Battery concept #11 features a structural carrier frame from which the battery modules, power distribution unit, busbars and cooling plates are mounted. The carrier frame provides a stiffer structure to mount the battery components from compared to the other concepts (e.g., mounting from the base plate). Several different concepts of structural frame were considered and explored. The final frame concept featured two Dual Phase grade longitudinal members, primarily providing vertical stiffness with roll formed Martensitic lateral cross members provide load reaction in side crash. The frame features no top cover – the BIW floor provides the upper sealing function. The frame is mounted to the BIW via fixings into BIW floor cross members. After the battery pack is assembled to the BIW, a structural undertray panel is fixed to the base of the BIW, completing the sealing of the battery compartment and providing impact and jacking load resistance from underneath. Figures 6.3.4.6 show the overall Concept #11 layout and the Phase 1 design of the battery pack and structural carrier frame.

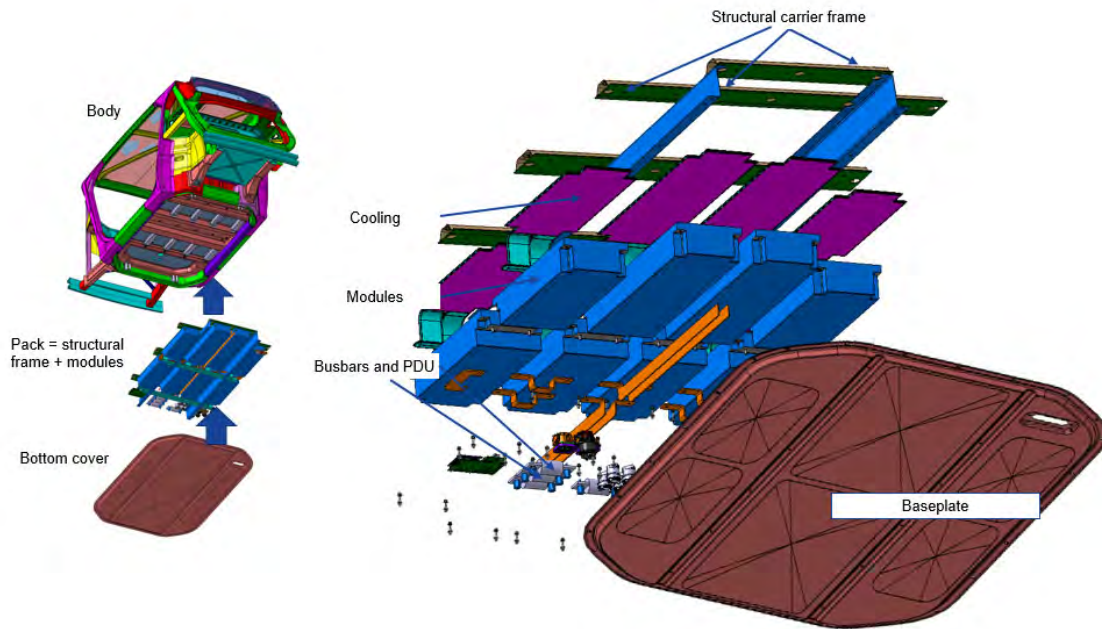


Figure 6.3.4.7 Battery concept #11 (See Appendix 4 for larger image)

Selection of battery concept:

A concept selection matrix was devised to evaluate and identify the battery concept which provided the best overall performance given the requirement of the Steel E-Motive project. A scoring system was used to rate each concept comparatively. A combination of CAD design data, FEA calculations and subjective opinion was used. The main requirements and considerations for the battery concept selection were defined as:

- Battery and BIW sealing. For many of the concepts this was a considerable challenge, requiring more complex design of seals. All designs would meet the requirements for sealing. Higher scores were awarded to concepts with a lower risk and lower complexity of sealing design
- Available internal battery volume: A larger battery internal volume enables a larger battery to be housed and may also offer benefits such as improved cooling. A larger internal battery volume was awarded a higher score. The absolute available volumes were calculated from CAD, therefore the results were aligned to objective metrics
- Thermal runaway suppression: Whilst all packs were expected to meet safety requirements, some back designs would provide better suppression of a thermal runaway incident than other designs. A higher score was awarded to designs with better thermal runaway suppression. This evaluation was purely subjective
- Battery pack weight: This is the overall weight of the battery pack, including supporting structure, frames, busbars, cooling, PDU and cover plate. Values were calculated in CAD. More lightweight concepts were scored higher
- Battery pack and BIW midzone weight. As some concept featured overlap and integration with the packs and BIW, the combine weight was assessed (similar to above)
- Manufacture build time (battery and pack): Higher scoring concepts had relatively simple assembly processes. Lower scoring concepts were estimated to have longer TAKT times and additional build steps, jigs, and fixtures
- Complexity (number of parts): concepts requiring more parts would typically be higher cost and have higher life cycle impact. More simple concepts with lower parts were scored higher
- Debris impact performance: Concepts where the modules are mounted to the baseplate/undertray may potentially have a higher damage risk from road debris and accidental jacking than concepts where the modules are mounted further away from the groundline or have improved protection. Concepts with good protection were scored higher
- Modal performance (pack only). There is an NVH requirement for the first installed battery mode to be $>35\text{Hz}$. In most cases, the battery concepts were able to demonstrate that this target was achieved. Concepts were scored higher where the target was comfortably met, or limited design changes or countermeasures were required
- Body torsion: relates to static torsional stiffness performance. With the battery pack contributing significantly to overall body stiffness, concepts were scored higher where a higher combined torsional stiffness was achieved (evaluated using FEA)
- Service and rework: concepts with easier, shorter, and less complex steps to access the battery in the case of servicing or repair were scored higher
- Cost: whilst no specific costs were calculated at this stage, a subjective approach was taken to evaluate each pack cost comparatively. Packs expected to be lower costs scored higher
- Recycling (End of life): the propulsion battery has a significant contribution to the overall greenhouse gas emissions of a vehicle. Concepts were assessed subjectively as to the recycling efforts and potential
- Demonstration of steel: an additional evaluation where concepts demonstrating unique steel grades, fabrication processes or exceptional performance in steel were scored higher

Each concept was rated 1 to 5 for each of the above assessments. The scoring was undertaken amongst the engineering and design teams. The results of the concept are shown below (Figure 6.3.4.8) and graphically in a radar plot (Figure 6.3.4.9)

| Attribute / Battery Concept | Concept 7 | Concept 5 | Concept 8 | Concept 9 | Concept 11 |
|---|-----------|-----------|-------------|-----------|-------------|
| Battery (and BIW) sealing | 4 | 2 | 4 | 3 | 4 |
| Available internal batt pack volume | 2 | 3 | 5 | 4 | 5 |
| Thermal runaway suppression (risk) | 5 | 3 | 2 | 4 | 2 |
| Battery Pack Mass | 2 | 4 | 5 | 1 | 5 |
| Batt Pack and BIW Midzone Mass | 2 | 4 | 5 | 1 | 5 |
| Manufacture Build Time (battery pack and vehicle) | 3 | 5 | 1 | 2 | 5 |
| Complexity (number of parts) | 5 | 2 | 4 | 1 | 6 |
| Debris Impact Performance (| 4 | 4 | 5 | 5 | 5 |
| Modal Performance (Pack only) | 3 | 3 | 5 | 4 | 4 |
| Body Torsion | 3 | 3 | 5 | 4 | 4 |
| Service and Rework | 4 | 5 | 3.5 | 3 | 3.5 |
| Cost | 4 | 4 | 4 | 2 | 5 |
| Recycling (EOL) | 4 | 4 | 4 | 2 | 5 |
| Demonstration of steel | 2 | 3 | 4 | 3 | 4 |
| Total | 47 | 49 | 56.5 | 39 | 62.5 |

Figure 6.3.4.8 Battery concept evaluation matrix

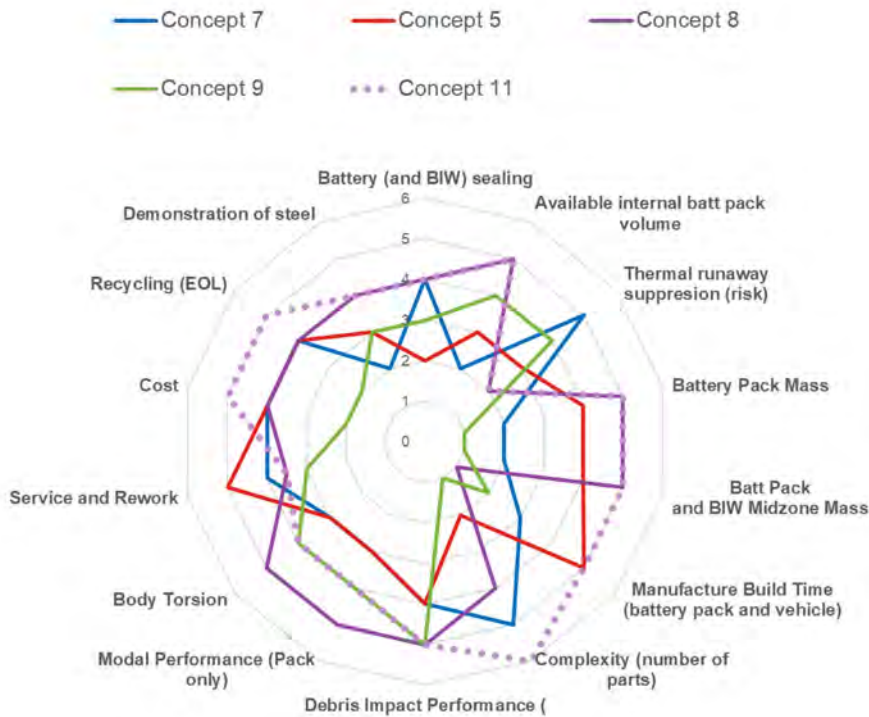


Figure 6.3.4.9 Battery concept evaluation radar plot

The evaluation concluded that concept #11 provided the best overall performance. Assembling the battery modules and components to the carrier frame overcomes the assembly challenges of concepts 8 and 9, whilst the structural carrier frame provides good stiffness and support to the modules, which also have increased clearance to the baseplate meaning better impact resistance. At the time of the study, the engineering teams were not aware of similar concepts in production or in development, hence, concept #11 offered a unique solution and was expected to be able to meet all targets. Preliminary FE analysis of concept #11 confirmed the structural performance. Concept #11 was selected as the primary design direction at the end of Phase 1. Phase 2 focussed on further refinement and validation of concept #11.

6.3.5 Development of closures concepts

The preliminary studies in Phase 0 identified that a “sliding” side door design would be best suited for the Steel E-Motive vehicles. This would improve the accessibility to vehicle users, both able bodied and disabled. The term “sliding” refers to the motion of the doors relative to the vehicle (i.e., along the length of the vehicle instead of hinged and swinging outwards). Achieving a “sliding” side door trajectory could be achieved by different mechanisms. Two such door mechanisms were evaluated in Phase 1; a sliding “track and rail” approach and a “scissor” door approach.

6.3.5.1 Track and rail sliding door

Sliding track and rail side doors are common on larger, present day passenger cars, multi-purpose vehicles (MPV) and light commercial vehicles. An example of a sliding door using track and rails is shown in Figure 6.3.5.1.1



Figure 6.3.5.1.1 Track and rail sliding door, Ford B-Max passenger car (images from a2mac1)

The door is supported and connected to the body at 3 locations; an upper rail, centre rail (which is partially visible on the exterior) and a lower rail. The 3 rails are mounted and integrated into the body structure. The door attaches to the 3 rails via guides and brackets – the upper and lower guides feature a roller wheel which locates inside the door side rails.

The shape and profile of the rail determines the path of the door on opening and closing. The path of the door on initial opening needs to be outwards (laterally) to provide clearance for the door to then slide rearwards. The door rails therefore feature a curved then straight profile as shown in Figure 6.3.5.1.2



Figure 6.3.5.1.2 Ford B-Max sliding door track profile (plan view, image from a2mac1)

The sliding door tracks are integrated into the body structure. The curved profile results in a significant impingement into the body structure as shown in Figure 6.3.5.1.3. This requirement may lead to a degradation to overall structural performance and may compromise side crash performance where the strength of the rocker and cantrail are important. The package for the lower rail is likely to encroach into the battery pack, reducing effective volume and compromising structural integrity.



Lower rail, encroaching into rocker space

Figure 6.3.5.1.3 Ford B-Max BIW, showing lower sliding door rail position encroaching on rocker and floor (image from a2mac1)

A concept design study was undertaken to develop a track and rail sliding door concept for the SEM1 vehicle. Given the size of the door aperture and the overall length of the vehicle, it was not possible to package a split (2 doors) arrangement due to insufficient space for the

mid track front. A single door sliding to the rear of the vehicle was therefore configured as shown in Figure 6.3.5.1.3.

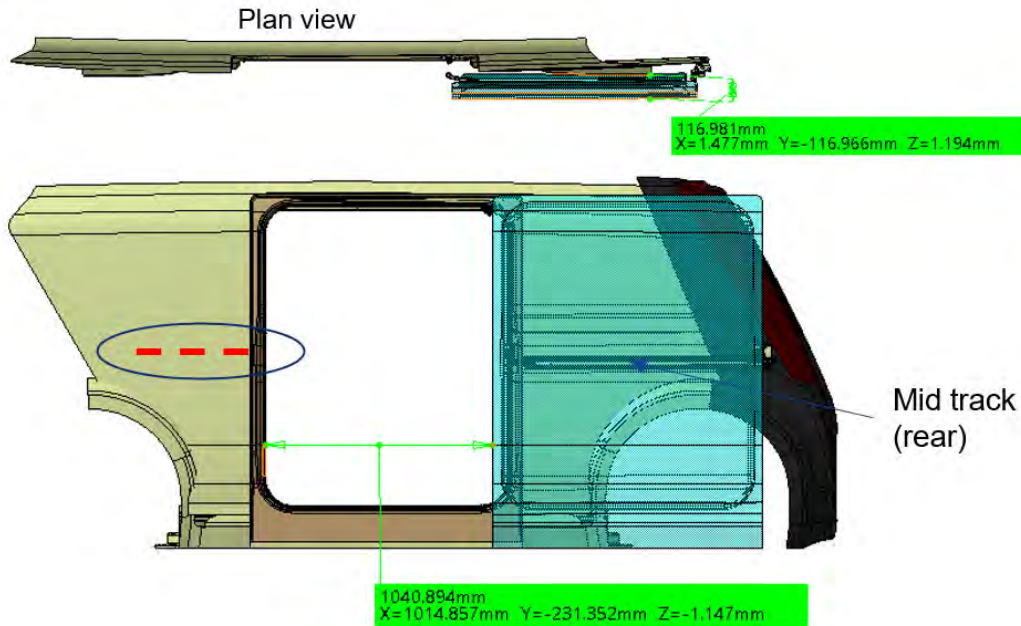


Figure 6.3.5.1.3 SEM1 track and rail sliding door concept study.

The design of the upper and lower door tracks investigated the impact on the rocker and battery compartment. A significant encroachment of the rocker and its crash structure was required to accommodate the lower track. The battery compartment package was also impacted as shown in Figure 6.3.5.1.4.

Design studies attempted to develop countermeasures, however FEA analyses predicted a significant degradation in the side pole crash performance with the sliding door track arrangement.

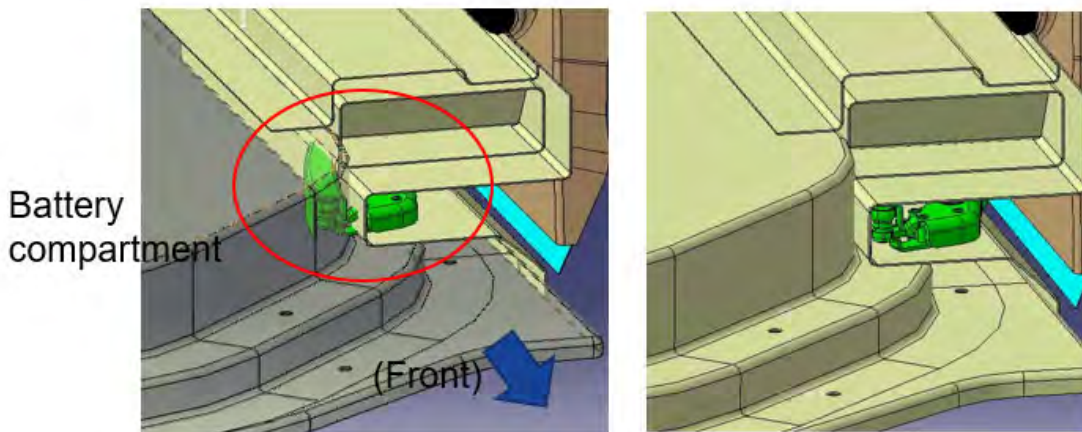
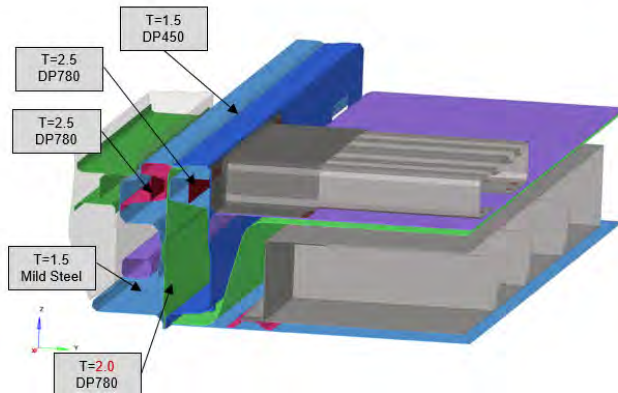


Figure 6.3.5.1.4, battery compartment package clash with sliding door lower track



| Metric | CAE Target | Status |
|----------------------|------------|----------|
| Rebound | - | 29ms |
| Pole Force | - | 718kN |
| Floor crush | < 25mm | 40mm |
| Sill energy | > 80% | 46kJ |
| Ratio | | 77% |
| Sill mass per length | < 18kg/m | 21.9kg/m |

Figure 6.3.5.1.5 Section in X showing left side rocker, sliding door incorporating lower track. Degradation in structural performance due to packaging of lower track in the rocker

6.3.5.2 Scissor hinge sliding door

“Outward swing door mechanism” (referred to as scissor door mechanism in the Steel E-Motive project) are commonly found on bus and coach vehicles, an example shown below in Figure 6.3.5.2.1

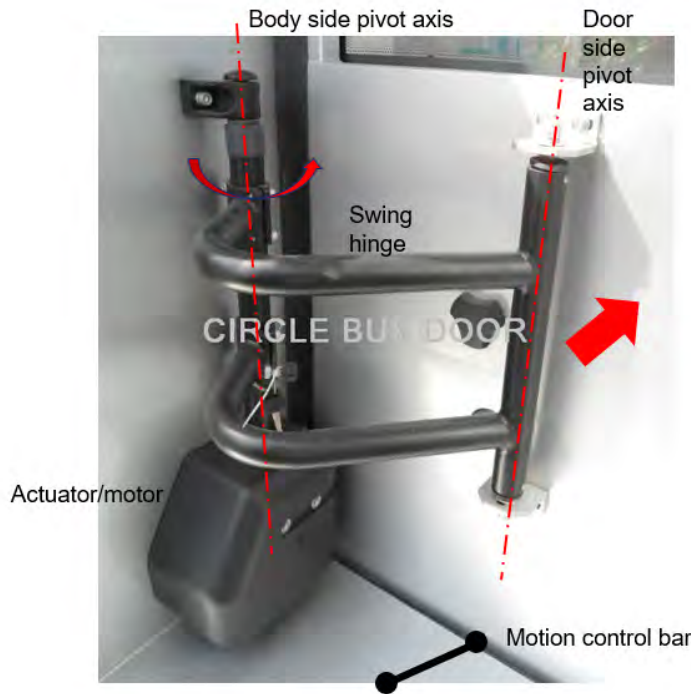


Figure 6.3.5.2.1. Example of scissor (outward swing door mechanism). Image source <http://www.circlebusdoor.com/products/eom100-electric-outswing-bus-door-mechanism-for-bus-and-vehicle/>

The actuator provides an input torque to the body side pivot bar, rotating the bar through approximately 120degrees. The resultant moment pushes (swings) the door initially outwards away from the door aperture then longitudinally along the length of the vehicle to

provide the opening. A motion control bar constrains the rotational motion of the door around the door pivot axis and guides the door as it opens. The challenges with the scissor door mechanism are the higher distance in lateral offset (or kerbside encroachment) when the door is opened compared to track and rail. The hinge and actuator can be significant in size and encroach on occupant space and the moving parts are a potential injury risk. The hinge on the door side is mounted to the centre of the door structure so some structure is required to support the door side hinge brackets. Preliminary concepts were developed for Steel E-Motive as shown in Figure 6.3.5.2.2.

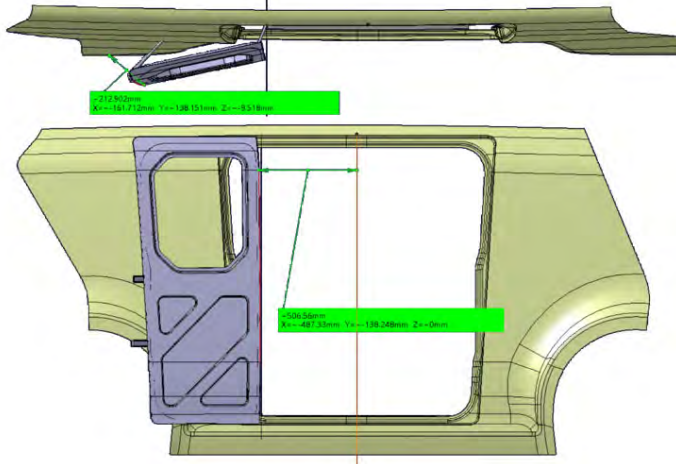


Figure 6.3.5.2.2 Scissor door, preliminary Steel E-Motive concept

The study showed that the hinge and door could be design and packaged effectively and the curb encroachment distance in the open position calculated at 250mm (versus 117mm on the track and rail concept).

During Phase 1, the body structure concept was modified to incorporate inclined A and C pillars which were moved forwards (A) and rearwards (C) in order to improve the loadpath distribution.

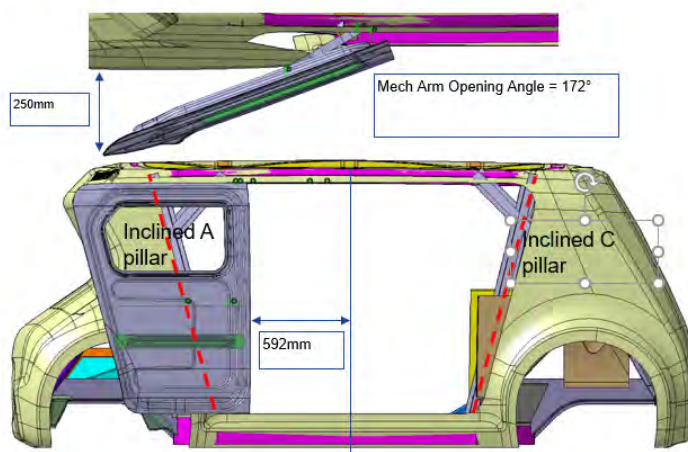


Figure 6.3.5.2.3 Door aperture width increase a door design change

The door aperture increased from 1012mm to 1184mm. The curb side encroachment increased from 138mm to 250mm. The track and rail and scissor door concept then underwent evaluation and concept selection as described below in Section 6.3.5.3

6.3.5.3 Evaluation and selection of sliding door concept

The MoSCoW prioritisation process was used to assist the selection of one sliding door concept to progress and develop in Phase 2. The key criteria identified for the side closures were:

- Mechanical package. The space and encroachment challenges imposed by the door structure, hinge, actuators, and tracks
- Kerbside ingress. This maximum lateral distance that the door opens by, encroaching on to the kerbside
- Opening aperture. The minimum effective distance between the doors when fully open
- Weight. Weight of complete door system, including body side components
- Cost. (note, no specific cost evaluation was done at this stage)
- Glazing. The potential to feature a reasonable sized glazed area on the doors
- Side crash. The challenge or additional risk imposed on side crashworthiness performance by the door design
- Front crash. The challenge or additional risk imposed on front crashworthiness performance by the door design

The MoSCoW evaluation is shown in Figure 6.3.5.3.1. This concluded that the scissor door mechanism posed the least integration challenges compared to the track and rail concept. The higher curb side encroachment in the scissor door design was deemed to be acceptable. The scissor door concept was selected as the primary concept for further development and refinement in Phase 2.

| | Meets requirement | Scissor | Sliding (track and rail) |
|--|-----------------------------------|---|--|
| M | Meets requirement | | |
| S | | | |
| C | | | |
| W | Not recommended | | |
| M | Mechanical Package | Mech arm and motor can be well packaged. Fixed upper pivot arm easy to package | 3 sliding rails provide a lot of packaging challenges taking up a lot of space |
| S | Kerbside Ingress (Minimal) | Currently ~212mm at open kerbside ingress but can be tuned - 312mm during sweep | |
| M | Opening Aperture >1000 | ~1184mm (with detail will be approx. 1050/1100mm) | 827mm - overlap of aperture with Dorito door shape |
| M | Mass (Estimate) | TBC, was 20.4kg/side on Incremental | Was 31.7kg on Incremental, likely to be heavier |
| M | Cost (\$0.00) | Not assessed | |
| C | Glazing | | |
| M | Side Crash | Door structure can be utilised to help side crash (virtual b-pillar) | Door structure available but slider detrimental to rocker |
| S | Front Crash | Waistrail tertiary path possible (not assessed) | Waistrail tertiary path possible (not assessed) |
| Conclusion for SEM1 application | | | |

6.3.5.3 Rear tailgate concept development

The rear closure or tailgate enables access to the rear luggage compartment and forms the rear exterior surface of the vehicle. The tailgate aperture should be sufficient to enable everyday items such as luggage and shopping to be safely stowed. No specific rear closure concept designs were generated in Phase 0. Six concepts were generated within Phase 1 as shown below in Figure 6.3.5.3.1

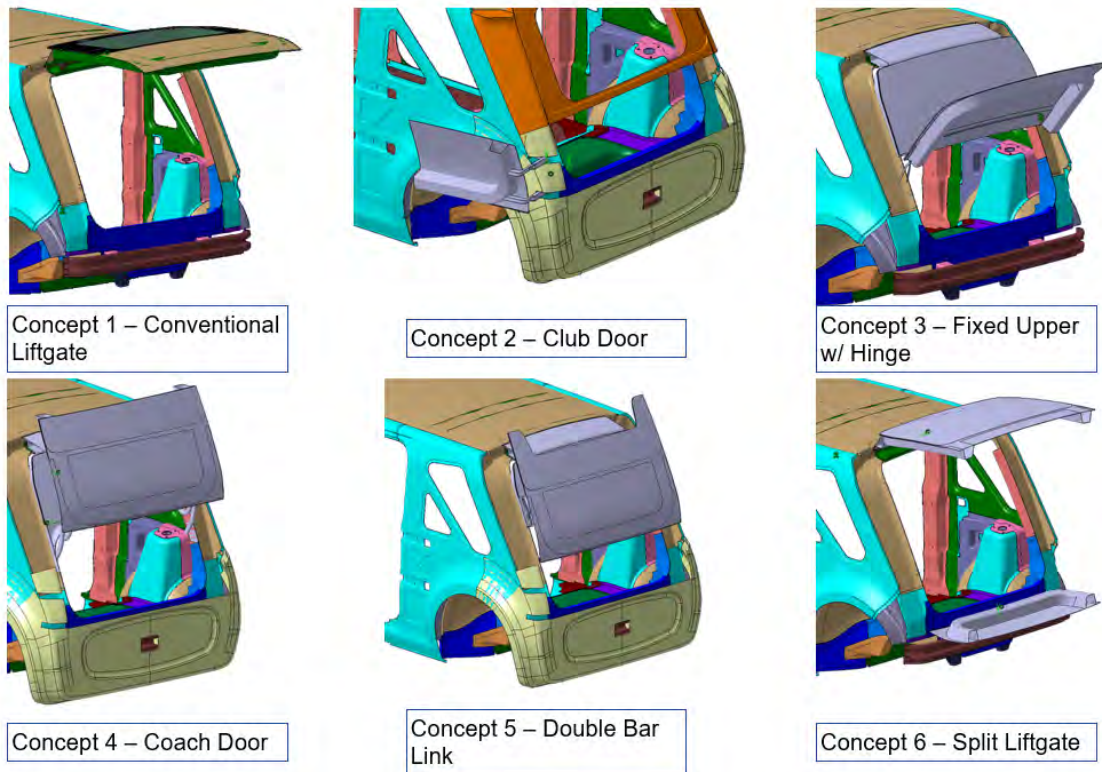


Figure 6.3.5.3.1 Rear tailgate concept designs for SEM1

Concept 1 was based on a conventional liftgate as seen on estate and SUV style passenger cars. The door is mounted to the body via hinges (usually two) mounted to the rear header rail of the body. Gas struts provide assisted opening and powered mechanism are common also. Club door (concept 2) features single or twin doors, hinged on the rear D pillar. Whilst unique in style, the rearward swing motion encroaches on the rear of the vehicle and could be challenging for taxi like operations. Operation of these doors is challenging if the hinges are not oriented vertically. Concept 3 is similar to Concept 1 liftgate, but the upper portion of the closure is fixed (glazing) with just the lower half of the door able to open. Concept 4 coach door is based on a design commonly found on the underside stowage compartments of large coach vehicles. Hinges are mounted on the rear D pillars and a parallelogram hinge mechanism results in a vertical and upward motion of the door with reduced rear encroachment. Concept 5 features a D pillar mounted twin link bar mechanism, similar to concept 4, resulting in a more vertical door motion but with reduced door aperture. Concept 6 is a split rear tailgate, seen on some Sport Utility Vehicles. It provides a large aperture but the drop of the rear liftgate can give challenges when loading and unloading. Given the number of concept design, a descriptive concept selection matrix was devised and populated as shown in Figure 6.3.5.3.2.

| Attribute | BASELINE | | | | SELECTED | | | |
|---|---|--|---|--|--|---|---|---|
| | Concept 1 – Conventional Liftgate | Concept 2 – Club Door | Concept 3.1 – Half Liftgate with Exposed Hinge | Concept 3.3 – Half Liftgate with Flat 500 Hinge | Concept 4.1 – Coach Door | Concept 4.5 – Coach Door Revision | Concept 5 – Double Link Hinge | Concept 6 – Split Liftgate |
| Tailgate Opening (mm) | 1431 | 440 | 440 | 610 | 688 | 690 | 462 | 1431 |
| Interior Intrusion | N/A | N/A | N/A | N/A | 235mm (x) from back of closest passenger | Crank of looped arms currently sits 352mm (x) from back of closest passenger | N/A | N/A |
| Mechanical Package | Simple hinge design with powered strut mounted to BIW | Connecting arm must be exposed to allow for secondary hinge axis to be outside the vehicle Requires A-Surface to move | Hinges must be exposed to allow for correct sweep that doesn't clash with glazing | Full hinge assembly with base/door plates packages well into BIW | Large connecting arms difficult to package Hinge axis can be changed to allow for more efficient package and eliminate some current clashes | Needs consideration for driving mechanism (Stabilus Powerise or motor) Connecting arms package more efficiently than previous concept 4.1 due to reduced crank throw | Concept needs to be further developed to efficiently package hinge design without BIW clashes | Concept needs to be further developed to efficiently package hinge design without BIW clashes |
| Kerbside Ingress (mm) | N/A | 635 | N/A | N/A | N/A | N/A | N/A | N/A |
| Vehicle Height Impact (m) | 1.99 (+0.11) | N/A | N/A | N/A | 2.03 (+0.15) | 2.03 (+0.15) | 1.98 (+0.10) | 2.02 (+0.14) |
| Rear Overhang (mm) | 646 | 695 | 363 | 447 | 185 | 197 | 113 | 296 |
| Overhang at Open Position (mm) (measured from bumper A-Surface) | 653 | -114 | / | 258* | / | -66 | -40 | 296 |
| Fixed Glazing | N | Y | Y | Y | Y | Y | Y | N |
| Rear Box Section Potential (global stiffness contribution) | N | Y | Y | Y | Y | Y | Y | N |
| Door Panel Mass Estimate (kg) | 10.62 | 7.47 | / | 10.6 | / | 11.8 | 10.6 | 10.2 |
| Cost Estimate | WIP | | | | | | | |

Figure 6.3.5.3.2 Rear closures concept selection matrix (See Appendix 4 for larger image)

The study concluded that Concept 4 coach door provided the best solution for Steel E-Motive vehicles. The hinge mechanism enables reasonable opening aperture and has lower rear encroachment. This helps when operating in confined areas, for example, when the vehicles are queued in a taxi rank or at an airport. Concept 4 coach door was selected for further development and refinement in Phase 2.

6.3.6 Front crashworthiness challenges and strategy

6.3.6.1 Introduction and background to front crashworthiness challenge

One of the most significant challenges encountered during the engineering development of the Steel E-Motive concepts was the achieving front crashworthiness performance. The front crash loadcases and targets are described in Section 4.2.3. One particular challenge was achieving a solution that balanced the conflicting requirements of the USNCAP 56kph full width rigid barrier (FFB) and the IIHS 64kph small overlap rigid barrier (SORB). The FFB test requires a crush zone engineered to decelerate the vehicle progressively and controllably, with minimum deceleration pulse. Crush intrusion into the occupant compartment should also be minimised and be within the targets. Conversely, the SORB test requires a significant amount of strength in the front crash structure. With the 25% front barrier overlap and higher impact velocity, the front crash structure needs to “work” much harder to manage the energy and prevent intrusion. A higher strength structure is required to manage the crash loads in the SORB test, but this is too stiff and strong for the FFB test. This results in high deceleration pulse in FFB as a smaller crush length is used. Essentially the front crash structure needs to be engineered for two quite different requirements. Due to the higher impact speed and small overlap, the SORB test encompasses more of the vehicle than the FFB test. The front suspension, wheels and tyres, rocker and front door structures are all impacted by the crash event and the design of these components and system contribute to crashworthiness performance in SORB. Because of this, a more comprehensive FEA model

was required. Therefore, a complete understanding of the SORB performance and challenges was not possible until mid-way through engineering Phase 1, where the design of the components and systems were sufficiently mature for a representative FEA could be constructed. The front crashworthiness challenge was further compounded by the overall size and compactness of Steel E-Motive – with a short frontend and overhang distance, there is less “metal” to absorb the crush energy. The package space in the front motor compartment is generally more compact, resulting in systems such as the EDU contributing or disrupting the crash structure behaviour.

6.3.6.2 Desktop benchmarking of front crash strategies

The USNCAP 64kph FFB test is well established and the strategies and solutions for achieving performance are well understood. It was established early in Phase 0 and 1 that SEM1 could be engineered to meet the crashworthiness targets for this test by engineering of front longitudinal crush members and rigidly mounted front subframe. The IIHS SORB test was introduced in 2012 and as this is a US specific consumer focussed assessment, IIHS evaluations are typically carried on larger sized vehicles where the sales volumes of smaller compact vehicles (e.g., European A, B, C sized vehicles) are lower compared to D, E segment, SUVs, and pickup trucks. The IIHS publish results from crash tests on their website (<https://www.iihs.org/>), with more detailed test data made available through their “techdata” portal, requiring a specific account and login. The smallest sized vehicles evaluated by IIHS at the time of the Steel E-Motive project were the BMW i3 and Volvo XC40 recharge (both with hybrid electric powertrain). Both vehicles achieved the highest “good” rating for the SORB and the moderate overlap deformable barrier test. Figure 6.3.6.2.1 shows a still image from the Volvo XC40 test. The video for the test can be viewed at <https://www.iihs.org/ratings/vehicle/volvo/xc40-recharge-4-door-suv/2022>



Figure 6.3.6.2.1 Volvo XC40 Recharge (2021MY) IIHS 64kph frontal small overlap test

The animation shows that as the vehicle strikes the barrier, it is deflected laterally, such that by the time the barrier reaches the hinge pillar (as in the still image), the vehicle has moved laterally such that there is reduced contact and impact with the barrier. The vehicle continues with a reasonable onward velocity. The vehicle is said to “glance” off the SORB barrier, resulting in less vehicle kinetic (moving) energy being converted to crush energy, therefore resulting in lower vehicle deceleration levels, lower crush forces in the front structure and lower intrusion levels. Further evaluation of the numerical test data showed

very low cabin intrusion levels and low dummy injury forces. Overall, the XC40 demonstrated a clear (“glance off”) strategy for management of the SORB test. Other observations showed that the front wheel completely detached shortly after impact. It is possible that the front suspension was engineered to fail in this way, such that wheel does not provide a loadpath into the rocker and inhibits the “glance off” motion.

A similar evaluation of the Mazda CX-30 was performed. Again, this vehicle achieved “good” performance for both IIHS front crash tests. Figure 6.3.6.2.2 shows an image from the crash test and the full animations can be seen via the link <https://www.iihs.org/ratings/vehicle/Mazda/cx-30-4-door-suv/2020> .

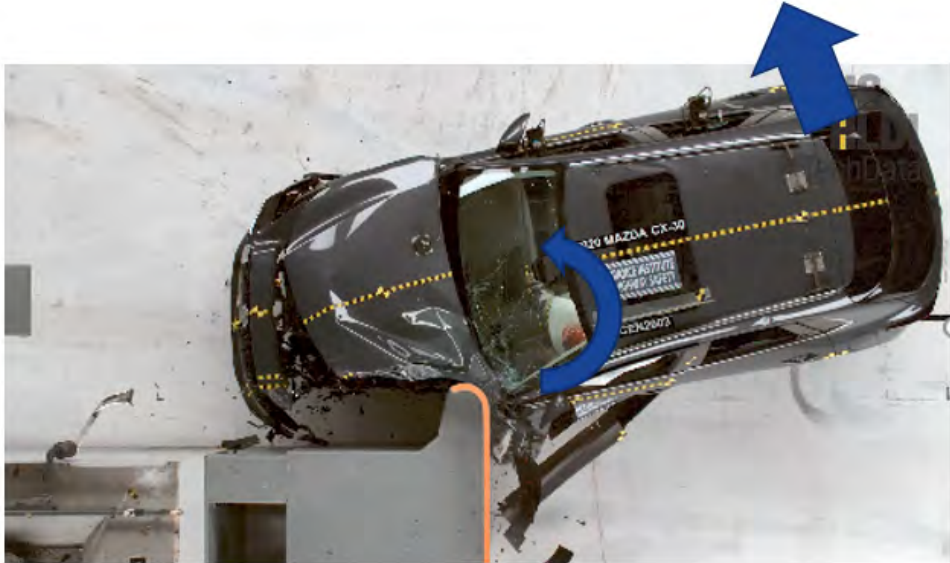


Figure 6.3.6.2.2 Mazda CX-30 2020MY, IIHS small overlap test

Here, the forward motion of the vehicle is seen to stop, with some of the kinetic energy converted to a rotational (yaw) movement. Instead of “glancing” off the barrier, the vehicle is observed to crush then “snag” at the hinge pillar. Further analysis of the test data showed the Mazda CX-30 had slightly higher measured vehicle pulse, cabin intrusions and crash test dummy forces. It can be concluded that achieving a “glance off” in SORB may tend to achieve improved crashworthiness performance than a vehicle with a “snag” (note, both vehicles achieve IIHS “good” and “Top Safety Pick” ratings from IIHS. The Safety Restraint System including seat belts and air bags may also contribute to the different performance of the vehicles).

The findings from this benchmarking study were applied and considered for the Steel E-Motive concept compared to a conventional passenger car (“B”) as shown in Figure 6.3.6.3.1.

6.3.6.3 Development of front crashworthiness strategy for Steel E-Motive

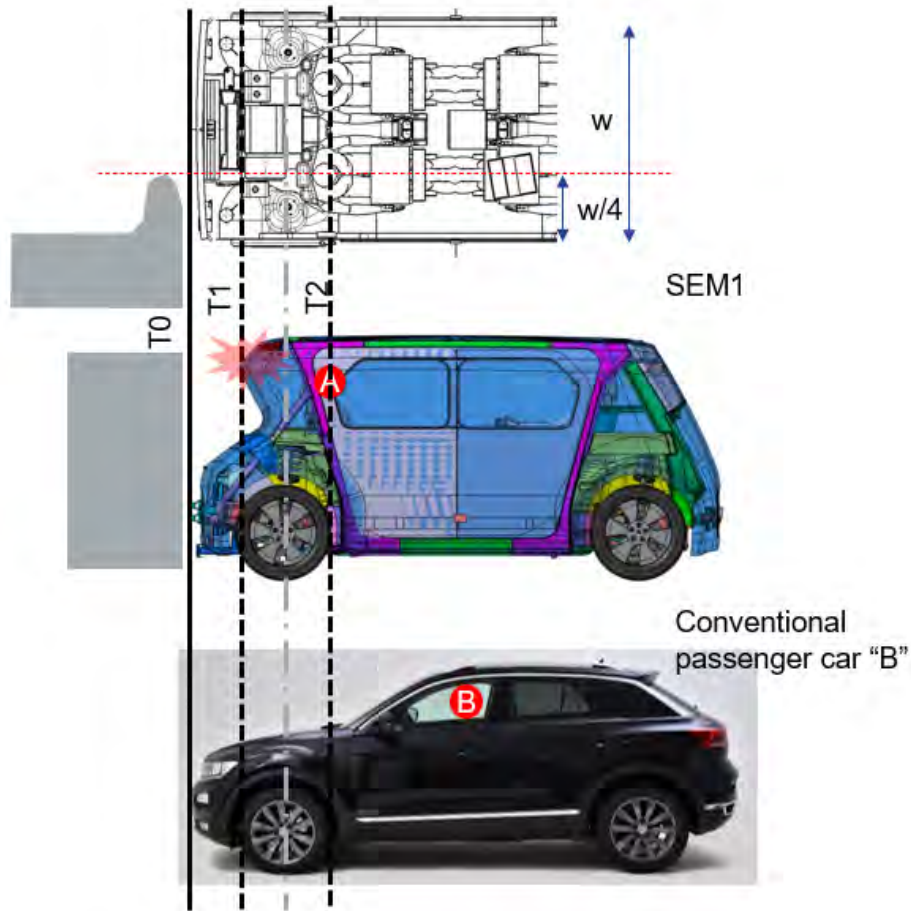


Figure 6.3.6.2.2 Comparison of IIHS SORB crash event for SEM1 compared to a conventional passenger car

The relative positions of the occupant (heads) are shown as positions A and B. For the passenger car B, the SORB crash event is largely completed by the time the vehicle reaches T2. With the front occupant of SEM1 being closer to the crash event, a more comprehensive approach to the management of the loads and protection of the occupant would be required. A strategic decision was made to target a “glance off” crash mode for SEM1 in the SORB test. The justification for this being that a “glance off” results in reduced crush energy for the crash structure to manage, therefore protection of the occupant in a more vulnerable location would be less of a challenge than adopting the “snag” approach.

The strategy for management of the SORB crash event is shown in Figure 6.3.6.2.4.

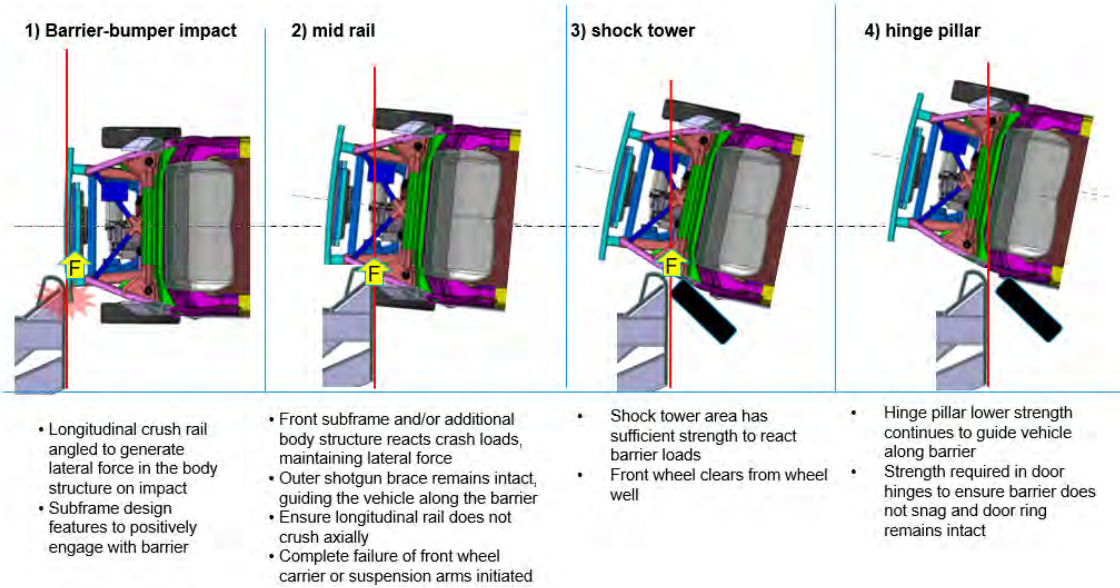


Figure 6.3.6.2.4 SEM1 IHS 64kph SORB front crash strategy (See Appendix 4 for larger image)

On initial impact, the body structure needs to react with the SORB barrier such that a lateral load is generated. Positioning the longitudinal crush rails with a positive plan view angle towards the barrier should develop a lateral force component. The longitudinal rail should maintain overall shape (i.e., not crush axially). The front subframe could also feature extensions forward, positively engaging with the SORB barrier. The front bumper beam could be engineered such that it bends on impact, enabling a lateral force component to be generated. An additional brace between the front crash rails and/or front subframe would also strengthen the front end and ensure higher lateral load reaction. As the barrier reaches the middle of the motor compartment, there is less structure to react the barrier loads. (This is the collapsible crush zone for management of the FFB energy). A high strength structure is therefore required on the outside of the motor compartment to maintain the interface with the barrier, ensuring the vehicle “slides” or “glances”. The SORB barrier needs to be aligned appropriately (outside) before reaching the shock tower. If the barrier is inboard of the shock tower then a “snag” may occur. The shock tower structure has the potential to provide a good level of lateral load reaction to the barrier loads and provide high lateral acceleration and displacement. With this zone being very high strength and appropriately designed, the barrier should remain outside of the shock tower, continuing the glance motion of the vehicle. As the barrier reaches the hinge pillar, and rocker, high strength structure is required such that the cabin structural integrity is maintained, and intrusion levels are minimised. The side door structure and hinges require sufficient strength such that the SORB barrier does not become lodged into the door front edge.

Considering the above strategy for the SORB test and the crush requirements for the FFB test, the following design approach was proposed for the SEM1 front structure.

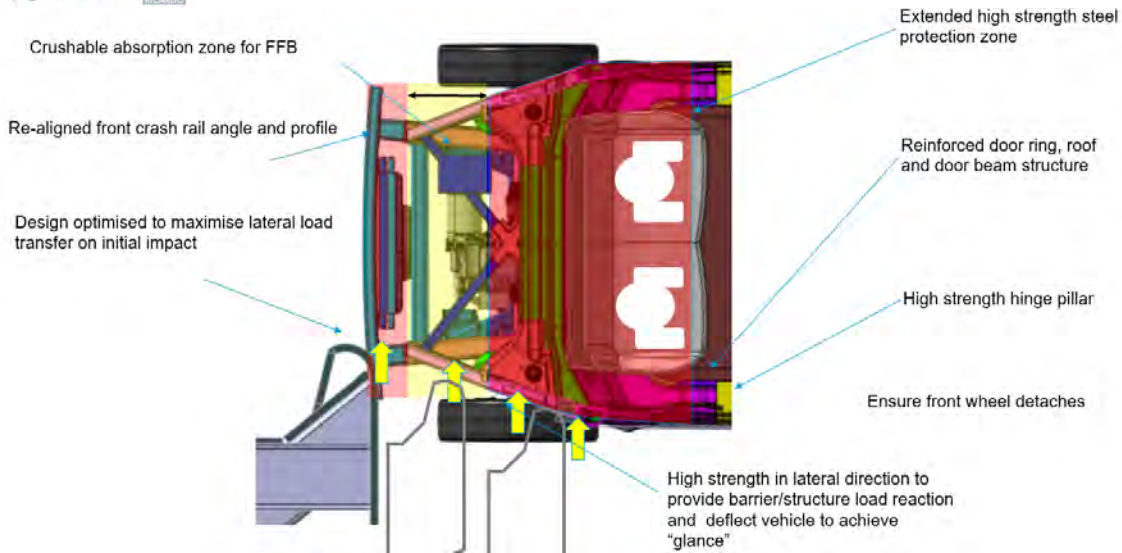


Figure 6.3.6.2.5 Front crash structure design approach for achieving USNCAP FFB and IIHS SORB with “glance off” strategy

The front crash structure is divided into 3 zones. The front zone is engineered to allow longitudinal crush for low speed and FFB impact requirements but must have very high lateral strength for the SORB test. The front zone should be engineered such that very high lateral reaction forces are generated on initial impact. The middle zone (yellow) is protected for FFB. The mid-zone structure must have the freedom to crush axially, absorbing the vehicle kinetic energy with highest efficiency possible, resulting in progressive deceleration. The motor compartment package should ensure that no “stack up” of large components such as the EDU occur in this zone. To maintain the glance motion in the SORB test, an outer lateral structure maintains engagement with the barrier, guiding the vehicle along the desired trajectory. The beam must maintain structural integrity whilst not interfering with the crush requirements in FFB. The rear zone (red) is an extended high-strength passenger safety cell. The zone should begin in front of the shock tower and extending rearwards as required (for side crash also). The objective of the protection zone is to minimise intrusion to the cabin and battery compartment. The front wheel should be engineered to detach during the front crash event and exit the wheel compartment.

6.3.6.4 Development of SEM1 front crash structure, resolving FFB and SORB conflict

Given the strategy and design approach defined above, a simulation led development activity was undertaken to develop the SEM1 vehicle front crash structure. The full vehicle crash FEA model was updated to represent the latest design. Many crash FEA iterations were performed, evaluating the key parameters shown in Figure 6.3.6.4.1 below

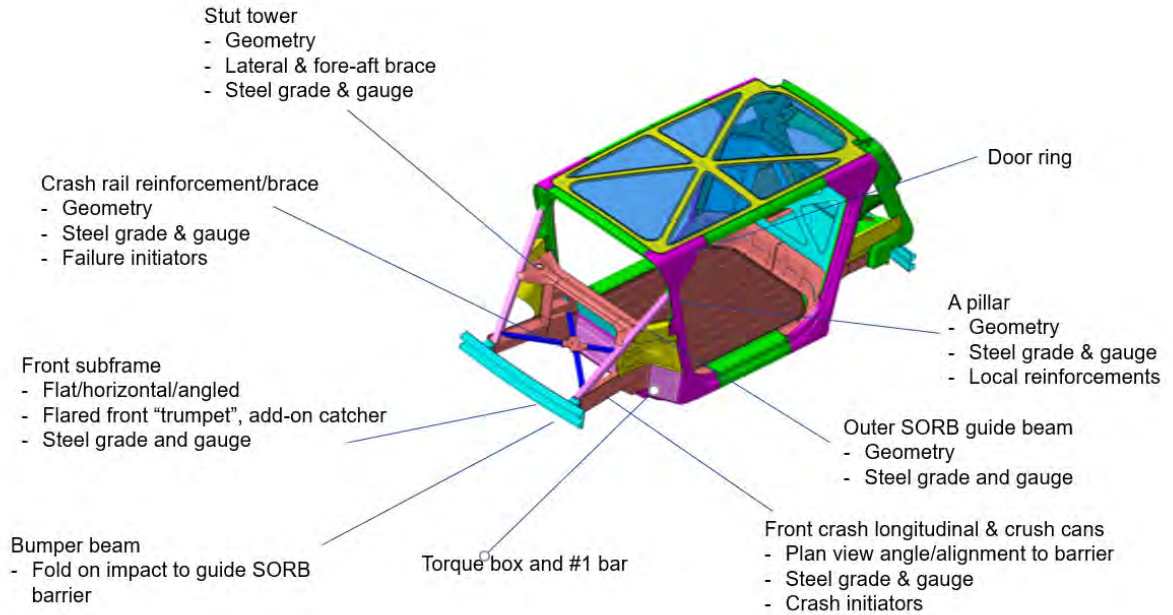
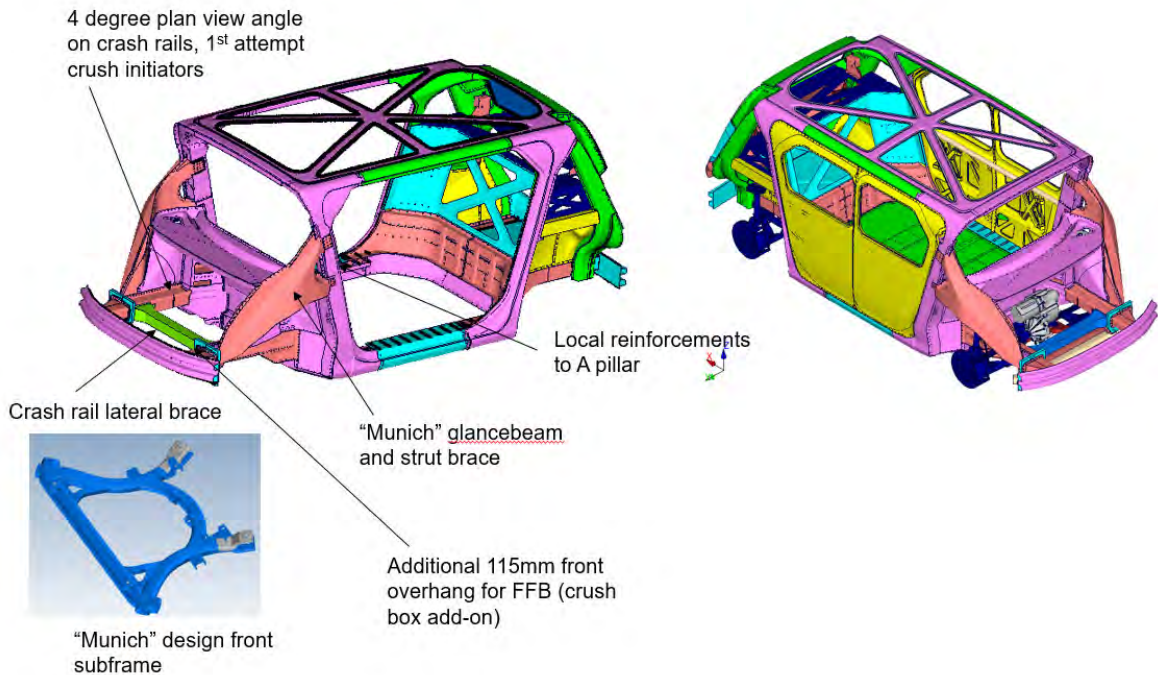
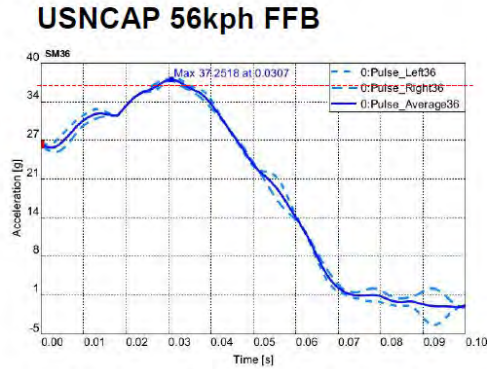


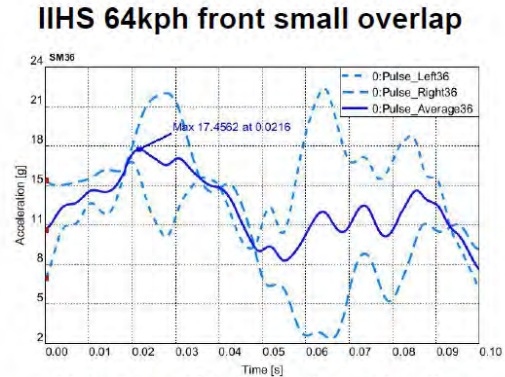
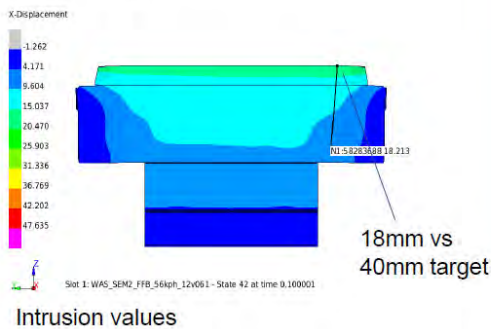
Figure 6.3.6.4.1 summary of design iterations considered in the front crashworthiness development

Figure 6.3.6.4.2 shows the final Phase 1 design of SEM1 BIW





vehicle pulse at B pillar equivalent location, target <35g



vehicle pulse at B pillar equivalent location (<35g target)

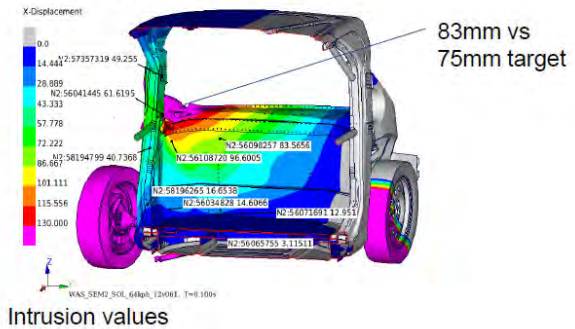


Figure 6.3.6.4.3 front crash FEA results of Phase 1 final design concept

The results show that because of the front crash strategy and design philosophy, the crashworthiness of the Phase 1 SEM1 design was within 10% of the overall performance targets. This was evaluated in the Phase 1 <CS> gateway and accepted as positive indication that the design could achieve 100% target with further engineering development.

6.3.6.5 Considerations for the protection of rear facing front occupants in frontal collision

Positioning the front occupants in a rear facing configuration benefits the spacious and openness feeling of the vehicle interior and takes advantage of the freedoms enabled by fully autonomous driving. The front occupants are however located in a more challenging location with respect to protection from frontal collisions. Compared to a conventional passenger car, the occupant head and torso is located closer to the impact zone, where intrusions of the front structure may impact the occupants causing injuries. The occupant legs and feet are further from the front impact zone and may be subject to a lower injury risk. In a frontal impact, forward facing occupants are decelerated by the safety restrain system, namely the seat belts and air bags. The forces exerted on the occupants from seat belts and air bags can lead to serious injuries to the torso legs and arms. For rear facing occupants in a frontal collision, primary deceleration of the occupant is provided by contact forces between the torso and legs. With a greater contact area than seat belts, the deceleration forces are more distributed over the torso hence injuries may be lower for a rear facing occupant. The risk of neck injury or whiplash is significant in this configuration due to the potential for differential motion and deceleration of the occupant torso and head.

The frontal collision for a rear facing front occupant is equivalent to a forward-facing passenger experiencing a rear impact. The protection of forward-facing occupants in a rear collision is well understood, with regulations, tests and guidelines in place for the seat and headrest design. However, the impact speeds and deceleration levels for a frontal collision are typically higher than a rear collision. The seating structure and headrest design for a rear facing front occupant configuration must therefore be engineered to consider the higher impact loads from frontal impact. The headrest requires particular attention to minimise the risk of whiplash. Advantage could be taken of the autonomous functionality of Steel E-Motive by inhibiting movement of the vehicle if occupants are not seated appropriately. Also, the variability in the sizes of occupants should be accounted for in MaaS (taxi) vehicles. Automatically adjusting headrests could be employed to minimise whiplash injury risks. The specific engineering of the seating structure and restraints systems was not considered within the Steel E-Motive programme, however, consideration for the space and packaging for the front seat structure was provisioned for. The frontal impact crashworthiness targets were also adjusted to account for the rear facing front occupant. The consideration and approach for the rear facing front occupants is summarised in Figure 6.3.6.5.1

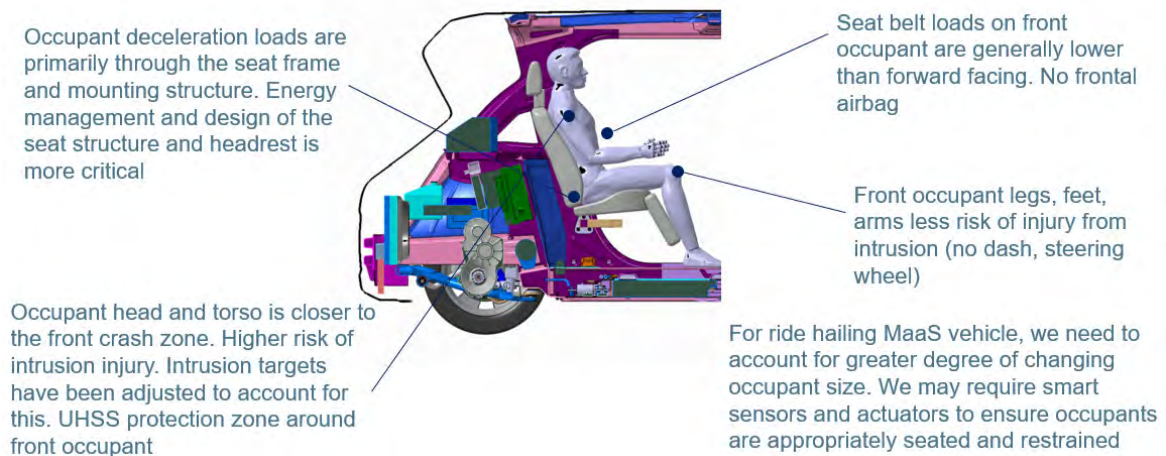


Figure 6.3.6.5.1 Considerations and approach for protection of the rear facing front occupants in a frontal collision (See Appendix 4 for larger image)

6.4 Technical Approach, Phase 2

6.4.1 Phase 2 objectives and approach

The objectives of Phase 2 of the Steel E-Motive programme were to optimise and refine the Phase 1 vehicle and body structure design such that all the performance targets and requirements were achieved. This included ensuring the designs are suitable for manufacturing (e.g., stamping, roll forming, press hardening), body assembly process (including joining methods such as spotwelding, laser welding) and complete vehicle assembly. The complete steel grade portfolio was utilised and applied in the design as well as all the fabrication processes as detailed in Section 5.0.

The combined approach of applying 3D CAD and FEA tools to drive the design continued, with more refined levels of modelling and optimisation applied.

Technical review gateways were held throughout Phase 2 to track the progress and progression towards 100% target achievement. An interim gateway was held midway

through Phase 2 (2A), then 2 “countdown” gateways (CD-2, CD-1) were held in the lead up to the final technical gateway CD (“concept definition”).

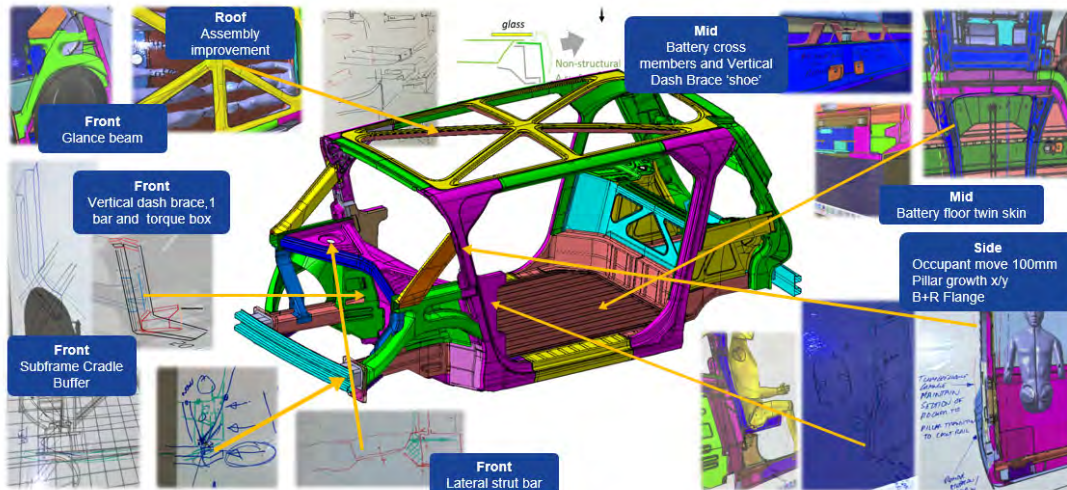
At this stage of the project, the covid-19 pandemic restrictions had been lifted in many regions and the project benefitted significantly from several collaborative, face-to-face technical workshop events.

6.4.2 Technical Design Workshop

The first activity undertaken in Phase 2 was an in person, 1-week technical design review workshop. The objectives of the workshop were to:

- Critique the Phase 1 SEM1 body design
- Review the performance results
- Brainstorm design improvement suggestions
- Consider the application of steel grades and fabrication processes from the complete portfolio
- Consider the panel fabrication, body assembly and vehicle assembly requirements and consider these in the design brainstorming
- Develop a CAD “design brief”, giving clear instructions to the 3D CAD teams to initiate the development of the Phase 2 concept

The workshop was attended by the programme technical lead team. The workshop was structured into “deep dive” technical reviews by body zone (i.e., front zone, mid zone, rear zone). Ideas were developed and captured mainly through 2D sketches, whiteboard notes and then documented in MS Excel. Figures 6.4.2.1 show some examples of the output from the workshop.



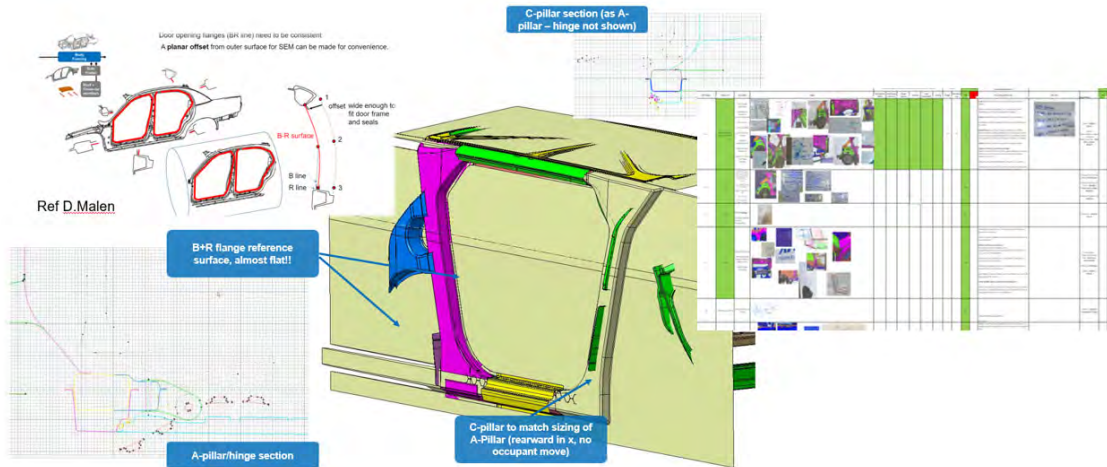


Figure 6.4.2.1 Example outputs for the technical design workshop

Following the design workshop, the 3D CAD and FEA models were created, and structural performance of the body evaluated. The results demonstrated a continued progression towards target achievement. Further design iterations were performed, primarily focussed on optimising the front crash structure and integration of the closures and battery design, which were maturing in parallel with the body concept.

6.4.3 Materials application technical workshop

The WorldAutoSteel consortium features a rich pool of knowledge and experience in the automotive application of Advanced High-Strength Steels, steel manufacturing, steel fabrication, joining and vehicle production & assembly. To canvass this knowledge and enable a democratic approach and selection of steel technologies to the Steel E-Motive concept, a three-day, face-to-face collaborative workshop was held in Los Angeles, mid-way through Phase 2. The objectives of the workshop were:

- Review the project-based steel grade portfolio (Section 5.0) and agree on global grade availability and specification
- Review the Steel E-Motive concept design and identify suitable and optimum steel grades for given subassemblies
- Identify moderate design changes that would enable potential performance improvements
- Explore opportunities to push the boundaries of current steel technologies and their application

Figure 6.4.3.1 shows the overall approach applied during the workshop.

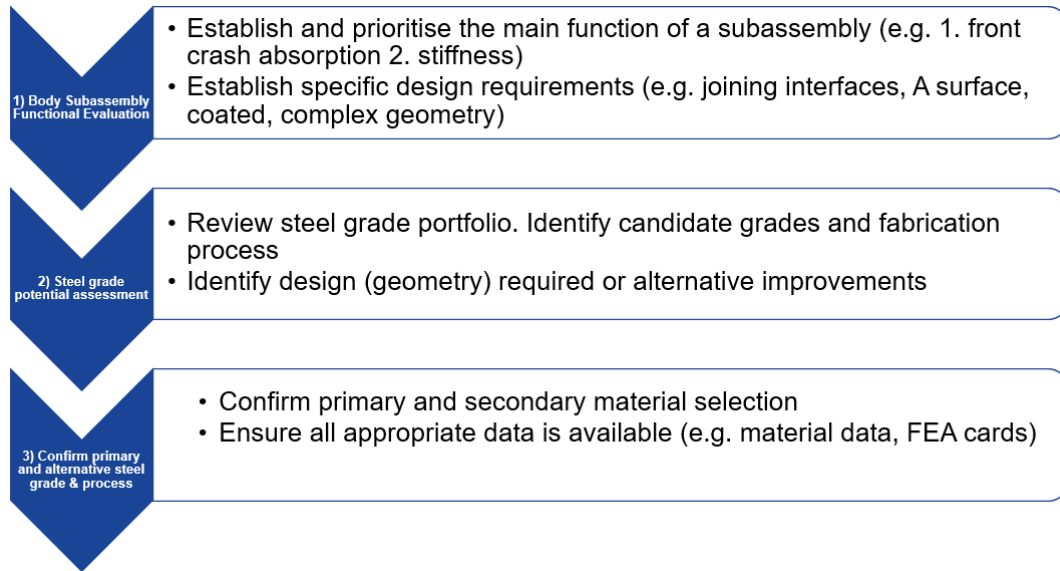


Figure 6.4.3.1 Approach for materials application technical workshop

The approach for the material grade selection was “function led” – meaning that the selection of steel grades and fabrication processes were driven primarily by the body components function and requirements (i.e., “what does the part need to do”). Other requirements such as complex geometries, joining and interfaces to other subassemblies, visible/A surface and corrosion resistant parts were identified and documented for each body subassembly (this was done in advance of the workshop). During the workshop, each subassembly was reviewed, and the functional requirements agreed. Opinions on the potential steel grades was then canvassed, with the pros and cons of each recommendation discussed. The overall vehicle design goals of comfort, safety, sustainability, and cost were considered throughout the discussion and selection. A final selected of “primary” steel grade and “alternative” (second choice) steel grade was then made and documented. In some cases, further discussion and debate was required where unconventional approaches were suggested, such as the application of very thin gauges (<0.7mm) and suitability of 3rd generation grades. The evaluations and recommendations for each subassembly were documented, as per the example shown in Figures 6.4.3.2 to 6.4.3.3

Functionality diagram - Glance Beam

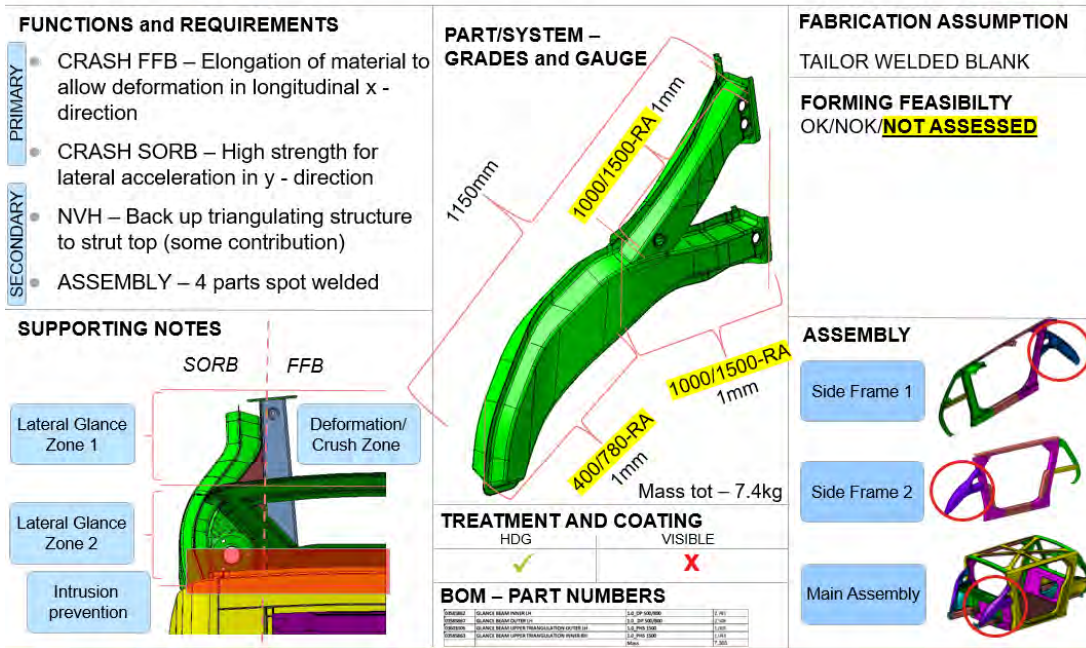


Figure 6.4.3.2 Material technologies workshop – example of subassembly functional evaluation

Glance Beam – Member feedback and discussion

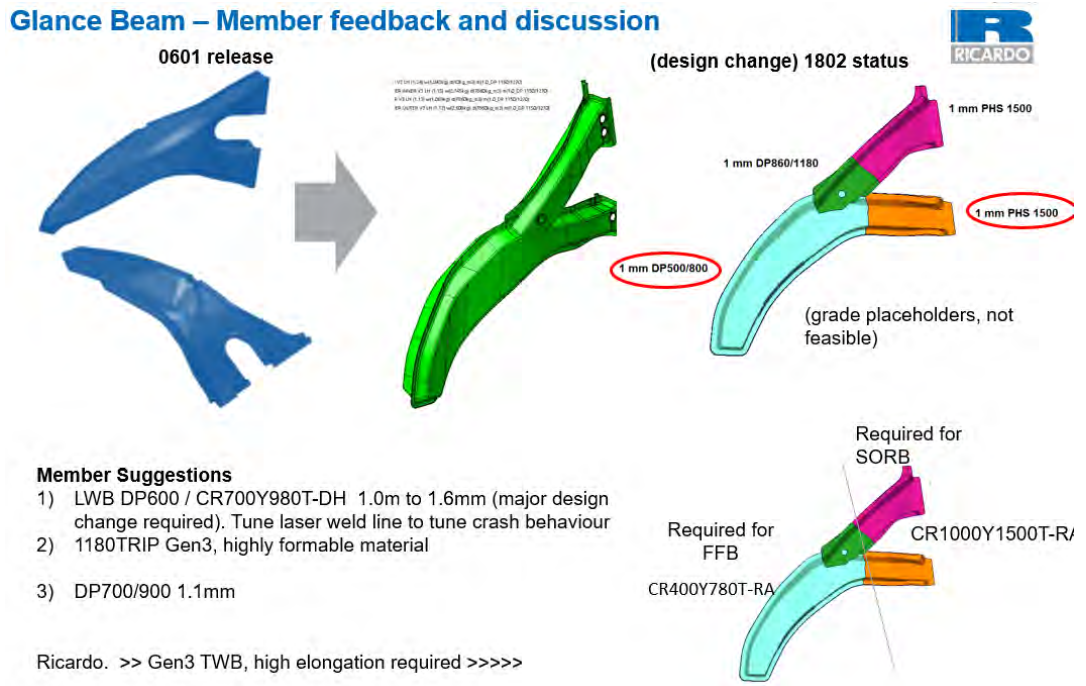


Figure 6.4.3.3 Materials technologies workshop – example of consortium members' feedback

Glance Beam – Final recommendation



Core design

Welding RA1500 to PHS?
MS grade to the interface
on the A Post for
weldability?

HSLA risk of cracking in
critical zone

Put the HSLA through the
hot form process



| Part | Fab'n process | Material Grade | Gauge (mm) | Coating/ Visible |
|-------|---------------|----------------|------------|------------------|
| Front | | TWB PHS500 | | |
| Rear | | TWB PHS1500 | | |
| Front | | HSLA780 | | |
| Rear | | PHS 1500 | | |

Alternative solutions

Ford Focus Benchmark –
DP800

Tailor tempering to soften
areas for folding up

1470-MS – challenge for
lower part

1300-MS



| Part | Fab'n process | Material Grade | Gauge (mm) | Coating/ Visible |
|-------|------------------|------------------|------------|------------------|
| | Hydroform | DP1000 | | |
| Front | | HSLA780 | | |
| Rear | | PHS 1500 | | |
| Front | | TWB PHS500 | | |
| Rear | | TWB PHS1500 | | |
| | Air Forming | MS Grade | | |
| | Split Lower in 2 | MS1300 or MS1470 | | |

Figure 6.4.3.3 Materials technologies workshop – confirmation of primary and alternative steel grade selection

The workshop successfully delivered a revised specification of steel grades and fabrication processes, that were subsequently used by the engineering teams to assess in CAD and FEA simulations. Further iterations and grade changes were assessed and implement throughout the remainder of Phase 2.

6.5 Engineering Tools

The following engineering tools and software were used throughout the Steel E-Motive engineering programme

| Activity / calculation | Software tool and version |
|---------------------------------------|---|
| 3D CAD design | Catia V5 |
| PLM data management | Windchill |
| FEA model creation | ANSA 21.1.3 |
| FEA linear statics (stiffness, NVH) | Nastran 2019.1 |
| FEA Non-linear (strength, durability) | LS-Dyna R11_1_0_x64 |
| FEA non-linear (crash simulation) | LS-Dyna R11_1_0_x64 |
| FEA structural topology optimisation | Optistruct 2019.2 |
| Lifecycle Analysis | MS Excel tool, originally created by University of California Santa Barbara |
| Body costing evaluation | MS Excel tool, originally created by Massachusetts Institute of Technology |
| Project management | Jira |

7.0 SEM1 final design

7.1 Vehicle design and key features

The Steel E-Motive vehicle design encompasses many innovative design features and approaches that deliver an autonomous Mobility as a Service vehicle of the future. These are summarised below and detailed in the subsequent sections of the report.

- The Steel E-Motive vehicle design embraces the features and potential of level 5 (full) autonomous driving. The direct driver controls such as steering wheel, pedals, turn indicators are completely removed enabling cabin space and weight saving. The design accommodates space for mounting of the autonomous driving sensors (such as radar and lidar). The front occupants are oriented in a rear facing configuration. To assist entry and egress from the vehicle, the body structure B pillar is removed from the body in white and placed into the side doors. The doors open in a sliding “scissor” action, enabling a wide opening (aperture). For the occupant, this means getting in and out of the vehicle much easier. The rear tailgate features a parallelogram life mechanism (or “coach door”). This minimises the outswing distance, enabling the vehicle to operate in a confined spaces
- The complete vehicle design has been engineered around the propulsion battery (see section 7.4). This results in a space optimised solution, where the battery occupies minimum space, resulting in more space and a flat floor in the cabin
- All four wheels are steered, resulting in a minimum steering circle radius of 7.4m. The vehicle can therefore achieve 180 degree “U turns” in tighter spaces, resulting in more convenient passenger access and journeys. Four-wheel steering also allows Steel E-Motive to “crab steer” when manoeuvring to curb side collections and drop offs
- The design and performance of the body structure delivers high levels of passenger comfort, convenience and safety. This achieved through a combination of innovate design approaches and features in the structure combined with the properties of Advanced High-Strength Steels
- Modular architecture, enabling smaller urban (SEM1) and extra-urban (SEM2) variants. Potential for commercial vehicle application such as light delivery van. Vehicle and body designed for high volume production using conventional, existing manufacturing facilities (see section 7.5)
- Efficient design and use of the latest Advanced High-Strength Steel grades and fabrication processes in the body structure results in a lightweight, cost-effective solution (see section 7.1.4 and 7.2.1)
- A combination of vehicle design features and operation in ride hailing MaaS demonstrates the potential to significantly reduce life cycle greenhouse gas emissions (LCA approach and results are detailed in Section 10)
- Features Steel E-Motive exterior lattice styling, reinforcing the emotion of the steel structure design and visionary vehicle of the future (See Section 10.0)

SAE Level 5 autonomous driving:

- Fully autonomous, SAE level 5
- Deletion of direct driver controls (steering wheel, pedals, dashboard)
- Package accommodation of autonomous vehicle sensors
- Suitable for deployment on existing highway networks, operating alongside Level 1 to 4 vehicles



Spacious, comfortable cabin interior

- Inward facing seating configuration
- Scissor doors with wide door aperture providing improved entry and egress for passengers
- Glazing surfaces maximised, enabling light and airy cabin space environment
- Steel E-Motive frame mounted integrated battery solution results in a flat floor interior and low step in height
- Vehicle systems packaged and positioned to provide maximum interior space

Advanced High Strength Steel Body Structure:

- Achieves high speed vehicle crashworthiness standards. Predicted to achieve IIHS "good" rating
- High stiffness and strength body structure. Good levels of comfort and NVH
- Lightweight steel design
- Significant reduction in lifecycle greenhouse gas emissions comparing 2035 operation to 2020 conventional battery electric vehicle

Optimised propulsion system

- 75kWh battery electric powerunit. Front electric drive unit. Potential for 12 hour operation on a single charge
- Potential for conversion to hydrogen fuel cell powertrain
- All wheel steer, enabling 7.4m turning circle

Figure 7.1.1 Engineering 3D CAD image of SEM1 vehicle. Key design features and achievements (See Appendix 4 for larger image)

7.1.1 SEM1 Vehicle external and internal dimensions

Figure 7.1.1.1 shows the external dimensions of the SEM1 vehicle including a comparison to a typical European C segment passenger car. The overall length of SEM1 is slightly smaller than a C segment vehicle and overall height higher, which is necessary due to the occupant location and more upright position.

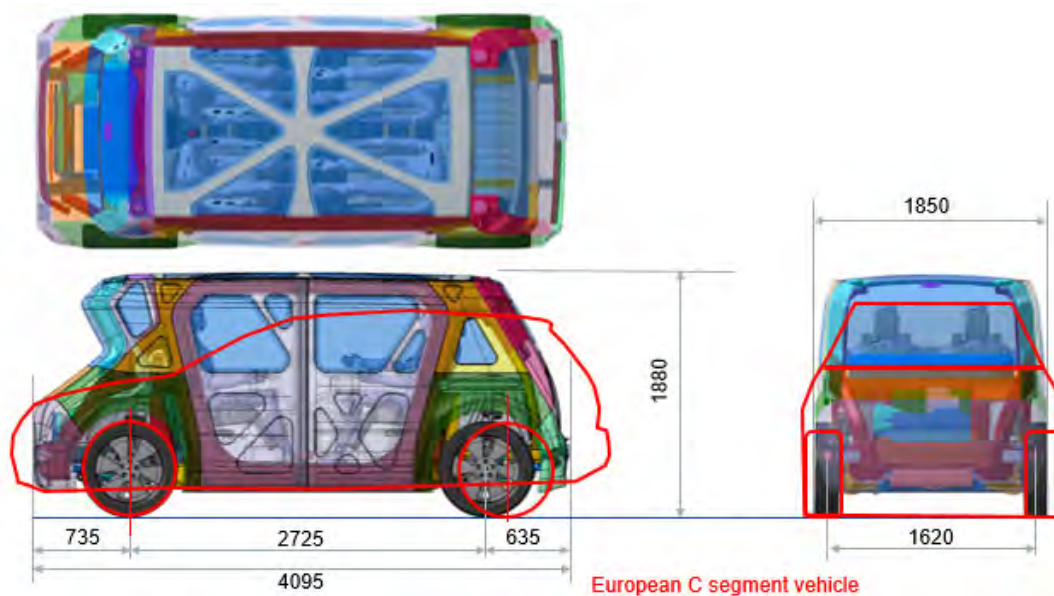


Figure 7.1.1.1 SEM1 vehicle external dimensions

The Steel E-Motive concept features a relatively spacious interior given the overall vehicle dimensions. The occupant positioning and level 5 autonomous features enable this. Overall interior dimensions are shown in Figure 7.1.1.2.

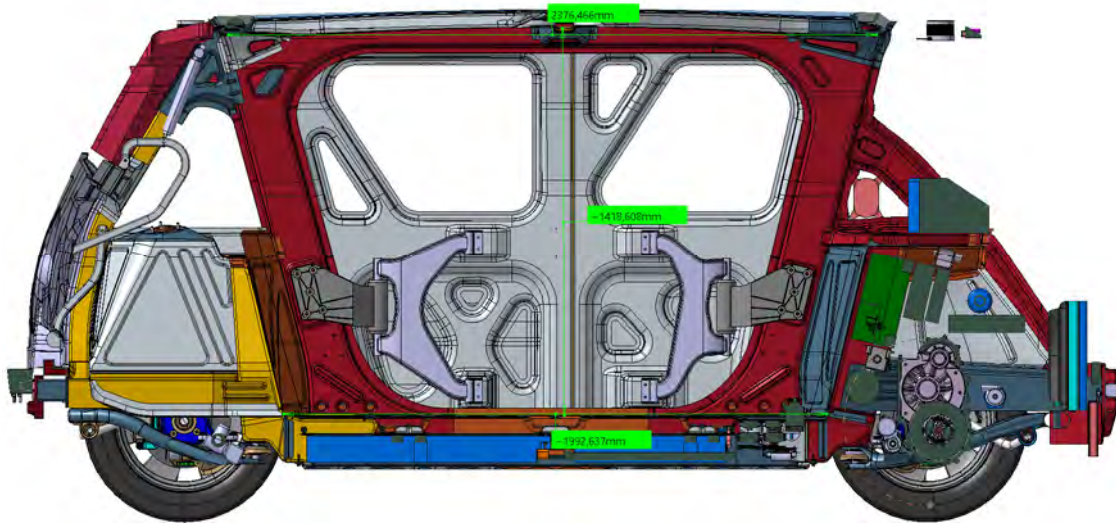


Figure 7.1.1.2 Overall SEM1 interior dimensions

7.1.2 Vehicle design considerations for SAE Level 5 autonomy

The Steel E-Motive concept designs have been engineered to enable SAE Level 5 autonomous operation. This means the vehicle drives itself on a conventional highway, with the human operator or passenger requesting a journey start and end location. The vehicle will manage the route optimisation, interface with the fleet operator network, connect with road traffic infrastructure (such as traffic signals), interface with other vehicles. The onboard vehicle sensors (radars and lidars) will determine the proximity of nearby objects such as other vehicles, stationary objects, pedestrians and will determine its location using satellite Global Positioning Systems (GPS) and 4G telecommunications. The sensory data is processed by an on-board processor and the motion trajectories and vehicle response are calculated. The roadmap in Section 3.3 outlines the development and evolution of the autonomous vehicle technology, concluding that widescale deployment should be feasible in the 2030 to 2035 timeframe. The autonomous vehicle sensors have been positioned and packaged in the Steel E-Motive design. Whilst detailed design of the sensor mounting was not been undertaken, the sensors are positioned in locations with significant supporting structure, such as the top of the A pillar and on roof bow structures. This should ensure requirements such as attachment stiffness and vibration isolation are attainable.

Level 5 autonomy means that the vehicle is controlled autonomously 100% of the time during its operation. The user or operator will not directly control the vehicle at any time. This therefore means that the conventional controls such as steering wheel, column, accelerate and brake pedals, gear shift and turn indicator controls can be eliminated from the vehicle. Additionally, the dashboard and driver information panels can be deleted and replaced with on-board information screens. Overall a net weight saving of 135kg is estimated based on deletion of driver controls and addition of autonomous sensors and controls (see figure 7.1.5.3). The vehicle changes associated with Level 5 autonomy also

enable improvements to cabin space and interior. There is no requirement for occupants to view the road or traffic conditions, therefore vision and obscuration requirements do not apply. In the Steel E-Motive concept, the front occupants are therefore positioned in a rear facing orientation and the seating position moved to the front of the vehicle where a conventional vehicle dashboard. This creates an inward “sitting room” configuration, with improved legroom and personal space, enhancing the user’s journey experience.



Figure 7.1.2.1 SEM1 engineering 3D CAD model, section cutaway in X, looking to the front of the vehicle showing front occupant (95th percentile mannequins) in rear facing, front seat configuration. Occupants are positioned where conventional vehicle controls would be located. (doors in open position).

7.1.3 Vehicle design considerations enabling passenger comfort and ergonomics

To enable easier access (ingress and egress) to the vehicle, Steel E-Motive concept features sliding or “scissor” action doors with A and C pillar mounted hinges. Deletion of the body in white B pillar (with the structure located in the doors) enables a wide (1.01m) aperture with the doors in the fully open position. This provides users with very convenient access to the vehicle during pick up and drop offs. The scissor motion of the doors also minimises the distance that the doors swing outwards when opened (referred to as “kerbside encroachment”). This enables the vehicle to manoeuvre closer to the kerbside during passenger pick-ups and drop offs, providing added convenience for users. A completely flat interior floor is enabled in the Steel E-Motive design due to the engineering packaging of the propulsion battery and supporting structure. This facilitates easier and unobstructed movement within the vehicle. The floor and step-in heights are also competitive for the size of vehicle and offer convenient access for the user.

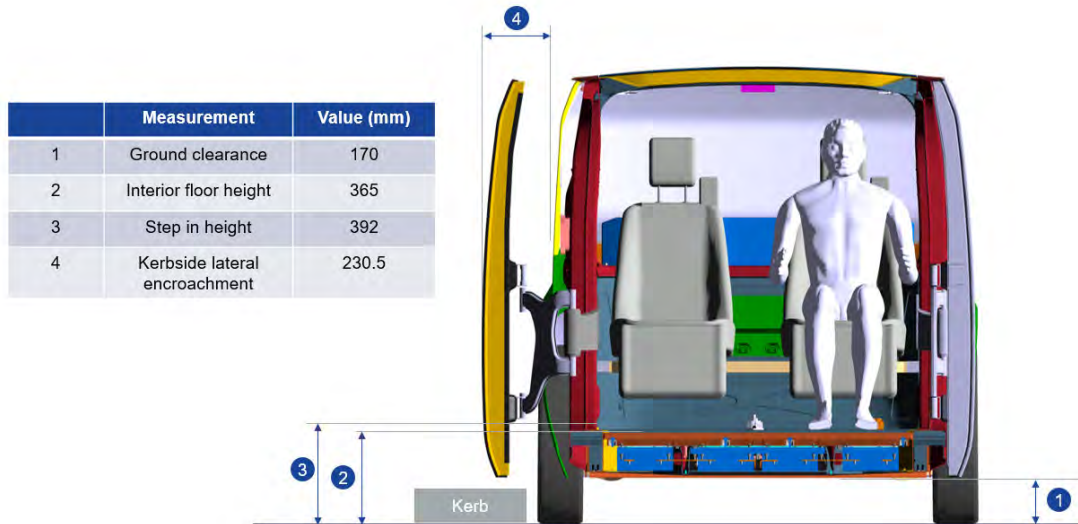


Figure 7.1.3.1 SEM1 ground clearance, floor, step in height and kerbside lateral encroachment



Figure 7.1.3.2 SEM1 occupant ingress and egress study (95th percentile male) using Virtual Reality tools



Figure 7.1.3.3 rear compartment access evaluation using Virtual Reality tools



Figure 7.1.3.4 SEM1 interior space evaluation using Virtual Reality tools

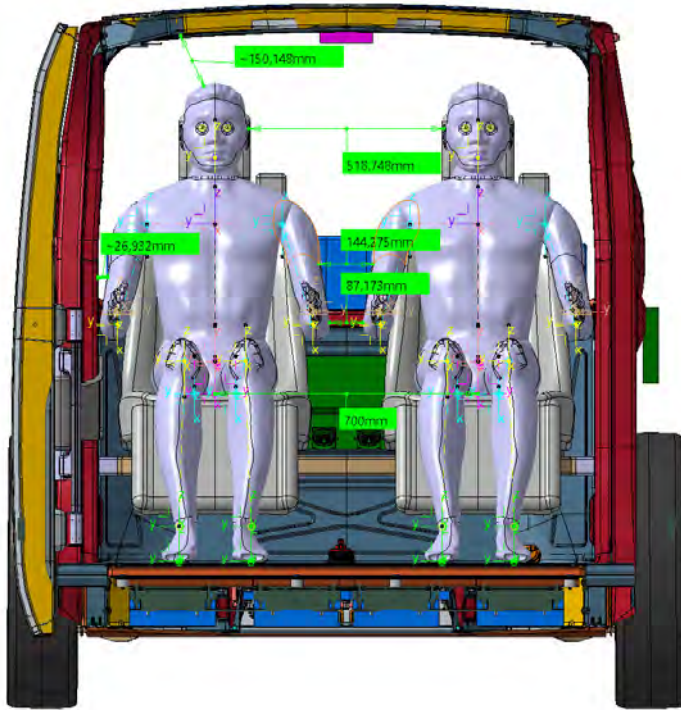


Figure 7.1.3.5 SEM1 occupant seating position and clearance using 95th percentile mannequin

Despite the compact vehicle size, the seating positions in SEM1 provide reasonable levels of clearance from occupant to vehicle and occupant to occupant as show in Figure 7.1.3.5

The 400 litres luggage capacity target was achieved by occupying the combined spaces of the upper and lower boot (388 litres) and additional space made available underneath the bench seats.

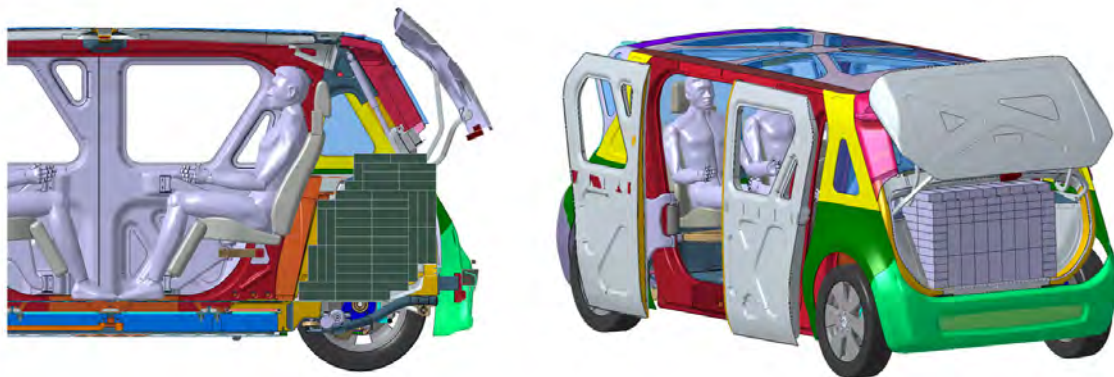


Figure 7.1.3.6 SEM1 luggage capacity estimation. 388litres

Motion sickness can be a common occurrence and aggravation when humans are subjected to journeys by land vehicles where and external vision and focal points are less accessible. This is therefore a risk in autonomous vehicles where the users' vision is likely to be focussed on tasks inside the vehicle. The glazed area of the Steel E-Motive concept has therefore been enhanced in order to maximise the natural light potential and minimise the risk and severity of vehicle motion sickness. Despite there being no legal requirements for driver vision or obscuration, a "conventional" front windscreen provides good forward vision and natural lighting. The roof features a lattice structure with large glazed in-fills. The side closures feature fixed glazing incorporated into the lattice styling and the rear tailgate features a fully glazed upper panel. Overall, the Steel E-Motive enables a light and airy interior space despite the compact vehicle size.

7.1.4 Vehicle design considerations for disabled and impaired users

One of the significant benefits and motivational factors for fully autonomous vehicles is the ability to serve the underserved. Users who don't have the ability or capability to drive a conventional vehicle will now be able to enjoy the travel freedoms beyond taxi or public transport services. This includes disabled, elderly and physically impaired users and able-bodied passengers who are recovering from injury or long-term treatment. With journeys being monitored and securely operated, unaccompanied children may also be able to use autonomous vehicle services with some limitations. With the added freedoms that autonomous vehicles enable, the vehicle itself must be fit for purpose for disabled users. Mobility as a Service fleet operators would specifically cater for disabled users by engineering unique vehicle variants that specifically accommodate disabled users. The modifications would include the permanent removal of one or two of the fixed passenger seats and wheelchair tie-down fixings added to the floor and pillar structures. The reduced kerbside encroachment, step in height and flat floor (as described in 7.1.3) ensure that disabled users can conveniently access the vehicle with the assistance of an on-board ramp (not specifically engineered). Virtual Reality (VR) 3D visualisation tools were used to assist confirm the suitability of the Steel E-Motive concept for wheelchair users. Specific vehicles would require minor vehicle adaptations, including the removal of a portion of the seat (or engineering of a device to temporarily remove a portion of the bench seat), inclusion of a pull-out wheelchair ramp from the floor structure and addition of wheelchair location points and fixings. Mobility as a Service operators would be expected to adapt a number of vehicles for disabled user needs within their fleets.



Figure 7.1.4.1 SEM1 wheelchair user vehicle access evaluation using Virtual Reality tools

7.1.5 Vehicle weight

A low vehicle weight enables efficiency savings at both the design and operational level. Low weight vehicles generally utilise less material in their construction, resulting in lower greenhouse gas emissions as a result of the manufacture and assembly. Low vehicle weight also results in lower propulsion force and energy needs, enabling a smaller battery for an equivalent range and smaller traction motor. Steel E-Motive SEM1 achieves an estimated unladen weight of 1512kg. The value is derived based on calculations from 3D CAD for the systems specifically engineered (designed) in the Steel E-Motive programme and estimations for other systems based on statistical benchmark data from services such as a2mac1 (<https://www.a2mac1.com/>).

Figure 7.1.5.1 shows the SEM1 vehicle curb weight breakdown

| Subsystem | SEM 1 Status CD | Source/estimation |
|--------------------------|-----------------|---|
| Body non-structure | 177.2 | Estimated from a2mac1 statistical analysis. Includes seating, trim panels, glazing, front end clip, exterior panels |
| Body Structure | 282.0 | <CD> design value from 3D CAD |
| Front sub-frame | 16.5 | <CD> design value from 3D CAD |
| Battery case (structure) | 59.0 | <CD> design value from 3D CAD |
| Rear sub-frame | 10.2 | <CD> design value from 3D CAD |
| Front suspension | 114.0 | <CD> design value from 3D CAD |
| Rear suspension | 114.0 | <CD> design value from 3D CAD |
| Braking | 59.7 | Estimated from a2mac1 statistical analysis |
| Steering | 26.0 | Estimated from a2mac1 statistical analysis (steering rack and tie rods only, no wheel column, EPAS etc) |

| | | |
|----------------------------|---------------|---|
| Tires and wheels | 84.0 | Estimated from a2mac1 statistical analysis |
| Motor Trans Front | 63.0 | Estimated from a2mac1 statistical analysis and Fiat 500e |
| Battery system less case | 245.6 | <CD> Ref BOM including 5kg of fluids, busbars, cooling plate, modules and PDU |
| Propulsion controls | 60.0 | Estimated from a2mac1 statistical analysis |
| Electrical-non propulsion | 35.7 | Estimated from a2mac1 statistical analysis |
| Cooling and heating | 30.0 | Estimated from a2mac1 statistical analysis |
| Closures | 109.3 | <CD> design value from 3D CAD |
| Bumpers | 26.0 | Estimated from a2mac1 statistical analysis |
| Vehicle curb weight | 1512.2 | kg |

Weight performance of the body in white and battery structure are discussed in section 7.2.1.

The relative competitiveness of vehicle curb weight can be expressed using comparison of vehicle dimensions and weight performance. Figure 7.1.5.2 shows a comparison of a sample of battery electric vehicles, comparing curb weight to the occupied volume area (vehicle length x vehicle width x vehicle height). The reference vehicle sample includes vehicles with steel, aluminium and mixed/multi-material body structures. A statistical regression analysis enables a “line of fit” to be calculated for the data sample, drawing a relationship between the vehicle curb weight and vehicle occupied volume.

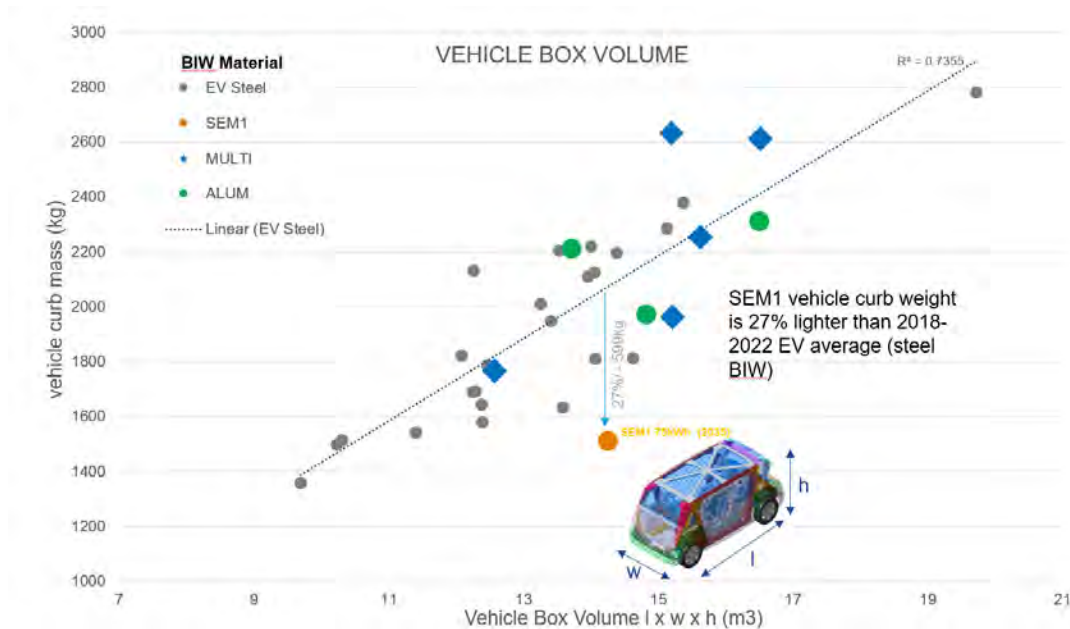


Figure 7.1.5.2 Vehicle curb weight versus box volume comparison. Reference vehicle data source www.a2mac1.com (See Appendix 4 for larger image)

The comparison shows that the Steel E-Motive SEM1 concept has good weight efficiency performance, achieving a curb weight that is 27% lower than the statistical estimation for the vehicle data sample. The study also shows that Steel E-Motive design is competitive compared to vehicles with aluminium and multi-material body structures. One consideration for this calculation is that battery electric vehicle weights are heavily impacted by the

propulsion battery capacity. Many of the sample vehicles with >15m box volume have significantly large batteries (>90kWh), which result in a considerably higher curb weight. However, most of the vehicles within the size of SEM1 do have comparable sizes and specifications of propulsion batteries. Another important consideration in vehicle curb weight calculation is the consideration of autonomy level. Most vehicles in the data sample are level 1 to 2, with conventional driver controls. Steel E-Motive features level 5 autonomy, with the direct driver controls deleted and replaced with an array of motion sensors. Figure 7.1.5.3 shows a projected “weight walk”, comparing the SEM1 vehicle curb weight to a conventional SAE level 1 to 3 vehicle (2022 Model Year). The difference in curb weight can be attributed to; lower weight propulsion battery as a result of expected future battery technology enhancements and efficient Steel E-Motive battery structure design, deletion of the direct driver interfaces, controls and main dashboard, additional weight for autonomous vehicle sensors, estimated weight reduction of other vehicle systems such as suspension, wheels and tyres and weight reduction efforts of the body in white structure (detailed in section 7.2.1).

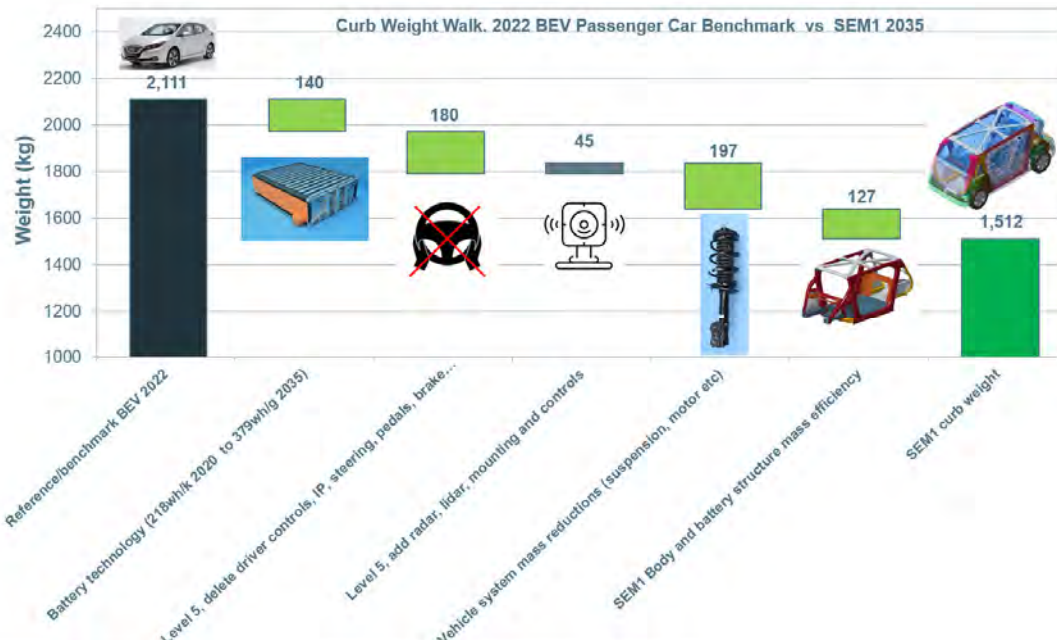


Figure 7.1.5.3 vehicle curb weight walk, comparing 2022 BEV (SAE level 1 to 2) to SEM1

7.2 Steel E-Motive body architecture design and material selection

This section describes the approach and philosophy of the Steel E-Motive body structure design concept with respect to the requirements and the performance achieved. The considerations and justification of the selected material grades and fabrication process are also detailed as well as the geometry and shape considerations. The design decisions were mainly driven and influenced by the requirements and performance targets as defined in Section 4. Section 8 provides comprehensive performance results of SEM1.

7.2.1 Steel E-Motive Body in White (BIW) design, steel grades and fabrication processes

The Steel E-Motive Body in White (BIW) is a monocoque construction consisting of Advanced High Strength Steel (AHSS) sheets, primarily stamped or roll formed parts and assembled using resistance spotwelding (RSW) and laser welding methods. The AHSS steel grades were determined and selected based on the specific requirements of the parts or subassemblies (such as crash, stiffness, formability). Section 7.3 describes the design, AHSS grade selection and fabrication process considerations and selection in detail with respect to each of the specific performance requirements. Figures 7.2.1.1, 7.2.1.2 and 7.2.1.3 show the Steel E-Motive SEM1 BIW design and the application of steel grade family for “core” design. (An “alternative” grade assignment study was performed to further demonstrate and promote the breadth of steel grades available. This is reported in Section 7.5). The Steel E-Motive (core design) BIW uses 34% Press Hardened Steel (PHS), 11% Martensitic, 17% Dual Phase and Complex Phase, 22% 3rd generation (including Retained Austenite, high formability Dual Phase and Complex Phase) and 15% High Strength Low Alloy / Bake Hardenable steels by weight. The Bill of Materials for SEM1 BIW is provided in Appendix 1.1. This details the specific material grade, gauge thickness, weight and fabrication process for each part in the BIW.

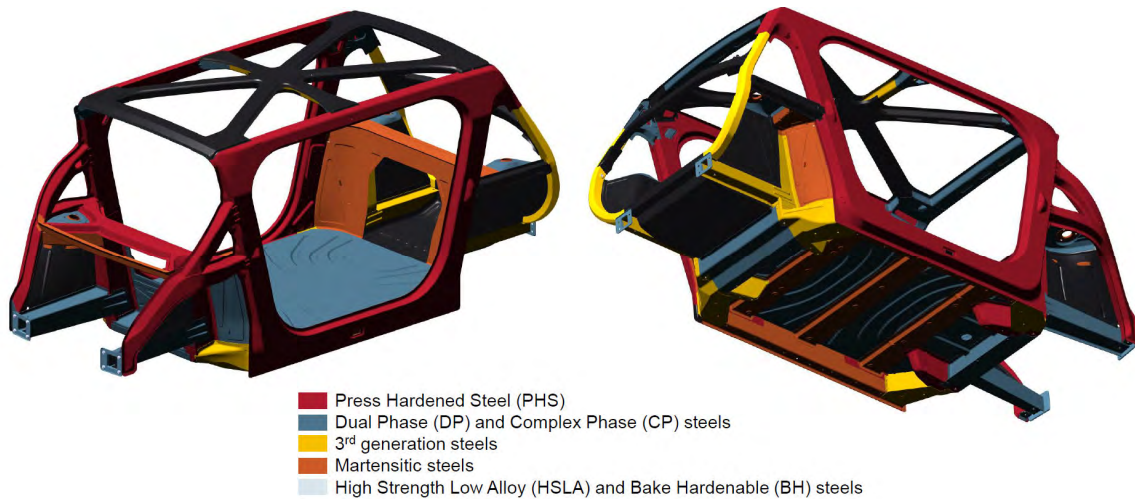


Figure 7.2.1.1 Steel E-Motive SEM1 BIW design and distribution of AHSS (See Appendix 4 for larger image)

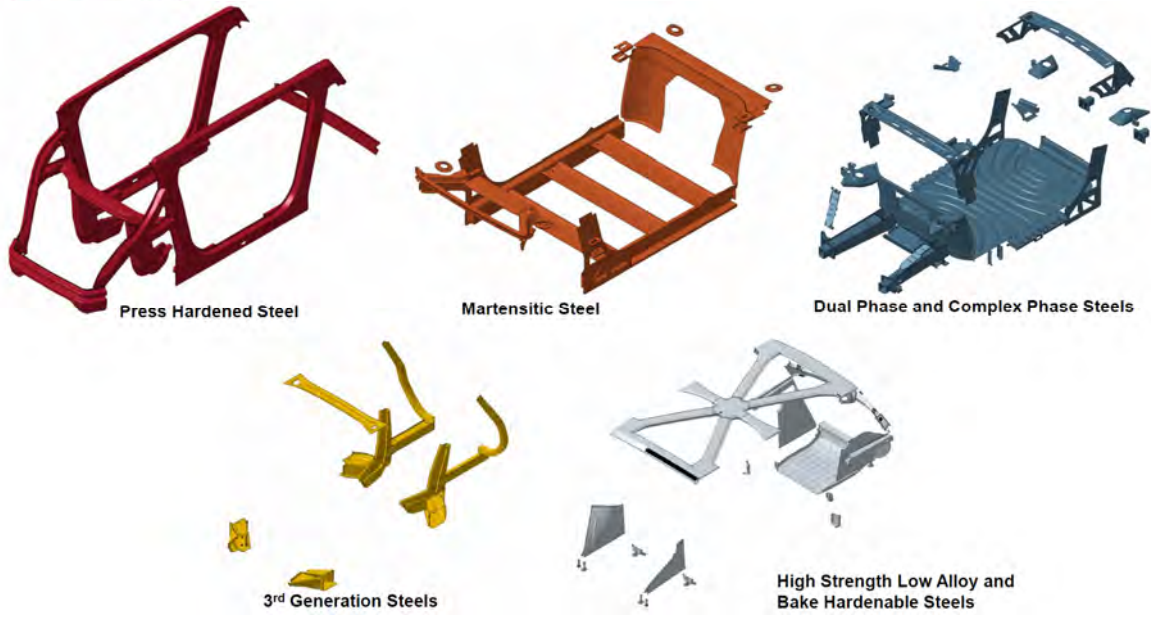


Figure 7.2.1.2 Steel E-Motive BIW AHSS grade allocation (See Appendix 4 for larger image)

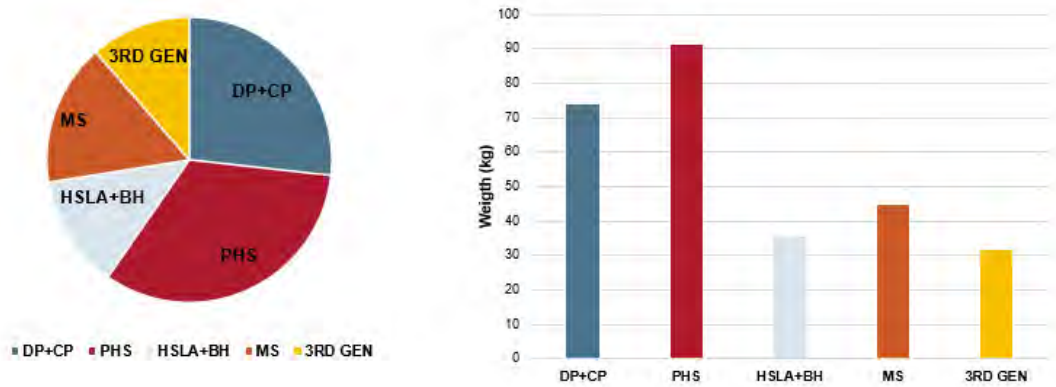


Figure 7.2.1.3 Steel E-Motive BIW AHSS grade distribution (See Appendix 4 for larger image)



Figure 7.2.1.4 Steel E-Motive SEM1 BIW AHSS grades (exploded view) (See Appendix 4 for larger image)

The Steel E-Motive body structure draws on the various fabrication processes available for sheet steel body structures. Cold forming is widely used as it provides high speed and efficiency for high volume production, facilitates lower cost and high quality. Advanced High-Strength steels feature high elongation properties making cold forming a readily applicable solution for many parts. Roll forming and roll stamping is applied to panels with continuous section profiles. Roll stamping provides an additional freedom for sections with some out of plane curvature or features. (See Section 5). Where very high strength and cold forming methods cannot be applied to parts with complex geometry then Press Hardened Steels (PHS) have been applied. The performance demands of the Steel E-Motive resulted in the requirement for a significant quantity of >1000MPa UTS grades, especially for the management of front and side crash loadcases. Where possible, 3rd generation and martensitic grades were applied. For parts with geometry that fall outside of the forming limits of these grades then Press Hardened Steels were applied. Figure 7.2.1.5 shows the BIW fabrication process usage by weight.

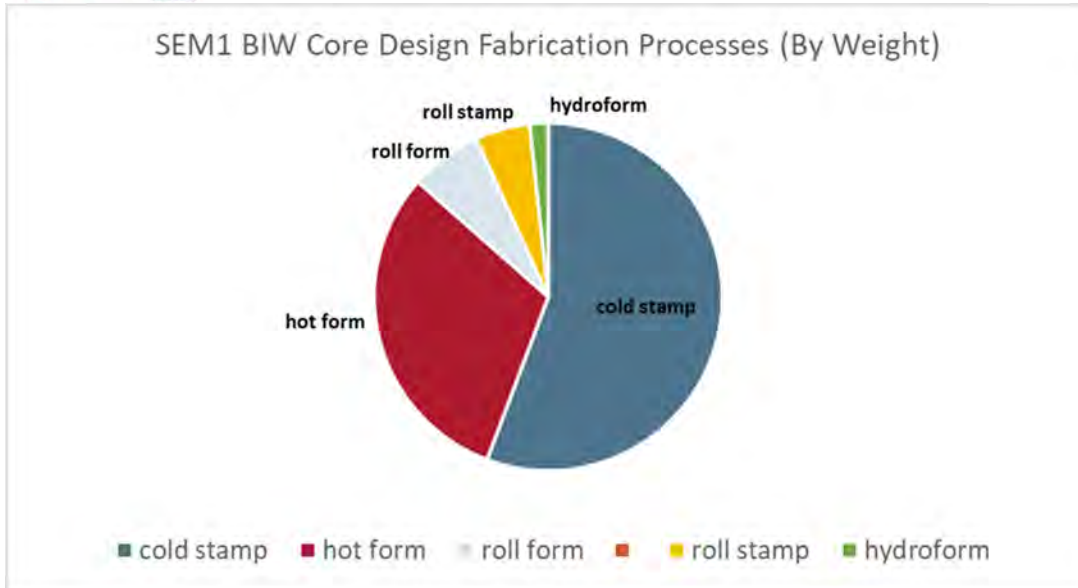


Figure 7.2.1.5 SEM1 BIW fabrication process application by weight

7.2.2 Steel E-Motive body structure design approach and features for weight, stiffness and NVH performance

The Steel E-Motive concept achieves very good body structure weight, static stiffness and NVH performance, as summarised in Figure 7.2.2.1 below.

| Loadcase/requirement | Target value | SEM1 performance |
|--|---|--|
| Body in white weight | <309.3kg | 282kg |
| Static torsional stiffness | >25,000 Nm/deg | 63,285 Nm/deg |
| Static vertical bending stiffness | >9,000 N/mm | 13,438 N/mm |
| Trimmed BIW first mode | >28Hz | 32Hz |
| Trimmed BIW first battery mode | >35Hz | 35Hz |
| Trimmed BIW local dynamic attachment stiffness | >5 x equivalent dynamic bushing stiffness | 5 x dynamic bushing stiffness achieved |

Figure 7.2.2.1 SEM1 body weight and stiffness performance versus targets

The main design factors that enable the weight, stiffness and NVH performance are summarised below:

- Optimum structural loadpaths throughout the body. Placing structure where it is needed
- Using the right material in the right place by applying the appropriate Advanced High Strength Steels grades. The Steel E-Motive project portfolio contained steel grades with Ultimate Tensile Strengths up to 2000MPa and gauge thicknesses from 0.4mm to 5.0mm. Technologies such as Tailor Welded Blanks (TWB) and Tailor Rolled Blanks (TRB) enable refinement of steel grade and gauge within in a single part. This enabled a good balance of weight, strength and stiffness to be achieved in the body structure design
- Development of the body structure as a complete system, considering the contribution of the propulsion battery structure and cover, the chassis subframes, closures and bumper beams. The integrated battery solution in the Steel E-Motive concept provides a significant contribution to overall body stiffness performance

- Optimum size and shape of structural members in the body structure. Fabricated steel structures enable cross sections with high polar moment of areas and weight efficiency.
- Local geometry and design features. Orientation and design of the fabricated panel joint flanges. Use of panel swaging and beading to improve local stiffness
- Appropriate selection of joining methods and locations
- Inherent Young's Modulus value (207GPa) of steel, irrespective of specific steel grade

BIW weight:

The weight target for the SEM1 body in white (BIW) was derived using a similar principle to the vehicle curb weight comparison as described in Section 7.1.5. A dataset of Multi-Purpose Vehicles (MPV) and mini-vans was assembled and statistical regression calculations performed to identify suitable weight versus dimensional relationships as the basis for the target. MPVs and mini-vans were selected as they feature more of an overall “one-box” exterior shape (similar to SEM1), compared to conventional passenger cars featuring two or three box shapes. The BIW occupied box surface area was found to present a strong relationship to the BIW weight and was therefore selected as the primary function to derive the weight target. Figure 7.2.2 shows the BIW weight regression evaluation and derivation of weight target. The “Benchmark/average” BIW weight for a vehicle of SEM1 dimensions was calculated using a logarithmic function of the statistical regression relationship and a value of 374.1kg was derived. The BIW weight target was then calculated based on a factor of 3 times the Standard Deviation value of the benchmark average weight. Based on the SEM1 BIW dimensions, the statistical dataset for MPV/mini-vans and the Standard Deviation factor, a target weight value of 309.3kg was derived.

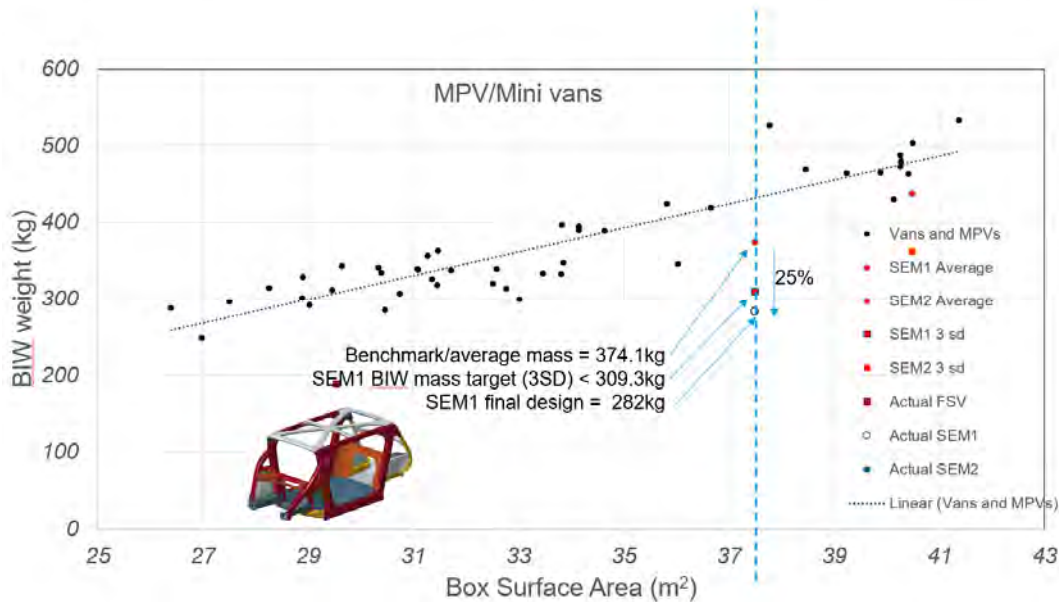


Figure 7.2.2.2 Body In White weight regression analysis (See Appendix 4 for larger image)

The final design weight of the SEM1 body in white is 282kg, representing a 25% improvement on the benchmark/reference vehicle weight and 8% lower than the weight target. The statistical dataset chosen for the BIW weight target setting exercise consisted of MPVs and mini-vans with Internal Combustion Engine powertrain. This was due to the body structure designs being more consistent in shape, therefore providing a good statistical

relationship between weight and dimensions. Battery electric vehicle body structures currently have a larger variability in shape and construction due to the different approaches taken for integrating the propulsion battery. The statistical relationship between BIW weight and dimensions for battery electric vehicles is not as strong as the MPV and mini-van dataset. Nevertheless, a comparison of the SEM1 BIW weight performance and current production (2018 to 2022 model year) battery electric vehicles was performed. Figure 7.2.2.3 shows a similar BIW weight evaluation using the occupied box volume as the dimension parameter. The greater level of data “scatter” demonstrates more inconsistency in the relationship between weight and occupied box volume and therefore unsuitability for weight target derivation (note low the r^2 values which describe the consistency of the dataset relationship of weight and dimensions). This evaluation does however demonstrate good weight efficiency performance of the Steel E-Motive BIW concept. For the data sample evaluated, it can be concluded that the Steel E-Motive AHSS structure has comparable weight performance to aluminium and multi-material body structures. The SEM1 BIW weight is also in line and on a similar trend to the Future Steel Vehicle BIW concept, further demonstrating that steel solutions can be engineered to be as weight efficient as aluminium and multi-material structures. It should be noted that the Steel E-Motive BIW weights quoted do not include considerations for paint and NVH trim pads, which are accounted for in the a2mac1 data, therefore the actual weight performance of SEM1 BIW versus the benchmark a2mac1 data would be slightly reduced.

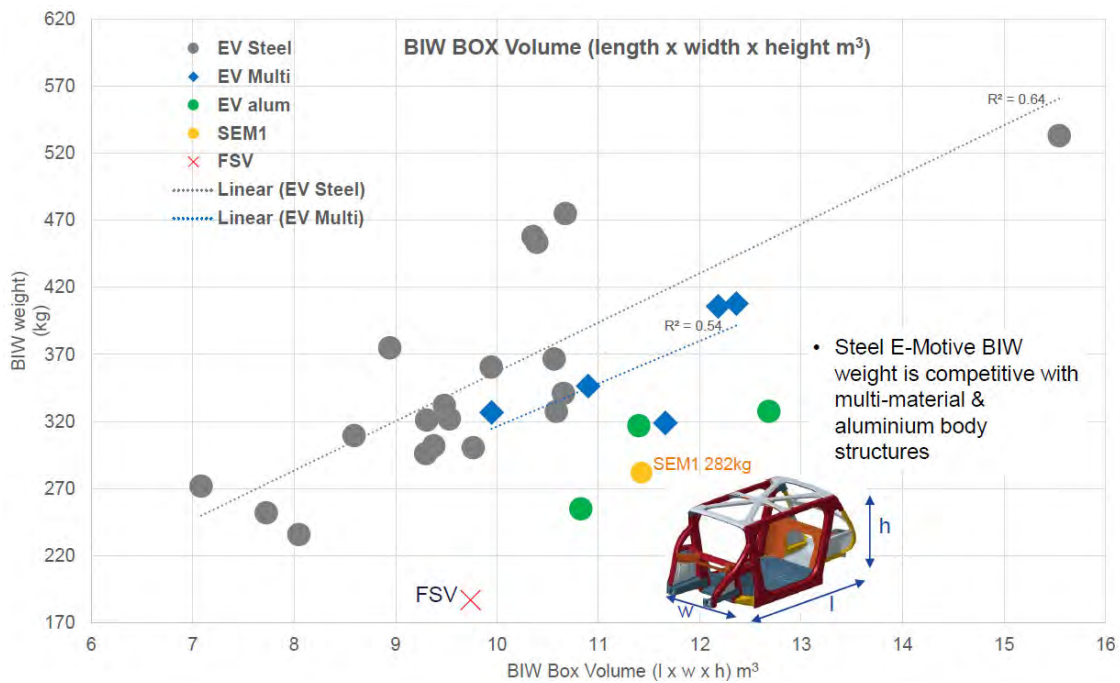


Figure 7.2.2.3 Body In White weight versus occupied box volume comparison. 2018 to 2022 battery electric passenger cars. (data source www.a2mac1.com)

Body Structure Stiffness:

Section 6.2.4 outlines the approach taken for the topology structural loadpath optimisation, a methodology that assists designers to place material in the most appropriate and efficient locations within the available volume of body structure. Section 6.3.2 demonstrates how the outputs from the topology loadpath optimisation were interpreted into the design of the SEM1 body structure. The placement of the key structural members in the Steel E-Motive body structure was guided by the early concept structural topology optimisation. Figure

7.2.2.4 shows the SEM1 body design with the key structural loadpaths highlighted. For a static torsional loadcase with equal and opposite forces applied at the front strut top mount a *front torsion loop* consisting of left and right vertical dash braces, a lateral strut brace and lower #1 bar creates a ring structure to react the twist loads.

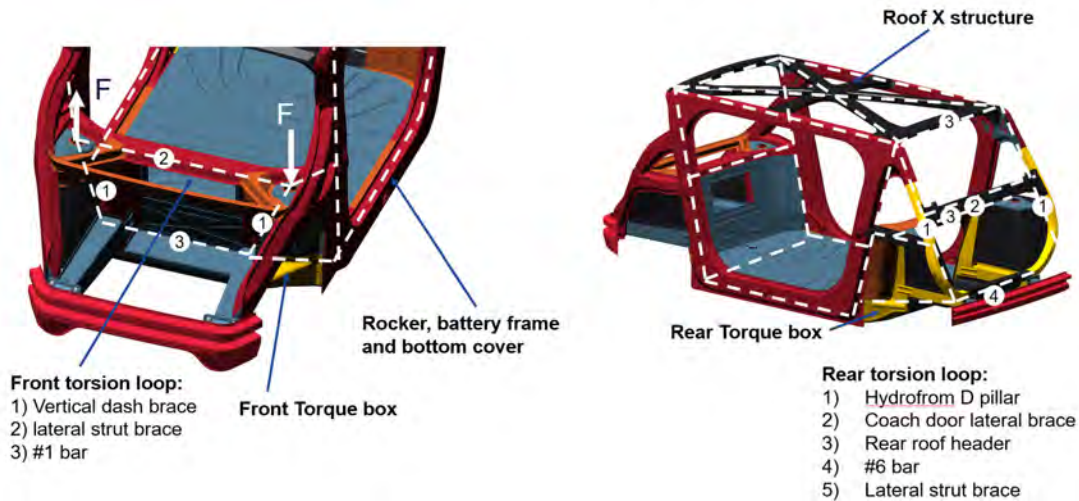


Figure 7.2.2.4 SEM1 body structure key loadpaths (See Appendix 4 for larger image)

The front strut tops themselves are located in close proximity to key structural members such as lateral strut brace and the front crash SORB structure as shown in Figure 7.2.2.5. This provides enhanced local stiffness and integration to the body structure loadpaths.

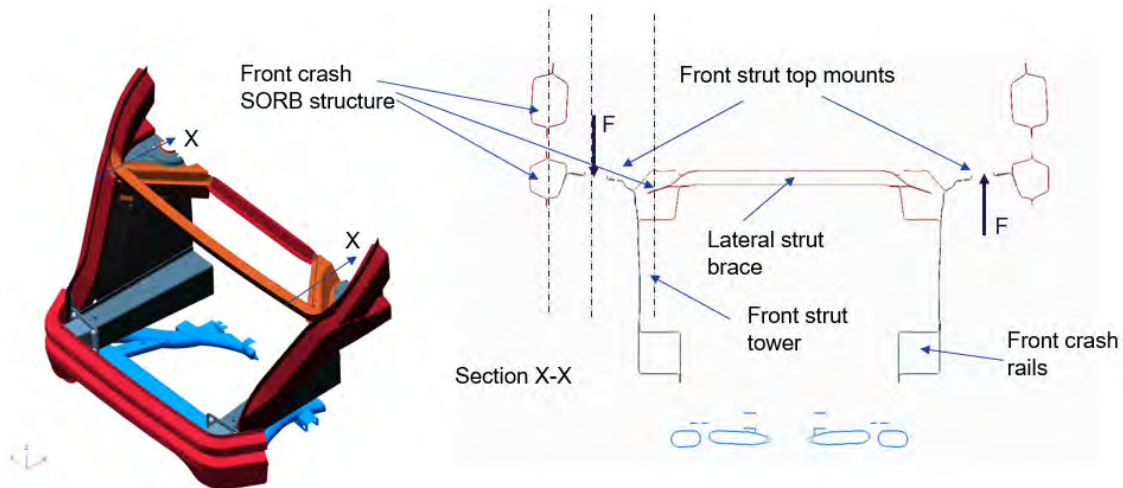


Figure 7.2.2.5 BIW section in X-X through front strut top mounts (See Appendix 4 for larger image)

With the Steel E-Motive concept featuring an open cockpit and B pillarless structure, the loadpaths through the upper and lower sections of the body structure required additional attention and focus in order to ensure the stiffness targets were achieved. Additionally, the propulsion battery is integrated to the body structure via a carrier frame. The BIW features a cavity opening to house the battery. A continuous underbody chassis-type structure ensures the crash and road loads are managed throughout the length of the vehicle as shown in Figure 7.2.2.6

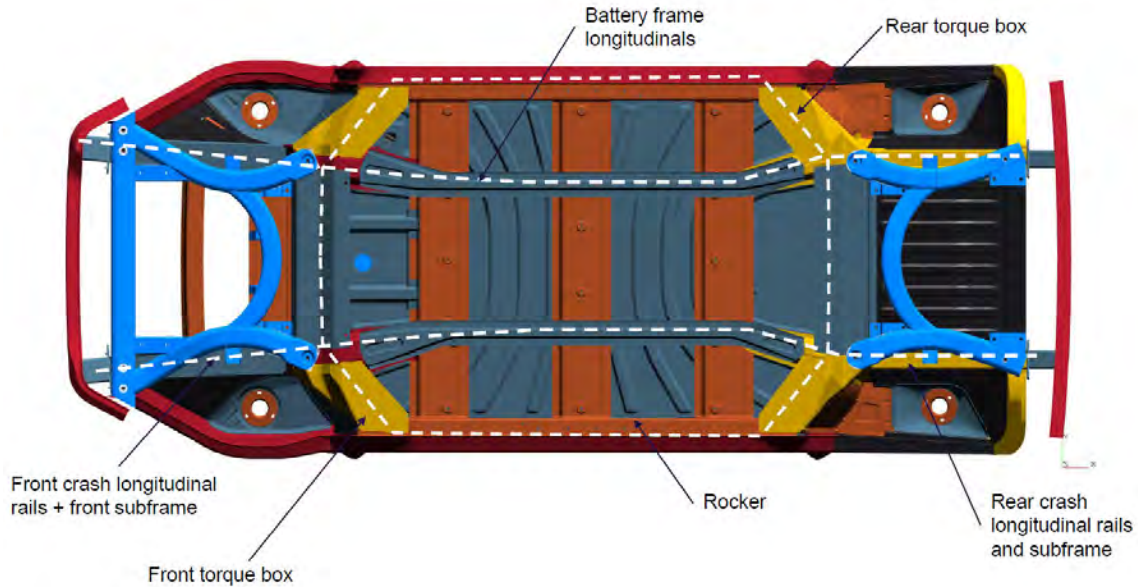


Figure 7.2.2.6 Underbody structural loadpaths and features (note, battery cover plate removed from image for clarity)

The rigidly mounted front subframe and front crash rail longitudinals combine to provide the main element of the forward front structure. The front subframe features forward and rearward lateral braces providing local chassis attachment stiffness as well as assisting front crash loadpaths. The #1 bar and front torque box structures combine to distribute loads from the front subframe and longitudinals outwards to the rocker sections. Additionally, the bolt-in battery carrier frame features longitudinals which align to the front and rear longitudinals. This provides a continuous loadpath (or “spine”) along the length of the vehicle and provides particular contribution to the static and dynamic (NVH) vertical bending stiffness as well as support to the battery modules. The central loadpath is completed by the battery cover plate (Figure 7.2.2.7), which is attached to the BIW via 34 x M8 fixings and to the battery carrier frame by 8 weldnuts. This provides a significant enhancement to body stiffness as well as supporting the sealing function to the battery from outside. The battery carrier frame also contributes to the overall body stiffness. The frame is connected to the body via 22 fixings from the frame cross members to equivalent positioned cross members in the body in white floor as shown in Figure The battery modules are attached to the carrier frame through 4 fixings per module (total 32 fixings).

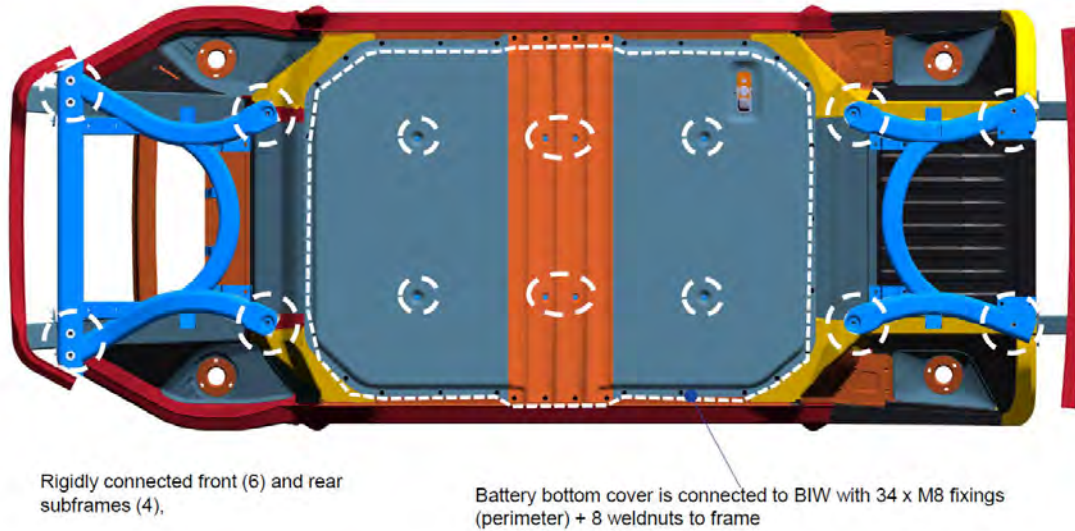


Figure 7.2.2.7 Subframe and battery cover fixings

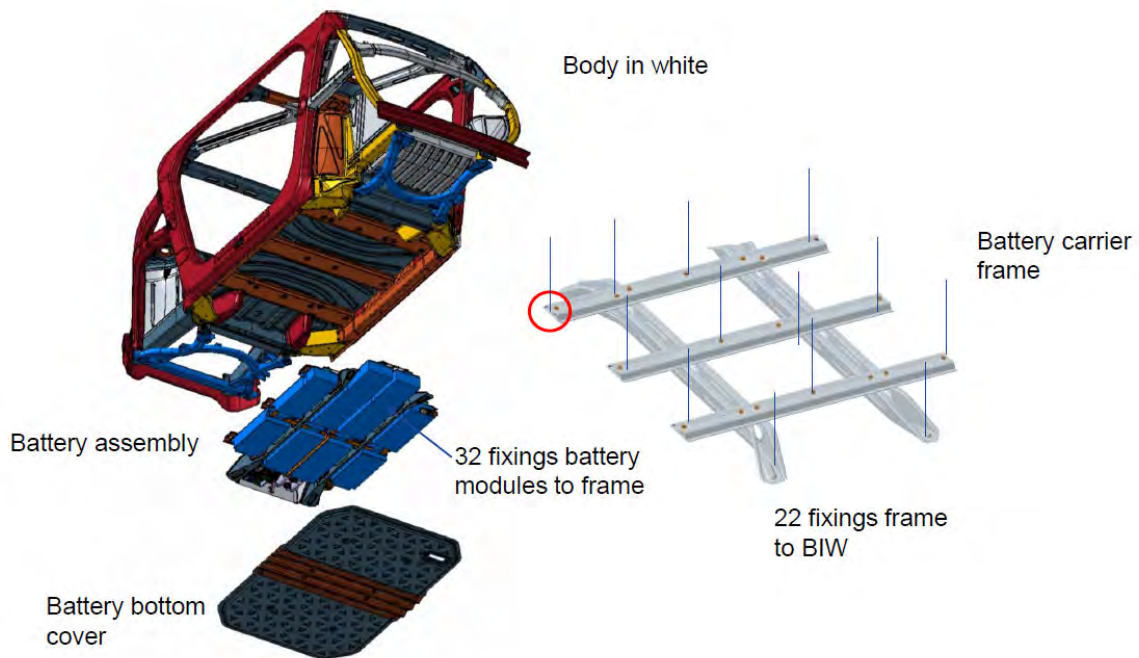


Figure 7.2.2.8 Battery carrier frame fixings to body in white (See Appendix 4 for larger image)

The roof structure features a unique “X brace” configuration, connecting the front and rear corners of the body structure through a central node (Figure 7.2.2.4). The roof structure provides stiffness and crash loadpaths as well as enabling large glazed areas. The rear body structure features single part hydroformed D-pillars which offer a lightweight and stiff solution and forms part of the rear torsion loop.

Stamped and fabricated structures achieve high stiffness and low weight due the ability to produce cross section profiles with high second and polar moment of inertias. When coupled with the inherent high Young’s Modulus of steel, a monocoque body in white structure can



be lightweight and achieve high stiffness. The section profiles and dimensions in the Steel E-Motive body structure concept were guided by CAE optimisation tools, results and requirements from all loadcases including crash, stiffness, strength and weight and design guidelines and principles. Appendix 2.2 shows the cross-section properties for the main parts of the body in white and Figure 7.2.2.9 shows the cross-section profile for the rocker section. The size and configuration of the profile was primarily driven by global body stiffness and side crash requirements.

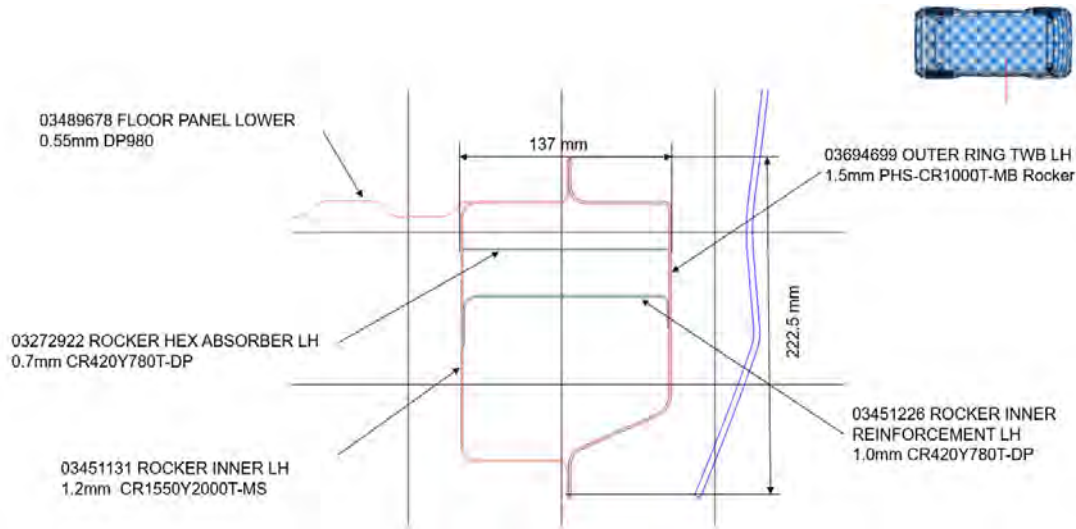


Figure 7.2.2.9 Rocker cross section profile (full BIW section profiles are shown in Appendix 2.2)

Another benefit of fabricated sheet structures is the ability to efficiently locally reinforce sections where specifically needed. The Steel E-Motive body concept features a number of local reinforcements as shown in Figures 7.2.2.10 and 7.2.2.11. The corner gusset reinforcements in the body side structure provide a loadpath through the bending axis of the cross section (Z-Z in Figure 7.2.2.10). This provides improved stiffness and strength through the section.

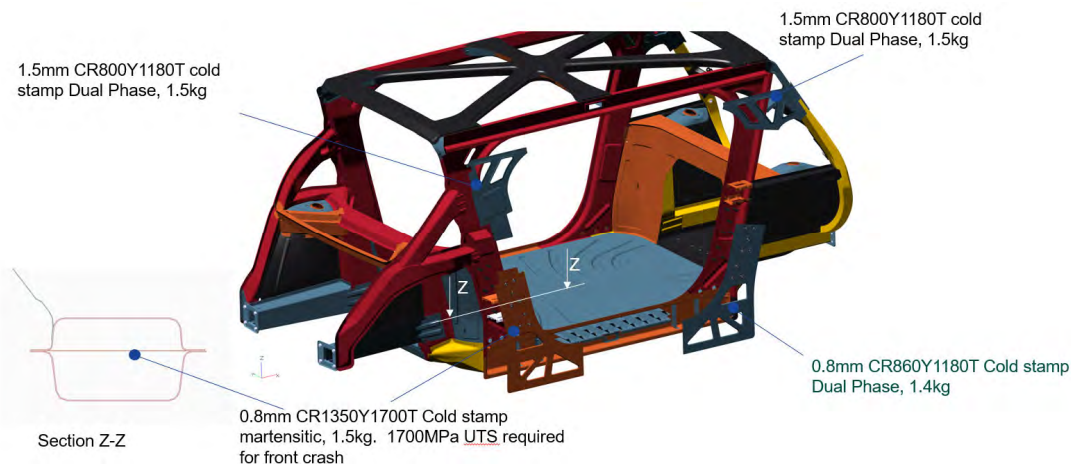


Figure 7.2.2.10 Localised gusset reinforcements adding efficient stiffness and strength improvements (See Appendix 4 for larger image)

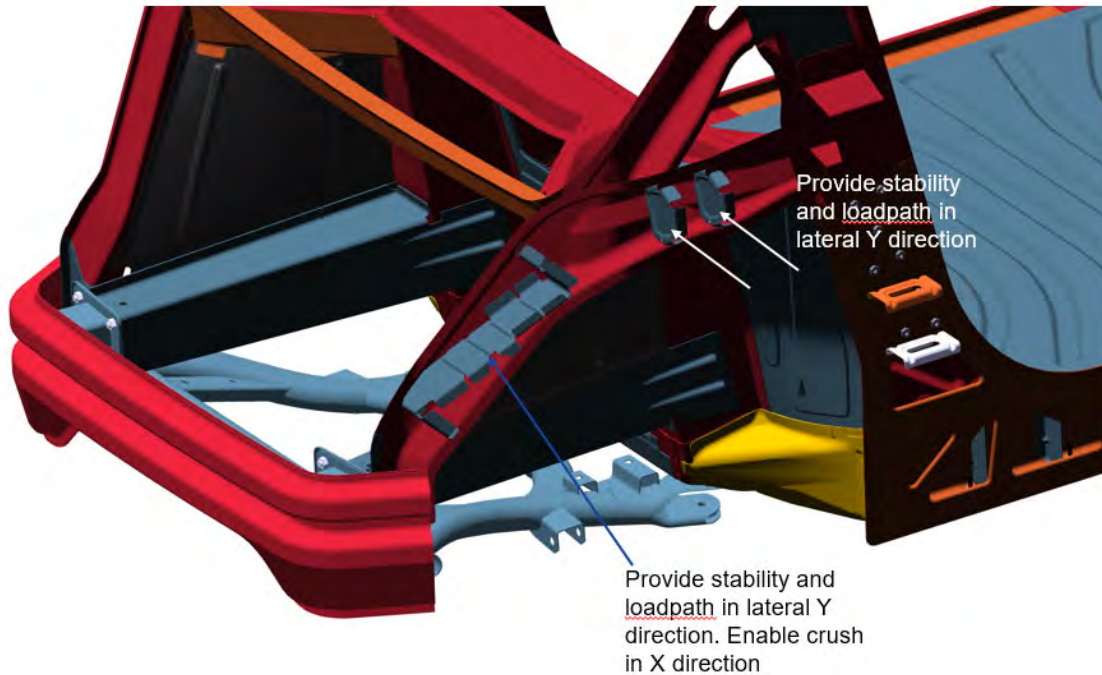


Figure 7.2.2.11 Glance beam reinforcements providing local section support

Gauge thickness for weight, stiffness and strength

The Steel E-Motive body structure utilises the broad range of gauge thicknesses available for sheet steel coils. Thinner gauges such as 0.7mm are applied to large panels which are weight sensitive. For parts such as damper strut tops, where stiffness and strength is required then gauges of 2.4mm can be applied. The selection of each specific panel gauge thickness was based on a number of factors: stiffness, weight, crash strength, durability, formability, availability. CAE gauge optimisations methods as described in section 6.4.5 were used to guide engineers in the selection of panel gauges. Figure 7.2.2.12 and 7.2.2.13 shows the distribution of panel gauge thickness for the Steel E-Motive body in white design.

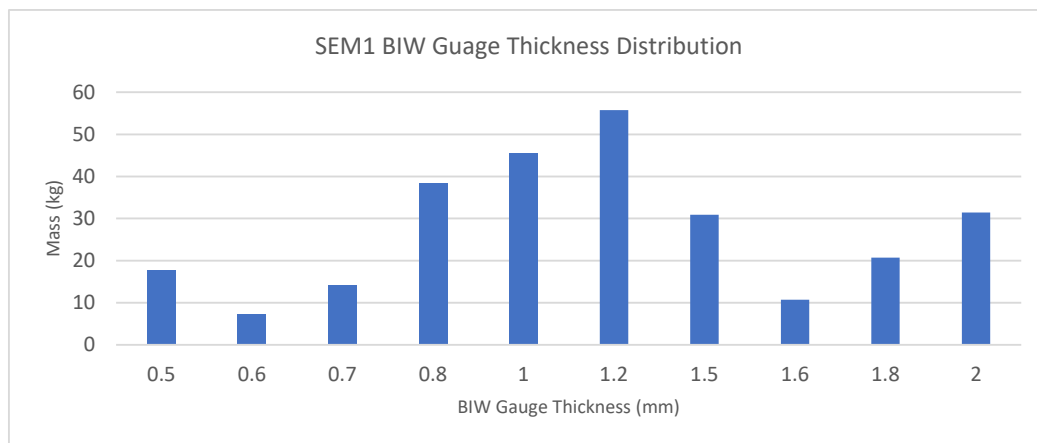


Figure 7.2.2.12 Gauge thickness distribution in SEM1 BIW

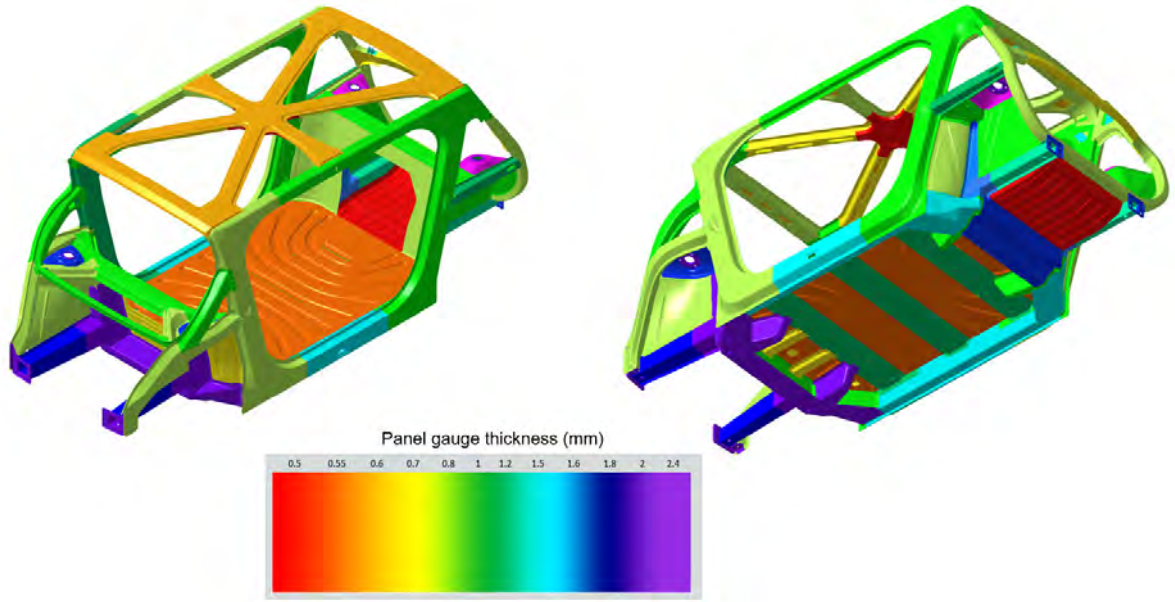


Figure 7.2.2.13 Gauge thickness assignment in SEM1 BIW

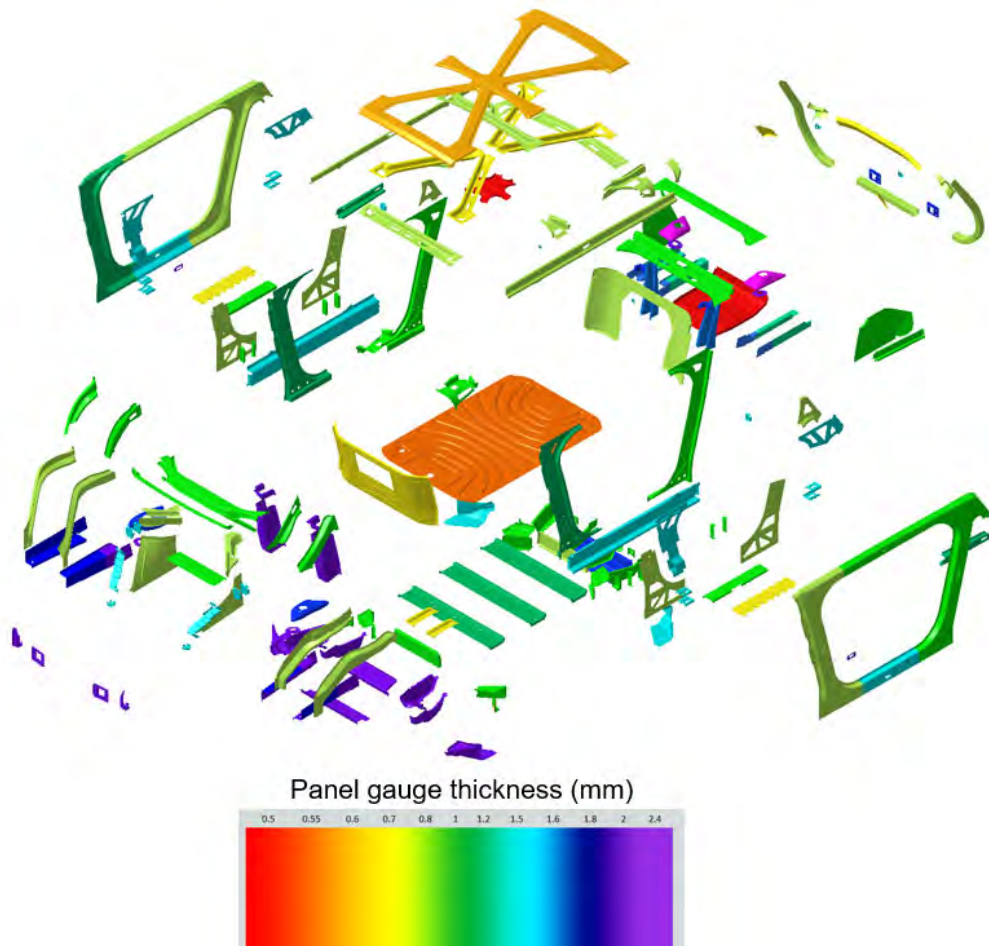


Figure 7.2.2.14 Gauge thickness assignment in SEM1 BIW (exploded view) (See Appendix 4 for larger image)

BIW Joining Methods

The joining methods used in a fabricated body structure have a significant influence on overall stiffness, strength at both body and complete vehicle level. The fabricated steel structure of Steel E-Motive concept uses resistance spotweld (RSW) (more information provided in Section 5) methods as the primary method of joining, with seam/mig welding, seam laser welding and structural adhesive applied in specific locations where required. RSW was selected as the primary joining method as it provides a robust and low-cost solution for stamped steel body structures. RSW enables the joining of up to 5 individual sheets (subject to specific considerations for the design of joint, welding parameters and the potentials for some strength degradation). The Steel E-Motive SEM1 body structure features 3,219 spotwelds though 3 sheet thicknesses (3T), 777 through 3T and 38 4T. The rear D pillars consist of single part hydroformed tube sections which cannot be spotwelded using conventional 2 sided welding guns. To overcome this, single sided spotwelding process is applied. The spotweld positions and pitch (distance between the welds) was optimised based on the requirements from specific loadcases such as crash, stiffness and durability. MIG and laser welding was applied where a constant seam weld was required in the body structure, such as the perimeter of the body floor panel (to provide sealing to the underbody battery compartment)

- Welding**
-  • 2 sheet spot Weld 3219
-  • 3 sheet spot Weld 777
-  • 4 sheet spot Weld 38
-  • One side spot Weld 34
- Glue**
-  • Structural adhesive 8276 mm
- Seam Welding**
-  • Seam/MIG Weld 15394 mm
- Seam Welding**
-  • Laser Weld 1686 mm

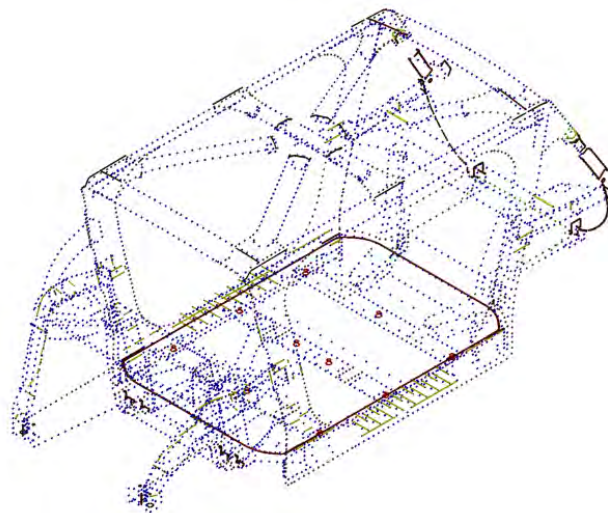


Figure 7.2.2.14 Body in White joining methods (See Appendix 4 for larger image)

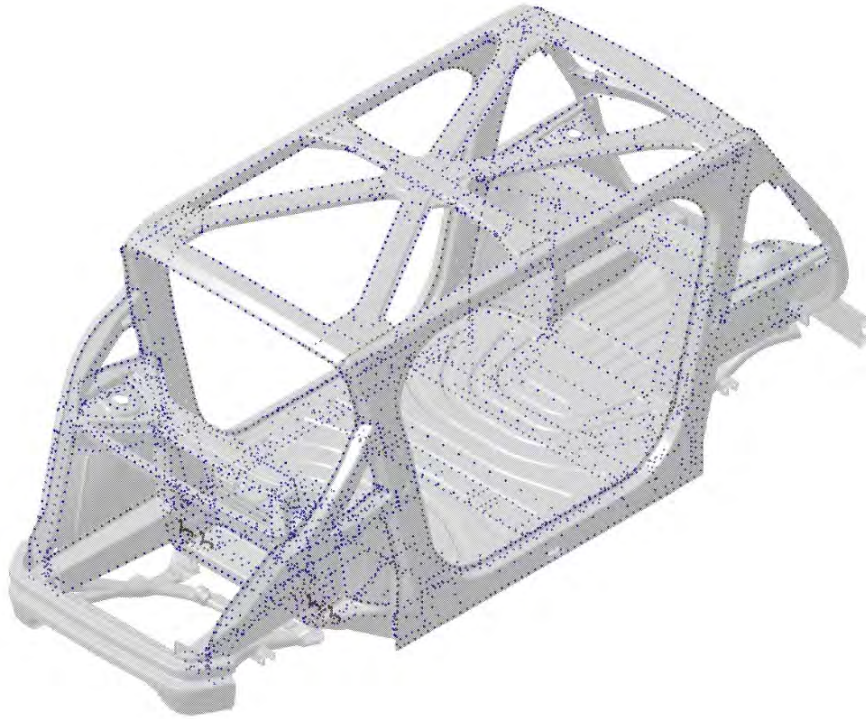


Figure 7.2.2.15 SEM1 Body in White spotweld locations

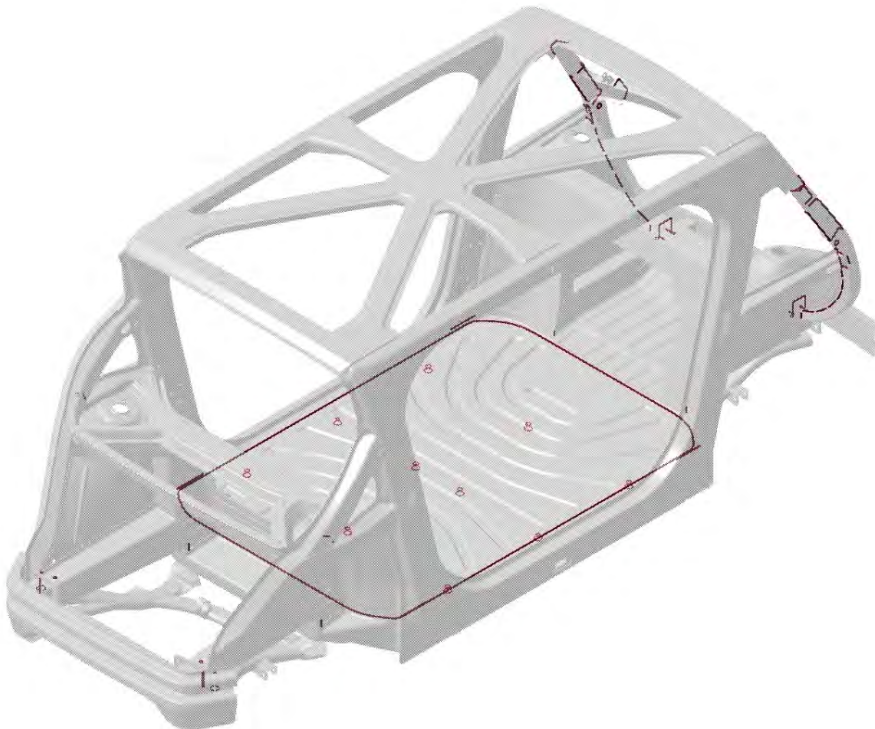


Figure 7.2.2.16 SEM1 Body in White laser weld locations

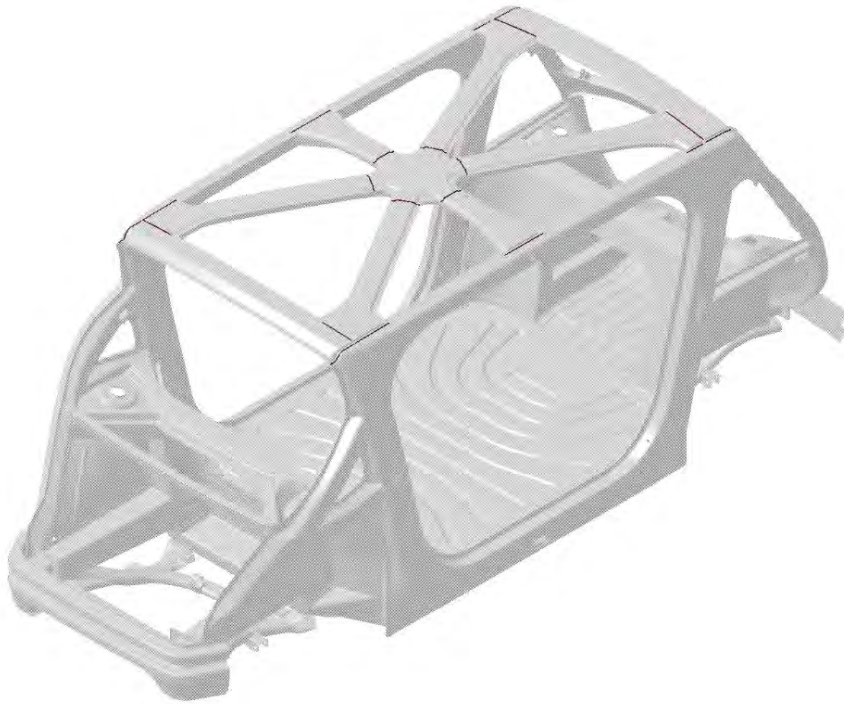


Figure 7.2.2.17 SEM1 Seam weld locations

Further localised stiffening features can be achieved with stamped steel body structures by the introduction of panel swaging. These are depressions or features which are oriented such that bending or in-plane stiffness is increased. These features are employed on large body panels such as front and rear bulkheads, floor panel and battery bottom cover and provide enable increased panel modal frequencies and static stiffness.

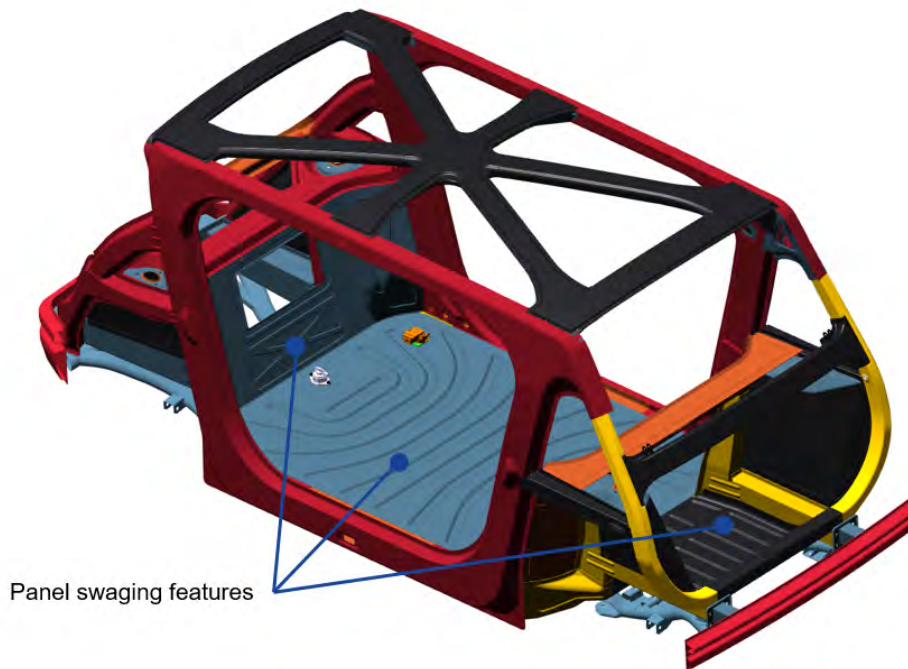


Figure 7.2.2.18 panel swaging features

Attaining a suitable body structure static torsional stiffness performance ensures that the body twist under static and dynamic (i.e. asymmetrical road loads) is well managed and the risk of quality issues such as squeak, rattle, fit and finish are minimised. Appropriate static torsional stiffness also ensures the vehicle chassis is able to perform as required, although specific attributes such as dynamics and handling will be less critical for a fully autonomous vehicle.

The Steel E-Motive body design features described in section 7.2.1 combine to deliver a lightweight and high stiffness structure. The static torsional stiffness of the body structure (including BIW, battery frame, bottom cover, subframes, front windscreen clip and bumper beams) was calculated as 63,285 Nm/deg versus a target of 25,000Nm/deg. The BIW alone achieves a torsional stiffness of 34,236Nm/deg. Figure 7.2.2.19 shows the predicted strain energy distribution and displaced shape of the body structure for the static torsional stiffness loadcase. The lower plot shows the rotational twist angle of the body structure along the X axis. It can be observed that the gradient of the line is fairly constant, demonstrating that the torsional stiffness of the body structure is consistent. Significant gradient changes in the plot would highlight localised regions of lower stiffness and it is evident that no such areas are present in the Steel E-Motive structure. This demonstrates a consistent, robust body structure design.

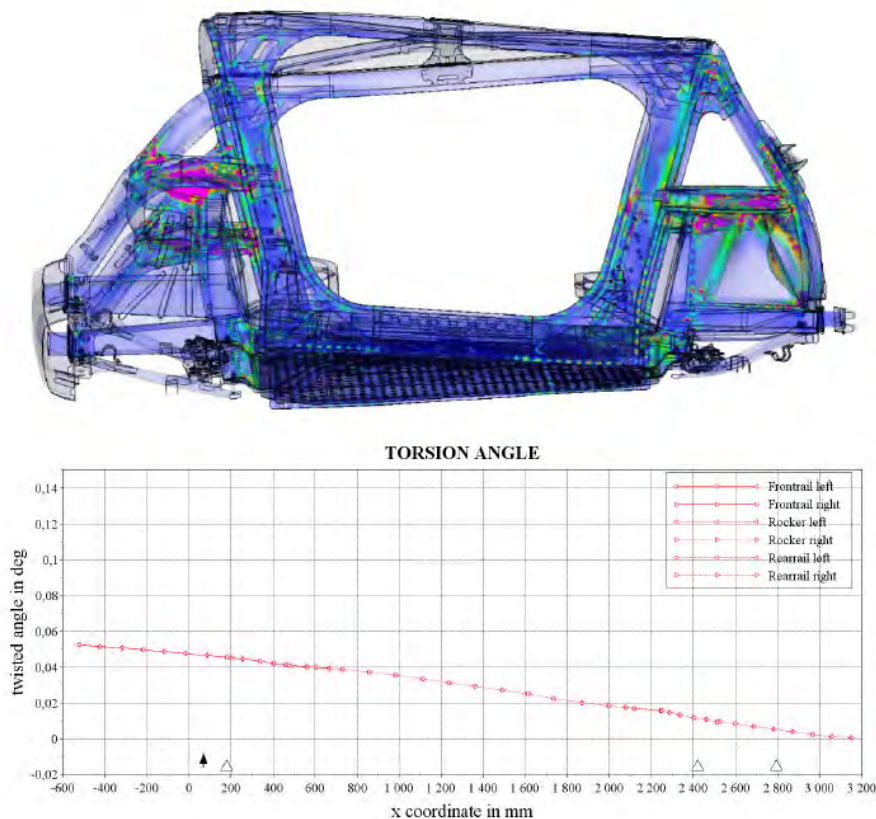


Figure 7.2.2.19 static torsional stiffness displaced shape, strain energy and rotation angle vs length results



The relative contribution of the body structure sub-assemblies to the static torsional stiffness performance were investigated in order to provide further insight into the Steel E-Motive concept. Figure 7.2.1.20 shows the torsional stiffness “walk” from BIW to dressed body. The study shows that the battery frame and cover provide the largest contribution to overall torsional stiffness. The rigidly connected front and rear subframes show a low contribution to torsional stiffness but this is likely caused by the battery frame and cover not being present in that specific loadcases. The combined effect of battery frame, battery cover and rigidly connected subframe is expected to be significant.

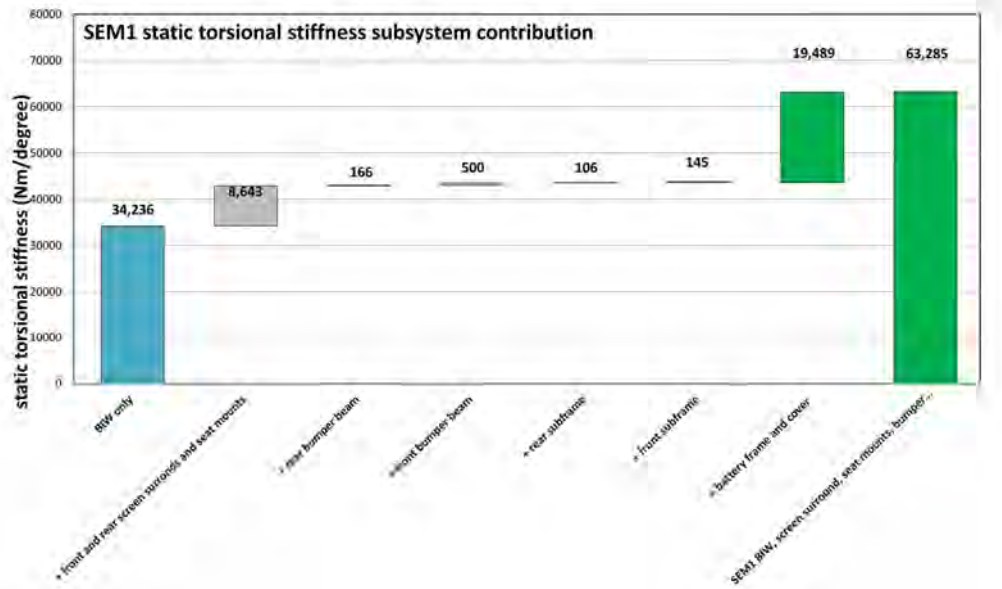
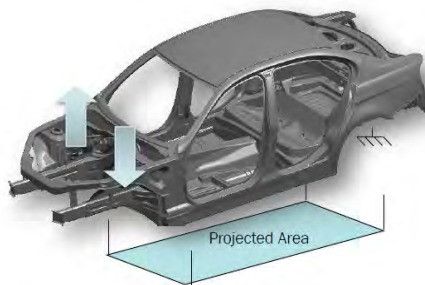


Figure 7.2.1.20 static torsional stiffness contribution

Lightweight design coefficient

Lightweight design coefficient is an industry standard metric to measure the weight efficiency of a body structure. It takes into consideration the static torsional stiffness, weight of the body structure and accounts of the dimensional size. Lightweight design coefficient is calculated using the equation below:



$$\text{Lightweight design coefficient} = \frac{\text{Body-in-white mass (kg)}}{\text{Area (m}^2\text{)} \times \text{Torsion stiffness (N-m/deg)}}$$

Figure 7.2.2.21 Lightweight design coefficient calculation

A low value of lightweight design coefficient demonstrates a “lightweight” design, where a low body structure weight, combined with high stiffness achieves a low value. Figure

7.2.2.22 shows the calculated lightweight design coefficient for Steel E-Motive compared to a number of current production passenger car body structures. Although the body structure design of Steel E-Motive is different to a conventional passenger car body structure, a comparison of the lightweight design coefficient provides a useful insight into performance of the structure. The comparison shows that the Steel E-Motive BIW achieves a very low value of lightweight design coefficient value of 1.87. The vehicles in the comparison are ICE 2010 to 2018 model year. Despite the difference in age and vehicle type, this still demonstrates that the Steel E-Motive concept is lightweight and high stiffness design.

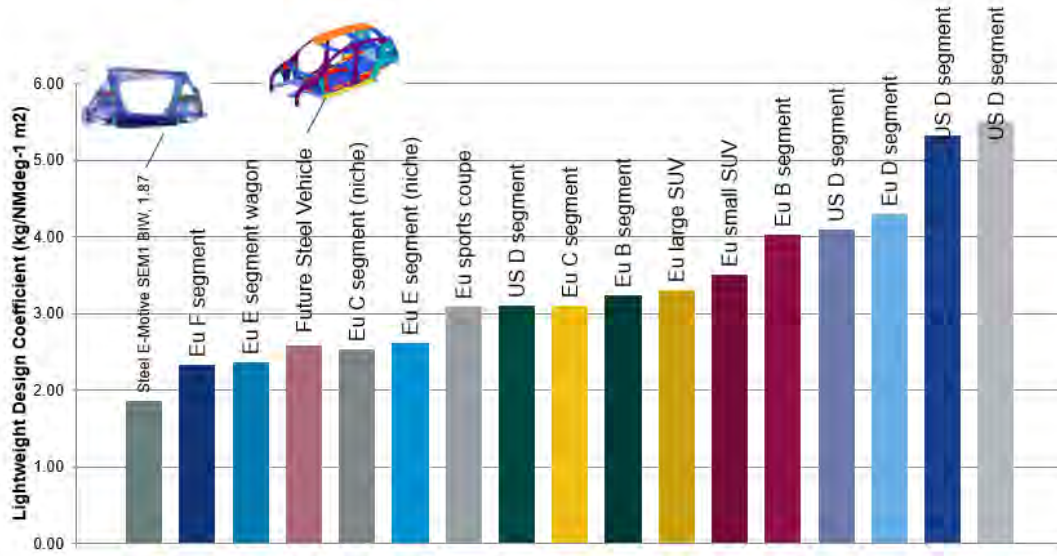


Figure 7.2.2.22 Comparison of lightweight design coefficient

Static vertical bending stiffness

As per the static torsional stiffness loadcases, vertical bending stiffness ensures the body achieves appropriate levels of quality as a result of vertical loads applied within the vehicle (such as passengers and luggage). The Steel E-Motive body structure comfortably achieves the vertical stiffness target and also demonstrate uniform stiffness throughout, as shown in Figure 7.2.2.23

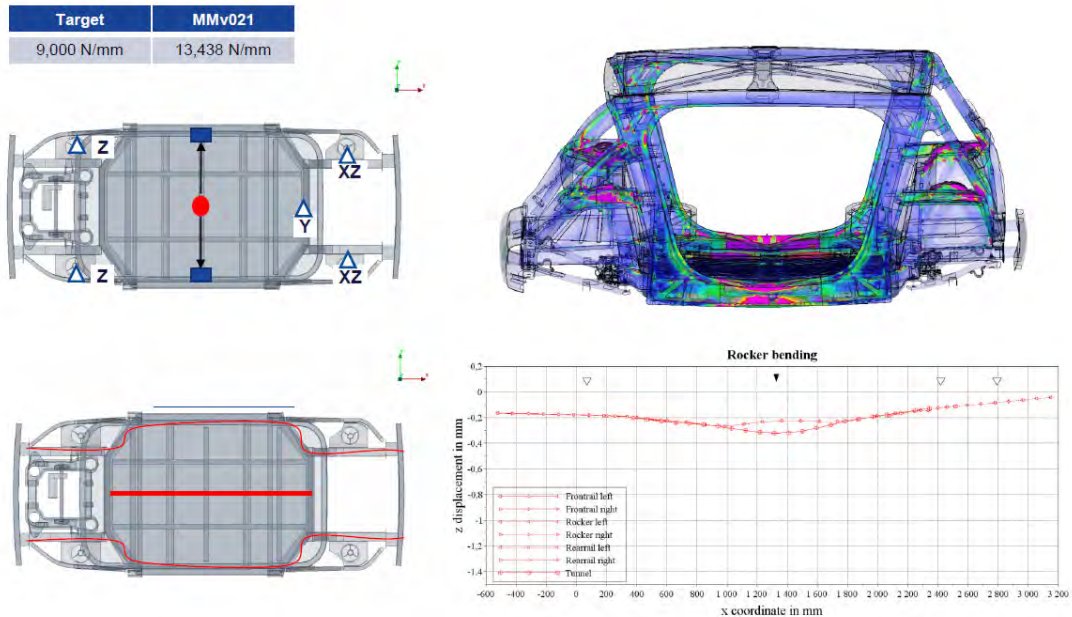


Figure 7.2.2.23 Steel E-Motive body structure static vertical stiffness performance

NVH performance

Noise, Vibration and Harshness (NVH) is an important attribute for achieving good passenger comfort performance. Unwanted and unacceptable levels of noise as a result of road/tyre, wind/aerodynamic and powertrain/motor noise can be a source of annoyance to passengers. Similarly, high levels of vibration in a vehicle can lead to passenger discomfort. Harshness defines the characteristics and interaction of noise and vibration. The Steel E-Motive vehicle has been engineered to achieve competitive levels NVH performance with specific focus on the body structure attributes. Low frequency vibration of the vehicle and body structure (i.e. <math><50\text{Hz}</math>) needs to be addressed in passenger cars due to the mechanics of human response and sensitivity. Many of the vibration excitation sources and system modal frequencies such as the primary vehicle rigid body modes (bounce, pitch, yaw), wheel hop modes, powertrain rigid body modes and body structure modes occur in a similar frequency band, and where coupling of excitation and modes occur can lead to resonances and high vibration amplitudes. To mitigate the risk of modal coupling, a *modal mapping* approach was taken to ensure that the primary excitation and response modes were sufficiently decoupled and acceptable levels of vibration and passenger comfort were achieved. Figure 7.2.2.24 shows the modal map table for the SEM1 vehicle. The x axis defines the modal frequencies and the vertical columns describe the primary excitation sources and the major subsystem modal frequencies. Targets for the body structure modal frequencies were based on achieving sufficient separation from excitation and other system modes. The target for the first body structure mode was set at greater than 28Hz. Additionally, the relatively high weight of the battery may cause a floor heaving mode and induce high vibration amplitudes in the body structure if coupled with other modes. An additional target for the first battery structure mode was defined as greater than 35Hz in order to attenuate the risk of high vibration response. With a unique exterior shape and vehicle interior enabled by the autonomous nature of Steel E-Motive concept, the internal air cavity resonance mode may shift significantly resulting in low frequencies booming noise. This risk was mitigated by FEA calculations to predict the modal frequencies of the interior

air cavity. A target of greater than 40Hz was defined and the first air cavity mode predicted to be 67Hz.

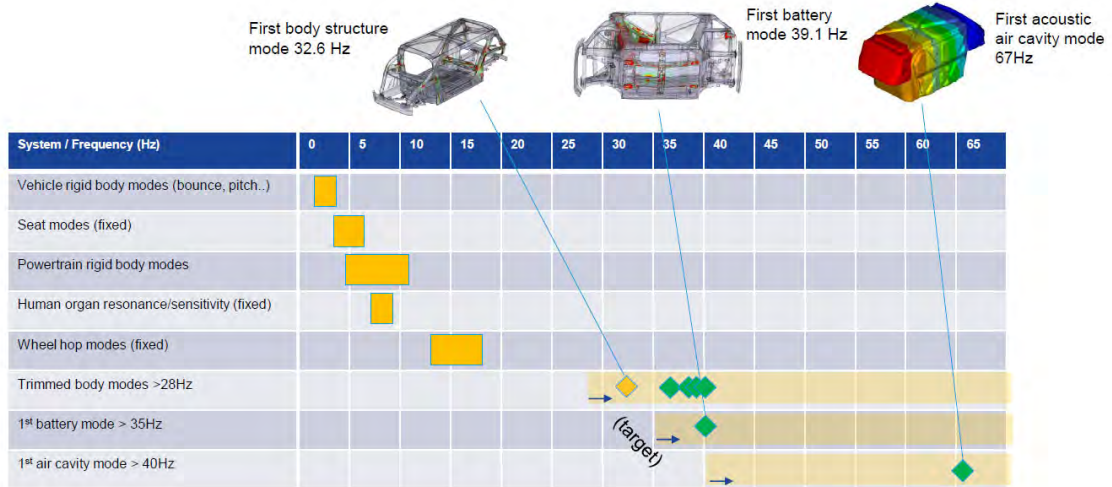


Figure 7.2.2.24 SEM1 Vehicle NVH modal map (See Appendix 4 for larger image)

Figure 7.2.2.25 shows the predicted first body structure mode and strain energy at 32.6Hz

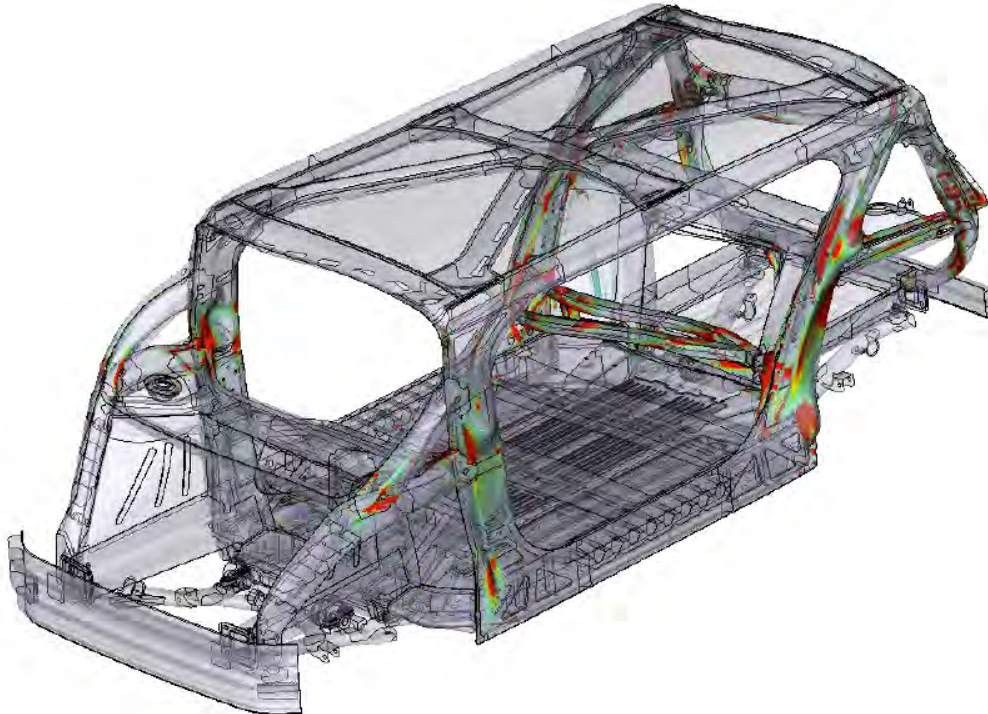


Figure 7.2.2.25 First body structure mode 32.6Hz (versus >28Hz target)

Typically for an automotive passenger car, the first mode shape of the body structure is a twisting or torsion type mode. With Steel E-Motive being a unique shape and construction, a lateral “lozenging” mode shape is observed. The mode shape and strain energy distribution demonstrates a very stiff lower body structure, achieved by the integrated battery structure, subframes, bottom cover, rocker section and floor design. The highest strain energy and compliance is observed in the A and C pillars. The frequency of the first body mode was increased to above the 28Hz target by the introduction of small internal reinforcements (bulkheads) to the A and C pillars as well as structural adhesive applied on the weld flanges.

The first battery mode shape is shown in Figure 7.2.2.26. The mode shape also includes a component of the front roof vertical mode. The displaced shape and strain energy distribution highlights that the battery carrier frame and lateral frame longitudinals and floor cross members contribute to the modeshape and frequency. Specific design and engineering focus was applied to these parts to ensure the first modal frequency of the installed battery structure was above the 35Hz target. Figure 7.2.2.X shows the final design of the battery frame longitudinals and cross members.

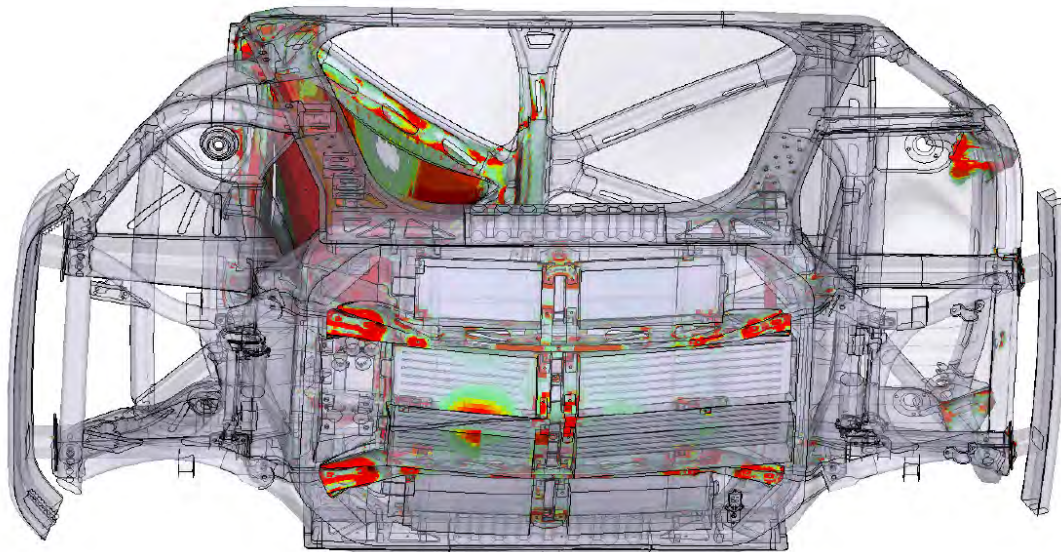


Figure 7.2.2.26 Battery structure first mode (39.1Hz versus >35Hz target)

Figure 7.2.2.27 shows the final design of the battery frame longitudinals and cross members. The longitudinals are a single piece cold stamping using DP450, which with a typical elongation of 25% enable the deep draw section (the width of the longitudinals is driven by the space allocation of the battery modules (not shown)). The single piece cold stamping removes any joins or welds in the parts, improving overall stiffness. Laser cut-outs are added to the longitudinals in specific locations to provide some weight reduction, whilst not compromising stiffness in the critical direction. The lateral cross members consist of top hat cross section profiles and roll stamped (upper) and roll formed (lower) parts. The battery frame cross members are bolted to the body structure floor cross members through fixings as shown in Figure 7.2.1.6. The combined design approach and integration approach delivers a first battery mode that meets the >35Hz target requirement.

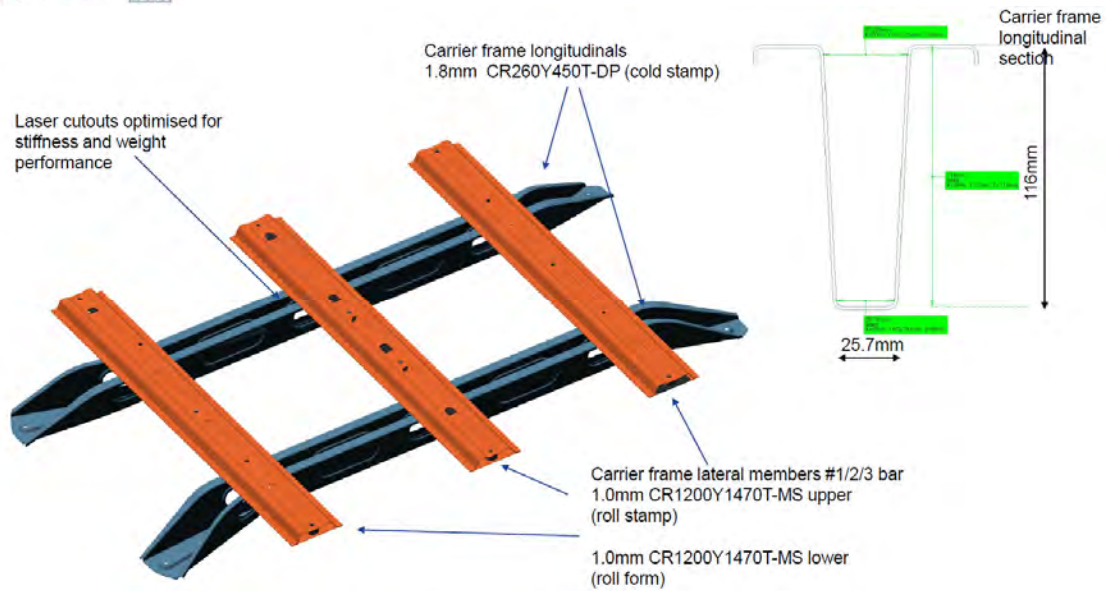


Figure 7.2.2.27 battery carrier frame structural members

Driving Point Inertance/Local Dynamics Stiffness

In addition to the modal mapping approach, the higher frequency structural response (50Hz to 250Hz) of the body structure was assessed and developed for Local Dynamic Stiffness (LDS). LDS is a measure of a key body attachment point dynamic stiffness to a unit dynamic excitation. It is a key factor in the design of body isolation systems and NVH performance for the chassis, body and powertrain systems. For an isolation system to function properly, the body structural dynamic stiffness should be at least 5 times the bushing dynamic stiffness with optimum performance achieved with 10 times stiffness. Suspension bushings are typically rubber or polymeric compounds with their stiffnesses tuned in specific directions for static and dynamic compliance requirements such as vehicle handling and powertrain primary modes. The target for the body side LDS performance is therefore dependant on the bushing isolation stiffness. As the primary focus of the Steel E-Motive programme was the development of the body structure, the design of the chassis system was not considered in detail, therefore the static and dynamic bushing stiffnesses were estimated based on data from vehicles with comparable suspension types and vehicle sizes. The driving dynamics requirements and considerations are assumed to be less significant for a fully autonomous vehicle where there is no direct handling feedback to the occupants. Attributes such as ride comfort and road disturbance impact are however important for achieving good passenger comfort. The evaluation considered the chassis bushes for the *critical loading directions* – these being the primary directions of road loads. For the front suspension, these are the front damper strut top mounts and the lower arm rear bushing and for the rear suspension, the rear damper strut top and the lower arm front bushing. Figure 7.2.2.28 shows the locations of the LDS measurement points, the assumed static bushing stiffness, the predicted local dynamic stiffness (LDS) values from the trimmed BIW model and the calculated ratio of LDS to bushing static stiffness. The results demonstrate the target ratio of 5 times factor of dynamic structural stiffness to dynamic bushing stiffness was achieved and a with a minimum factor of 8 achieved for all locations. This demonstrates that the body structure has sufficient dynamic stiffness performance for the chassis isolation system to operate correctly.

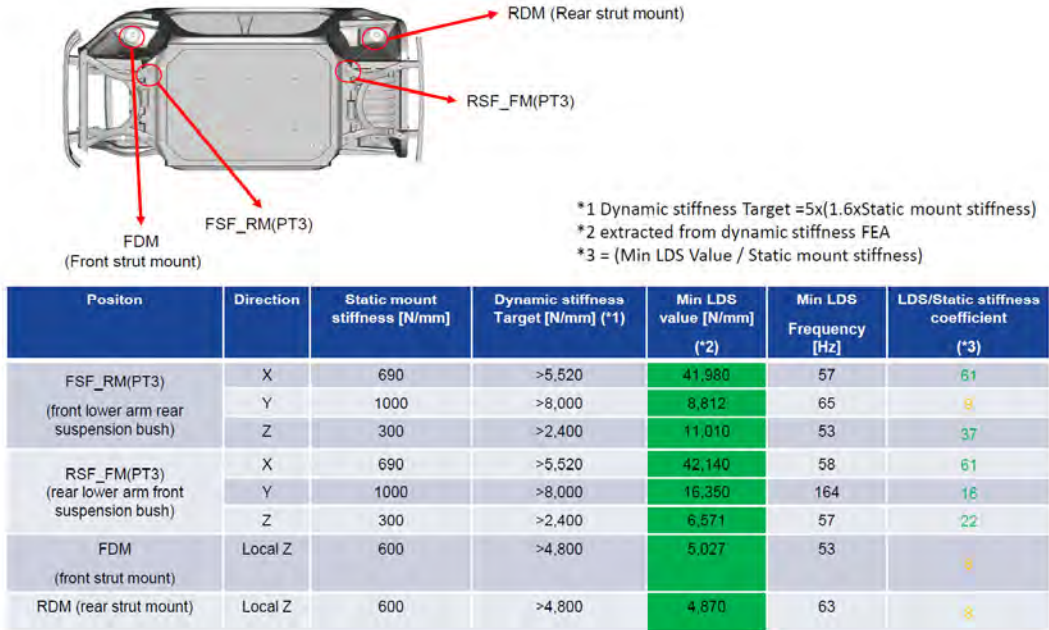


Figure 7.2.2.8 shows the predicted frequency dependant local dynamic stiffness curves for front strut mount in Z. Results for the all the attachment points are documented in Appendix 1 of this report.



Figure 7.2.2.8 Local Dynamic Stiffness (LDS) of front damper strut top (trimmed BIW FE analysis)

7.2.3 Steel E-Motive body structure design approach and features for front crash performance

The front zone of the Steel E-Motive body structure was designed to serve the following functions:

- Safety: Management of high-speed front crash loads and provide protection to occupants and high voltage battery
- Management of road induced loads and loads and vibrations from the powertrain
- Contribute to local and global body stiffness (as described in Section 7.2.2)
- Provide mounting and support for subsystems such as electric drive unit, cooling pack, HV electronics, HVAC, exterior panels, and glazing
- Management of low-speed collisions (low speed collision and pedestrian protection is generally managed by the bumper plastic trim and was therefore not specifically considered within this project. For a 2035 model year launch it is anticipated that significant enhancements would be made in active and reactive safety systems for low speed and pedestrian protection)

The majority of the front zone design decisions and AHSS grade selections were based on the requirements for front crash performance. This section is therefore dedicated to describing the strategy and design approach for achieving front crash performance. Figure 7.2.3.1 shows the major components or subassemblies of the front crash structure.



Figure 7.2.3.1 Primary subassemblies in SEM1 front crash structure (See Appendix 4 for larger image)

Table 4.2.3.1 describes the front crash loadcases and targets considered for the Steel E-Motive design. The main challenges and constraints when considering the development of the Steel E-Motive front crash structure are listed below:

- Compact vehicle size, short front overhang, short crush distance, challenging to manage crash loads. Challenging to balance FFB and SORB crash requirements

- The front occupants were positioned in a rear facing forward position, taking advantage of the fully autonomous functionality of the vehicle. This places them closer to the front crash impact zone, resulting in a greater challenge for their protection
- Electric Drive Unit (EDU) package in front compartment. The EDU is very stiff compared the surrounding body structure. In a front crash event, the EDU may “lock out”, resulting in high crash pulse (deceleration loads) and intrusion into the front bulkhead

Section 6.3.6 describes the strategy and approach taken for the Phase 1 development of the front crash structure. The development in Phase 2 focussed on refining and optimising the front crash structure and fine tuning of the AHSS grades and gauges to ensure that the crash targets were achieved, as well as other performance targets such as stiffness and weight. The strategy for the management of the front crash loads was carried over from Phase 1. For the USNCAP 56kph FFB and IIHS 64kph ODB tests the crash loads were managed primarily through the front longitudinal crash rails, providing a “crush zone” for the kinetic energy to be contained and converted to crush energy and the vertical dash braces, #1 bar and front bulkhead providing crush load reaction and preventing intrusion to the cabin. Figure 7.2.3.2 and 7.3.3.3 shows the front zone crush deformation behaviour throughout the stages of the USNCAP 56kph FFB loadcase. The deformation mode is comparable for the IIHS 64kph ODB test, with a single rail being the crushable element.

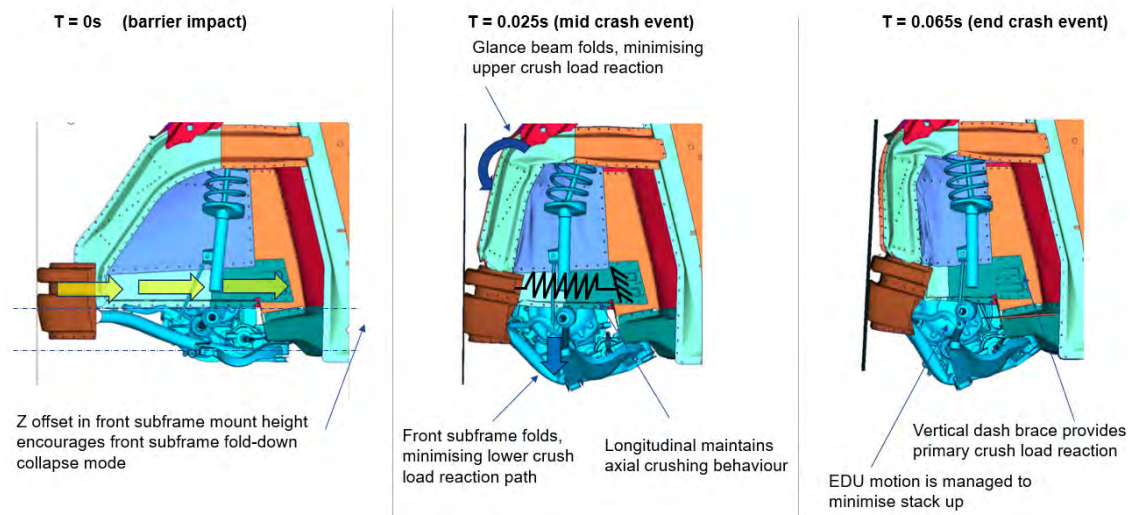


Figure 7.2.3.2 USNCAP 56kph FFB crash test. Vehicle CAE simulation showing the front crush zone deformation behaviour (some parts removed for clarity) (See Appendix 4 for larger image)

The front longitudinal crush rails are engineered to be the primary absorbing elements in the FFB and ODB tests. The rails are cold formed tailor welded blank Dual Phase grade.

The geometry and AHSS grade selection of the front subframe helps to promote a folding collapse mode which minimises longitudinal crush load reaction. The subframe collapse mode is mirrored by the glance outer beam, which also folds around a hinge point in the Z plane in line with the strut tops.

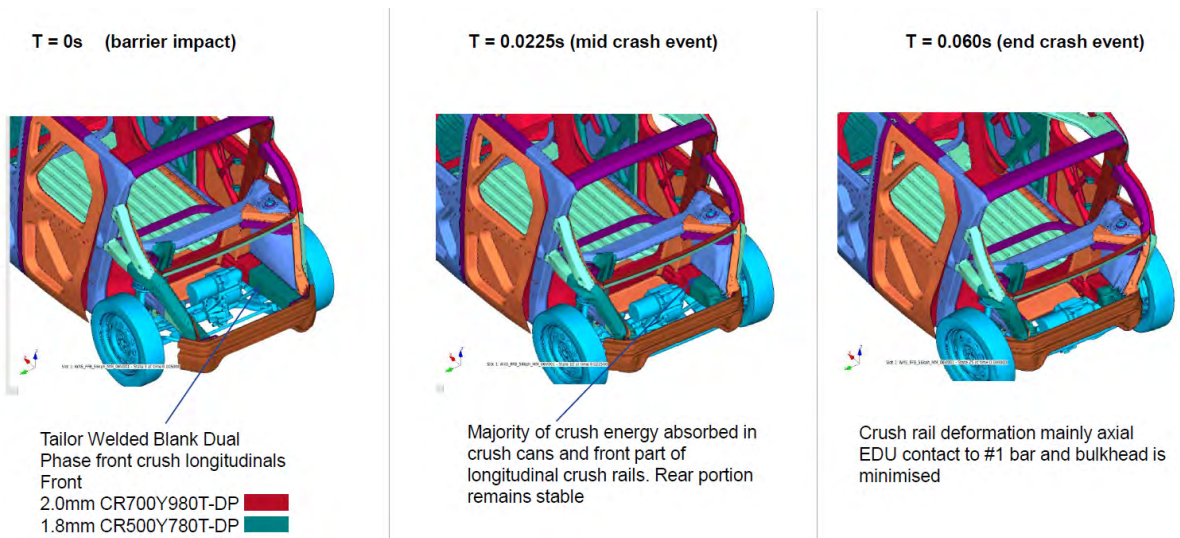


Figure 7.2.3.2b USNCAP 56kph FFB crash test. Vehicle CAE simulation showing the front crush zone deformation behaviour (some parts removed for clarity) (See Appendix 4 for larger image)

Figure 7.2.3.3 shows the vehicle deceleration profile for the USNCAP 56kph FFB loadcase. The peak (instantaneous) predicted pulse is 33.1g and average deceleration rate is 29.9g

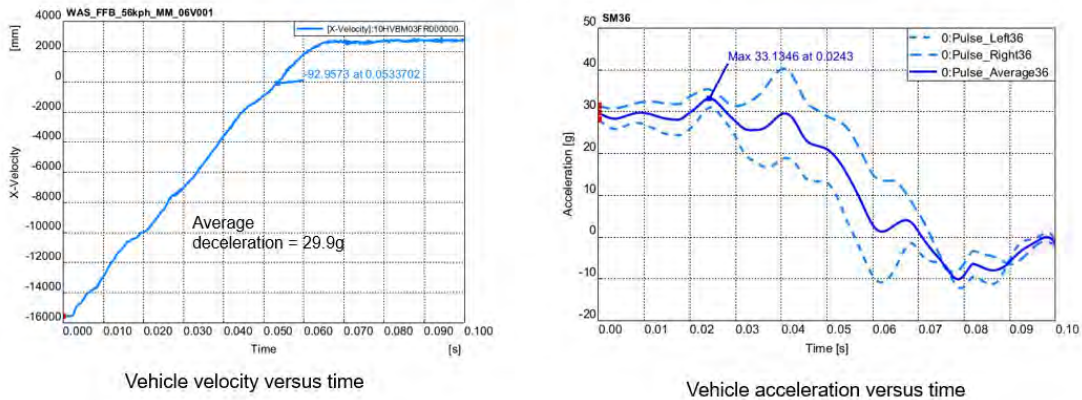
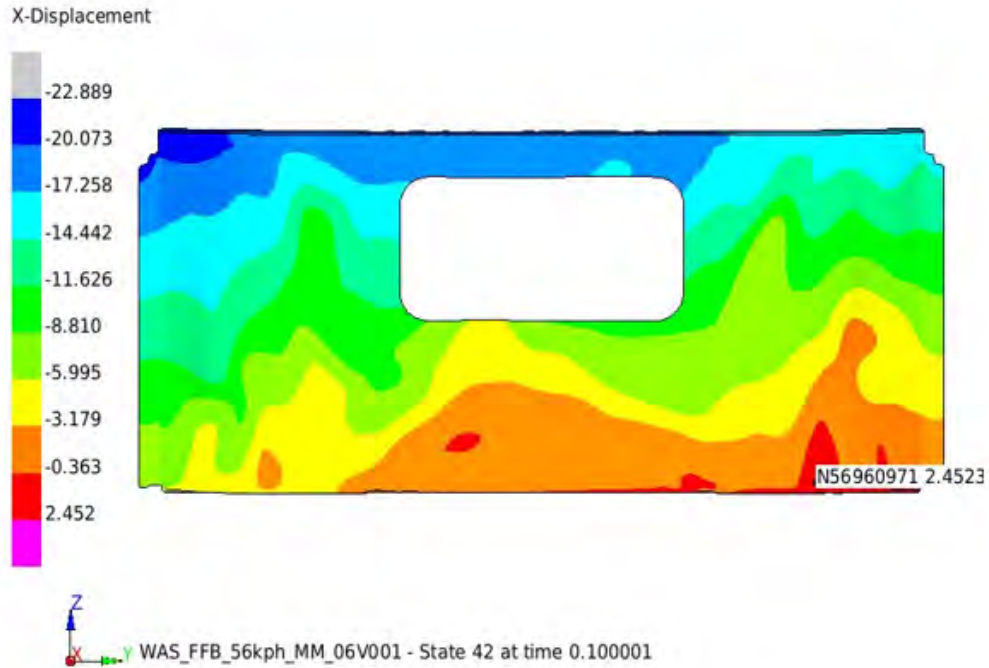


Figure 7.2.3.3 USNCAP 56kph FFB, predicted vehicle pulse (measured at BIW floor equivalent B pillar position)

Figure 7.2.3.4 shows the predicted intrusion values at the front bulkhead, the maximum value being 2.4mm.



The peak pulse (33.1g) and maximum intrusion (2.4mm) are well within the target values of 35g and 40mm. This suggests that a “good” level of crash protection is provided to the occupants.

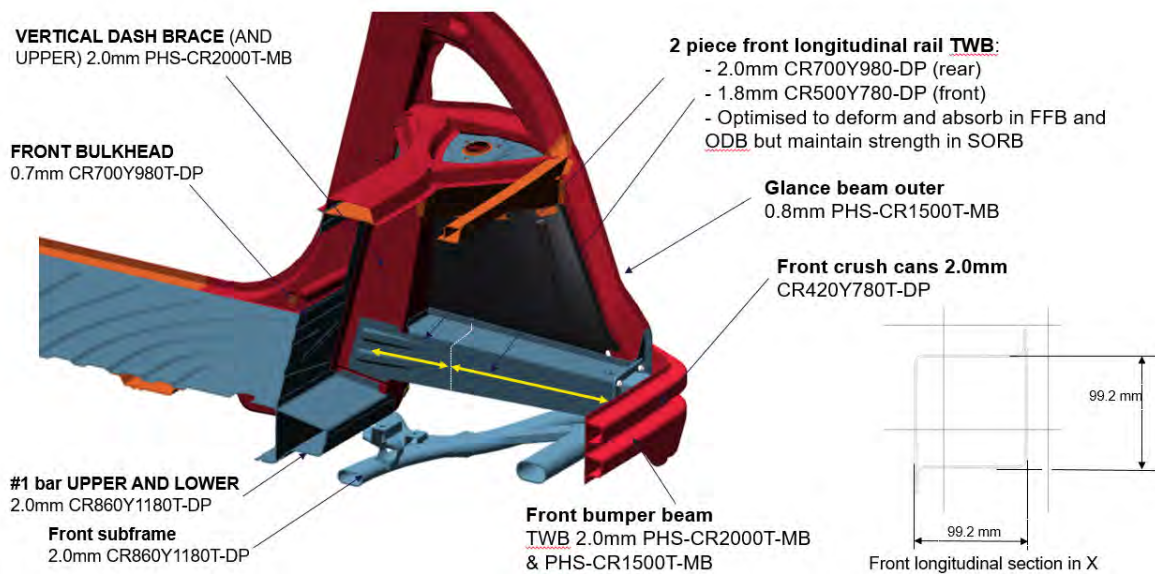


Figure 7.2.3.5 Front crash FFB and ODB key components and AHSS grades & gauges (See Appendix 4 for larger image)

The key elements of the USNCAP FFB and IIHS ODB front crash structure are shown in Figure 7.2.3.5. The front crash performance can be attributed to the combination of design

and AHSS grade selection. The front crush longitudinal rails are comprised of 2 cold stamped “L” profile sections, spot welded along the length. Each section is a Tailor Welded Blank (TWB) with the forward section being 1.8mm CR500Y780-DP and the rear section 2.0mm CR700Y980-DP. The forward section enables the axial crush and the higher strength and stiffer rear section maintains the rail integrity at the interface to the vertical dash brace. The TWB provides an efficient method of achieving different mechanical properties within a single stamped component. The 2 L sections form a closed box section, approximately 99mm square. The front subframe and glance beam outer are engineered to fold in the FFB and ODB crash loadcases as shown in Figure 7.2.3.2. The front subframe is 2.0mm CR860Y1180T-DP throughout and the glance beam outer is 0.8mm PHS-CR1500T-MB. The glance beam outer’s primary function is management of loads in IIHS SORB loadcase and is discussed in detail later. The front subframe gauge and grade provides the stiffness and strength required for chassis loads (durability) whilst enabling appropriate collapse in FFB and ODB. The front subframe construction also contributes to the IIHS SORB crash performance (discussed later). The front longitudinal rails join to the vertical dash brace which forms part of the occupant protection zone as shown in Figure 7.2.3.6. The function of the vertical dash brace is to provide load reaction to the longitudinal crush rails and minimise intrusion into the cabin. A high UTS is required for these parts and given the geometry/shape requirements 2.0mm PHS2000 grade was selected. The lower vertical dash brace provides some crash and body stiffness load transfer to the battery carrier frame longitudinals and is also 2.0mm PHS2000 grade. The lower vertical dash brace parts also house the mounting brackets for the front subframe rear mounting point. The two #1 bar lateral members consist of an upper and lower cold stamped CR860Y1180T-DP and provide intrusion protection to the propulsion battery and also contribute to global body stiffness. The torque box provides some crash load reaction and also body stiffness contribution. These are cold stamped in a 3rd generation AHSS, a high-formability dual phase (DH) grade enables a 1180MPa UTS and up to 10% total elongation allows the subassembly to be made from two parts per side. The front bulkhead provides the final element of the crash intrusion prevention structure and being a large panel with high weight sensitivity and high strength requirement is made from 0.7mm CR700T980T-DP grade.

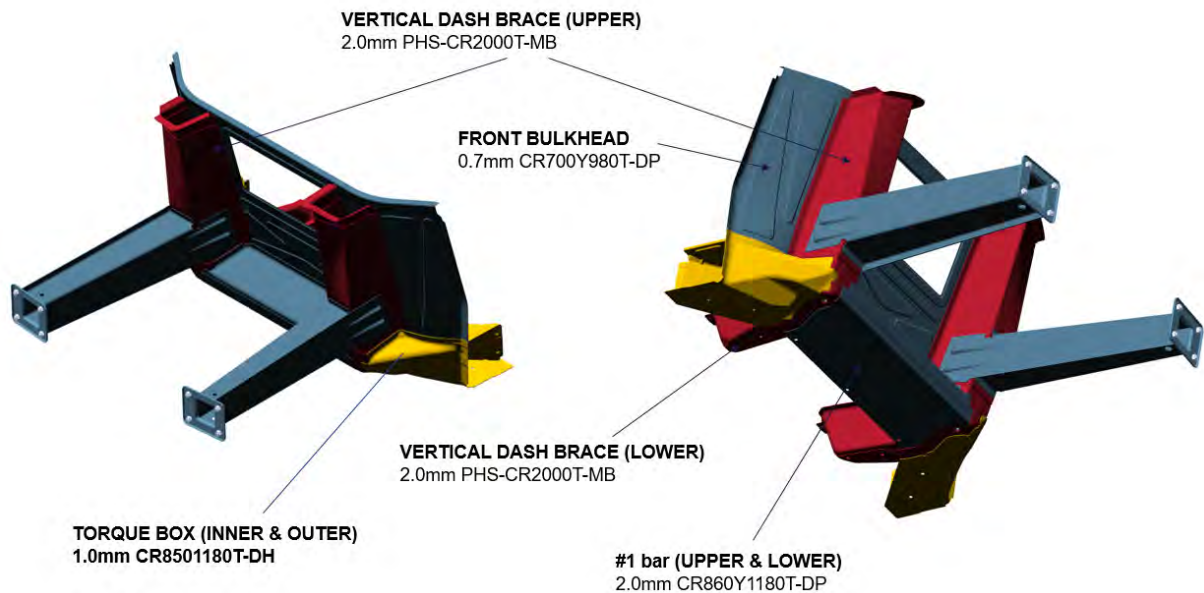


Figure 7.2.3.6 Front crash structure, components and AHSS grades contributing to intrusion prevention

To summarise, the Steel E-Motive front crash performance for the USNCAP 56kph FFB and IIHS 64kph ODB tests can be attributed to the following body structure design features:

- Box section profile longitudinal crush members. AHSS TWB with 1.8mm DP780 and 2.0mm DP980 enabling the progressive and controlled crush behaviour
- Front subframe and glance beam outer structures engineered to fold in FFB test. This enables the longitudinal to crush in a primary axial direction, maximising the crush efficiency and enabling a steady deceleration rate during the crash event. Whilst these components fold in the FFB and ODB loadcases and enable the crush longitudinal to work effectively, the components behave differently in the IIHS SORB loadcase where high lateral load reaction is required to achieve glance off
- Crash load reaction and intrusion members. The PHS2000 vertical dash brace, DP1180 #1 bar, DP980 front bulkhead and DH1180 torque box combine to manage the crash loads and minimise intrusion levels to the cabin

The Steel E-Motive vehicle is also engineered for the IIHS 64kph Small Overlap Rigid Barrier (SORB). This is a challenging test due to the high vehicle impact speed, rigid barrier type and the initial frontal impact overlap of 25%. The approach and strategy for managing the test was devised in the earlier phases of the project and applied to the final concept in Phase 2 (Section 6.3.6). The “glance off” strategy was adopted in order to reduce the conversion of moving vehicle kinetic to crush energy and minimise the resultant deceleration pulse and intrusion levels. Figure 7.2.3.7 to Figure 7.2.3.9 show the key stages of the SORB crash event and the design approach for how the glance off was achieved. The crash event can be broken down into the 3 stages: Stage 1 initial impact with the SORB barrier, Stage 2 mid impact, Stage 3 final stage. As discussed in Section 6.3.6, the strategy for achieving glance off in the Steel E-Motive concept was to initiate and maintain sufficient vehicle lateral acceleration during the SORB crash event such that the vehicle lateral displacement was sufficient for the vehicle to be deflected from the barrier. The high lateral acceleration was achieved by developing an AHSS front crash structure that provides sufficient lateral force reaction with the SORB barrier. This requirement for lateral force reaction ability (or strength) conflicts with the USNCAP FFB and IIHS ODB requirements for absorption or crush longitudinally. The careful design and AHSS grade assignment of the front crash structure enabled both requirements to be met.

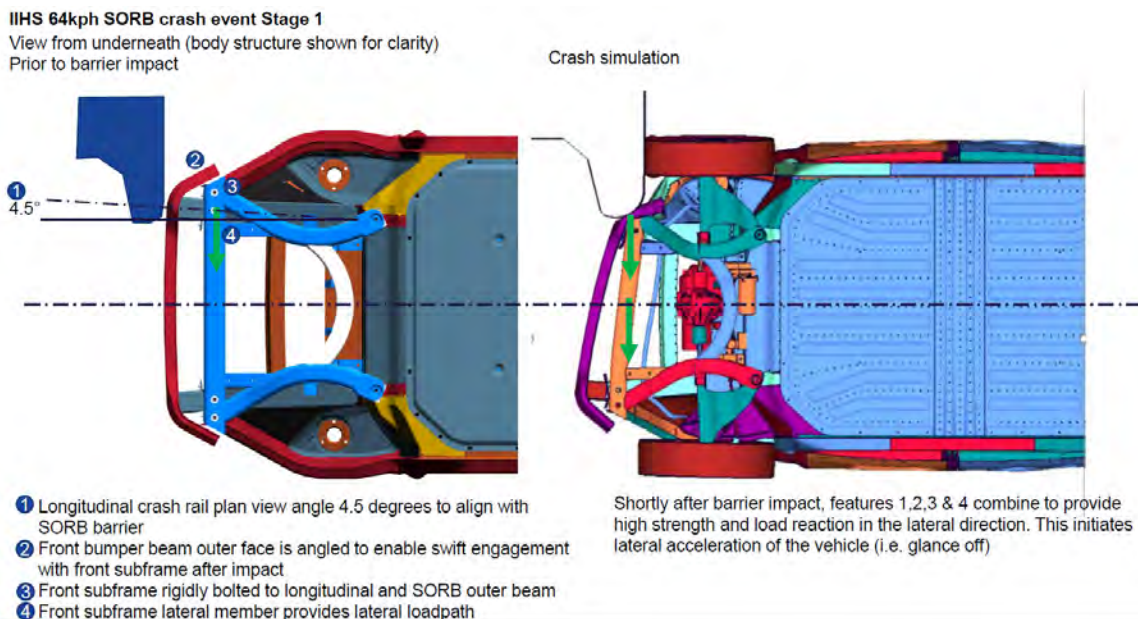


Figure 7.2.3.7 IIHS 64kph SORB crash loadcase, impact Stage 1. Design features and crash simulation results.

The initial impact stage (1) of the IIHS SORB crash event is critical for initiating lateral acceleration and deflection from the barrier. The Steel E-Motive front crash structure employs a number of features to achieve this. Firstly, the longitudinal crash rail has a plan view angle of 4.5 degrees. A number of crash simulation iterations were performed to determine the optimum angle of the rail. Angling the rail greater than 4.5 degrees resulted in significant initial crush and collapse of the rail, resulting in the front body structure not being able to withstand the barrier loads through the later stages of the crash event. With an angle of less than 4.5 degrees, the vehicle was observed to “skid” along the longitudinal rail. The front bumper beam profile was angled (in plan view) to align with the shape of the SORB barrier. During initial impact, the front bumper beam deforms slightly and contacts the front subframe, whilst still maintaining contact with the SORB barrier. With the subframe rigidly bolted to the BIW, this provides a direct lateral loadpath from the SORB to the front subframe and body structure. A lateral cross member is positioned at the front of the front subframe to provide a loadpath from the impact side of the vehicle to the non-impact side (left to right in the case of the example shown). Despite the high magnitudes of forces generated, the design features and AHSS properties provide sufficient strength and structural integrity react the SORB barrier loads and initial lateral acceleration of the vehicle.

As the SORB crash event progresses, it is important to maintain the structural integrity of the front crash structure, particularly in the lateral direction. The features shown in Figure 7.2.3.8 show how this was achieved in the Steel E-Motive concept.

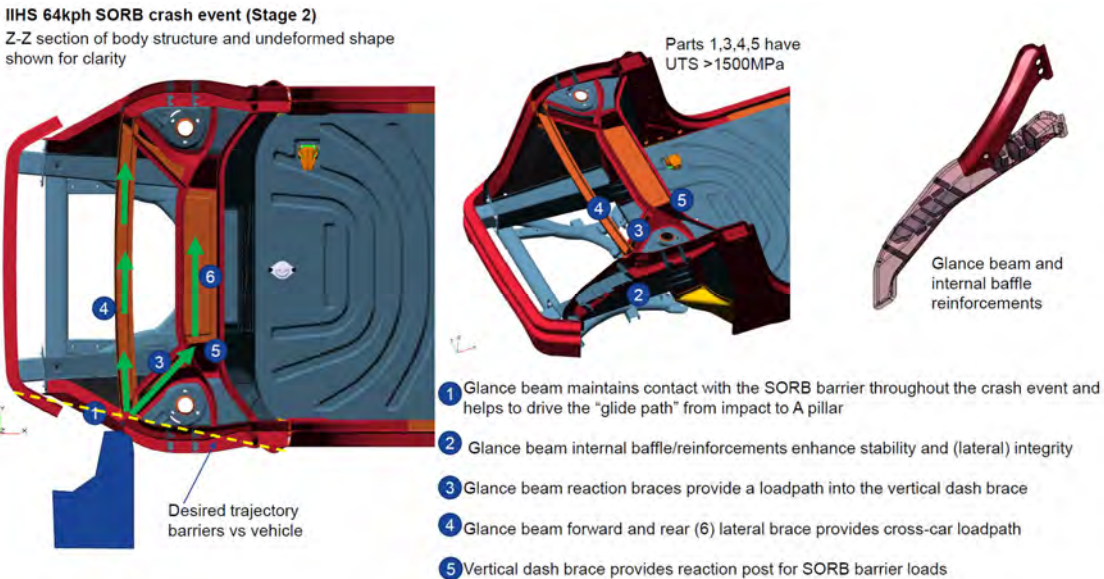


Figure 7.2.3.8 IIHS 64kph SORB front crash. Stage 2 of the crash event, showing the key elements of the body structure that enable and maintain the glance off

The glance beam is a fundamental component in the SORB crash event. It’s geometry approximates the desired trajectory of the barrier to vehicle contact point, starting at the outer face of the longitudinal crush rails and ending by A pillar. The specific plan view profile was optimised to ensure the vehicle glides along the barrier throughout the crash event. Despite the very high loads experienced by the direct contact to the SORB barrier the PHS1500MPa UTS AHSS grade ensures the glance beam largely remains intact and is able to distribute the crash loads to the glance reaction and lateral beams. The DP780 MPa

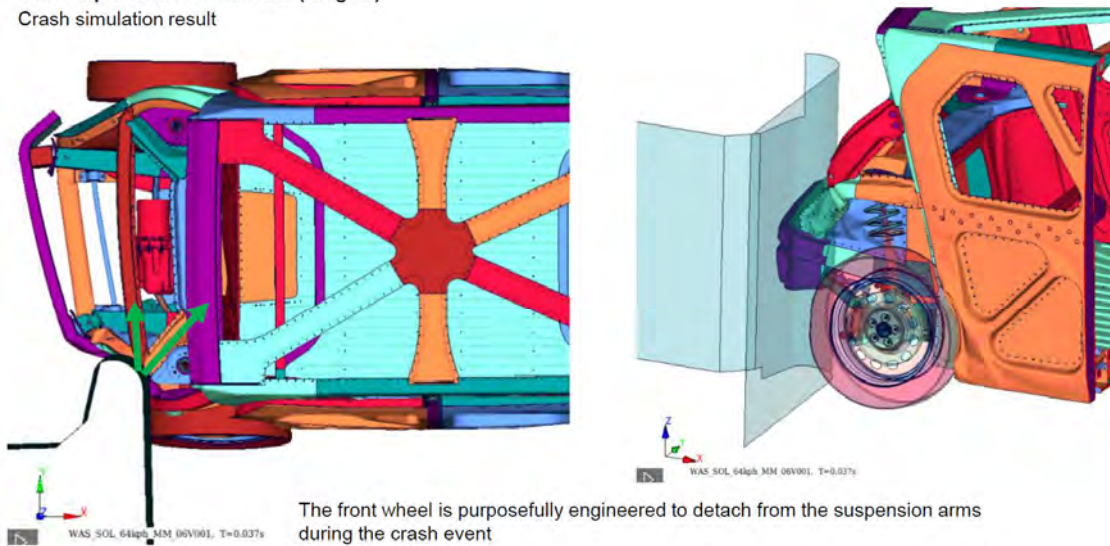


internal baffles have been optimised to provide additional support and reinforcement to the glance beam section in the lateral direction whilst allowing the beam to fold and collapse in the USNCAP 56kph FFB and IIHS 64kph ODB tests. The glance beam reaction and forward lateral beams (parts 3 and 4 shown in Figure 7.2.3.8) provide loadpaths cross-car and into the vertical dash brace (5). The front damper strut cross members (5) provide an additional cross-car loadpath.

Figure 7.2.3.9 shows the crash simulation results at Stage 2 of the crash event (37ms). The results show that the front crash rail structural integrity is generally maintained. Whilst the glance beam undergoes significant collapse and deformation, it maintains its ability to provide a loadpath to the glance lateral and reaction beams. These structures and loadpaths combine to ensure that the vehicle continues lateral acceleration and deflection from the SORB barrier. An important feature of the SORB glance strategy is to purposefully engineer the front wheel on the struck side to detach during the event. If the front wheel remains within the wheel well, it can provide a loadpath from the SORB barrier to the rocker and this can induce a pivot or hinging effect and limit the lateral deflection of the vehicle from the barrier. Crash simulations confirmed this behaviour.

IIHS 64kph SORB crash event (Stage 2)

Crash simulation result



The front wheel is purposefully engineered to detach from the suspension arms during the crash event

This ensures the wheel "departs" the wheel well. If the wheel remains in the wheel well it creates a loadpath to the barrier and can impinge the ability of the vehicle deflect laterally

Figure 7.2.3.9 IIHS 64kph SORB crash simulation at 37ms (Stage 2)

Stage 3, the final step in the SORB crash event relies on structure around the front damper strut mounts and A pillar to provide loadpaths. It is important to maintain the lateral glance movement of the vehicle in this stage of the crash event as the vehicle can easily "snag" on the A pillar. Figure 7.2.3.10 shows the key parts of the body structure that contribute the SORB crash event in Stage 3.

IIHS 64kph SORB crash event (Stage 3)
Z-Z section of body structure and undeformed shape shown for clarity

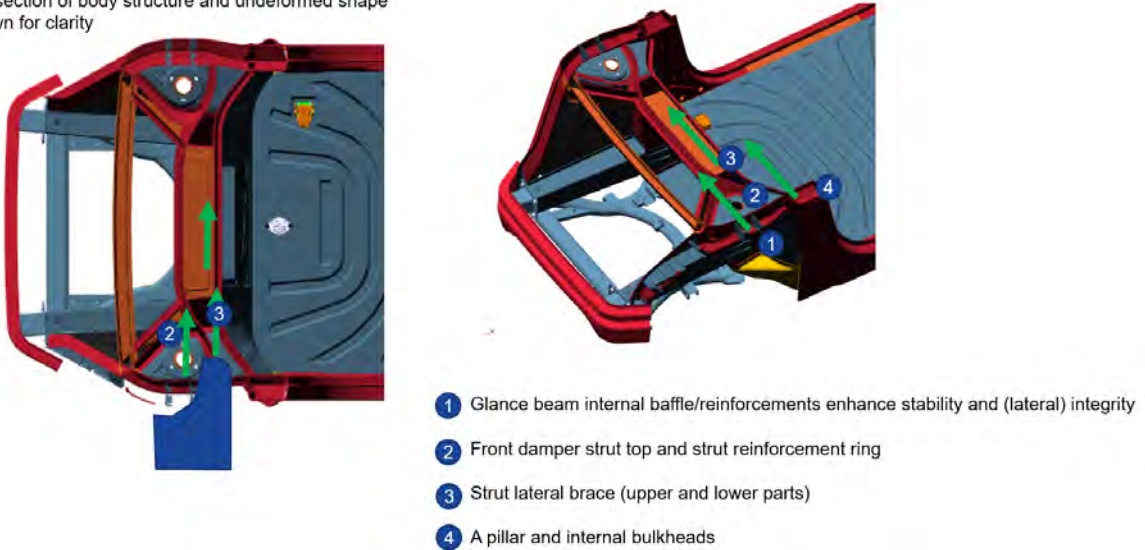


Figure 7.2.3.10 IIHS 64kph SORB front crash. Stage 3 of the crash event, showing the key elements of the body structure that enable and maintain the glance off

To maintain a lateral loadpath in the structure, further bulkhead reinforcements are placed inside the glance beam (1), in line with the front strut top mounts. The front strut top mounts (2) feature a DP1180 main panel (1.8mm) and a MS1470 strut reinforcement ring (2.0mm). This arrangement also provides good stiffness and durability performance. An integrated strut top lateral brace (3) consisting of upper (1.0mm PHS2000) and lower closing plate (1.0mm MS1470) completes the lateral loadpath. The A pillar provides the final component in the SORB event. By applying PHS2000 AHSS in 1.2mm for the inner and outer parts and using internal bulkheads or reinforcements in specific locations helps to maintain the integrity of the structure and the glance motion of the vehicle relative to the SORB barrier. The A pillar outer forms part of the door ring outer panel which is a Tailor Welded Blank and is critical for side crash protection (discussed later).

Figure 7.2.3.11 shows the crash simulation results for Stage 3 of the SORB crash event. The results show that the SORB barrier is close to the outer side of the vehicle, indicating that the vehicle is well on course to achieve a full glance off. Whilst the glance beam has undergone significant deformation, it maintains sufficient integrity to provide a loadpath to the strut mounts and lateral strut brace. The front wheel has completely detached from the chassis and is outboard of the wheel well. Despite some contact with the door outer skin, the wheel does not impact the vehicle glance behaviour.

IIHS 64kph SORB crash event (Stage 3)
Crash simulation result

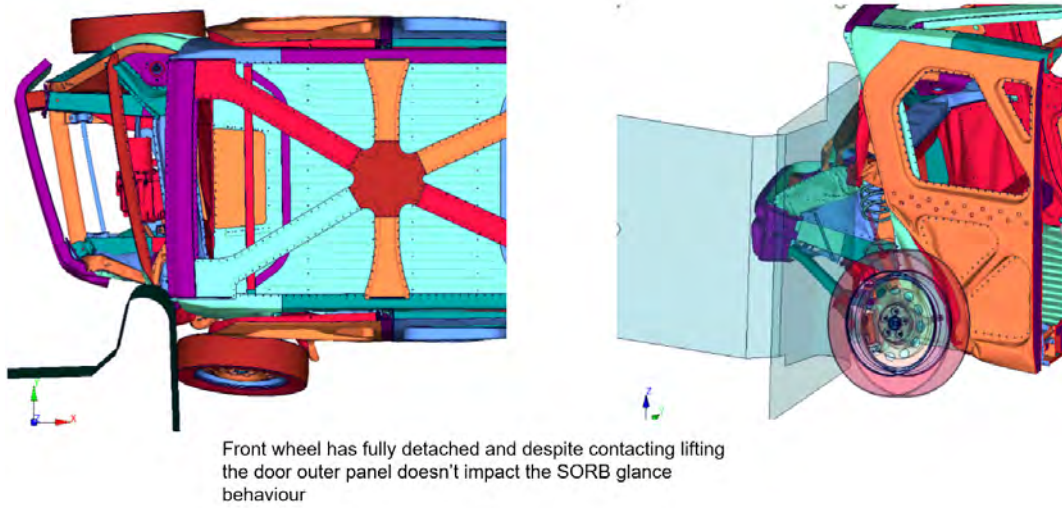


Figure 7.2.3.11 IIHS 64kph SORB crash simulation at 37ms (Stage 3)

The very high strength AHSS grades in this region do not impact the USNCAP 56kph FFB and IIHS 64kph ODB crash performance as they are outside (or rearwards) of the body structure crush zone. They also form part of the intrusion prevention zone or safety cell, providing protection for the vehicle occupants and battery.

The design approach and AHSS grade selection combine to produce impressive crashworthiness performance for the IIHS SORB loadcase, enabled by a vehicle full glance off from the barrier. Figure 7.2.3.12 shows the total lateral displacement of the vehicle over the duration of the SORB impact and the approximate alignment of the crash event Stages 1, 2 and 3.

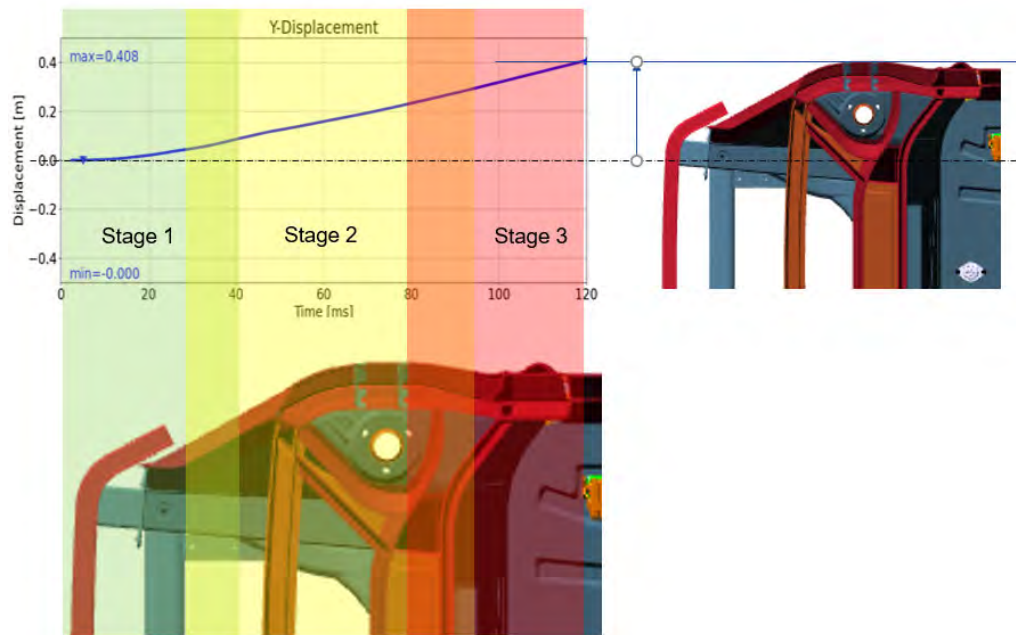


Figure 7.2.3.12 Vehicle lateral displacement vs time during SORB impact and the approximate alignment of the crash event Stages 1, 2 and 3.

Figure 7.2.3.12 shows the predicted intrusion levels and deceleration pulse from the crash simulation. The maximum intrusion levels fall within the IIHS “good” rating scale. A maximum vehicle crash pulse of 19.9g was predicted versus the 35g target.

IIHS 64kph Small Overlap Rigid Barrier (SORB) Predicted intrusion values

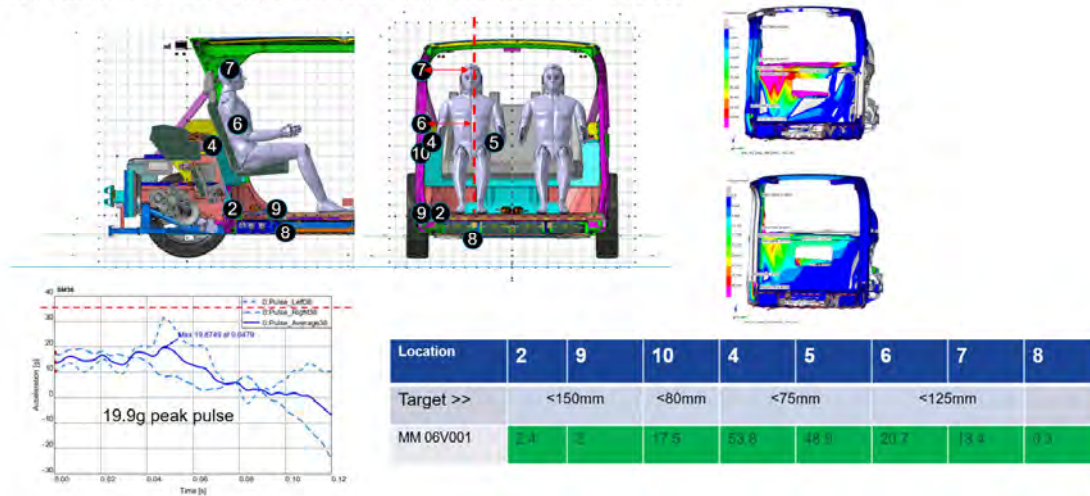


Figure 7.2.3.12 IIHS 64kph SORB vehicle crash simulation results. Predicted vehicle pulse and intrusion values.

The predicted intrusion levels are below the threshold for attaining the IIHS “good” rating. (note, this is the highest safety rating for the SORB test that can be achieved). The IIHS provide access to measured crash test result data for vehicles that have undergone testing within their facilities. Some of this data was extracted, processed and compared with the Steel E-Motive crash simulations results in order to further quantify and validate the performance. Figure 7.2.3.13 shows a graph comparing measured upper dash intrusion values (Y axis, cm) and vehicle pulse (X axis, g) for a sample of 8 current production vehicles, 4 vehicles having Internal Combustion Engines (ICE) and 4 Battery Electric Vehicles (BEVs). All vehicles are D segment sized sedan or Sport Utility Vehicles. During the SORB crash test, the vehicles were observed to either “glance” (or deflect/bounce) from the barrier or “snag”. (“Snag” meaning that the vehicle is fully decelerated by the impact, usually by the time the impact reaches the A pillar. Any remaining vehicle kinetic energy is then converted to vehicle rotation or yaw motion around a point at the A pillar). The results show that that 4 vehicles that have an observed “snag” crash behaviour tend to have higher upper dash intrusion and higher vehicle pulse levels than the “glance” behaviour vehicles. A lower crash deceleration pulse usually results in lower forces acting on the vehicle occupants and lower intrusion levels generally result in lower risk or magnitude of vehicle to occupant contact forces (the Safety Restraint System (seat belt and air bags) also have a significant influence on the forces witnessed by occupants and the subsequent injury levels). Lower intrusion and pulse values are observed in the “glance” vehicles as they maintain a greater forward velocity after the impact with the barrier, hence the deceleration rate is lower, resulting in lower forces and energy levels observed during the impact with the barrier. It should be noted that all 8 vehicles in the data sample achieve the IIHS “good” rating for the SORB test. The predicted results from the SEM1 vehicle crash simulation are plotted on the same graph and show that the vehicle deceleration pulse is comparable to those of the “glance” vehicles. The predicted SEM1 upper dash intrusion values are slightly higher than

the sample vehicles. This may be because SEM1 is a smaller vehicle than the comparative vehicles, having a lower crush length and dash panel closer to the frontal crush zone.

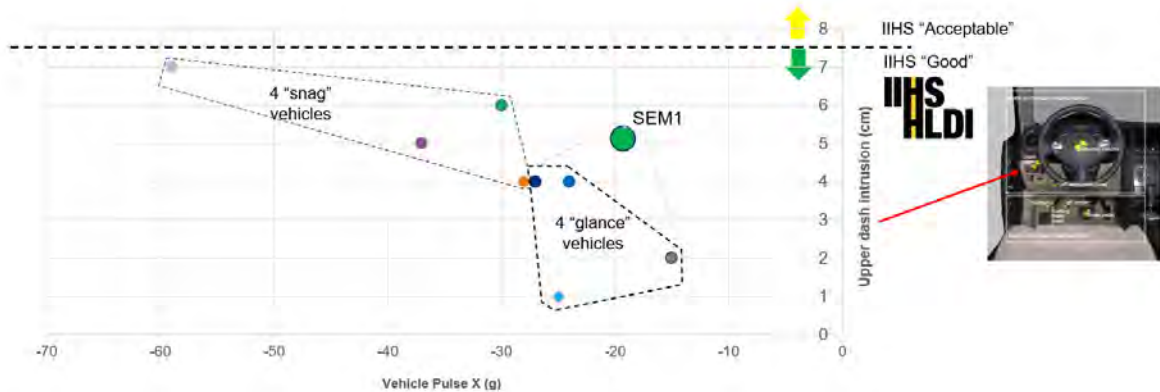


Figure 7.2.3.13 IIHS 64kph SORB crash test. Comparison of measured upper dash intrusion vs vehicle X pulse for sample of 8 vehicles. Data courtesy of <https://www.iihs.org/>

Figure 7.2.3.14 shows measured data for the same sample of vehicles, comparing vehicle frontal crash dummy Head Injury Criteria (HIC15), (X) and Vehicle deceleration pulse (Y axis, g). HIC15 is a measure of the likelihood and severity of head injury arising from an impact. The assessment is based on the magnitude and duration of acceleration experience by occupant (or crash test dummy) head in an impact. A lower HIC15 value suggests a lower risk and severity of head injury. A HIC15 value lower than 560 is required for vehicles to obtain the IIHS “good” safety rating. The Steel E-Motive programme did not consider crash dummy models in the vehicle simulations therefore no HIC data was calculated. Figure 7.2.3.14 shows a reasonable correlation between measured HIC15 values and vehicle deceleration pulse, with lower HIC15 values correlating to lower vehicle pulse levels. The 4 “glance” vehicles showed generally lower pulse and HIC15 levels than the 4 “snag” vehicles. Again, this can be attributed to the glance behaviour resulting in reduced vehicle velocity change during the impact event. With the Steel E-Motive vehicle achieving a predicted peak pulse of 19.9g, it could be expected that the resultant HIC15 values would be of a similar magnitude as the “glance” vehicles. This would be subject to the design and implementation of a suitable Safety Restraint System. Additionally, the different orientation of the front occupants in SEM1 should be considered when attempting occupant injury and safety assessments in SEM1. The front occupants are rearward facing, therefore the forces acting on the occupants will be different in location and magnitude to a conventional forward facing seating configuration. In a rear facing seat, the main deceleration loads acting on the occupants in a frontal crash event will be via the seat back. This has the potential to reduce loads on the occupant thorax, legs and arms but there is an increased risk of neck injury or whiplash if the head is not properly supported with a suitably designed headrest. For a taxi vehicle, with frequent changes in occupant size, seating technologies such as adaptive headrests may be required in order to ensure occupants are safely positioned in the vehicle and the risks of injuries due to collisions are minimised.

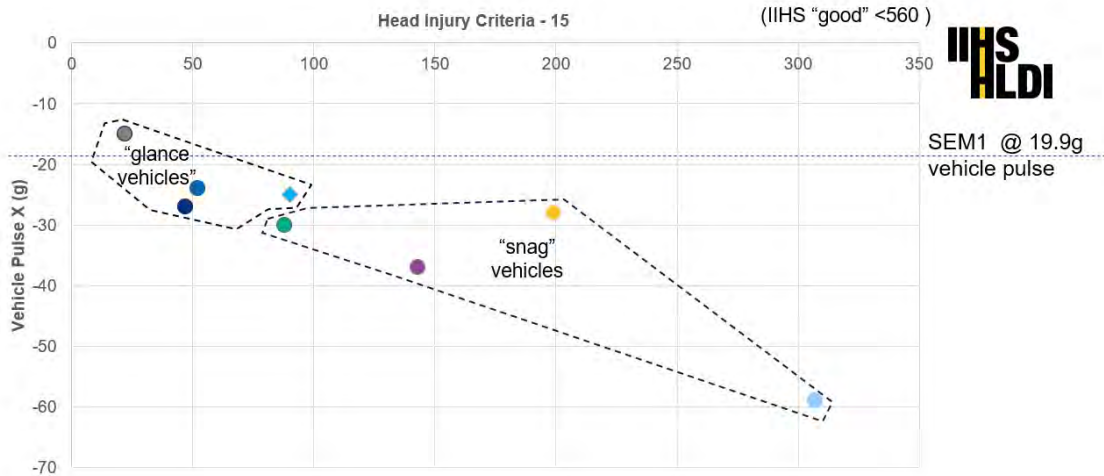


Figure 7.2.3.14 IIHS 64kph SORB crash test. Comparison of measured vehicle X pulse versus Head Injury Criteria for sample of 8 vehicles. Data courtesy of <https://www.iihs.org/>

The crashworthiness performance of a vehicle should consider the protection of occupants during the impact event itself and the post-event extraction and recovery of the occupants. Removal of the occupants firstly requires the side closures to be opened by the emergency services. Although not specifically engineered for in the Steel E-Motive project, any door locking mechanism and latches would be released or disengaged by the safety restraint system (e.g. air bags). Additional features would enable manual release and opening of the door by internal and externally mounted emergency access handles. Specific guidelines, regulations and tests are typically applied to ensure the forces required to open doors post-impact are not excessive and manageable by emergency services. Examples of this are a 750N maximum door load opening requirement assessed by EuroNCAP. Given the limitations of CAE tools applied for the Steel E-Motive concept, it was not possible to calculate the door opening load for SEM1, however, the efforts to open the door post-impact are generally driven by the level of crash deformation of the door aperture and door structure itself. A significant deformation of the door aperture can result in significant interference (or "jamming") between the door and body structure, which impinges the ability to open the door and extract the occupants. The door and door frame deformation as a result of the crash test loadcases was assessed in the CAE models during the Steel E-Motive project. The final design showed impressive performance as shown in Figure 7.2.3.14. The predicted door frame deformation for the most severe frontal crash loadcase (IIHS 64kph SORB) shows very minimal deformation, suggesting that the door could be opened post-impact within the expected requirements (exact physical tests would be required to validate this). The door frame construction and AHSS usage is discussed in Section 7.2.4.

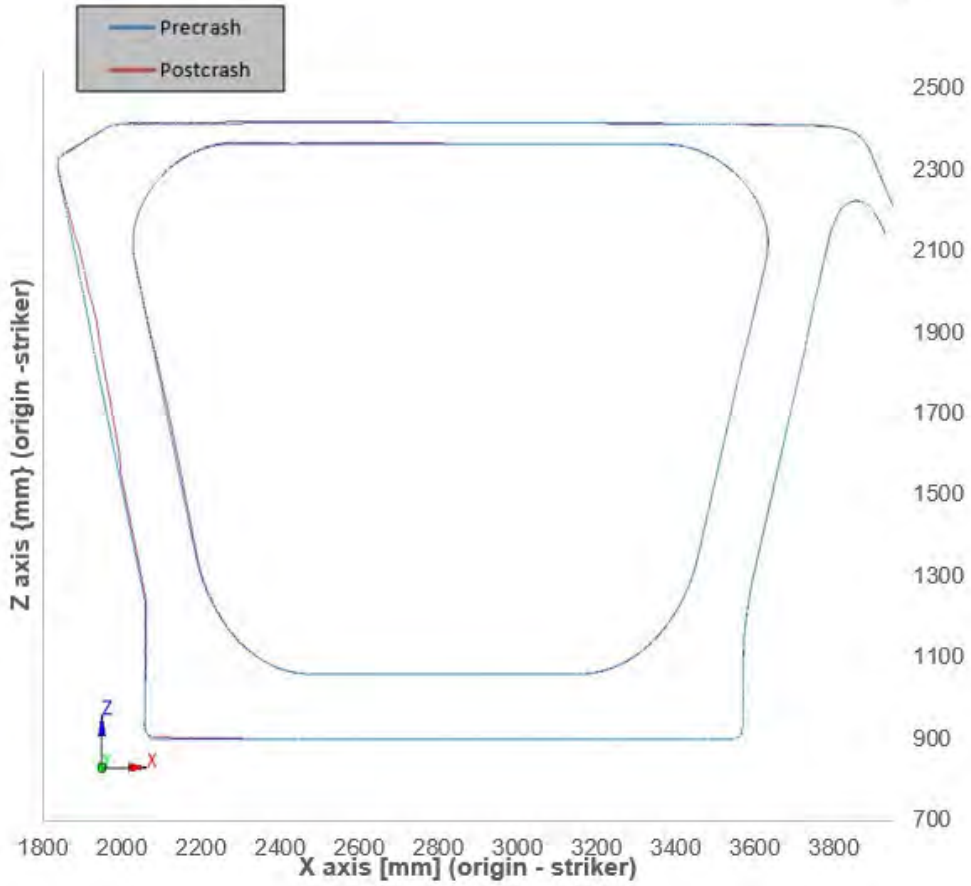


Figure 7.2.3.14 BIW door frame deformation as a result of IIHS 64kph Small Offset Rigid Barrier

Figures 7.2.3.15 to 7.2.3.20 provide a pictorial breakdown of the Advanced High Strength Steel grades and fabrication processes applied in the Steel E-Motive front crash structure.

| Front Bumper Beam | |
|-----------------------------------|---|
| Geometry/design | Bumper beam outer faces angled and oriented to align with IIHS SORB barrier impact location. In early stage of SORB crash event the bumper beam deforms to contact with front subframe providing lateral force loadpath to initiate glance off motion |
| Part 1: front bumper panel | 2.0mm PHS-CR2000T-MB / Hot form |
| Part 2: rear bumper panel | 2.0mm PHS-CR1500T-MB/ Hot form |
| Part 3: front crush cans | 2.0 mm CR420Y780T-DP / Cold Stamp |
| Part 4: interface panel | 1.2mm CR780Y980T-CP / Cold Stamp |

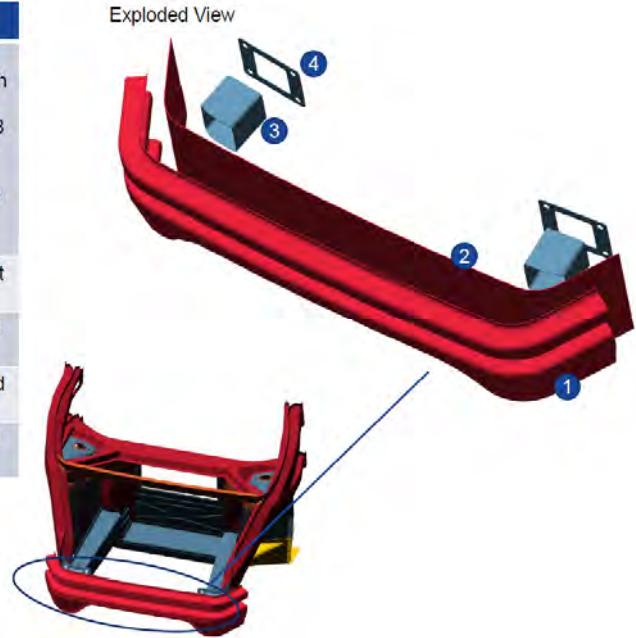


Figure 7.2.3.14 Front bumper beam AHSS grades (See Appendix 4 for larger image)

| Front crush zone | |
|--|--|
| Geometry/design | Longitudinal crush rails 1 and 2 provide primary crush absorption for FFB, ODB and MPDB tests. Tailor Welded blank parts enable uniform axial crush performance and vehicle deceleration. Vertical dash brace parts 4, 5, 6 and 7 provide crush load reaction and limits intrusion. One bar parts 8,9 & 10 limit lower intrusion and protect battery |
| Part 1: LONGITUDINAL MID RAIL INNER FRONT RH | TWB 1.8/2_0_CR500Y780T-DP/CR700Y980T-DP / Cold stamp |
| Part 2: LONGITUDINAL MID RAIL OUTER FRONT RH | TWB 1.8/2_0_CR500Y780T-DP/CR700Y980T-DP / Cold stamp |
| Part 3: BUMPER BEAM INTERFACE PLATE FRONT RH | 2.0mm CR860Y1180T-DP / Cold stamp |
| Part 4: VERTICAL DASH BRACE FRONT LH | 2.0mm PHS-CR2000T-MB / Hot form |
| Part 5: VERTICAL DASH BRACE UPPER FRONT | 2.0mm PHS-CR2000T-MB / Hot form |
| Part 6 & 7: VERTICAL DASH BRACE LOWER INNER & OUTER | 2.0mm PHS-CR2000T-MB / Hot form |
| Part 8 & 9: ONE BAR UPPER AND LOWER | 1.0mm CR860Y1180T-DP / Cold stamp |
| Part 10: ONE BAR INNER | 2.0mm CR8501180T-DH / Cold stamp |
| Part 11: STRUT TOWER FRONT RH | 0.8mm CR350Y450T-LA / Cold stamp |
| Part 12: STRUT TOP FRONT RH | 1.8mm CR860Y1180T-DP / Cold stamp |
| Part 13: STRUT RING FRONT | 2.0mm CR1200Y1470-MS / Cold stamp |



Figure 7.2.3.15 Front crush zone AHSS grades (See Appendix 4 for larger image)

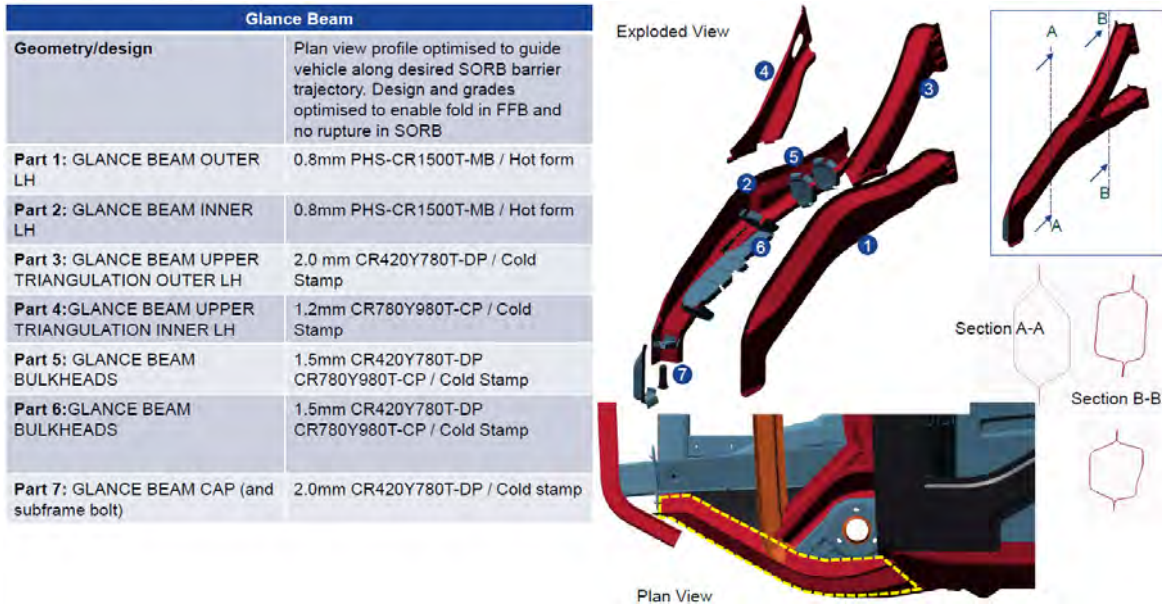


Figure 7.2.3.16 Glance beam AHSS grades (See Appendix 4 for larger image)

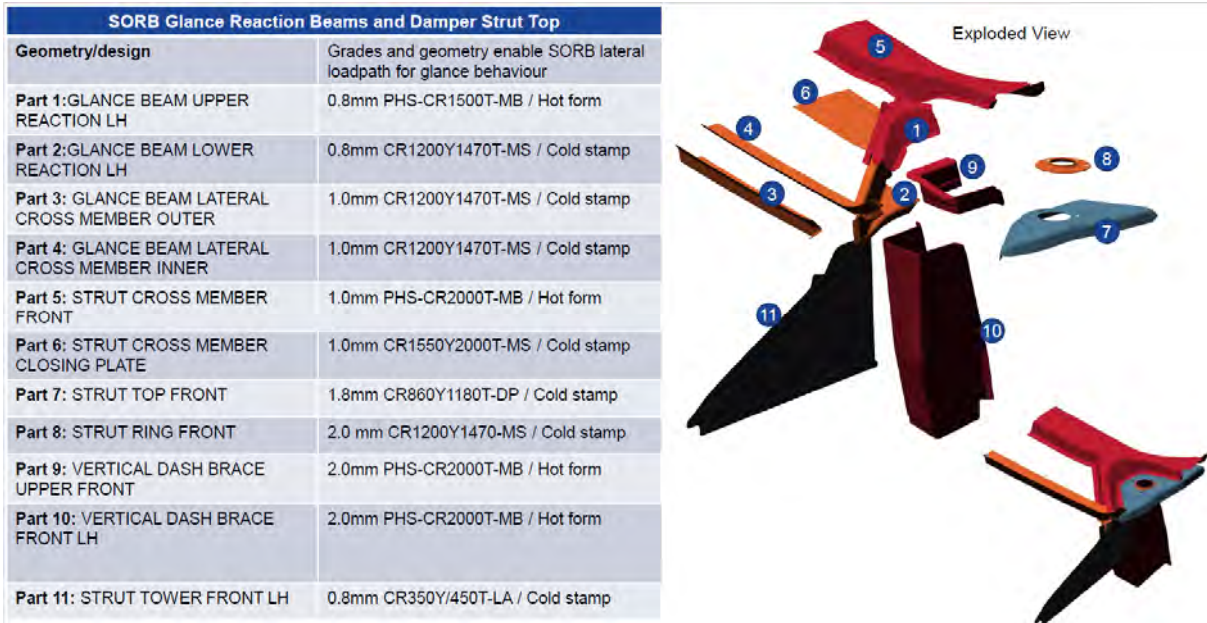


Figure 7.2.3.17 SORB glance reaction beam and damper strut top AHSS grades (See Appendix 4 for larger image)

| Front Subframe | |
|---|--|
| Geometry/design | <p>Rigidly connected to BIW at points A (front longitudinal crush rails) B (glance beam), C (Vertical dash brace lower). Provides global body stiffness contribution and crash loadpaths. Front lateral beam (1) provides SORB lateral loadpath</p> <p>Z offset (D) promotes subframe folding collapse mechanism in front FFB, ODB and MPDB loadcases</p> <p>2.0mm gauge selected as standard for corrosion resistance for chassis parts</p> |
| Part 1:FRONT SUBFRAME LATERAL BEAM (FRONT) | 2.0mm CR860Y1180T-DP / Cold rolled tube |
| Part 2:FRONT SUBFRAME LONGITUDINAL LH | 2.0mm CR860Y1180T-DP / Cold rolled tube |
| Part 3: FRONT SUBFRAME LATERAL BEAM (REAR) | 2.0mm CR860Y1180T-DP / Cold rolled tube |
| Part 4: MISC. BRACKETS | 2.0mm CR860Y1180T-DP / Cold stamp |

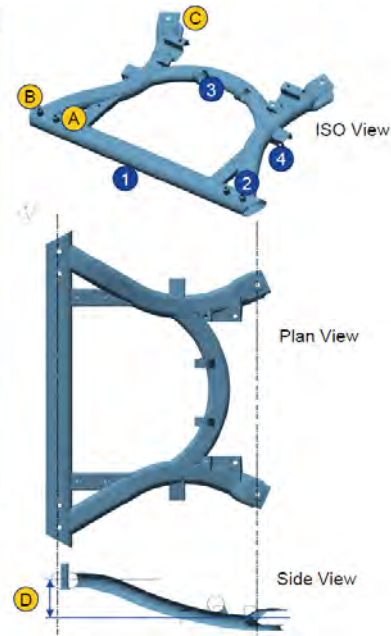


Figure 7.2.3.18 Front subframe AHSS grades (See Appendix 4 for larger image)

| Front Crash Protection / Intrusion Zone | |
|--|--|
| Geometry/design | |
| Part 1:VERTICAL DASH BRACE FRONT LH | 2.0mm PHS-CR2000T-MB / Hot form |
| Part 2:VERTICAL DASH BRACE UPPER FRONT LH | 2.0mm PHS-CR2000T-MB / Hot form |
| Part 3: VERTICAL DASH BRACE LOWER INNER & OUTER | 2.0mm PHS-CR2000T-MB / Hot form |
| Part 4: ONE BAR UPPER AND LOWER | 1.0mm CR860Y1180T-DP / Cold stamp |
| Part 5: ONE BAR INNER | 2.0mm CR8501180T-DH / Cold stamp |
| Part 6: FRONT BULKHEAD | 2.0mm CR860Y1180T-DP / Cold stamp |
| Part 7: TORQUE BOX OUTER AND INNER | 2.0mm CR400Y780T-RA (outer), 1.0mm INNER / Cold stamp |
| Part 8: STRUT CROSS MEMBER FRONT | 1.0mm PHS-CR2000T-MB / Hot form |
| Part 9: STRUT CROSS MEMBER CLOSING PLATE | 1.0mm CR1550Y2000T-MS / Cold stamp |
| Part 10: A PILLAR OUTER | 1.2mm PHS-CR2000T-MB / Hot form (part of TWB OUTER RING) |
| Part 11: A PILLAR INNER | 1.2mm PHS-CR2000T-MB / Hot form |

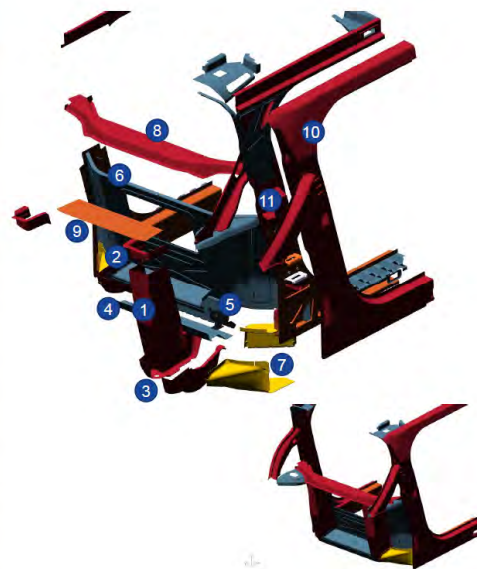


Figure 7.2.3.19 Front crash protection / intrusion prevention zone AHSS grades (See Appendix 4 for larger image)

7.2.4 Steel E-Motive body structure design approach and features for side crash and mid zone performance

The mid zone of the Steel E-Motive body structure consists of the BIW, propulsion battery and carrier frame and scissor doors. The subassemblies combine to deliver structural performance for crash, stiffness and strength requirements. The propulsion battery is described in detail in Section 7.3 and the scissor doors in Section 7.4. This section describe the sub-assemblies combine to deliver side crash performance. Figure 7.2.4.1 shows the key parts of the mid zone structure.

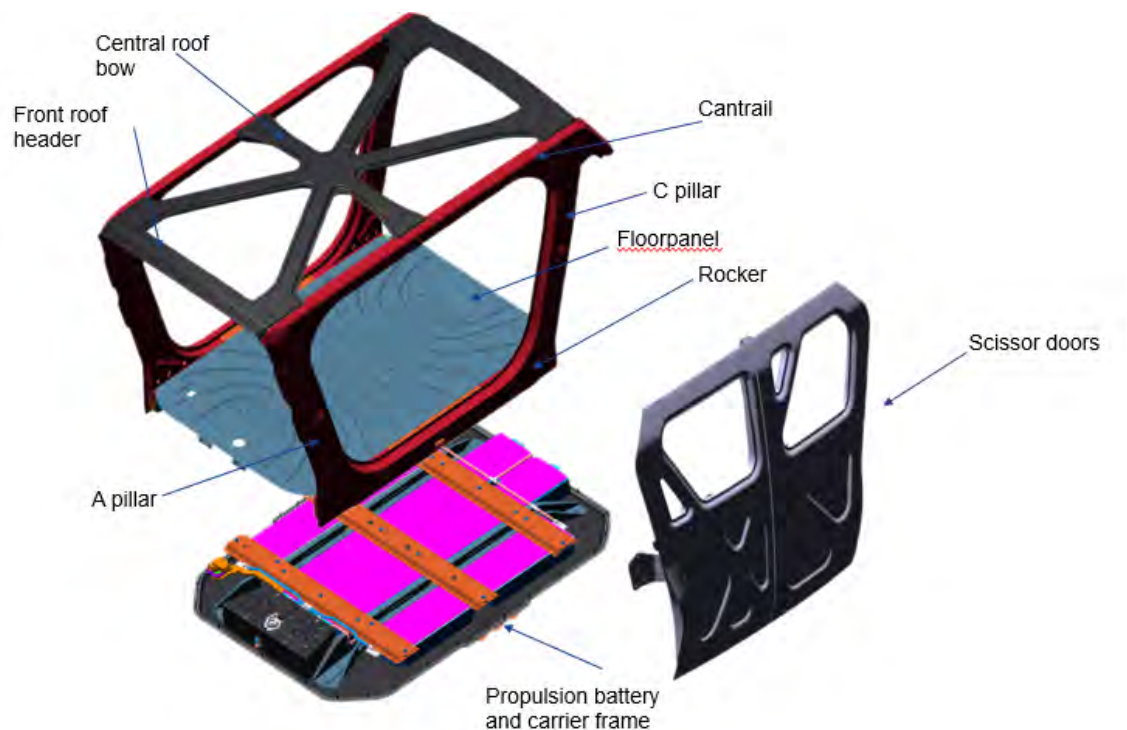


Figure 7.2.4.1 SEM1 body structure mid zone subassemblies and components

The main requirements of the body structure mid zone can be summarised as:

- Provide a comfortable & safe environment for the vehicle occupants
- Provide protection to the occupants and battery in the event of a side impact, roof crush and underbody debris impact
- Provide loadpaths for the front and rear crash zones
- Provide housing and location for the propulsion battery
- Provide aperture and mounting for the scissor doors and interior parts such as seating, trim, glazing and lighting
- Provide required sealing and protection from external elements such rain, solar

The main challenges, constraints, and considerations for the Steel E-Motive mid zone structure were:

- Removal of the B pillar from the body in white structure. This reduces overall BIW strength and stiffness which needs to be compensated elsewhere
- Positioning of the front occupants in a rear facing configuration
- Occupant protection in side crash. Crush load is concentrated over a small area in the side pole test

- Protection of the occupant battery in side crash. Proximity of the propulsion battery to the rocker results in limited crush space to manage the loads and energy
- Achieving a flat floor and floor height, given the requirement to package battery systems
- Comparatively narrow width of the vehicle. Occupants and battery are placed closer to the side crash impact zones compared to larger segment vehicles

Section 4.2 describes the side crash loadcases and targets and Section 6.3.3 describes the preliminary conceptual studies for the Steel E-Motive side crash structure. Figure 7.2.5.2 shows the alignment of the two side crash barrier loadcases to the final SEM1 design and the strategy for the side crash load management and intrusion prevention.

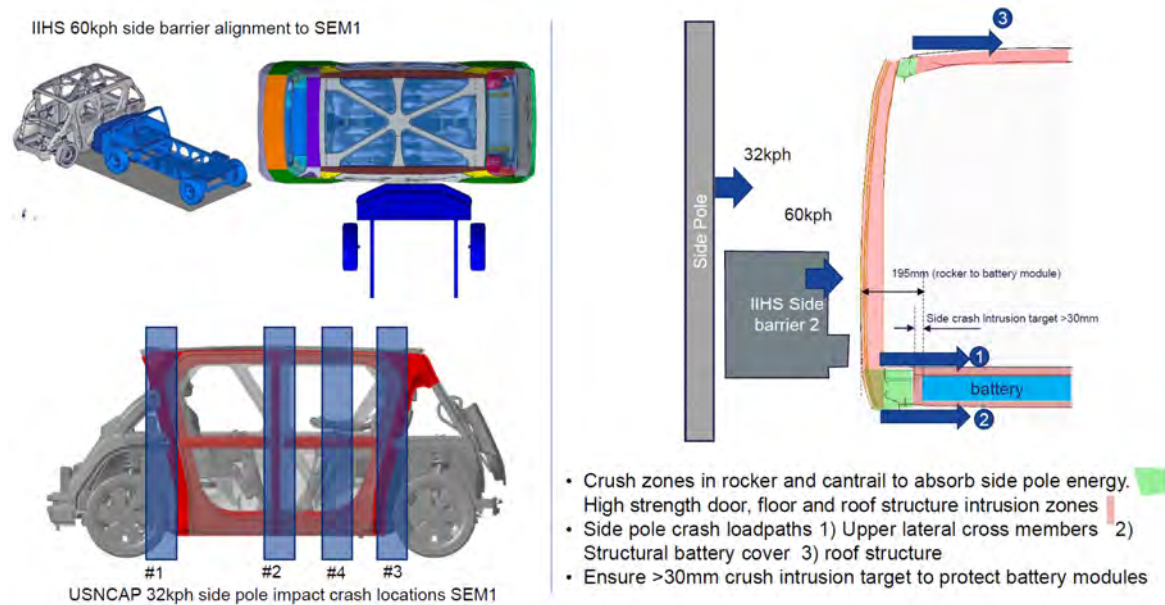


Figure 7.2.5.2 SEM1 side crash barrier alignment and strategy for loadpath and intrusion management (See Appendix 4 for larger image)

For the IIHS 60kph side barrier loadcase, the profile of the barrier largely misses the rocker meaning that the side door structure should be engineered to withstand the majority of the barrier impact loads. Typically, side barrier loads are managed by a vertical B pillar within the BIW structure. In the Steel E-Motive concept, the BIW B pillar is removed to create an open space within the cabin when the doors are open. To compensate for this, the side doors have been engineered with an AHSS B pillar structure effectively within the door structure itself. Crush zones are provisioned for within the rocker structure and cantrail, providing some side crash energy management. The AHSS side closures are full height, with the structure effectively wrapping over the cantrail at the top and rocker at the bottom. With the high strength door structure, a large component the IIHS side barrier crash loads are effectively transferred to the crushable rocker and cantrail parts by the wrap-around door.

The propulsion battery of a battery electric vehicle is particularly vulnerable in a side impact event. The proximity of the battery modules to the side crash event may result in the damage or rupture to the modules, leading to a thermal runaway event and potential vehicle fire. The risk is generally more severe than for the front and rear crash loadcases. The design packaging activity in Phase 0 optimised the battery layout to position the modules, ensuring a maximum distance from the rocker outer surface to the outer face of the modules, thus

enabling the largest side crush distance possible to manage the side crash loads. The body structure was then optimised to use the available crush space to manage the side crash loads. The battery modules were protected by a crushable AHSS member in the rocker section and very high strength steel grades placed between the rocker and battery modules. Very high strength lateral cross members in the floor and battery frame provide loadpaths across the body structure and a battery lower cover plate provides a lower lateral loadpath. The specific design features and AHSS grades applied are discussed later in this section.

IIHS 60kph side barrier performance.

The structural performance targets for the side crash loadcases are detailed in Section 4.0. For the IIHS side barrier test, the requirement is to maintain a >180mm clearance from the maximum point of crush intrusion to the centreline of the occupant seat. Figure 7.2.5.3 shows the predicted side crash intrusion performance from the CAE simulation.

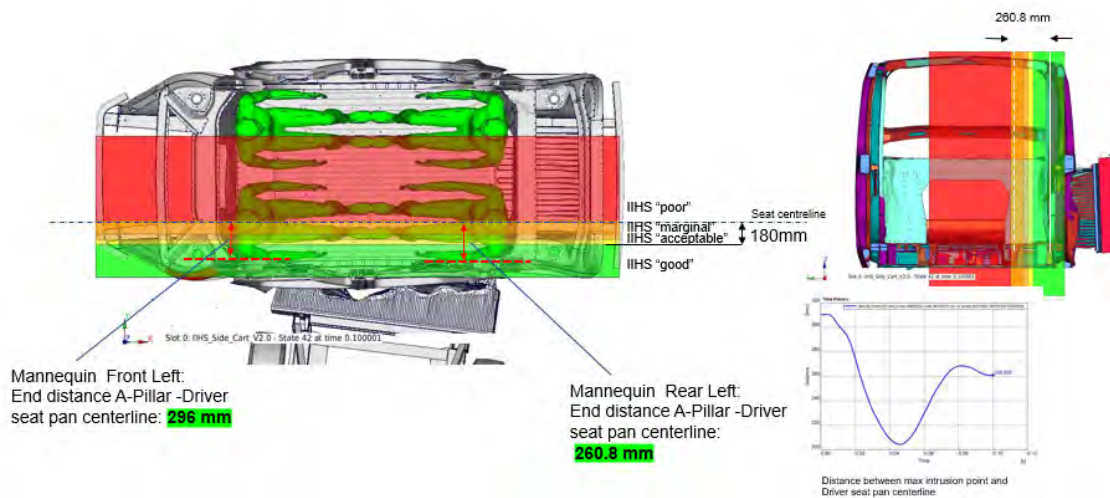
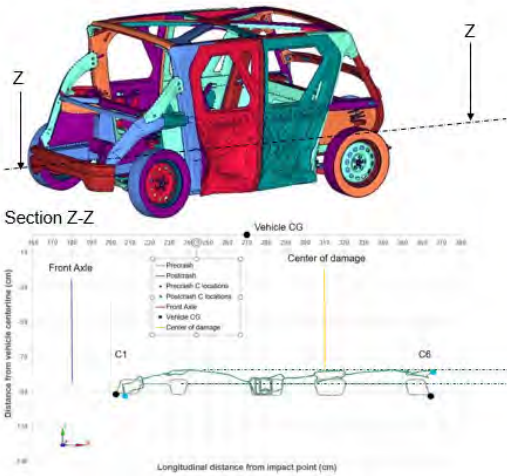


Figure 7.2.5.4 Crash CAE simulation of IIHS 60kph side barrier. Predicted intrusion values are in the IIHS “good” zone. (See Appendix 4 for larger image)

The intrusion clearance attained for the front occupant was calculated at 296mm and 261mm for the rear occupant. This is greater than the 180mm of clearance required in order to achieve the IIHS “good” rating for intrusion performance. Additional measurements such as dummy injury and forces are required in order to achieve an overall “good” rating but these were not considered within the Steel E-Motive programme. The IIHS side barrier CAE results were compared with real world crash test measurements provided by IIHS. Figure 7.2.5.5 shows predicted intrusion values through a horizontal section below the waist rail compared to measured values for a current production C/D segment battery electric vehicle (achieved IIHS “good” rating for side crash). The comparison shows that the predicted crash intrusion values of Steel E-Motive are much less than the measured passenger car. This demonstrates a very good level of occupant protection offered by the Steel E-Motive AHSS body concept for the IIHS side barrier loadcase.

Steel E-Motive (IIHS “good” rating)



C/D segment battery electric vehicle (IIHS “good” rating)

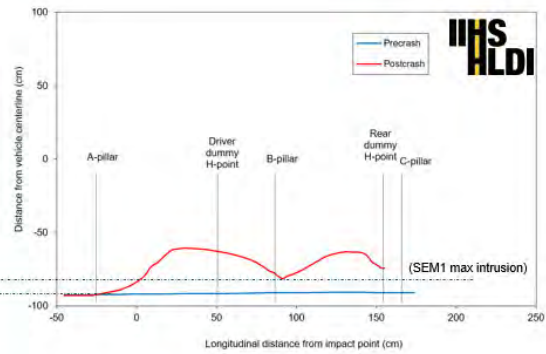


Figure 7.2.5.5 Comparison of predicted (Steel E-Motive) and measured (C/D segment BEV, 2022 model year) intrusion from IIHS 60kph side barrier test

For the USNCAP 32kph side pole test the real-world assessments are based on test dummy injuries alone. As no dummies or SRS was applied for the development of the Steel E-Motive concept, the occupant protection was assessed using the IIHS side barrier intrusion protocol (>180mm intrusion clearance, as described above). Protection of the battery was assessed by the >30mm static intrusion clearance to the outer face of the battery module. Figure 7.2.5.6 shows the predicted intrusion levels for the USNCAP side pole loadcase. For the 4 loadcases/impact positions considered, the predicted intrusion clearance was above the target value of 180mm, demonstrating a good level of occupant protection.

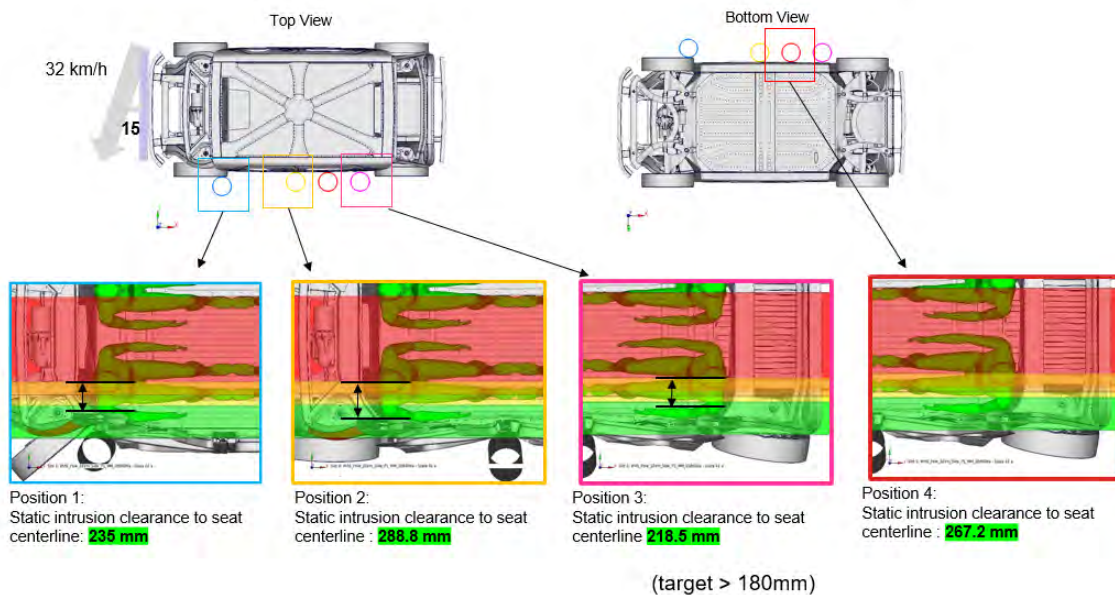


Figure 7.2.5.6 USNCAP 32kph side pole, predicted intrusion values for 4 test locations (See Appendix 4 for larger image)

Figure 7.2.5.7 shows the predicted intrusion values relative to the battery modules for the USNCAP 32kph side pole loadcases. The results show that for the 4 impact locations, the predicted static intrusion values are below the 30mm target and no contact occurs between the body structure and battery modules. This demonstrates that the Steel E-Motive body structure demonstrates a good level of crashworthiness protection of the propulsion batteries in the side pole test.

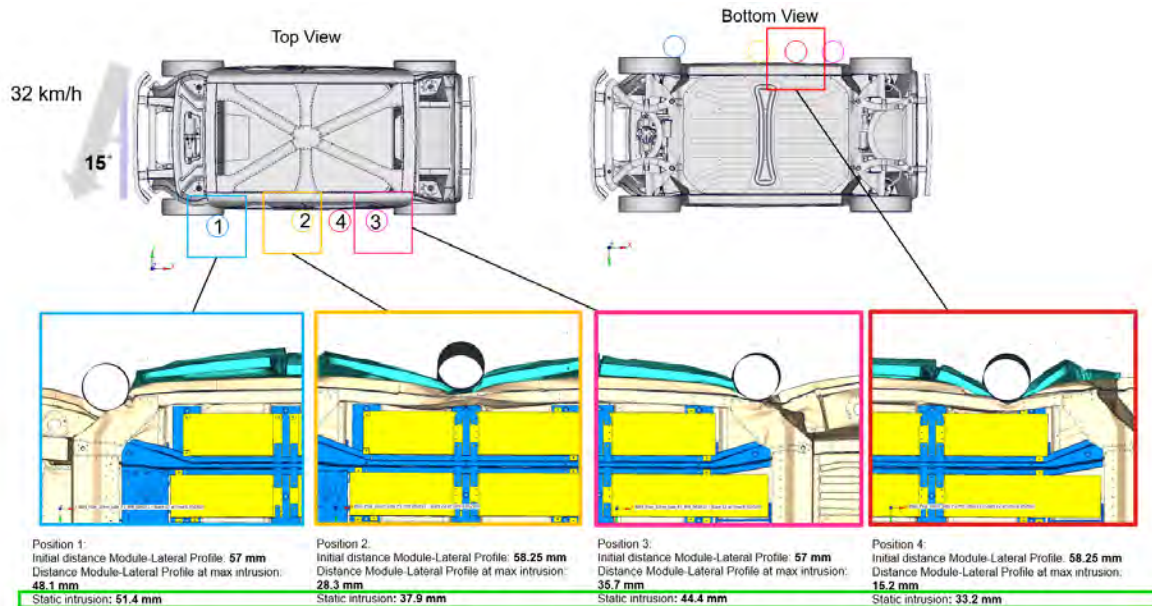


Figure 7.2.5.7 predicted intrusion values for the USNCAP 32kph side pole test (4 locations) (See Appendix 4 for larger image)

AHSS grades and design for protection of front and rear occupants in IIHS side barrier test:

Protection of the occupants and battery for the IIHS side barrier test is provided by the combination and integration of the side door and body structure. The side doors contain 2 B pillar vertical braces, the cross sections of which overlap but do not contact in a no-crash condition. The front door houses a vertical brace on it's rear face and the rear door houses a vertical brace on it's front face. An acute section profile is enabled by hydroforming and high strength achieved by using a CR400Y690T-RA (or "TRIP 690") in 1.2mm. The height of the door vertical braces extend to overlap the cantrail at the top and rocker at the bottom. In a side collision event, the front and rear door vertical braces deform and become interlocked together, providing enhanced overall strength. The vertical braces then come into contact with the rocker and cantrail providing loadpaths into the body in white. The front and rear door vertical braces are joined to horizontal door struts – "U" sectioned roll stamped beams in 1.5mm CR1200Y1470T-MS grade. Despite the vertical positioning of the horizontal door struts being slightly higher than the side barrier impact location, the interaction with the door vertical beams provides a loadpath for the crash loads outwards to the A and C pillars. From the A pillars, the front and rear lateral strut braces provide loadpaths across the vehicle, as shown in Figures 7.2.5.8a, b and c.

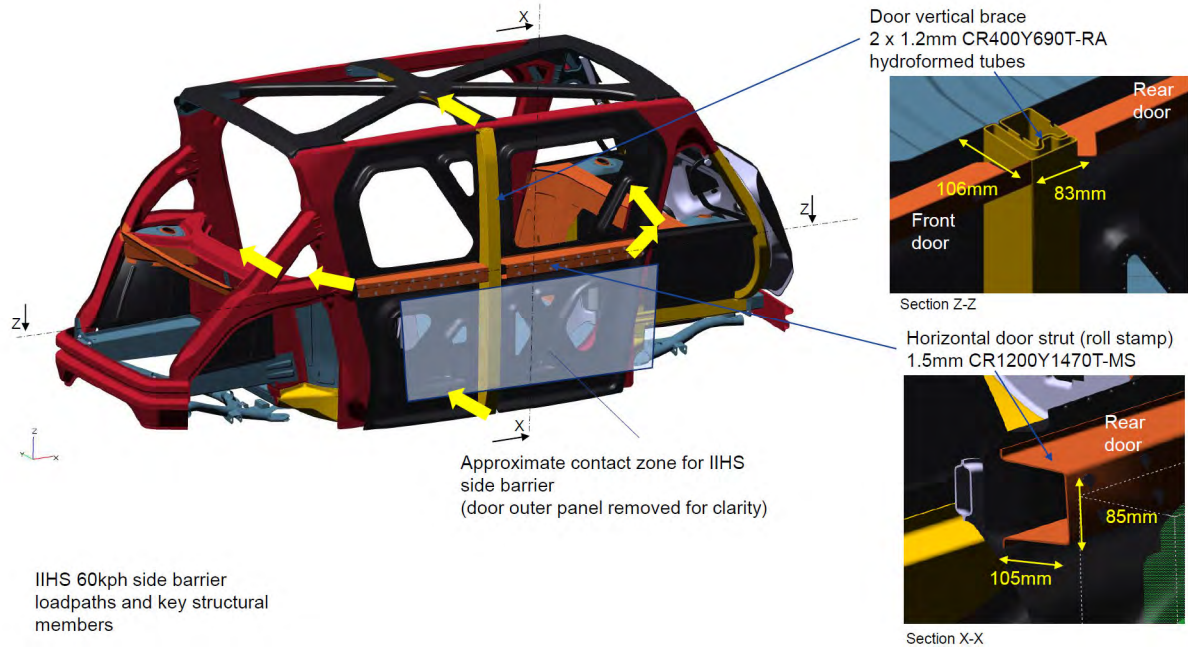


Figure 7.2.5.8a Door structural members and loadpaths into body structure for the IIHS side barrier loadcase (body structure shown for clarity) (See Appendix 4 for larger image)

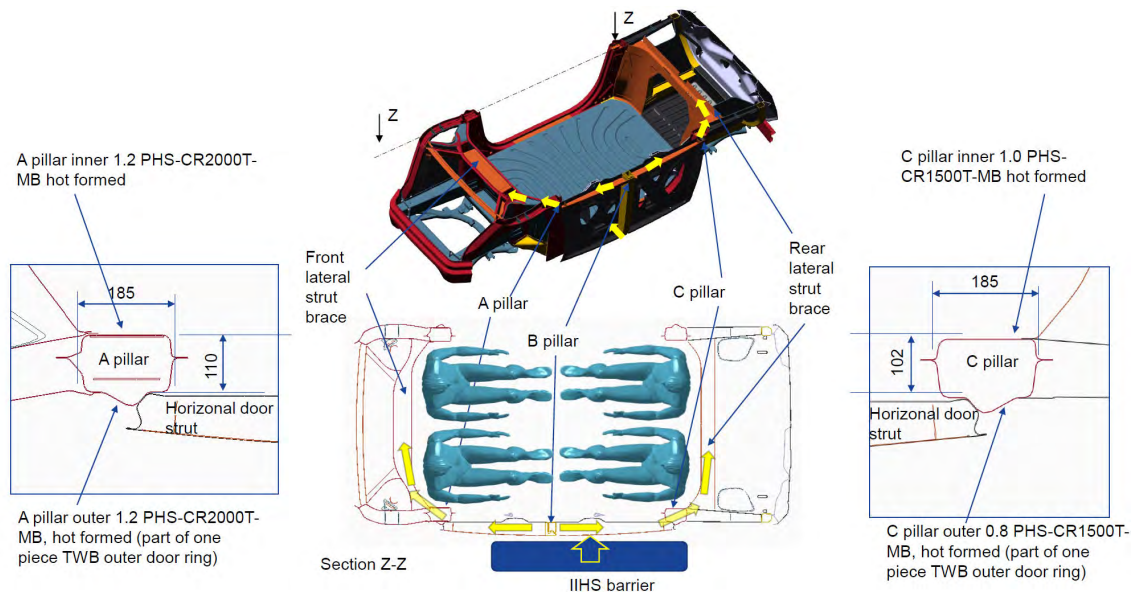


Figure 7.2.5.8b Door structural members and loadpaths into body structure for the IIHS side barrier loadcase (body structure shown for clarity) (See Appendix 4 for larger image)

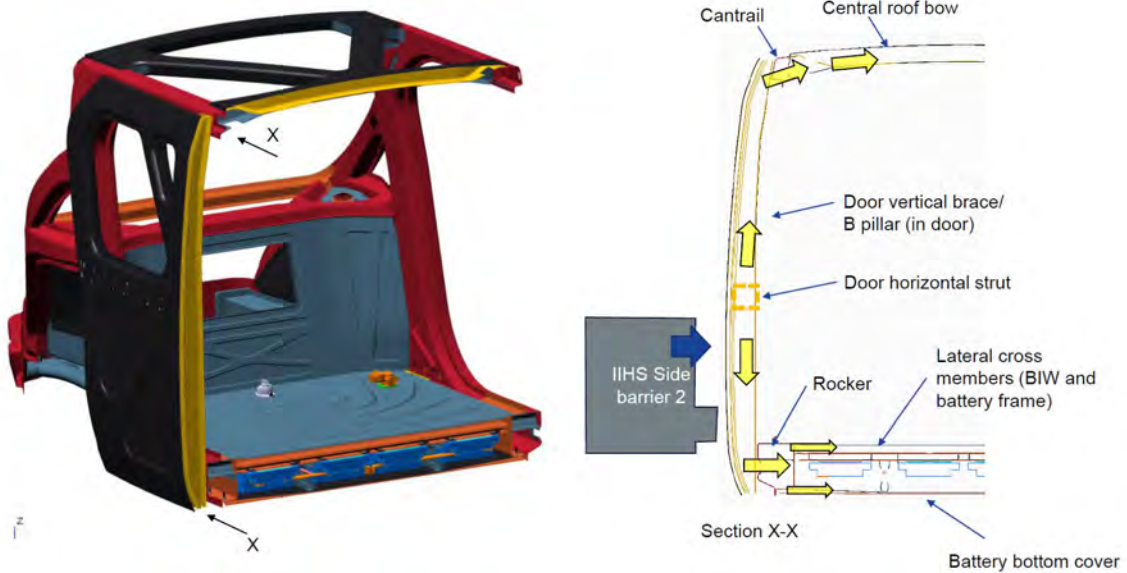


Figure 7.2.5.8c Door structural members and loadpaths into body structure for the IIHS side barrier loadcase (body structure shown for clarity)

The A and C pillars locations are predominantly outboard and in line with the front (A pillar) and rear (C pillar) occupant seating locations. The A and C pillar cross sections and AHSS grades provide very high strength and side crash load reaction, resulting in low crash intrusion values around the occupants.

Figure 7.2.5.8.c shows how the side crash loadpaths are also managed in the vertical plane via the rocker and roof structure. The interlocking vertical door braces (B pillar) combine to provide high bending strength, with minimum plastic deformation, results in a significant transfer of side crash load into the BIW roof and rocker. The construction and contribution of the roof and rocker to side crash is discussed later in this section.

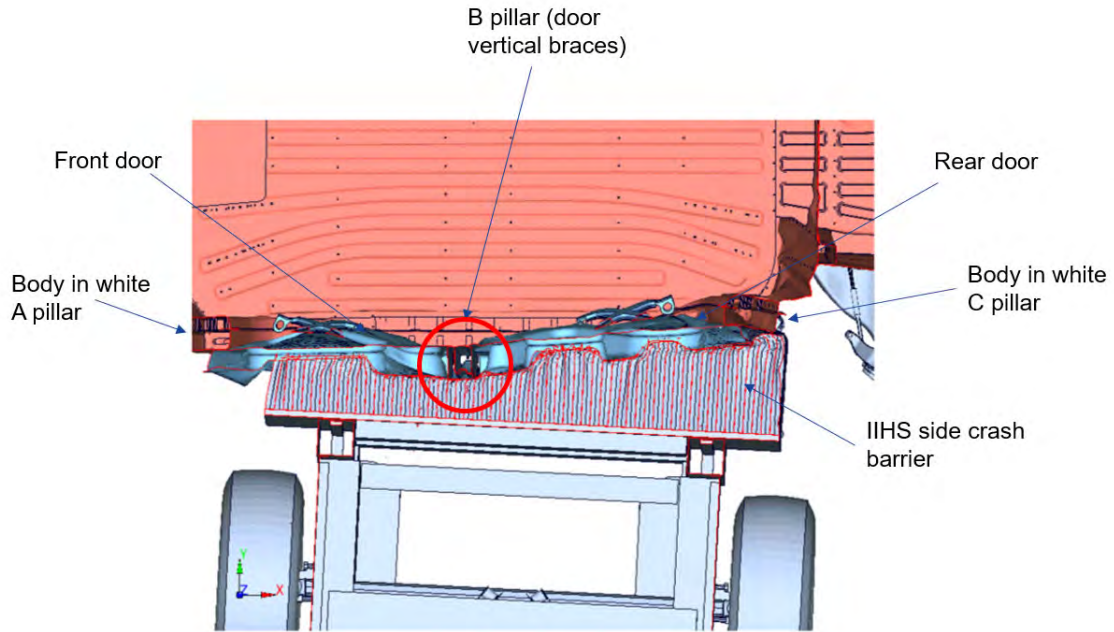


Figure 7.2.5.9 IIHS side barrier crash simulation (end of crash event), section in Z-Z plane showing B pillar/door vertical braces remaining largely undeformed

AHSS grades and design for protection of front and rear occupants side pole crash loadcases.

The management of the side pole crash loads and protection of occupants and battery place greater demands on the body in white structure than the closures, primarily as the impact load is more concentrated over a smaller area contact area and the doors become relatively sacrificial in the during the initial stages of the crash events. Figure 7.2.5.10 shows the impact location for position 1 crash loadcase which is in line with the front occupant head position.

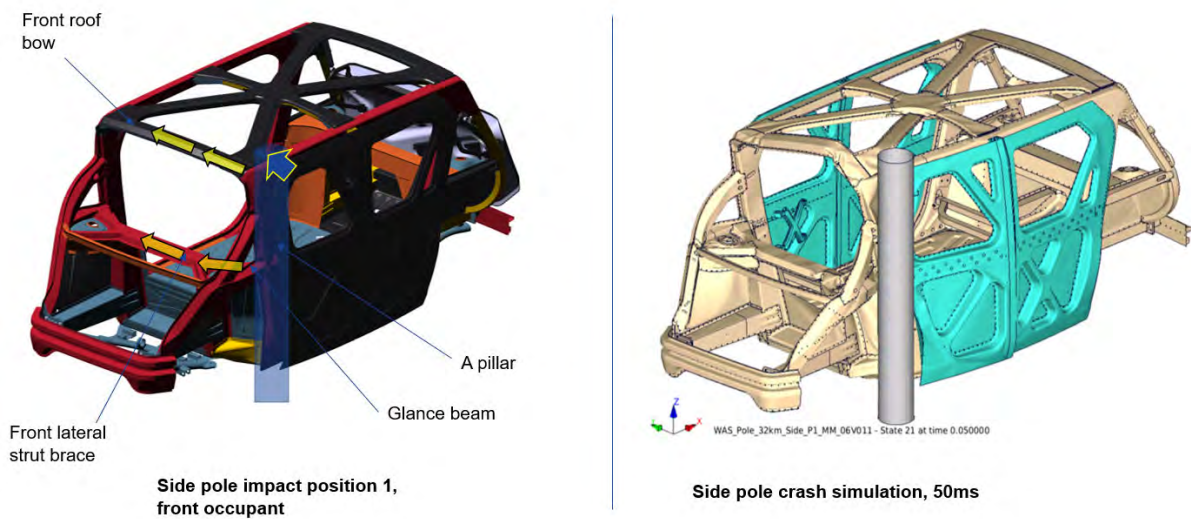


Figure 7.2.5.11 USCAP 32kph side pole crash loadcase, position 1. Loadpaths and crash simulation result (See Appendix 4 for larger image)



The pole impacts the body structure directly on the upper section of the A pillar. The A pillar section and AHSS grades (as described above for the side barrier loadcase) provide primary load reaction. The front lateral strut brace, glance beam and front roof bow header provide lateral loadpaths across the vehicle in a similar way to the IIHS side barrier loadcase (Figure 7.2.5.8b). This results in intrusion levels that are well within the IIHS target intrusion levels that enable “good” rating.

Protection of the rear occupant in the side pole loadcase (position 3) is provide by a similar strategy to the front occupant (position 1). The pole impacts primarily the lower portion of the C pillar, the construction and AHSS grades of which are similar to the A pillar. Cross-car load reaction is provided by the rear torque box and five bar, the rear lateral strut brace and rear roof bow.

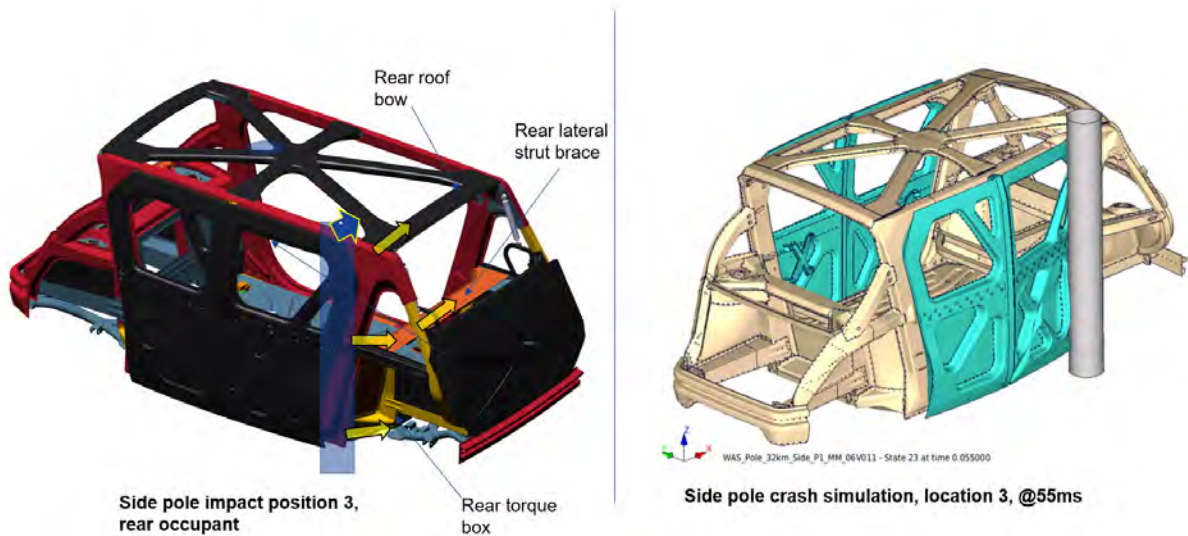


Figure 7.2.5.12 USCAP 32kph side pole crash loadcase, position 3. Loadpaths and crash simulation result (See Appendix 4 for larger image)

Side pole impact locations 2 and 4 are primarily intended to evaluate the body structural integrity for the protection of the batteries. Location 2 is directly in line with the front and rear door split (B pillar) and location 4 is at a midpoint along the length of the rear door. Both positions were selected as potential locations of weakness in the body structure. The strategy for managing the crash loads for positions 2 and 4 is shown in Figure 7.2.5.2. During the initial stages of the pole impact in position 2, the B pillar deforms considerably (due to the small contact area and concentrated load), providing some crush energy absorption, before the pole and door impacts with rocker and floor and roof assembly.

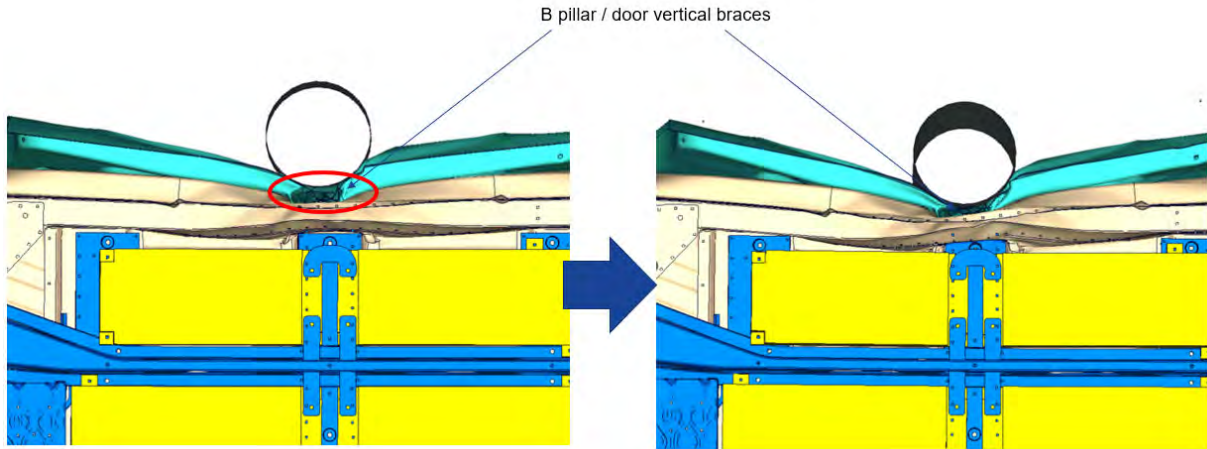


Figure 7.2.5.13 USNCAP 32kph side pole position 2. View from underneath with battery cover removed

Figure 7.2.5.14 shows the main parts of the door, rocker, floor and battery assembly that contribute to the side pole crash performance for positions 2 and 4. (The battery internals e.g. modules, cooling have been removed for clarity). The door, rocker outer panel (outer door ring TWB) and the rocker hex absorber parts act as energy absorbing or crushable elements of the side pole crash strategy (as shown in Figure 7.2.5.2). The rocker hex absorber has been engineered to provide high crush energy absorption with low weight. The part consists of 2 roll formed sheets in DP780, 0.7mm in thickness and spotwelded together. The edges of the 2 sheets produce a “hex” profile, and the large concentration of edges orientated perpendicular to the impact direction result in significant plastic deformation of the part, resulting in a high level crush energy absorption. The rocker hex absorber is supported in the rocker section by a support shelf (not shown) in 1.0mm CR420Y780T-DP.

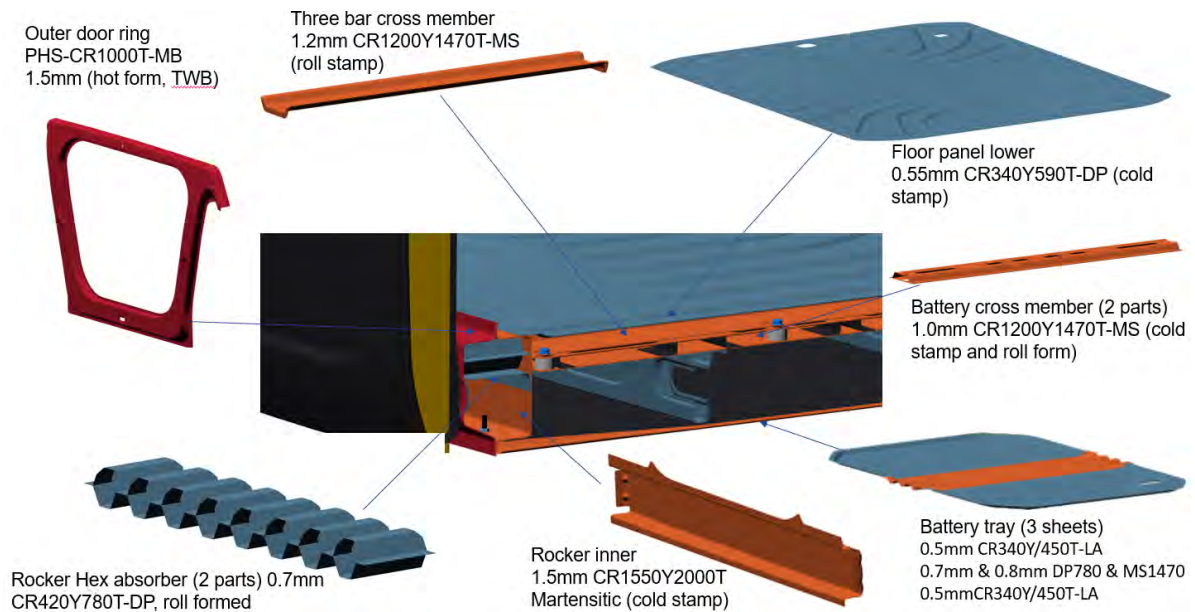


Figure 7.2.5.14 body structure cross section in X at door split point, side pole position 2. (battery modules, cooling plates, interconnects removed for clarity) (See Appendix 4 for larger image)

The second part of the side pole battery protection strategy is the intrusion prevention in the proximity of the battery modules. Here, the higher strength grade steels combine to minimise the penetration of the deformed body structure around the battery modules. Following the crushing of the rocker hex absorber the rocker inner panel in 1.5mm MS2000 grade forms the first part of the battery protection stage. Inboard of the rocker inner panel, the side pole crush loads are dispersed via upper and lower cross vehicle loadpaths as shown in Figure 7.2.5.15.

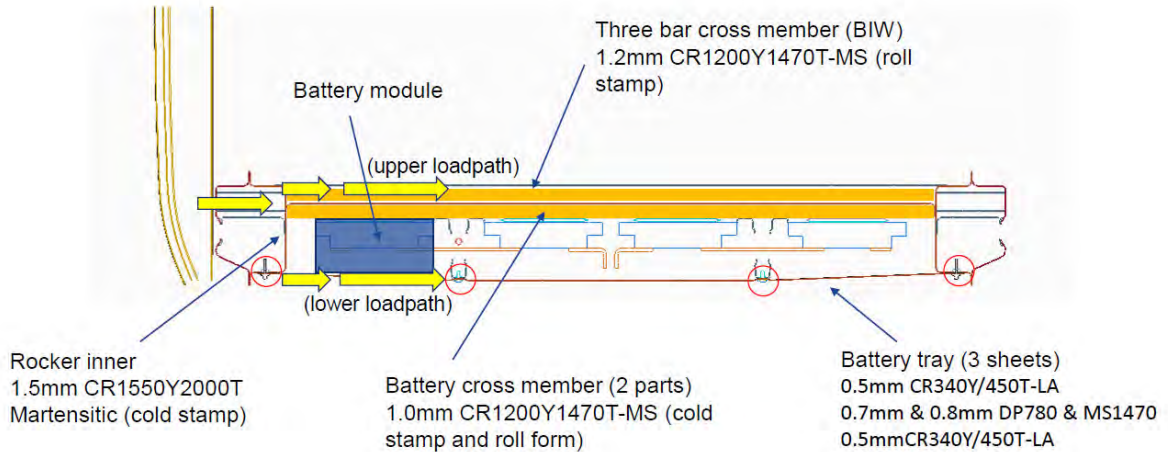


Figure 7.2.5.15 body structure cross section in X showing side pole crash intrusion prevention measures and upper & lower loadpaths (See Appendix 4 for larger image)

The 3 lateral cross members in the BIW floor (“three bar, four bar, five bar”) combined with the 3 battery carrier frame cross members provide high strength upper lateral loadpaths for the rocker crash loads as shown in Figure 7.2.5.16. For side crash pole position 2, the “three bar” cross members are in line with the crush loads. For crash pole position 4, the impact location spans the “three bar” and “four bar” cross member, however both cross members combine to provide overall lateral strength and loadpaths.

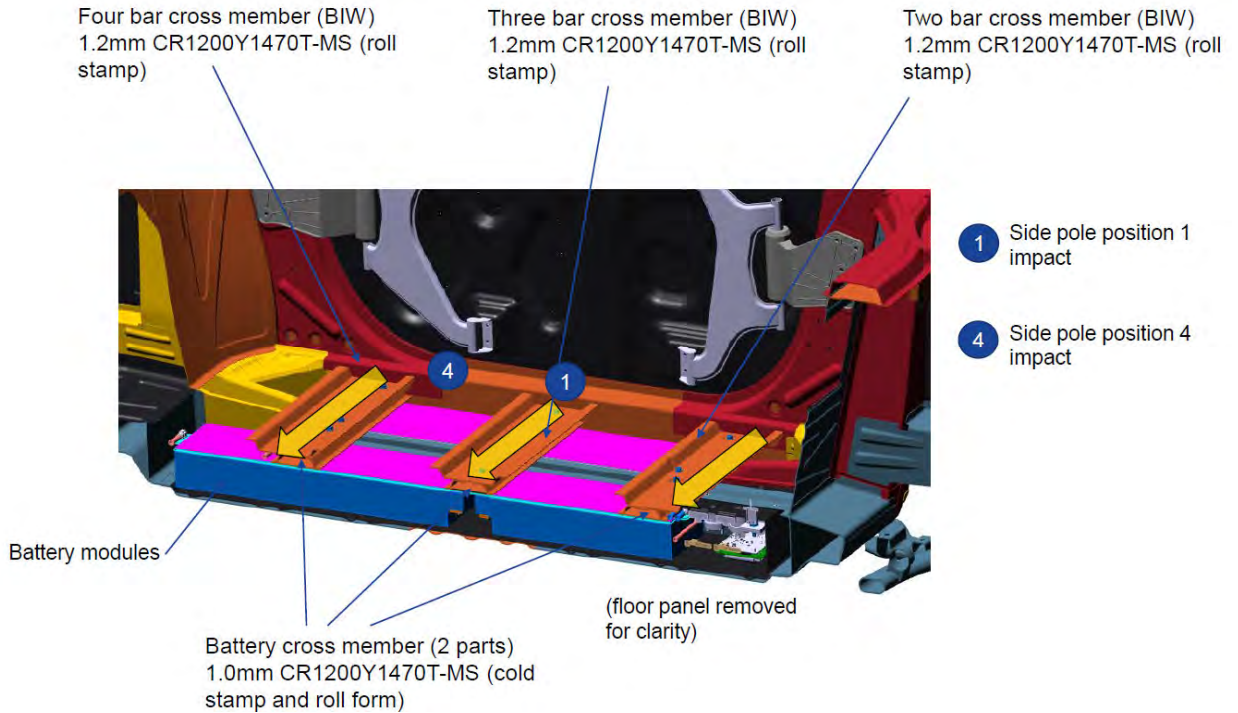


Figure 7.2.5.16 Body structure (floor panel removed) showing body cross members (two, three and four bar) and battery cross members (upper loadpaths) (See Appendix 4 for larger image)

A lower cross vehicle loadpath is provided via the battery tray which is fastened to the rocker via M8 bolts around the perimeter. The battery covers' primary function is to protect the battery from debris impacts and provide sealing externally and internally (discussed in more detail in Section 7.3). The battery tray consists of 3 sandwich sheets which combine to provide the required stiffness and strength performance. The bottom sheet is a TWB part with a MS1470 centre section which provides additional strength to manage the side pole (position 2) impact loads. The lower loadpath provides stability to the rocker section in side pole impact, minimise rotation of the rocker section around the X axis and ensures that the rocker hex absorber functions properly.

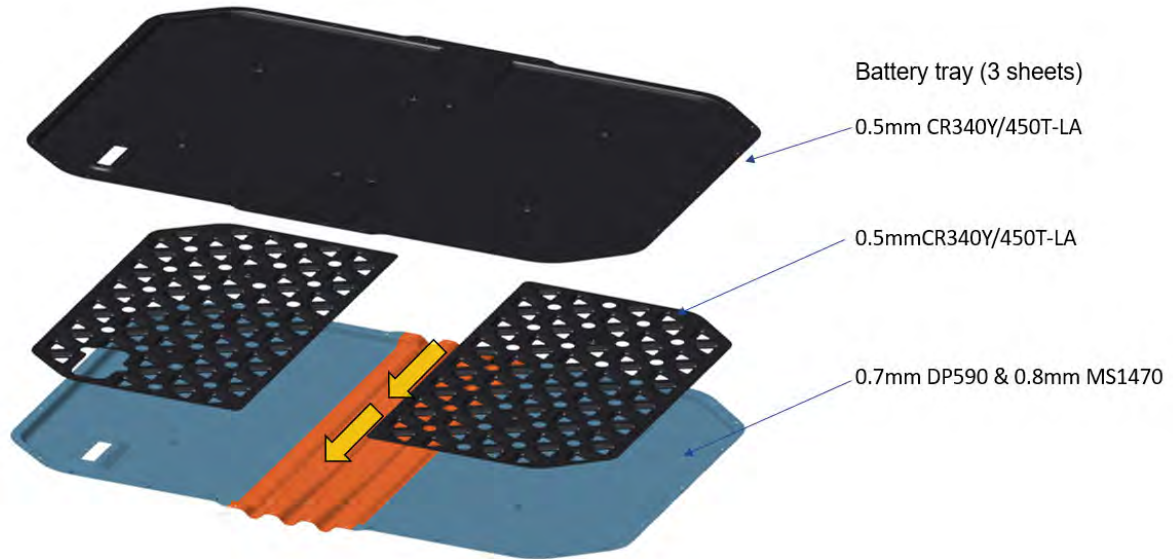


Figure 7.2.5.17 battery tray (exploded view) showing 3 sheet construction and tailor welded lower sheet with MS1470 part to assist side pole crash performance (lower loadpath). The strategy and combination of crush zones and loadpath management around the battery modules results in a maximum intrusion value of 37.9mm for position 2 and 33.2mm for position 4. This means that the body structure does not contact the battery modules for the side pole loadcases, resulting in a significantly lower risk of damage or rupture in a side crash event.

Upper body structure contribution to side crash.

Whilst the lower body structure, namely the scissor doors, rocker, floor and battery structure provide the primary side crash load management, the upper body structure does provide some overall contribution, namely maintaining overall stability of the structure and providing some cross-vehicle loadpaths. Figure 7.2.5.2 shows that the upper body structure is engineered to feature crush and intrusion zones as per the lower structure. With the strength demands on the upper structure being lower in comparison to the lower, AHSS grades of a lower strength were applied. Figure 7.2.5.18 shows the upper structure and forward roof zone that contributes to side pole impact location 1 performance. The A pillar upper (Outer Ring TWB) and cantrail section deform considerably on impact providing some crush energy absorption. The front roof bow section provides the primary upper lateral loadpath to the pole. Whilst the front roof bow does undergo some collapse, the overall strength is sufficient to ensure the intrusion values are well within the targets (Figure 7.2.5.6). For the side pole impact locations 2 and 4, the middle roof bow and roof diagonal members provides upper lateral loadpaths. An 1180MPa 3rd generation Retained Austenite AHSS grade was selected for the mid roof bow inner panel (Figure 7.2.5.18) providing higher strength than DP or CP grades and having formability qualities enabling stamping. Some panels feature lightening holes or cut-outs in the roof structure providing some weight saving benefit.

| Roof structure (front) | |
|---|---|
| Part 1: OUTER RING TWB LH | TWB (A PILLAR PHS-CR2000T-MB 1.2mm, C PILLAR PHS-CR1500T-MB 0.8mm, Cantrail/roof outer PHS-CR1000T-MB 1.5mm, Rocker PHS-CR1000T-MB 1.5mm) |
| Part 2: A POST INNER REINFORCEMENT UPPER | 1.5mm CR800Y1180T-DP / Cold stamp |
| Part 3: ROOF SIDE RAIL INNER LH | 0.8mm PHS-CR1500T-MB / Hot form |
| Part 4: FRONT HEADER INNER | 0.8mm CR780Y980T-CP / Roll stamp |
| Part 5: FRONT HEADER OUTER A-SURFACE | 0.6mm CR260Y/370T-BH / Cold stamp |
| Part 6: DIAGONAL INNER PANEL FRONT | 0.7mm CR550Y/620T-LA/ Cold stamp |
| Part 7: FRONT INNER ROOF HEADER GUSSET MOUNT | 1.0mm CR700Y980T-DP / Cold stamp |
| Part 8: FRONT OUTER ROOF HEADER GUSSET MOUNT | 1.0mm CR700Y980T-DP / Cold stamp |

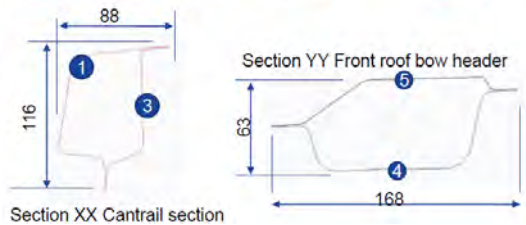


Figure 7.2.5.18 SEM1 mid zone upper structure AHSS grades (See Appendix 4 for larger image)

| Roof structure (middle) | |
|--|-----------------------------------|
| Geometry/design | |
| Part 1: MID ROOF BOW OUTER A-SURFACE | 0.6mm CR260Y/370T-BH / Cold stamp |
| Part 2: MID ROOF BOW INNER | 0.8mm CR820Y1180T-RA / Roll stamp |
| Part 3: MID INTERSECTION OUTER A-SURFACE PANEL | 0.6mm CR260Y/370T-BH / Cold stamp |
| Part 4: MID INTERSECTION INNER PANEL | 0.5_CR260Y/370T-BH / Cold stamp |
| Parts 5, 7 8 & 9 : DIAGONAL OUTER A SURFACE | 0.6mm CR260Y/370T-BH / Cold stamp |
| Parts 10, 11, 12, 13 : DIAGONAL INNER PANEL | 0.7mm CR550Y/620T-LA/ Cold stamp |

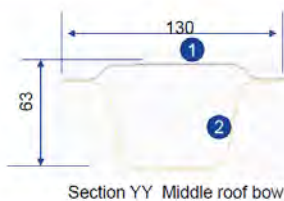


Figure 7.2.5.19 SEM1 mid zone roof structure and AHSS grades (See Appendix 4 for larger image)

The Outer Ring (door ring) is a fundamental part of the body structure mid-zone and contributes significantly to overall body stiffness and strength, front crash, side crash, rear crash and roof crush performance. The part is a large tailor welded blank consisting of 4 unique press hardened steel grades and gauges and provides stiffness and strength benefits compared to individual stamped and spotwelded assembly. The grades and gauges were selected (tailored) based on the specific localised requirements. This part is unique in that the side assembly does not feature a conventional “body side outer” A surface. The PHS TWB outer door ring is essentially the external visible surface. However, given that the scissor doors provide significant coverage of the vehicle side exterior, it was deemed that an

additional body side outer panel was not required (the primary function of a body side outer panel is to provide the A surface and is typically a lower grade, high formability steel such as Bake Hardenable or HSLA). Deleting the body side outer panel enabled a cost saving and approximate overall 27kg weight reduction. With the scissor doors in the open position, the PHS outer door ring will be exposed/visible however, with advances in press hardening fabrication methods it was deemed that a suitable quality of B surface could be attained with additional garnish cover parts/patches added to the exposed surface as required. The front and rear quarters (fenders) of the exterior A surface use a 0.6mm BH370 grade (these parts were not specifically engineered within Steel E-Motive concept design).



Figure 7.2.5.20 SEM1 outer ring and approach for A surfaces (See Appendix 4 for larger image)

The TWB outer door ring features some complex geometric features and underwent forming simulation to develop and demonstrate the feasibility. The forming simulation results for this part (and other body panels) are reported in Appendix 2.

7.2.5 Steel E-Motive body structure design approach and features for roof crush performance

The SEM1 roof crush performance was assessed according to IIHS Roof Strength Protocol Version 1, with the target to achieve “good” rating, which requires a Strength To Weight Ratio (SWR) > 4.0. This means that the body structure must be able to withstand a static load of at least four times the curb weight of the vehicle and the displacement of the load platen greater than 127mm. Figure 7.2.5.1 shows the roof crush test specification and the results from the CAE simulation. The results show that a Strength to Weight ratio of 9.58 was achieved, therefore the IIHS “good” rating attained comfortably. The performance can be attributed to the roof structure design and AHSS grade selection. The A pillar is located and oriented approximately in line with the roof load platen device providing a very good primary loadpath, with the section and 2000MPa grade AHSS providing the necessary strength to achieve the load capacity required.

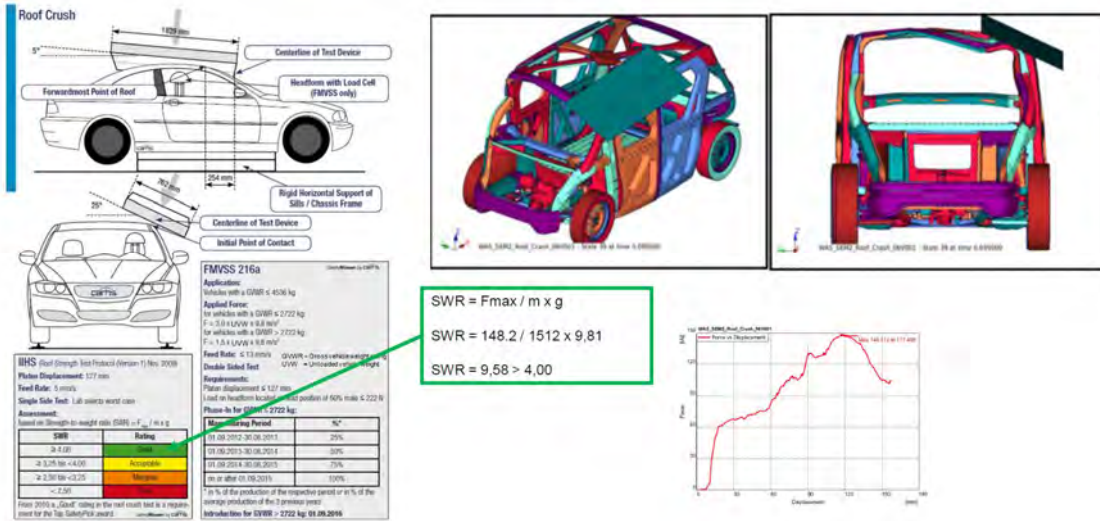


Figure 7.2.5.1 IIHS Roof Crush Strength Evaluation 1 and SEM1 CAE calculation (See Appendix 4 for larger image)

7.2.6 Steel E-Motive body structure design approach and features for rear crash performance

The rear zone of the Steel E-Motive body structure was engineered to deliver the following primary functions and requirements:

- Manage rear collision impact loads
- Provide location/storage of trunk/luggage
- Provide support and manage loads to rear chassis and coach door
- Support to roof and battery structure
- Contribution to global and local (attachment) body stiffness

The specific design challenges and constraints encountered during the development of the Steel E-motive rear structure include:

- Achieving an efficient package space, such that luggage carrying capacity can be achieved
- Compact vehicle size means more challenging to manage rear crash loads. Packaging of rear wheel steer system and impact on body structure
- Integration of hydroformed tube D pillars

The contribution of the rear structure to global and local body stiffness is discussed in Section 7.2.2 of this report and the rear packaging considerations in Section 7.1.3. This section discusses the development of the body structure rear zone development for crashworthiness performance. Figure 7.2.6.1 shows the main subassemblies of the body structure rear zone. The rear zone crash structure was developed and optimised for the FMVSS305 EV, which incorporates FMVSS301 rear impact, an 80kph moving deformable barrier impacting the rear of the vehicle with a 70% overlap. Figure 7.2.6.2 shows the barrier alignment to the body structure and the crash load and energy management strategy. A similar strategy is adopted in the rear structure to the front. The rear longitudinal rails provide the primary crash energy absorption with the subframe engineered to fold allowing the rails to deform uniformly and axially. The rear longitudinal rails are located more inboard toward

the centreline due to the requirement for wheel and tyre package clearance driven by the rear wheel steering lock angle. Vertical dash braces and horizontal beams (five and six bar), rear bulkhead and torque box form the intrusion zones, protecting battery and occupants.

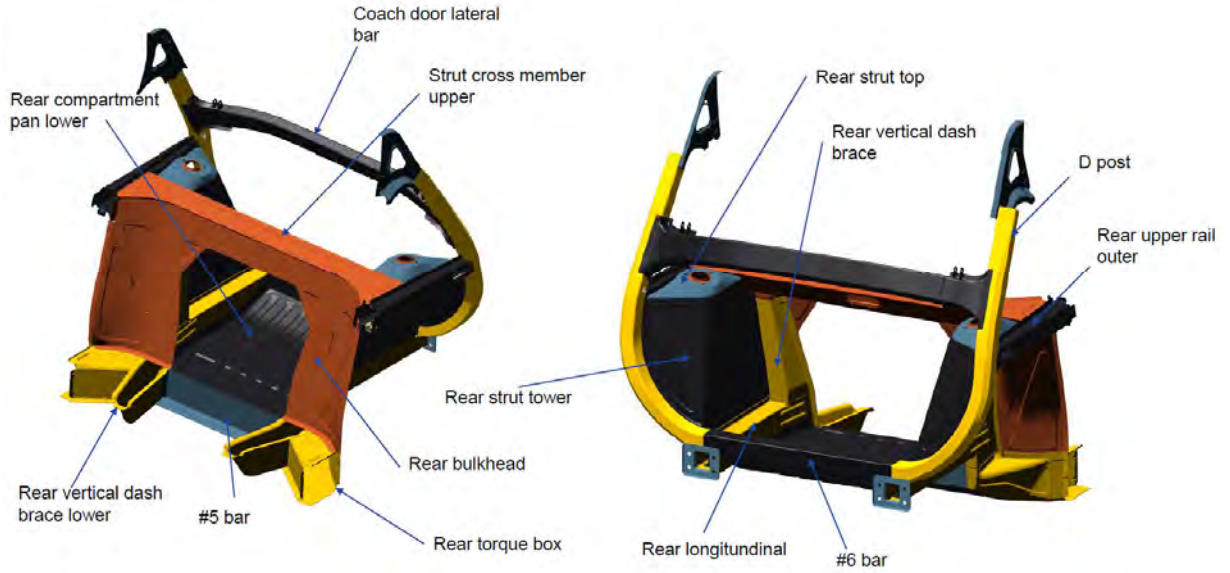


Figure 7.2.6.1 Rear zone subassemblies (See Appendix 4 for larger image)

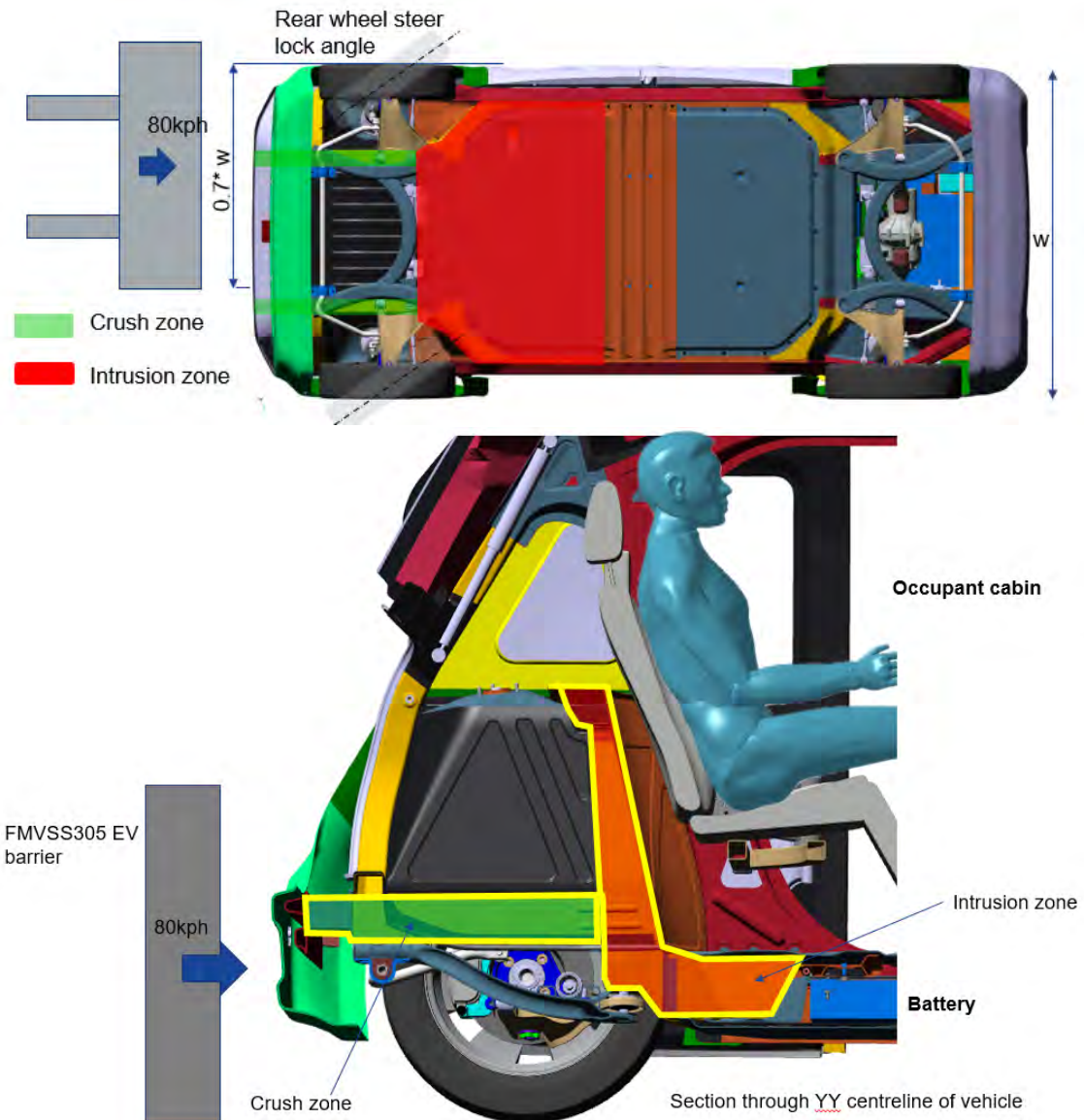


Figure 7.2.6.2 Steel E-Motive rear crash strategy

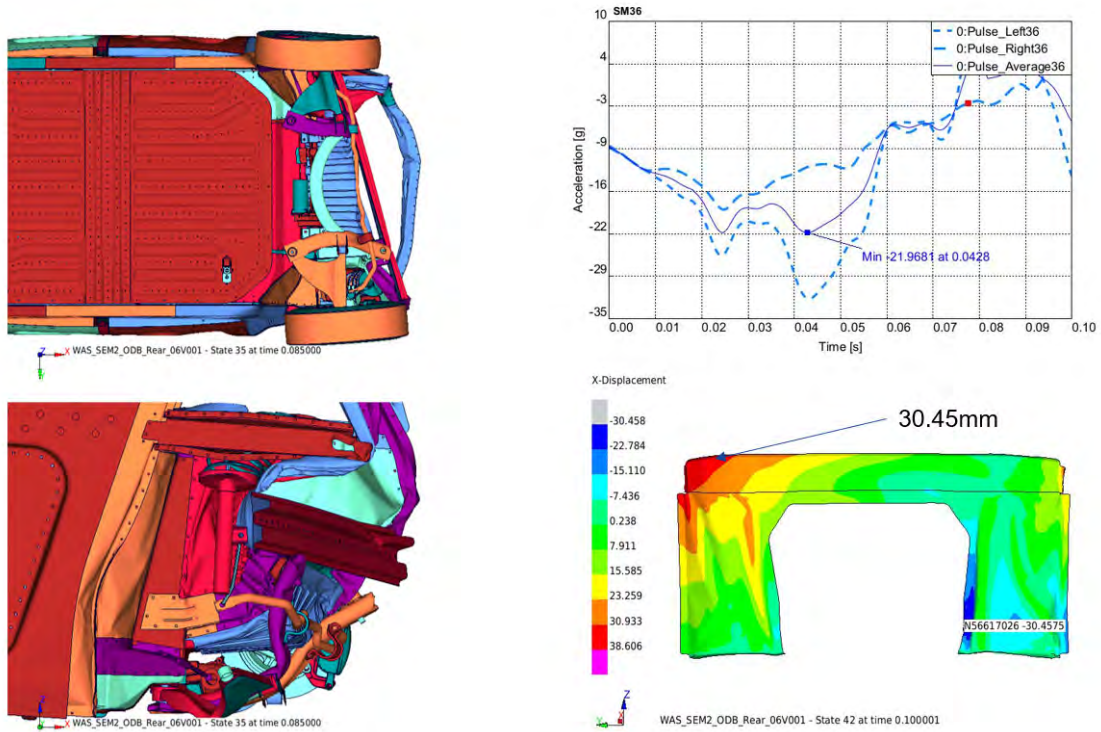


Figure 7.2.6.3 SEM1 FMVSS305 EV rear crash simulation results

The results from the full vehicle crash simulation are shown in Figure 7.2.6.3. A maximum predicted deceleration pulse of 21.9g, cabin intrusion of 30.45mm demonstrates comfortable compliance with the targets (<35g and <40mm intrusion). No contact between the battery modules and body structure was observed, demonstrating compliance with FMVSS305 EV (limiting electrolyte leakage).

Figure 7.2.6.4 shows the design and AHSS grades of the rear crush zone. The PHS rear bumper beam ensures that the barrier loads are distributed across the rear body structure on impact. The rear crush cans and longitudinal rails form the main part of the crush zone, with the grades tuned and optimised using crash CAE tools to achieve the target pulse and intrusion values. A Retained Austenite AHSS grade was selected for the rear longitudinal as the work hardening properties provide a greater crush energy absorption than a typical Dual Phase grade, which was required due to the relatively short crush length available.

| Rear body structure (crush zone) | |
|---|---|
| Geometry/design | Crush cans (2) and longitudinal rails (3) tuned to crush axially under FMVSS305 EV loadcase. Longitudinals are 2 grade TWB. Rear subframe is rigidly bolted to BIW and engineered to fold in rear crash |
| Part 1: REAR BUMPER BEAM | 2.0mm PHS-CR2000T-MB / hot formed |
| Part 2: REAR CRUSH CAN | 1.5mm CR350Y600T DP / cold formed |
| Parts 3: REAR LONGITUDINAL RAILS (2 PARTS) | TWB: (A) 1.6mm CR820Y1180T-RA (B) 1.4mm CR600Y980T-RA / cold formed |
| Part 4: REAR SUBFRAME | 2.0mm CR860Y1180T-DP / hydroformed tubes |
| Part 5: REAR COMPARTMENT PAN LOWER | 0.5mm CR350Y/450T-LA / cold formed |

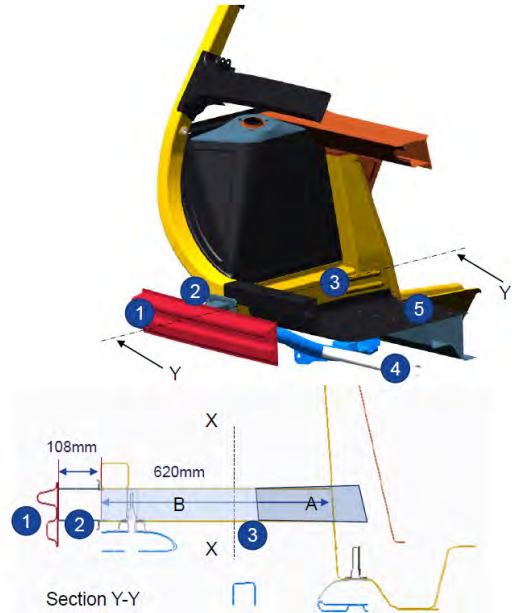
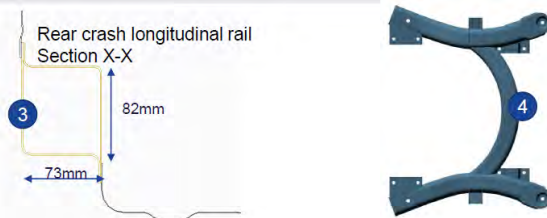


Figure 7.2.6.4 SEM1 Body structure rear zone (See Appendix 4 for larger image)

| Rear body structure (intrusion zone) | |
|---|---|
| Geometry/design | Vertical dash braces provides primary crash load reaction in rear crash. Five bar provides intrusion protection for battery. Rear strut cross member and rear bulkhead provide crush load reaction and intrusion strength |
| Part 1: REAR VERTICAL DASH BRACE | 1.6mm CR820Y1180T-RA / cold formed |
| Parts 2 & 3: FIVE BAR (INNER & OUTER) | 0.8mm CR900Y1180T-CP & 1.8mm CR420Y780T-DP / cold formed |
| Parts 4 & 5: REAR STRUT CROSS MEMBER (UPPER AND LOWER) | 1.0mm CR1200Y1470T-MS |
| Part 6: REAR BULKHEAD | TWB (A) 1.0mm CR1200Y1470T-MS & (B) 0.8mm CR1000Y1470T-MS |



Figure 7.2.6.5 SEM1 Body structure rear zone (See Appendix 4 for larger image)

Protection of occupants and battery in the event of a rear collision is provided primarily by the parts shown in Figure 7.2.6.5. The rear body structure is developed for a single crash loadcase, the requirements from the structural are generally lower than the front crash zone, therefore lower strength steel grades have been applied. The rear vertical dash brace provides significant crush load reaction to the longitudinal rails and braces between the rear strut cross member above and the torque box and five bar in the z plane of the battery. The rear bulkhead consists of a 2 part tailor welded blank in 0.8mm and 1.0mm locally at the top to provide additional strength where required. The rear torque box, five bar and lower vertical dash brace combine to provide crash protection for the battery in rear crash and also

contribute to global body stiffness and strength. Cold stamped Retained Austenite steel grades were selected for the torque box parts, based on the requirements for high strength (~1200MPa UTS) and formability/shape requirements.

| Rear body structure (torque box, five bar, lower vertical dash brace) | |
|---|---|
| Geometry/design | Rear torque box and five bar assembly forms the lower part of the rear crash intrusion zone. The assembly also provides contribution to global body stiffness |
| Parts 1 & 2: REAR VERTICAL DASH BRACE LOWER (INNER & OUTER) | 1.0mm CR820Y1180T-RA / cold formed |
| Parts 3 & 4: TORQUE BOX REAR (INNER & OUTER) | 1.5mm CR400Y780T-RA / cold formed |
| Part 5: FIVE BAR OUTER | 0.8mm CR900Y1180T-CP / cold formed |
| Part 6: FIVE BAR INNER | 0.8mm CR900Y1180T-CP / cold formed |

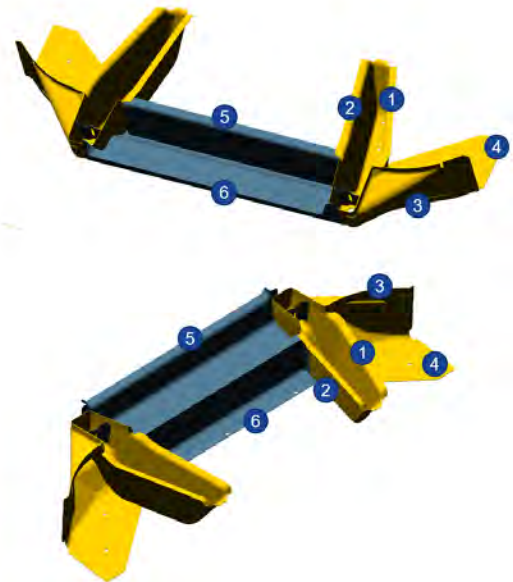


Figure 7.2.6.6 Rear torque box and five bar assembly (See Appendix 4 for larger image)

7.3 Steel E-Motive battery concept

7.3.1 Overview

The Steel E-Motive vehicle features battery electric powertrain with the propulsion battery mounted within the BIW via a carrier frame. Section 6.3 describes the exploration and selection of the battery concept. The SEM1 vehicle features a 75kWh battery capacity, formed from 8 battery modules. The specification of the battery modules are purposefully agnostic, meaning that different battery cell types (pouch, prismatic, cylindrical) could be accommodated within the modules. The final design and AHSS grade selections of the battery are discussed in this section. Figure 7.3.1.1 shows the SEM1 vehicle battery system assembly. The Steel E-Motive concept differs from many current production vehicle batteries by being an “open” (unsealed) unit prior to assembly into the vehicle. The battery modules, cooling plates, interconnects and busbars are assembled onto the structural carrier frame, off-line from the vehicle assembly facility. Typically, this assembly would be a fully sealed/encapsulated unit at this stage –the Steel E-Motive concept is an “un-sealed” battery at this stage. If the battery assembly were to undergo transportation of significant distance (i.e. from an external supplier facility to vehicle final assembly facility) then an additional transportation stillage or carrier device would be required to seal the battery during transit. This would be required to overcome safety requirements such as 1m drop tests. The battery would be removed from the stillage/carrier at the vehicle final assembly and the stillage returned back to the battery supplier facility to be reused. The battery is assembled into the vehicle at the vehicle final assembly facility and located and fasted to the body structure with bolted connections between the carrier frame cross members and body in white floor cross members. A protective battery tray (bottom cover) is then assembled to the underside of the vehicle, sealing the battery within the body structure.

The Steel E-Motive battery concept provides the following advantages and benefits in comparison to current production batteries with sealed pack units:

- Cost and weight saving benefit. The Steel E-Motive battery concept uses the BIW floor as the effective top cover of the battery. The battery pack does therefore not feature a bespoke top cover, enabling cost and weight savings
- The battery carrier frame provides strength and stiffness contribution to the body structure. Typically, the battery is housed a large void in the BIW which can introduce structural weakness or stiffness deficiency. The carrier frame and bottom cover on the Steel E-Motive concept bridges the void, ensuring structural continuity throughout the body structure
- Servicing and repair of the battery will be lower cost. The battery modules and system can be accessed by removing the bottom cover. A damaged or defective battery module would be identified (by the on-board Battery Management System), removed and replaced without having to remove the complete battery pack from the vehicle. This is important for a MaaS vehicle where vehicle usage time is important for Total Cost of Ownership

The AHSS battery carrier frame and tray are discussed in detail in the following sections.

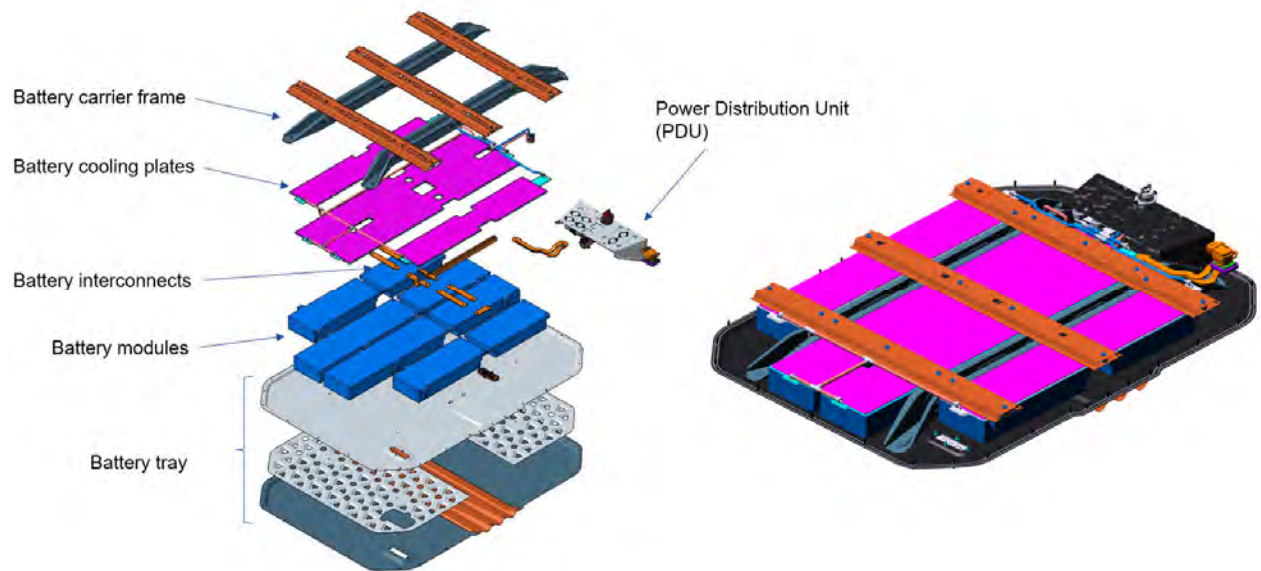


Figure 7.3.1.1 Steel E-Motive battery assembly

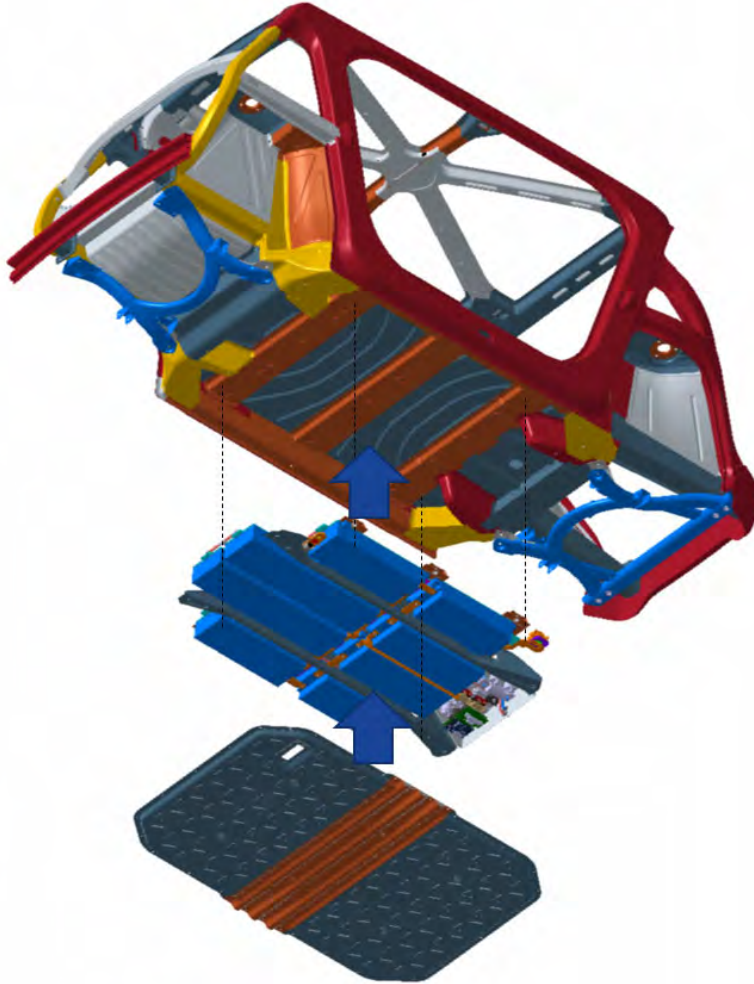


Figure 7.3.1.2 Steel E-Motive battery assembly into body structure

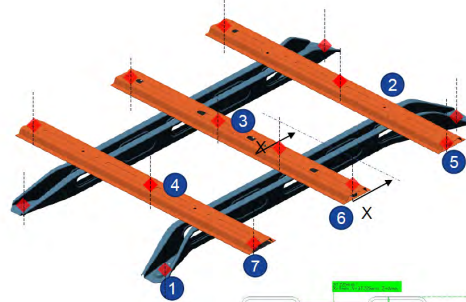
7.3.2 Battery carrier frame

The primary function and requirements of the battery carrier frame are summarised below:

- Support and locate (carry) the battery modules and other battery systems such as cooling, busbars, Power Distribution Unit
- Enable the battery to be assembled “off-line” (i.e. away from the vehicle final assembly)
- Provide stiffness and strength contribution to the global body structure (Section 7.2.2)
- Provide sufficient strength and stiffness such that installed NVH modes of the battery are above the 35Hz target
- Provide location and fixing points for connection to the body structure
- Provide a loadpath from the battery tray to the body structure in the event of underbody debris strike or accidental car jacking (lifting)

Figure 7.3.2.1 shows the SEM1 battery frame and AHSS grades applied for the final SEM1 design.

| Battery carrier frame | |
|--|------------------------------------|
| Part 1 : CARRIER FRAME LONGITUDINAL (LEFT & RIGHT) | 1.8mm CR260Y450T-DP / cold formed |
| Part 2: UPPER CROSS MEMBER #3 | 1.0mm CR1200Y1470T-MS / roll stamp |
| Parts 3 & 4: UPPER CROSS MEMBER #2 & 3 | 1.0mm CR1200Y1470T-MS / roll form |
| Parts 5,6 & 7: LOWER CROSS MEMBERS #3, #2, #1 | 1.0mm CR1200Y1470T-MS / roll form |



◆ Fixing position to body structure

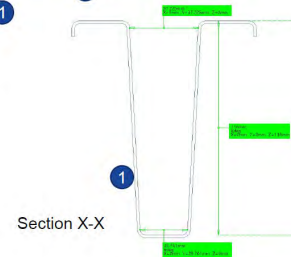


Figure 7.3.2.1 SEM1 battery carrier frame design and AHSS grades (See Appendix 4 for larger image)

The frame longitudinals feature a narrow width profile, enabling a larger packing volume for the battery modules and a deep section, required for higher bending stiffness and enveloping the height of the modules. The front and rear end sections of the longitudinals are flared out to align and marry to the front and rear BIW crash longitudinals and lower parts of the vertical dash braces. This ensures continuity of crash and stiffness loadpaths throughout the body structure. Options for 3 piece longitudinals were considered, with the mid section being a roll formed part and cold stampings at the ends. A single stamped solution was achieved by applying a DP450 AHSS grade, which has good elongation and formability characteristics for the complex geometry and a yield and UTS strength for crash and durability. The single stamped longitudinals would also have slightly improved stiffness compared to a 3 part solution due to the welding required across the 3 part interfaces. The 3 battery frame cross members provide support to the battery modules. The cross members are connect to the longitudinals via bolted joints. The battery modules are suspended from the cross members via fixing bolts. The battery frame cross members align to the BIW floor cross members as shown in Figure 7.2.5.16, and provide a cross vehicle loadpath for side crash loads (Figure 7.2.5.15) . The battery and body in white lateral cross members are MS1470 AHSS grade, and are fabricated using cold stamped, roll formed or roll stamped methods depending on specific geometry of the part. The battery frame (including all the battery parts) is bolted to the body in white via 22 M8 bolted fixings at locations as shown in Figure 7.3.2.1. The frame to BIW fixings and locations ensure that the battery is very well integrated to the parent body structure. This can be demonstrated by the first installed modal frequency of the battery and floor being greater than the 35Hz target (actual value 39.1Hz).

7.3.3 Battery tray and BIW floor sealing

The battery bottom cover (or “battery tray”) was engineered to provide the following functions:

- Protect the battery from impact loads from underneath the vehicle, such as road debris, accidental jacking of the vehicle via the undertray

- Provide a sealing function, protecting the battery from external contaminants such as water and prevent leakage from the battery to outside of the vehicle (e.g. electrolyte, cooling fluid)
- Provide stiffness and strength contribution to body structure
- Provide an aerodynamic cover to the vehicle underside

Figure 7.3.3.1 shows the battery tray construction and AHSS grades

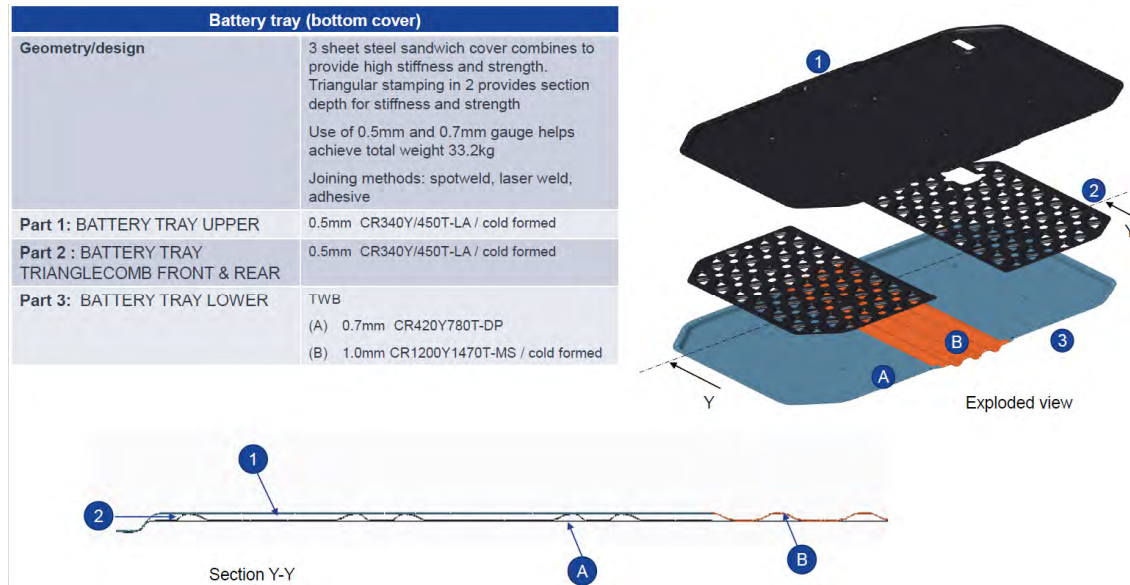


Figure 7.3.3.1 Battery tray design and AHSS grades (See Appendix 4 for larger image)

The battery tray is engineered to provide underbody debris impact protection according to the loadcases defined in Section 4.2.5.2. The performance was developed and assessed using CAE analysis, the results of the final design are shown in Figure 7.3.3.2

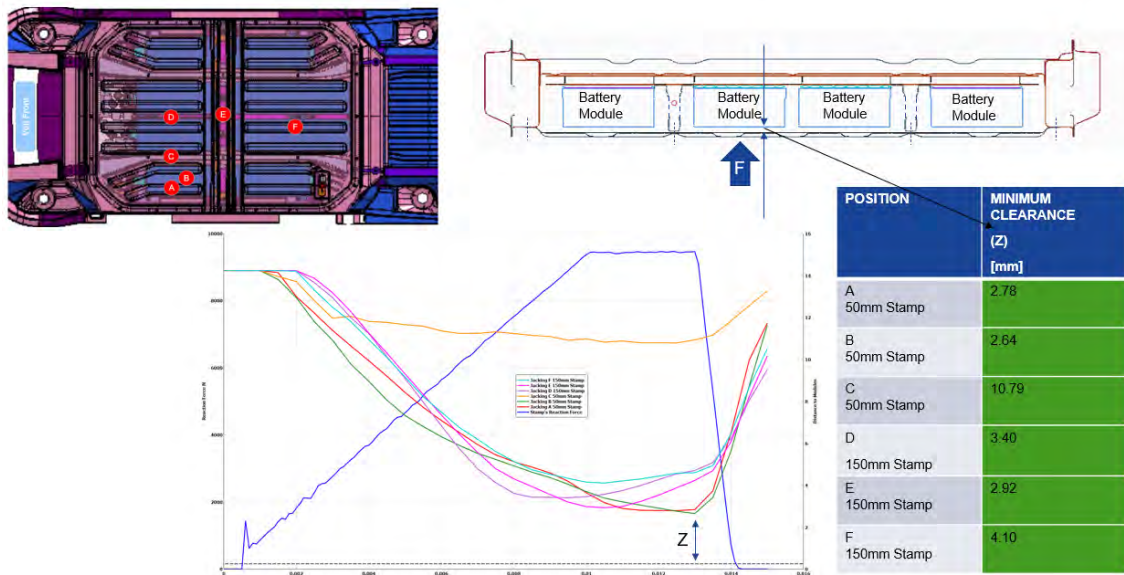


Figure 7.3.3.2 CAE results of battery tray debris and jacking loadcases (See Appendix 4 for larger image)



For all the locations and impactor sizes considered, a minimum clearance distance greater than 2.64mm was calculated, suggesting that the no contact would occur between the battery tray and the battery module in the event of underbody debris impact or accidental jacking. The performance can be attributed to the design concept of the Steel E-Motive battery and the AHSS grades. For impactor location A and B, the strength and stiffness of the AHSS battery tray are sufficient to withstand the impactor loads, with the deflection of tray minimised. The rocker (1) and battery longitudinals provide loadpaths to the body structure. For impactor location C, the battery frame longitudinal provides a direct loadpath to react the load. The worst case impactor locations are D and E, around the centre of the battery and furthest away from the battery frame longitudinals. The AHSS battery tray still manages to prevent contact between the tray and battery modules. This enhanced protection is enabled by the battery architecture and the modules being suspended from the BIW floor, providing a static air-gap clearance between the battery tray and battery modules.

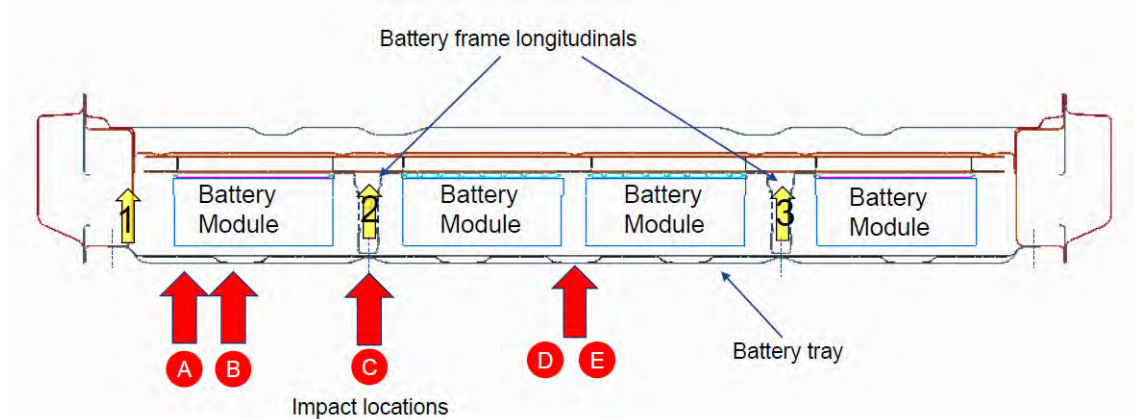


Figure 7.3.3.3 Section in X showing battery, impact locations and loadpaths

The Steel E-motive battery has also been developed for fatigue/durability (Power Spectral Density) performance, drop test and static load crush tests. The results from the CAE analysis demonstrate compliance with the requirements and standards as shown in Figures 7.3.3.4 to 7.3.3.5.

Battery Durability FEA. Predicted PSD Analysis Root Mean Square Von-Mises stress

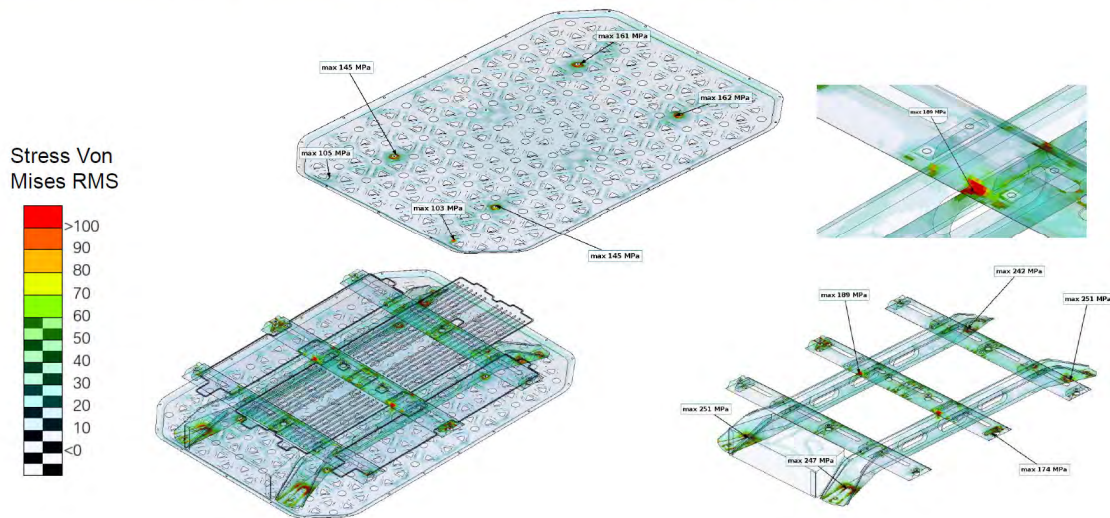


Figure 7.3.3.4 Battery durability FEA. Predicted Von-Mises stresses (Root Mean Square)

Shock 25G
Displacement Scale x10 v10

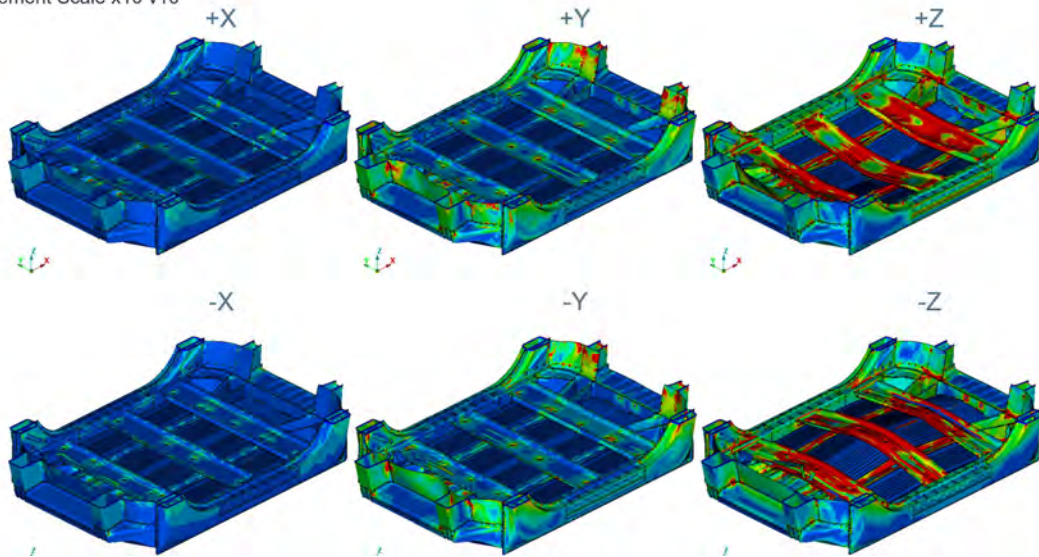


Figure 7.3.3.5 Drop test, 25g shock loading FEA results

Battery sealing:

High voltage batteries pose many safety risks therefore adequate sealing should be provisioned for to prevent the release of any gases from the battery to the passenger compartment, prevent ingress of contaminants from the passenger compartment to the battery compartment (such as fluid/liquid spillages) and prevent ingress of contaminants from outside of the vehicle to the battery compartment (such as water). The Steel E-Motive battery is engineered according to the sealing standards IP6k9k and IP67, requiring ingress protection from dust and water to a depth of 1m for a duration of 30 minutes. Figure 7.3.3.6 shows the sealing configuration for the battery tray.

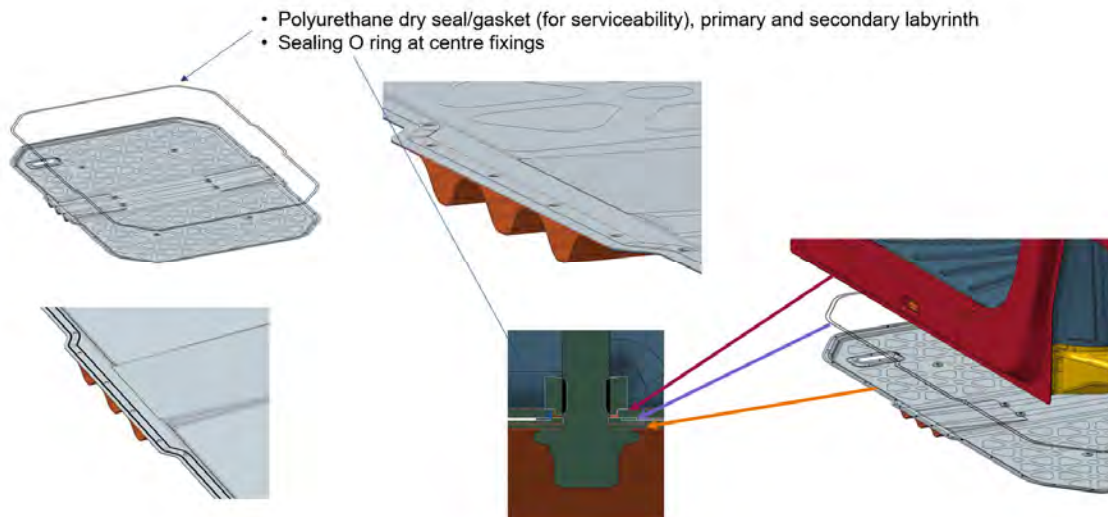


Figure 7.3.3.6 Steel E-Motive battery tray sealing configuration (See Appendix 4 for larger image)

A 2 part (outer and inner) labyrinth dry seal was selected, enabling the cover to be easily removed for battery and module servicing and repair. The battery tray is fastened to the body in white with 36 M8 bolts around the tray perimeter. This ensures appropriate sealing pressure for the labyrinth seal. Additionally the, battery tray is fastened to the battery frame (longitudinals) with 8 M8 bolts. All bolts feature O rings to provide sealing. A key feature of the Steel E-Motive battery is the deletion of the top cover from the pack – this function is provided by the floor of the BIW. This therefore requires BIW to floor to have appropriate sealing treatment. Laser seam welding is applied and for the perimeter weld of the floor panel (Figure 7.2.2.16), providing the appropriate sealing between occupant compartment and the battery. In addition to mechanical/physical seal, the battery compartment would undergo a vehicle production line validation pressure test to ensure the battery compartment sealing was to the required standard. Additionally, battery condition monitoring systems (e.g. temperature) would be installed to alert the occupants and fleet operators to any anomalies with the battery system. In the event of a battery malfunction, the fully autonomous nature of the vehicle would enable the vehicle to manoeuvre and stop in a safe location, open the doors, instruct the occupants to vacate the vehicle and notify the emergency services.

7.4 Steel E-Motive Closures

7.4.1 Side (Scissor) Doors

7.4.1.1 Overview & side door requirements

Section 6.3.5.3 describes the side door concept exploration, evaluation and selection of scissor type doors for the Steel E-Motive design. This section describes the final concept design. The following requirements were considered during the development of the scissor concepts:

- provide closing/encapsulation of body structure whilst in closed position. Enable safe, unobstructed access to the vehicle in the open position
- provide protection and sealing from external elements (e.g. moisture, noise)
- enable visibility/provision glazing
- contribution to vehicle crashworthiness, with respect to protection of occupants and battery
 - side barrier and side pole loadcases have direct impact
 - front and rear crash loadcase contribution
- provide contribution to overall body stiffness, with low cost and weight
- have sufficient durability and strength to withstand fatigue and abuse loads
- meet the aesthetic safety and operational requirements for a fully autonomous vehicle (e.g. condition monitoring, automated controls activation)
- integrated within the overall vehicle styling theme

7.4.1.2 SEM Scissor door design

Figures 7.4.1.2.1 shows the SEM1 scissor doors in the open and closed position and Figure 7.4.1.2.2 shows the hinging and actuator mechanism.



Figure 7.4.1.2.1 SEM1 scissor doors – open and closed positions

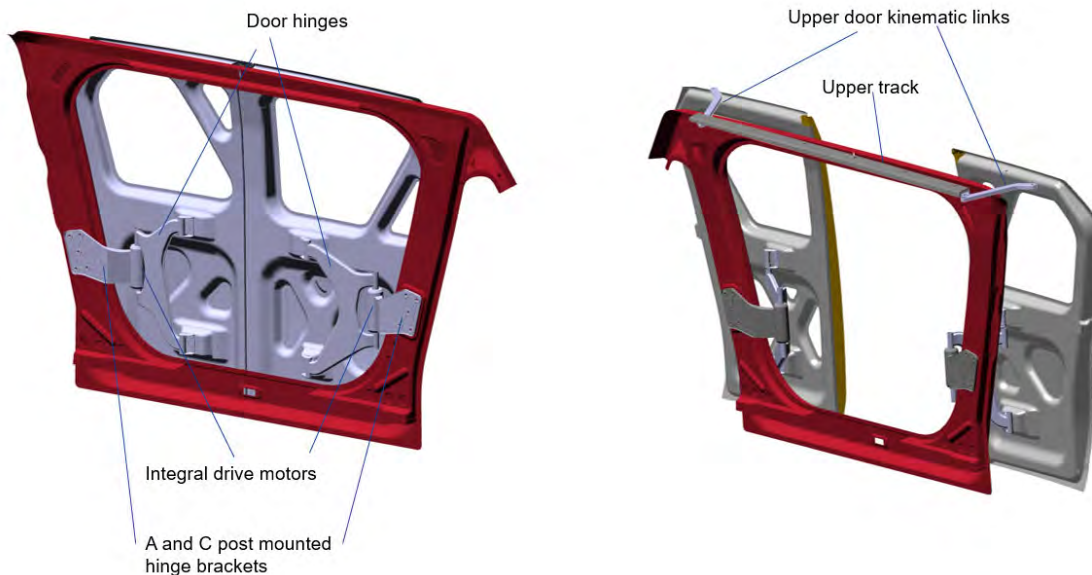


Figure 7.4.1.2.2 SEM1 scissor doors – actuators and hinges

The SEM1 scissor doors have fully automated operation. The electronics and control systems for the doors were not specifically considered within the scope of this project. An electronically controlled integral drive motor provides the primary door opening method. The motors are mounted from A and C pillar hinge brackets. The motor torque is applied to the doors via hinges. A combination of the hinge design and upper kinematic track and links determines the opening motion of the scissor doors as shown in Figure 7.4.1.2.3

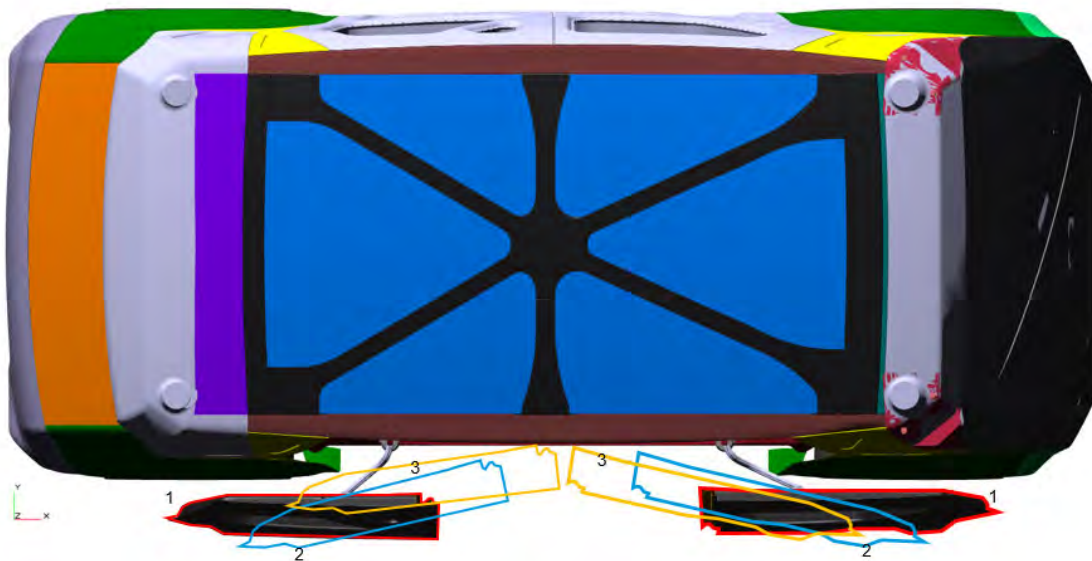
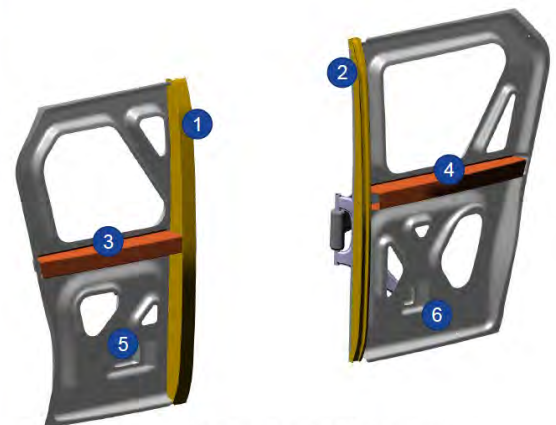


Figure 7.4.1.2.3 SEM1 scissor door closing steps

The scissor door structures feature hydroformed B pillars in RA690 grade and horizontal door beams in roll stamped MS1470. These combine to provide side crashworthiness performance as described in Section 7.2.4. A decision was made during the concept phase to specify fixed glazing in the scissor doors. This was primarily driven by operational safety requirements, however fixed glazing offers cost and weight savings also. Appropriate and automated Heating, Ventilation and Air Conditioning (HVAC) systems would be able to maintain appropriate levels of thermal comfort within the passenger cabin. Figure 7.4.1.2.4 shows the AHSS grades used in the SEM1 scissor door structure.

| Scissor Door Structure | |
|--|---|
| Geometry/design | B pillars (1 & 2) and horizontal door struts (3 & 4) provide main crash loadpaths for IIHS side barrier. B pillars overlap the cantrail (top) and rocker sections (bottom) to provide crash loadpath into BIW structure. Mild steel door inner panels and bake hardenable outer panels. Lattice features provide some |
| Parts 1 & 2: B PILLAR (FRONT AND REAR) | 1.2mm CR400Y690T-RA / Hydroformed |
| Parts 3 & 4: HORIZONTAL DOOR STRUTS (FRONT AND REAR) | 1.5mm CR1200Y1470T-MS / roll stamp |
| Parts 5 & 6: DOOR INNER PANEL (FRONT AND REAR) | 1.2mm Mild140/270 / cold stamp |
| Parts 7 & 8: DOOR OUTER PANEL(not shown) (FRONT AND REAR) | 0.7mm CR280Y/400T-BH / cold stamp |



(door outer A surface panel removed)

Figure 7.4.1.2.4 AHSS grades in SEM1 scissor doors (See Appendix 4 for larger image)

7.4.2 Rear tailgate (coach) door

The Steel E-Motive rear door concept was selected during the preliminary concept Phase 0. The “coach door” features a parallel swing arm and powered lift device, resulting in a reduced outward swing distance, providing improved operation in compact spaces.

The tailgate structure features a cold stamped mild steel inner panel and bake hardenable outer A surface panel. The outer A surface features the exterior styling lattice structure features.

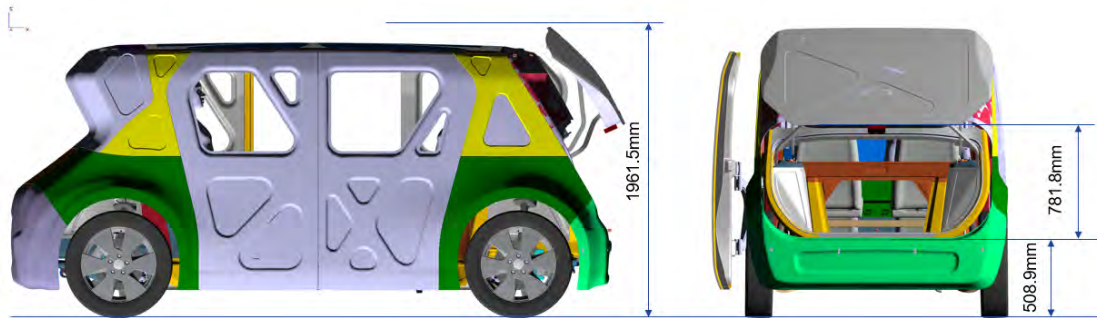


Figure 7.4.2.1 Rear coach door tailgate key dimensions

| Rear Tailgate (coach) Door Structure | |
|---|-------------------------------------|
| Geometry/design | |
| Part 1 A SURFACE OUTER | 0.7mm CR280Y/400T-BH / cold stamp |
| Parts 2: HORIZONTAL DOOR STRUTS (FRONT AND REAR) | 1.2mm MILD STEEL 140/170 cold stamp |

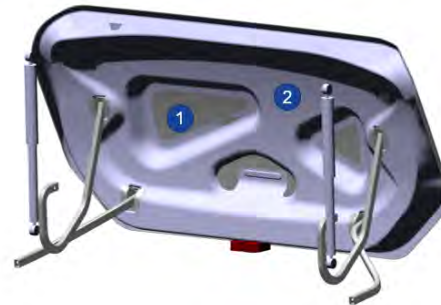


Figure 7.4.2.2 Rear coach door tailgate AHSS grades (See Appendix 4 for larger image)

7.5 Steel E-Motive body in white manufacture and assembly process

The stamping feasibility for the most challenging parts (shape and grade) of the body structure were developed and assessed with the assistance of Autoform stamping simulation software. This was a parallel activity during the design of the body structure. An example of the output from the Autoform stamping simulation is shown in Figure 7.5.1, and the results for the panels evaluated are shown in Appendix 2.1.



Figure 7.5.1 Example from Autoform stamping simulation output

The Steel E-Motive vehicles have been engineered for high volume production, with an expected capacity of 250,000 vehicles per year, at any global manufacture facility. To achieve the high-volume capacity, conventional body and vehicle assembly processes and procedures have been employed. The body structure is divided into assemblies and sub-assemblies that facilitate the efficient assembly of the body structure. The complete sub-assemblies and body structure assembly process is described in Appendix 2.2. A summary of the main BIW sub assemblies is shown in Figure 7.5.2.

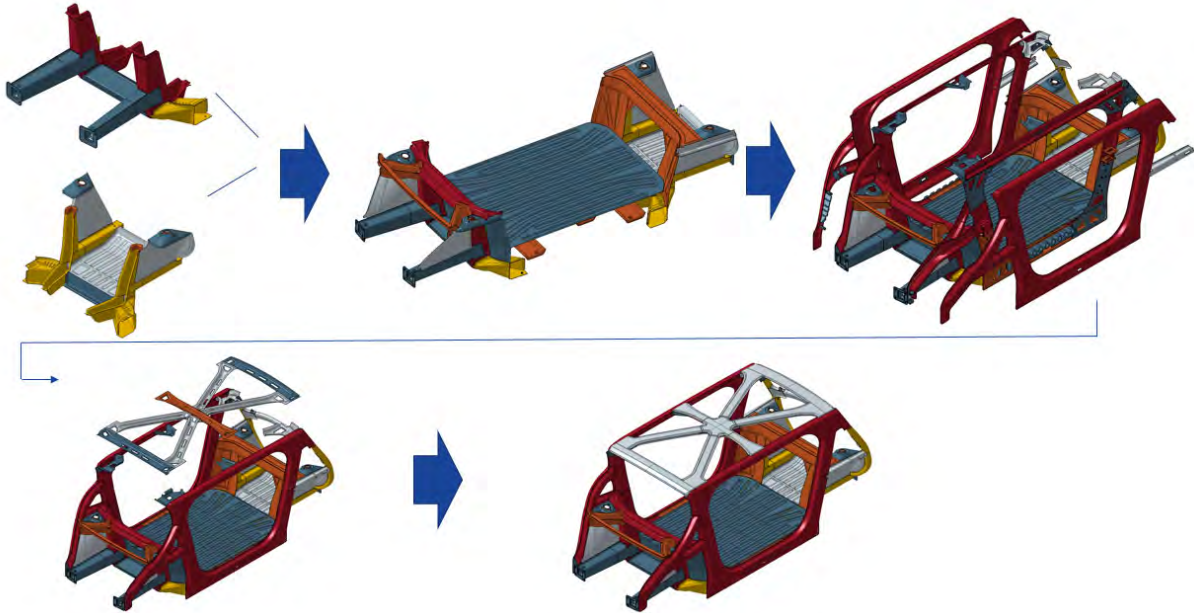


Figure 7.5.2 BIW sub-assemblies (See Appendix 3 for complete body assembly and sub-assembly definition)

7.6 SEM1 body structure cost evaluation

7.6.1 Introduction and approach for cost evaluation

A full costing evaluation of the SEM1 body structure, including BIW, closure, bumper beams and battery frame was undertaken using a modified Excel tool, originally created by The Massachusetts Institute of Technology (MIT). The tool was updated with the material prices at the time of the project. The Covid-19 pandemic saw some significant fluctuations in material prices. The final material prices applied were from November 2022 period, when the disturbance from the pandemic had largely abated. Material costs are defined in the model with a base material price, such as hot or cold steel, then additional price premiums for the specific steel grade (e.g. BH, HSLA, DP, CP, RA, DH, PHS, MS), coatings and finish (hot dip galvanic, AISi, A surface), tailor welded & tailor coil premium and tube stock premiums. A material scrap price enables cost recovery for return scrap. Nominal vehicle parameters such as powertrain type, overall dimensions, production volumes and platform sharing are defined, along with manufacturing inputs such as energy costs, worker salaries, building and maintenance costs. The body structure is largely defined from the Bill Of Materials, containing material grade, gauge and weight. The part blank sizes are defined, enabling an estimation of part material usage and scrap. The part manufacturing processes are defined, such as blanking, trimming, stamping and rework, roll forming, hydroforming. Different stamping machines can be selected depending on the part size and complexity. The costing tool calculates body structure total cost, and breakdowns for material cost, manufacturing costs and paint costs. The tool also makes an interpolation on total vehicle cost.

7.6.2 SEM1 cost estimates

Figure 7.6.2.1 shows the costing tool calculations for SEM1 body structure and vehicle

| | Body structure parts cost (\$) *1 | Paint costs (\$) | Assembly costs (\$) | Total body structure cost (\$) | Total Vehicle MSRP (\$) *2 |
|---------------|-----------------------------------|------------------|---------------------|--------------------------------|----------------------------|
| BIW | 1203 | 130 | 146 | 1818 | 40,406 |
| Battery frame | 154 | | | | |
| closures | 186 | | | | |
| Total | 1543 | | | | |

*1 includes: Equipment, Tooling, Building, Maintenance, Energy, Labour, Overhead, Process, Materials (excludes: assembly & paint costs)

*2 includes approximates for battery, powertrain, electrical, interior, chassis. Does not include costs for autonomous vehicle systems (such as radar & lidar)

Figure 7.6.2.1 SEM1 body structure and vehicle cost estimates

Figure 7.6.2.2 shows the contributions to the body in white parts costs

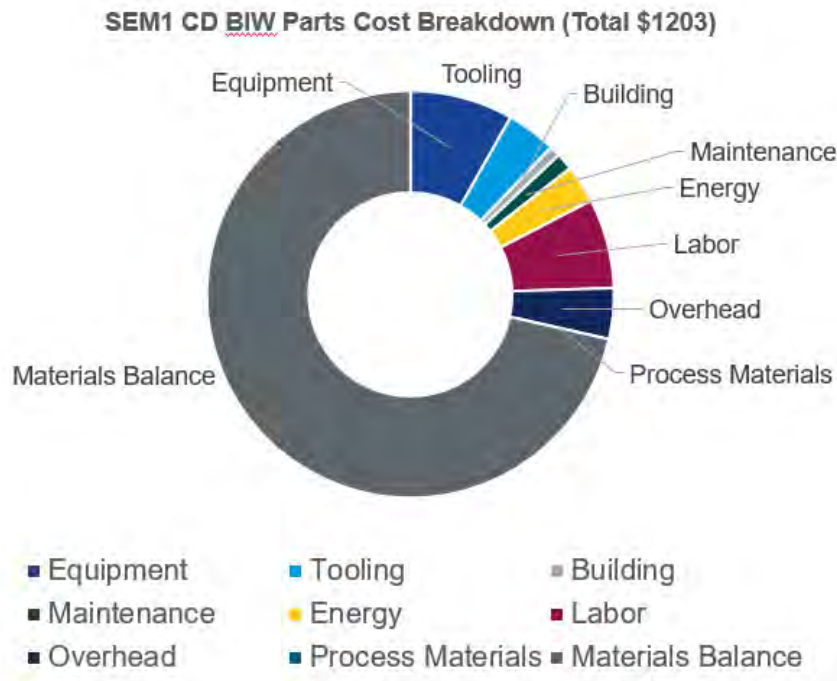
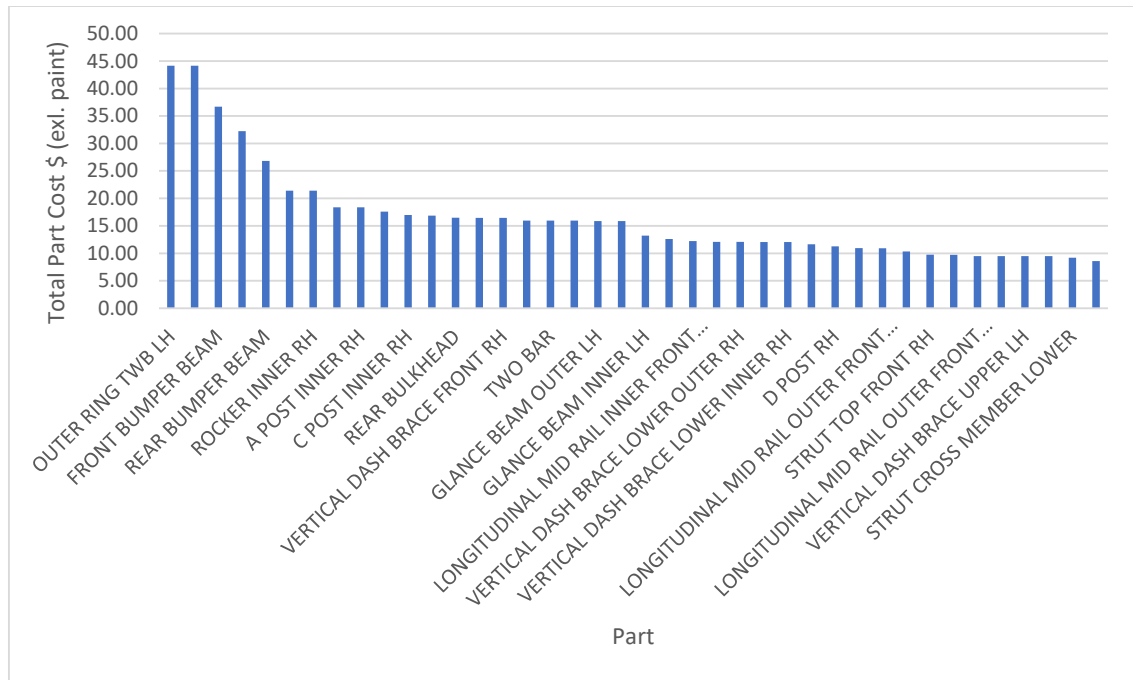


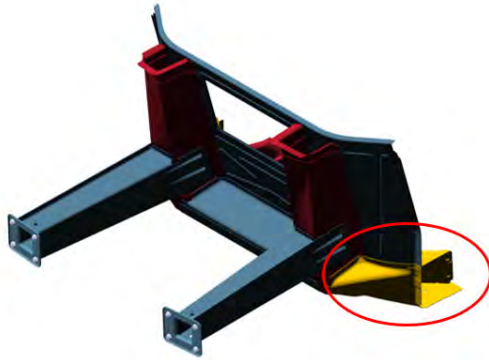
Figure 7.6.2.2 SEM1 Body in White parts cost contribution

Figure 7.6.2.3 shows a pareto of the highest 45 part costs in the SEM1 BIW



The following cost saving measures were introduced to the body structure design throughout the development of SEM1

- Use of conventional high volume steel stamping, fabrication and assembly methods
- Deletion of the BIW body side outer panel. The side closures cover much of the body side outer surface, hence it was therefore deemed that a low grade (BH/HSLA) body panel with specific purpose to be the A surface would be redundant and not required. The quality of the visible PHS panel when the doors are in the open position as deemed to be acceptable. Lightweight cover/garnish trim panels could be added to areas where the surface quality was deemed unacceptable. In addition to the cost saving, an estimated weight reduction of 26kg is achieved by deletion of the body side outer panels
- SEM1 and SEM2 battery housing features innovative “coverless” housing. The BIW floor assumes the role of the battery top cover
- BIW weight saving. SEM1 is estimated to be 25% lower in weight than a vehicle of similar dimensions. The weight saving would also equate to a reasonable cost saving.
- Use of AHSS grade qualities to achieve greater part integration, resulting in a lower number of part and lower tooling costs. An example of this is the front torque box, where the high formability and high strength characteristics of Retained Austenite AHSS enabled an existing 3 part assembly to be converted to a lower cost 2 part assembly.



2 part FRONT TORQUE BOX (INNER & OUTER)
1.0mm CR8501180T-DH

7.7 Body in white alternative AHSS grades and fabrication processes study

The AHSS selected for the final concept design of SEM1 were based on the engineering and performance requirements, such as strength, durability, formability, cost and weight. Given the breadth of AHSS available, it is widely acknowledged that there could be multiple alternative grade and fabrication solutions for a given part. To demonstrate this, an “alternative AHSS grades” study was performed. Each part in the BIW was review and assessed with respect to it’s performance requirements and potential for alternative AHSS grade and fabrication process. Alternative grades and processes were assigned on a subjective basis (additional CAE analyses would be required to confirm the feasibility of the alternative grades). The complete Bill of Materials for the alternative AHSS grades study is in Appendix 1B. A narrative on the selection and justification of alternative AHSS grade and process is provided in the BoM. Figure 7.7.1 shows the comparison AHSS grade distribution of the SEM1 BIW baseline (or “core”) design compared to the alternative grades. Appendix 1.5 shows the BIW Bill of Materials for the alternative grade configuration.

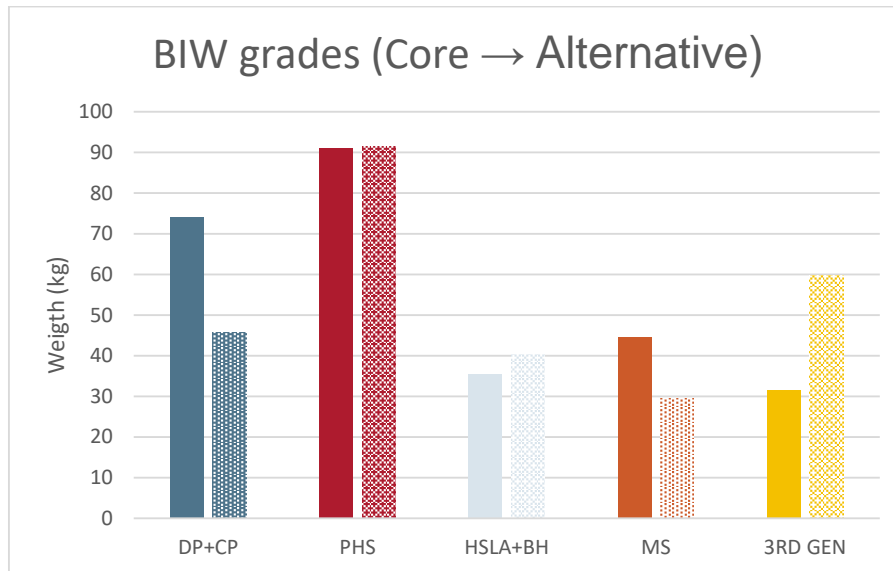


Figure 7.7.1 Comparison of AHSS grade use in SEM1 “core design” BIW and alternative grades

8.0 SEM1 performance

8.1 Introduction & overview

This section describes the specification and performance of the final SEM1 design. For reference and completeness, the results are presented in table and graphical formats.

8.1.1 Vehicle dimensions, exterior & interior

(refer to Section 7.13 and Section 11.0 SEM2 and comparison to SEM1 vehicle dimensions)

8.2 Front crashworthiness

| <i>Vehicle Crashworthiness</i> | | | | |
|--|--|--|----------------------------|--|
| | Loadcase | Target Value | Result Value | Comments |
| Front (core loadcases) | US - NCAP 56 km/h FFB | <35 G Deceleration | 33.1 | - progressive, controlled collapse of crush rail - front subframe collapse encourages EDU ride down, reducing impact to front bulkhead - see Figure 8.2.2 |
| | | < 40 mm bulkhead intrusion | 2.5 | |
| | IIHS 64 km/h 40% ODB | <35 G Deceleration | 20.5 | Targets described in Figure 4.2.3. Intrusion values are within IIHS "good" rating - see Figure 8.2.3 |
| | | Footwell intrusion (1,2,3) < 150mm | 1) 2.4 2) 4.1 3) 1.4 | |
| | | Bulkhead Intrusion (4,5) < 50mm | 4) 3.4 5) 5.2 | |
| | | A pillar Y intrusion (6,7) >180mm clearance to seat centreline | 6) >180mm 7) >180mm | |
| | | No contact body structure to battery | (no contact observed) | |
| | IIHS 64 km/h 25% SORB | <35 G Deceleration | 19.9 | - IIHS "good" rating achieved. Vehicle exhibits "glance off" motion with 420mm lateral deflection - intrusion levels close to target but within 75mm IIHS "good" target - very stable A pillar and door ring - see Figure 8.2.4 |
| | | Footwell intrusion (1,2,3) < 150mm | 1) 2.0 2) 2.4 3) 4.2 | |
| | | Bulkhead Intrusion (4,5) < 75mm | 4) 53.8 5) 48.9 | |
| A pillar Y intrusion (6,7) >180mm clearance to seat centreline | | 6) >180 7) >180 | | |
| No contact body structure to battery | | (no contact observed) | | |
| Front (reference loadcase) | OEM Centre Rigid Pole 64km/h, 253mm Pole | <40 G Deceleration | 39 | - <40g pulse for all loadcases - < 70mm dash intrusions - Passenger cell integrity remains good |
| | | < 80 mm bulkhead intrusion | 1.6 | |
| | NHTSA 90kph 35% 15 degree oblique | <40g | 31.9 | - see Figure 8.2.5 to 8.2.7 |
| | | <80mm intrusion | 70 | |
| | NCAP - MPDB | <40 G Deceleration | 33.3 | |
| < 80 mm bulkhead intrusion | | 1.3 | | |

Figure 8.2.1 SEM1 front crashworthiness results (from full vehicle simulation)

USNCAP 56kph 0 degree frontal rigid barrier (FFB)

| | |
|---------------------|----------------------------------|
| Model level | V06v001 |
| Peak pulse (g) | 33.1 g (@ B pillar) sliding mean |
| Peak intrusion (mm) | 2.5 mm |

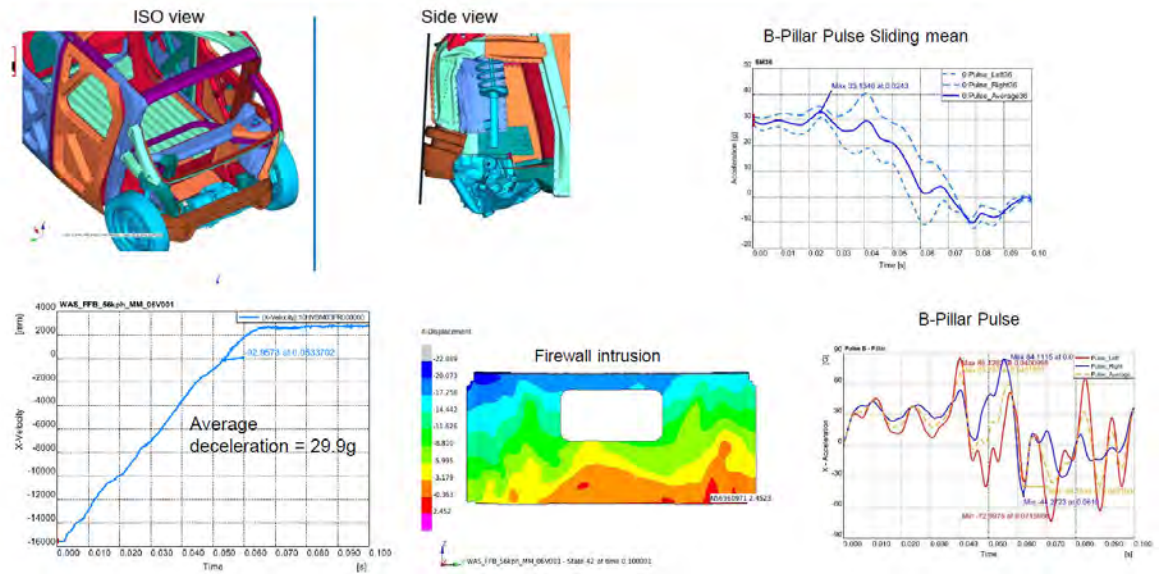
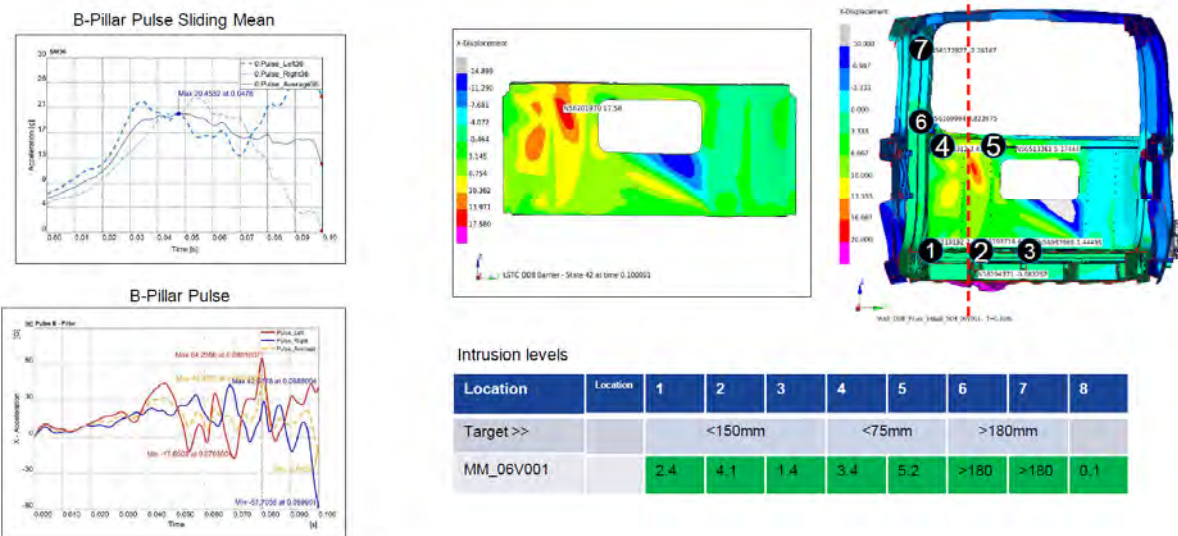


Figure 8.2.2 SEM1 USNCAP 50kph front FFB crash simulation results

IIHS 64kph 40% Moderate Overlap (Offset Deformable Barrier "ODB")

| | |
|---------------------|----------------------------------|
| Model level | V06v001 |
| Peak pulse (g) | 20.5 g (@ B pillar) sliding mean |
| Peak intrusion (mm) | 17.6 mm |



| Intrusion levels | | Location 1 | Location 2 | Location 3 | Location 4 | Location 5 | Location 6 | Location 7 | Location 8 |
|------------------|--|------------|------------|------------|------------|------------|------------|------------|------------|
| Target >> | | <150mm | | | <75mm | | >180mm | | |
| MM_06V001 | | 2.4 | 4.1 | 1.4 | 3.4 | 5.2 | >180 | >180 | 0.1 |

Figure 8.2.3 SEM1 IIHS 64kph ODB crash simulation results

| IIHS 64kph 25% Small Overlap (Small Offset Rigid Barrier "SORB") | |
|--|----------------------------------|
| Model level | V06v001 |
| Peak pulse (g) | 19.9 g (@ B pillar) sliding mean |
| Peak intrusion (mm) | 74.6 mm |

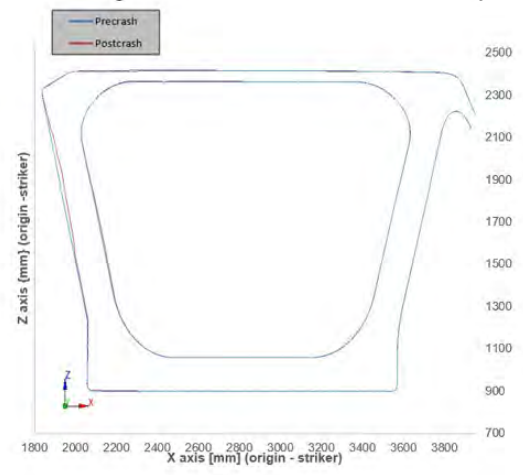
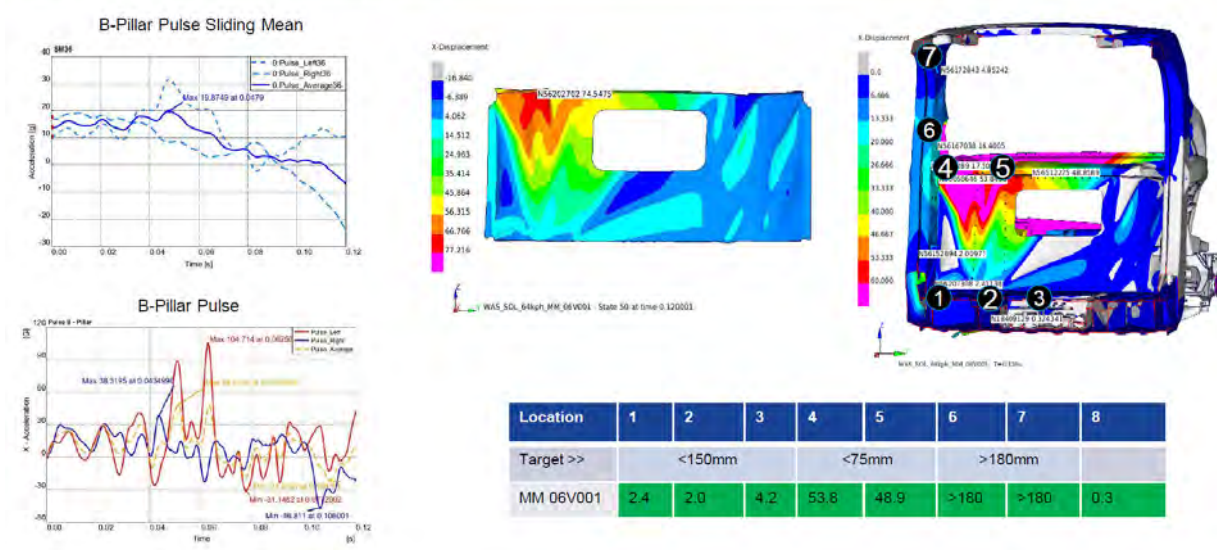


Figure 8.2.4 SEM1 IIHS 64kph front SORB crash simulation results

| Reference Loadcase: Front 64kph Rigid Pole | |
|--|----------------------------------|
| Model level | V06v001 |
| Peak pulse (g) | 39.0 g (@ B pillar) sliding mean |
| Peak intrusion (mm) | 1.6 mm |

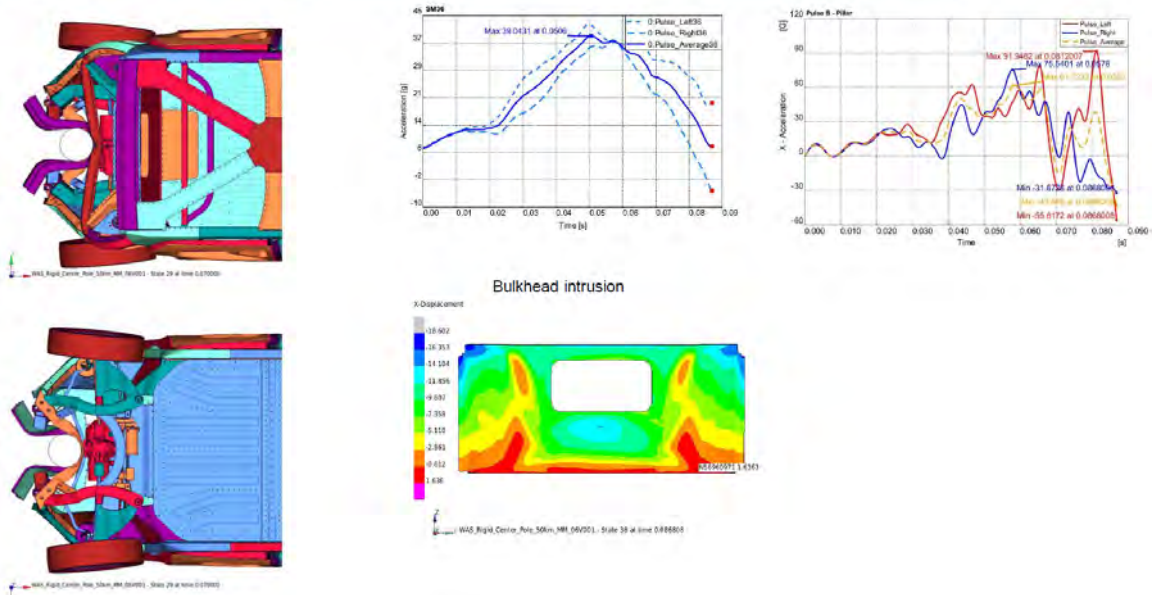


Figure 8.2.5 SEM1 Front 64kph 254mm rigid pole crash simulation results

| Reference Loadcase: NHTSA front 90kph Oblique Moving Deformable Barrier (OMDB) | |
|--|----------------------------------|
| Model level | V06v001 |
| Peak pulse (g) | 32.0 g (@ B pillar) sliding mean |
| Peak intrusion (mm) | 70.1 mm |

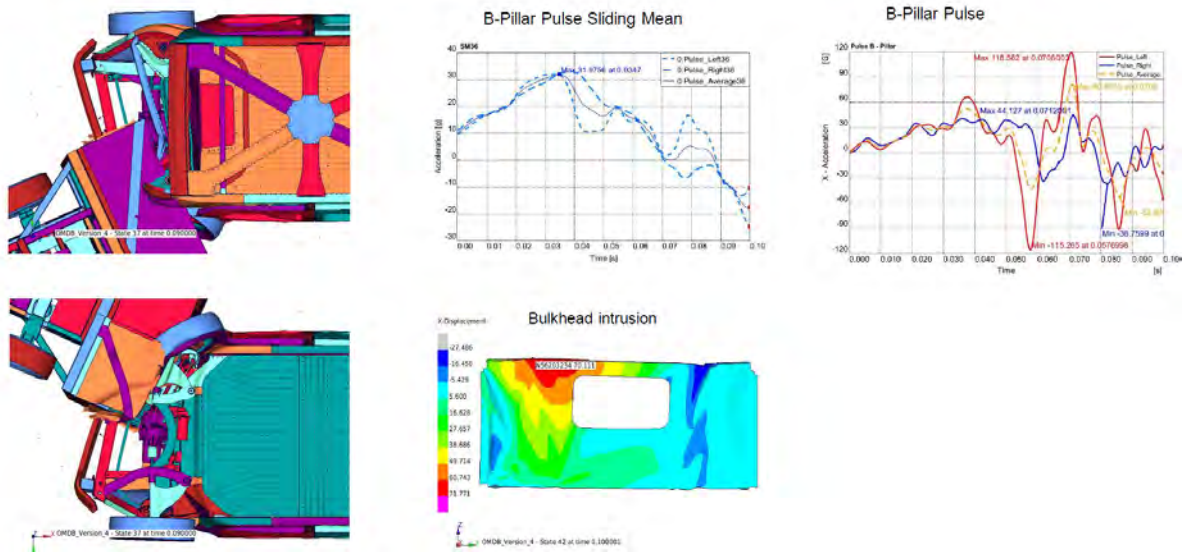


Figure 8.2.6 SEM1 NHTSA 90kph front OMDB crash simulation results

| Reference loadcases. Euro NCAP MPDB, 50km/h | |
|---|----------------------------------|
| Model level | V06v001 |
| Peak pulse (g) | 33.3 g (@ B pillar) sliding mean |
| Peak intrusion (mm) | 1.4 mm |

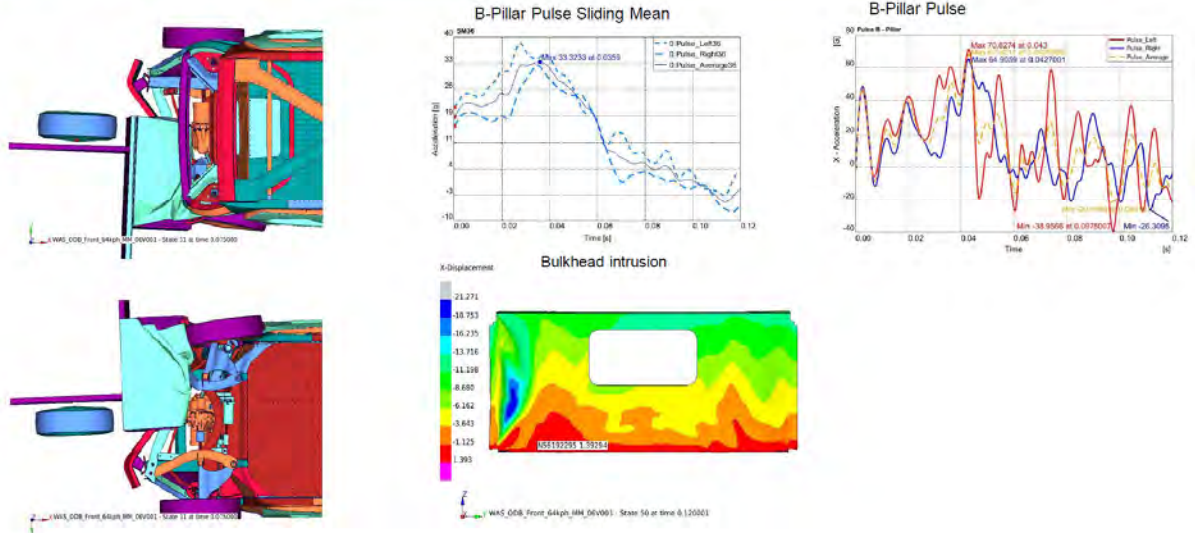


Figure 8.2.7 SEM1 EuroNCAP 50kph Front Moving Progressive Deformable Barrier (MPDB)

8.3 Side crashworthiness

| | | Vehicle Crashworthiness | | |
|------|--------------------------------|--|--------------|--|
| | Loadcase | Target Value | Result Value | Comments |
| Side | SIDE IIHS 60 km/h MDB | "good" = >180mm intrusion clearance to driver seat c/l | 296 | Occupant intrusion clearance is comfortably achieved (note IIHS 2 barrier). = IIHS "good" rating >30mm intrusion clearance to battery |
| | SIDE US-NCAP 32km/h Rigid pole | (IIHS side barrier intrusion targets >180mm clearance) | 236 | - Occupant intrusion levels are acceptable (by applying IIHS intrusion guidelines to USNCAP pole) - > 30mm clearance to HVC battery achieved |
| | D254mm | > 30 mm clearance inner rocker to battery module | 33 | |

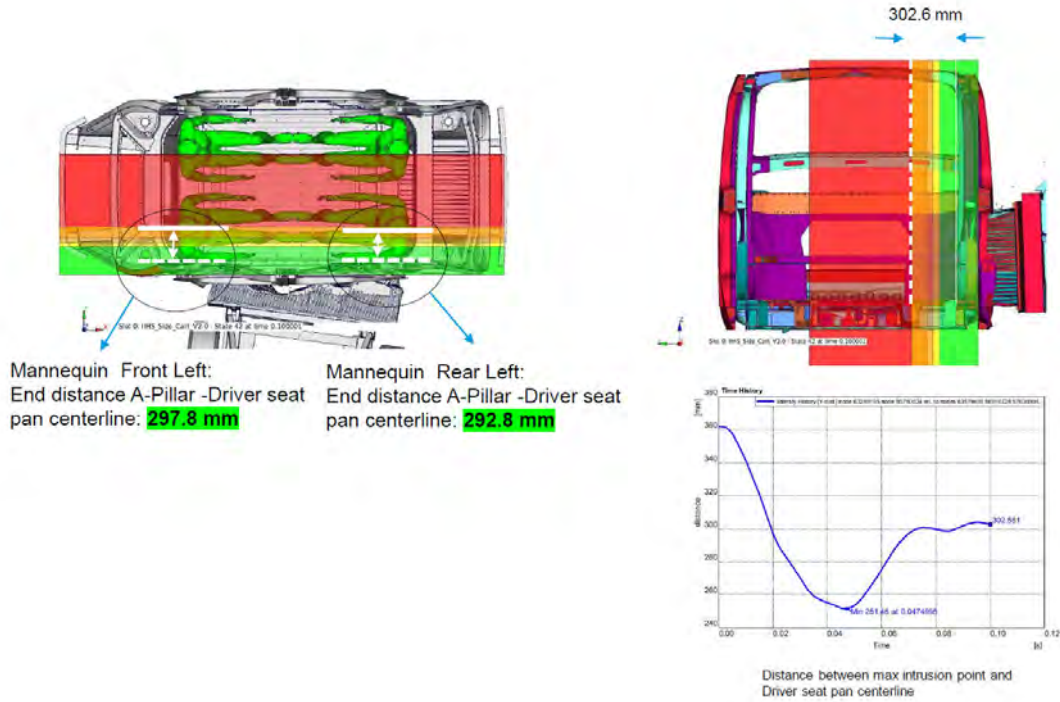


Figure 8.3.2 IIHS 60KPH side barrier (II) crash simulation results (See Appendix 4 for larger image)

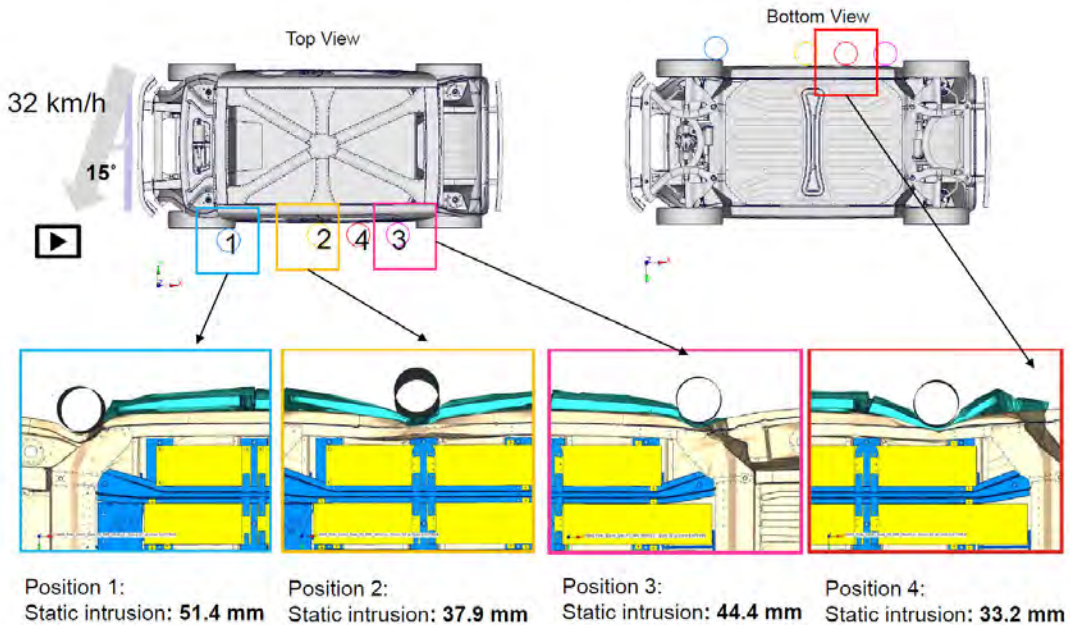
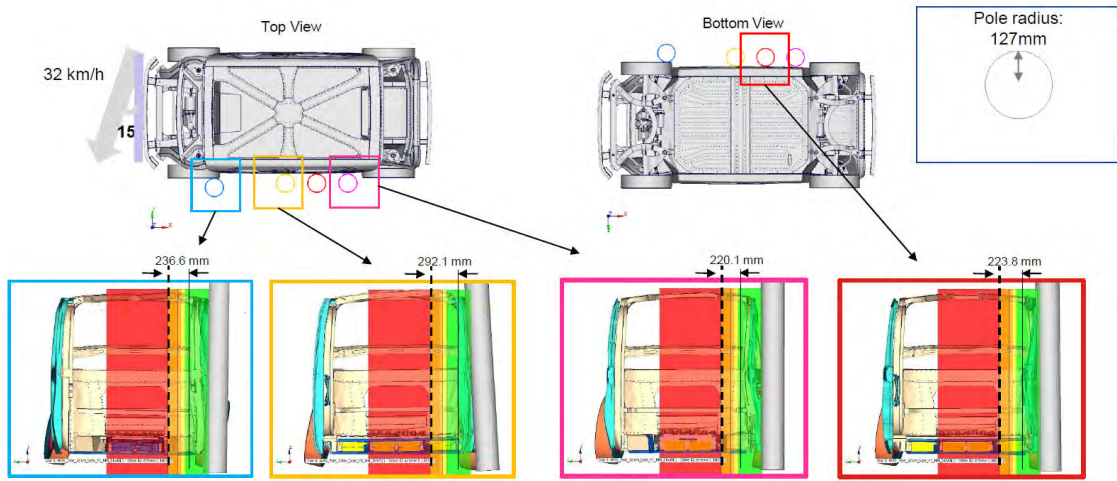


Figure 8.3.3 USNCAP 32kph side pole crash simulation results, battery protection (See Appendix 4 for larger image)



Distance between max intrusion point and Driver seat pan centerline

Figure 8.3.4 USNCAP 32kph side pole crash simulation results, occupant protection (See Appendix 4 for larger image)

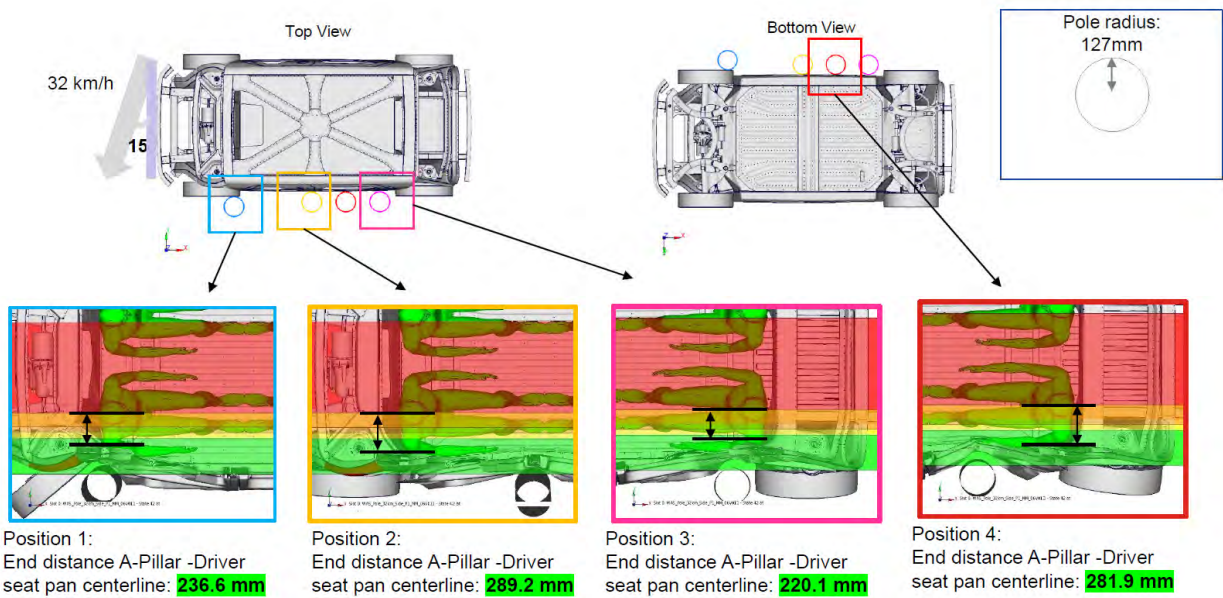


Figure 8.3.5 USNCAP 32kph side pole crash simulation results, occupant protection (See Appendix 4 for larger image)

8.4 Rear crashworthiness, FMVSS305 EV

| Rear FMVSS305 EV, 80kph 70% Deformable barrier | |
|--|----------------------------------|
| Model level | V06v001 |
| Peak pulse (g) | 21.9 g (@ B pillar sliding mean) |
| Peak intrusion (mm) | 30.5 mm |

UN

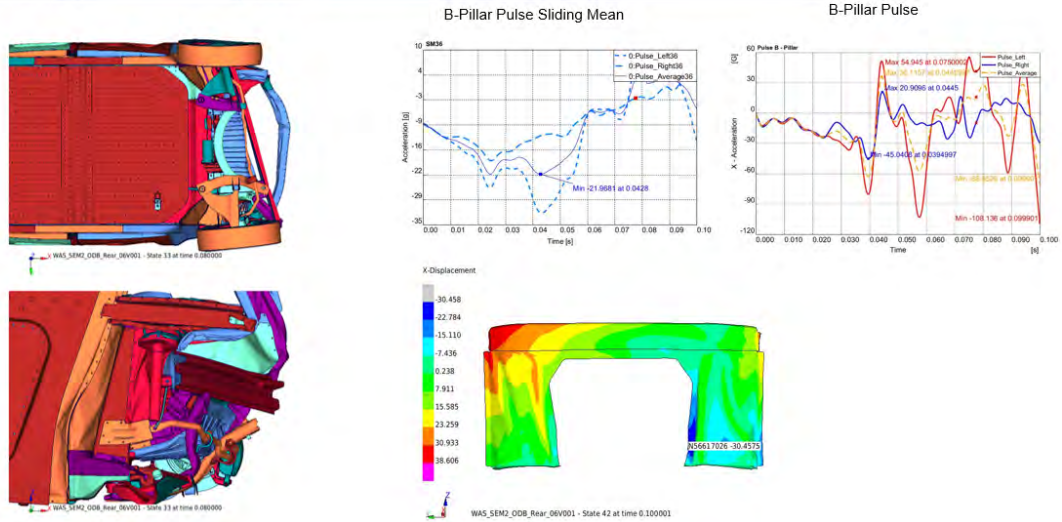


Figure 8.4.1 Rear crash simulation results, FMVSS305 EV

8.5 Roof crush

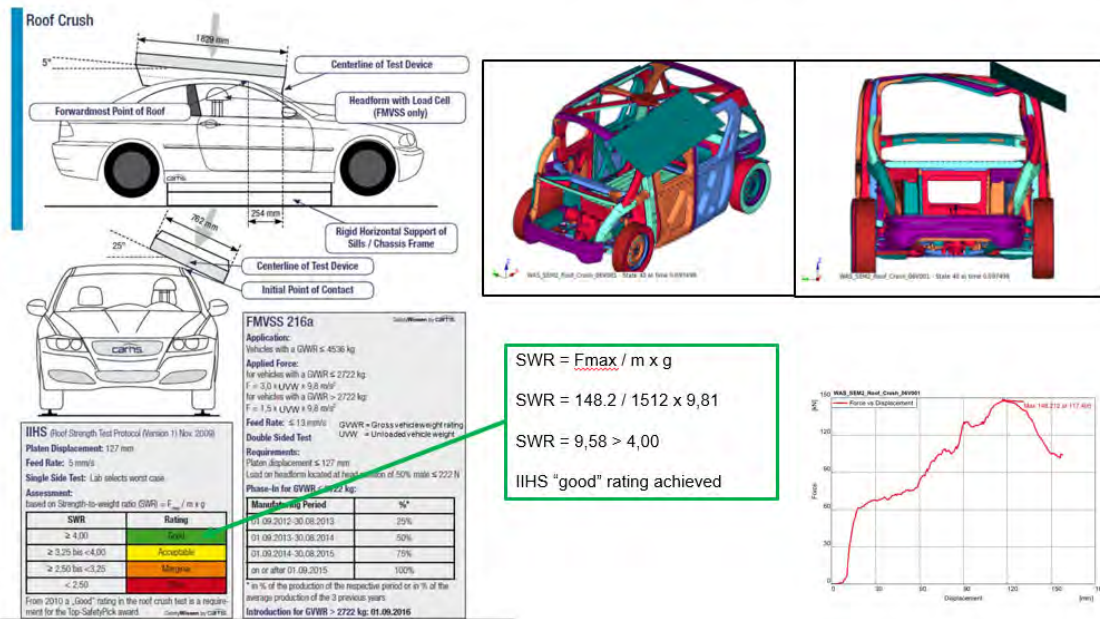


Figure 8.5.1 Roof crush strength simulation results

8.6 Vehicle and subsystem weight

| Subsystem | SEM 1 weight (kg) | Comment |
|---------------------------------|-------------------|---|
| Body non-structure | 177.2 | Estimated from a2mac1 statistical analysis. Includes seating, trim panels, glazing, front end clip, exterior panels |
| Body In White | 282.0 | <CD> design from CAD |
| Front sub-frame | 16.5 | <CD> design from CAD |
| Battery case (structure) | 59.0 | <CD> design from CAD |
| Rear sub-frame | 10.2 | <CD> design from CAD |
| Front suspension | 114.0 | Design New Architecture |
| Rear suspension | 114.0 | Design New Architecture |
| Braking | 59.7 | Estimated from a2mac1 statistical analysis |
| Steering | 26.0 | column, EPAS etc) |
| Tires and wheels | 84.0 | Estimated from a2mac1 statistical analysis |
| Motor Trans Front | 63.0 | Estimated from a2mac1 statistical analysis and Fiat 500e |
| Motor Trans Rear (N/A SEM1) | | Estimated from a2mac1 statistical analysis and technology roadmap |
| Battery system less case | 245.6 | Ref BOM including 5kg of fluids, busbars, cooling plate, modules and PDU |
| Propulsion controls | 60.0 | Estimated from a2mac1 statistical analysis |
| Electrical-non propulsion | 35.7 | Estimated from a2mac1 statistical analysis |
| Cooling and heating | 30.0 | Estimated from a2mac1 statistical analysis (+BYD HAN EV, Xpeng P7 vehicles) |
| Closures | 109.3 | <CD> design from CAD |
| Bumpers | 26.0 | Estimated from benchmark regression (Xpeng P7 vehicles) |
| | | |
| Vehicle Curb Weight | 1512 | |
| Maximum payload | 500 | based on 4 occupants and luggage |
| Gross Vehicle Weight GVW | 2012 | |

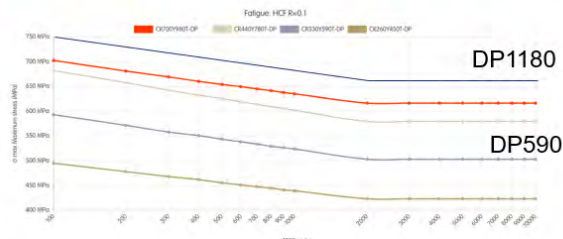
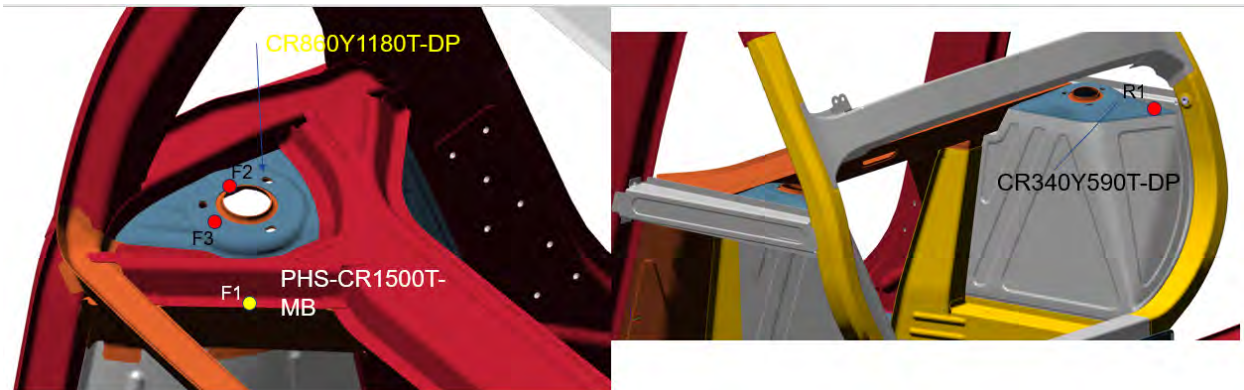
8.7 Body in White Stiffness and NVH

| <i>BIW Stiffness & NVH</i> | | | |
|---|-----------------------|--------|--|
| Item | Target Value | Result | Comments |
| BIW Weight (kg) | <309 | 282 | |
| Static Torsional Stiffness (kNm/deg) (kNm/deg) | >25 | 63.285 | 63,285Nm/deg is trimmed BIW (including battery, subframes, bumper beam). 43,000Nm/deg BIW only |
| Static Vertical Bending (kN/mm) | >9 | 13.438 | trimmed BIW |
| 1st Mode (trimmed) Hz | >28 | 32 | 32Hz = first lateral body mode |
| Installed battery 1st mode (Hz) | >35 | 35 | trimmed BIW |
| Dynamic attachment point stiffness (inertance / point mobility) | >5-10x bush stiffness | OK | target achieved |

8.7 BIW durability

Results from static FEA assessment.

| | Loadcase | Max stress (MPa) | Location | Comment |
|-----------------------|---------------------------------|------------------|----------|---|
| Fatigue | Braking fatigue | 127 | F1 | Predicted stresses are within material fatigue limits |
| | | 140 | R1 | |
| | Acceleration fatigue | 111 | F1 | |
| | | 170 | R1 | |
| | Cornering fatigue LH | 180 | F2 | |
| | | 194 | R1 | |
| | Settling at GVW-proof | 106 | F1 | |
| | | 147 | R1 | |
| | Max rebound | 134 | F1 | |
| | | 215 | R1 | |
| Limit forward braking | 236 | F3 | | |
| | 122 | R1 | | |
| Abuse | Limit cornering LH | 248 | F2 | |
| | | 163 | R1 | |
| | Vertical 30deg positive fatigue | 364 | F1 | |
| | | 507 | R1 | |
| | Max bump and braking | 341 | F1 | |
| | | 440 | R1 | |
| | Pothole braking | 474 | F3 | |
| | | 597 | R1 | |



8.10 Body system cost evaluation

| | Body structure parts cost (\$) *1 | Paint costs (\$) | Assembly costs (\$) | Total body structure cost (\$) | Total Vehicle MSRP (\$) *2 |
|---------------|-----------------------------------|------------------|---------------------|--------------------------------|----------------------------|
| BIW | 1203 | 130 | 146 | 1818 | 40,406 |
| Battery frame | 154 | | | | |
| closures | 186 | | | | |
| Total | 1543 | | | | |

*1 includes: Equipment, Tooling, Building, Maintenance, Energy, Labour, Overhead, Process, Materials (excludes: assembly & paint costs)

*2 includes approximates for battery, powertrain, electrical, interior, chassis. Does not include costs for autonomous vehicle systems (such as radar & lidar)

8.11 Battery structural performance

| <i>HV Battery</i> | | | |
|-------------------------------------|--|--|--|
| Item | Target Value | Results Status | Comments |
| Battery Pack Power SEM1 (kWh) | >75 | 75 | |
| Pack Energy Density Wh/l Wh/kg | 2022 - 165-270Wh/l 11-224Wh/kg | 622Wh/l (mod) 377Wh/kg (mod) 280Wh/l (pack) 266Wh/kg (pack) | Wh/l - >600Wh/l for Module Wh/kg - >300Wh/kg for Module |
| ECE R100 Vibration/Fatigue | Endurance Stress of Material selection | Pass | |
| ISO 12405-2 PSD Random Vibration | Endurance Stress of Material selection | Pass | |
| GB/T 31485 and 31467 Crush | Pass/Fail | Pass | |
| Intrusion - Jacking | J - 50% GVW (50mm coin) | Pass | |
| 1st battery Modal (Hz) | >35 | 35 | |
| Battery Pack Mass (kg) | <360 | 304 | |
| Battery Enclosure Mass (kg) | <70 | 59 | |

9.0 Sustainability and Lifecycle Analysis

9.1 Introduction

The contribution of transportation modes to greenhouses gas (GHG) emissions, and hence global warming, is well documented and understood. Vehicle OEMs, fleet operators and transport users all have responsibilities to limit individual and collective environmental impacts to the planet, and contribute to meeting national and global climate change mitigation objectives. Mobility as a Service transport solutions such as Steel E-Motive have the potential to contribute to the net reduction in GHG emissions and help achieve these global targets and also specific policy objectives.

Life Cycle Assessment (LCA) is a methodology that considers a product's entire life cycle, with cradle-to-grave assessments typically utilising a boundary to include impacts from raw material extraction and production (manufacturing phase), through its useful life (use phase), and to the end-of-life disposal or recycling of the product (end-of-life phase). It also takes into account the full life cycle of energy sources used across all lifecycle phases. This LCA approach was applied throughout the development of the Steel E-Motive concept.

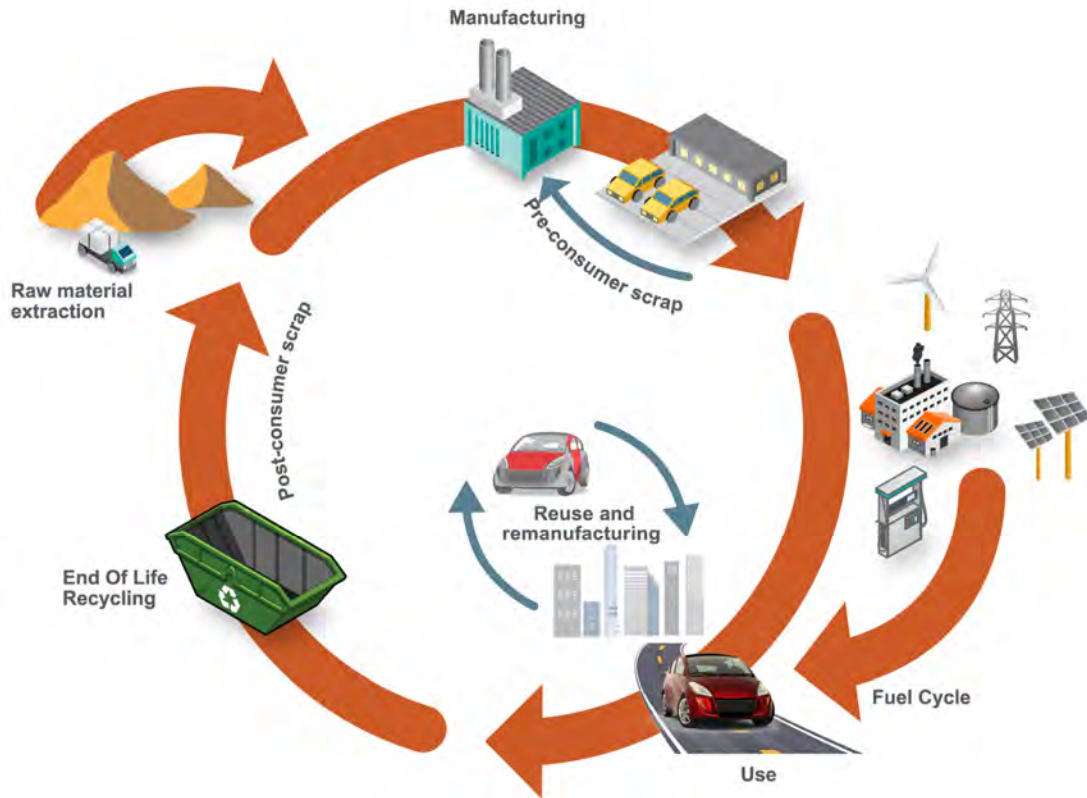


Figure 9.1.1 Life Cycle Assessment, considering the entire life of the vehicle, from raw material extraction to end of life

LCA can cover a range of environmental impacts; in this study the focus was on GHG emissions (through the GWP-100 indicator) and total energy consumption (through the Cumulative/Primary Energy Demand and Fossil Energy Consumption indicators).

The GHG emissions and total energy contributions from the vehicle manufacture and assembly, vehicle use and end of life/recycling phases were calculated using a Microsoft Excel

LCA tool created for WorldAutoSteel by Dr. Roland Geyer at the University of California Santa Barbara (UCSB). As the specific LCA calculation processes, guidelines and legislation is currently being defined and the MaaS vehicle have the potential to operate in different modes and regions, a calculation sensitivity approach was applied which demonstrated the influence of different vehicle operational boundary conditions, manufacture and design considerations on the total vehicle GHG values. The LCA results for the Steel E-Motive vehicle and sensitivities were compared to a present day “reference” battery electric vehicle (BEV).

9.2 Lifecycle Analysis Technical Approach and UCSB tool enhancements & adjustments for Steel E-Motive

The primary inputs to the UCSB LCA tool are: general vehicle specification, such as powertrain type (BEV), vehicle size/category (B-C segment), vehicle drive cycle type (WLTP) and total life (mileage). A breakdown of the approximate vehicle material composition is also required. The UCSB LCA tool has embedded datasets and formulae which are combined with the specific vehicle inputs to calculate GHG (kg CO₂ equivalent) and total primary energy consumption (Mega Joules). The embedded datasets include material CO₂ emissions (per kg), vehicle drive cycle energy consumption, fossil fuel embedded emissions, electricity grid supply CO₂ and calculations for the end of vehicle life contributions, using different approaches and methodologies.

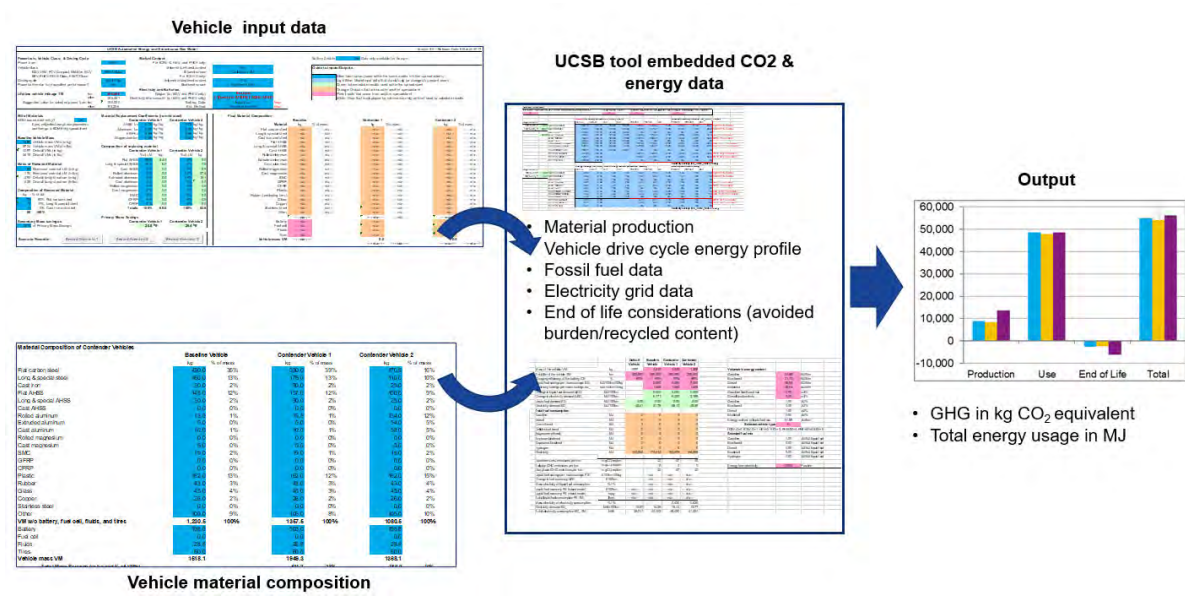


Figure 9.2.1 UCSB Life Cycle Analysis tool data flow (See Appendix 4 for larger image)

Vehicle life cycle performance can vary considerably depending on where the vehicle is manufactured and operated. To account for this, life cycle performance of the Steel E-Motive concept was calculated for Europe, US, China, Japan and India regions.

With the Steel E-Motive concept assuming a hypothetical manufacturing date of 2030, a number of specific enhancements and additional datasets were added to the UCSB model, summarised below (specific details of the enhancements are reported later)

- **Steel and Aluminium primary production:** “Baseline” (non-decarbonised) values contained within the UCSB dataset were validated and checked. Steel and aluminium makers are making significant progress in the decarbonisation of primary materials. By

2035, a significant proportion of the material in a vehicle construction is expected to be manufactured using decarbonised production methods. The UCSB tool was updated with decarbonised (or “green”) steels and aluminium. These were calculated using GaBi simulation tools and validated with WorldAutoSteel members.

- **Propulsion battery production emissions data:** Whilst the Steel E-Motive concept features a purposefully “agnostic” battery technology and chemistry, the LCA model dataset was updated to include future forecasts and projections of battery decarbonisation potential. Data from Ricardo’s collaborative research programmes on battery decarbonisation were included.
- **Electricity grid supply mix and associated GHG emission values:** With the Steel E-Motive vehicle being battery electric propulsion, the energy source for the vehicle during its use phase is provided by 100% electricity grid supply. With increasing amounts of renewable energy (such as wind and solar power) being deployed in grid networks, the potential for vehicle GHG emissions during the use phase could be reduced significantly. The electricity grid mix estimates in the UCSB model were updated with forecasts up to 2040 using data from the International Energy Agency (IEA World Energy Outlook, 2021) (IEA, 2021).
- **Vehicle life cycle performance:** This is usually calculated and reported in total kg CO₂-eq (greenhouse gases expressed in units of carbon dioxide equivalents), and MJ (total primary energy, expressed in units of oil equivalents). Mobility as a Service (MaaS) and ride hailing vehicles target increased utilisation and occupancy rates enabling journey cost savings for the user and reducing traffic congestion. This is also results in net vehicle life cycle emission reductions, as fewer vehicles are required to transport the same or a greater number of people. MaaS vehicles may also have a longer lifetime (total kilometers) than private or taxi vehicles, resulting in lower overall life cycle emissions, as this may result in a lower number of vehicles produced, with lower production greenhouse gas emissions. To account for this, the metric/measurement applied for the Steel E-Motive LCA calculations was changed to kg CO₂-eq per passenger-kilometer. The GHG emissions and total primary energy calculated for the total life cycle of the Steel E-Motive were divided by the average number of occupants assumed during the vehicle service life, multiplied by the total expected lifetime kilometers of the vehicle. This was deemed to be a more representative metric for MaaS vehicles and to demonstrate the importance and potential of ride sharing in addressing transportation contributions to GHG emissions.

For the LCA calculations and sensitivity studies, a number of different vehicle input parameters were evaluated. These are summarised and described in the table below.

| LCA parameter | Value |
|--|---|
| description | Text description of the LCA model (e.g. "reference", "Steel E-Motive baseline") |
| Su-title Level 1 | Further model description (e.g. "drivecycle smoothing" study) |
| power train | (is Battery Electric for all vehicles in the LCA study) |
| % ethanol | (=0% for all (BEV) vehicles in the LCA study) |
| Vehicle class | (= "FSV A class" for all vehicles in the LCA study. This is standard option in UCSB tool) |
| Driving cycle | Standard test drive cycle used for use phase calculation (e.g. WLTP) |
| Driving cycle smoothing reduction | % reduction in drive cycle energy, based on autonomous vehicle speed and throttle control potential |
| Lifetime km | Total expected life of vehicle (kilometers) |
| Battery lifetime (km) | Total expected life of propulsion battery (kilometers) |
| pyrometall. LIB recycling share | Propulsion battery recycling approach |
| Grid mix (both SDS and STEPS for future scenarios) | Electricity grid supply timeline (data from IEA) |
| Region | Vehicle operation (grid supply) location (Europe, US, Japan, China, India) |
| EoL method | LCA End of life methodology (avoided burden, recycled content) |
| "green" steel share | % steel of reduced carbon production steel used (100% = all steel used in vehicle is manufactured using decarbonised process) |
| "green" Al share | % of reduced carbon production aluminium used (100% = all aluminium used in vehicle is manufactured using decarbonised process) |
| Vehicle occupancy (ride sharing) | Number of vehicle occupants in LCA calculations |

Figure 9.2.2 LCA model input parameters (See Appendix 4 for larger image)

- **Lithium-ion battery end-of-life recycling:** at the end of the vehicle's service life, its lithium-ion battery pack may be recycled in two main ways, either by feeding it to a high-temperature furnace (pyrometallurgical recycling), or by subjecting it to a series of wet chemical separation processes (hydrometallurgical recycling). The former process is currently prevalent because it can use the same facilities that are already used for primary metal ore smelting; however, it is very energy demanding, and it does not allow the recovery of lithium or any of the of the lightweight battery components (e.g., the graphite anode). In contrast, the latter process is significantly less energy-intensive, and allows a high recovery rate for all battery materials; however, it is not yet commercially used on a large scale because the hitherto limited quantities of EoL EV batteries have not yet led to sufficiently lucrative economies of scale. In light of the above, a 50%/50% mix of pyrometallurgical/hydrometallurgical recycling was conservatively assumed for the EoL treatment of the batteries in the reference "present day" (~2020) battery electric vehicle (BEV), whereas 100% hydrometallurgical recycling was assumed in all other scenarios for Steel E-Motive vehicles based on a hypothetical 2030 manufacture and start-of-operation date.
- **Electricity grid supply mix scenarios:** LCA calculations for all scenarios ("baseline" current vehicle and all sensitivity variations of future Steel E-motive vehicle) were repeated twice to accommodate two alternative future electricity grid mix evolution scenarios, respectively corresponding to the International Energy Agency (IEA) World Energy Outlook (WEO) "Sustainable Development Scenario" (SDS), and "Stated Policies Scenario" (STEPS). More detail on this aspect of the calculations is provided below in **Section 9.3.2.3**.
- **End of life allocation method:** In LCA, a number of alternative EoL allocation methods are possible, whereby different shares of the impacts arising from material recycling are assigned respectively to the product generating the EoL waste materials, vs. the product that subsequently uses the recycled materials as inputs in its production process. In this study, two such methods were considered, respectively referred to as

“cut-off” (or “100:0”) and “avoided burden” (or “0:100”). More detail on this aspect of the calculations is provided below in **Section 9.3.2.7**.

9.3.2 Reference taxi vehicle definition (“baseline” vehicle)

An important consideration in LCA calculations is to establish an appropriate “reference point” (or vehicle) from which subsequent calculations and sensitivities can be made. For Steel E-Motive, the reference starting point was assumed to be a “present day” (~2020) battery electric vehicle (BEV), operating in taxi mode, with driver plus one occupant. The vehicle and battery lifetime was assumed to be 300,000km, and the construction using 100% conventional (i.e. 0% “green”) steel and aluminium. The vehicle end of life methodology used the Avoided Burden approach (whereby the recycled metals are assumed to displace equivalent quantities of their virgin counterparts, and are assigned corresponding emission and energy demand credits). 50% pyrometallurgical recycling was assumed for the battery packs. The reference taxi vehicle curb weight was estimated using the statistical reference data study (Figure 7.1.5.2), and assuming the same overall dimensions to Steel E-Motive SEM1, equates to an estimated curb weight of 1,949kg. The material utilisation was based on data from a similar vehicle specification and is shown in Figure 9.3.2.1. The vehicle occupancy rate was assumed to be 1.4, based on a combination/average of “empty” and passenger carrying journeys.

Reference "Taxi" BEV Vehicle Material Breakdown (1949kg)

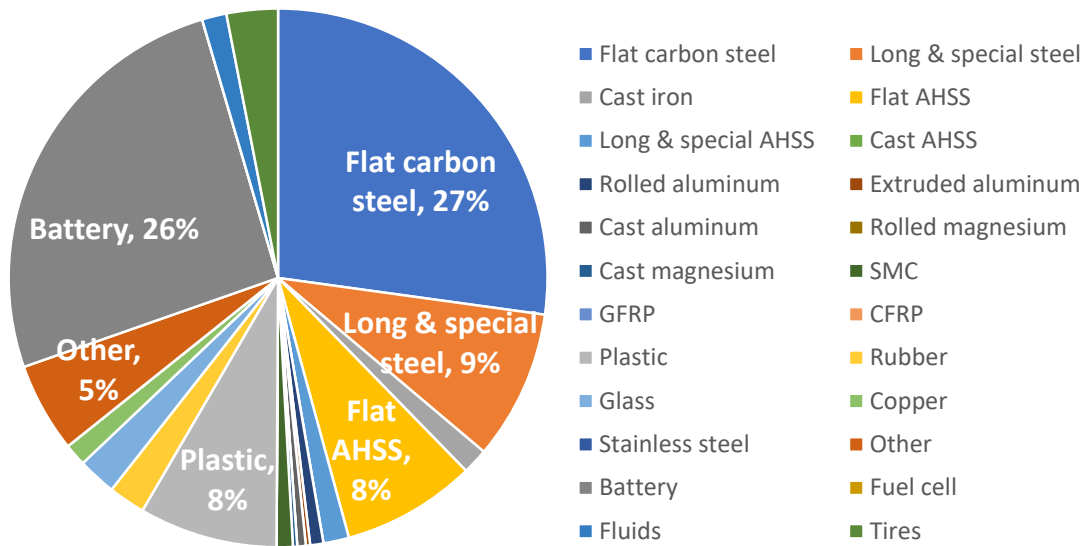


Figure 9.3.2.1 Reference taxi vehicle material breakdown

9.3.1 Steel E-Motive “default” vehicle definition

The Steel E-Motive vehicle life cycle calculations were based on a hypothetical 2030 manufacture and 2030 to 2035 start-of-operation date. The electricity grid supply mix was therefore updated to include the average of the IEA scenario estimations for 2030 and 2040. The nominal SEM1 vehicle curb weight of 1,512kg was applied in the LCA model and the vehicle Bill of Materials updated as per the breakdown shown in Figure 9.3.1.1 below. For comparative purposes, 0% of “green” steel and “green” aluminium were considered, as well as a vehicle occupancy rate of 1.4, standard WLTP drive cycle with zero autonomous drive cycle smoothing, and equal 300,000km battery and vehicle lifetimes. The Avoided Burden allocation method was used for the end-of-life calculation as the default.

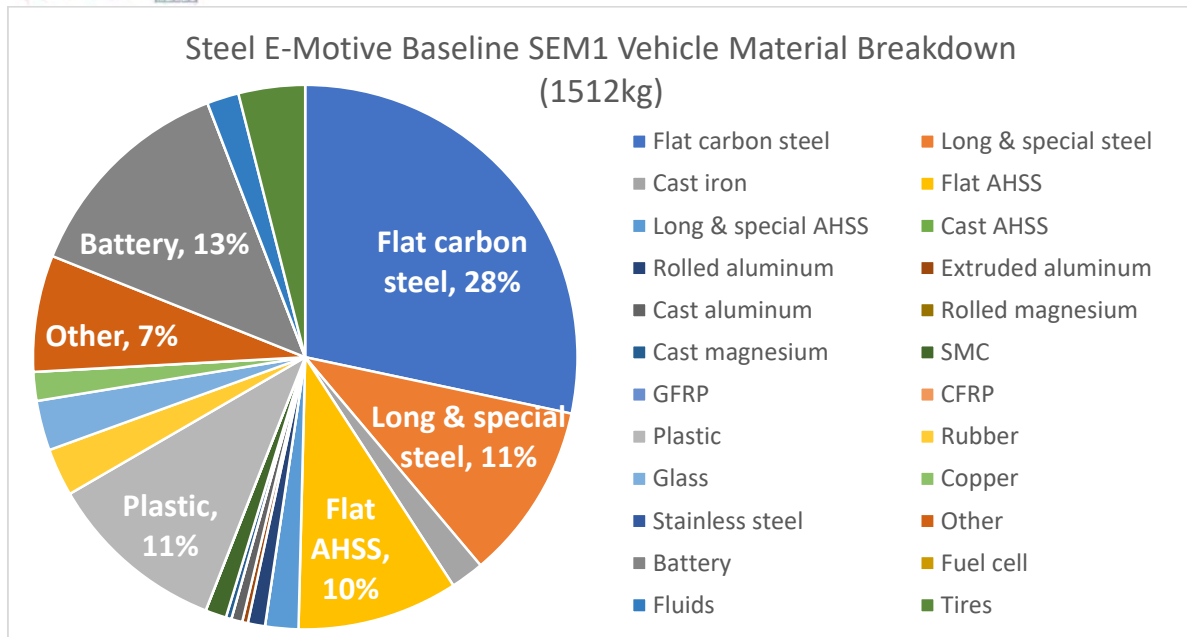


Figure 9.3.1.1 Steel E-Motive SEM1 vehicle material breakdown

9.3.2 Steel E-Motive LCA sensitivity studies

9.3.2.1 Reduced carbon steel and aluminium production

The production of steel firstly involves the conversion of iron ore to pig iron - conventional methods use a Blast Furnace (BF). In the first stage of this process, the iron ore (containing iron oxides) is mixed with coke (derived from coal), which acts as the reducing agent, and other elements such as limestone and then forced air (oxygen) are passed through the mixture, resulting in the chemical reduction of the iron oxides in the ore to impure metallic “pig” iron. A secondary Basic Oxygen Furnace (BOF) process is then used to drive down the carbon content and impurities in pig iron, by forcing oxygen through it at very high (supersonic) velocities for a duration of 25 to 45 minutes, the result being low-carbon steel. The molten low-carbon steel is then poured (or tapped) from the BOF furnace for subsequent processing into steel products, such as slabs, blumes and billets using continuous casting process. This conventional steel making process is referred to BF-BOF. Though BOF steelmaking is a very energy-efficient process (separating the iron from the oxygen at less than two times the theoretical minimum), the use of coke as a reducing agent and the subsequent generation of CO and CO₂ offers opportunities for carbon reduction.

The Electric Arc Furnace (EAF) process is an alternative to the BOF and used primarily for converting scrap steel (as opposed to virgin iron ore) to molten steel. A very high electrical current is passed through graphite electrodes, exposing the charged material (scrap steel) to an electric arc, producing molten steel. The steel is then refined and passed to continuous casting process. EAF can be lower cost and significantly less carbon intensive than BOF where the source electricity is generated from renewable sources and the advantage of lower cost off-peak electricity rates can be applied. Approximately 70% of global steel production uses BF-BOF process and 30% EAF.

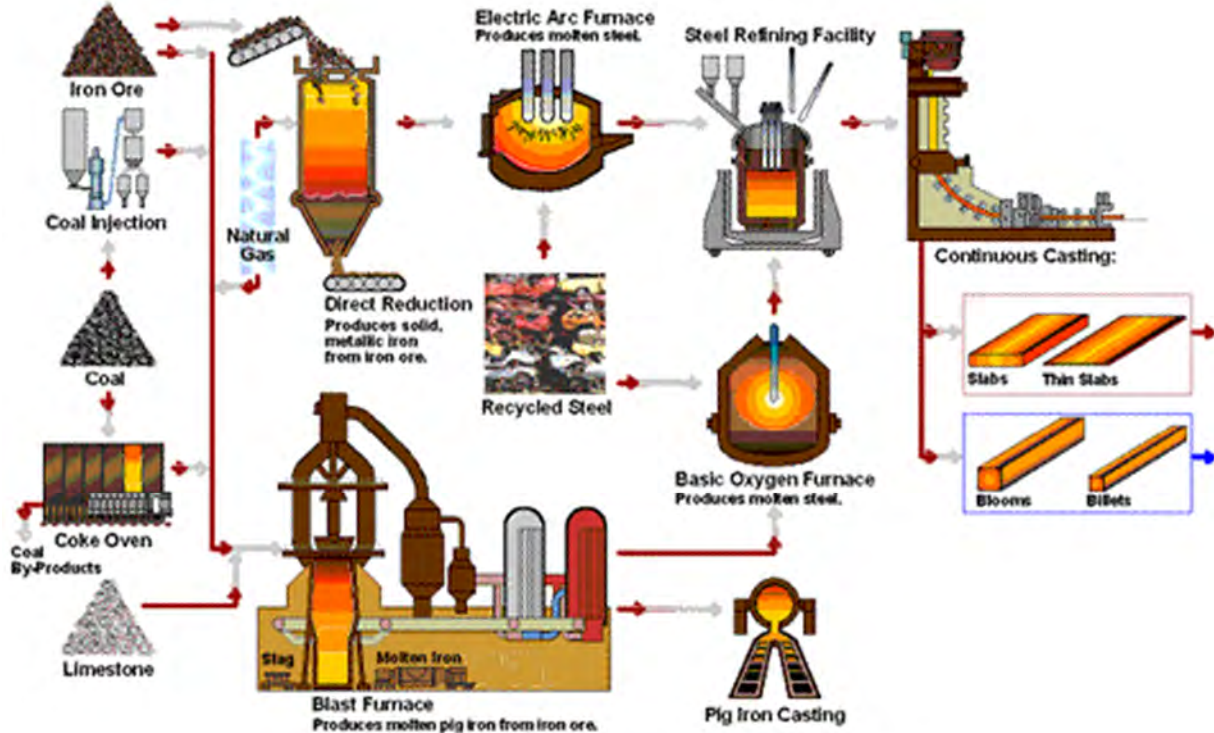


Figure 9.3.2.1.1 Steel production methods (courtesy of AISI <https://www.steel.org/steel-technology/steel-production/>)
<https://worldsteel.org/about-steel/about-steel/steelmaking/>

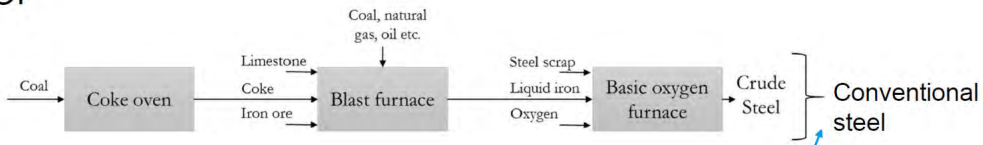
Steel producers are then developing and implementing new iron & steel production methods to significantly reduce GHG emissions – these are commonly referred to as “green” steels.

An alternative to the Blast Furnace method for iron production from virgin iron ore is the Direct Reduced Iron (DRI) process. Instead of using coal-based coke to chemically reduce the iron ore to metallic iron, hydrogen is used as the reducing agent, at a temperature below the iron melting point, resulting in a “direct” conversion from iron ore to iron. The energy consumption and GHG emissions of DRI are therefore lower than conventional Blast Furnace method. The DRI method produces hot-iron briquettes or sponge iron which can then be converted to steel using BOF and EAF methods. Also, importantly, using hydrogen in the DRI method provides further potential to decarbonise the steel production process. Hydrogen produced via water electrolysis powered by renewable electricity (“green” hydrogen) in a DRI process combined with EAF steel production, once again using renewable electricity, provides the best overall potential for decarbonised steel production. At the time of the Steel E-Motive project, a small number of DRI pilot production facilities were in operation, with many larger scale plants planned or under construction. Assuming a hypothetical production timeframe of 2030-2035 for the Steel E-Motive concept, it may be expected that “green” steel will be more widely available, and the latter was therefore considered within the vehicle LCA studies. (Note: “green” steel has the same chemical and mechanical properties as BF-BOF steels and can therefore be assumed as a direct substitution within automotive body structures).

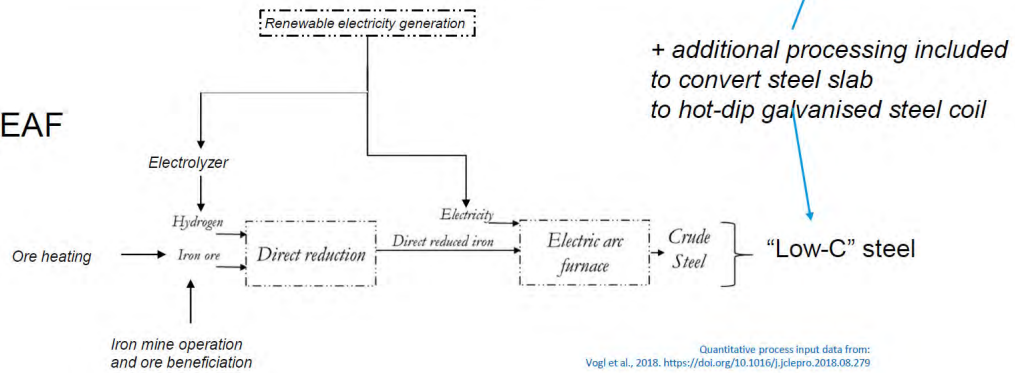
In order to evaluate the potential reduction in GHG emissions with green steel production, an LCA sub-model using GaBi software was constructed, modelling the comparison between the conventional BF-BOF production route, and the low-carbon green-H₂-DRI-EAF route. The

process flows for the BF-BOF and DRI-EAF routes are shown in Figure 9.3.2.1.2 and the GaBi modelling approach for the latter is shown in Figure 9.3.2.1.3.

BF-BOF



DRI - EAF

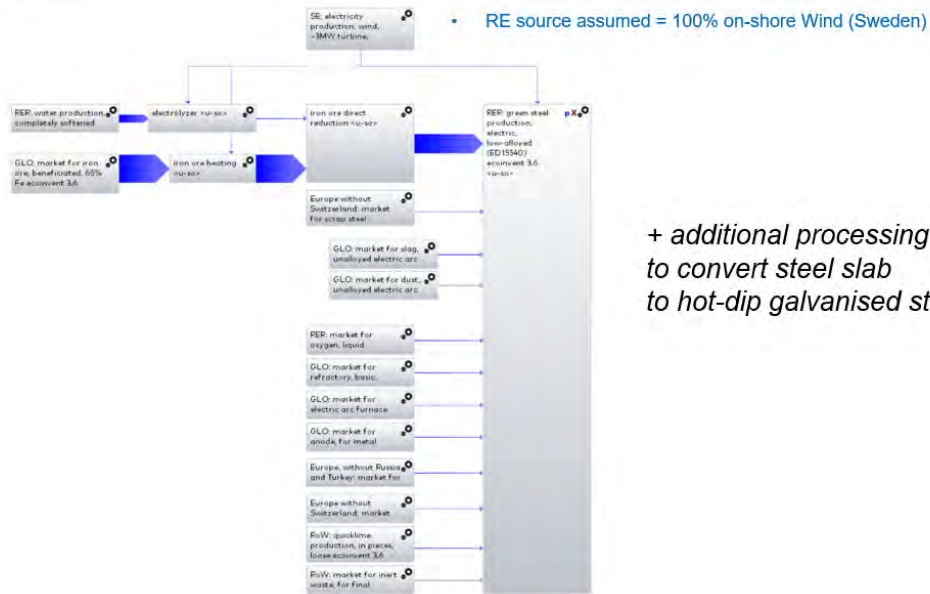


Quantitative process input data from: Vogl et al., 2018. <https://doi.org/10.1016/j.jclepro.2018.08.279>

Figure 9.3.2.1.2 Life Cycle Analysis modelling considerations for BF-BOF and DRI-EAF steel production methods (See Appendix 4 for larger image)

Low-C DRI steel slab

The names of the basic processes are shown:



+ additional processing included to convert steel slab to hot-dip galvanised steel coil

Figure 9.3.2.1.3 GaBi modelling of DRI-EAF steel production (See Appendix 4 for larger image)

The results from the GaBi LCA modelling showed the potential to reduce the GHG emissions for hot dip galvanised steel production from 3 kgCO₂eq/kg (BF-BOF steel) to 0.6 kgCO₂eq/kg (DRI-EAF), i.e., a factor-of-5 reduction. Also, the demand for fossil fuel primary energy resources for green steel production was predicted to be reduced by a factor of 3.8.

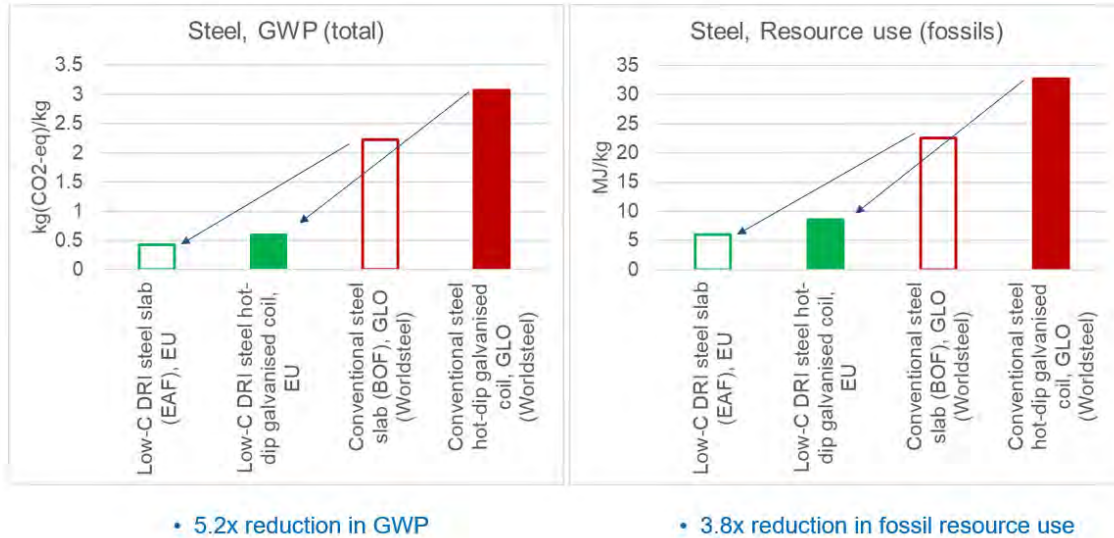


Figure 9.3.2.1.4 Predicted GHG emissions and fossil fuel primary energy demand effects of “green” steel production. (BF-BOF data provided by WorldSteel association). (See Appendix 4 for larger image)

The results from these calculations were embedded within the UCSB LCA Excel tool and applied in subsequent vehicle sensitivity studies.

9.3.2.2 Propulsion battery GHG contribution

Present-day propulsion batteries in electric vehicles can contribute up to 30% of the total vehicle production greenhouse gas emissions. Vehicle manufacturers and suppliers are therefore developing battery technologies resulting in significant reductions in GHG emissions. Given the hypothetical production dates, estimates on the potential reductions were estimated for the 2030 to 2035 timeframe. Results and data from a Ricardo led study for the European Commission was applied to the UCSB LCA tool (Ricardo et al., 2020). (<https://op.europa.eu/o/opportal-service/download-handler?identifier=1f494180-bc0e-11ea-811c-01aa75ed71a1&format=pdf&language=en&productionSystem=cellar&part=>)

| Parameter | Modelled setting/value | Modelling intermediate and final outputs |
|--|--|---|
| Chemistry | NMC solid-state | <p>2030 Manuf. BOM (Pack), % Mass</p> <p>Battery production impacts, share by component/stage (GWP)</p> |
| Energy density | 500 Wh/kg (cell) 375 Wh/kg (pack) | |
| Capacity | 75 kWh | |
| Manufacturing year/location | 2030, EU (plus sensitivities for CN, US, JP) | |
| Manufacturing energy source | 100% Renewable electricity, EU (plus sensitivities for CN, US, JP grid mix in 2030) | |
| Calculated 2030 output manufacturing impact (pack) | 25.2 kgCO ₂ e/kWh (pack) | |

Figure 9.3.2.2.1 Considerations and data applied for modelling propulsion battery decarbonisation in Steel E-Motive (Ricardo modelling for a 2030 battery pack)

Figure 9.3.2.2.2 shows the predicted impacts of the introduction of new battery technologies and battery manufacturing decarbonisation for a European facility. Using Ricardo data and methodology, the production GHG contribution for a 2020 battery pack was calculated to be significantly higher than the baseline assumption in the UCSB model (the default calculation parameters in the UCSB were understood to be pessimistic). An estimated 72% reduction in GHG emissions for the battery production was estimated, comparing 2020 to 2030 technologies, primarily due to improved energy density (resulting in fewer materials) and 100% use of renewable electricity in manufacturing. This value excludes considerations for end-of-life methodologies and recycling.

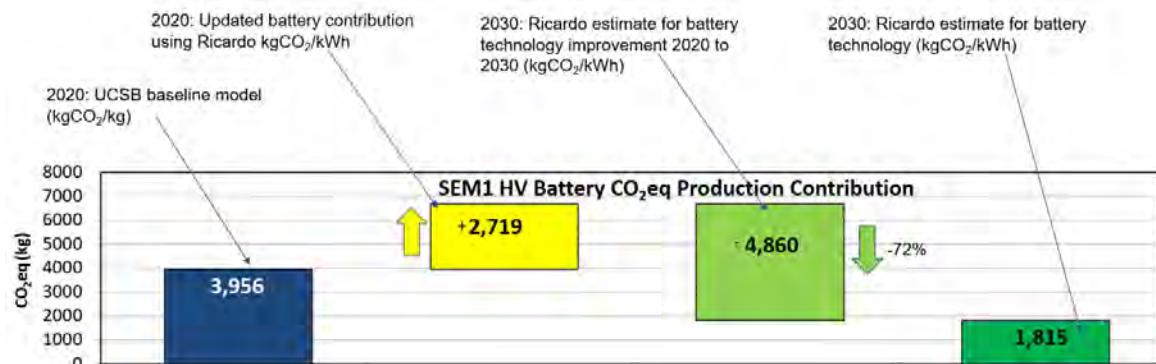


Figure 9.3.2.2.2 SEM1 battery production GHG contribution (Europe), 75kWh battery

9.3.2.3 Electricity grid carbon intensity

The “fuel” for Battery Electric Vehicles comes from mains grid supplied electricity, which is generated from many sources such as coal, gas, nuclear and renewables (wind, solar, hydro-electric). The differing electricity sources and projected future trends were considered in the Steel E-Motive LCA calculations. International Energy Agency (IEA) World Energy Outlook (WEO) <https://iea.blob.core.windows.net/assets/4ed140c1-c3f3-4fd9-acae-789a4e14a23c/WorldEnergyOutlook2021.pdf> (IEA, 2021) scenarios were used. Specifically, the IEA provide predictions for electricity grid supply carbon intensity for a “Sustainable Development Scenario” (SDS), where global climate targets would be achieved, and also for a “Stated Policies Scenario” (STEPS), a more conservative scenario assuming not all government targets would be achieved. Forecast data for Europe, US, China, India and Japan for SDS and STEPS were extracted and included in the UCSB model and Steel E-Motive LCA calculations. The IEA provide data and estimates for 2020, 2030, 2040 and 2050. Hybrid grid mix scenarios for “2020 to 2030” and “2030 to 2040” were derived from the data (Figure 9.3.2.2.3) and applied to the UCSB tool and Steel E-Motive calculations.

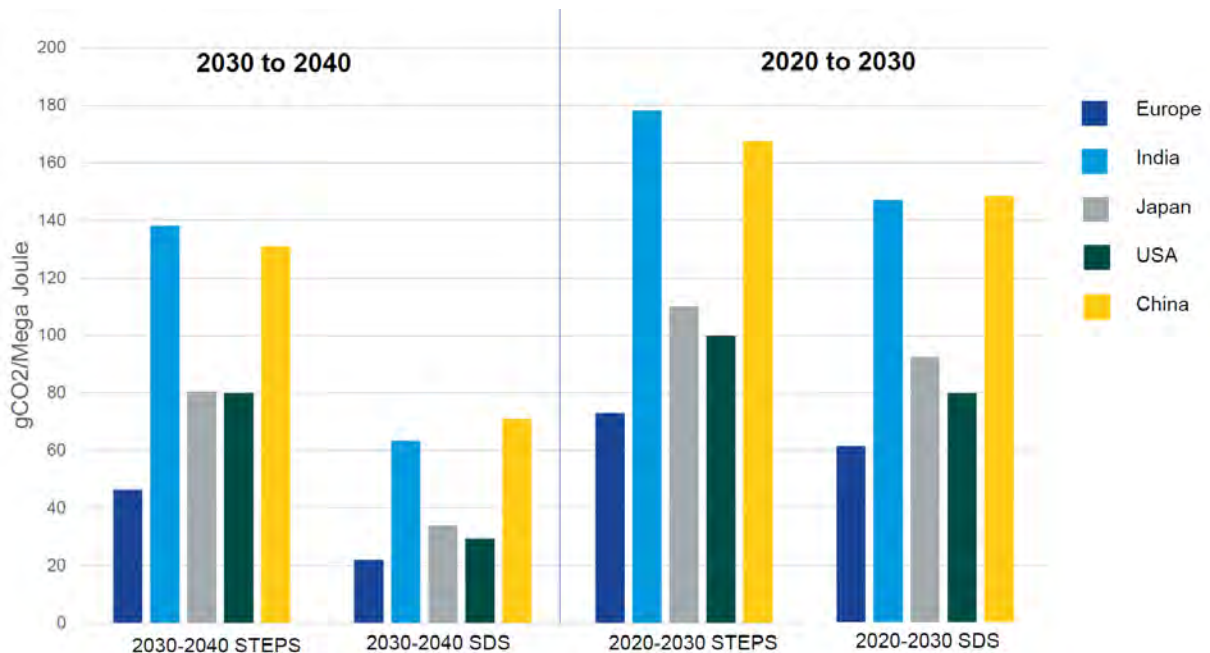


Figure 9.3.2.2.3 Electricity grid carbon intensity data used applied for Steel E-Motive LCA (data source taken from IEA WEO 2021)

9.3.2.4 Autonomous MaaS Vehicle real world driving cycle, and drive cycle smoothing

Autonomous vehicles and MaaS vehicles will operate differently to conventional human-operated vehicles. A ride hailing vehicle with increased passenger occupancy will have a different drive cycle compared to a conventional private or taxi passenger. Also, the ability for autonomous vehicles to communicate with other vehicles (“V2V”) and road infrastructure such as traffic signals (“V2X”) may unlock additional efficiencies through advanced control in response to the data received. For example, with the vehicle communicating with traffic signals, an autonomous vehicle will know when the signal is about to change to red/stop, and can therefore adjust its speed accordingly. On approach to the signal, the autonomous vehicle has the possibility to reduce its speed ahead of a red signal changing to green, therefore

maintaining more of its kinetic energy and reducing overall vehicle energy consumption. This enables “drive cycle smoothing”. A value of 15% reduction in overall vehicle energy consumption was therefore assumed to model autonomous control cycle smoothing.

A combined traffic and vehicle simulation modelling approach was taken for assessing the Steel E-Motive vehicles over a MaaS drive cycle. Firstly, a one-dimensional (1D) vehicle energy simulation model (Figure 9.3.2.5.2) was constructed to simulate the SEM1 and SEM2 vehicle energy consumption over specific duty or drive cycles. Ricardo’s in-house software code IGNITE was used with the modelling input parameters as per table 9.3.2.5.1.

| | Value | Unit | Source |
|--------------------------|------------|------|--------------|
| Vehicle | | | |
| Vehicle type | SEM1 BEV | - | 0_General |
| Drive | FWD | | 0_General |
| Kerb mass | 1640 | kg | 0_General |
| GVW total | 2140 | kg | 0_General |
| Aero Cd | 0.35 | - | 0_General |
| Aero Frontal Area | 3.0 | m2 | CAD estimate |
| overall height | 1880 | mm | 0_General |
| overall width | 1850 | mm | 0_General |
| Vmax | 130 | km/h | 0_General |
| Accel time for 0-102km/h | 9 | s | 0_General |
| Braking system | CAT A | - | 8.0 Chassis |
| Tyre, front & rear | 175/60 R19 | - | 8.0 Chassis |
| Battery | | | |
| Battery capacity | 75 | kWh | 4.0 Battery |
| Battery voltage | 800 | V | 4.0 Battery |
| Module capacity | agnostic | Ah | 4.0 Battery |
| Module voltage | 44-50 | V | 4.0 Battery |
| Number of module | 8 | - | 4.0 Battery |
| EDU | | | |
| Number of speed | 1 | - | 6.0 EDU |
| Motor continuous power | 115 | kW | 6.0 EDU |
| Motor peak power | 230 | kW | 6.0 EDU |

Table 9.3.2.5.1 IGNITE vehicle simulation model input parameters

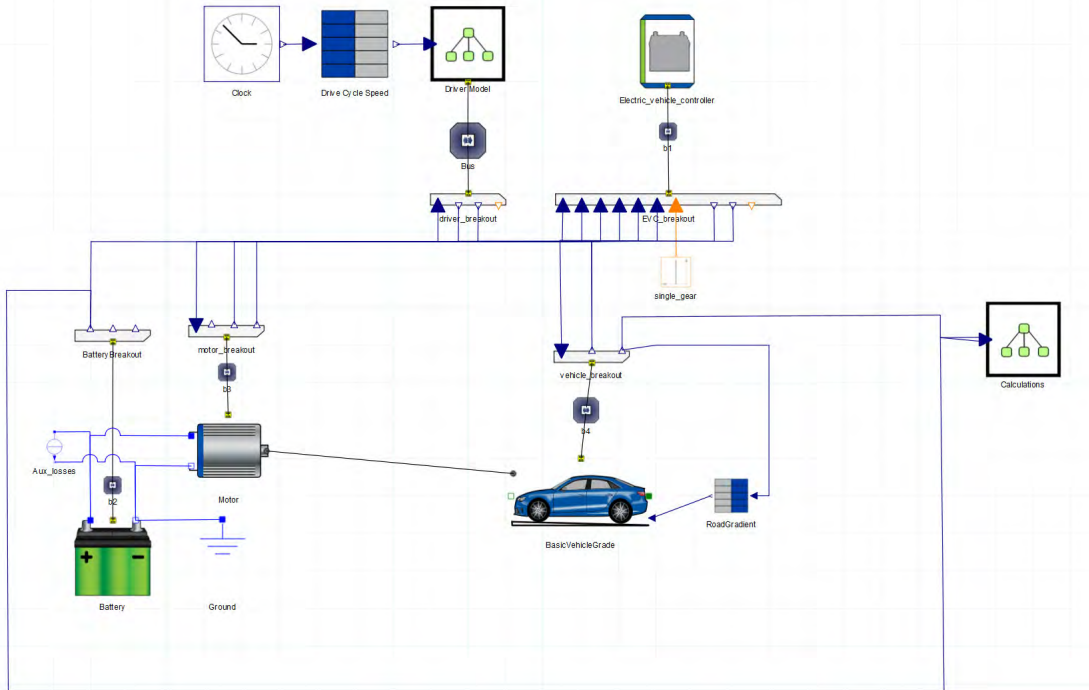


Figure 9.3.2.5.2 1D IGNITE vehicle energy simulation model schematic (See Appendix 4 for larger image)

Vehicle energy consumption is usually calculated for standard, defined drive cycle profiles such as a Worldwide Harmonised Light Vehicle Test Procedure (WLTP) and Federal Test Procedure 76 (FTP-75). The drive cycle for the Steel E-Motive SEM1 vehicle is expected to be more aggressive than the defined drive cycles, due to the more frequent instances of stop-start events (i.e., passenger collection and drop-offs) and operation within city centres. Real world drive cycles applicable for SEM1 were therefore defined such that more realistic vehicle energy consumption values could be calculated and used as input into the LCA studies. Additionally, the vehicle energy usage calculations were used to confirm the 75kWh battery specification. Daily usage profiles were devised, combining the real world SEM1 specific drive cycles, resulting in expected battery State of Charge (SoC) estimations, which were used to confirm the available vehicle operation (or “up time”) throughout a daily cycle. The real world SEM1 drive cycles were calculated using the traffic modelling software tool SUMO (<https://www.eclipse.org/sumo/>). The tool enables modelling of road networks, with vehicle traffic models injected, enabling individual vehicle drive profiles to be extracted and used as an input to the IGNITE energy simulation model. The predicted vehicle energy usage for the calculated real world drive cycles was then used to estimate the daily battery SoC status, and as an input to the UCSB simulation tool. The process flow is shown in Figure 9.3.2.5.3

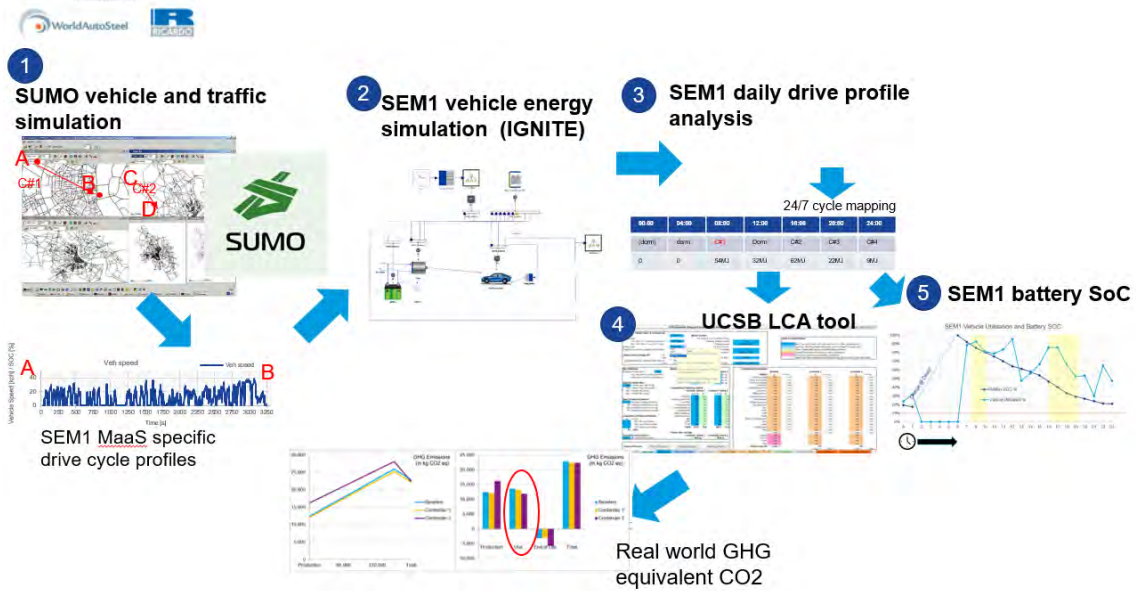


Figure 9.3.2.5.3 Traffic & drive cycle generation, vehicle energy simulation, Life Cycle Analysis process flow applied in Steel E-Motive (See Appendix 4 for larger image)

The SUMO traffic flow and drive cycle generation activity used the Brighton and Hove area of the UK as the basis for the real-world drive cycle routes. Brighton and Hove is a medium sized seaside city, situated on the South Coast of the UK. It contains a mixture of rural, suburban and urban city environments. The topology features some moderate hills and gradients inland. The city has good rail and public transport networks, and the city centre and arterial routes suffer from traffic congestion at peak times. Five unique journeys profiles or “missions” were defined for the Brighton and Hove area. These were selected based on anticipated journeys that SEM1 would likely operate. A hypothetical fleet depot location was assumed on the outskirts of the city, from which the main vehicle charging and servicing operations would be undertaken. The SUMO tool has the functionality to model different traffic congestion levels, therefore scenarios for “low” (off peak) and “high” (peak) were calculated. Figure 9.3.2.5.4 shows a map of the mission routes and Table 9.3.2.5.5 shows the output from the SUMO traffic simulation modelling.

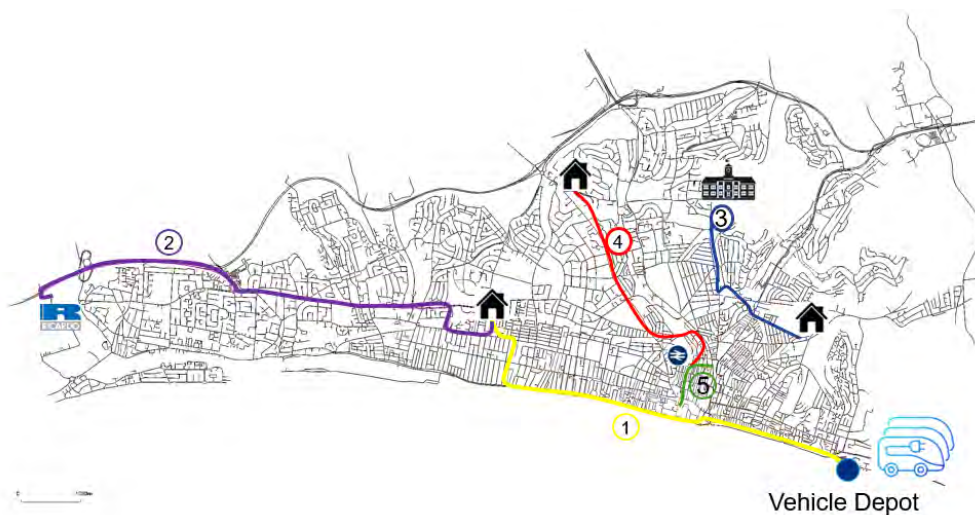


Figure 9.3.2.5.4 Map of SEM1 SUMO model mission routes (See Appendix 4 for larger image)

| Mission number | Description | Journey distance (km) | Journey type | Journey time (minutes) (low traffic/off peak) | Average vehicle speed (km/h) (low traffic/off peak) | Journey time (minutes) (high traffic/peak) | Average vehicle speed (km/h) (high traffic/peak) |
|----------------|-----------------------------------|-----------------------|----------------------|---|---|--|--|
| 1 | Depot to home collection | 8.37 | Suburban to suburban | 11.9 | 41.7 | 13 | 37.6 |
| 2 | Home to office | 9.11 | Suburban to rural | 10.0 | 53.8 | 10.0 | 53.8 |
| 3 | Home to school | 3.22 | Suburban to suburban | 6.2 | 30.4 | 6.2 | 30.4 |
| 4 | Home to city centre train station | 4.08 | Suburban to city | 7.1 | 33.9 | 7.1 | 33.9 |
| 5 | City centre journey | 1.67 | City centre | 3.6 | 27.1 | 9.2 | 11.5 |

Table 9.3.2.5.5 SUMO traffic modelling output for SEM1 missions (See Appendix 4 for larger image)

The outputs from the SUMO traffic simulation were verified using Google maps journey time predictions and from personal experience of the missions/journeys. For each mission, unique vehicle drive cycles were produced in the form of vehicle speed versus time profiles, examples of which are shown in Figure 9.3.2.5.6.

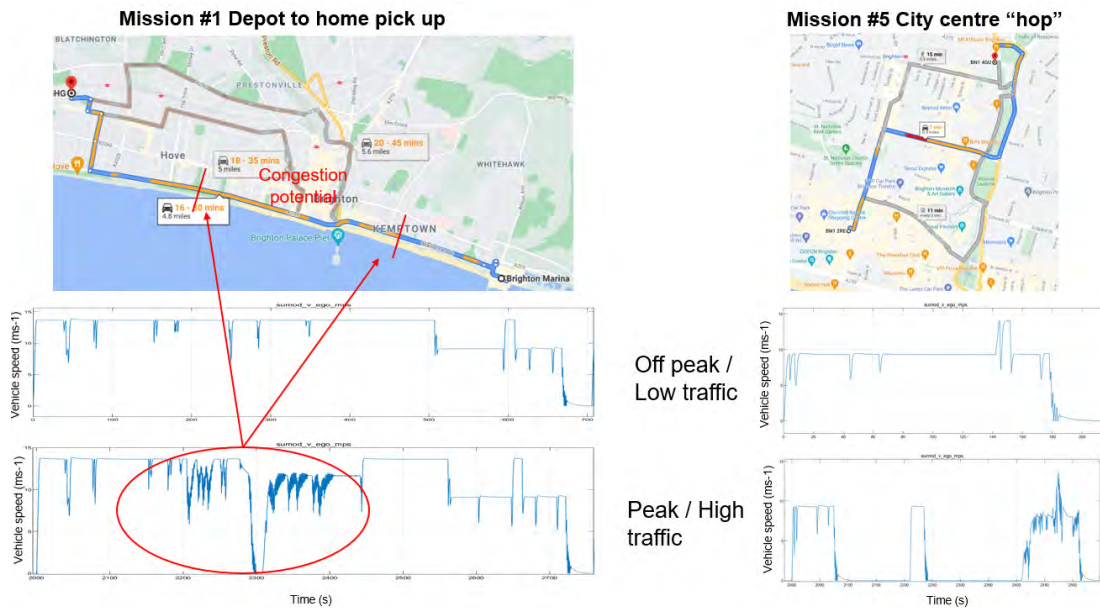


Figure 9.3.2.5.6 SUMO traffic modelling drive cycle profiles for low and high traffic scenarios (See Appendix 4 for larger image)

The mission drive cycle profiles were then used as inputs to the vehicle energy simulation model. This enabled the vehicle energy consumption over the drive cycle, as well as the battery SoC state to be calculated. To account for varying vehicle occupancy, the vehicle energy consumption was calculated for *low weight* and *high weight* scenarios. The calculated SEM1 vehicle energy consumption values for the 5 mission profile, in low & high traffic and low and high weight scenarios is shown in Figure 9.3.2.5.7.

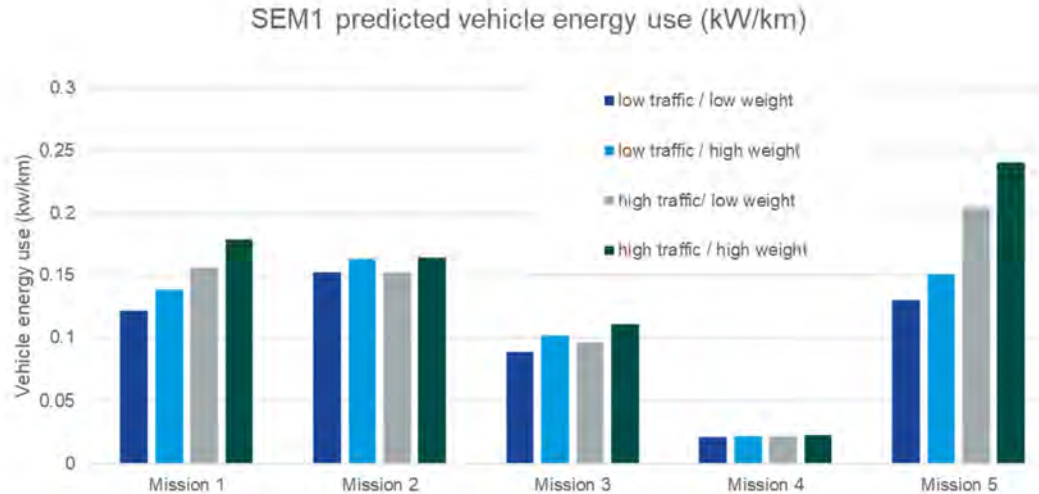


Figure 9.3.2.5.7 SEM1 predicted vehicle energy consumption for Brighton and Hove city mission profiles (values without autonomous vehicle cycle smoothing)

It should be noted that the Mission 4 has a (home) starting point at a higher altitude and destination than sea level in the city centre, therefore the downhill gradient results in overall low levels of vehicle energy consumption. The predicted vehicle energy consumption values were then used for the use phase calculations in the complete vehicle LCA calculations (discussed later). The SEM1 battery capacity and SoC through a typical daily operation were evaluated by combining the mission profiles 1 to 5 over a 24-hour period. The daily profile was assembled subjectively, based on expected journeys for a Monday to Friday period. A more thorough approach would require real-world vehicle tracking and measurement of present-day vehicles such as taxis. Figure 9.3.2.5.7 shows how the mission profiles were combined over a 24-hour duration. Between the hours of 02:00 and 06:00, the vehicle is expected to be based at the fleet operator's depot, undergoing checking, maintenance and battery charging. The vehicle would ramp up service from 06:00, with a high demand for home to office, home to school and home to train station journeys until 10:00. Demand would then expect dwindle, with a switch to more recreational journeys such as home to shopping centres. Drive cycles 2,3 and 4 are expected to be appropriate for these journeys. Demand would expect to decrease considerably after lunchtime before increasing for the evening rush hour between 15:00 (school closing) and 18:00 (office closing). Journey types would switch to recreational during the evening, with home to city and inner city journeys. Demand would then be reduced from 23:00 to 02:00 hours when the vehicle would return to the fleet depot. Combinations of low/high traffic and low/high vehicle weight cycles and vehicle energy consumption were selected depending on the expected traffic conditions and vehicle occupancy during the 24-hour profile. The vehicle energy simulation model calculated the required propulsion energy demand from the battery. It did not consider the vehicle ancillary or "hotel" energy requirements which need to be included for battery SoC estimations. A standard 2.5kW ancillary load was added to the propulsion energy requirement. This was considered worst case, accounting for the autonomous vehicle system electrical loads and heating, ventilation and air conditioning (HVAC) which were assumed to be higher than a conventional passenger car due to the higher frequency of door operation and the wider door opening area, resulting in a higher thermal loading on the vehicle interior.

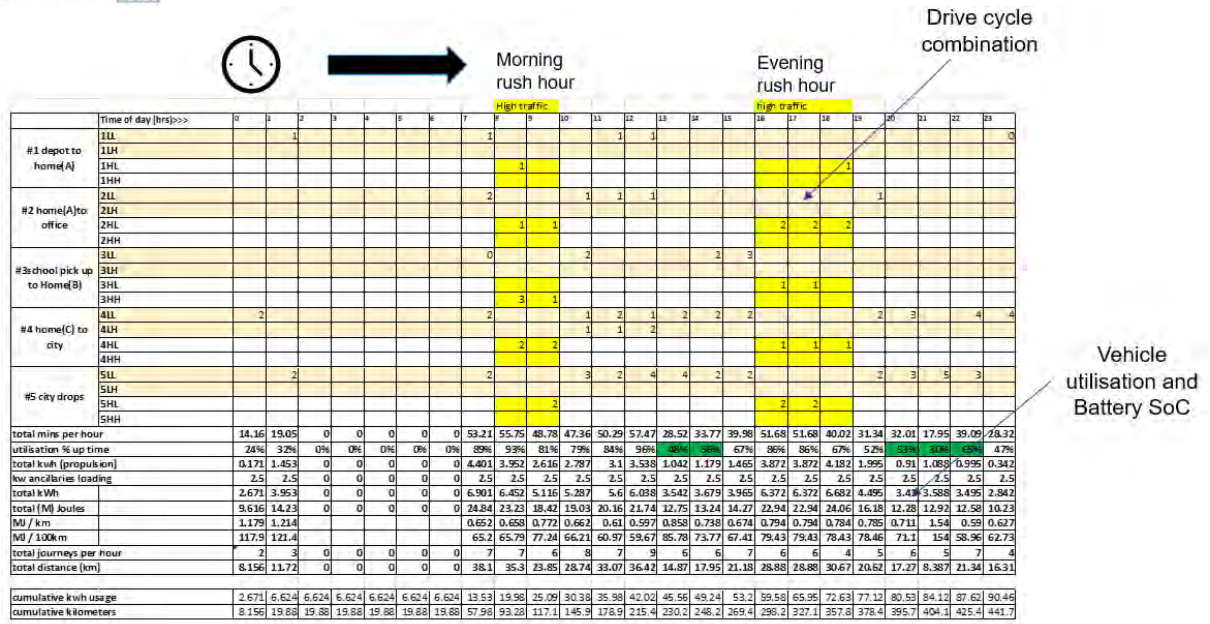


Figure 9.3.2.5.8 24 hour SEM1 vehicle mission profile, combining mission segments #1 to #5, at low/high traffic and low/high weight (See Appendix 4 for larger image)

The output from the 24-hour mission profile study was overall vehicle utilisation (%) and calculated battery SoC state (%) (Figure 9.3.2.5.9). Assuming the battery is at 98% SoC at the start of the day (assuming a full 100% SoC is not achievable in real life), it was predicted that the vehicle could operate on a full charge until 19:00hrs. Given the expected low journey demand period during the afternoon, the vehicle would be able to recharge at the main depot, and with a high capacity charger, a full charge could be re-established in time to support the high demand evening rush hour. With the vehicle assuming a high vehicle occupancy, driverless operation, it could be expected that the high degree of soiling of the interior may occur during the daily operation. Fleet operators may therefore be inclined to bring vehicles in for cleaning, inspection throughout the day. The mid-day charging operation would enable the vehicle to undergo simultaneous valeting and inspection.

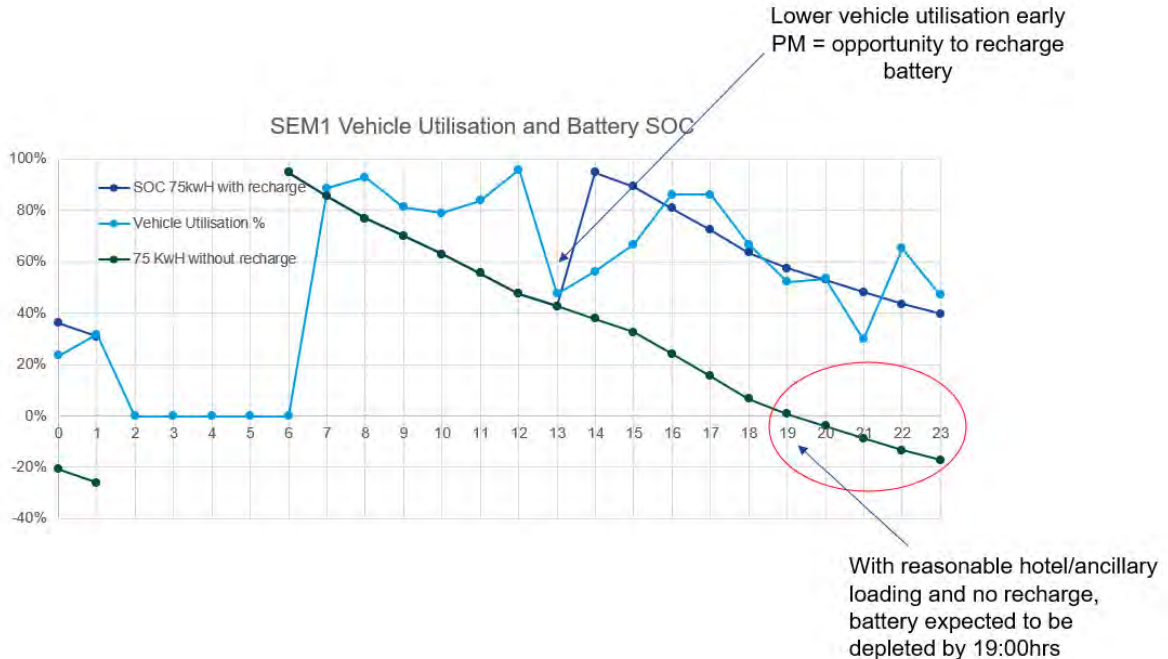


Figure 9.3.2.5.9 Predicted SEM1 vehicle utilisation (%) and battery state (SoC) over 24 hour duty cycle (autonomous vehicle drive cycle smoothing not applied)

This study concluded that the SEM1 vehicle and battery specification is able to support the expected journey requirements and demands of a typical city.

9.3.2.6 Vehicle and battery life extension. Increased vehicle occupancy

Passenger cars and vehicles are typically engineered for a given lifetime duration, in order to satisfy warranty and consumer expectations. Extending the life of a vehicle means that a lower cumulative number of new vehicles are required to maintain a given fleet size. A lower number of vehicles in turn leads to lower cumulative GHG emissions for the fleet as a whole. This is accounted for in the Steel E-Motive calculations as the GHG contribution is expressed as $\text{kgCO}_2\text{-eq}/(\text{passenger}\cdot\text{kilometer})$. Therefore extending the required life of a vehicle reduces the $\text{kgCO}_2\text{-eq}/(\text{passenger}\cdot\text{kilometer})$ value. A default consideration of 300,000km vehicle lifetime was considered, extended up to 600,000km as a stretch potential for the 2035 market. Similarly, extending the propulsion battery life will have a net beneficial impact on life cycle emissions. The Steel E-Motive battery design is engineered such that the individual battery modules are easily accessible and replaceable. This would enable failed battery modules to be easily replaced where typically the complete may be replaced currently. This was modelled in the LCA calculations by assuming a default battery life of 300,000km and an extended battery life of 600,000km.

9.3.2.7 End of life methodology sensitivity

In LCA, the “cut-off” EoL allocation method (also referred to as “100:0”) requires that the environmental impact associated to the recycling of the waste materials generated at EoL be excluded from the system boundary of the product under assessment, and that at the same time no impact credit be assigned for the virgin materials that such EoL recycling allows to displace. At the opposite end of the scale in terms of EoL impact allocation, the “avoided burden” method (also referred to as “0:100”) requires that 100% of the impact associated to the recycling of the waste materials generated at EoL be assigned to the product under

assessment, in addition to the full impact credit for the corresponding virgin materials that are assumed to be displaced; however, to avoid double counting, in this method no material input to manufacturing may be assumed to be of secondary (i.e., recycled) origin.

In this study, this latter “avoided burden” method was adopted as the default option, while a separate sensitivity analysis was carried out to investigate the effect of the alternative use of the “cut-off” method.

9.4 Life cycle analysis results

Figure 9.4.1 summarises the 11 lifecycle analysis studies and boundary conditions. 2 reference/baseline conditions and 9 Steel E-Motive sensitivity studies were evaluated. These included alternative assumptions on LCA end-of-life modelling methodology, lifetime vehicle activity (and battery lifetime), alternative operational life energy consumption sensitivities, sensitivities on the use of ‘green’ steel and on vehicle occupancy rates.

| Scenario n. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|--|--|-----------------------------------|---|---|--|--|---|---|---------------------------------------|--|--|
| description | BASELINE: 2018-2030 grid mix, private/taxi, EU | Future grid mix, private/taxi, EU | Future grid mix, private/taxi, EU, recycled content EoL | Future grid mix, 100% low-C steel, private/taxi, EU | Future grid mix, extended life, 2 batt, private/taxi, EU | Future grid mix, extended life, 1 batt, private/taxi, EU | Future grid mix, private/taxi, "real world" cycle, EU | Future grid mix, autonomous, private/taxi, "real world" cycle, EU | Future grid mix, ride sharing low, EU | Future grid mix, ride sharing high, EU | Future grid mix, autonomous, ride sharing high, EU |
| Title Level 1 | Baseline vehicle | Steel e-Motive; | Recycled | Low-C steel | Extended life, 2 | Extended life, 1 | "Real-World" | "Real-World" | Ride sharing low | Ride sharing high | Extended life, |
| Title Level 2 | 2018 | Steel e-Motive; | Recycled | Low-C steel | Extended life, 2 | Extended life, 1 | "Real-World" | "Real-World" | Ride sharing low | Ride sharing high | Extended life, |
| Title Level 3 | Baseline | Default | Recycled | Low-C steel | Extended life, 2 | Extended life, 1 | "Real-World" | "Real-World" | Ride sharing low | Ride sharing high | Extended life, |
| power train | BEV | BEV | BEV | BEV | BEV | BEV | BEV | BEV | BEV | BEV | BEV |
| % ethanol | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Vehicle class | FSV A-class | FSV A-class | FSV A-class | FSV A-class | FSV A-class | FSV A-class | FSV A-class | FSV A-class | FSV A-class | FSV A-class | FSV A-class |
| Driving cycle | WLTP | WLTP | WLTP | WLTP | WLTP | WLTP | real-world cycle | real-world cycle | WLTP | WLTP | WLTP |
| Driving cycle smoothing reduction | 0% | 0% | 0% | 0% | 0% | 0% | 0% | -15% | 0% | 0% | 0% |
| Lifetime km | 300,000 | 300,000 | 300,000 | 300,000 | 600,000 | 600,000 | 300,000 | 300,000 | 300,000 | 300,000 | 600,000 |
| Battery lifetime (km) | 300,000 | 300,000 | 300,000 | 300,000 | 300,000 | 600,000 | 300,000 | 300,000 | 300,000 | 300,000 | 600,000 |
| pyrometall. UB recycling share | 50% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Grid mix (both SDS and STEPS for future scenarios) | 2018 | 2030-2040 | 2030-2040 | 2030-2040 | 2030-2040 | 2030-2040 | 2030-2040 | 2030-2040 | 2030-2040 | 2030-2040 | 2030-2040 |
| Region | Europe | Europe | Europe | Europe | Europe | Europe | Europe | Europe | Europe | Europe | Europe |
| EoL method | Av. Burden | Av. Burden | Recycled content | Av. Burden | Av. Burden | Av. Burden | Av. Burden | Av. Burden | Av. Burden | Av. Burden | Av. Burden |
| "green" steel share | 0% | 0% | 0% | 100% | 0% | 0% | 0% | 0% | 0% | 0% | 100% |
| "green" Al share | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Vehicle occupancy (ride sharing) | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 2 | 3 | 3 |

Figure 9.4.1 Lifecycle analysis studies and model boundary conditions (See Appendix 4 for larger image)

Figure 9.4.2 shows the absolute calculated life-cycle GHG emissions, in units of kgCO₂-eq/(passenger-kilometer), for the 11 scenarios studied, with the individual contributions of vehicle manufacturing, vehicle use and end of life phase presented. The difference between use phase emissions under, respectively, SDS and STEPS electricity grid mix scenarios are also presented. For the baseline Steel E-Motive scenario (2), the breakdown and contributions to the vehicle manufacture GHG are shown in the accompanying pie chart.

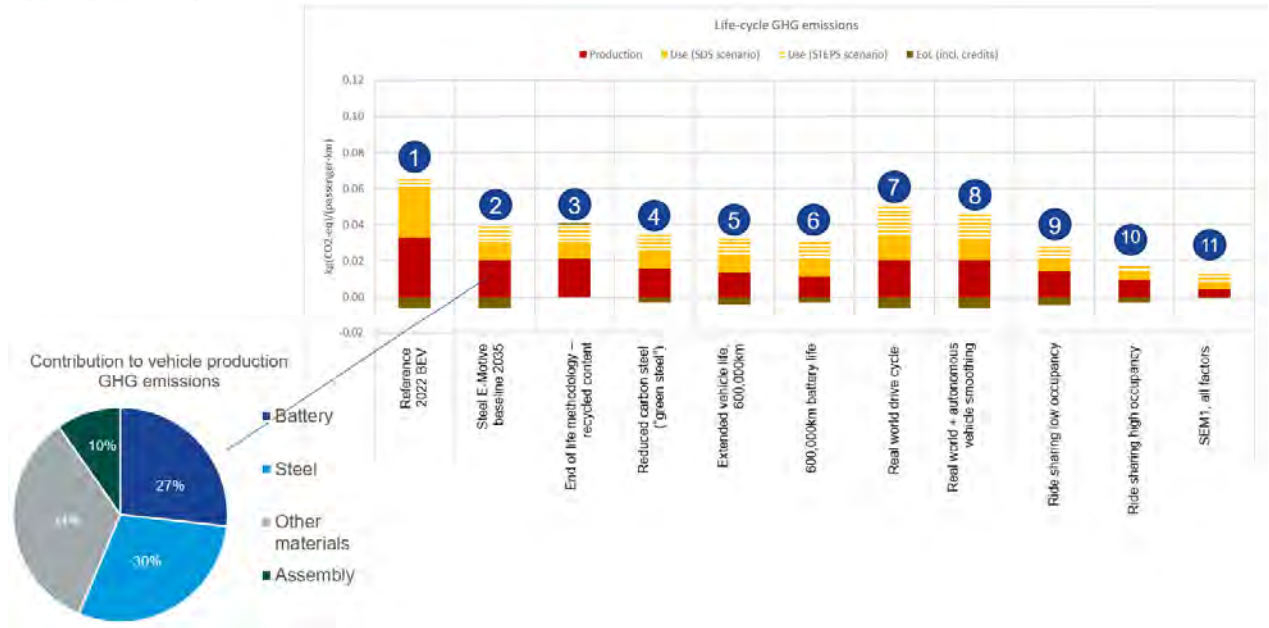


Figure 9.4.2 lifecycle analysis GHG CO₂ calculations (CO₂ equivalent per passenger-kilometers) (See Appendix 4 for larger image)

Figure 9.4.3 shows the total lifecycle GHG emissions for the 11 scenarios, expressed as a percentage of the reference 2022 BEV. Figure 9.4.4 provides a narrative on the comparative results for Europe region.

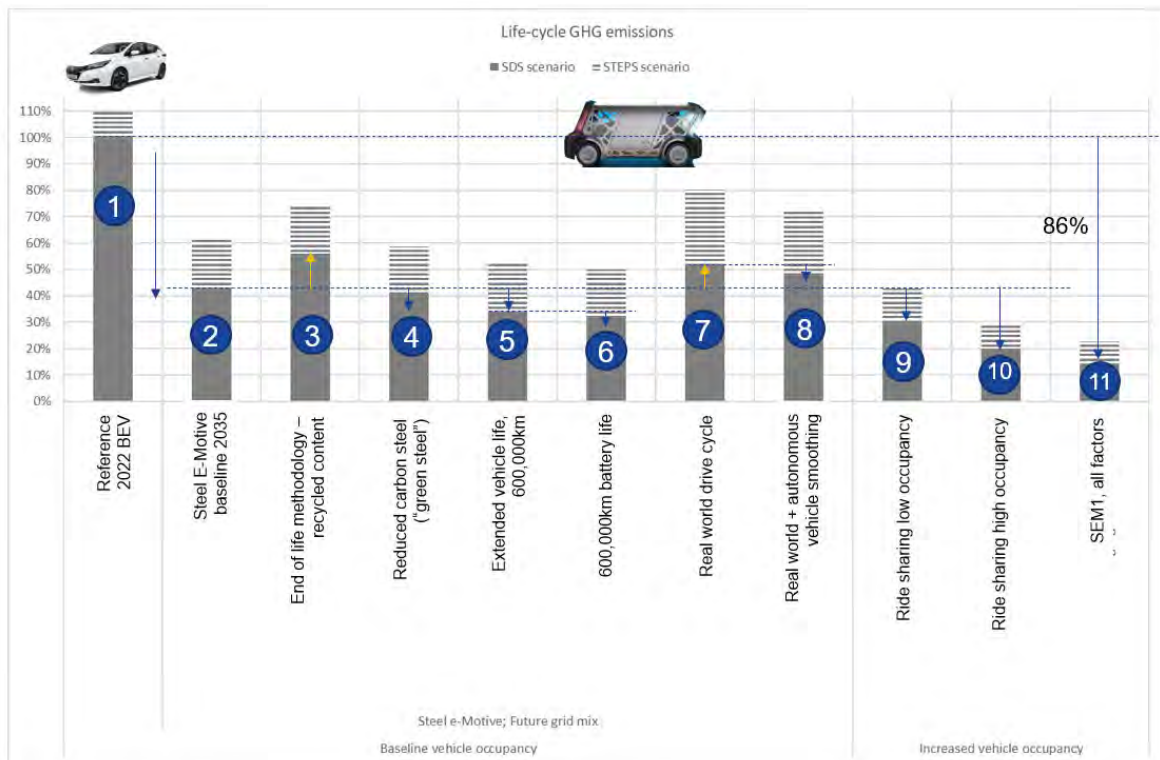


Figure 9.4.3 lifecycle analysis GHG CO₂ calculations, expressed as % of reference 2022 BEV (See Appendix 4 for larger image)

| Model/result number | Description | Key Result |
|---------------------|---|--|
| 1 | Reference BEV, 2022 | Used as datum/reference for SEM |
| 2 | Baseline Steel E-Motive. 25% vehicle weight reduction versus (1), 2030-2040 electricity grid mix | 57% life cycle GHG reduction compared to (1) |
| 3 | Steel E-Motive. As (2) with End of Life methodology changed from avoided burden method to recycled content | Recycled content EOL methodology results in a 13% increase in lifecycle GHG |
| 4 | Steel E-Motive. As (2) with all AHSS in the vehicle substituted with decarbonised steel production | 22% reduction in vehicle production GHG emissions. 3% decrease in GHG over vehicle lifecycle. Note, the effect is diluted due to the GHG contribution in the use phase |
| 5 | Steel E-Motive. As (2), with vehicle lifetime kilometers increased from 300,000km (2) to 600,000km (5) | 20% reduction in vehicle lifecycle GHG |
| 6 | Steel E-Motive. As (5), with battery lifetime increased from 300,000km to 600,000km | A further 7% reduction in lifecycle GHG emissions compared to (5) |
| 7 | Steel E-Motive. As (2) with real-world driving cycle. (all other models assume a standard WLTP drive cycle) | Real world drive cycle results in overall 21% increase in lifecycle GHG emissions |
| 8 | Steel E-Motive. As (7) with effect of autonomous vehicle drive cycle smoothing | 7% reduction in lifecycle GHG emissions compared to (7) |
| 9 | Steel E-Motive. As (2) with vehicle occupancy passenger increased from 1.4 to 2.0 | 30% reduction in lifecycle GHG emissions compared to (2) |
| 10 | Steel E-Motive. As (2) with vehicle occupancy passenger increased from 1.4 to 3.0 | 53% reduction in lifecycle GHG emissions compared to (2) |
| 11 | Steel E-Motive. As (2), with combined effects of (4), (5), (6), (10) | 86% reduction in lifecycle GHG emissions compared to reference 2022 BEV vehicle (1) |

Figure 9.4.4 LCA results narrative (See Appendix 4 for larger image)

The LCA calculations were also separately performed for Europe, United States, China and Japan regions, where the corresponding region-specific electricity grid carbon intensities were applied (Figure 9.3.2.2.3). Results for the regional variances and the overall potential reduction in GHG values are shown in Figure 9.4.5.

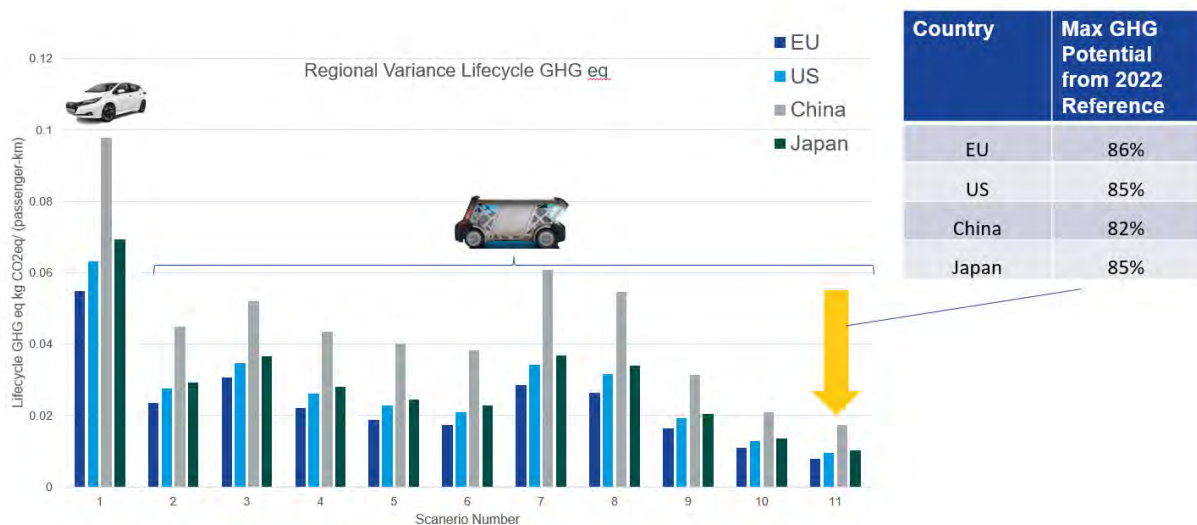


Figure 9.4.5 Lifecycle calculations for Eu, US, China and Japan regions (See Appendix 4 for larger image)

9.5 Life cycle analysis results discussion and conclusions

Fully autonomous Mobility as a Service vehicles such as the Steel E-Motive concept have the potential to address the ongoing and future requirements for decarbonisation of passenger transportation. The Steel E-Motive concept demonstrates the potential to reduce lifecycle greenhouse gas emissions by up to 86%, when compared to a present day battery electric vehicle operating as a taxi. This potential can be realised by adopting the following measures:

- Reducing vehicle production and manufacturing embedded emissions, by utilising 100% reduced carbon (“green”) steel, improving battery technology and increasing the use of renewable electricity in battery manufacturing, and increasing/improving battery recycling.
- Ensuring the vehicle weight of autonomous vehicles is managed, and the potential weight reduction benefits are realised and implemented. The Steel E-Motive body structure and battery housing demonstrates good weight efficiency.
- Increasing the overall lifespan of the vehicle and battery. The fatigue and durability properties of AHSS can enable enhanced vehicle lifetime. The Steel E-Motive battery design enables easy replacement of specific modules (i.e., those which may fail or be damaged), which should enable an overall extended battery life.
- Autonomous vehicle control providing smoothing of the drive cycle. The vehicle acceleration and deceleration rates can be optimised to match the driving conditions and road topography. This reduces energy consumption and subsequent GHG emissions.
- Increasing passenger occupancy rates to at least 3 per vehicle via MaaS.

The projected net GHG emissions for the Steel E-Motive vehicle operating with the flexibilities described above already represent a very significant reduction vs. the current baseline. Achieving net zero emissions would require additional measures such as manufacturing offsetting manufacturing impacts (e.g. through compensatory credits from atmospheric carbon capture and storage) and transitioning to 100% renewable electricity grid.

10.0 Exterior Vehicle Styling

The SEM1 exterior vehicle styling was adjusted to take into account any necessary adjustments that were made during the engineering development of the body structure. The selected styling theme was maintained. Figure 10.0.1 to 10.0.10 show the final exterior vehicle styling images for SEM1, with in-situ renderings included to demonstrate real life application.









11.0 Design and development of SEM2, extra-urban 6 passenger variant

11.1 Introduction & Objectives

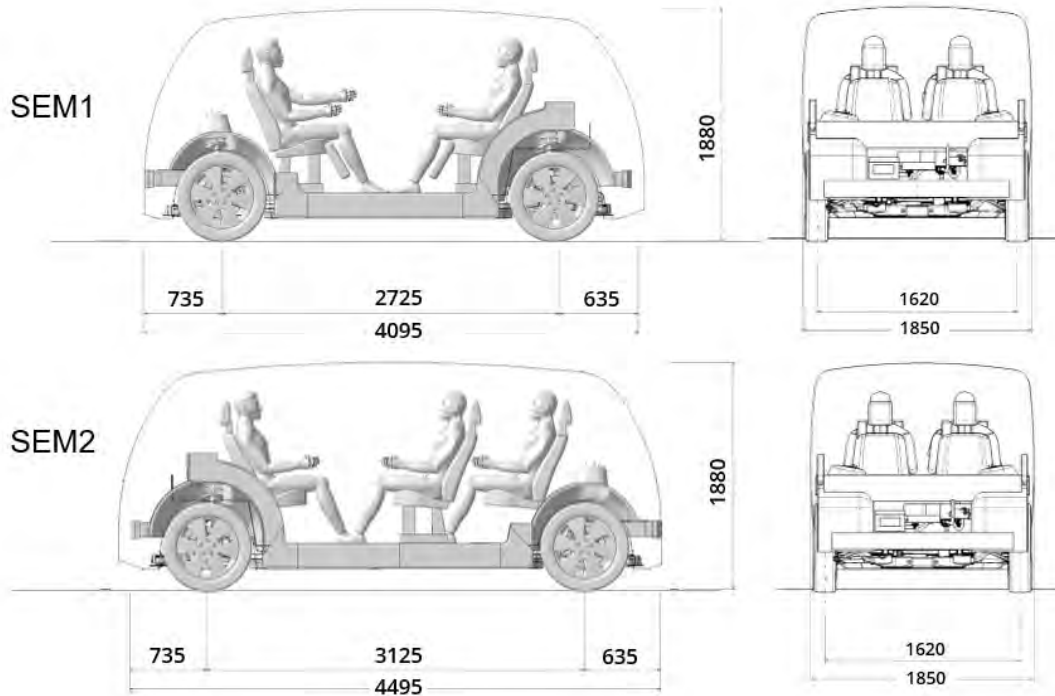
The Steel E-Motive concept is engineered to enable multiple vehicle variants to be developed from a common basis (or platform). The main detailed engineering activities focussed on the smaller 4 passenger SEM1, as documented in this report. To demonstrate the platform and scalability principals, a larger 6 passenger variant SEM2 was engineered, using a combination of 3D CAD design and “desktop” engineering approach.

11.2 SEM2 Targets

| Target | SEM1 | SEM2 | Comment |
|---|--|-------|--|
| Overall vehicle length (mm) | 4100 | 4495 | |
| Overall vehicle width (mm) | 1850 | 1850 | |
| Overall vehicle height (mm) | 1850 | 1850 | |
| Wheelbase (mm) | 2725 | 3125 | (SEM2 +400mm wheelbase stretch) |
| Track, front and rear (mm) | 1620 | | |
| Vehicle turning circle (metres) | <7.6 | <9.5 | |
| Autonomy level (SAE) | 5 | | |
| Vehicle curb weight (kg) | <1640 | <1800 | |
| Vehicle Gross Vehicle Weight GVM, (kg) | <2140 | <2600 | Based on 6 passengers + 150kg payload No towing requirement No roof carrying requirement (e.g. roofbox) |
| Vehicle acceleration 0-102km/h (sec) | <9 | | SEM2 has front and rear EDU to provide additional traction effort |
| Maximum vehicle speed km/h | 130 | | |
| Towing requirements | | | (vehicle not required to perform towing operation) |
| Range on 1 full battery charge(km) | >500 | >500 | Battery size increased to 96kwh |
| Battery charging Time (minutes) | <20 | | |
| Target vehicle life (km) | >500,000 | | |
| Sustainability and Life Cycle performance | Demonstrate ability to make a significant contribution to net zero lifetime vehicle greenhouse gas emissions | | |
| Body manufacturability and vehicle assembly | Maximise commonality between parts | | To use conventional sheet steel fabrication processes for the body structure (for example, but not limited to; hot and cold stamping, roll forming, roll stamping, hydroforming). Body assembly to use Resistance Spot Welding (RSW), laser welding, brazing, structural adhesives, mechanical fasteners Utilise a conventional high volume vehicle assembly processes and approaches |

| | | | |
|--|-------------------------------|-------------------------------|--|
| | | | The design to be suitable for production in global locations and facilities |
| Anticipated production volumes (per year) | 250,000 | 100,000 | Lower volume for SEM2 |
| Anticipated Start of Production (SOP) date | 2030 to 2035 | | |
| Luggage volume capacity (litres) | 400 | | |
| Passenger ergonomics | Comfortably seat 4 passengers | Comfortably seat 6 passengers | To have a minimum side door aperture opening width >1.0m To be compliant with disabled user requirements (e.g., wheelchair, ramp access) To seat 4 passengers comfortably, assuming 95% ile mannequin To accommodate breadth of potential users (e.g., babies, children, elderly) |
| Vehicle servicing and repair | | | Steel E-Motive design to ensure that minor service points (such as coolant, screen wash, brake fluid reservoir) to be readily accessible without the requirement for hand tools. Ensure major servicing of parts such as brake pads & discs, tyres can be completed within industry standard timelines and efforts Major repair parts such as high voltage battery can be undertaken in competitive timelines |

With the exception of weight, the SEM2 BIW performance targets were targeted to be the same as SEM1. The same weight-dimension regression analysis principals (Figure 4.2.2.1) as applied for SEM1 BIW weight were applied for SEM2. Using the same approach, a target value of 362kg was defined for SEM2 BIW.



11.3 Technical Approach

Consideration for the development of the SEM2 variant was provided during the preliminary concept development and vehicle package study in Phase 0. To account for the higher kerb and gross weights, an additional rear EDU was specified, in order to provide additional tractive effort and power when required. The front EDU was changed from single speed (SEM1) to 2 speed (SEM2). The greater size of SEM2 was achieved by increasing the wheelbase by 400mm rearwards of the door split line. This would enable the front and rear body structure zones to be largely common and carry-over from SEM1, with SEM2 specific parts for the mid zone. The 6 occupants are accommodated with an additional 3rd row of seating, with the middle row of seats converted to sliding and folding to enable passenger ingress/egress access. The SEM1 3D CAD data was used as the basis for the detailed development of the SEM2 variant. A subject and desktop attribute appraisal approach was then taken to determine further modifications to SEM2 that may be required.

11.4 SEM2 vehicle concept

11.4.1 SEM2 Vehicle layout, weight analysis & occupant positioning

Figure 11.4.1.1 shows the comparison of SEM1 and SEM2 vehicle design, proportions, and interior configuration. The scissor doors are largely carry-over from SEM1, with the exception of the rear door outer surface profile which is adjusted to match the effect of stretched wheelbase. The wide door opening aperture and low step in height is maintained in SEM2, providing good access for the occupants.

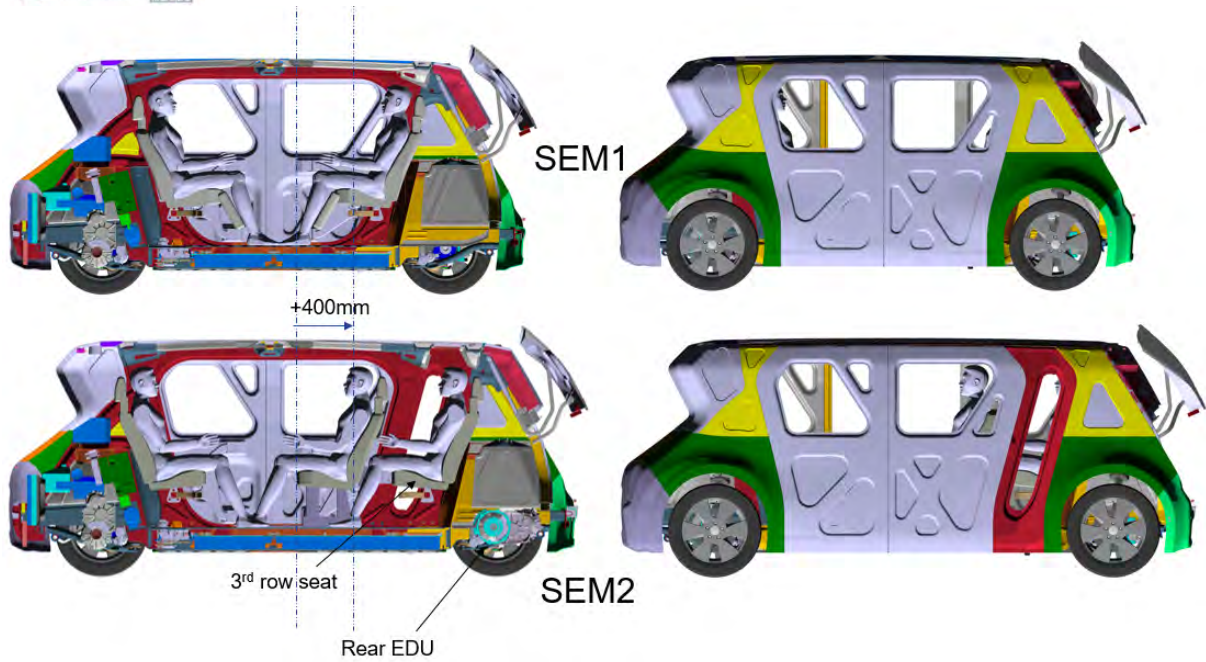


Figure 11.4.1.1 Comparison of SEM1 and SEM2 vehicles and interior configuration

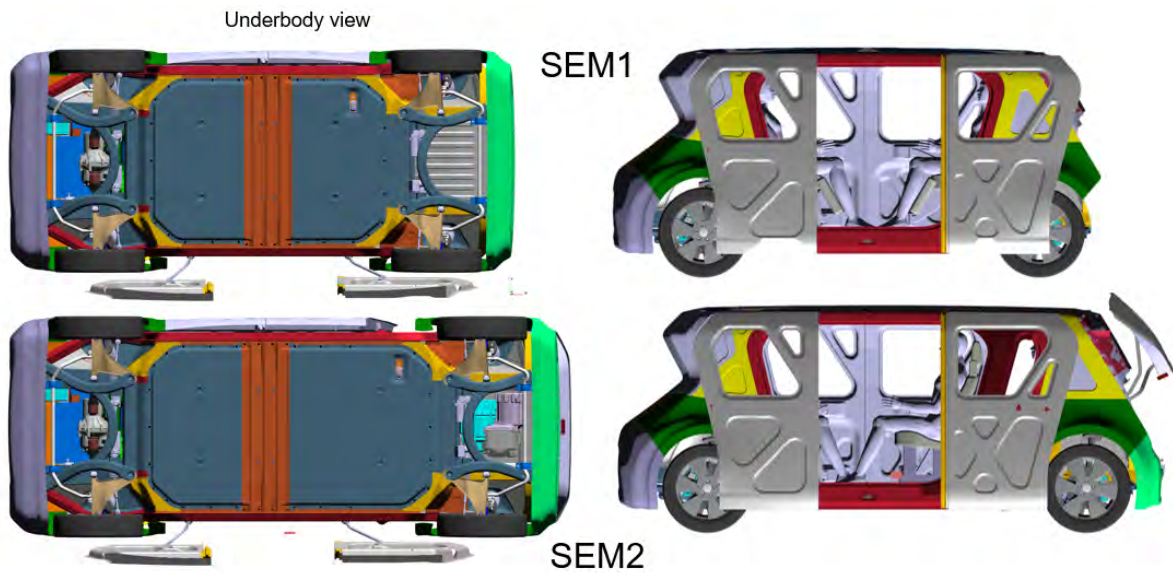


Figure 11.4.1.2 Comparison of SEM1 and SEM2 complete vehicle

The vehicle curb and gross weights were estimated based on the carry over SEM1 systems (green text in Figure 11.4.1.3) and new/modified parts and systems for SEM2 (red text in Figure 11.4.1.3). SEM2 is estimated to have a curb weight value 24% higher than SEM1. The SEM2 Gross Vehicle Weight (GVW) was estimated to be 2548kg.

| Subsystem | SEM 1 | SEM 2 | SEM2 comment |
|---------------------------------|---------------|---------------|---|
| Body non-structure | 177.2 | 293.2 | additional seat row, glazing, trim size |
| Body In White | 282.0 | 323 | from 3D CAD and adjusted BoM |
| Front sub-frame | 16.5 | 16.5 | carry over SEM1 |
| Battery case (structure) | 59.0 | 70 | from 3D CAD model |
| Rear sub-frame | 10.2 | 10.2 | carry over SEM1 |
| Front suspension | 114.0 | 131.1 | SEM2 chassis parts for higher GVW |
| Rear suspension | 114.0 | 131.1 | SEM2 chassis parts for higher GVW |
| Braking | 59.7 | 65.7 | 10% large disc and caliper for SEM2 |
| Steering | 26.0 | 26 | carry over SEM1 |
| Tires and wheels | 84.0 | 96.6 | SEM2 chassis parts for higher GVW |
| Motor Trans Front | 63.0 | 72.45 | SEM2 chassis parts for higher GVW |
| Motor Trans Rear (N/A SEM1) | | 80 | SEM2 rear EDU only |
| Battery system less case | 245.6 | 295.6 | SEM2 96kWh battery |
| Propulsion controls | 60.0 | 60 | carry over SEM1 |
| Electrical-non propulsion | 35.7 | 36 | minor adjustment for SEM2 |
| Cooling and heating | 30.0 | 30 | |
| Closures | 109.3 | 109.3 | adjustment to rear door outer skin geometry. No mass impact |
| Bumpers | 26.0 | 26 | carry over SEM1 |
| | | | |
| Curb mass | 1512.2 | 1872.7 | kg |
| Curb mass delta | | 24% | SEM2 has 24% higher curb mass than SEM1 |
| Maximum payload | 500 | 675 | |
| Gross Vehicle Weight GVW | 2012.2 | 2547.7 | |
| GVW delta | | 27% | SEM2 has 27% higher GVW than SEM1 |

Figure 11.4.1.3 Comparison of SEM1 and SEM2 subsystem weight, vehicle curb and gross weight

As per the SEM1 development, Virtual Reality tools were used to assess and confirm the occupant positioning and ingress/egress performance. The middle row seats are configured as sliding and folding enabling access for the third row.

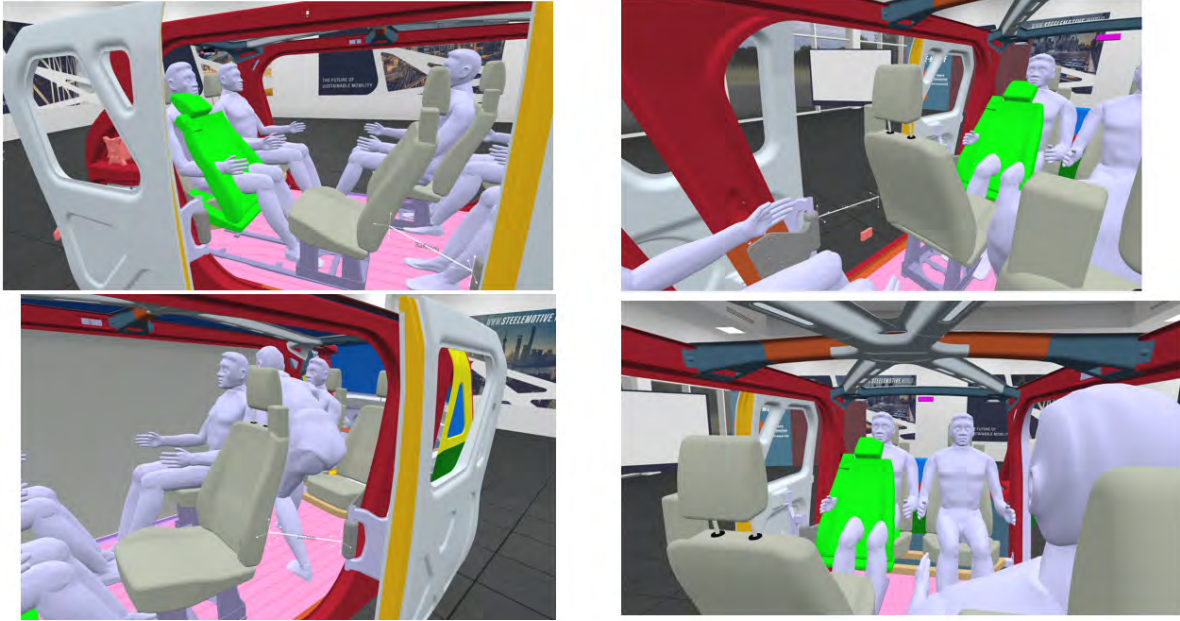


Figure 11.4.1.4 SEM2 Virtual Reality assessment of occupant position, ingress and egress

11.4.2 SEM2 Body structure

The SEM2 BIW is designed to use maximum carry-over/commonality with SEM1. The higher vehicle curb and gross weights result in higher crush and energy levels for frontal and rear crash loadcases, therefore some adjustments were required in order to ensure the crashworthiness performance was in line with SEM1 and targets. Figures 11.4.2.1 and 11.4.2.1 show where changes to the AHSS grade or gauge thickness was made for specific SEM2 parts. These changes were estimated on an engineering judgement basis. Full vehicle crash simulation as performed for SEM1 would be required to validate these recommendations. In some cases, existing SEM1 tooling could be used for some of the unique SEM2 front and rear zone parts. Full forming feasibility calculations would be required to validate this. The SEM2 BIW weight is 323kg versus a target of 361.9kg.

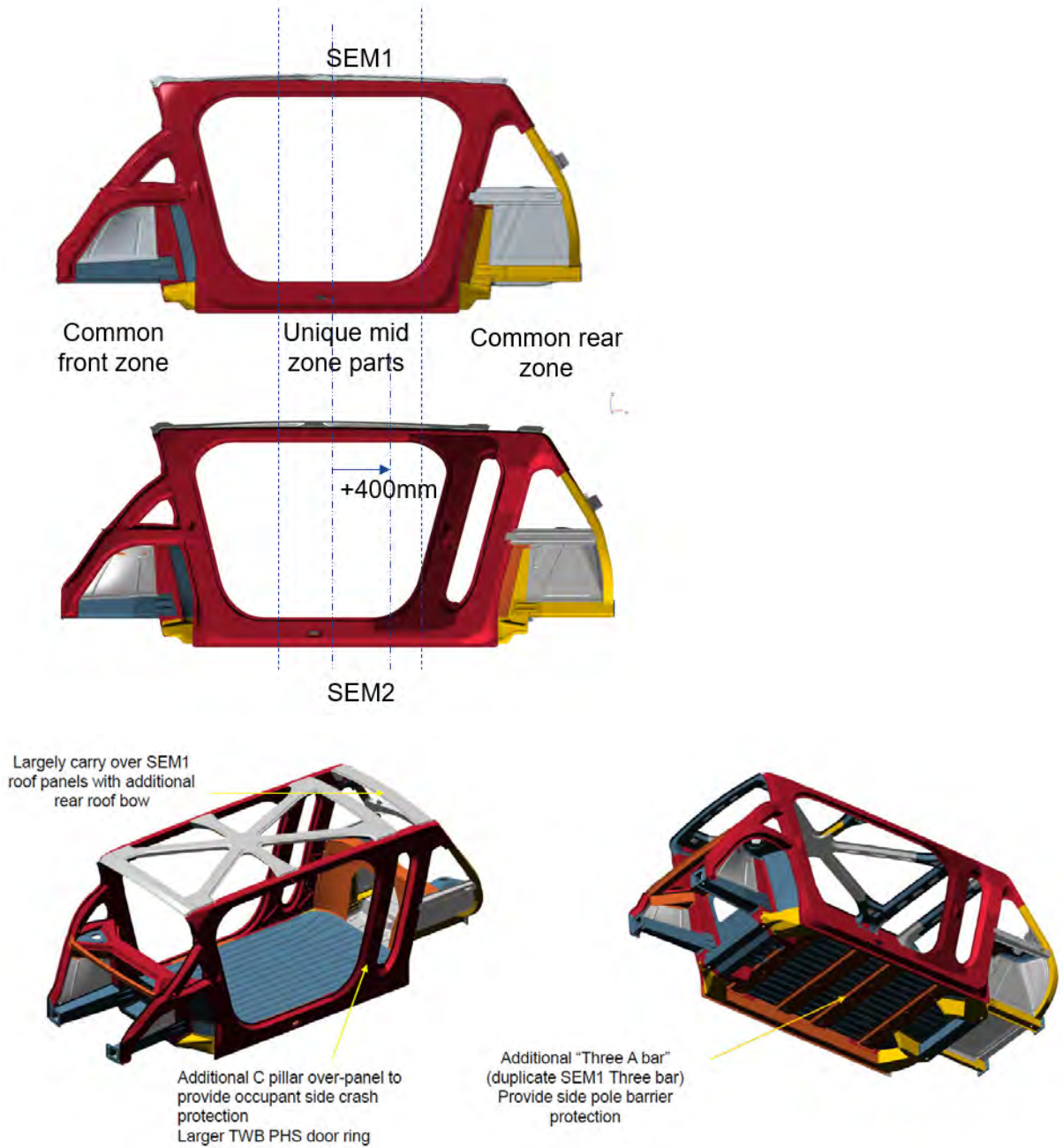
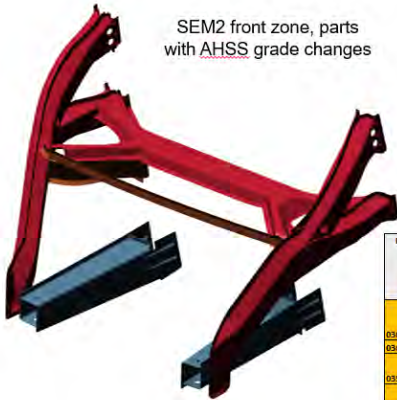


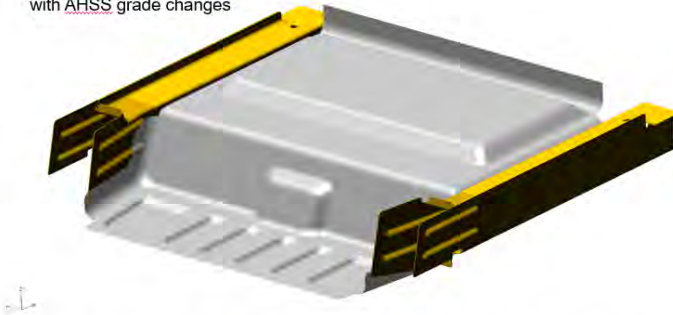
Figure 11.4.2.1 SEM2 BIW design approach and commonality with SEM2



SEM2 front zone, parts with AHSS grade changes

| Part Number | Part Name | AHSS Grade | Gauge (mm) | C = Carry over SEM1 G = grade/gauge change N = New geom | Part Mass (kg) | SEM2 change |
|-------------|--|-----------------------------|------------|---|----------------|---|
| 0364318_2 | GLANCE BEAM LOWER REACTION RH | CR1200Y1470F-M5 | 1.2 | G | 0.72 | change from 0.8mm to 1.2mm |
| 03640761_2 | GLANCE BEAM UPPER REACTION RH | PHS-CR1500T-M5 | 1.0 | G | 0.92 | change from 0.8mm to 1.2mm |
| 03553269_2 | LONGITUDINAL MID RAIL OUTER FRONT RH | CR300Y780T-0P/CR700Y980T-0P | 2.0 | G | 3.51 | change from 1.8mm/2.0mm TWB to 2.0mm throughout |
| 0359010_2 | LONGITUDINAL MID RAIL OUTER FRONT LH | CR300Y780T-0P/CR700Y980T-0P | 2.0 | G | 3.51 | change from 1.8mm/2.0mm TWB to 2.0mm throughout |
| 03585863_2 | GLANCE BEAM UPPER TRIANGULATION INNER LH | PHS-CR1500T-M5 | 1.2 | G | 1.32 | change from 0.8mm to 1.2mm |
| 03642244_2 | GLANCE BEAM LOWER REACTION LH | CR1200Y1470F-M5 | 1.2 | G | 0.72 | change from 0.8mm to 1.2mm |
| 03553270_2 | LONGITUDINAL MID RAIL INNER FRONT RH | CR300Y780T-0P/CR700Y980T-0P | 2.0 | G | 3.79 | change from 1.8mm/2.0mm TWB to 2.0mm throughout |
| 03618987_2 | GLANCE BEAM OUTER RH | PHS-CR1500T-M5 | 1.2 | G | 2.83 | change from 0.8mm to 1.2mm |
| 03618991_2 | GLANCE BEAM UPPER TRIANGULATION OUTER RH | PHS-CR1500T-M5 | 1.2 | G | 1.27 | change from 0.8mm to 1.2mm |
| 03640760_2 | GLANCE BEAM UPPER REACTION LH | CR1200Y1470F-M5 | 1.2 | C | 0.42 | change from 0.8mm to 1.2mm |
| 03618990_2 | GLANCE BEAM UPPER TRIANGULATION INNER RH | PHS-CR1500T-M5 | 1.2 | G | 1.32 | change from 0.8mm to 1.2mm |
| 03643540_2 | GLANCE BEAM LATERAL CROSS MEMBER OUTER | CR1200Y1470F-M5 | 1.2 | G | 1.32 | change from 0.8mm to 1.2mm |
| 03603008_2 | GLANCE BEAM UPPER TRIANGULATION OUTER LH | PHS-CR1500T-M5 | 1.2 | G | 1.27 | change from 0.8mm to 1.2mm |
| 0359011_2 | LONGITUDINAL MID RAIL INNER FRONT LH | CR300Y780T-0P/CR700Y980T-0P | 2.0 | G | 3.51 | change from 1.8mm/2.0mm TWB to 2.0mm throughout |
| 03640758_2 | STRUT CROSS MEMBER FRONT | PHS-CR2000T-M5 | 1.2 | G | 3.31 | change from 1.0mm to 1.2mm |
| 03618989_2 | GLANCE BEAM INNER RH | PHS-CR1500T-M5 | 1.2 | G | 2.36 | change from 0.8mm to 1.2mm |
| 03585867_2 | GLANCE BEAM OUTER LH | PHS-CR1500T-M5 | 1.2 | G | 2.83 | change from 0.8mm to 1.2mm |

SEM2 rear zone, parts with AHSS grade changes



| Part Number | Part Name | AHSS Grade | Gauge (mm) | C = Carry over SEM1 G = grade/gauge change N = New geom | Part Mass (kg) | SEM2 change |
|-------------|---------------------------------|------------------------------|------------|---|----------------|--------------------------------------|
| 03596995_2 | REAR COMPARTMENT PAN LOWER | CR HSLA350/450 | 0.5 | N | 2.89 | New geometry for rear EDU package |
| 03477701_2 | LONGITUDINAL REAR RAIL INNER RH | CR820Y1180T-RA_1.4_CR600Y980 | 1.8 | G | 1.90 | change from 1.4mm/1.6mm TWB to 1.6mm |
| 03476382_2 | LONGITUDINAL REAR RAIL INNER LH | CR820Y1180T-RA_1.4_CR600Y980 | 1.6 | G | 1.90 | change from 1.4mm/1.6mm TWB to 1.6mm |
| 03477703_2 | LONGITUDINAL REAR RAIL OUTER RH | CR820Y1180T-RA_1.4_CR600Y980 | 1.6 | G | 1.81 | change from 1.4mm/1.6mm TWB to 1.6mm |
| 03476381_2 | LONGITUDINAL REAR RAIL OUTER LH | CR820Y1180T-RA_1.4_CR600Y980 | 1.6 | G | 1.81 | change from 1.4mm/1.6mm TWB to 1.6mm |

Figure 11.4.2.2 Unique SEM2 BIW parts: front and rear zones (See Appendix 4 for larger image)

The SEM2 mid zone features more unique parts and less commonality with SEM1 due to the geometric changes as a result of the +400mm length increase. Nevertheless, a significant number of common parts were enabled in the mid zone by incorporating a largely carry-over roof structure, A pillar inners and floor cross members (two, three, four bars) as shown in Figure 11.4.2.3.



SEM2 BIW mid zone



SEM2 BIW mid zone parts that are common/carry over SEM1

Figure 11.4.2.3 Unique SEM2 BIW parts: mid zones, common/carry over from SEM1

The overall BIW part commonality between SEM1 and SEM2 is shown in Figure 11.4.2.4. From a total of 229 SEM2 BIW parts, 68% are carry-over/unmodified from SEM1, 9% are carry-over from SEM1 but with a material grade or gauge thickness change (subject to forming feasibility) and 23% are unique parts with unique tooling. This platform commonality approach ensures SEM2 (and also SEM1) achieves an overall competitive BIW and vehicle cost.

SEM2 BIW Carry Over/grade change/unique parts

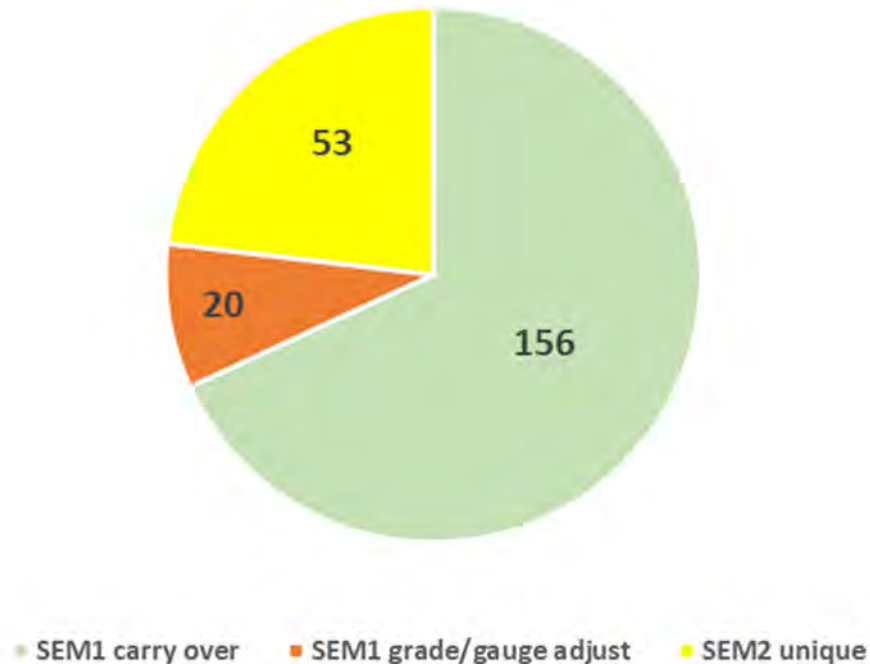


Figure 11.4.2.4 SEM2 BIW part commonality with SEM1

11.4.3 SEM2 Propulsion battery

The SEM2 propulsion battery energy is increased to 96kWH configured with 8 modules. The modules are mounted to 4 structural roll formed and roll stamped Martensitic grade cross members, which are common in design and AHSS grade with SEM1. The SEM2 battery longitudinals are unique to SEM2 and cold formed in DP1180. The SEM2 battery bottom cover applies the same concept and AHSS grades as SEM1 design (Figure 7.2.5.17).

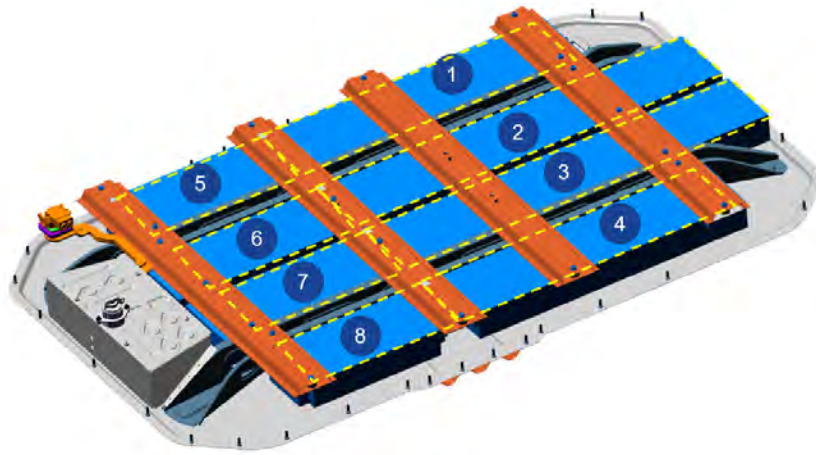


Figure 11.4.3.1 SEM2 96kWh battery and module configuration

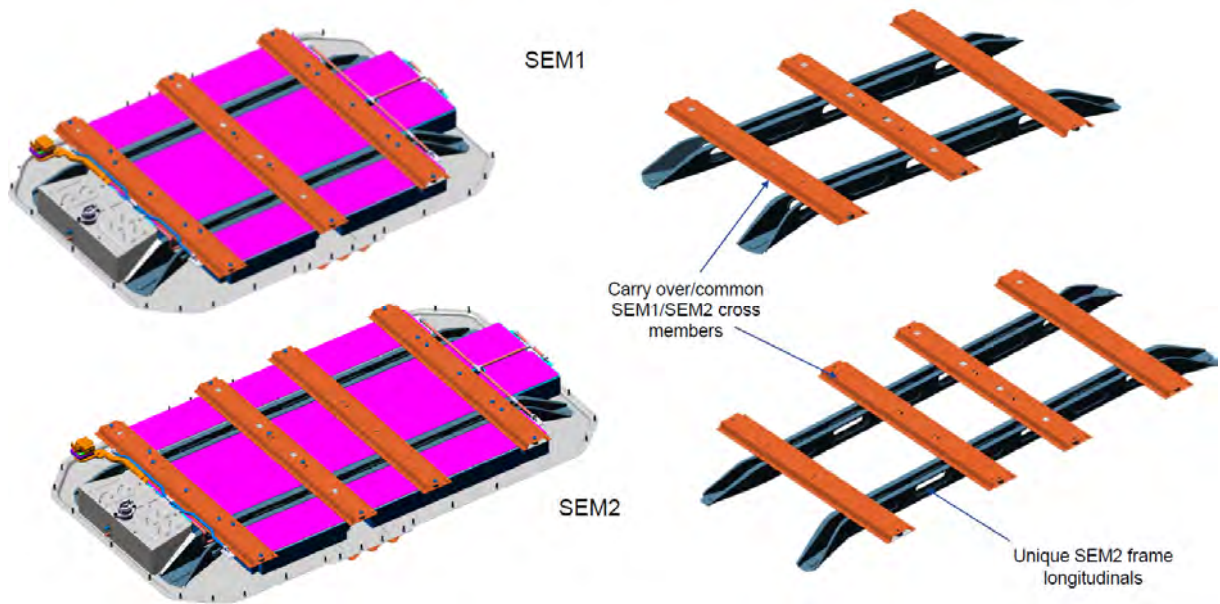


Figure 11.4.3.1 Comparison of SEM1 and SEM2 batteries and carrier frames

11.5 SEM2 subjective performance evaluation

A subjective performance evaluation was performed to help guide the SEM2 design and advise any AHSS grade and gauge changes.

| Attribute/Requirement | Impact of SEM1 to SEM2 | Design mitigation and countermeasures |
|---------------------------------------|---|--|
| Front crash | SEM2 higher 24% curb mass, therefore front crash will have higher energy levels to manage | Increase strength of front longitudinals to enable greater energy absorption. Increase gauge thickness of PHS2000 SORB parts |
| Side crash | IIHS side barrier. Larger side aperture. Heavier vehicle. SEM1 has very good side barrier crash performance Pole: Alignment to occupant won't change so no issue expected. Pole to HV battery potentially an issue with stretched door aperture | Additional C pillar to protect 3 rd row occupants |
| Rear crash & roof crush | Higher GVW. SEM1 performance is comfortable so no significant issue expected | None |
| Body stiffness and NVH | Stretched, longer body structure therefore modal frequencies expected to reduce, potentially below target. Higher battery mass will further reduce the batter first mode | Additional structural adhesive applied to recover NVH modal frequencies |
| Durability | Higher curb mass = higher durability loads. SEM1 has some margin on durability performance so no change is expected | None |
| BIW Mass | SEM2 BIW mass increase will be: additional/stretch mid-zone section. Impact of secondary countermeasures. There could be a -ve mass spiral effect with more mass being required due to higher curb mass. E.g. body needs to be heavier due to heavier battery | None |
| Cost | New mid-zone panels (tooling) and increased grade and gauges in front zone | Cost increases expected to be in line with other vehicle platform approach |
| Life Cycle Assessment | Higher vehicle mass, more steel. Less aggressive real world duty cycle (less city stop-start) Need to ensure high occupancy rate >2 | None |
| Manufacture & assembly | Don't expect significant manufacture issues beyond usual vehicle variant lines | |
| HV battery, jacking, China crush, PSD | Higher mass, higher jacking load. Larger battery cover area. More challenging to meet targets | None |

Figure 11.5.1 Subjective performance evaluation for SEM2 (See Appendix 4 for larger image)

CAE calculations are required in order to validate the subjective evaluations.

12.0 Additional SEM1 and SEM2 engineering studies conducted by academic institutions

This section describes supporting/complementary engineering studies undertaken by global academic institutions using Steel E-Motive concept and data as a basis. These studies serve to further demonstrate the validity of the Steel E-Motive concept and provide students the opportunity to develop and demonstrate their engineering learning on a futuristic vehicle.

12.1 Concept development of hydrogen fuel cell SEM1 variant

This study was undertaken by a final year UK undergraduate study as part of a Masters of Engineering Degree in Automotive Engineering at Loughborough University. The student supported the Steel E-Motive project design activities at Ricardo during a “gap year”.

Objectives of the study:

- Optimise a Fuel Cell Hybrid configuration for Steel E-Motive to maximise performance while keeping system cost and weight to a minimum.
- Explore the feasibility of a Fuel Cell Hybrid configuration to be used in Steel E-Motive when compared to original BEV variant

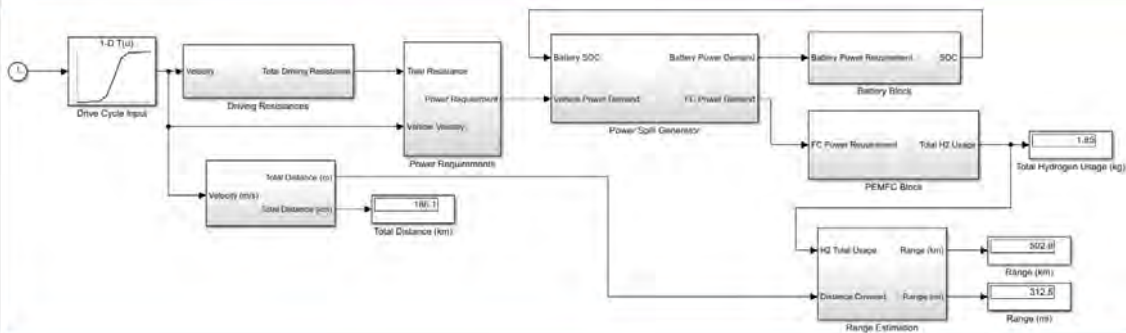
Technical Approach:

1. Produce a vehicle simulation and fuel cell system model, using MATLAB and Simulink, to output PEMFC performance characteristics based on adjustable vehicle parameters
2. Using data obtained from objective 1.1, create analysis of generated FCHV system performance in context of MaaS application
3. Using optimised system parameters, explore packaging feasibility of a fuel cell system in SEM-1 while changing as little architecture as possible
4. Using data obtained from objective 1.1 as well as data obtained from 2030 roadmaps and other literature sources, construct an analysis of the generated FCHV system and its feasibility of being used as a fleet vehicle for MaaS applications

The following slides are taken from the final engineering report for the study, demonstrating fuel cell simulation modelling & optimisation and 3D CAD package study.

Model Construction

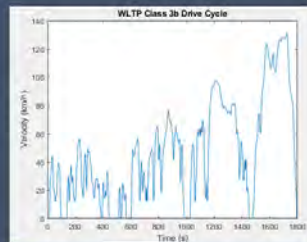
Model Overview



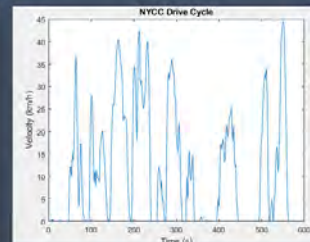
Model Construction

Model Inputs

- System inputs ran through preliminary MATLAB script before running simulation
 - Vehicle Parameters
 - Drive Cycle
 - Battery Parameters
 - PEMFC Parameters
- Drive Cycle Input
 - Primary: WLTP Class 3b
 - Secondary: New York City Cycle



Elapsed Time: 1800 Seconds
Distance Covered: 23.26 km

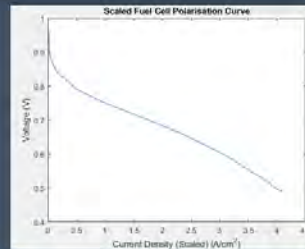
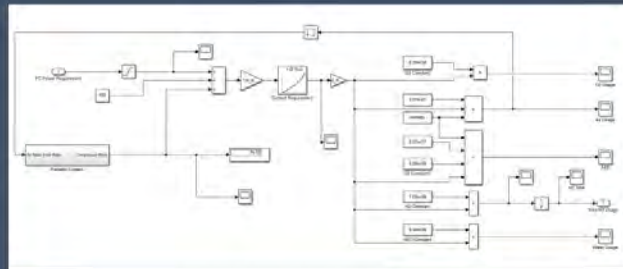


Elapsed Time: 599 Seconds
Distance Covered: 1.89 km

Model Construction

PEMFC Block

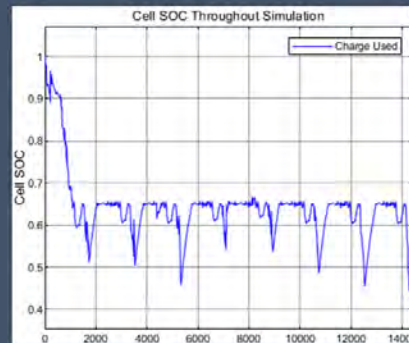
- Battery Block Principles:
 - Input: Fuel Cell Power Requirement
 - Output: H2 Usage
- Assumes cell behaviour is uniform across pack
- Accounts for parasitic losses and auxiliary component load
- Polarization Curve scaled to meet 2030 FCHU targets
 - Cell Power Density = 2 W/cm²



MODEL CONSTRUCTION

Hybrid Power Split

- Battery:Fuel Cell Power Split Dictated by battery state of charge (SOC)
 - Linear relationship between 65-100% SOC
 - Non-Linear <65%
- Aim of hybrid system is to maintain SOC between 50-65% during operation
- When battery SOC is below threshold, fuel cell power output is increased to recharge battery



System Optimisation & Results

Parameter Selection

- 4 parameters chosen to optimise for system and use case
- Measured parameters shown below
- Fuel Cell cost and Battery cost and mass figures obtained from APC roadmap
 - Fuel Cell Cost = 54 \$/kW
 - Battery Cost = 77 \$/kWh
 - Battery Gravimetric Density = 240 Wh/kg
- Fuel Cell mass derived from benchmarking Toyota Mirai and Hyundai Nexo stack system
 - Fuel Cell Gravimetric Density = 1.53 kW/kg
- Performance coefficient created to quantify system performance

| Parameter | Value 1 | Value 2 | Value 3 | Unit |
|-------------------------|---------|---------|---------|------|
| Number of Fuel Cells | 300 | 400 | 500 | / |
| Battery Capacity | 1 | 2 | 3 | kWh |
| Power Split Lower Bound | 0.2 | 0.25 | 0.3 | / |
| Power Split Upper Bound | 0.5 | 0.6 | 0.7 | / |

| Parameter | Abbreviation | Unit |
|-------------------------|-----------------|------|
| Range | Ra | km |
| Fuel Cell System Cost | C _{FC} | \$ |
| Fuel Cell System Mass | m _{FC} | kg |
| Battery Pack Cost | C _B | \$ |
| Battery Pack Mass | m _B | kg |
| Performance Coefficient | S | / |

$$S = \frac{Ra^2}{(m_{FC} + m_B) \cdot (C_{FC} + C_B)}$$

System Optimisation & Results

Optimisation Results

| Parameter | Value | Unit |
|-------------------------|-------|------|
| Number of Fuel Cells | 300 | / |
| Fuel Cell Stack Power | 120 | kW |
| Battery Pack Capacity | 1 | kWh |
| Power Split Lower Bound | 0.3 | / |
| Power Split Upper Bound | 0.6 | / |
| Range | 504 | km |
| Powertrain Mass | 82.6 | kg |
| Powertrain Cost | 6557 | \$ |
| Performance Coefficient | 0.469 | / |

First Optimisation Run

| Parameter | Optimal | Unit |
|-------------------------|---------|------|
| | Value | |
| Number of Fuel Cells | 260 | / |
| Fuel Cell Power | 104 | kW |
| Battery Pack Capacity | 1.6 | kWh |
| Power Split Lower Bound | 0.3 | / |
| Power Split Upper Bound | 0.6 | / |
| Range | 502.8 | km |
| Powertrain Mass | 74.64 | kg |
| Powertrain Cost | 5739.2 | \$ |
| Performance Coefficient | 0.59 | / |

Second Optimisation Run

| Parameter | Value 1 | Value 2 | Value 3 | Value 4 | Value 5 | Value 6 | Unit |
|----------------------|---------|---------|---------|---------|---------|---------|------|
| Number of Fuel Cells | 260 | 270 | 280 | 290 | 300 | 310 | / |
| Battery Capacity | 1 | 1.2 | 1.4 | 1.6 | / | / | kWh |

System Optimisation & Results

Final Results

- Maximum range target: 402km
 - *UITP Taxi Benchmark Study*

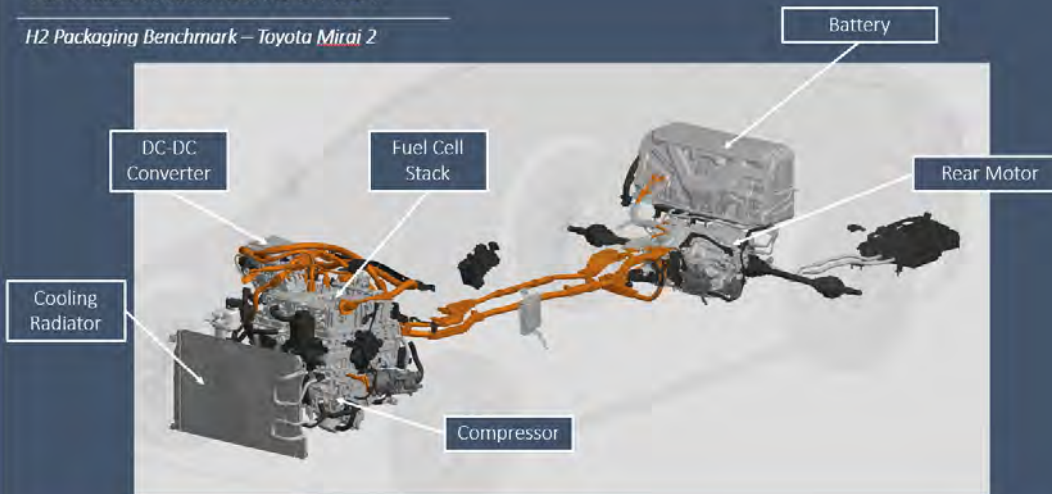
- H2 consumption target: 1kg/100km
 - *FCHJU 2030 SoA Target*

| Parameter | Optimal | |
|-------------------------|---------|------|
| | Value | Unit |
| Number of Fuel Cells | 260 | / |
| Fuel Cell Power | 104 | kW |
| Battery Pack Capacity | 1.6 | kWh |
| Power Split Lower Bound | 0.3 | / |
| Power Split Upper Bound | 0.6 | / |
| Range | 502.8 | km |
| Powertrain Mass | 74.64 | kg |
| Powertrain Cost | 5739.2 | € |
| Performance Coefficient | 0.59 | / |

| Drive Cycle | Parameter | Value | Unit |
|-------------|----------------|-------|----------|
| WLTP 3b | Range | 502.8 | km |
| | H2 Consumption | 0.994 | kg/100km |
| NYCC | Range | 823 | km |
| | H2 Consumption | 0.607 | kg/100km |

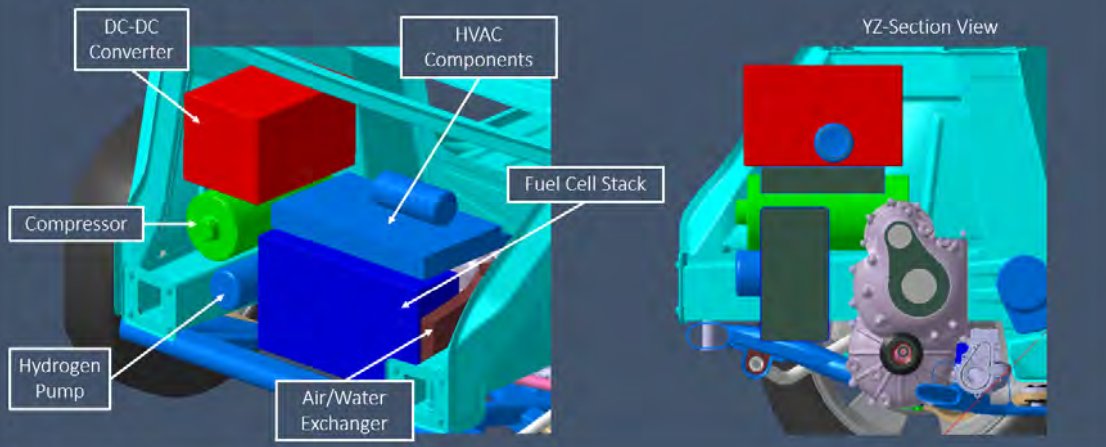
VEHICLE PACKAGING STUDY

H2 Packaging Benchmark – Toyota Mirai 2



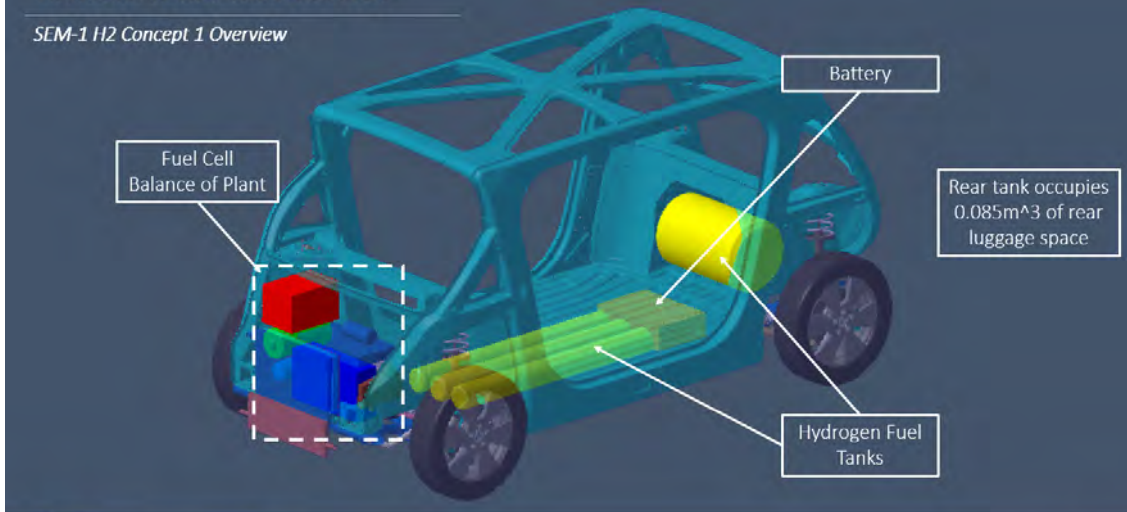
VEHICLE PACKAGING STUDY

SEM-1 H2 Balance of Plant Package



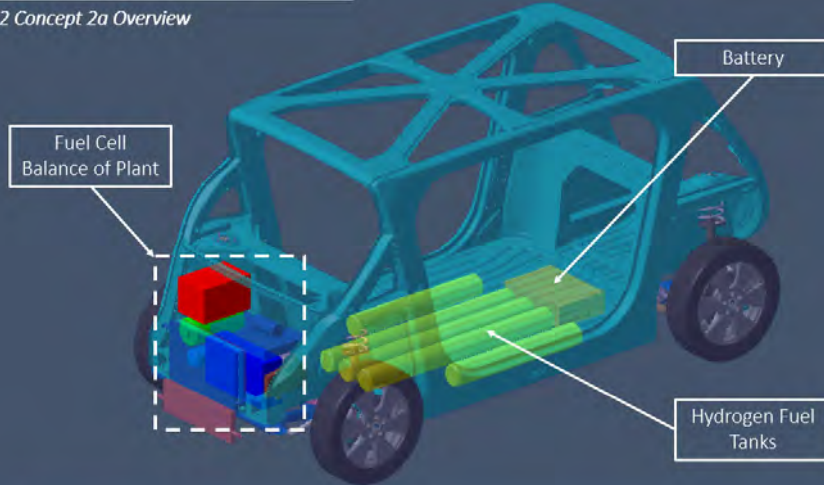
VEHICLE PACKAGING STUDY

SEM-1 H2 Concept 1 Overview



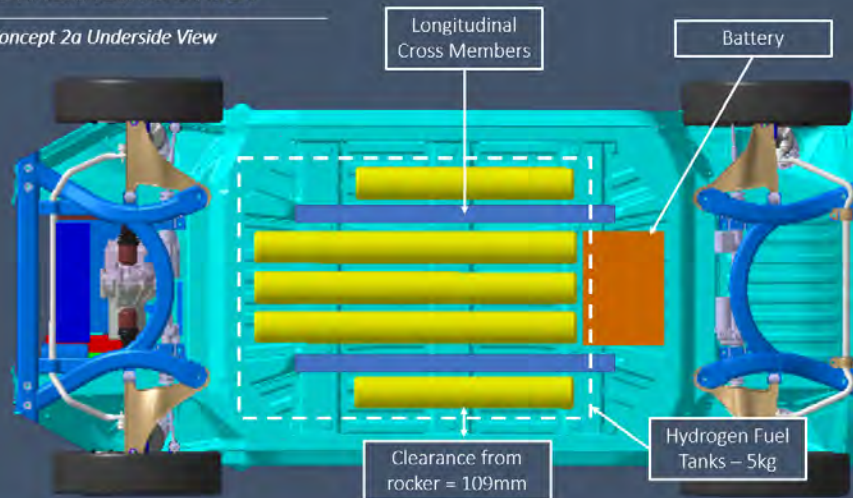
VEHICLE PACKAGING STUDY

SEM-1 H2 Concept 2a Overview



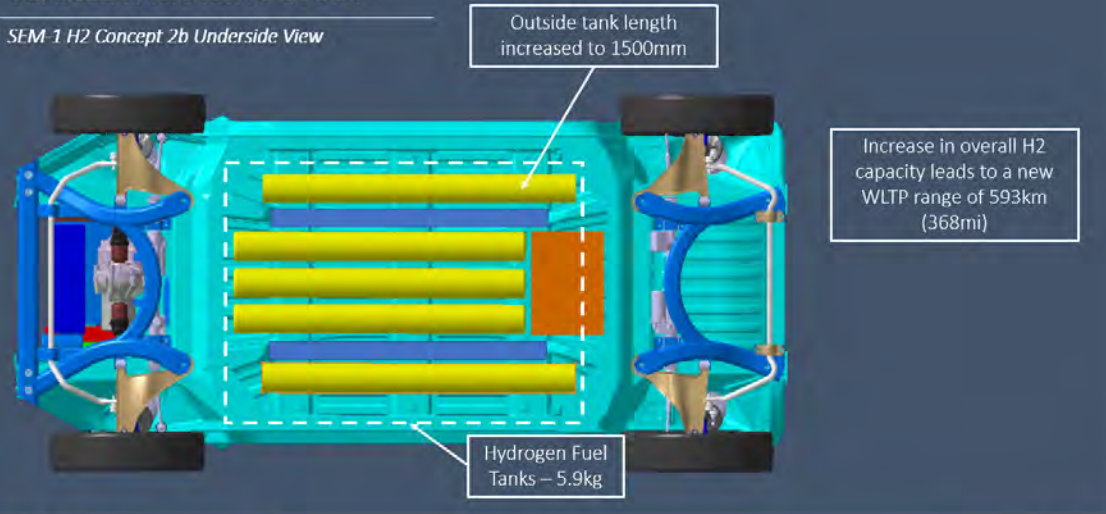
VEHICLE PACKAGING STUDY

SEM-1 H2 Concept 2a Underside View



VEHICLE PACKAGING STUDY

SEM 1 H2 Concept 2b Underside View



Future Work

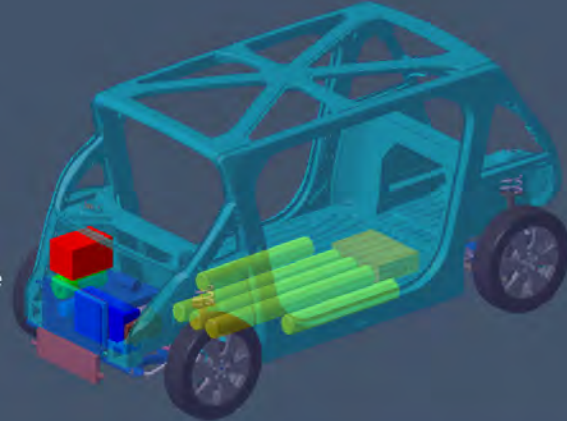
Model Enhancements

SIMULATION MODEL

- Create automated hybrid system optimisation process
- Create secondary power split control strategy
- Implement full battery recharge strategy

CAD PACKAGE

- Further work to understand complete mechanical package in detail
 - i.e. tank packaging, cable and pipe routing



Conclusion

Is an FCHV feasible for a MaaS application?

- Fuel Cell technology is advanced enough to compete with BEVs from a performance perspective
- H2 global infrastructure is too premature to be a feasible option for an autonomous MaaS powertrain in 2030 on a large scale
- Potential for some isolated cases to work in specific cities
 - *i.e. Los Angeles or Tokyo*

12.2 Michigan Technological University – Senior Capstone Project #1: Steel E-Motive Side Door Functionality, Door Hinge Assessment

MTU Senior Capstone Team: Gavin Sheffer, Leander Daavettila, Rob Oestreich, Steven Turnbull, Andrew Mitteer, and Jesse Ebenhoeh

Status

2 Semester program, complete

Introduction / Background

The MTU Senior Capstone Design Team, sponsored by WorldAutoSteel and the Auto/Steel Partnership, was challenged to design a new door hinge for the Steel E-Motive side closure mechanism. The current hinge design was provided as a reference, but a few operational issues were identified for this team's assessment and engineering study.

- The previous hinge design interferes with the all-wheel steering, meaning in emergency situations, passengers could get trapped in the vehicle. For SEM1, it was also observed that when the wheels are turned, they would block the doors from opening fully, constraining passenger exit (Figure 1 below).
- An emergency release mechanism was needed to allow users to escape in the event a crash or electrical failure prevented the doors from opening.
- Power requirements and electric motor sizing for the hinge mechanism needed to be defined.

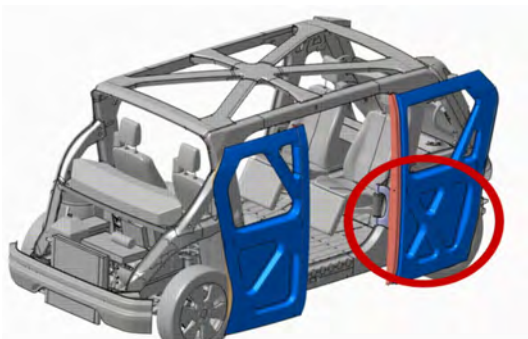




Figure 1: Side door opening constrained by present hinge mechanism and wheel position.

Project Details, Results

MTU’s design solution uses a four-bar linkage hinge design to keep the door parallel to the body of the vehicle to avoid damage to either the door or the body. The team used a 4:1 gear ratio for the drive motor to open the door. Finally, one of the pins in the secondary arm linkage is accessible by passengers and removable, allowing users to manually push the door open in the event of an emergency (see Figure 2).

Their solution includes pressing a button to open and close the door. The stepper motor receives the input from the button and rotates the gears; the gears then rotate the primary arm which drives the door. The primary arm is mounted to the door in two locations with bolts. The secondary arm is added to the mechanism to create a four-bar linkage, which helps maintain door orientation during operation. An emergency release was designed and added to the secondary arm to release the four-bar linkage. This allows the door to swivel around a turned wheel in the event of an emergency.

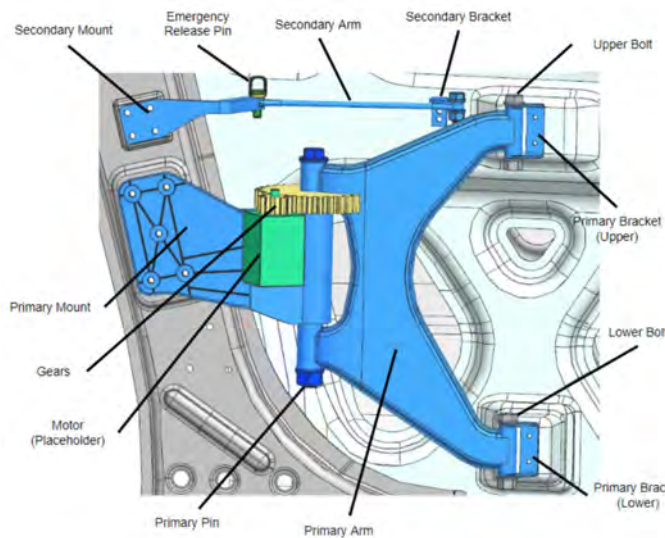


Figure 2: 3D model of the final design less the gear cover for clarity.

The emergency release was designed for safety and manufactur-ability. The emergency release pin was simplified to utilize off-the-shelf pins. A relay is suggested to cut power to the motor and allow the door to be manually pushed open. A gear cover was added for safety to protect the occupants from getting pinched by the gears. To maintain and service the design, each part of the assembly was designed to be attached with threaded fasteners.

A gear drive was created so we could use a more cost-efficient motor. The gear ratio decreased the amount of torque required. The material was chosen based on strength and sustainability.

Conclusions

The CAD geometry and the quarter-scale prototype were able to meet all the engineering requirements and objectives. The CAD model defines the mass and emergency release mechanism, and the kinematics are verified by the quarter-scale prototype. The FEA simulation verified *set and sag* under normal and abusive loading conditions. In identifying specifications required for the full model, the projected production cost for one mechanism is \$471. This includes stamped and cast components, off-the-shelf components such as the stepper motor and fasteners, and the cost of assembly. The team compared using AHSS for the components as opposed to an aluminum alloy. Steel components are stronger, half the price of aluminum, and produce 1/3 of the carbon emissions compared to the same amount of aluminum.

The prototype was 3D printed from PLA plastic at quarter scale. This serves as a model to be shown by Auto/Steel Partnership for future presentations. It was also used to verify the kinematics of the door motion.

12.3 The Ohio State University - Senior Capstone Project #3: Welding Capabilities of a Five Sheet Stack-up of High-Strength Steels Using Resistance Spot Welding

OSU Senior Welding Engineering Capstone Team: Rachel Blankenship, Koushin Jacquet, Hunter Flading

Status

2 Semester program – complete

Introduction/Background

WorldAutoSteel sponsored The Ohio State University’s Senior Capstone Projects to confirm viability of a complex RSW joint comprising of 5 individual sheet layers for Mobility as a Service (MaaS) vehicles. Our hope is that this 5 layer stack-up weld project will demonstrate technical feasibility that allows manufacturers to leverage current manufacturing infrastructure, lowering investment costs and improving sustainability.

AHSS are widely used in the automotive industry for resistance spot welding (RSW); however, they come with many challenges. These include susceptibility to hydrogen cracking, martensite formation during rapid cooling, and porosity. The same weld parameters that are successfully used for mild steel assembly applications must be adapted with higher levels of quality control to achieve required weld integrity and production reliability – but these weld conditions and QC practices are now well-understood and implemented in industry.

The Steel E-Motive vehicles are composed of welds made using spot welding, laser welding, and structural adhesive. Steel grades being used in the vehicle include press hardened steels (PHS), martensitic steels (MS), 3rd generation steels and dual phase steels (DP).

The welded joint under consideration is in the front extended passenger protection zone of the car, specifically the vertical dash brace and upper glance beam reaction area. The various material grades include MS1200, PHS2000, and MS2000 with gauges of 1 to 2 mm and coatings of EG and AS150 (for the PHS grades). Current practice for these types of joints is to create a singular spot weld with the bottom 3 sheets, which would include the strut cross member closing plate, the glance beam lower reaction LH, and the vertical dash brace upper front LH. This 3-sheet stack (Group 2) would then be welded to a 2-sheet stack (Group 1) composed of the top two layers of the 5 stack, the strut cross member front and the glance beam upper reaction LH. The cross section of this joint as well as its position within the vehicle can be seen in Figure 1 below.

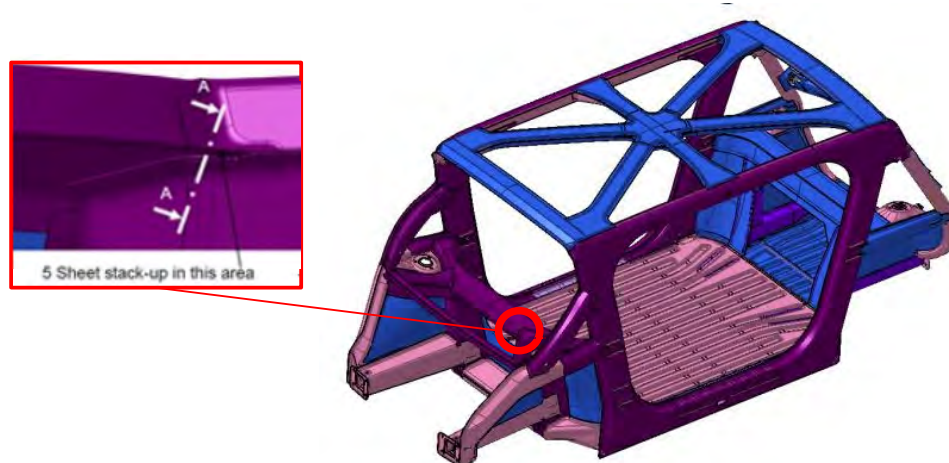


Figure 1: SEM1 body structure and front extended passenger protection zone, showing joint location

Project Details, Results

This team’s plan was to create a single 5-t stack-up RSW joint total stack thickness = 6 mm (see Table 1). Project Objectives:

- 1) Determine optimal RSW parameters for a 5-T stack-up.

- 2) Determine whether 5-stack resistance spot weld is possible, or if a 2 plus 3 stack resistance spot weld is needed.

| Group Number | Stack-up Position | Part Number | Name | Grade | Gauge (mm) | Coating |
|--------------|-------------------|-------------|------------------------------------|--------------|----------------------|---------|
| 1 | Top | 03640760 | Glance Beam Upper Reaction LH | MS 1200/1470 | 1.0 spec; 1.2 actual | EG |
| 1 | 2 | 03640758 | Strut Crossmember Front | PHS2000 | 1.0 spec, 1.2 actual | AS150 |
| 2 | 3 | 03671385 | Vertical Dash Brace Upper Front LH | PHS2000 | 2.0 | AS150 |
| 2 | 4 | 03642244 | Glance Beam Lower Reaction LH | PHS2000 | 1.0 spec, 1.2 actual | AS150 |
| 2 | Bottom | 03642357 | Strut Cross Member Closing Plate | MS2000 | 1.0 | EG |

Table 1: Individual components, steel grades in 5-t Stack-up.

Steps

Task 1 - Our team first conducted a literature search, where previous experiments and projects were studied to acquire a background on the 5T stack-up. These included procedures and results of 3T and 4T stack-ups performed previously by other scholars (in our research found no current examples of successful spot welding of 5 sheets simultaneously).

Next, we referenced previous work by WorldAutoSteel and used lessons learned to guide parameter selection decisions for our welding trials.

Task 2 - We acquired materials from WorldAutoSteel members, who sent 2 types of materials with varying thicknesses for this project. The joint in question included MS1200, PHS2000, and MS2000 of varying coatings and thicknesses. Members were able to supply PHS2000 was provided with an AS150 coating and 2 sheet thicknesses = 1.2 mm and 2.0 mm, and MS (Martensitic) 1500 steel, with EG coating and 1.2 mm thickness.

Expert conclusion is that the thickness variation was less important than the symmetry of the joint, and the metallurgical chemistries which were quite similar for grades belonging to the same product family.

Task 3 - The parameters for the welding process were determined using Simufact Welding 2021, a welding simulation software. The literature found in Task 1 was used as a basis for welding parameter selection and lab trials.

Task 4 - Welding Trials and Inspection. Using the Obara MFDC resistance spot welder and parameters determined in Task 3, various welds were conducted and evaluated via destructive testing, to determine optimal parameterization to meet target weld criteria. Samples were mounted and prepared for microscopic visual analysis.

For experimental purposes, RSW welding trials were performed with five flat coupons representing the stack-up materials, thicknesses and coatings. The benefits of welding all 5 coupons at once versus welding 2 separate stacks and then joining those together include lower power, cost, increased efficiency and decreased welding time. Additional benefits include less electrode wear between welds and less time cleaning electrodes due to a singular weld. The penetration also gradually increases with each pulse to the weld.

Task 5 - Data Analysis. Macroscopic pictures were taken of the samples and evaluated to compare weld nugget size, porosity, deformation, cracking, and indentation.

Conclusions

4. A five-layer stack-up spot weld can be successfully created with advanced high strength steels using a range in number of pulses, currents, forces, and times, indicating sufficient process robustness.
5. Simufact Welding successfully models weld nugget development and final weld size, that narrows parameter selection avoiding costly trial and error practices.
6. Using a pulsation current schedule with descending current pulses was just as successful in creating welds as using the same current level pulses. This was perhaps assisted by joint symmetry.
7. A single spot weld for a five-layer stack-up has greater time and cost efficiency than welding a two-layer and a three-layer stack-up into a combined five layers.

12.4 Michigan Tech University – Senior Capstone Project #2: Adaptation of SEM2 from People Mover to Commercial Delivery Vehicle

MTU Senior Capstone Team: Kyle Davis, Nick Palatka, Evan Larson, Logan Pietila, Blake Pietila, Tej Bergin

Status

2 Semester program, 1 semester complete

Introduction / Background

This Senior Capstone Design Team was sponsored by World Auto Steel and Ricardo Engineering (UK engineering and consultancy firm), to develop a solution for expanding the servicability within a 24-hour period for Steel E-Motive 2 (SEM2), their extra-urban autonomous electric vehicle concept. The SEM2 vehicle is a stretched 6-passenger commuter targeting longer journeys, with expanded occupancy or additional luggage capacity. In non-commuting hours, the Mobility Fleet Operator would like to continue revenue generation by quickly adapting the vehicle for commercial delivery services. Currently, occupant packaging contrasts with the storage requirements of a package delivery vehicle, thus the SEM2 vehicle's can only be utilized to either transport people or goods. Our project objective is to develop interior seating that enables quick removal and adaptation to an optimal delivery van.

Project Details, Results

From the requirements outlined by WorldAutoSteel, the team focused further research on interior vehicle and seat design. Modern delivery methods, delivery vehicle layout, passenger vehicle seat safety requirements, and seat folding or locking mechanisms were sub-categories of research that hold value within the scope of the project. The main takeaways from our research include different pin and slot mechanisms that are incorporated into a preliminary design for a quick release system. We also benchmarked a vertical folding seat based on International Harvester designs and we have modified these for application to the SEM2 vehicle's specific needs.

The quick release system will benefit MSP technicians responsible for performing the conversion of multiple SEM2 vehicles in its fleet at their depot during off-commuting hours. In under 30 minutes, the fleet operators (MSP) must be able to convert the vehicle from a vehicle stressing passenger comfort to an autonomous delivery van and vice versa, using common tools and techniques while meeting all necessary safety standards and regulations. The fleet operators that provide the robo-taxi service are not expected to see any major disruption in ride services, however they may observe improved utilization and profitability if they use the vehicles for package delivery.

Our current engineering requirements include:

- maximum total payload of 675 kg (6 passengers and 6 seats)
- individual seat weight of 30kg (6 seats)
- total volumetric storage space requirement of 1 cubic meter
- total seating width equal to or less than 1220 mm
- changeover time less than 30 minutes and
- minimal number of changeover movements (fewer than 50 for the complete conversion from passenger to cargo transportation)

Concept Solutions

A graphical rendering of our selected system-level concept is provided in Figure 1. This design showcases two pairs of T-shaped rails placed in the fore-aft direction of the vehicle. These T-Rails are compatible with a slider system that connects to the bottom of each seat leg. A sliced view of the rails and slider system are seen in Figure 2. On each slider, in the port-starboard direction, a circular slot approximately 20 mm in diameter (dependent on pin material and size) is cut-out to allow for the insertion of a spring-loaded steel pin. This pin engages both the slider as well as an equivalent slot cut into the rail, to allow the seat to be locked into a specified position along the rail (Figure 3). The rails run the full length of the vehicle's interior, and allow for 3

seating modules to be placed and locked into a position. Insertion and removal of the slider on the rails will be possible through narrow sections on the rails where the slider can be vertically lifted or placed on the rail system. In order to “drop the seats” onto the rails without manual lifting, the team has designed an accompanying “pallet jack accessory” that will be able to hold, transport, and lower the seating modules onto the rail system through the use of an industry standard pallet jack with a lifting range of 6 inches. The pallet jack accessory can be seen in Figure 1, item C.

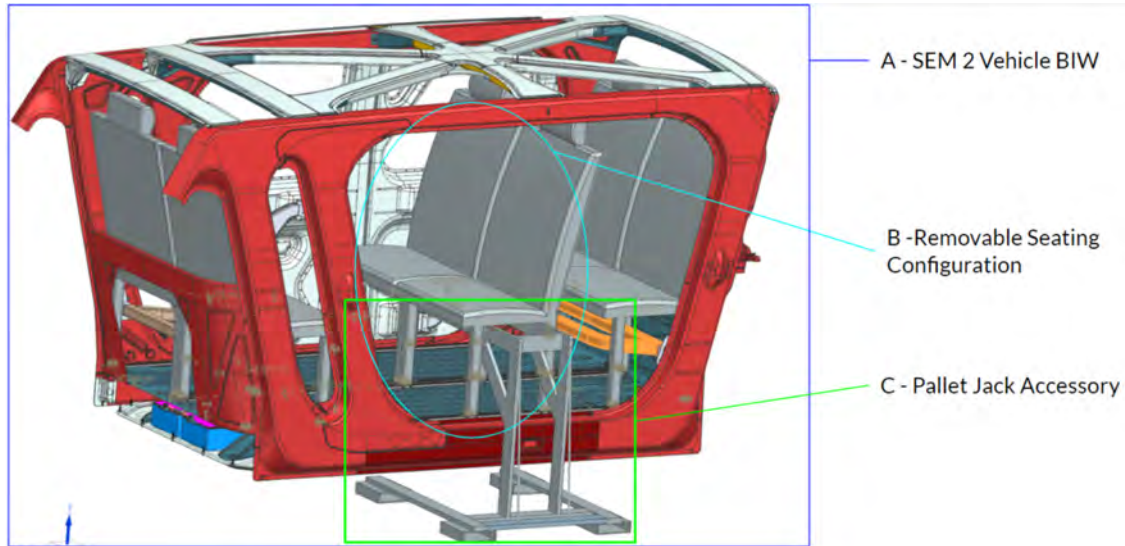
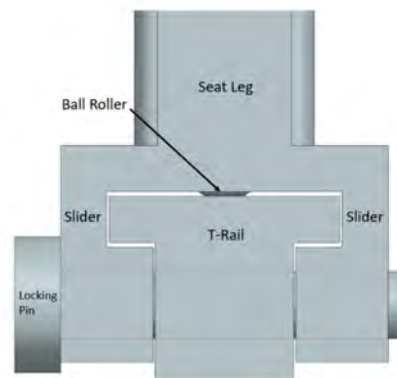


Figure 1: System level concept – rapid adaptation of SEM2 to autonomous delivery services

The slider mechanism, seen in Figure 2, will house a ball roller bearing that allows for the translational motion along the rail to slide the seats into position.

The roller bearing bolts into the slider mechanism allowing for easy replacement. The T-Rails are then bolted to the structural members of the vehicle, where engineers from WorldAutoSteel have confidence the design can withstand any and all static and dynamic loading scenarios. The rails will feature a narrow section near the center allowing for the removal of the seating module. This narrow section is tapered to allow the slider to be “homed” and slid into its final, fixed position.

Figure 2: T-rail system for fast removal of seats.



The arms of the pallet jack system reach out to allow a set of seats to be placed on the rail at one time. The pallet jack will drive through the open slots on the ground, lift the seats to the vehicle, align itself using markings on the vehicle and drop the seats into the rails where they can then be manually moved to their correct position. The system is designed to remove and insert these seats as fast as possible, while exerting minimum effort that might stress the MSP technician. With ease of use and safety being the critical elements of every project, we’ve removed manual lifting from the equation, as well as ensured a factor of safety of 2 is kept for all required crash loads under our current design.

Many integral components are COTS parts and can be bought in bulk to use for mass production as well as reserved parts, helping maintain low cost of ownership for the MSP. The components that are not COTS items, such as the rails and sliders, can be manufactured using high volume, low cost fabrication techniques such as stamping. Assembly of the system will be just as easy,

as all components are connected together using industry standard fastening and welding techniques.

Conclusions

Validation – to confirm the ease of changeover and our objectives, a simulation was conducted to estimate the time and difficulty of changing from delivery service to people transporter. In a warehouse setting, a location was established as the “vehicle maintenance spot”. We developed a “seat module storage area” approximately 30 meters away. In this simulation, the following steps were conducted:

1. A pallet jack was pre-staged near the vehicle, signaling the beginning of the conversion and timer.
2. A technician walked 30 m to the seating storage area and picked up the seats via accessory.
3. They carried seats back over to the vehicle and aligned the pallet jack with the vehicle door.
8. Lowered seats onto the rail system and removed the pallet jack accessory from the
1. vehicle.
9. Slid the seats into the correct position and inserted the locking pin into its slot.

This simulation was repeated two more times to replicate the insertion of all six seats. To remove the seats, the steps would be reversed. After five runs of this simulation, ensuring adequate time to perform each simulated step, the average time to complete the simulation was 5 minutes 17 seconds with a total of 24 required movements.

These values were well within the 30 minute and 50 movement objectives. For further validation, we'll repeat these simulations in the opposite direction, ie removing the seats to transform to the delivery van. Finally, in Phase 2 of this project we'll continue to evaluate seat frame / track componentry to ensure robustness and durability in the proposed solutions.

Appendices

Appendix 1.1 SEM1 Body in White Bill of Materials

Appendix 1.2 SEM1 Battery Bill of Materials

Appendix 1.3 SEM1 scissor doors Bill of Materials

Appendix 1.4 Coach door Bill of Materials

Appendix 1.5 SEM1 BIW Alternative grades Bill of Materials

Appendix 1.6 SEM2 Body in White Bill of Materials

Appendix 2.1 Panel formability simulation results

Appendix 2.2 SEM1 BIW section profiles

Appendix 3 Body in White Assemblies

Appendix 4 Full size images/figures

Appendix 1.1 SEM1 Body in White Bill of Materials

| CAD PART NUMBER | PART NAME | Gauge thickness (mm) | Material Grade (code) | Advanced High Strength Steel Category | Part mass (kg) | Fabrication Process |
|-----------------|--|----------------------|---|---------------------------------------|----------------|---------------------|
| 03272922 | ROCKER HEX ABSORBER LH | 0.7 | CR420Y780T-DP | Dual Phase | 0.70 | Roll form |
| 3438889 | A POST INNER LH | 1.2 | PHS-CR2000T-MB | Press Hardened Steel | 5.06 | Hot form |
| 03440399 | C POST INNER LH | 1.0 | PHS-CR1500T-MB | Press Hardened Steel | 4.02 | Hot form |
| 3451131 | ROCKER INNER LH | 1.5 | CR1550Y2000T-MS | Martensitic | 7.40 | Cold stamp |
| 3451226 | ROCKER INNER REINFORCEMENT LH | 1.0 | CR420Y780T-DP | Dual Phase | 1.06 | Cold stamp |
| 3451542 | ROOF SIDE RAIL INNER LH | 0.8 | PHS-CR1500T-MB | Press Hardened Steel | 2.15 | Hot form |
| 3470012 | MID ROOF BOW MOUNT LH | 0.8 | CR700Y980T-DP | Dual Phase | 0.41 | Cold stamp |
| 03503803 | A POST INNER REINFORCEMENT LH | 0.8 | CR1350Y1700T-MS | Martensitic | 1.46 | Cold stamp |
| 3510150 | C POST INNER REINFORCEMENT LH | 0.8 | CR860Y1180T-DP | Dual Phase | 1.36 | Cold stamp |
| 03553241 | A POST INNER RH | 1.2 | PHS-CR2000T-MB | Press Hardened Steel | 5.06 | Hot form |
| 3553252 | FRONT INNER ROOF HEADER GUSSET MOUNT RH | 1.0 | CR700Y980T-DP | Dual Phase | 1.26 | Cold stamp |
| 03553334 | C POST INNER RH | 1.0 | PHS-CR1500T-MB | Press Hardened Steel | 4.02 | Hot form |
| 03553361 | ROCKER INNER RH | 1.5 | CR1550Y2000T-MS | Martensitic | 7.40 | Cold stamp |
| 03553374 | ROCKER INNER REINFORCEMENT RH | 1.0 | CR420Y780T-DP | Dual Phase | 1.06 | Cold stamp |
| 03553378 | ROCKER HEX ABSORBER RH | 0.7 | CR420Y780T-DP | Dual Phase | 0.70 | Roll form |
| 03553379 | ROOF SIDE RAIL INNER RH | 0.8 | PHS-CR1500T-MB | Press Hardened Steel | 2.15 | Hot form |
| 3553390 | REAR INNER ROOF-HEADER GUSSET MOUNT RH | 0.8 | HSLA490/600 | High Strength Low Alloy | 1.26 | Cold stamp |
| 03553397 | A POST INNER REINFORCEMENT RH | 0.8 | CR1350Y1700T-MS | Martensitic | 1.46 | Cold stamp |
| 03553400 | C POST INNER REINFORCEMENT RH | 0.8 | CR860Y1180T-DP | Dual Phase | 1.36 | Cold stamp |
| 03559985 | MID ROOF BOW MOUNT RH | 0.8 | CR700Y980T-DP | Dual Phase | 0.41 | Cold stamp |
| 3572146 | INNER ROCKER BULKHEAD LH | 1.0 | CR420Y780T-DP | Dual Phase | 0.11 | Cold stamp |
| 03573480 | INNER ROCKER BULKHEAD RH | 1.0 | CR420Y780T-DP | Dual Phase | 0.11 | Cold stamp |
| 03598246 | REAR OUTER ROOF HEADER GUSSET MOUNT LH | 0.8 | CR490Y/600T-LA | High Strength Low Alloy | 0.14 | Cold stamp |
| 03599223 | REAR INNER ROOF HEADER GUSSET MOUNT LH | 0.8 | CR490Y/600T-LA | High Strength Low Alloy | 0.67 | Cold stamp |
| 03470750 | FRONT INNER ROOF HEADER GUSSET MOUNT LH | 1.0 | CR700Y980T-DP | Dual Phase | 0.63 | Cold stamp |
| 03620666 | REAR OUTER ROOF HEADER GUSSET MOUNT RH | 0.8 | CR550Y/620T-LA | High Strength Low Alloy | 0.14 | Cold stamp |
| 3629368 | ROCKER FRONT CAP INNER LH | 1.0 | CR1200Y1470T-MS | Martensitic | 0.14 | Cold stamp |
| 03636509 | FRONT OUTER ROOF HEADER GUSSET MOUNT LH | 1.0 | CR700Y980T-DP | Dual Phase | 0.22 | Cold stamp |
| 03636520 | FRONT OUTER ROOF HEADER GUSSET MOUNT RH | 1.0 | CR700Y980T-DP | Dual Phase | 0.22 | Cold stamp |
| 03636521 | ROCKER REAR CAP INNER LH | 1.0 | CR550Y/620T-LA | High Strength Low Alloy | 0.14 | Cold stamp |
| 03636524 | ROCKER REAR CAP INNER RH | 1.0 | CR550Y/620T-LA | High Strength Low Alloy | 0.14 | Cold stamp |
| 03647858 | ROCKER FRONT CAP INNER RH | 1.0 | CR1200Y1470T-MS | Martensitic | 0.14 | Cold stamp |
| 03694699 | OUTER RING TWB LH | TWB 1.2, 1.0 | TWB_PHS-CR2000T-MB, 1.2, PHS-CR1000T-MB Upp | Press Hardened Steel | 16.69 | Hot form |
| 03703692 | SLEEVE FRONT LH | SOLID | NA EN8 | Mild Steel | 0.35 | (solid part) |
| 03703694 | SLEEVE FRONT RH | SOLID | NA EN8 | Mild Steel | 0.35 | (solid part) |
| 3703801 | A POST INNER REINFORCEMENT UPPER LH | 1.5 | CR800Y1180T-DP | Dual Phase | 1.46 | Cold stamp |
| 03703802 | A POST INNER REINFORCEMENT UPPER RH | 1.5 | CR800Y1180T-DP | Dual Phase | 1.46 | Cold stamp |
| 03707049 | A POST INNER REINFORCEMENT UPPER REAR LH | 1.5 | CR800Y1180T-DP | Dual Phase | 1.13 | Cold stamp |
| 03707053 | A POST INNER REINFORCEMENT UPPER REAR RH | 1.5 | CR800Y1180T-DP | Dual Phase | 1.13 | Cold stamp |
| 03707551 | SLEEVE REAR LH | SOLID | NA EN8 | Mild Steel | 0.33 | (solid part) |
| 03707552 | SLEEVE REAR RH | SOLID | NA EN8 | Mild Steel | 0.33 | (solid part) |
| 03709256 | OUTER RING TWB RH | TWB 1.2, 1.0 | TWB_PHS-CR2000T-MB, 1.2, PHS-CR1000T-MB Upp | Press Hardened Steel | 16.69 | Hot form |
| 03721342 | BULKHEAD_C_PILLAR_MIDDLE LH | 1.5 | CR1550Y2000T-MS | Martensitic | 0.19 | Cold stamp |
| 03722991 | BULKHEAD_C_PILLAR_LOWER LH | 1.5 | CR1550Y2000T-MS | Martensitic | 0.19 | Cold stamp |
| 03725754 | BULKHEAD_C_PILLAR_MIDDLE RH | 1.5 | CR1550Y2000T-MS | Martensitic | 0.19 | Cold stamp |
| 03725762 | BULKHEAD_C_PILLAR_LOWER RH | 1.5 | DP 800/1180 | Dual Phase | 0.19 | Cold stamp |
| 03730371 | BULKHEAD_A_POST REINFORCEMENT UPPER LH | 1.5 | CR1550Y2000T-MS | Martensitic | 0.24 | Cold stamp |
| 03730603 | BULKHEAD_A_POST REINFORCEMENT LOWER LH | 1.5 | CR1550Y2000T-MS | Martensitic | 0.24 | Cold stamp |
| 03730608 | BULKHEAD_A_POST REINFORCEMENT UPPER RH | 1.5 | CR1550Y2000T-MS | Martensitic | 0.24 | Cold stamp |
| 03730609 | BULKHEAD_A_POST REINFORCEMENT LOWER RH | 1.5 | CR1550Y2000T-MS | Martensitic | 0.24 | Cold stamp |
| 3747655 | OUTER RING REINF. PLATE LH | 2.0 | CR340Y590T-DP | Dual Phase | 0.08 | Cold stamp |
| 03748482 | INNER ROCKER BULKHEAD LH | 1.0 | CR420Y780T-DP | Dual Phase | 0.11 | Cold stamp |
| 03749650 | INNER ROCKER BULKHEAD RH | 1.0 | CR420Y780T-DP | Dual Phase | 0.11 | Cold stamp |
| 03750014 | OUTER RING REINF. PLATE RH | 2.0 | CR340Y590T-DP | Dual Phase | 0.08 | Cold stamp |
| 3820779 | REINFORCEMENT LATCH RIGHT LH | 1.5 | PHS-CR1000T-MB | Press Hardened Steel | 0.56 | Hot form |
| 3824181 | REINFORCEMENT LATCH LEFT LH | 1.5 | PHS-CR1000T-MB | Press Hardened Steel | 0.55 | Hot form |
| 03842798 | REINFORCEMENT LATCH LEFT RH | 1.5 | PHS-CR1000T-MB | Press Hardened Steel | 0.55 | Hot form |
| 03842803 | REINFORCEMENT LATCH RIGHT RH | 1.5 | PHS-CR1000T-MB | Press Hardened Steel | 0.56 | Hot form |
| 3451626 | FRONT HEADER OUTER A-SURFACE | 0.6 | CR260Y/370T-BH | Bake Hardenable | 1.15 | Cold stamp |
| 03451793 | FRONT HEADER INNER | 0.8 | CR780Y980T-CP | Complex Phase | 1.67 | Roll stamp |
| 03461692 | MID ROOF BOW OUTER A-SURFACE | 0.6 | CR260Y/370T-BH | Bake Hardenable | 1.05 | Cold stamp |
| 03462738 | MID ROOF BOW INNER | 0.8 | CR820Y1180T-RA | Retained Austenite | 1.77 | Roll stamp |
| 03475937 | DIAGONAL OUTER A-SURFACE PANEL FRONT LH | 0.6 | CR260Y/370T-BH | Bake Hardenable | 0.78 | Cold stamp |
| 03476375 | REAR HEADER OUTER A-SURFACE | 0.6 | CR260Y/370T-BH | Bake Hardenable | 1.21 | Cold stamp |
| 03476383 | DIAGONAL OUTER A-SURFACE PANEL REAR LH | 0.6 | CR260Y/370T-BH | Bake Hardenable | 0.81 | Cold stamp |
| 03476397 | REAR HEADER INNER | 0.8 | CR780Y980T-CP | Complex Phase | 1.69 | Roll stamp |
| 03484374 | DIAGONAL INNER PANEL REAR LH | 0.7 | CR550Y/620T-LA | High Strength Low Alloy | 1.35 | Cold stamp |
| 03496795 | MID INTERSECTION OUTER A-SURFACE PANEL | 0.6 | CR260Y/370T-BH | Bake Hardenable | 0.63 | Cold stamp |
| 03512374 | MID INTERSECTION INNER PANEL | 0.5 | CR260Y/370T-BH | Bake Hardenable | 0.62 | Cold stamp |
| 03483873 | DIAGONAL INNER PANEL FRONT LH | 0.7 | CR550Y/620T-LA | High Strength Low Alloy | 1.29 | Cold stamp |
| 03512803 | DIAGONAL OUTER A-SURFACE PANEL FRONT RH | 0.6 | CR260Y/370T-BH | Bake Hardenable | 0.78 | Cold stamp |
| 03512805 | DIAGONAL INNER PANEL FRONT RH | 0.7 | CR550Y/620T-LA | High Strength Low Alloy | 1.29 | Cold stamp |
| 03512806 | DIAGONAL OUTER A-SURFACE PANEL REAR RH | 0.6 | CR260Y/370T-BH | Bake Hardenable | 0.81 | Cold stamp |
| 03512808 | DIAGONAL INNER PANEL REAR RH | 0.7 | CR550Y/620T-LA | High Strength Low Alloy | 1.35 | Cold stamp |
| 03476381 | LONGITUDINAL REAR RAIL OUTER LH | TWB | TWB_1.6_CR820Y1180T-RA_1.4_CR600Y980T-RA | Retained Austenite | 1.51 | Cold stamp |
| 03476382 | LONGITUDINAL REAR RAIL INNER LH | TWB | TWB_1.6_CR820Y1180T-RA_1.4_CR600Y980T-RA | Retained Austenite | 1.56 | Cold stamp |
| 03477701 | LONGITUDINAL REAR RAIL INNER RH | TWB | TWB_1.6_CR820Y1180T-RA_1.4_CR600Y980T-RA | Retained Austenite | 1.51 | Cold stamp |
| 03477703 | LONGITUDINAL REAR RAIL OUTER RH | TWB | TWB_1.6_CR820Y1180T-RA_1.4_CR600Y980T-RA | Retained Austenite | 1.51 | Cold stamp |
| 03484382 | D POST LH | 0.8 | CR400Y690T-RA | Retained Austenite | 2.05 | Hydroform |
| 3486016 | STRUT TOWER REAR LH | 1.0 | CR350Y/450T-LA | High Strength Low Alloy | 2.13 | Cold stamp |
| 3486032 | STRUT TOP REAR LH | 2.4 | CR340Y590T-DP | Dual Phase | 1.64 | Cold stamp |
| 3491092 | D POST INNER UPPER LH | 0.8 | CR340Y590T-DP | Dual Phase | 0.42 | Cold stamp |
| 3553188 | STRUT CROSS MEMBER LOWER REAR | 1.0 | CR1200Y1470T-MS | Martensitic | 2.75 | Cold stamp |
| 03553189 | STRUT CROSS MEMBER REAR UPPER | 1.0 | CR1200Y1470T-MS | Martensitic | 1.94 | Cold stamp |
| 03553338 | STRUT TOWER REAR RH | 1.0 | CR350Y/450T-LA | High Strength Low Alloy | 2.13 | Cold stamp |
| 03553340 | STRUT TOP REAR RH | 2.4 | CR340Y590T-DP | Dual Phase | 1.64 | Cold stamp |
| 03553521 | TORQUE BOX INNER UPPER REAR LH | 1.0 | CR400Y780T-RA | Retained Austenite | 0.78 | Cold stamp |
| 03553522 | TORQUE BOX INNER UPPER REAR RH | 1.0 | CR400Y780T-RA | Retained Austenite | 0.78 | Cold stamp |
| 3555308 | FIVE BAR INNER | 0.8 | CR900Y1180T-CP | Complex Phase | 0.96 | Cold stamp |
| 03557786 | D POST RH | 0.8 | CR400Y690T-RA | Retained Austenite | 2.05 | Hydroform |
| 03557884 | D POST INNER UPPER RH | 0.8 | CR340Y590T-DP | Dual Phase | 0.42 | Cold stamp |
| 3558422 | UPPER RAIL INNER REAR RH | 0.8 | CR350Y/450T-LA | High Strength Low Alloy | 0.84 | Cold stamp |
| 03558955 | UPPER RAIL OUTER REAR RH | 1.2 | CR350Y/450T-LA | High Strength Low Alloy | 1.25 | Cold stamp |

| CAD PART NUMBER | PART NAME | Gauge thickness (mm) | Material Grade (code) | Advanced High Strength Steel Category | Part mass (kg) | Fabrication Process |
|-----------------|--|----------------------|--|---------------------------------------|----------------|---------------------|
| 03560014 | REAR SUBFRAME BUSHMOUNT FRT RH | EN8 | EN8 | Mild Steel | 0.36 | (solid part) |
| 03560015 | REAR SUBFRAME BUSHMOUNT RR LH | EN8 | EN8 | Mild Steel | 0.36 | (solid part) |
| 03560016 | REAR SUBFRAME BUSHMOUNT RR RH | EN8 | EN8 | Mild Steel | 0.36 | (solid part) |
| 3559093 | BUMPER BEAM INTERFACE PLATE REAR LH | 1.8 | CR860Y1180T-DP | Dual Phase | 0.31 | Cold stamp |
| 03570677 | BUMPER BEAM INTERFACE PLATE REAR RH | 1.8 | CR860Y1180T-DP | Dual Phase | 0.32 | Cold stamp |
| 03572151 | FIVE BAR OUTER | 1.8 | CR420Y780T-DP | Dual Phase | 3.93 | Cold stamp |
| 3593060 | VERTICAL DASH BRACE UPPER REAR LH | 1.6 | CR820Y1180T-RA | Retained Austenite | 2.32 | Cold stamp |
| 03593521 | VERTICAL DASH BRACE UPPER REAR RH | 1.6 | CR820Y1180T-RA | Retained Austenite | 2.32 | Cold stamp |
| 03596982 | REAR BULKHEAD | TWB 1.0, 0.8 | TWB_1.0_CR1200Y1470T-MS, 0.8_CR1000Y1470T-MS | Martensitic | 4.57 | Cold stamp |
| 03596995 | REAR COMPARTMENT PAN LOWER | 0.5 | CR350Y/450T-LA | High Strength Low Alloy | 2.61 | Cold stamp |
| 3630350 | VERTICAL DASH BRACE LOWER OUTER REAR LH | 1.0 | CR820Y1180T-RA | Retained Austenite | 0.89 | Cold stamp |
| 03630351 | VERTICAL DASH BRACE LOWER INNER REAR LH | 1.0 | CR820Y1180T-RA | Retained Austenite | 0.73 | Cold stamp |
| 03633267 | BULKHEAD SUBFRAME BUSH LH | 1.0 | CR350Y/450T-LA | High Strength Low Alloy | 0.06 | Cold stamp |
| 03633268 | BULKHEAD SUBFRAME BUSH RH | 1.0 | CR350Y/450T-LA | High Strength Low Alloy | 0.06 | Cold stamp |
| 03634578 | VERTICAL DASH BRACE LOWER OUTER REAR RH | 1.0 | CR820Y1180T-RA | Retained Austenite | 0.89 | Cold stamp |
| 03634581 | VERTICAL DASH BRACE LOWER INNER REAR RH | 1.0 | CR820Y1180T-RA | Retained Austenite | 0.73 | Cold stamp |
| 3716555 | VERTICAL DASH BRACE UPPER REAR LH | 1.8 | CR1200Y1470T-MS | Martensitic | 0.22 | Cold stamp |
| 03716556 | VERTICAL DASH BRACE UPPER REAR RH | 1.8 | CR1200Y1470T-MS | Martensitic | 0.22 | Cold stamp |
| 3736010 | BRACKET COACH DOOR UPPER LH | 1.5 | CR350Y/450T-LA | High Strength Low Alloy | 0.72 | Cold stamp |
| 03736011 | BRACKET COACH DOOR UPPER RH | 1.5 | CR350Y/450T-LA | High Strength Low Alloy | 0.05 | Cold stamp |
| 3736543 | BRACKET STABILUS LH | 1.5 | CR350Y/450T-LA | High Strength Low Alloy | 0.03 | Cold stamp |
| 03736547 | BRACKET STABILUS RH | 1.5 | CR350Y/450T-LA | High Strength Low Alloy | 0.03 | Cold stamp |
| 3750809 | TORQUE BOX REAR LH | 1.5 | CR400Y780T-RA | Retained Austenite | 1.65 | Cold stamp |
| 03753560 | COACH DOOR LATERAL BAR | 0.7 | CR350Y/450T-LA | High Strength Low Alloy | 1.82 | Cold stamp |
| 03753727 | COACH DOOR LATERAL BAR REINFORCEMENT IN | 0.7 | CR350Y/450T-LA | High Strength Low Alloy | 0.20 | Cold stamp |
| 03753729 | COACH DOOR LATERAL BAR REINFORCEMENT IN | 0.7 | CR350Y/450T-LA | High Strength Low Alloy | 0.20 | Cold stamp |
| 03753730 | COACH DOOR LATERAL BAR REINFORCEMENT OL | 0.8 | CR350Y/450T-LA | High Strength Low Alloy | 0.31 | Cold stamp |
| 03753731 | COACH DOOR LATERAL BAR REINFORCEMENT OL | 0.8 | CR350Y/450T-LA | High Strength Low Alloy | 0.31 | Cold stamp |
| 03753743 | TORQUE BOX REAR RH | 1.5 | CR400Y780T-RA | Retained Austenite | 1.65 | Cold stamp |
| 03753904 | SIX BAR | 0.8 | CR350Y/450T-LA | High Strength Low Alloy | 1.33 | Cold stamp |
| 3755567 | UPPER RAIL INNER REAR LH 2 | 1.0 | CR350Y/450T-LA | High Strength Low Alloy | 0.84 | Cold stamp |
| 03755570 | UPPER RAIL OUTER REAR LH 2 | 1.2 | CR350Y/450T-LA | High Strength Low Alloy | 1.25 | Cold stamp |
| 03765101 | UPPER RAIL BULKHEAD REAR LH | 1.5 | CR420Y780T-DP | Dual Phase | 0.11 | Cold stamp |
| 03765106 | UPPER RAIL BULKHEAD REAR RH | 1.5 | CR420Y780T-DP | Dual Phase | 0.11 | Cold stamp |
| 3776067 | STRUT RING REAR LH | 2.0 | CR1200Y1470-MS | Martensitic | 0.23 | Cold stamp |
| 03776068 | STRUT RING REAR RH | 2.0 | CR1200Y1470-MS | Martensitic | 0.23 | Cold stamp |
| 03489683 | TWO BAR | 1.2 | CR1200Y1470T-MS | Martensitic | 3.25 | Roll stamp |
| 3489678 | FLOOR PANEL LOWER | 0.5 | CR340Y590T-DP | Dual Phase | 14.56 | Cold stamp |
| 3489675 | THREE BAR | 1.2 | CR1200Y1470T-MS | Martensitic | 3.26 | Roll stamp |
| 3489676 | FOUR BAR | 1.2 | CR1200Y1470T-MS | Martensitic | 3.25 | Roll stamp |
| 3753899 | PDU SUPPORT LONGID RIGHT | 0.7 | CR340Y590T-DP | Dual Phase | 0.27 | Cold stamp |
| 03753903 | PDU SUPPORT LONGID LEFT | 0.7 | CR340Y590T-DP | Dual Phase | 0.27 | Cold stamp |
| 3438410 | ONE BAR INNER | 1.0 | CR8501180T-DH | High Formability Dual Phase | 1.27 | Cold stamp |
| 03439464 | FRONT SUBFRAME BUSHMOUNT RR RH | SOLID | N/A EN8 | Mild Steel | 0.36 | (solid part) |
| 03439413 | FRONT SUBFRAME BUSHMOUNT RR LH | SOLID | N/A EN8 | Mild Steel | 0.36 | (solid part) |
| 03448749 | VERTICAL DASH BRACE LOWER OUTER FRONT LH | 2.0 | PHS-CR1500T-MB | Press Hardened Steel | 2.05 | Hot form |
| 03448755 | VERTICAL DASH BRACE LOWER OUTER FRONT RH | 2.0 | PHS-CR1500T-MB | Press Hardened Steel | 2.05 | Hot form |
| 03448854 | TORQUE BOX FRONT RH | 2.0 | CR400Y780T-RA | Retained Austenite | 2.15 | Cold stamp |
| 03469873 | TORQUE BOX FRONT LH | 2.0 | CR400Y780T-RA | Retained Austenite | 1.94 | Cold stamp |
| 03475858 | FRONT SUBFRAME BUSHMOUNT FRT LH | SOLID | N/A EN8 | Mild Steel | 0.45 | (solid part) |
| 03475860 | FRONT SUBFRAME BUSHMOUNT FRT RH | SOLID | N/A EN8 | Mild Steel | 0.45 | (solid part) |
| 03506010 | LONGITUDINAL MID RAIL OUTER FRONT LH | TWB 2.0, 1.8 | 1.8/2.0_CR500Y780T-DP/CR700Y980T-DP | Dual Phase | 3.13 | Cold stamp |
| 03506011 | LONGITUDINAL MID RAIL INNER FRONT LH | TWB 2.0, 1.8 | 1.8/2.0_CR500Y780T-DP/CR700Y980T-DP | Dual Phase | 3.13 | Cold stamp |
| 0353245 | BUMPER BEAM INTERFACE PLATE FRONT LH | 2.0 | CR860Y1180T-DP | Dual Phase | 0.58 | Cold stamp |
| 0353253 | BUMPER BEAM INTERFACE PLATE FRONT RH | 2.0 | CR860Y1180T-DP | Dual Phase | 0.58 | Cold stamp |
| 0353269 | LONGITUDINAL MID RAIL OUTER FRONT RH | TWB 2.0, 1.8 | 1.8/2.0_CR500Y780T-DP/CR700Y980T-DP | Dual Phase | 3.16 | Cold stamp |
| 0353270 | LONGITUDINAL MID RAIL INNER FRONT RH | TWB 2.0, 1.8 | 1.8/2.0_CR500Y780T-DP/CR700Y980T-DP | Dual Phase | 3.13 | Cold stamp |
| 03585862 | GLANCE BEAM INNER LH | 0.8 | PHS-CR1500T-MB | Press Hardened Steel | 1.72 | Hot form |
| 03585863 | GLANCE BEAM UPPER TRIANGULATION INNER LH | 1.0 | PHS-CR1500T-MB | Press Hardened Steel | 0.92 | Hot form |
| 03585867 | GLANCE BEAM OUTER LH | 0.8 | PHS-CR1500T-MB | Press Hardened Steel | 1.75 | Hot form |
| 03601006 | GLANCE BEAM UPPER TRIANGULATION OUTER LH | 1.0 | PHS-CR1500T-MB | Press Hardened Steel | 1.04 | Hot form |
| 03601008 | FRONT BULKHEAD | 0.7 | CR700Y980T-DP | Dual Phase | 4.83 | Cold stamp |
| 3603910 | STRUT TOP FRONT LH | 1.8 | CR860Y1180T-DP | Dual Phase | 1.59 | Cold stamp |
| 3614349 | GLANCE BEAM LATERAL CROSS MEMBER INNER | 1.0 | CR1200Y1470T-MS | Martensitic | 1.45 | Cold stamp |
| 03618387 | GLANCE BEAM OUTER RH | 0.8 | PHS-CR1500T-MB | Press Hardened Steel | 2.19 | Hot form |
| 03618389 | GLANCE BEAM INNER RH | 0.8 | PHS-CR1500T-MB | Press Hardened Steel | 1.72 | Hot form |
| 03618390 | GLANCE BEAM UPPER TRIANGULATION INNER RH | 1.0 | PHS-CR1500T-MB | Press Hardened Steel | 0.92 | Hot form |
| 03618391 | GLANCE BEAM UPPER TRIANGULATION OUTER RH | 1.0 | PHS-CR1500T-MB | Press Hardened Steel | 1.08 | Hot form |
| 03618394 | STRUT TOP FRONT RH | 1.8 | CR860Y1180T-DP | Dual Phase | 1.59 | Cold stamp |
| 03630344 | VERTICAL DASH BRACE LOWER INNER LH | 2.0 | PHS-CR1500T-MB | Press Hardened Steel | 1.82 | Hot form |
| 03630345 | VERTICAL DASH BRACE LOWER INNER RH | 2.0 | PHS-CR1500T-MB | Press Hardened Steel | 1.82 | Hot form |
| 03633392 | BULKHEAD - SUBFRAME BUSH LH | 2.0 | CR350Y/450T-LA | High Strength Low Alloy | 0.39 | Cold stamp |
| 03633394 | BULKHEAD - SUBFRAME BUSH RH | 2.0 | CR350Y/450T-LA | High Strength Low Alloy | 0.39 | Cold stamp |
| 03640758 | STRUT CROSS MEMBER FRONT | 1.0 | PHS-CR2000T-MB | Press Hardened Steel | 2.73 | Hot form |
| 03640760 | GLANCE BEAM UPPER REACTION LH | 0.8 | PHS-CR1500T-MB | Press Hardened Steel | 0.52 | Hot form |
| 03640761 | GLANCE BEAM UPPER REACTION RH | 0.8 | PHS-CR1500T-MB | Press Hardened Steel | 0.52 | Hot form |
| 03642244 | GLANCE BEAM LOWER REACTION LH | 0.8 | CR1200Y1470T-MS | Martensitic | 0.47 | Cold stamp |
| 03642357 | STRUT CROSS MEMBER CLOSING PLATE | 1.0 | CR1550Y2000T-MS | Martensitic | 1.09 | Cold stamp |
| 3643340 | GLANCE BEAM LATERAL CROSS MEMBER OUTER | 1.0 | CR1200Y1470T-MS | Martensitic | 1.27 | Cold stamp |
| 03643407 | STRUT TOWER FRONT LH | 0.8 | CR350Y/450T-LA | High Strength Low Alloy | 1.46 | Cold stamp |
| 03643408 | STRUT TOWER FRONT RH | 0.8 | CR350Y/450T-LA | High Strength Low Alloy | 1.46 | Cold stamp |
| 03643418 | GLANCE BEAM LOWER REACTION RH | 0.8 | CR1200Y1470T-MS | Martensitic | 0.47 | Cold stamp |
| 3670456 | ONE BAR OUTER LOWER | 2.0 | CR860Y1180T-DP | Dual Phase | 3.31 | Roll form |
| 3670457 | ONE BAR OUTER UPPER | 2.0 | CR860Y1180T-DP | Dual Phase | 2.51 | Cold stamp |
| 03671385 | VERTICAL DASH BRACE UPPER FRONT LH | 2.0 | PHS-CR2000T-MB | Press Hardened Steel | 0.62 | Hot form |
| 03671386 | VERTICAL DASH BRACE UPPER FRONT RH | 2.0 | PHS-CR2000T-MB | Press Hardened Steel | 0.62 | Hot form |
| 03671429 | VERTICAL DASH BRACE FRONT LH | 2.0 | PHS-CR2000T-MB | Press Hardened Steel | 4.51 | Hot form |
| 03686769 | VERTICAL DASH BRACE FRONT RH | 2.0 | PHS-CR2000T-MB | Press Hardened Steel | 4.51 | Hot form |
| 03691527 | TORQUE BOX INNER FRONT LH | 1.0 | CR8501180T-DH | High Formability Dual Phase | 0.72 | Cold stamp |
| 03706556 | TORQUE BOX INNER FRONT RH | 1.0 | CR8501180T-DH | High Formability Dual Phase | 0.72 | Cold stamp |
| 03724993 | GLANCE BEAM CAP LH | 2.0 | CR420Y780T-DP | Dual Phase | 0.38 | Cold stamp |
| 03724994 | GLANCE BEAM CAP RH | 2.0 | CR420Y780T-DP | Dual Phase | 0.38 | Cold stamp |
| 03725636 | GLANCE BEAM BULKHEAD 2 LH | 1.5 | CR420Y780T-DP | Dual Phase | 0.81 | Cold stamp |
| 03727963 | FRONT SUBFRAME BUSHMOUNT FRT OTR LH | SOLID | N/A EN8 | Mild Steel | 0.29 | (solid part) |
| 03727964 | FRONT SUBFRAME BUSHMOUNT FRT OTR RH | SOLID | N/A EN8 | Mild Steel | 0.29 | (solid part) |
| 3729099 | GLANCE BEAM BULKHEAD 4 LH | 1.5 | CR420Y780T-DP | Dual Phase | 0.09 | Cold stamp |
| 03730823 | GLANCE BEAM BULKHEAD 2 RH | 1.5 | CR420Y780T-DP | Dual Phase | 0.45 | Cold stamp |
| 03730827 | GLANCE BEAM BULKHEAD 4 RH | 1.5 | CR420Y780T-DP | Dual Phase | 0.09 | Cold stamp |
| 03764469 | GLANCE BEAM BULKHEAD 5 LH | 1.5 | CR420Y780T-DP | Dual Phase | 0.18 | Cold stamp |
| 03764469 | GLANCE BEAM BULKHEAD 6 LH | 1.5 | CR420Y780T-DP | Dual Phase | 0.18 | Cold stamp |
| 03764609 | GLANCE BEAM BULKHEAD 5 RH | 1.5 | CR420Y780T-DP | Dual Phase | 0.18 | Cold stamp |
| 03764610 | GLANCE BEAM BULKHEAD 6 RH | 1.5 | CR420Y780T-DP | Dual Phase | 0.18 | Cold stamp |
| 3776065 | STRUT RING FRONT LH | 2.0 | CR1200Y1470-MS | Martensitic | 0.23 | Cold stamp |
| 03776066 | STRUT RING FRONT RH | 2.0 | CR1200Y1470-MS | Martensitic | 0.23 | Cold stamp |

Appendix 1.2 SEM1 Battery Bill of Materials

| CAD PART NUMBER | PART NAME | CAD/PLM gauge & grade code | Gauge thickness (mm) | Material Grade (code) | Advanced High Strength Steel Category | Part mass (kg) | Subassembly mass (kg) | Forming |
|-----------------|------------------------------------|----------------------------|----------------------|-----------------------|---------------------------------------|----------------|-----------------------|------------|
| | BATTERY STRUCTURE | (blank) | | | | | 54.90 | |
| 3647932 | BATTERY TRAY UPPER | 0.5 CR340Y/450T-LA | 0.5 | CR340Y/450T-LA | High Strength Low Allo | 9.96 | | Cold stamp |
| 3647933 | BATTERY TRAY LOWER | 0.7/0.8 CR420Y780T-DP/CR | TWB 0.7, 0.8 | DP780 & MS1470 | Dual Phase and Marter | 14.66 | | Cold stamp |
| 3747661 | WAS_PDU BRACKET_MUNICH | CR550Y/650T-LA | 1 | CR550Y/650T-LA | High Strength Low Allo | 2.29 | | Cold stamp |
| 3775874 | BATTERY TRAY TRIANGLECOMB FRON | 0.5 CR340Y/450T-LA | 0.5 | CR340Y/450T-LA | High Strength Low Allo | 3.17 | | Cold stamp |
| 03786286 | BATTERY TRAY TRIANGLECOMB REAR | 0.5 CR340Y/450T-LA | 0.5 | CR340Y/450T-LA | High Strength Low Allo | 3.07 | | Cold stamp |
| 3496839 | Structural Plate Crossmember_001_M | CR1200Y1470T-MS_1 | 1 | CR1200Y1470T-MS | Martensitic | 1.61 | | Roll stamp |
| 03496835 | Structural Plate Crossmember_004_M | CR1200Y1470T-MS_1 | 1 | CR1200Y1470T-MS | Martensitic | 1.61 | | Roll form |
| 03496838 | Structural Plate Crossmember_002_M | CR1200Y1470T-MS_1 | 1 | CR1200Y1470T-MS | Martensitic | 1.61 | | Roll form |
| 3496832 | Structural Plate_004_MUNICH | CR1200Y1470T-MS_1 | 1 | CR1200Y1470T-MS | Martensitic | 1.45 | | Roll form |
| 03496836 | Structural Plate_002_MUNICH | CR1200Y1470T-MS_1 | 1 | CR1200Y1470T-MS | Martensitic | 1.45 | | Roll form |
| 03496837 | Structural Plate_001_MUNICH | CR1200Y1470T-MS_1 | 1 | CR1200Y1470T-MS | Martensitic | 1.45 | | Roll form |
| 3702273 | BATTERY FRAME LONGITUDINAL LEFT | CR860Y1180T-DP_1.5 | 1.5 | CR860Y1180T-DP | Dual Phase | 5.99 | | Cold stamp |
| 03702274 | BATTERY FRAME LONGITUDINAL RIGH | CR860Y1180T-DP_1.5 | 1.5 | CR860Y1180T-DP | Dual Phase | 5.99 | | Cold stamp |
| 3720375 | SUPPORT BRACKET_11 | CR550Y/650T-LA_0.7 | 0.7 | CR550Y/650T-LA | High Strength Low Allo | 0.03 | | Cold stamp |
| 03720376 | SUPPORT BRACKET_12 | CR550Y/650T-LA_0.7 | 0.7 | CR550Y/650T-LA | High Strength Low Allo | 0.03 | | Cold stamp |
| 03720377 | SUPPORT BRACKET_13 | CR550Y/650T-LA_0.7 | 0.7 | CR550Y/650T-LA | High Strength Low Allo | 0.03 | | Cold stamp |
| 03720378 | SUPPORT BRACKET_21 | CR550Y/650T-LA_0.7 | 0.7 | CR550Y/650T-LA | High Strength Low Allo | 0.03 | | Cold stamp |
| 03720379 | SUPPORT BRACKET_22 | CR550Y/650T-LA_0.7 | 0.7 | CR550Y/650T-LA | High Strength Low Allo | 0.03 | | Cold stamp |
| 03720380 | SUPPORT BRACKET_23 | CR550Y/650T-LA_0.7 | 0.7 | CR550Y/650T-LA | High Strength Low Allo | 0.03 | | Cold stamp |
| 03720381 | SUPPORT BRACKET_24 | CR550Y/650T-LA_0.7 | 0.7 | CR550Y/650T-LA | High Strength Low Allo | 0.03 | | Cold stamp |
| 03720382 | SUPPORT BRACKET_31 | CR550Y/650T-LA_0.7 | 0.7 | CR550Y/650T-LA | High Strength Low Allo | 0.03 | | Cold stamp |
| 03720383 | SUPPORT BRACKET_32 | CR550Y/650T-LA_0.7 | 0.7 | CR550Y/650T-LA | High Strength Low Allo | 0.03 | | Cold stamp |
| 03720384 | SUPPORT BRACKET_33 | CR550Y/650T-LA_0.7 | 0.7 | CR550Y/650T-LA | High Strength Low Allo | 0.03 | | Cold stamp |
| 03723001 | SUPPORT BRACKET_25 | CR550Y/650T-LA_0.7 | 0.7 | CR550Y/650T-LA | High Strength Low Allo | 0.03 | | Cold stamp |
| 03723002 | SUPPORT BRACKET_26 | CR550Y/650T-LA_0.7 | 0.7 | CR550Y/650T-LA | High Strength Low Allo | 0.03 | | Cold stamp |
| 03723005 | SUPPORT BRACKET_27 | CR550Y/650T-LA_0.7 | 0.7 | CR550Y/650T-LA | High Strength Low Allo | 0.03 | | Cold stamp |
| 03723007 | SUPPORT BRACKET_28 | CR550Y/650T-LA_0.7 | 0.7 | CR550Y/650T-LA | High Strength Low Allo | 0.03 | | Cold stamp |
| 03723008 | SUPPORT BRACKET_14 | CR550Y/650T-LA_0.7 | 0.7 | CR550Y/650T-LA | High Strength Low Allo | 0.03 | | Cold stamp |
| 03723010 | SUPPORT BRACKET_15 | CR550Y/650T-LA_0.7 | 0.7 | CR550Y/650T-LA | High Strength Low Allo | 0.03 | | Cold stamp |
| 03723011 | SUPPORT BRACKET_16 | CR550Y/650T-LA_0.7 | 0.7 | CR550Y/650T-LA | High Strength Low Allo | 0.03 | | Cold stamp |
| 03723014 | SUPPORT BRACKET_17 | CR550Y/650T-LA_0.7 | 0.7 | CR550Y/650T-LA | High Strength Low Allo | 0.03 | | Cold stamp |
| 03723017 | SUPPORT BRACKET_37 | CR550Y/650T-LA_0.7 | 0.7 | CR550Y/650T-LA | High Strength Low Allo | 0.03 | | Cold stamp |
| 03723018 | SUPPORT BRACKET_36 | CR550Y/650T-LA_0.7 | 0.7 | CR550Y/650T-LA | High Strength Low Allo | 0.03 | | Cold stamp |
| 03723019 | SUPPORT BRACKET_35 | CR550Y/650T-LA_0.7 | 0.7 | CR550Y/650T-LA | High Strength Low Allo | 0.03 | | Cold stamp |
| 03723021 | SUPPORT BRACKET_34 | CR550Y/650T-LA_0.7 | 0.7 | CR550Y/650T-LA | High Strength Low Allo | 0.03 | | Cold stamp |

Appendix 1.3 SEM1 scissor doors Bill of Materials

| CAD PART NUMBER | PART NAME | Gauge thickness (mm) | Material Grade (code) | Advanced High Strength Steel Category | Part mass (kg) | Subassembly mass (kg) | Forming |
|-----------------|-------------------------|----------------------|-----------------------|---------------------------------------|----------------|-----------------------|------------|
| 03747733 | SCISSOR DOOR ASY | | | | | 84.05 | |
| 03645751 | REAR DOOR MOTOR | | | | 9.35 | | |
| 03645752 | FRONT DOOR MOTOR | | | | 9.35 | | |
| 03750018 | REAR DOORS_VAR 02 | | | | | | |
| 03750084 | OUTER DOOR RR | 0.7 | CR280Y/400T-BH | Bake Hardenable | 7.20 | | Cold stamp |
| 3750089 | B-PILLAR RR | 1.2 | CR400Y690T-RA | Retained Austenite | 4.07 | | hydroform |
| 03750085 | INNER DOOR RR | 1.2 | Mild 140/270 | Mild Steel | 14.14 | | Cold stamp |
| 03750087 | DOOR STRUT | 1.5 | CR1200Y1470T-MS | Martensitic | 3.01 | | roll stamp |
| 03786561 | REAR DOOR BRKTS BOTTOM | | | | 0.32 | | |
| 03786558 | REAR DOOR BRKTS TOP | | | | 0.32 | | |
| 3786580 | BRKT SUPPORT CUP REAR | 1.2 | Mild 140/270 | Mild Steel | 0.34 | | Cold stamp |
| 03843042 | DOOR SPLIT RR | 1.2 | Mild 140/270 | Mild Steel | 0.33 | | Cold stamp |
| 03750017 | FRONT DOORS_VAR 02 | | | | | | |
| 3613567 | DOOR STRUT 04 | 1.2 | CR400Y690T-RA | Retained Austenite | 5.57 | | Cold stamp |
| 03750471 | INNER DOOR FR | 1.2 | Mild 140/270 | Mild Steel | 12.36 | | Cold stamp |
| 03750465 | OUTER DOOR FR | 0.7 | CR280Y/400T-BH | Bake Hardenable | 6.97 | | Cold stamp |
| 03750473 | DOOR STRUT | 1.5 | CR1200Y1470T-MS | Martensitic | 2.67 | | roll stamp |
| 03786548 | FRONT DOOR BRKTS BOTTOM | | | | 0.32 | | |
| 03786545 | FRONT DOOR BRKTS TOP | | | | 0.32 | | |
| 03786579 | BRKT SUPPORT CUP FRONT | 1.2 | Mild 140/270 | Mild Steel | 0.43 | | Cold stamp |
| 03843038 | DOOR SPLIT FR | 1.2 | Mild 140/270 | Mild Steel | 0.46 | | Cold stamp |
| 03776787 | SCISSOR DOOR GLUE | | | | 0.00 | | |
| 03776789 | SCISSOR DOOR WELDS | | | | 0.68 | | |
| 03786540 | FRONT DOOR BOTTOM ARM 2 | | | | 2.68 | | |
| 03786537 | REAR DOOR BOTTOM ARM 2 | | | | 3.13 | | |

Appendix 1.4 Coach door Bill of Materials

| CAD PART NUMBER | PART NAME | Gauge thickness (mm) | Material Grade (code) | Advanced High Strength Steel Category | Part mass (kg) | Subassembly mass (kg) | Forming |
|-----------------|--|----------------------|-----------------------|---------------------------------------|----------------|-----------------------|------------|
| 03777904 | COACH DOOR MUNICH - TAILGATE | | | | | 22.17 | |
| 03777906 | COACH DOOR MUNICH - A-SURFACE SHEET | | BH450 | Bake Hardenable | 7.36 | | Cold stamp |
| 03777910 | COACH DOOR MUNICH - INNER SHEET | 1.2 | MILD STEEL 140/170 | Mild Steel | 14.18 | | Cold stamp |
| 03777912 | COACH DOOR MUNICH - LOCK MECHANISM | | | | 0.22 | | |
| 03777916 | COACH DOOR MUNICH - LEFT LOWER ARMS BRACKET | 1 | HSLA350/450 | High Strength Low Alloy | 0.13 | | Cold stamp |
| 03777919 | COACH DOOR MUNICH - RIGHT LOWER ARMS BRACKET | 1.5 | HSLA350/450 | High Strength Low Alloy | 0.13 | | Cold stamp |
| 03777920 | COACH DOOR MUNICH - LEFT UPPER ARMS BRACKET | 1.5 | HSLA350/450 | High Strength Low Alloy | 0.08 | | Cold stamp |
| 03777921 | COACH DOOR MUNICH - RIGHT UPPER ARMS BRACKET | 1 | HSLA350/450 | High Strength Low Alloy | 0.08 | | Cold stamp |

Appendix 1.6 SEM2 Body in White Bill of Materials

| Part Number | Part Name | AHSS Grade | Gauge (mm) | C = Carry over SEM1 G = grade/gauge change N = New geom. | Part Mass (kg) | SEM2 change | |
|-------------|---|------------------------------|------------|--|----------------|--------------------------------------|--|
| 0306995_2 | REAR COMPARTMENT PAN LOWER | CR HSLA 350/550 | 0.5 | N | 2.89 | New geometry for rear EDU package | |
| 0347201_2 | LONGITUDINAL REAR RAIL INNER RH | CR20Y1180T-RA 1.4 CR600Y980 | 1.8 | G | 1.90 | change from 1.4mm/1.6mm TWB to 1.6mm | |
| 0347382_2 | LONGITUDINAL REAR RAIL INNER LH | CR20Y1180T-RA 1.4 CR600Y980 | 1.6 | G | 1.90 | change from 1.4mm/1.6mm TWB to 1.6mm | |
| 0347373_2 | LONGITUDINAL REAR RAIL OUTER RH | CR20Y1180T-RA 1.4 CR600Y980 | 1.6 | G | 1.81 | change from 1.4mm/1.6mm TWB to 1.6mm | |
| 0347381_2 | LONGITUDINAL REAR RAIL OUTER LH | CR20Y1180T-RA 1.4 CR600Y980 | 1.6 | G | 1.81 | change from 1.4mm/1.6mm TWB to 1.6mm | |
| 0349435_2 | ROOF ASSEMBLY | (blank) | (bl) | | | | |
| 0403394 | REAR BACK HEADER OUTER A-SURFACE | CR20Y1370T-BH | 0.6 | N | 1.21 | | |
| 0404962 | REAR BACK HEADER INNER | CR20Y980T-CP | 0.8 | N | 1.74 | | |
| 0351286_2 | DIAGONAL INNER PANEL REAR RH | CR HSLA550/620 | 0.7 | C | 1.35 | | |
| 0351286_2 | DIAGONAL OUTER A-SURFACE PANEL REAR RH | CR20Y1370T-BH | 0.6 | C | 0.81 | | |
| 0351280_2 | DIAGONAL OUTER A-SURFACE PANEL FRONT RH | CR20Y1370T-BH | 0.6 | C | 0.78 | | |
| 0347397_2 | DIAGONAL OUTER A-SURFACE PANEL FRONT LH | CR20Y1370T-BH | 0.6 | C | 0.78 | | |
| 0351274_2 | MID INTERSECTION INNER PANEL | CR20Y1370T-BH | 0.5 | C | 0.62 | | |
| 0351285_2 | DIAGONAL INNER PANEL FRONT RH | CR HSLA550/620 | 0.7 | C | 1.29 | | |
| 03462738_2 | MID ROOF BOW INNER | CR20Y1180T-RA | 0.8 | C | 1.77 | | |
| 0347397_2 | REAR HEADER INNER | CR78Y980T-CP | 0.8 | N | 1.69 | | |
| 0347383_2 | DIAGONAL OUTER A-SURFACE PANEL REAR LH | CR20Y1370T-BH | 0.6 | C | 0.81 | | |
| 03461692_2 | MID ROOF BOW OUTER A-SURFACE | CR20Y1370T-BH | 0.6 | C | 1.05 | | |
| 03469795_2 | MID INTERSECTION OUTER A-SURFACE PANEL | 0.6 CR20Y1370T-BH | 0.6 | C | 0.64 | | |
| 03451793_2 | FRONT HEADER INNER | CR78Y980T-CP | 0.8 | C | 1.67 | | |
| 0348374_2 | DIAGONAL INNER PANEL REAR LH | CR HSLA550/620 | 0.7 | C | 1.35 | | |
| 03451626_2 | FRONT HEADER OUTER A-SURFACE | CR20Y1370T-BH | 0.6 | C | 1.15 | | |
| 03476375_2 | REAR HEADER OUTER A-SURFACE | CR20Y1370T-BH | 0.6 | N | 1.20 | | |
| 03483873_2 | DIAGONAL INNER PANEL FRONT LH | CR HSLA550/620 | 0.7 | C | 1.29 | | |
| 03489573_2 | FLOOR ASSEMBLY | (blank) | (bl) | | | | |
| 0348988_2 | TWO BAR | CR1200Y1470T-MS | 1.5 | C | 4.05 | | |
| 03733899_2 | POU SUPPORT LONGID RIGHT | CR340Y90T-DP | 0.7 | C | 0.27 | | |
| 03489678_2 | FLOOR PANEL LOWER | DP980 | 0.5 | N | 17.97 | | |
| 03733903_2 | POU SUPPORT LONGID LEFT | CR340Y90T-DP | 0.7 | C | 0.27 | | |
| 03489675_2 | THREE BAR | CR1200Y1470T-MS | 1.5 | C | 4.06 | | |
| 03489676_2 | FOUR BAR | CR1200Y1470T-MS | 1.5 | C | 4.05 | | |
| 03974152_2 | THREE A BAR | CR1200Y1470T-MS | 1.5 | N | 4.06 | | |
| 03483409_2 | SIDE ASSEMBLY | (blank) | (blank) | | | | |
| 03737652_2 | BULKHEAD C-PILLAR LOWER LH | 1.5 DP 800/1180 | 1.5 | C | 0.19 | | |
| 03766055_2 | A POST BULKHEAD COVER RH | PHS-CR200T-MB | 1.5 | N | 0.18 | | |
| 03451131_2 | ROCKER INNER LH | CR150Y2000T-MS | 1.2 | N | 7.23 | | |
| 03553378_2 | ROCKER HEX ABSORBER RH | CR420Y780T-DP | 0.7 | N | 0.98 | | |
| 03083528_2 | ROCKER REAR CAP INNER RH | CR HSLA550/620 | 1.0 | N | 0.14 | | |
| 03707552_2 | SLEEVE REAR RH | NA_ENG | N | N | 0.33 | | |
| 03730603_2 | BULKHEAD A POST REINFORCEMENT LOWER LH | CR150Y2000T-MS | 1.5 | C | 0.24 | | |
| 03725754_2 | BULKHEAD C-PILLAR MIDDLE RH | CR150Y2000T-MS | 1.5 | C | 0.19 | | |
| 03444399_2 | C-POST INNER LH | PHS-CR1500T-MB | 1.2 | N | 4.83 | | |
| 03553322_2 | FRONT INNER ROOF HEADER GUSSET MOUNT RH | CR70Y980T-CP | 1.0 | C | 0.22 | | |
| 03620666_2 | REAR OUTER ROOF HEADER GUSSET MOUNT RH | CR HSLA550/620 | 0.8 | N | 0.14 | | |
| 03636509_2 | FRONT OUTER ROOF HEADER GUSSET MOUNT LH | CR70Y980T-DP | 1.0 | C | 0.22 | | |
| 03781490_2 | A POST BULKHEAD COVER LH | PHS-CR200T-MB | 1.5 | N | 0.18 | | |
| 03592586_2 | REAR OUTER ROOF HEADER GUSSET MOUNT LH | CR HSLA490/620 | 0.8 | N | 0.14 | | |
| 03483889_2 | A POST INNER LH | PHS-CR200T-MB | 1.2 | C | 5.06 | | |
| 03721342_2 | BULKHEAD C-PILLAR MIDDLE LH | CR150Y2000T-MS | 1.5 | C | 0.19 | | |
| 03503803_2 | A POST INNER REINFORCEMENT LH | CR150Y1700T-MS | 1.0 | C | 1.79 | | |
| 03409405 | REAR INNER ROOF HEADER GUSSET MOUNT RH | CR HSLA490/620 | 0.8 | N | 0.28 | | |
| 03033949 | REAR BACK INNER ROOF HEADER GUSSET MOUNT LH | CR HSLA490/620 | 0.8 | N | 0.95 | | |
| 03975789 | SEM2 EXTENSION PILLAR OUTER LH | TWB_PHS-CR2000T-MB Apillar 1 | TWB | N | 3.90 | | |
| 04034069 | REAR OUTER BACK ROOF HEADER GUSSET MOUNT RH | CR HSLA550/620 | 0.8 | N | 0.13 | | |
| 04034066 | REAR OUTER BACK ROOF HEADER GUSSET MOUNT LH | CR HSLA490/620 | 0.8 | N | 0.13 | | |
| 03994934 | SEM2 EXTENSION PILLAR REINFORCEMENT LH | CR20Y1180T-DP | 0.8 | N | 0.92 | | |
| 03994885 | SEM2 EXTENSION PILLAR INNER LH | PHS-CR1500T-MB | 1.2 | N | 4.79 | | |
| 04028496 | SEM2 EXTENSION PILLAR OUTER RH | TWB_PHS-CR2000T-MB Apillar 1 | TWB | N | 3.90 | | |
| 04029609 | SEM2 EXTENSION PILLAR INNER RH | PHS-CR1500T-MB | 1.2 | N | 4.78 | | |
| 04028555 | SEM2 EXTENSION PILLAR REINFORCEMENT RH | CR20Y1180T-DP | 0.8 | N | 0.92 | | |
| 03553374_2 | ROCKER INNER REINFORCEMENT RH | CR420Y780T-DP | 1.0 | N | 1.63 | | |
| 03573480_2 | INNER ROCKER BULKHEAD RH | CR420Y780T-DP | 1.0 | C | 0.11 | | |
| 03707053_2 | A POST INNER REINFORCEMENT UPPER REAR RH | 1.5 CR20Y1180T-DP | 1.5 | N | 1.13 | | |
| 03707054_2 | SLEEVE FRONT RH | NA_ENG | N | C | 0.35 | | |
| 0378371_2 | BULKHEAD A POST REINFORCEMENT UPPER LH | CR150Y2000T-MS | 1.5 | C | 0.24 | | |
| 03766045_2 | REINFORCEMENT LATCH LOWER RH | PHS-CR1000T-MB | 1.5 | N | 0.62 | | |
| 03707553_2 | SLEEVE REAR LH | NA_ENG | N | N | 0.33 | | |
| 03784608_2 | BULKHEAD A POST REINFORCEMENT UPPER RH | CR150Y2000T-MS | 1.5 | C | 0.24 | | |
| 03474768_2 | ROCKER FRONT CAP INNER RH | CR1200Y1470T-MS | 1.0 | N | 0.14 | | |
| 03559985_2 | MID ROOF BOW MOUNT RH | CR70Y980T-CP | 0.8 | C | 0.41 | | |
| 03510150_2 | C-POST INNER REINFORCEMENT LH | CR20Y1180T-DP | 0.8 | N | 1.36 | | |
| 03407490_2 | FRONT INNER ROOF HEADER GUSSET MOUNT LH | CR70Y980T-CP | 1.0 | C | 0.62 | | |
| 0375146_2 | INNER ROCKER BULKHEAD LH | CR420Y780T-DP | 1.0 | N | 0.11 | | |
| 03751415_2 | REINFORCEMENT DOOR LATCH LH | PHS-CR1500T-MB | 1.5 | N | 0.25 | | |
| 03636521_2 | ROCKER REAR CAP INNER LH | CR HSLA550/620 | 1.0 | N | 0.14 | | |
| 03451542_2 | ROOF SIDE RAIL INNER LH | PHS-CR1500T-MB | 0.8 | N | 2.45 | | |
| 03707049_2 | A POST INNER REINFORCEMENT UPPER REAR LH | CR20Y1180T-DP | 1.5 | N | 1.13 | | |
| 03636520_2 | FRONT OUTER ROOF HEADER GUSSET MOUNT RH | CR70Y980T-DP | 1.0 | C | 0.22 | | |
| 03484699_2 | OUTER RING TWB LH | TWB_PHS-CR2000T-MB Apillar 1 | TWB | N | 18.64 | | |
| 03783022_2 | A POST INNER REINFORCEMENT UPPER RH | CR20Y1180T-DP | 1.5 | N | 1.12 | | |
| 03672922_2 | ROCKER ABSORBER LH | CR420Y780T-DP | 0.7 | N | 0.98 | | |
| 03592223_2 | REAR INNER ROOF HEADER GUSSET MOUNT LH | CR HSLA490/620 | 0.8 | C | 0.65 | | |
| 03553361_2 | ROCKER INNER RH | CR150Y2000T-MS | 1.2 | N | 7.23 | | |
| 03470012_2 | MID ROOF BOW MOUNT LH | CR70Y980T-CP | 0.8 | C | 0.41 | | |
| 03553241_2 | A POST INNER RH | PHS-CR2000T-MB | 1.2 | C | 5.06 | | |
| 03766029_2 | BULKHEAD A POST REINFORCEMENT LOWER RH | CR150Y2000T-MS | 1.5 | C | 0.24 | | |
| 03766044_2 | REINFORCEMENT DOOR LATCH RH | PHS-CR1500T-MB | 1.5 | N | 0.25 | | |
| 03733845_2 | REINFORCEMENT LATCH LOWER LH | PHS-CR1000T-MB | 1.5 | N | 0.62 | | |
| 03553397_2 | A POST INNER REINFORCEMENT RH | CR130Y1700T-MS | 1.0 | C | 1.79 | | |
| 03748482_2 | INNER ROCKER BULKHEAD QZ LH | CR420Y780T-DP | 1.0 | C | 0.11 | | |
| 03709256_2 | OUTER RING TWB RH | TWB_PHS-CR2000T-MB Apillar 1 | TWB | N | 18.64 | | |
| 03553390_2 | REAR INNER ROOF HEADER GUSSET MOUNT RH | CR HSLA490/620 | 0.8 | C | 0.65 | | |
| 03703692_2 | SLEEVE FRONT LH | NA_ENG | N | N | 0.35 | | |
| 03623968_2 | ROCKER FRONT CAP INNER LH | CR1200Y1470T-MS | 1.0 | N | 0.14 | | |
| 03750014_2 | OUTER RING REINF. PLATE RH | CR340Y90T-DP | 2.0 | N | 0.08 | | |
| 03703801_2 | A POST INNER REINFORCEMENT UPPER LH | CR20Y1180T-DP | 1.5 | N | 1.22 | | |
| 03553379_2 | ROOF SIDE RAIL INNER RH | PHS-CR1500T-MB | 0.8 | N | 2.45 | | |
| 03722290_2 | BULKHEAD C-PILLAR LOWER LH | CR150Y2000T-MS | 1.5 | N | 0.19 | | |
| 03553400_2 | C-POST INNER REINFORCEMENT RH | CR20Y1180T-DP | 0.8 | N | 1.36 | | |
| 03451226_2 | ROCKER INNER REINFORCEMENT LH | CR420Y780T-DP | 1.0 | N | 1.63 | | |
| 03747655_2 | OUTER RING REINF. PLATE LH | CR340Y90T-DP | 2.0 | C | 0.08 | | |
| 03749690_2 | INNER ROCKER BULKHEAD QZ RH | CR420Y780T-DP | 1.0 | C | 0.11 | | |
| 03553334_2 | C-POST INNER RH | PHS-CR1500T-MB | 1.2 | N | 4.83 | | |
| 03808141 | DS-WAS-1430 SCISSOR DOOR ASY SEM2 | (blank) | (blank) | | | | |
| 03645751 | REAR DOOR MOTOR | (blank) | (blank) | | | | |
| 03645752 | FRONT DOOR MOTOR | (blank) | (blank) | | | | |
| 04032463 | REAR DOORS SEM2 | (blank) | (blank) | | | | |
| 04033467 | DOOR SPLIT RR SEM2 | S101-Mild 140/270 | 1.2 | N | 0.33 | | |
| 04033464 | DOOR STRUT SEM2 | CR1200Y1470T-MS | 1.5 | N | 3.68 | | |
| 04033465 | BRKT SUPPORT CUP REAR SEM2 | S101-Mild 140/270 | 1.2 | N | 0.34 | | |
| 04033468 | B-PILLAR SEM2 | CR340Y90T-RA | 1.2 | N | 4.07 | | |
| 04033470 | INNER DOOR RR SEM2 | S101-Mild 140/270 | 1.2 | N | 14.95 | | |
| 04033466 | REAR DOOR BRKTS BOTTOM SEM2 | (blank) | (blank) | | | | |
| 04033469 | OUTER DOOR RR SEM2 | CR280Y400T-BH | 0.7 | N | 7.19 | | |
| 04033471 | REAR DOOR BRKTS TOP SEM2 | (blank) | (blank) | | | | |
| 03750017 | FRONT DOORS VAR QZ | (blank) | (blank) | | | | |
| 03483038 | DOOR SPLIT FR | S101-Mild 140/270 | 1.2 | C | 0.46 | | |
| 03786548 | FRONT DOOR BRKTS BOTTOM | (blank) | (blank) | | | | |
| 03786579 | BRKT SUPPORT CUP FRONT | S101-Mild 140/270 | 1.2 | C | 0.43 | | |
| 03786545 | FRONT DOOR BRKTS TOP | (blank) | (blank) | | | | |
| 03750473 | DOOR STRUT | CR1200Y1470T-MS | 1.5 | C | 2.94 | | |
| 03750465 | OUTER DOOR FR | CR280Y400T-BH | 0.7 | C | 2.94 | | |
| 03750471 | INNER DOOR FR | S101-Mild 140/270 | 1.2 | C | 12.36 | | |
| 03515597 | DOOR STRUT 04 | CR340Y90T-RA | C | 1.2 | C | 3.57 | |
| 03786540 | FRONT DOOR BOTTOM ARM 2 | (blank) | (blank) | | | | |
| 03786541 | SCISSOR DOOR GLUE | (blank) | (blank) | | | | |
| 03786542 | SCISSOR DOOR WELDS | (blank) | (blank) | | | | |
| 03786537 | REAR DOOR BOTTOM ARM 2 | (blank) | (blank) | | | | |

| | | |
|-----|-----|-------------------------|
| 68% | 156 | SEM1 carry over |
| 9% | 20 | SEM1 grade/gauge adjust |
| 23% | 53 | SEM2 unique |
| | 229 | TOTAL |


Appendix 2.1 Panel formability simulation results

A pillar Inner

OEM: ARRK
 Vehicle Program: Steel E-Motiv
 Project Name: Phase 2

Name: Nick Sephton
 Department: Engineering
 Date: 16-06-2022 Page 1 of 8

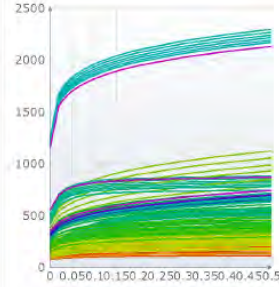


Sheet metal forming simulation

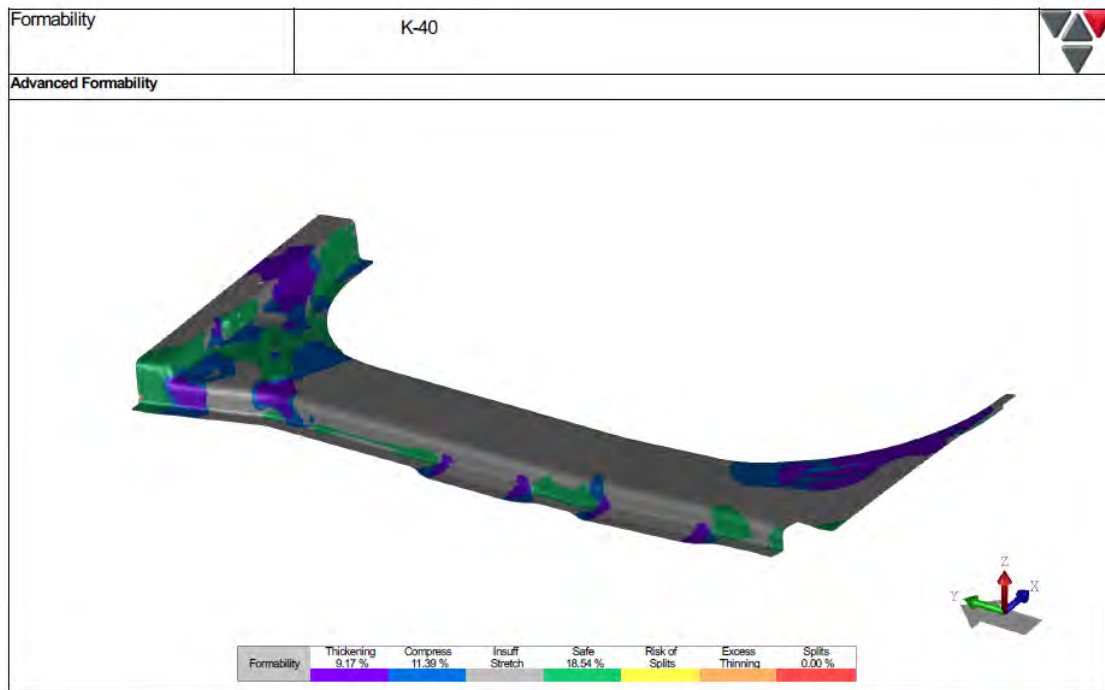
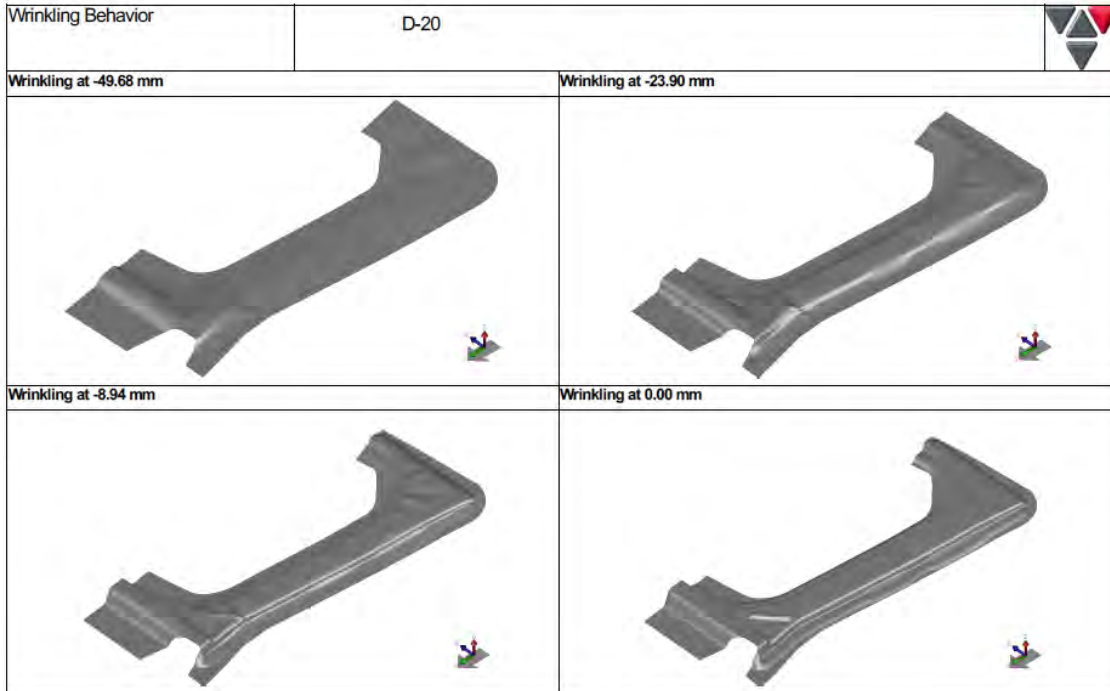
| Overview and Summary | | | | | |
|---|---------------|---|-----------|-------------------------------------|--------------------------|
| Part Info | | Criterion | OK | n OK | Status |
| Designation: 03438889-Body.1 | Type: Heating | FLD | 5.2 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Part No.: | Drawing No.: | Winkles | 5.24 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Nom. / Calculated Material: 22MnB5 | | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Nom. / Calculated Sheet Thickness: 1.000 mm | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Method Info | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Method Plan No.: | | Thinning | 5.6 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Drawing No.: | Rev.: | Martensite | 5.7 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Part  | | Temperature | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| | | Hardness | | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| | | Simulation Info: Filename: 03438889_A_Pillar_Inner_LH_NMS_16-6-22_it9 - NEW CAD.afd | | | |
| AutoForm | | Memory: 685.30 MB | | | |
| AutoForm Forming Solver Thermo R10.0.0 | | | | | |
| Process - Blank Die / Heating / Draw / Quenching / Laser Trim | | | | | |

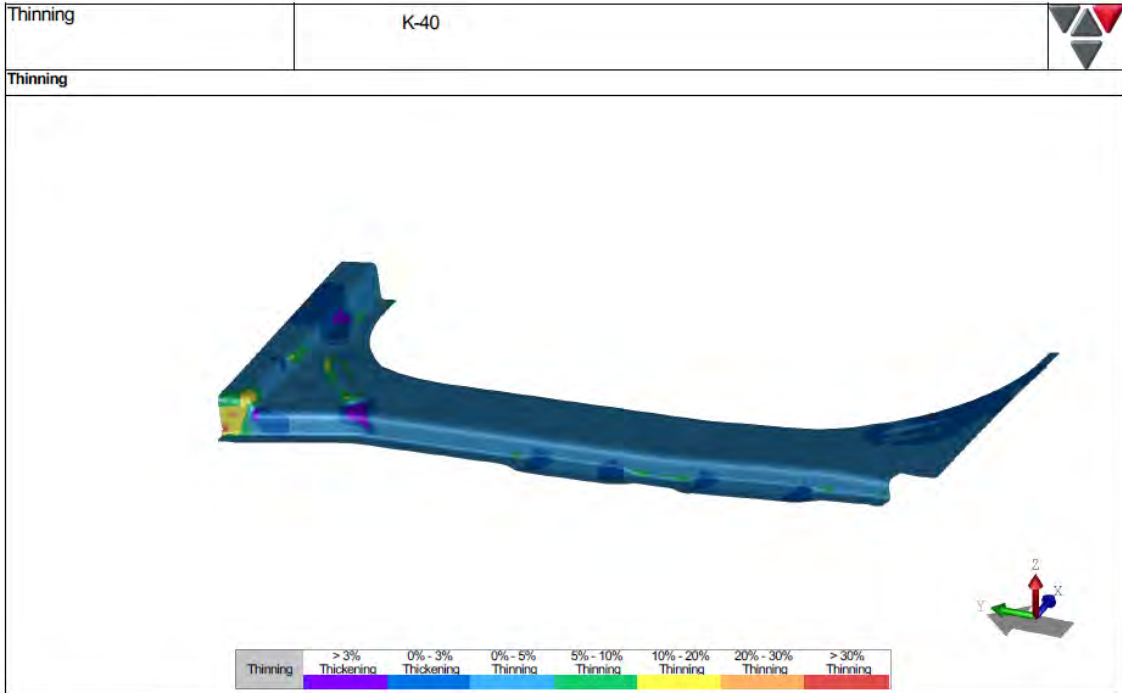
OEM: ARRK
 Vehicle Program: Steel E-Motiv
 Project Name: Phase 2

Name: Nick Sephton
 Department: Engineering
 Date: 16-06-2022 Page 2 of 8

Sheet metal forming simulation

| Input Data | | Material & Blank | |
|---|----------|---|----------|
| Calculated Material | 22MnB5 | Calc. Sheet Thickness | 1.000 mm |
| Yield Stress | r0 1.00 | r90 1.00 | |
| n-Value | r45 1.00 | E-Module | |
| Yield Curve  | | Yield Surface  | |
| MU - Part to Blank | | RAM tonnage - 110.3 tf | |
| 56.34 % | | | |
| | | Blank Info | |
| | | <input type="checkbox"/> Rectangular Blank | |
| | | <input checked="" type="checkbox"/> Shaped Blank | |
| | | Meshing | |
| Roll angle | | 0.00 ° | |
| Initial Element Size | | 20.00 mm | |
| Refinement Level | | 6 | |
| Max Element Angle | | 30.00 ° | |
| Blank Size - 1821.64 mm X 1021.57 mm | | | |
|  | | | |
| 22MnB5/1.000 mm | | | |



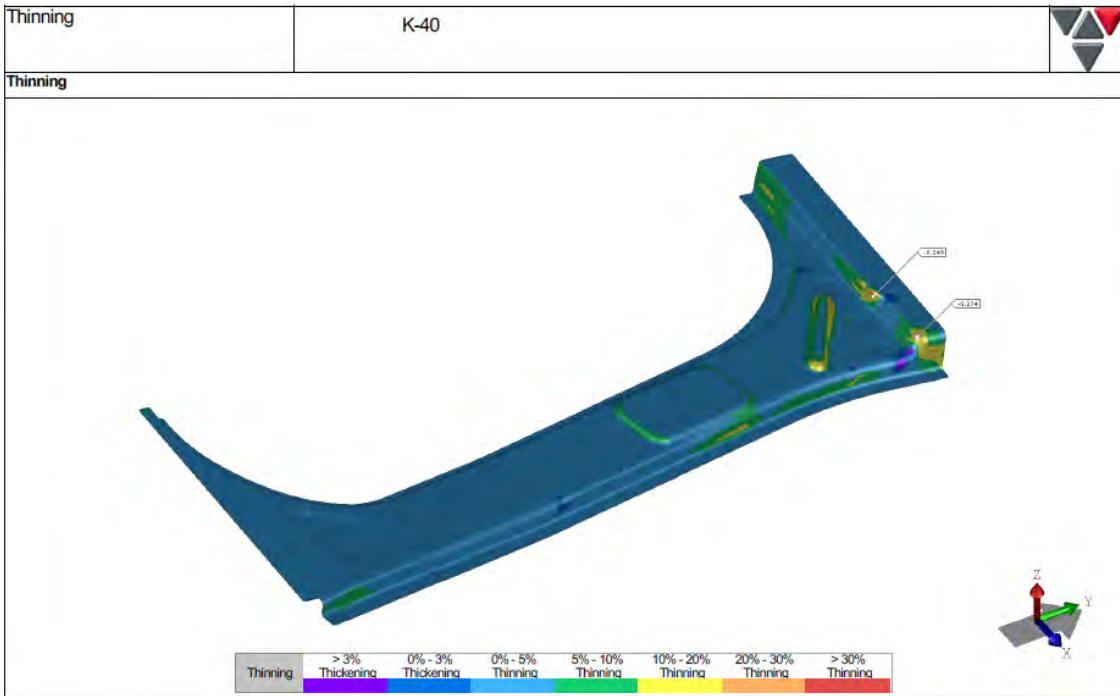
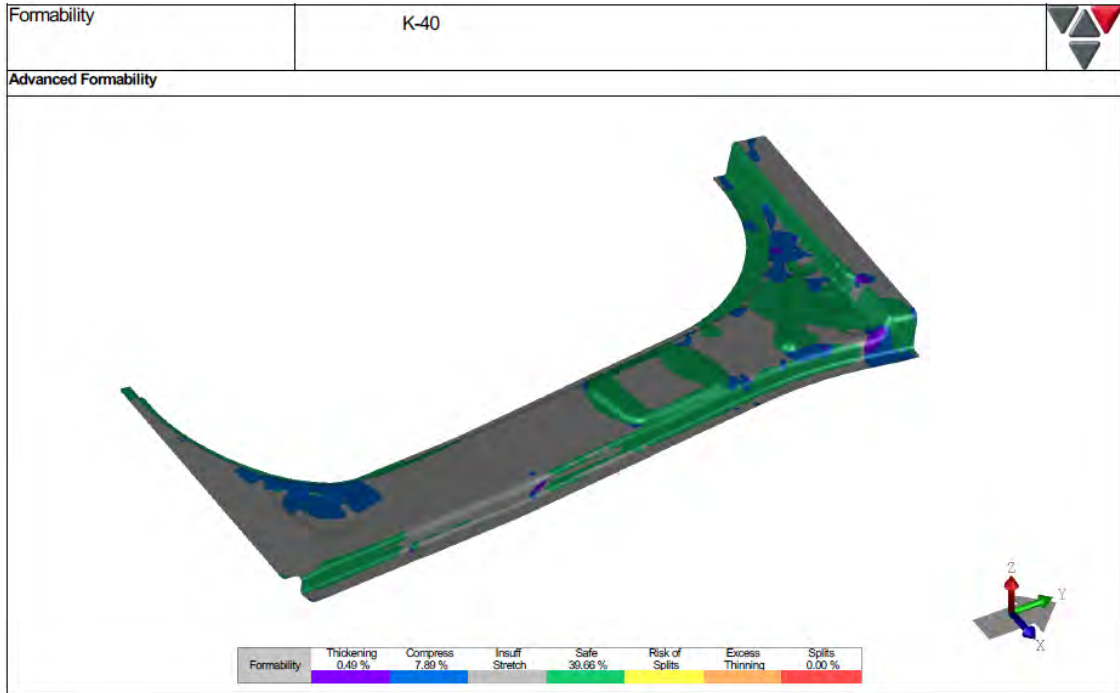


C pillar Inner

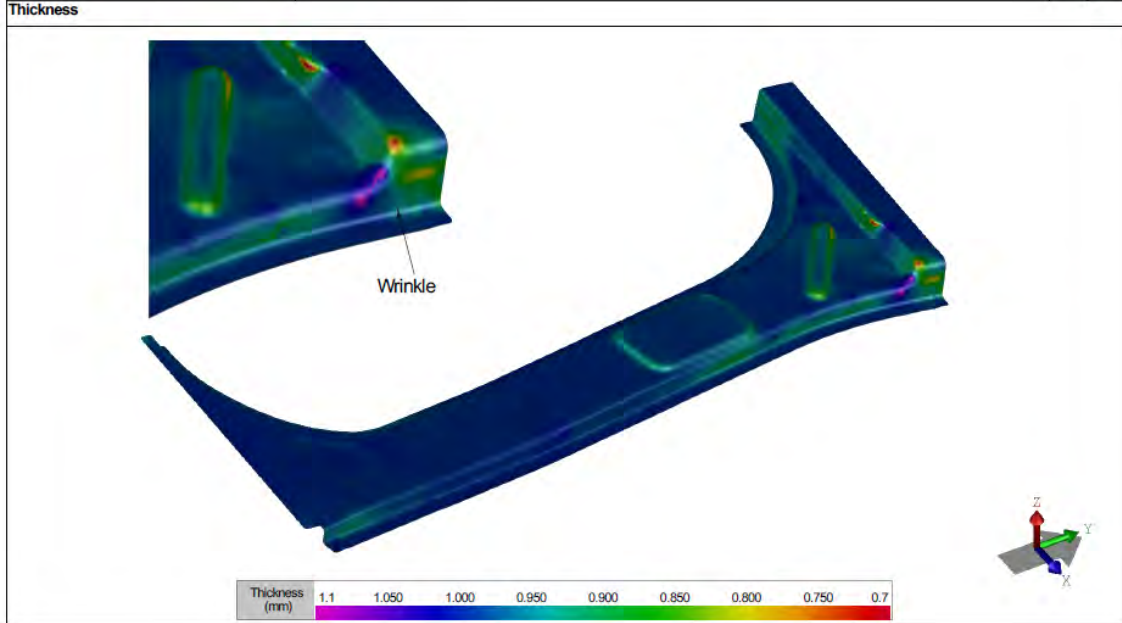
| Overview and Summary | | | | | | |
|--|---------------|---|------|-------------------------------------|--------------------------|---------------|
| Part Info | | Criterion | | OK | n OK | Status |
| Designation: 03440399-03328225 - C-PILLAR INNER LH | Type: Heating | FLD | 5.2 | <input type="checkbox"/> | <input type="checkbox"/> | |
| Part No.: | Drawing No.: | Wrinkles | 5.24 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Material: 22MnB5 | | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Sheet Thickness: 1.000 mm | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Info | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Plan No.: | | Thinning | 5.6 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Drawing No.: | Rev.: | Martensite | 5.7 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part | | Temperature | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Hardness | | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Simulation Info: | | | | |
| | | Filename: ARRK_03440399_C_Pillar_Inner_LH_NMS_31-8-22_it4 - EXTENSION MODS 3 - AutoForm Memory: 1450.10 MB AutoForm Forming Solver Thermo R10.0.0 | | | | |
| | | n | | | | |
| | | Process - Blank Die / Heating / Draw / Quenching / Laser Trim | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

| Input Data | | Material & Blank | | | |
|-------------------------------|--------|-----------------------|----------|--|----------|
| Calculated Material | 22MnB5 | Calc. Sheet Thickness | 1.000 mm | Blank Info | |
| Yield Stress | | r0 | 1.00 | <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| n-Value | | r45 | 1.00 | Meshing | |
| | | E-Module | | Roll angle | 0.00 ° |
| Yield Curve | | | | Initial Element Size | 20.00 mm |
| | | | | Refinement Level | 5 |
| Yield Surface | | | | Max Element Angle | 22.50 ° |
| | | | | Blank Size - 1778.49 mm X 1025.66 mm | |
| MU - Part to Blank 52.17 % | | | | | |
| RAM tonnage - 146.0 tf | | | | 22MnB5(1.000 mm) | |

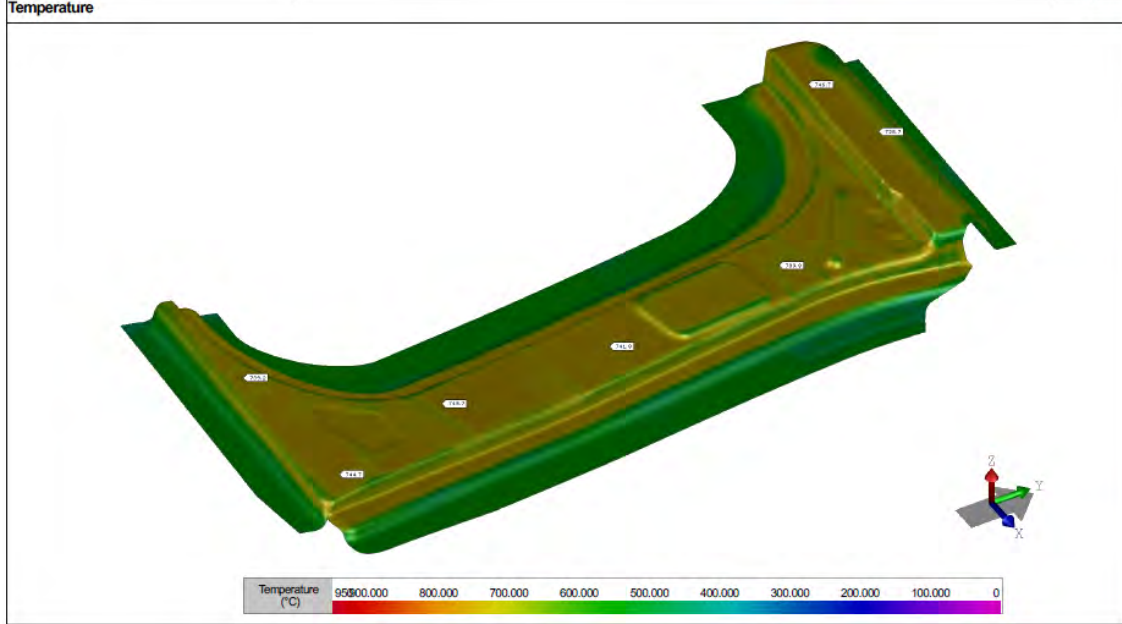
| Wrinkling Behavior | | D-20 | |
|-------------------------------|--|-------------------------------|--|
| Wrinkling at -54.97 mm | | Wrinkling at -27.67 mm | |
| | | | |
| Wrinkling at -10.10 mm | | Wrinkling at -1.00 mm | |
| | | | |




| | | |
|---------|------|--|
| Winking | K-40 | |
|---------|------|--|

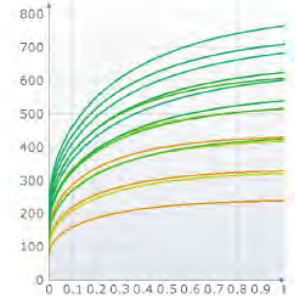
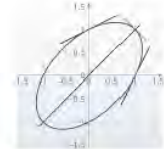
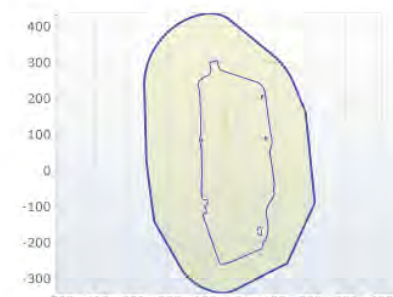


| | | |
|-------------|------|--|
| Temperature | K-40 | |
|-------------|------|--|

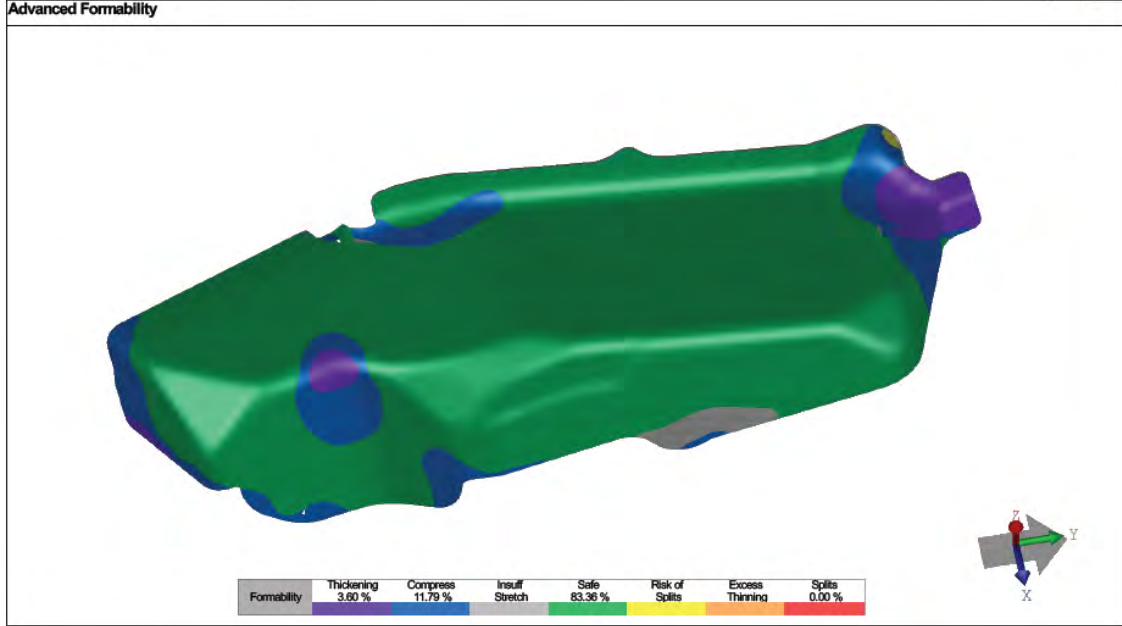


Vertical Dash Brace Lower

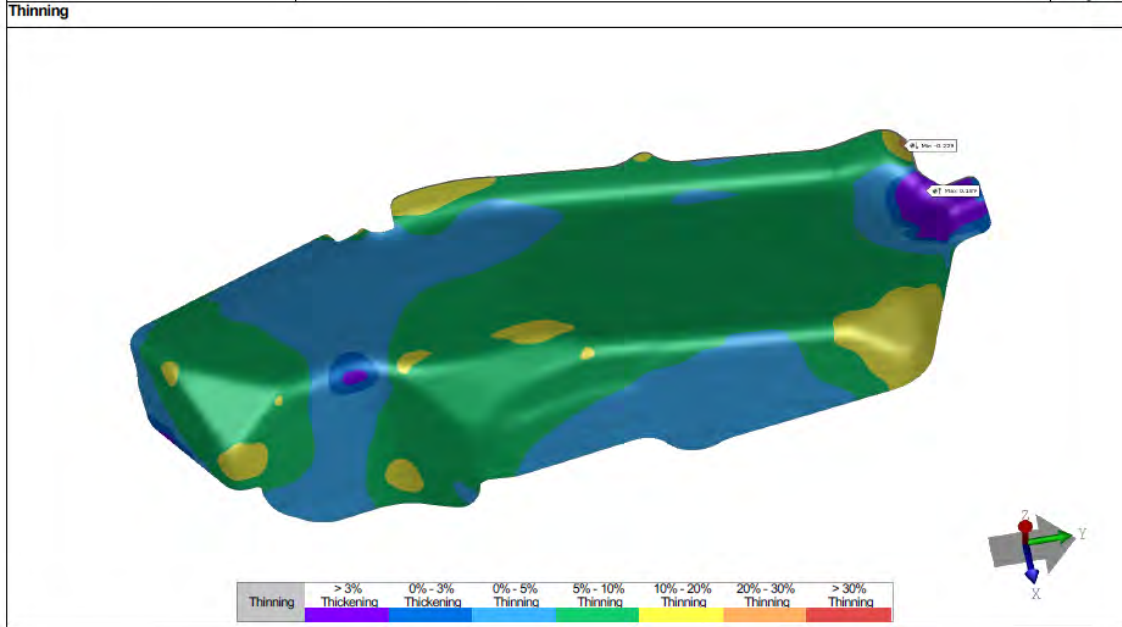
| Overview and Summary | | | |
|---|--------------------------|--|--|
| Part Info | | Criterion | OK n OK Status |
| Designation: 03448749 VERTICAL DASH BRACE OUTER | Type: Single Action Draw | FLD | 5.2 <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Part No.: | Drawing No.: | Flanging | 5.24 <input type="checkbox"/> <input type="checkbox"/> |
| Nom. / Calculated Material: Usibor1500_150mm_700C | | Gravity | 5.3 <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Nom. / Calculated Sheet Thickness: 2.000 mm | | Closing | 5.4 <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Method Info | | Forming | 5.5 <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Method Plan No.: | | Thinning | 5.6 <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Drawing No.: | | Martensite | 5.7 <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Rev.: | | Temperature | 5.8 <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Part | | Hardness | <input checked="" type="checkbox"/> <input type="checkbox"/> |
|  | | Simulation Info: | |
| | | Filename: ARRK_03448749_Vertical_Dash_Brace_LH_NMS_26-8-22_it13 - EXTENSION MODS 2 AutoForm Memory: 654.15 MB AutoForm Forming Solver Thermo R10.0.0 | |
| | | Process - Blank Die / Heating / Draw / Quenching / Laser Trim | |

| Input Data | | Material & Blank | |
|---|------------------|--|----------|
| Calculated Material | Usibor1500_150mm | Calc. Sheet Thickness | 2.000 mm |
| Yield Stress | r0 1.00 | r90 1.00 | |
| n-Value | r45 1.00 | E-Module | |
| Yield Curve | | Yield Surface | |
|  | |  | |
| MU - Part to Blank 45.67 % | | RAM Tonnage - 160.1 tf | |
| | | Blank Info <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| | | Meshing Roll angle 0.00 ° Initial Element Size 20.00 mm Refinement Level 5 Max Element Angle 22.50 ° | |
| | | Blank Size - 774.31 mm X 475.17 mm  | |

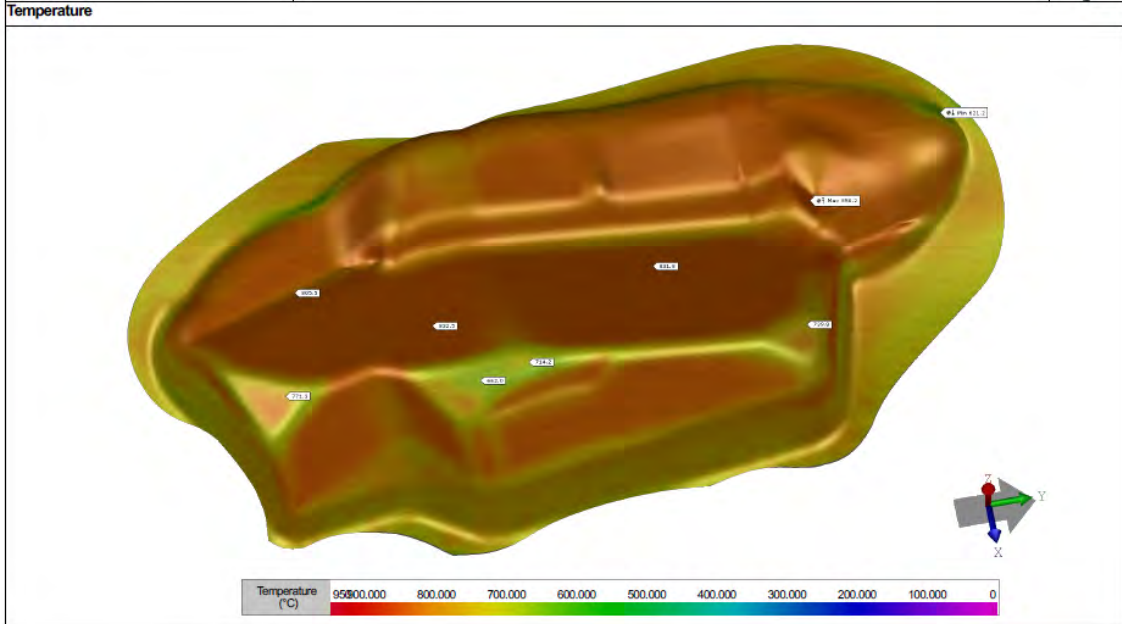
| | | |
|-------------|------|---|
| Formability | T-40 |  |
|-------------|------|---|




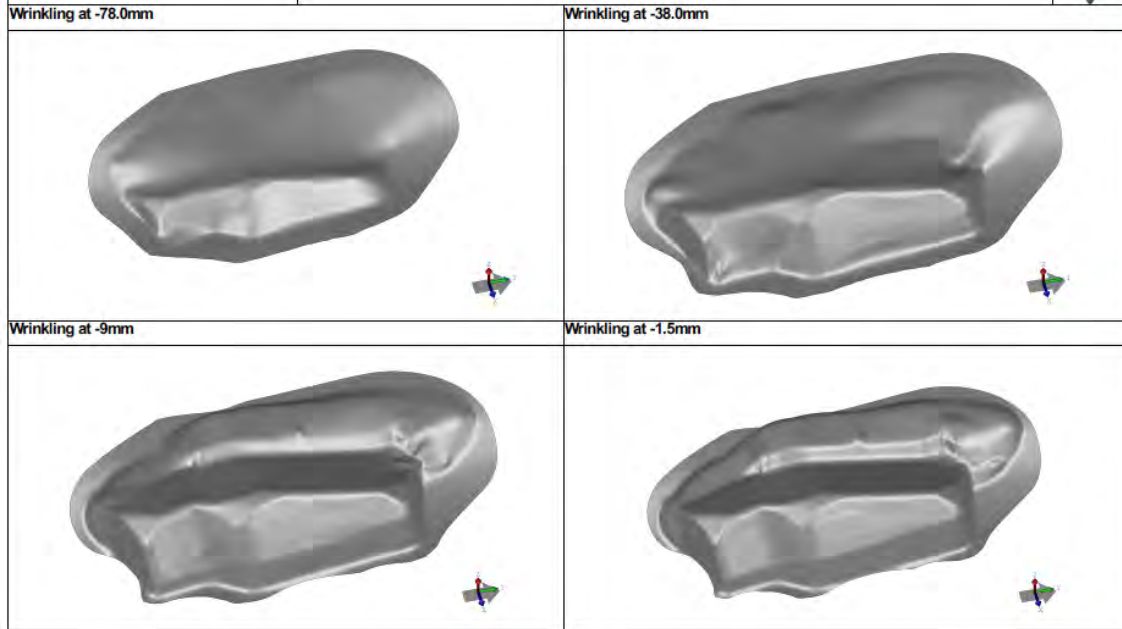
| | | |
|----------|------|---|
| Thinning | T-40 |  |
|----------|------|---|



| | | |
|-------------|------|---|
| Temperature | D-20 |  |
|-------------|------|---|



| | | |
|--------------------|------|---|
| Wrinkling Behavior | T-40 |  |
|--------------------|------|---|



Rocker Inner

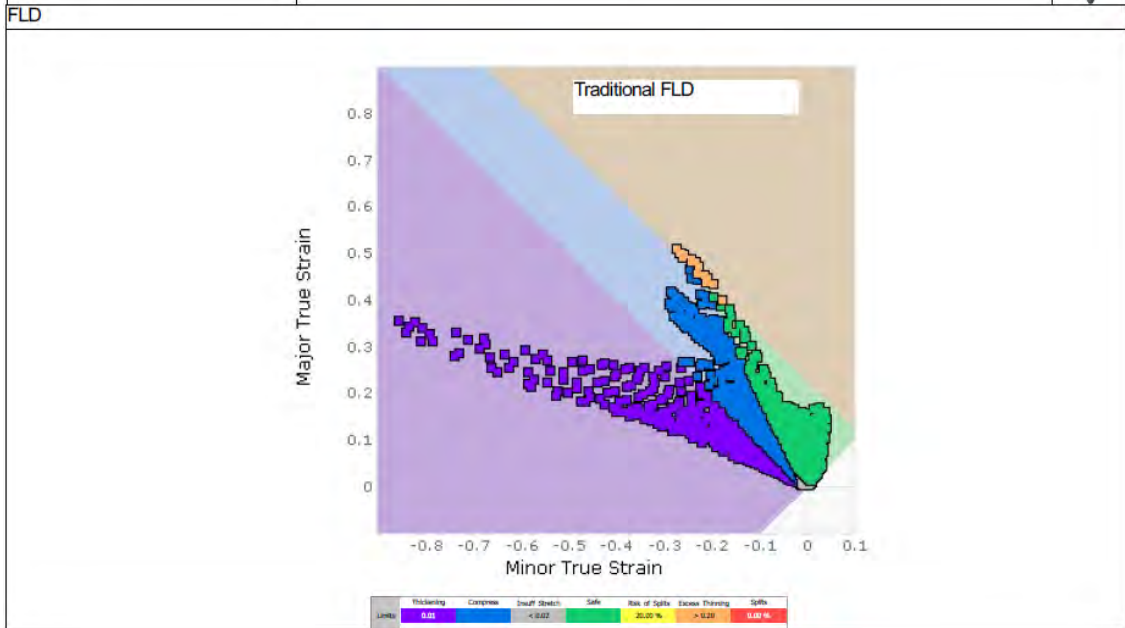
| Overview and Summary | | | | | |
|---|--|--|-------------------------------------|--------------------------|---------------|
| Part Info | | Criterion | OK | n OK | Status |
| Designation: 03451131 ROCKER INNER LH MW | | FLD | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Type: Heating | | Flanging | <input type="checkbox"/> | <input type="checkbox"/> | |
| Part No.: | | Gravity | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Drawing No.: | | Closing | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Material: 22MnB5 | | Forming | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Sheet Thickness: 1.500 mm | | Thinning | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Info | | Martensite | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Plan No.: | | Temperature | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Drawing No.: | | Hardness | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Rev.: | | Simulation Info: | | | |
| Part | | Filename: ARRK_03451131-Rocker_Inner_NMS_24-2-22_it1.afd | | | |
| | | AutoForm | | | |
| | | AutoForm Forming Solver Thermo R10.0.0 | | | |
| | | Memory: 629.87 MB | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

| Input Data | | Material & Blank | | | | | |
|--|--------|-----------------------|----------|---|----------|--|--|
| Calculated Material | | Blank Info | | | | | |
| Calculated Material | 22MnB5 | Calc. Sheet Thickness | 1.500 mm | <input checked="" type="checkbox"/> Rectangular Blank | | | |
| Yield Stress | | r0 | 1.00 | <input type="checkbox"/> Shaped Blank | | | |
| n-Value | | r45 | 1.00 | Meshing | | | |
| | | E-Module | | Roll angle | 0.00 ° | | |
| Yield Curve | | Yield Surface | | Initial Element Size | 40.00 mm | | |
| | | | | Refinement Level | 7 | | |
| <p>MU - Part to Blank</p> <p>84.18 %</p> | | | | Max Element Angle | 30.00 ° | | |
| | | | | | | | |

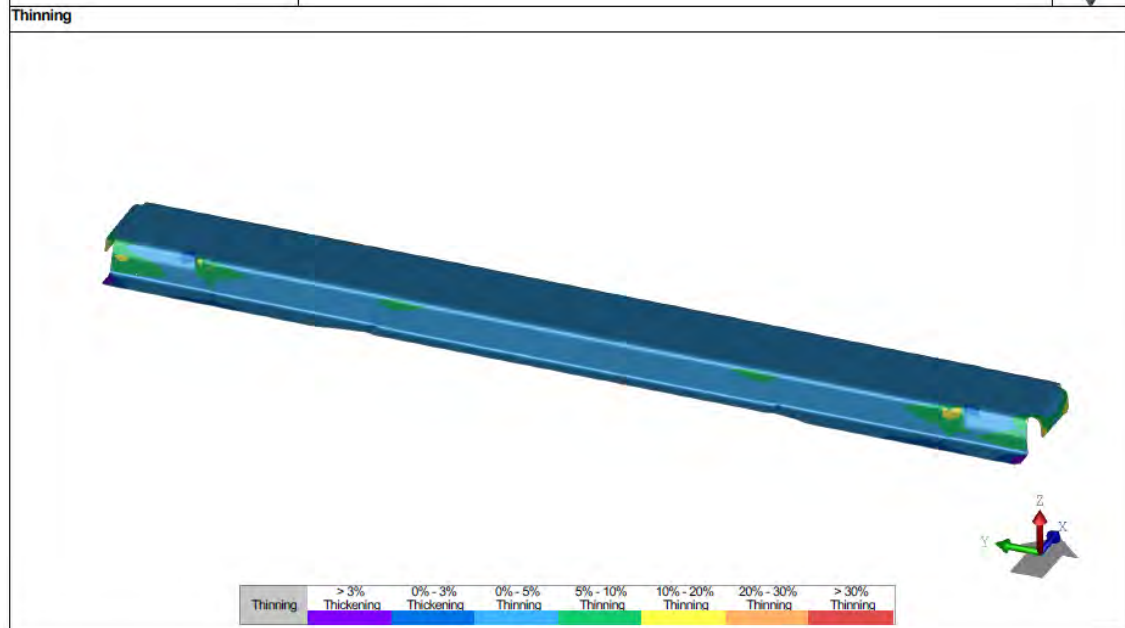
| | | | | | | | |
|------------------------------|-----------------------------|----------------|---------|-----------------------|----------|--|--|
| Input Data | | D-20 | | D-20 | | | |
| Tool Info | | | | Process Data | | | |
| Meshing Tolerance | 0.05 mm | | | Friction Coefficient | | | |
| Process Type | Single Action Draw | | | Constant | 0.450 | | |
| Tool Geometry Refers to | Lower Side of Initial Blank | | | Die - Blank | | | |
| Tools | Contact Side | Type | Gap | Punch - Blank | | | |
| Die | Upper Side of Blank | Rigid | | Binder - Blank | | | |
| Punch | Lower Side of Blank | Rigid | | Binderforce | | | |
| Binder | Lower Side of Blank | Gap Controlled | 0.50 mm | RAM | 153.0 tf | | |
| Tool Geometry 1st opp | | | | Binderforce/-pressure | 105.5 tf | | |
| | | | | | | | |

| | | | | | | | |
|-----------------------------|------------|----------|----------------|---------|----------------|-----------------|--------|
| Formability | | T-30 | | | | | |
| Advanced Formability | | | | | | | |
| | | | | | | | |
| Formability | Thickening | Compress | Insuff Stretch | Safe | Risk of Splits | Excess Thinning | Splits |
| | 1.23 % | 1.33 % | | 33.05 % | | | 0.00 % |

| | | |
|-------------|------|--|
| Formability | T-30 | |
|-------------|------|--|



| | | |
|----------|------|--|
| Thinning | T-30 | |
|----------|------|--|



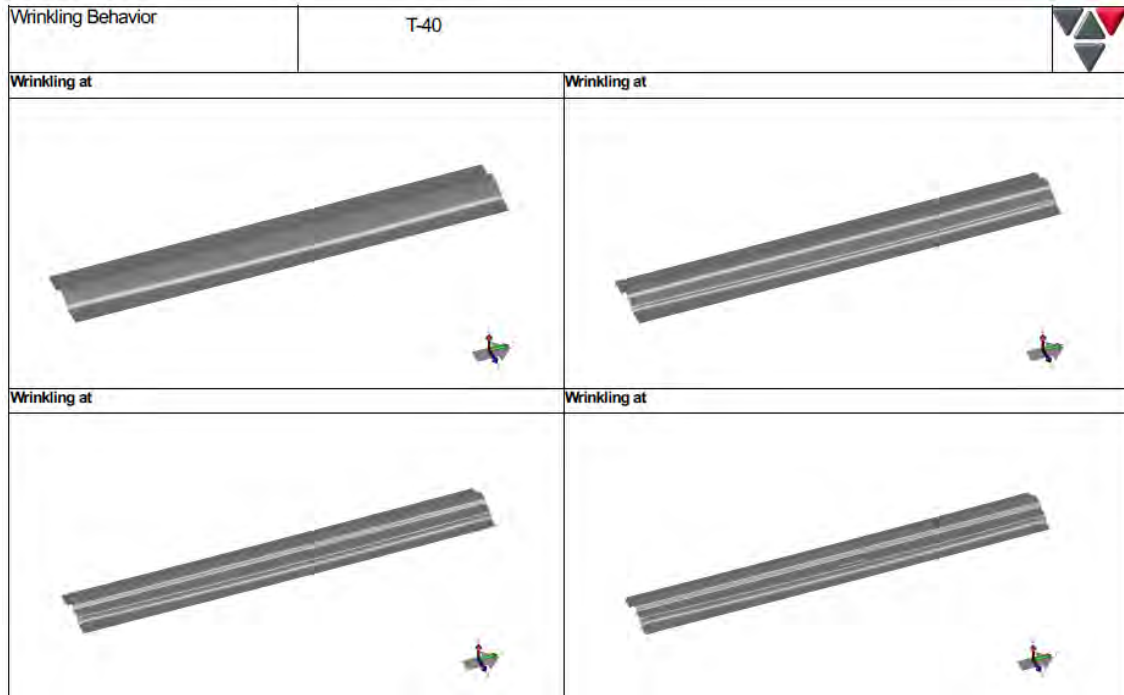
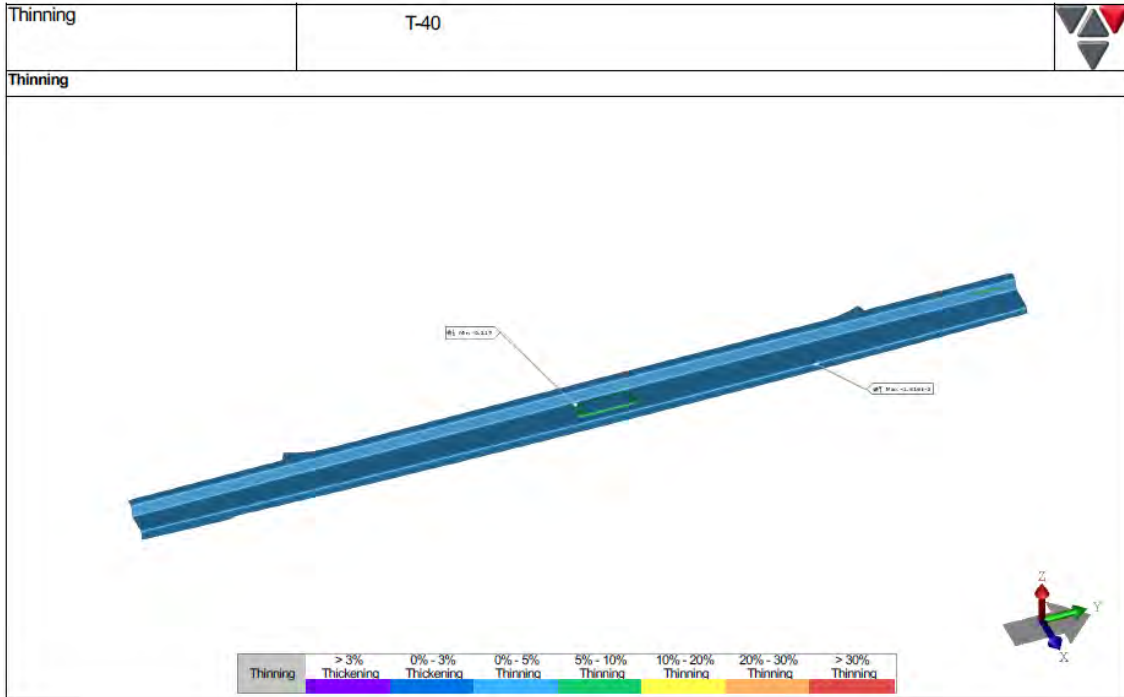
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|------------------------|--|------------------------|--|
| Wrinkling Behavior | | H-10 | |
| Wrinkling at -51.47 mm | | Wrinkling at -24.71 mm | |
| | | | |
| Wrinkling at -9.50 mm | | Wrinkling at 0.00 mm | |
| | | | |

Roof side rail inner

| | | | | | | |
|---|--|--|------|-------------------------------------|--------------------------|---------------|
| | | Overview and Summary | | | | |
| Part Info | | Criterion | | OK | n OK | Status |
| Designation: 03451542-Body.1 | | FLD | 5.2 | <input type="checkbox"/> | <input type="checkbox"/> | |
| Type: Single Action Draw | | Flanging | 5.24 | <input type="checkbox"/> | <input type="checkbox"/> | |
| Part No.: Drawing No.: | | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Material: Usibor1500_150mm_700C | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Sheet Thickness: 0.800 mm | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Info | | Thinning | 5.6 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Plan No.: | | Martensite | 5.7 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Drawing No.: Rev.: | | Temperature | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part | | Hardness | | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Simulation Info: | | | | |
| | | Filename:ARRK_03451542_Roof_Side_Rail_Inner_LH_NMS_7-6-22_it1.afd | | | | |
| | | AutoForm Memory: 1169.46 MB | | | | |
| | | AutoForm Forming Solver Thermo R10.0.0 | | | | |
| | | Remarks: No Issues | | | | |
| | | Process - Blank Die / Heating / Draw / Quenching / Laser Trim | | | | |
| | | | | | | |
| | | | | | | |

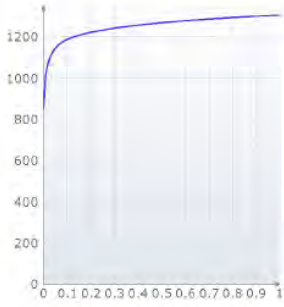
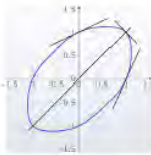
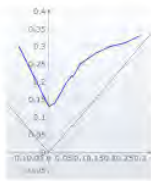
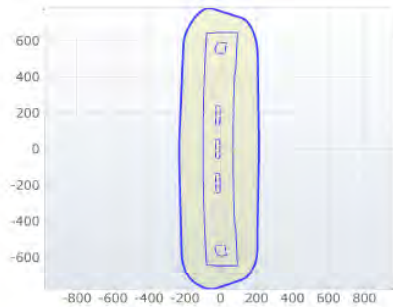
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|---------------------------------------|------------------|-------------------------------|----------|----------------------------------|------|--|
| Input Data | | Material & Blank | | | | |
| Calculated Material | Usibor1500_150mm | Calc. Sheet Thickness | 0.800 mm | | | Blank Info |
| Yield Stress | | r0 | 1.00 | r90 | 1.00 | <input checked="" type="checkbox"/> Rectangular Blank <input type="checkbox"/> Shaped Blank |
| n-Value | | r45 | 1.00 | E-Module | | Meshing |
| Yield Curve | | Yield Surface | | Roll angle | | 0.00 ° |
| | | | | Initial Element Size | | 40.00 mm |
| <p>MU - Part to Blank 33.06 %</p> | | <p>RAM Tonnage - 400.0 tf</p> | | Refinement Level | | 5 |
| | | | | Max Element Angle | | 22.50 ° |
| | | | | Blank Size - 2410.00 X 430.00 mm | | |
| | | | | | | |
| | | | | Usibor1500_150mm_200C0.800 mm | | |

| | | | | | | | |
|-----------------------------|------------|----------|----------------|---------|----------------|-----------------|--------|
| Formability | T-40 | | | | | | |
| Advanced Formability | | | | | | | |
| | | | | | | | |
| Formability | Thickening | Compress | Insuff Stretch | Safe | Risk of Splits | Excess Thinning | Splits |
| | 0.00 % | 0.09 % | | 26.14 % | | | 0.00 % |



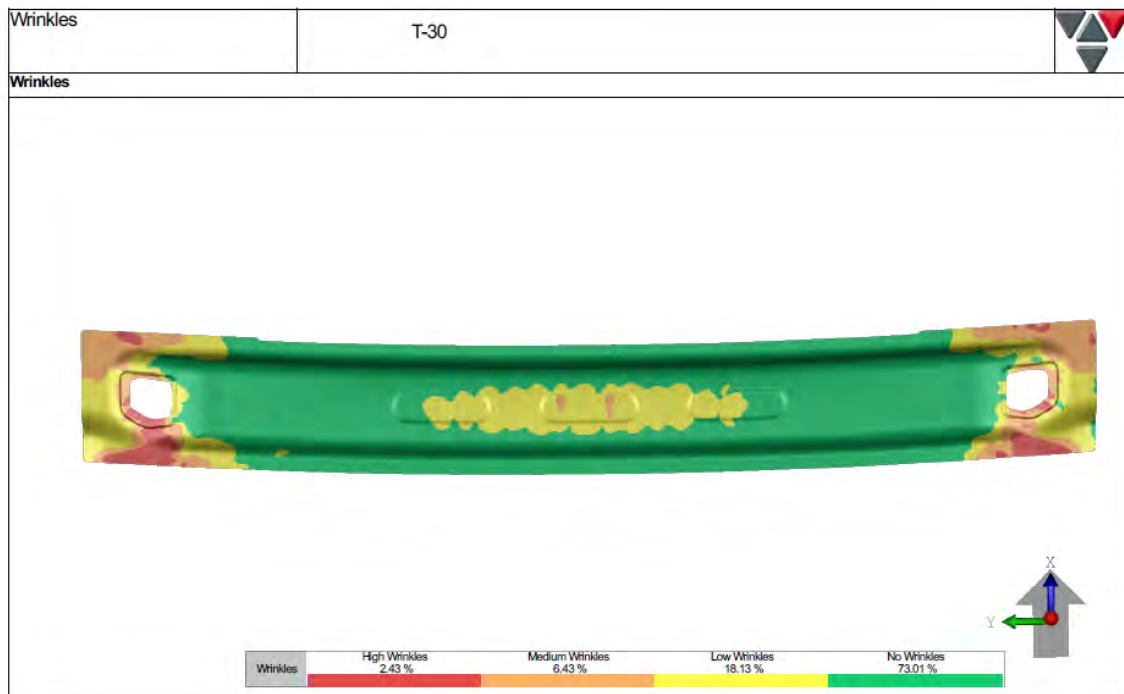
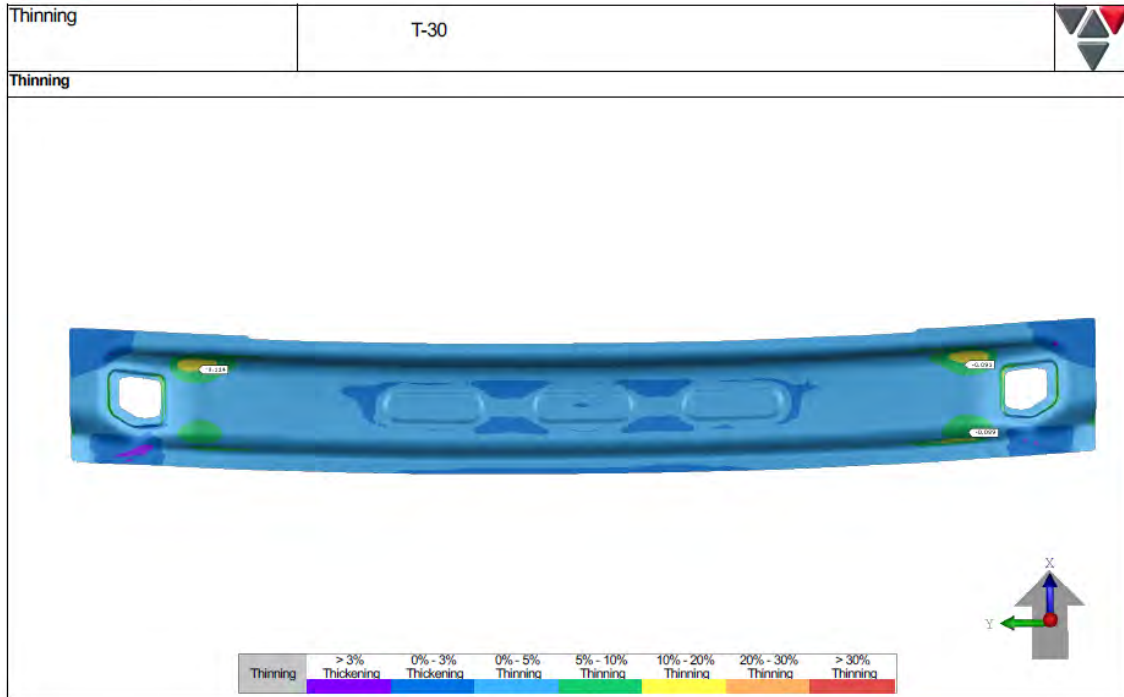
Front Header

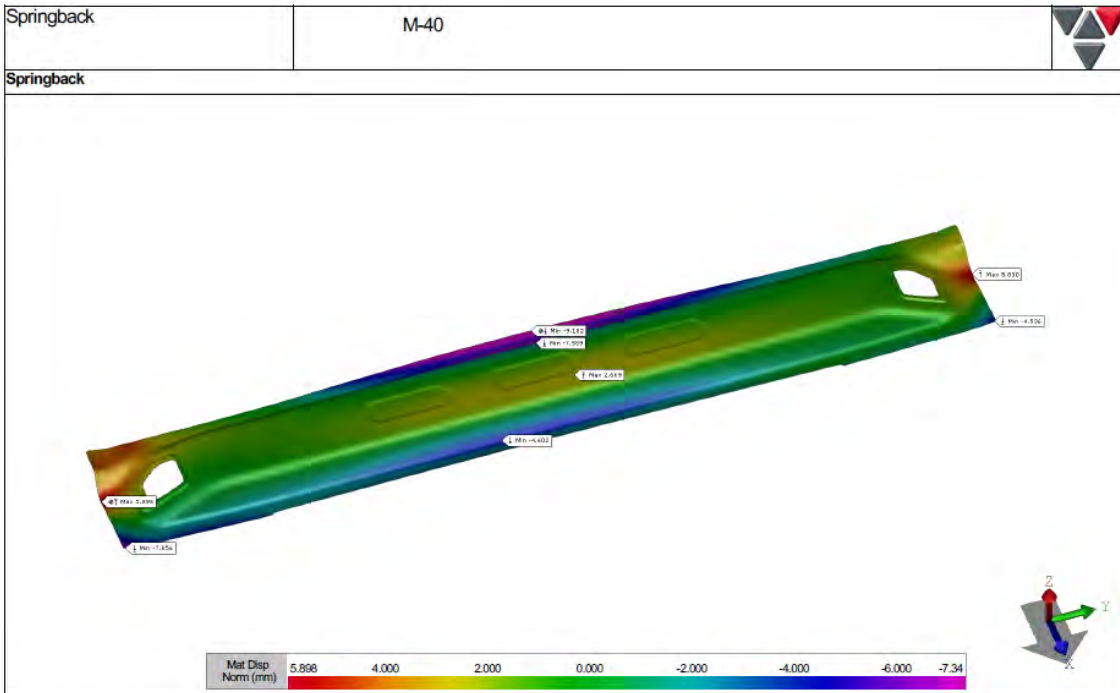
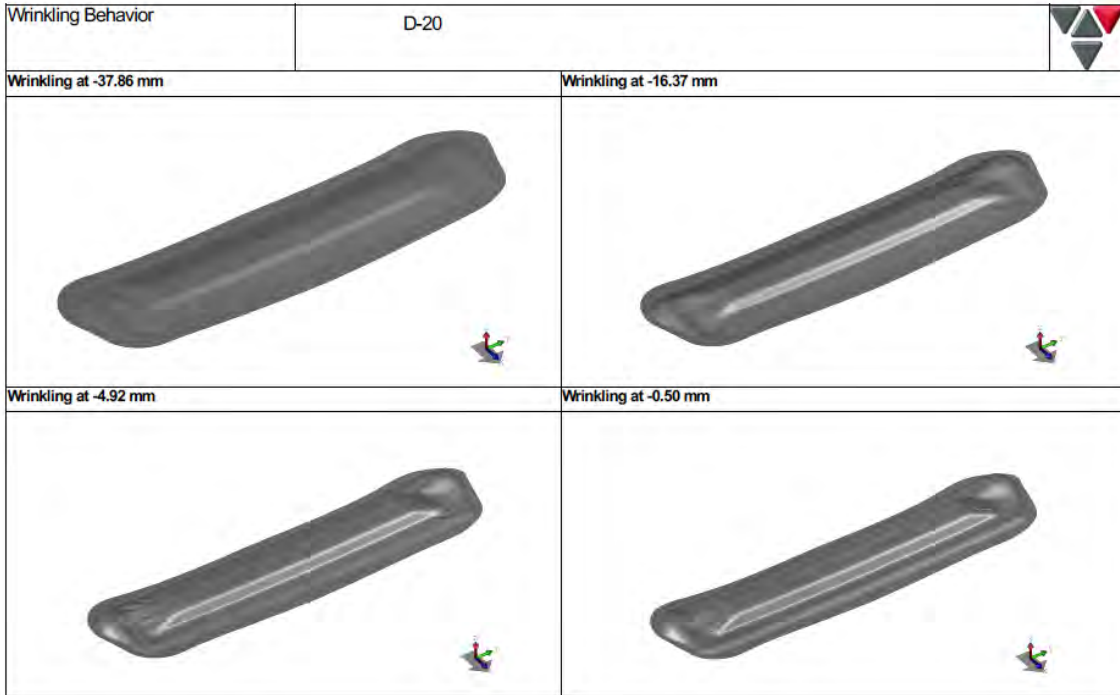
| Overview and Summary | | | |
|---|--------------------------|-------------------------|--|
| Part Info | | Criterion | OK n OK Status |
| Designation: 03451793-FRONT HEADER | Type: Single Action Draw | FLD 5.2 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Part No.: | Drawing No.: | Flanging 5.24 | <input type="checkbox"/> <input type="checkbox"/> |
| Nom. / Calculated Material: SSAB_CR780Y980T_CP | | Gravity 5.3 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Nom. / Calculated Sheet Thickness: 0.800 mm | | Closing 5.4 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Method Info | | Forming 5.5 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Method Plan No.: | | Thinning 5.6 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Drawing No.: | Rev.: | Strain 5.7 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Part | | Wrinkles 5.8 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
|  | | Springback 5.9 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| | | Simulation Info: | |
| Filename: ARRK_03451793_Front_Header_NMS_1-9-22_it6 - EXTENSION MODS 2 - EXTENDED AutoForm Memory: 1666.34 MB AutoForm Forming Solver R10.0.0 | | | |
| Process - Blank Die / Draw / Trim, CAM Pierce & Pierce / Trim, CAM Pierce and Pierce | | | |

| Input Data | | Material & Blank | |
|---|-----------------|--|--------------|
| Calculated Material | SSAB_CR780Y980T | Calc. Sheet Thickness | 0.800 mm |
| Yield Stress | 848.99 MPa | r0 | 0.88 |
| n-Value | 0.094 | r45 | 1.02 |
| | | E-Module | 2.00E+05 MPa |
| Yield Curve | | Yield Surface | |
|  | |  | |
| MU - Part to Blank 42.65 % | | Forming Limit Curve | |
| | |  | |
| | | Blank Info | |
| | | <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| | | Meshing | |
| | | Roll angle | 0.00 ° |
| | | Initial Element Size | 20.00 mm |
| | | Refinement Level | 6 |
| | | Max Element Angle | 22.50 ° |
| | | Blank Size - 1553.95 mm X 444.44 mm | |
| | |  | |
| | | SSAB_CR780Y980T_CP(0.800 mm) | |

| | | | | | | | |
|------------------------------|-----------------------------|------------------|-----|-----------------------|----------|--|--|
| Input Data | | D-20 | | D-20 | | | |
| Tool Info | | | | Process Data | | | |
| Meshing Tolerance | 0.05 mm | | | Friction Coefficient | Constant | | |
| Process Type | Single Action Draw | | | Constant | 0.100 | | |
| Tool Geometry Refers to | Lower Side of Initial Blank | | | Die - Blank | - | | |
| Tools | Contact Side | Type | Gap | Punch - Blank | - | | |
| Die | Upper Side of Blank | Rigid | | Binder - Blank | - | | |
| Punch | Lower Side of Blank | Rigid | | Binderforce | | | |
| Binder | Lower Side of Blank | Force Controlled | | RAM | 539.5 tf | | |
| Tool Geometry 1st opp | | | | Binderforce/-pressure | 180.0 tf | | |
| | | | | | | | |
| | | | | | | | |

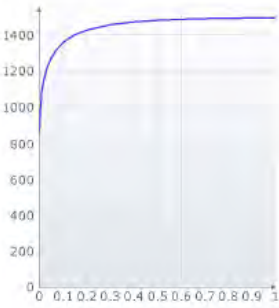
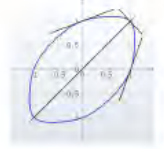
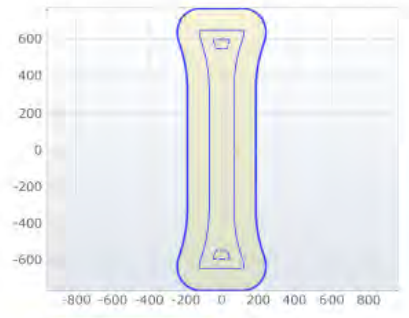
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|---|------------------|----------------|-----------------|-------------|--------------------------|------------------|------------------|----------------|-----------------|-------------|--------------------------|-----------------|------------------|
| Formability | | T-30 | | | | | | | | | | | |
| Advanced Formability | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| <table border="1"> <tr> <td>Adv. Formability</td> <td>Thickening 4.91%</td> <td>Compress 7.97%</td> <td>Insuff. Stretch</td> <td>Safe 23.86%</td> <td>Nonlinear Risk of Splits</td> <td>Excess Thinning</td> <td>Nonlinear Splits</td> </tr> </table> | | | | | | Adv. Formability | Thickening 4.91% | Compress 7.97% | Insuff. Stretch | Safe 23.86% | Nonlinear Risk of Splits | Excess Thinning | Nonlinear Splits |
| Adv. Formability | Thickening 4.91% | Compress 7.97% | Insuff. Stretch | Safe 23.86% | Nonlinear Risk of Splits | Excess Thinning | Nonlinear Splits | | | | | | |
| | | | | | | | | | | | | | |





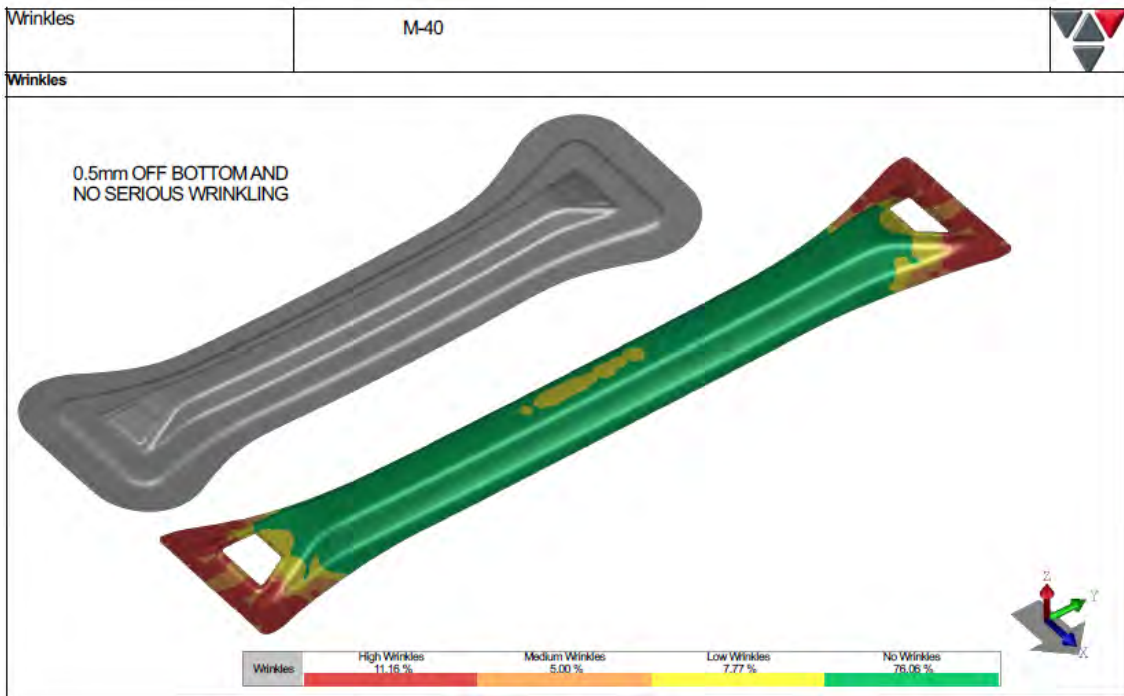
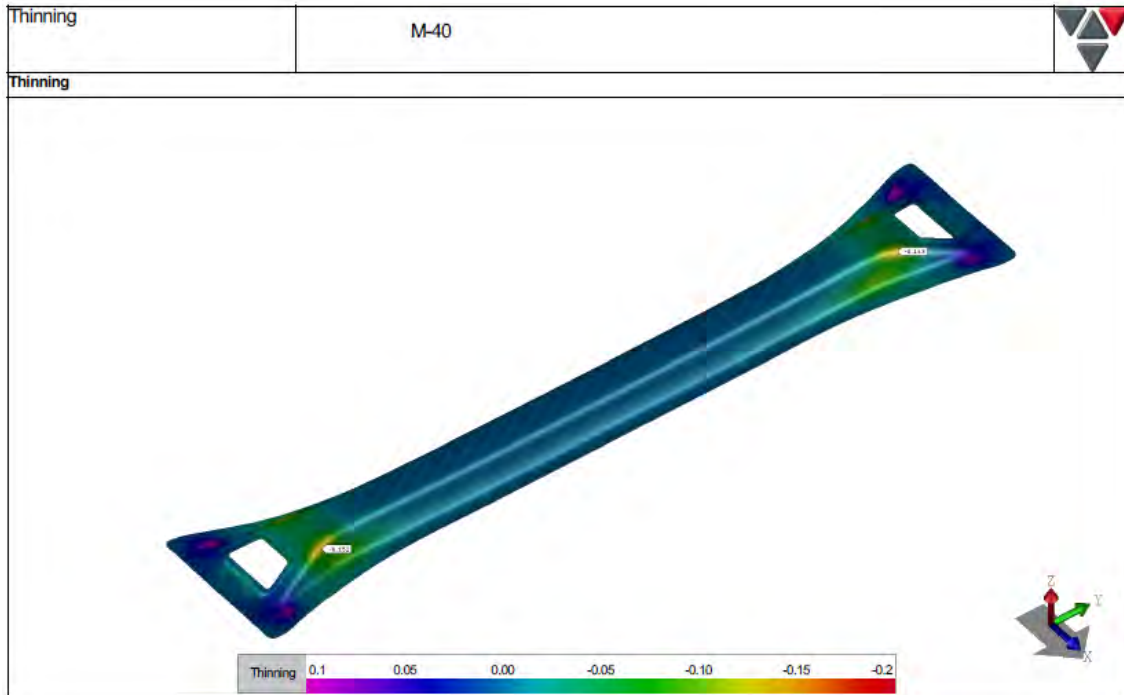
Inner roof frame middle

| Overview and Summary | | | |
|---|--------------------------|---|--|
| Part Info | | Criterion | Status |
| Designation: 03462738 INNER ROOF FRAME MIDDLE | Type: Single Action Draw | FLD 5.2 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
| Part No.: | Drawing No.: | Flanging 5.24 | <input type="checkbox"/> OK <input type="checkbox"/> n OK |
| Nom. / Calculated Material: CR820Y1180T_RA_CE+ | | Gravity 5.3 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
| Nom. / Calculated Sheet Thickness: 0.800 mm | | Closing 5.4 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
| Method Info | | Forming 5.5 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
| Method Plan No.: | | Thinning 5.6 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
| Drawing No.: | Rev.: | Strain 5.7 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
| Part | | Wrinkles 5.8 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
|  | | Springback 5.9 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
| | | Simulation Info: Filename: ARRK_03462738_Inr_Roof_Frame_Middle_NMS_8-9-22_it2 - EXTENSION MODS 1 - AutoForm AutoForm Forming Solver R10.0.0 Memory: 1157.50 MB | |
| Process - Blank / Draw / Laser Trim | | | |

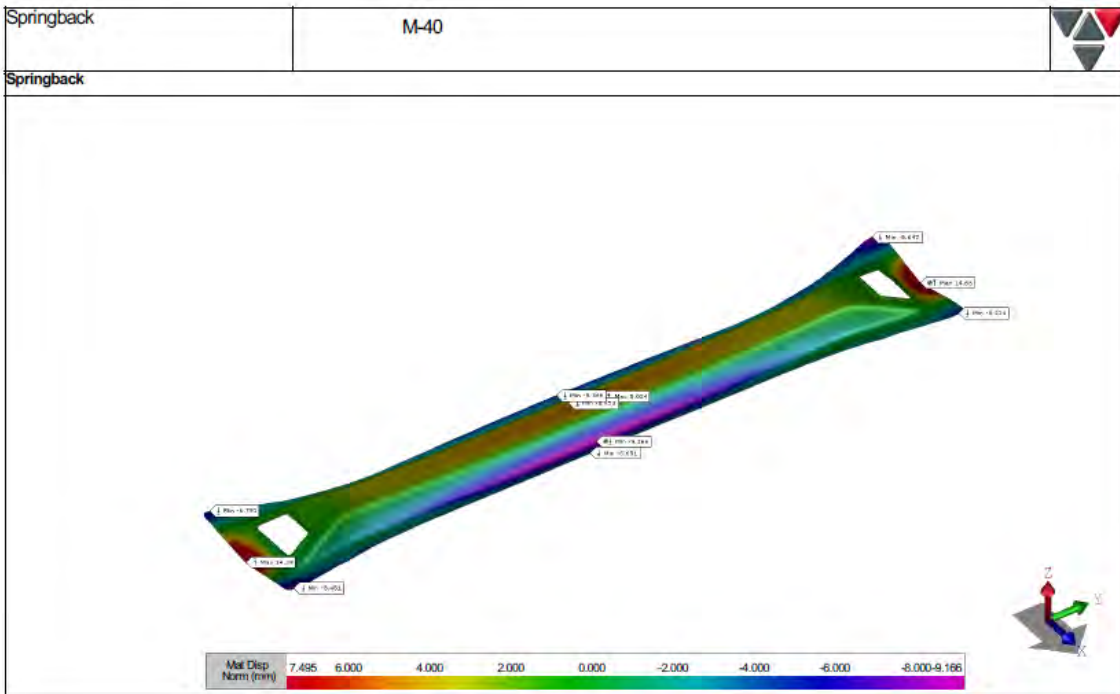
| Input Data | | Material & Blank | |
|--|----------------|---|--------------|
| Calculated Material | CR820Y1180T_RA | Calc. Sheet Thickness | 0.800 mm |
| Yield Stress | 869.85 MPa | r0 | 0.56 |
| n-Value | 0.119 | r45 | 0.77 |
| | | r90 | 0.61 |
| | | E-Module | 2.10E+05 MPa |
| Yield Curve | | Yield Surface | |
|  | |  | |
| MU - Part to Blank 45.39 % | | Forming Limit Curve | |
| | | Blank Info <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| | | Meshing | |
| | | Roll angle | 0.00 ° |
| | | Initial Element Size | 20.00 mm |
| | | Refinement Level | 6 |
| | | Max Element Angle | 22.50 ° |
|  | | | |

| | | | | | | | |
|------------------------------|-----------------------------|------------------|-----|-----------------------|----------|--|--|
| Input Data | | D-20 | | D-20 | | | |
| Tool Info | | | | Process Data | | | |
| Meshing Tolerance | 0.05 mm | | | Friction Coefficient | Constant | | |
| Process Type | Single Action Draw | | | Constant | 0.100 | | |
| Tool Geometry Refers to | Lower Side of Initial Blank | | | Die - Blank | - | | |
| Tools | Contact Side | Type | Gap | Punch - Blank | - | | |
| Die | Upper Side of Blank | Rigid | | Binder - Blank | - | | |
| Punch | Lower Side of Blank | Rigid | | Binderforce | | | |
| Binder | Lower Side of Blank | Force Controlled | | RAM | 488.2 tf | | |
| Tool Geometry 1st opp | | | | Binderforce/-pressure | 184.4 tf | | |
| | | | | | | | |

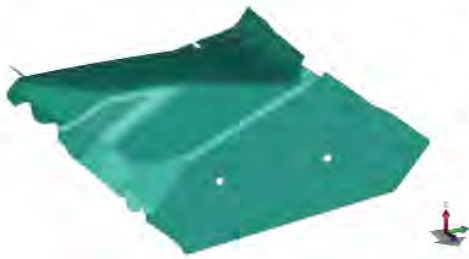
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|---|------------|----------|----------------|---------|----------------|-----------------|------------|----------|----------------|------|----------------|-----------------|--------|--|---------|--------|--|---------|--|--|--------|
| Formability | | M-40 | | | | | | | | | | | | | | | | | | | |
| Advanced Formability | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | |
| <table border="1"> <tr> <td>Formability</td> <td>Thickening</td> <td>Compress</td> <td>Insuff Stretch</td> <td>Safe</td> <td>Risk of Splits</td> <td>Excess Thinning</td> <td>Splits</td> </tr> <tr> <td></td> <td>19.11 %</td> <td>7.22 %</td> <td></td> <td>20.17 %</td> <td></td> <td></td> <td>0.00 %</td> </tr> </table> | | | | | | Formability | Thickening | Compress | Insuff Stretch | Safe | Risk of Splits | Excess Thinning | Splits | | 19.11 % | 7.22 % | | 20.17 % | | | 0.00 % |
| Formability | Thickening | Compress | Insuff Stretch | Safe | Risk of Splits | Excess Thinning | Splits | | | | | | | | | | | | | | |
| | 19.11 % | 7.22 % | | 20.17 % | | | 0.00 % | | | | | | | | | | | | | | |

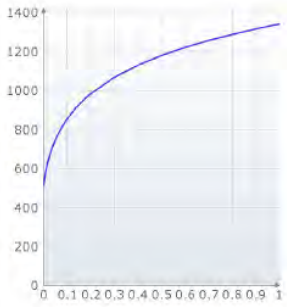
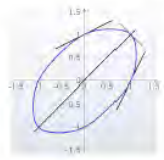




| | | | |
|------------------------|--|------------------------|--|
| Wrinkling Behavior | | D-20 | |
| Wrinkling at -42.55 mm | | Wrinkling at -26.32 mm | |
| | | | |
| Wrinkling at -11.07 mm | | Wrinkling at -1.50 mm | |
| | | | |




Front Torque Box

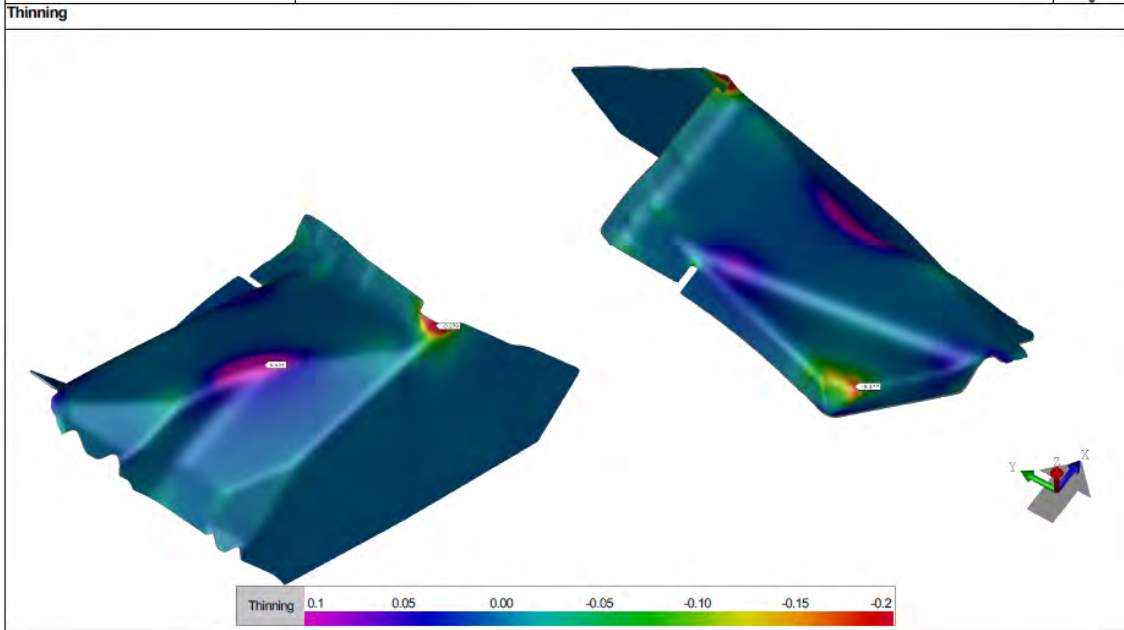
| Overview and Summary | | | | | |
|---|--------------------------|---|-----------|-------------------------------------|--------------------------|
| Part Info | | Criterion | OK | n OK | Status |
| Designation: 03469873 Torque Box Front | Type: Single Action Draw | FLD | 5.2 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Part No.: | Drawing No.: | Flanging | 5.24 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Nom. / Calculated Material: RA780 - CE | | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Nom. / Calculated Sheet Thickness: 1.800 mm | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Method Info | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Method Plan No.: | | Thinning | 5.6 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Drawing No.: | Rev.: | Strain | 5.7 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Part | | Wrinkles | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
|  | | Springback | 5.9 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| | | Simulation Info: Filename: ARRK_03469873_Front_Torque_Box_NMS_22-9-22_it1 - EXTENSION MODS 1 - CAD AutoForm AutoForm Forming Solver R10.0.0 | | | |
| | | Memory: 138.98 MB | | | |

| Input Data | | Material & Blank | | | |
|---|------------|--|----------|--|--------------|
| Calculated Material | RA780 - CE | Calc. Sheet Thickness | 1.800 mm | | |
| Yield Stress | 509.85 MPa | r0 | 1.00 | r90 | 1.00 |
| n-Value | 0.186 | r45 | 1.00 | E-Module | 2.10E+05 MPa |
| Yield Curve | | Yield Surface | | Blank Info | |
|  | |  | | <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| Forming Limit Curve | |  | | Meshing | |
| | | | | Roll angle | 0.00 ° |
| | | | | Initial Element Size | 40.00 mm |
| | | | | Refinement Level | 7 |
| | | | | Max Element Angle | 30.00 ° |
| | |  | | | |

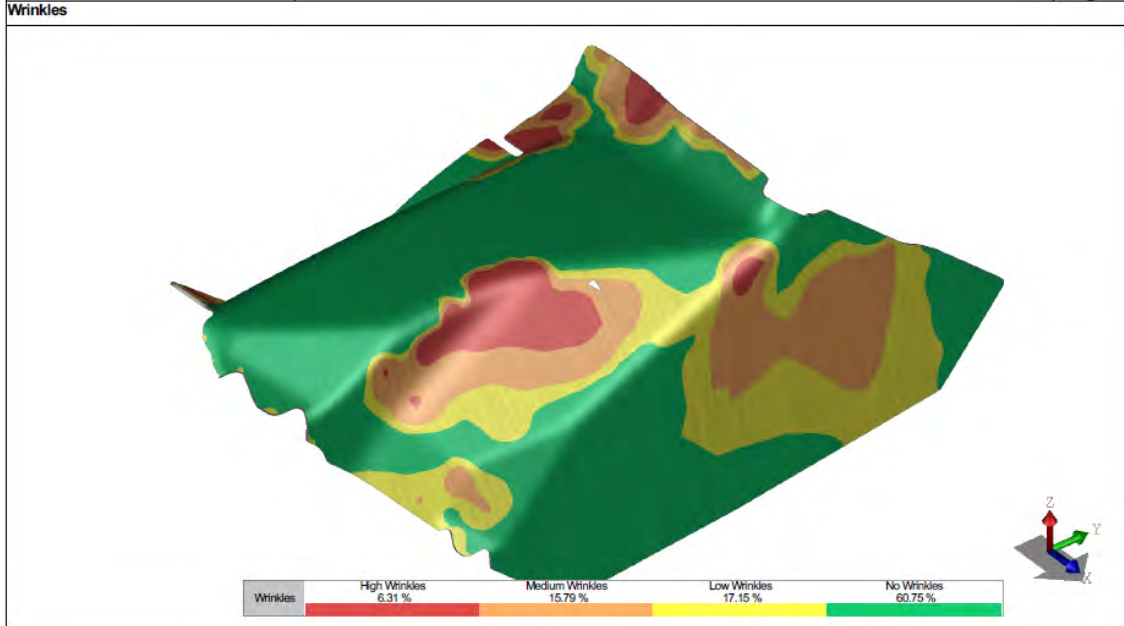
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|------------------------------|-----------------------------|------|------------------|------------------------------|--|----------|--|
| Input Data | | D-20 | | D-20 | | | |
| Tool Info | | | | Process Data | | | |
| Meshing Tolerance | 0.05 mm | | | Friction Coefficient | | | |
| Process Type | Single Action Draw | | | Constant 0.100 | | | |
| Tool Geometry Refers to | Upper Side of Initial Blank | | | Die - Blank | | | |
| Tools | Contact Side | Type | Gap | Punch - Blank | | | |
| Upr Steel | Upper Side of Blank | | Rigid | Binder - Blank | | | |
| Upr Pad | Upper Side of Blank | | Force Controlled | Binderforce | | | |
| Punch | Lower Side of Blank | | Rigid | RAM | | 223.1 tf | |
| Tool Geometry 1st opp | | | | Binderforce/-pressure | | | |
| | | | | 101.0 tf | | | |
| | | | | Tool Geometry 1st opp | | | |
| | | | | | | | |

| | | | | | | | | | | | | | |
|--|-----------------------|---------------------|-------------------|----------------|-----------------------------|--------------------|-----------------------|---------------------|-------------------|----------------|-----------------------------|--------------------|---------------------|
| Formability | | T-50 | | | | | | | | | | | |
| Advanced Formability | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| <table border="1"> <tr> <td>Adv Fbilty</td> <td>Thickening 24.78 %</td> <td>Compress 15.49 %</td> <td>Insuff Stretch</td> <td>Safe 4.71 %</td> <td>Nonlinear Risk of Splits</td> <td>Excess Thinning</td> <td>Nonlinear Splits</td> </tr> </table> | | | | | | Adv Fbilty | Thickening 24.78 % | Compress 15.49 % | Insuff Stretch | Safe 4.71 % | Nonlinear Risk of Splits | Excess Thinning | Nonlinear Splits |
| Adv Fbilty | Thickening 24.78 % | Compress 15.49 % | Insuff Stretch | Safe 4.71 % | Nonlinear Risk of Splits | Excess Thinning | Nonlinear Splits | | | | | | |

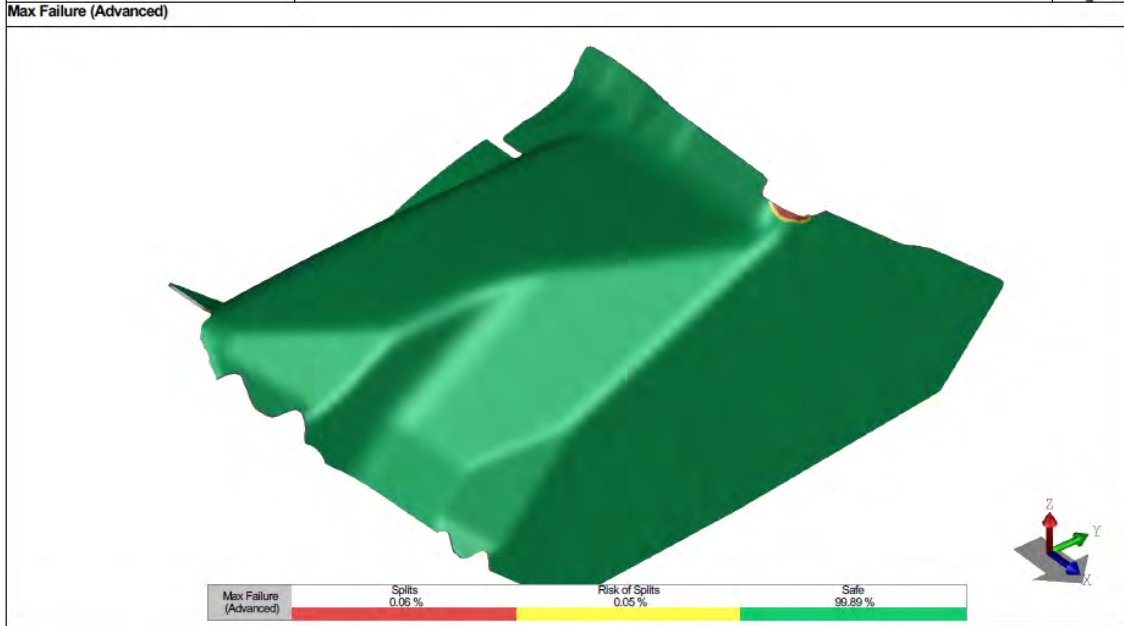
| | | |
|----------|------|---|
| Thinning | T-30 |  |
|----------|------|---|




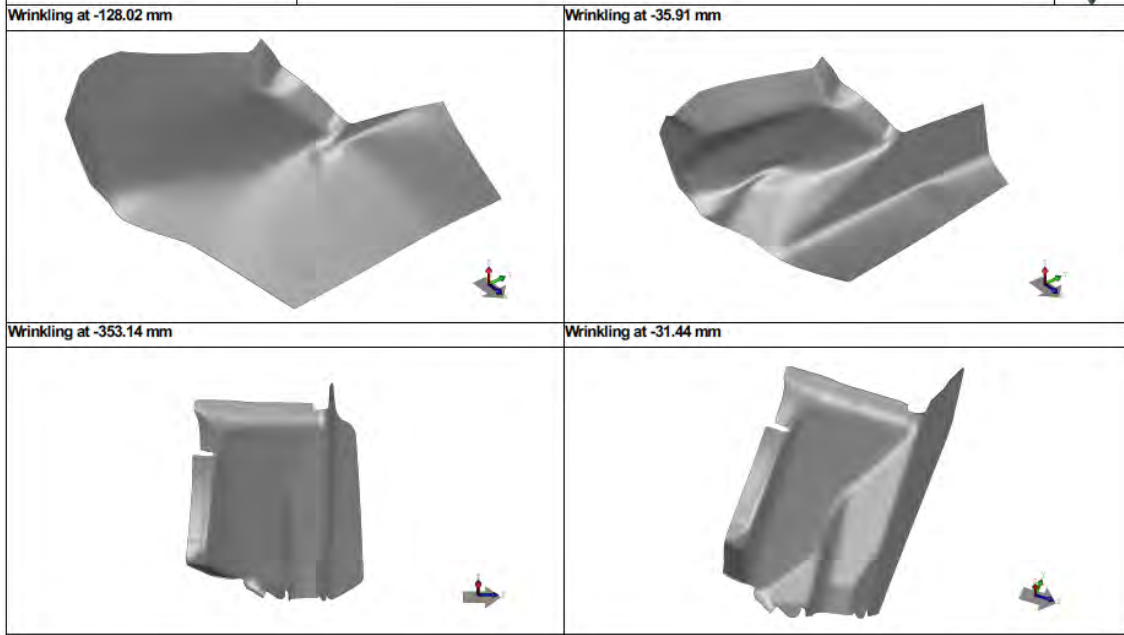
| | | |
|----------|------|---|
| Wrinkles | T-30 |  |
|----------|------|---|



| | | |
|-------------|------|---|
| Max Failure | T-30 |  |
|-------------|------|---|

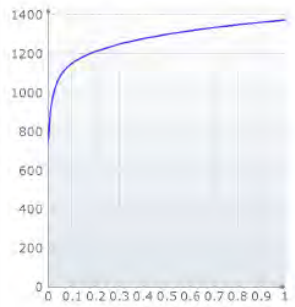
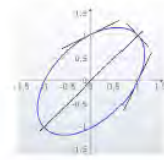
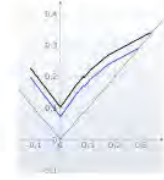
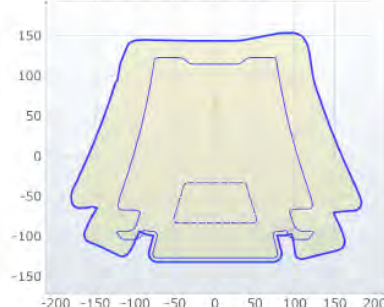



| | | |
|--------------------|------|---|
| Wrinkling Behavior | D-20 |  |
|--------------------|------|---|

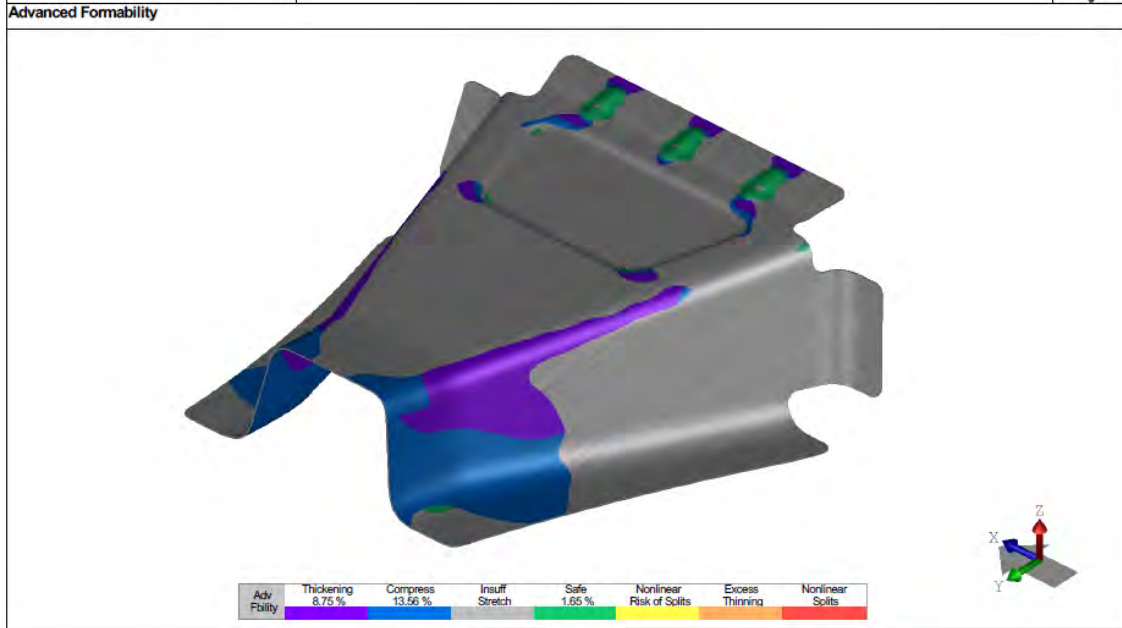


Mid roof bow mount LH

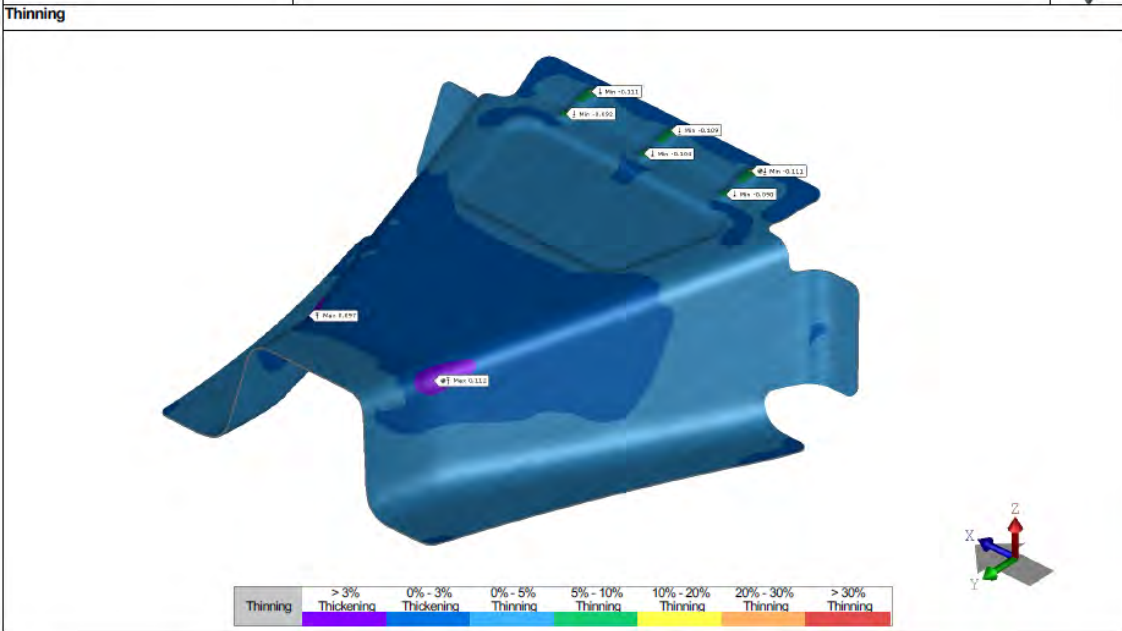
| Overview and Summary | | | |
|---|--------------|---|--|
| Part Info | | Criterion | OK n OK Status |
| Designation: 03470012 ROOF CROSSMEMBER REINF | Type: | FLD 5.2 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Part No.: | Drawing No.: | Flanging 5.24 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Nom. / Calculated Material: Dual_Phase_980_HY | | Gravity 5.3 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Nom. / Calculated Sheet Thickness: 0.800 mm | | Closing 5.4 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Method Info | | Forming 5.5 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Method Plan No.: | | Thinning 5.6 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Drawing No.: | Rev.: | Strain 5.7 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Part | | Wrinkles 5.8 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
|  | | Springback 5.9 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| | | Simulation Info: | |
| | | Filename: ARRK_03470012_Mid_Roof_Bow_Mount_LH_NMS_12-8-22_it3 - EXTENSION MODS 1 AutoForm Memory: 140.97 MB AutoForm Forming Solver R10.0.0 | |
| Process - Blank Die / Form / CAM Flange / Pierce | | | |


| Input Data | | Material & Blank | |
|---|-------------------|--|--------------|
| Calculated Material | Dual_Phase_980_HY | Calc. Sheet Thickness | 0.800 mm |
| Yield Stress | 745.58 MPa | r0 | 0.93 |
| n-Value | 0.128 | r45 | 0.95 |
| | | r90 | 1.04 |
| | | E-Module | 2.10E+05 MPa |
| Yield Curve | | Yield Surface | |
|  | |  | |
| MU - Part to Blank 81.31 % | | Forming Limit Curve | |
| | |  | |
| | | Meshing | |
| | | Roll angle | 90.00 ° |
| | | Initial Element Size | 40.00 mm |
| | | Refinement Level | 6 |
| | | Max Element Angle | 22.50 ° |
| | | Blank size - 285.41 mm X 363.38 mm | |
| | |  | |
| | | Dual_Phase_980_HY/0.800 mm | |

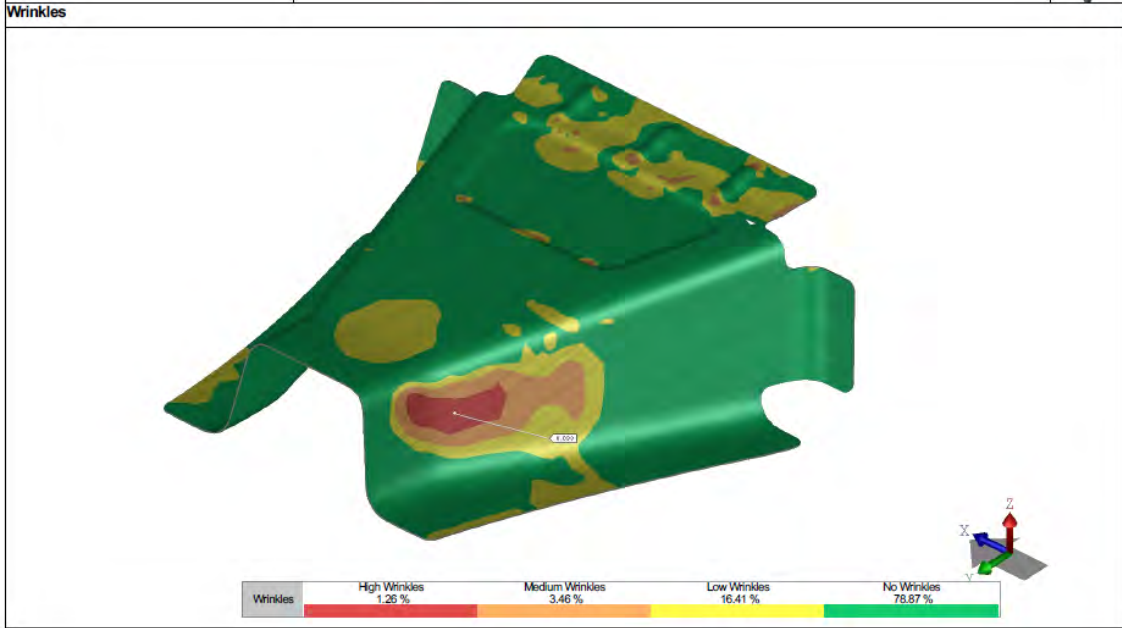
| | | |
|-------------|------|---|
| Formability | T-30 |  |
|-------------|------|---|




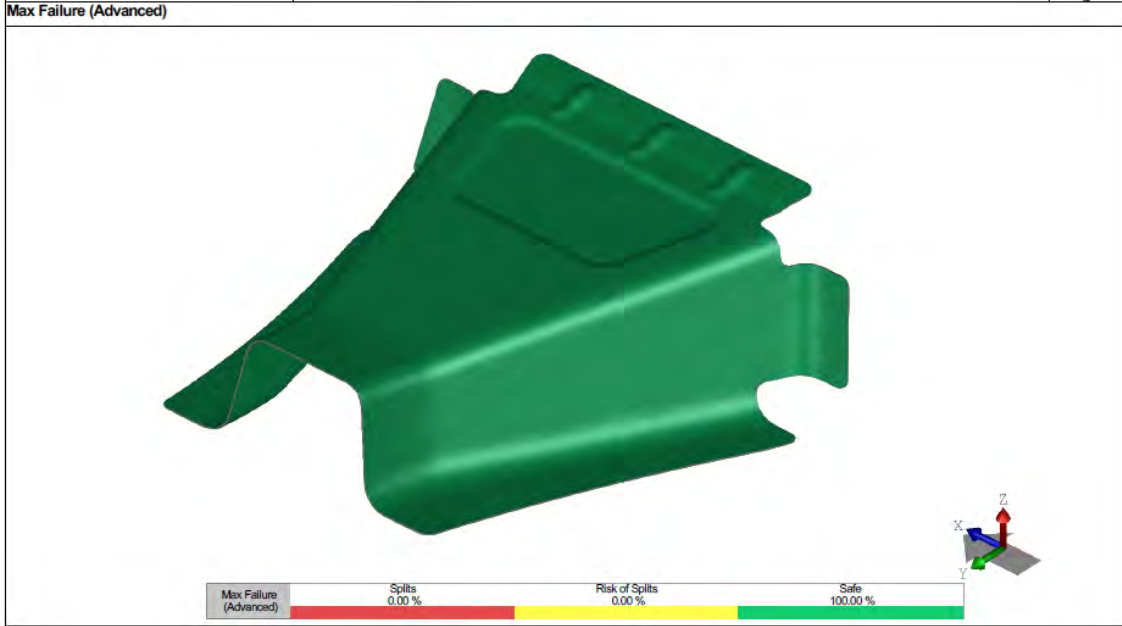
| | | |
|----------|------|---|
| Thinning | T-30 |  |
|----------|------|---|



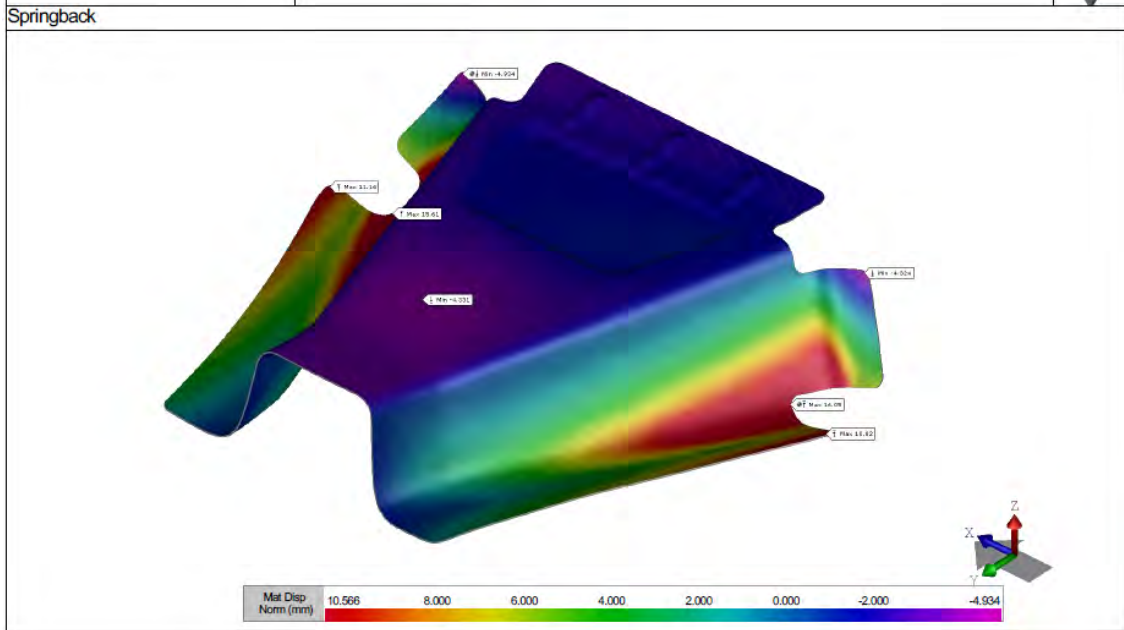
| | | |
|----------|------|---|
| Wrinkles | T-30 |  |
|----------|------|---|



| | | |
|-------------|------|---|
| Max Failure | T-30 |  |
|-------------|------|---|

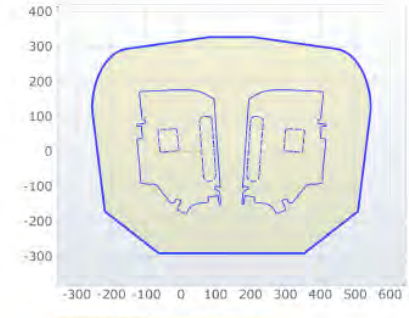
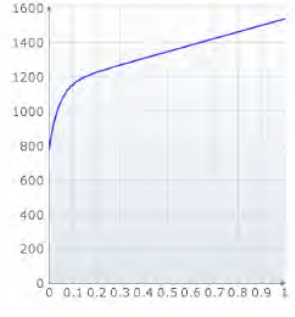

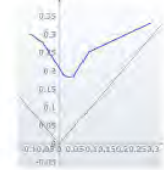


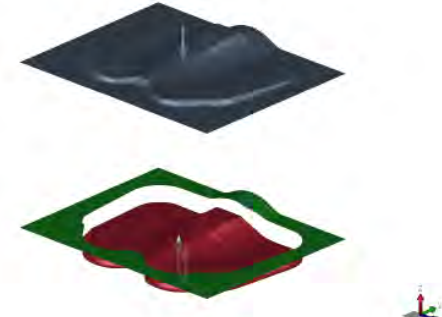


| | | |
|------------|------|--|
| Springback | M-40 | |
|------------|------|--|



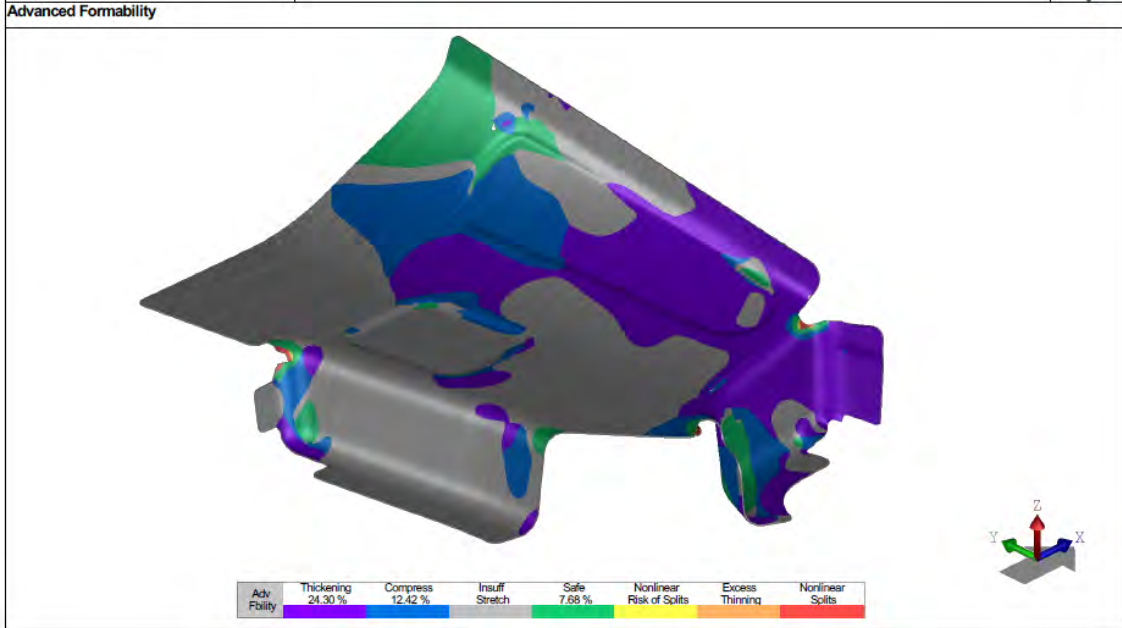
Front Header Roof Inerr Gusset Mount LH

| | | Overview and Summary | | | | |
|--|--------------|--|------|---|-------------------------------------|---------------|
| Part Info | | Criterion | | OK | n OK | Status |
| Designation: | Type: | FLD | 5.2 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| 03470750-A-PILLAR TOP CORNER LH | | Flanging | 5.24 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part No.: | Drawing No.: | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Material: CR700Y980T-DH-GI_DP1000-HD-Z | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Sheet Thickness: 1.000 mm | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Info | | Thinning | 5.6 | <input type="checkbox"/> | <input checked="" type="checkbox"/> | |
| Method Plan No.: | | Strain | 5.7 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Drawing No.: | Rev.: | Wrinkles | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part | | Springback | 5.9 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Simulation Info: | | | | |
| | | Filename: | | ARRK_03470750_Frt_Header_Rf_Inr_Gusset_Mount_LH_NMS_15-9-22_it6 - | | |
| | | AutoForm | | Memory: 576.48 MB | | |
| | | AutoForm Forming Solver R10.0.0 | | | | |
| | | Process - Blank Die / Draw / Form / Form / Laser trim | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

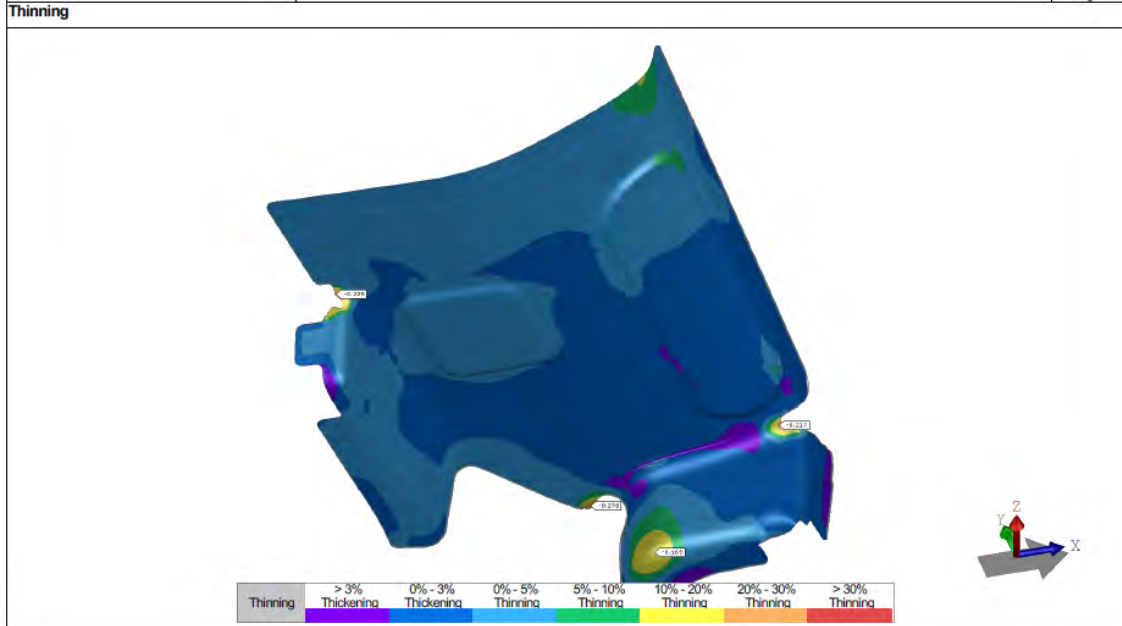
| Input Data | | Material & Blank | | | | Blank Info | |
|---|------------------------------|---|------|---|--------------|---|--|
| Calculated Material | CR700Y980T-DH-GI DP1000-HD-Z | Calc. Sheet Thickness | | 1,000 mm | | <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| Yield Stress | 776.93 MPa | r0 | 0.86 | r90 | 0.98 | Meshing Roll angle: 0.00 ° Initial Element Size: 40.00 mm Refinement Level: 6 Max Element Angle: 22.50 ° | |
| n-Value | 0.142 | r45 | 1.26 | E-Module | 2.10E+05 MPa | Blank size - 616.95 mm X 798.55 mm  | |
| Yield Curve  <p>MU - Part to Blank 36.65 %</p> | | Yield Surface  | | Forming Limit Curve  | | | |

| Input Data | | D-20 | | | | Process Data | |
|---|-----------------------------|--|-----|---|----------------------|----------------------|-------|
| Tool Info | | Process Data | | | | Friction Coefficient | |
| Meshing Tolerance | 0.05 mm | Single Action Draw | | | | Constant | 0.150 |
| Process Type | Single Action Draw | Lower Side of Initial Blank | | | | Die - Blank | - |
| Tool Geometry Refers to | Lower Side of Initial Blank | Tools | | | | Punch - Blank | - |
| Tools | Contact Side | Type | Gap | | Binder - Blank | - | |
| Die | Upper Side of Blank | Rigid | | | Binderforce | - | |
| Punch | Lower Side of Blank | Rigid | | | RAM | 295.0 tf | |
| Binder | Lower Side of Blank | Force Controlled | | | Binderforce/pressure | 19.7 tf | |
| Tool Geometry 1st opp | | Tool Geometry 2nd opp | | Tool Geometry 3rd opp | | | |
|  | |  | |  | | | |

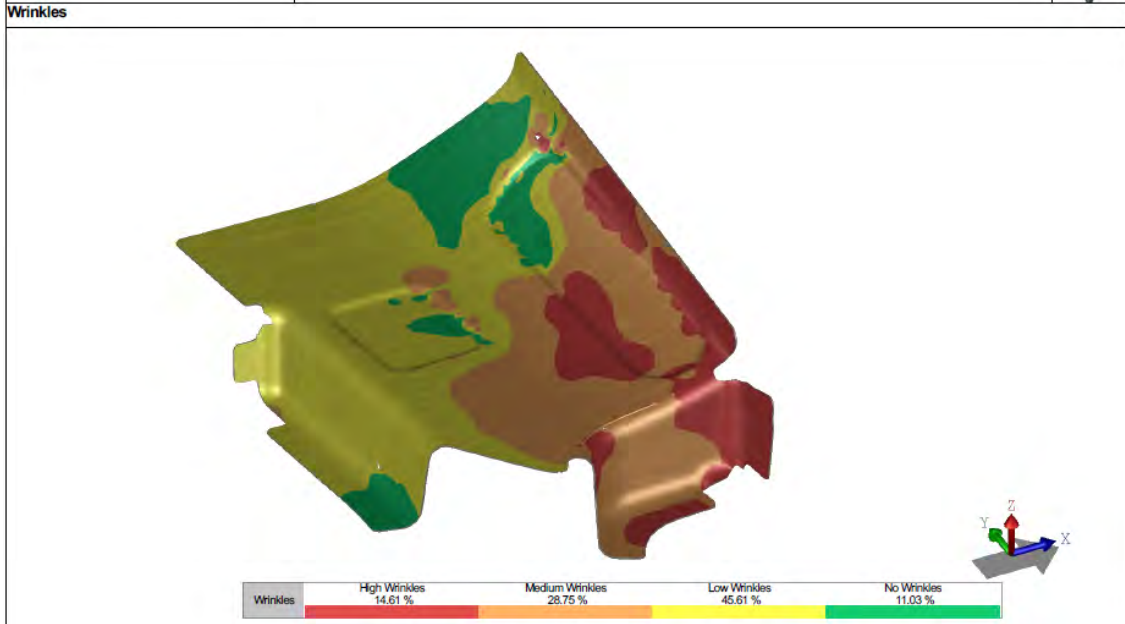
| | | |
|-------------|------|---|
| Formability | T-70 |  |
|-------------|------|---|



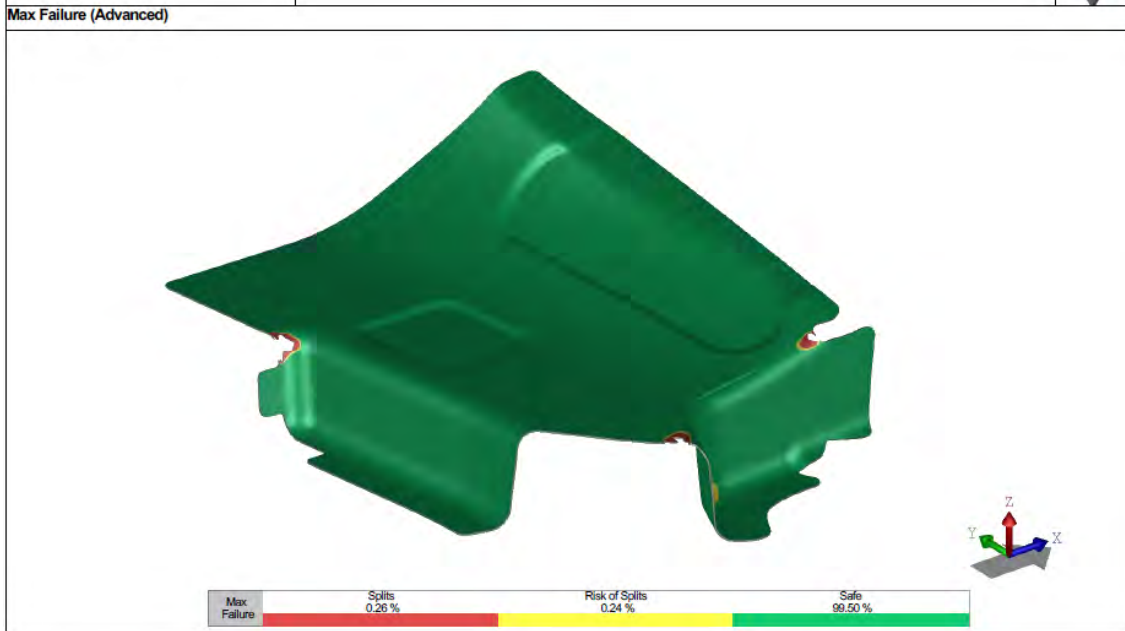
| | | |
|----------|------|---|
| Thinning | T-70 |  |
|----------|------|---|

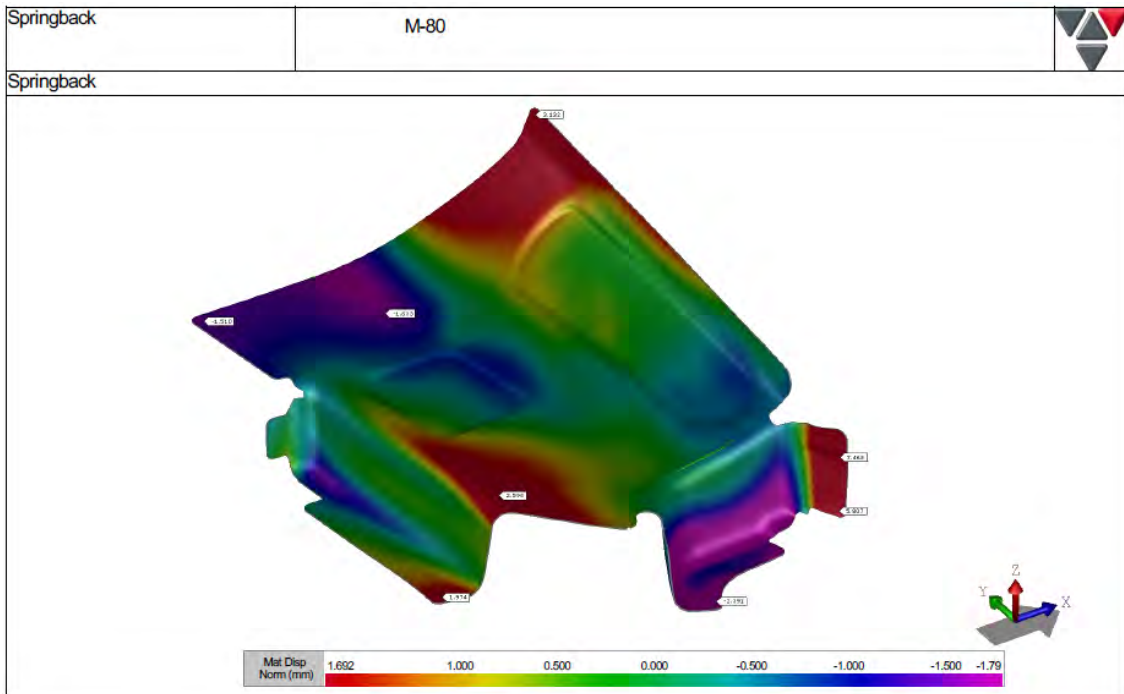
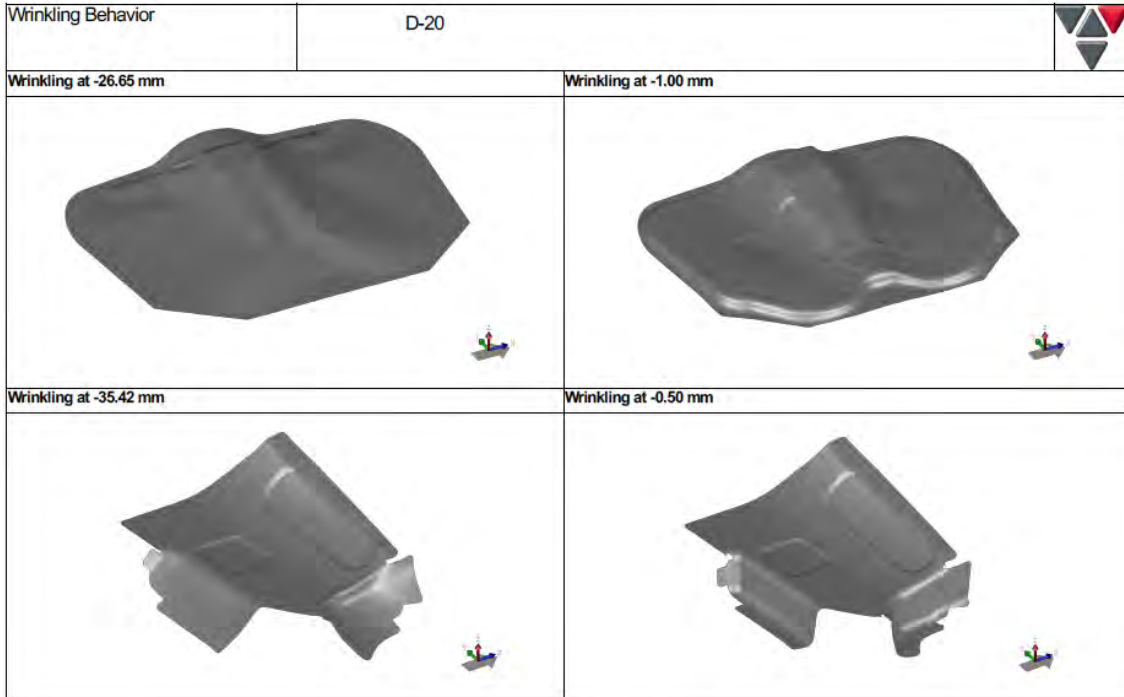


| | | |
|----------|------|--|
| Wrinkles | T-70 | |
|----------|------|--|




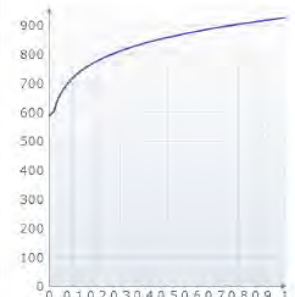
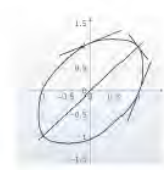


| | | |
|-------------|------|--|
| Max Failure | T-70 | |
|-------------|------|--|





Roof Frame Inner Rear Lower

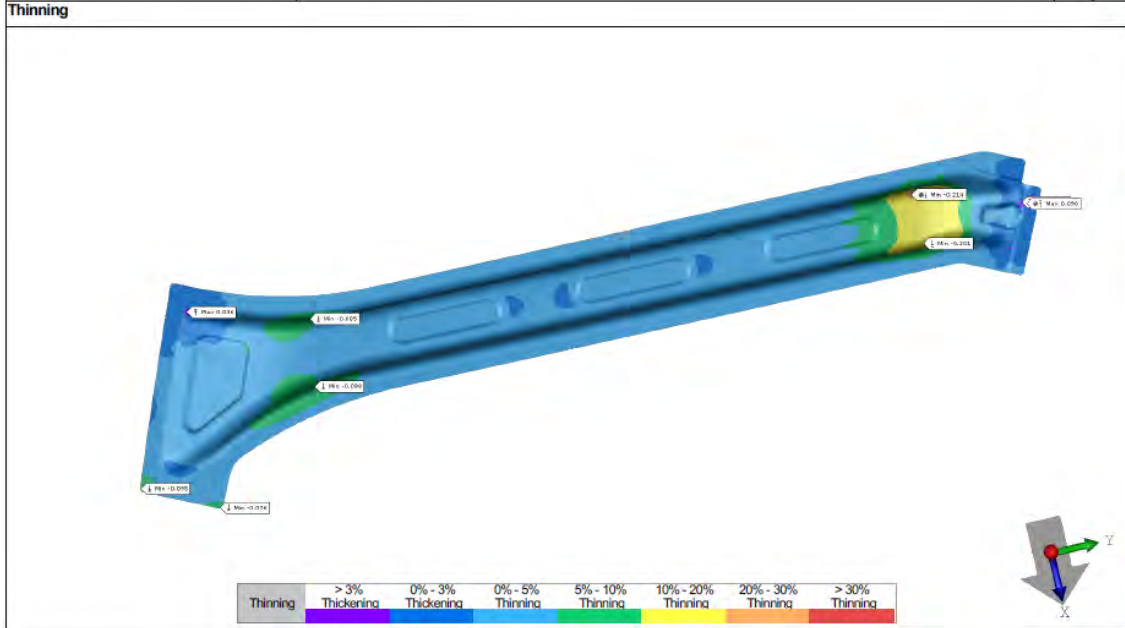
| Overview and Summary | | | |
|---|--------------------------|--|--|
| Part Info | | Criterion | OK n OK Status |
| Designation: 03484374 - ROOF FRAME ANGLE RR LE | Type: Single Action Draw | FLD 5.2 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Part No.: | Drawing No.: | Flanging 5.24 | <input type="checkbox"/> <input type="checkbox"/> |
| Nom. / Calculated Material: HD550LAD+Z 2.0-2.5 | | Gravity 5.3 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Nom. / Calculated Sheet Thickness: 0.700 mm | | Closing 5.4 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Method Info | | Forming 5.5 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Method Plan No.: | | Thinning 5.6 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Drawing No.: | Rev.: | Strain 5.7 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Part | | Wrinkles 5.8 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
|  | | Springback 5.9 | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| | | Simulation Info: | |
| | | Filename: ARRK_03484374_Roof_Frame_Angle_Rr_Lwr_MW_NMS_7-9-22_it5 - EXTENSION | |
| | | AutoForm Memory: 790.16 MB | |
| | | AutoForm Forming Solver R10.0.0 | |
| | | Remarks: Part mods eliminated splits. All OK for prototype. | |
| | | Process - Blank Die / Draw / Trim, CAM Pierce & Pierce / Trim, CAM Pierce & Pierce | |

| Input Data | | Material & Blank | |
|---|--------------------|--|--------------|
| Calculated Material | HD550LAD+Z 2.0-2.5 | Calc. Sheet Thickness | 0.700 mm |
| Yield Stress | 588.00 MPa | r0 | 0.61 |
| n-Value | 0.117 | r45 | 1.19 |
| | | r90 | 0.78 |
| | | E-Module | 2.10E+05 MPa |
| Yield Curve | | Yield Surface | |
|  | |  | |
| <p>MU - Part to Blank</p> <p>45.82 %</p> | | Forming Limit Curve | |
| | |  | |
| | | Blank Info | |
| | | <input type="checkbox"/> Rectangular Blank | |
| | | <input checked="" type="checkbox"/> Shaped Blank | |
| | | Meshing | |
| | | Roll angle | 0.00 ° |
| | | Initial Element Size | 20.00 mm |
| | | Refinement Level | 6 |
| | | Max Element Angle | 22.50 ° |
| | | Blank Size - 1433.46 mm X 528.25 mm | |
| | |  | |
| | | HD550LAD+Z 2.0-2.5/0.700 mm | |

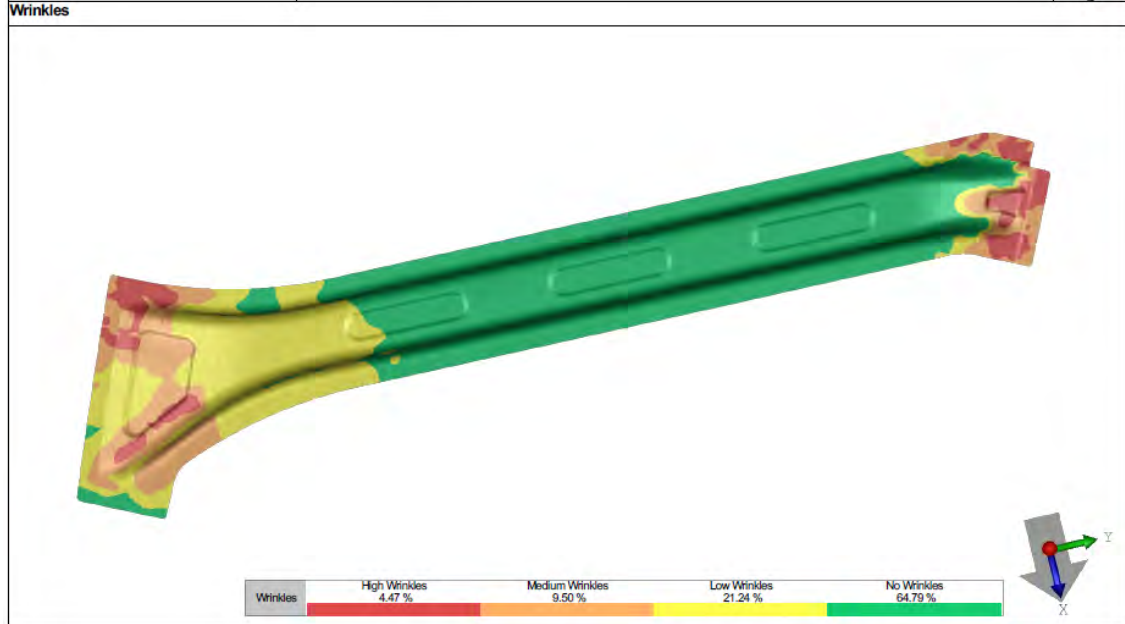
| | | | | | | | |
|------------------------------|-----------------------------|------------------|-----|-----------------------|----------|--|--|
| Input Data | | D-20 | | D-20 | | | |
| Tool Info | | | | Process Data | | | |
| Meshing Tolerance | 0.05 mm | | | Friction Coefficient | Constant | | |
| Process Type | Single Action Draw | | | Die - Blank | 0.100 | | |
| Tool Geometry Refers to | Lower Side of Initial Blank | | | Punch - Blank | - | | |
| Tools | Contact Side | Type | Gap | Binder - Blank | - | | |
| Die | Upper Side of Blank | Rigid | | Binderforce | - | | |
| Punch | Lower Side of Blank | Rigid | | RAM | 257.8 tf | | |
| Binder | Lower Side of Blank | Force Controlled | | Binderforce/-pressure | 106.3 tf | | |
| Tool Geometry 1st opp | | | | | | | |
| | | | | | | | |
| | | | | | | | |

| | | | | | | | | | | | | | |
|-----------------------------|---------------------|-------------------|-------------------|----------------|-----------------------------|--|---------------------|--|--|--|--|---------------|---------------------|
| Formability | | T-30 | | | | | | | | | | | |
| Advanced Formability | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | <table border="1"> <tr> <td>Adv Fality</td> <td>Thickening 4.61%</td> <td>Compress 5.65%</td> <td>Insuff Stretch</td> <td>Safe 35.00%</td> <td>Nonlinear Risk of Splits</td> <td>Excess Thinning</td> <td>Nonlinear Splits</td> </tr> </table> | | | | | | Adv Fality | Thickening 4.61% |
| Adv Fality | Thickening 4.61% | Compress 5.65% | Insuff Stretch | Safe 35.00% | Nonlinear Risk of Splits | Excess Thinning | Nonlinear Splits | | | | | | |
| | | | | | | | | | | | | | |

| | | |
|----------|------|--|
| Thinning | T-30 | |
|----------|------|--|




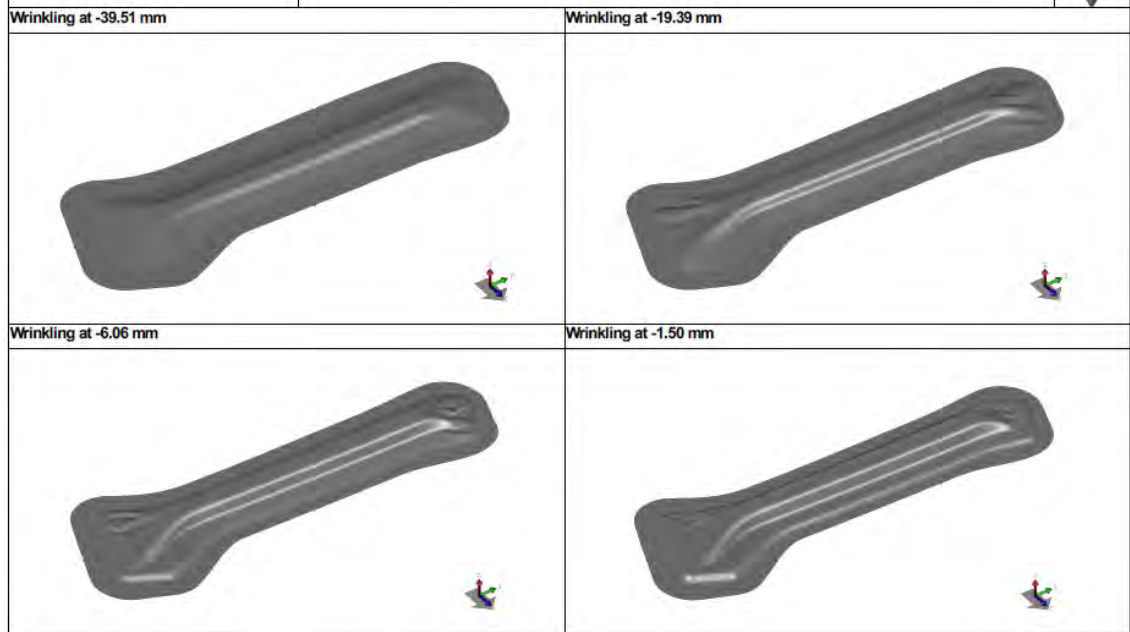
| | | |
|----------|------|--|
| Wrinkles | T-30 | |
|----------|------|--|

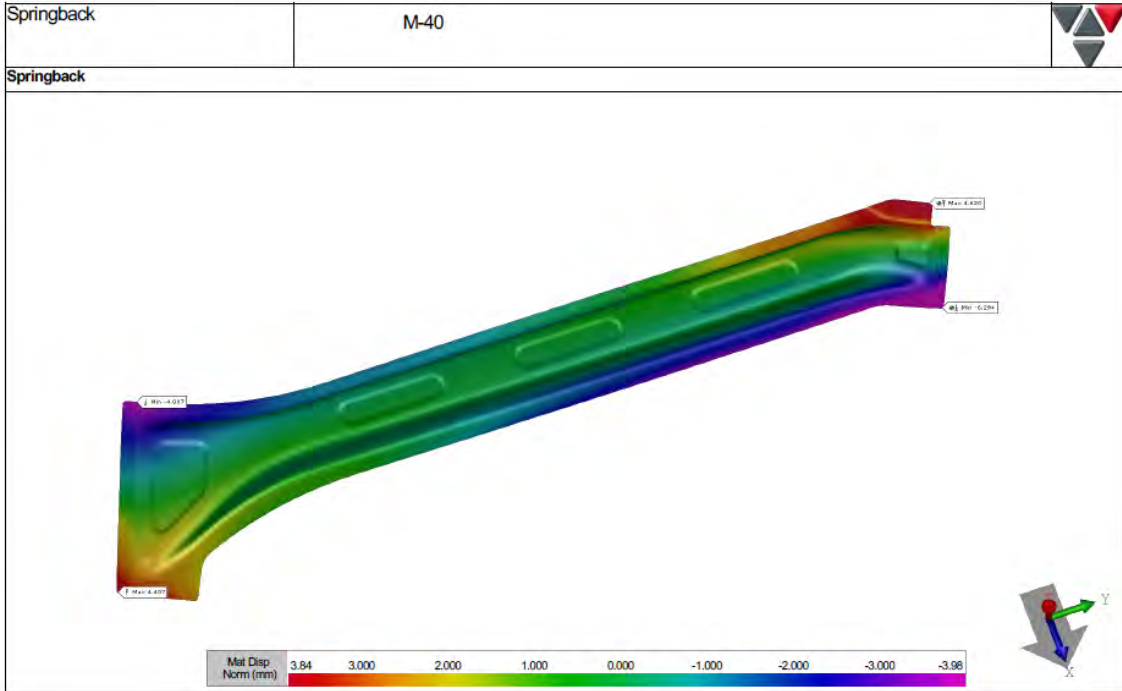


| | | |
|-------------|------|---|
| Max Failure | T-30 |  |
|-------------|------|---|




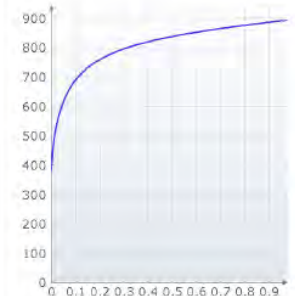



| | | |
|------------------|------|---|
| Winking Behavior | D-20 |  |
|------------------|------|---|







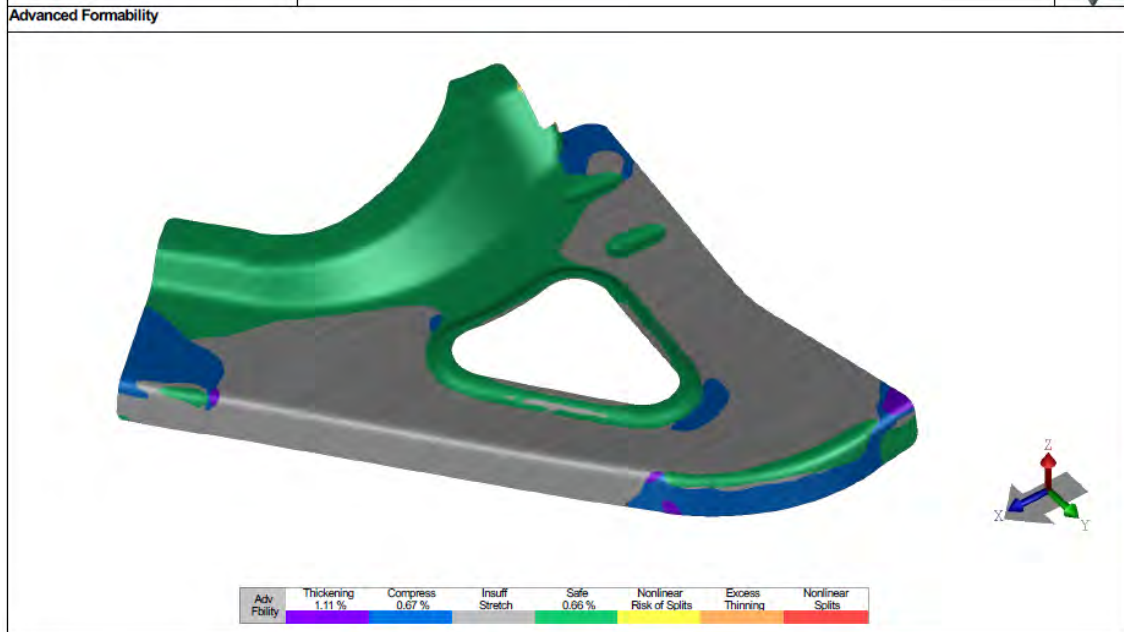
D post upper inner reinforcement

| Overview and Summary | | | | | |
|---|--------------|---|-----------|-------------------------------------|--------------------------|
| Part Info | | Criterion | OK | n OK | Status |
| Designation: 03491092-Body.1 | Type: | FLD | 5.2 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Part No.: | Drawing No.: | Flanging | 5.24 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Nom. / Calculated Material: SG-HC340-590DPD+Z-1.0 | | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Nom. / Calculated Sheet Thickness: 0.800 mm | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Method Info | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Method Plan No.: | | Thinning | 5.6 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Drawing No.: | Rev.: | Strain | 5.7 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Part | | Wrinkles | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| | | Springback | 5.9 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| | | Simulation Info: Filename: ARRK_03491092_D_Post_Inr_Upr_LH_NMS_15-8-22_it4 - EXTENSION MODS 3 - INC AutoForm Memory: 636.70 MB AutoForm Forming Solver R10.0.0 Remarks: Wrinkling issues on flanges are solved by adding a slip pad on the flanging operation. Proces - Blank Die / Draw / CAM Trim & Trim & Pierce / Trim / Flange | | | |
| | | | | | |
| | | | | | |

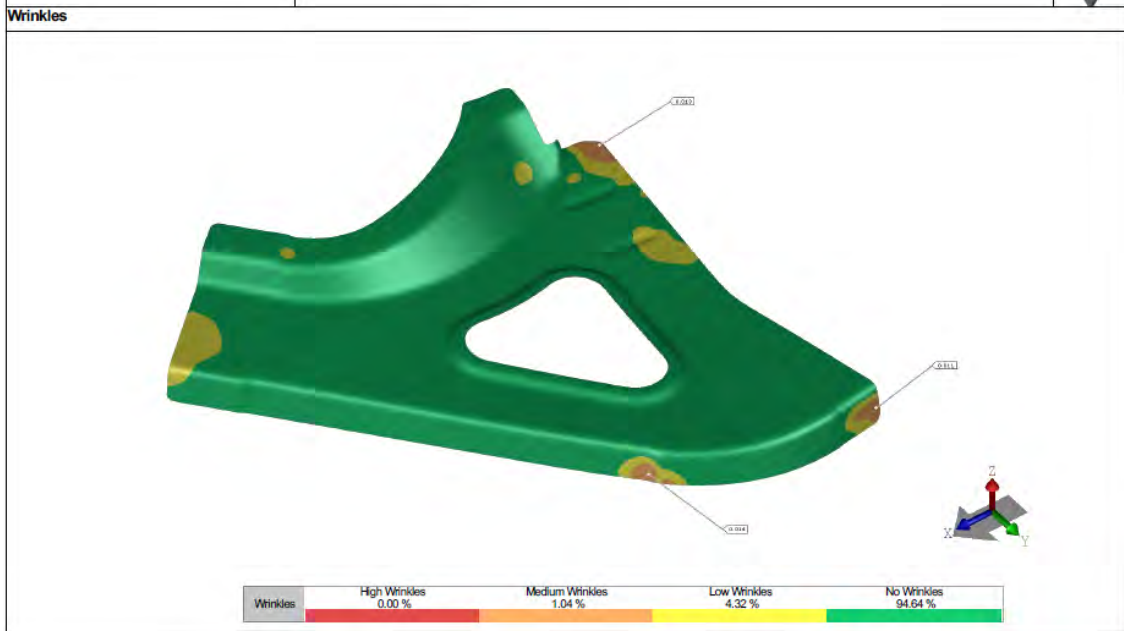
| Input Data | | Material & Blank | | | | Blank Info | |
|---|---------------------|---|------|---|--|---|--|
| Calculated Material | SG-HC340-590DPD+Z-1 | Calc. Sheet Thickness | | 0.800 mm | | <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| Yield Stress | 380.00 MPa | r0 | 0.85 | r90 1.05 | | Meshing Roll angle: 0.00 ° Initial Element Size: 40.00 mm Refinement Level: 6 Max Element Angle: 22.50 ° | |
| n-Value | 0.165 | r45 | 0.95 | E-Module 2.10E+05 MPa | | Blank Size - 860.64 mm X 484.93 mm  | |
| Yield Curve  | | Yield Surface  | | Forming Limit Curve  | | | |
| MU - Part to Blank 41.39 % | |  | | | | | |

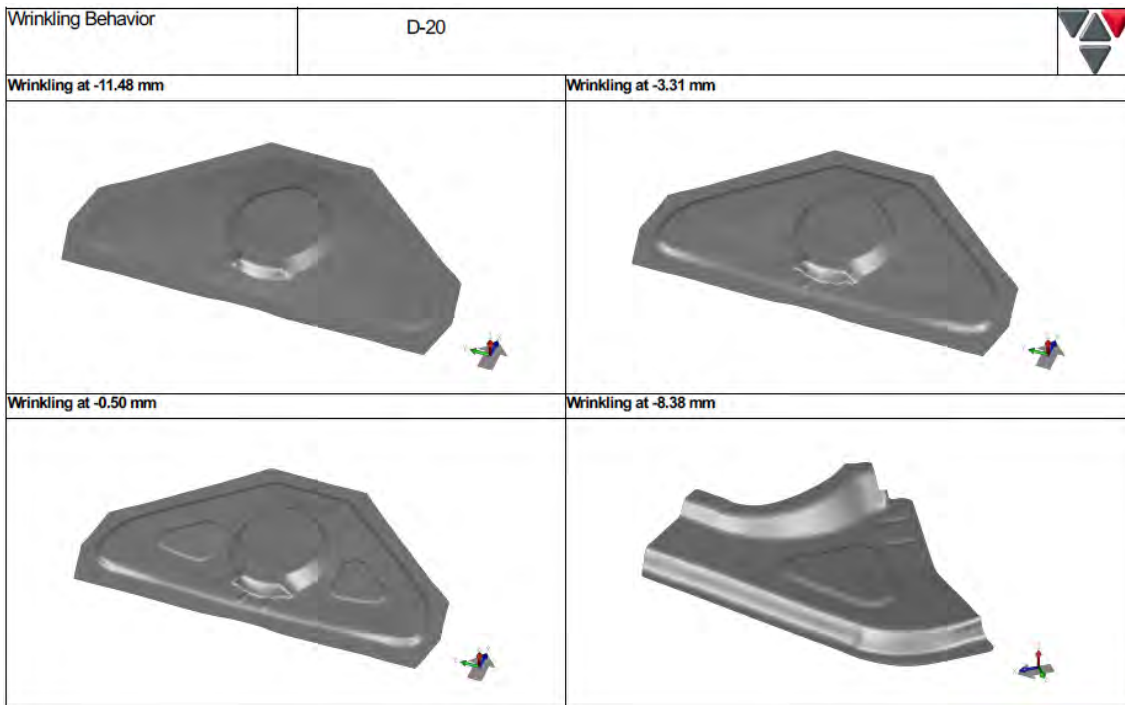
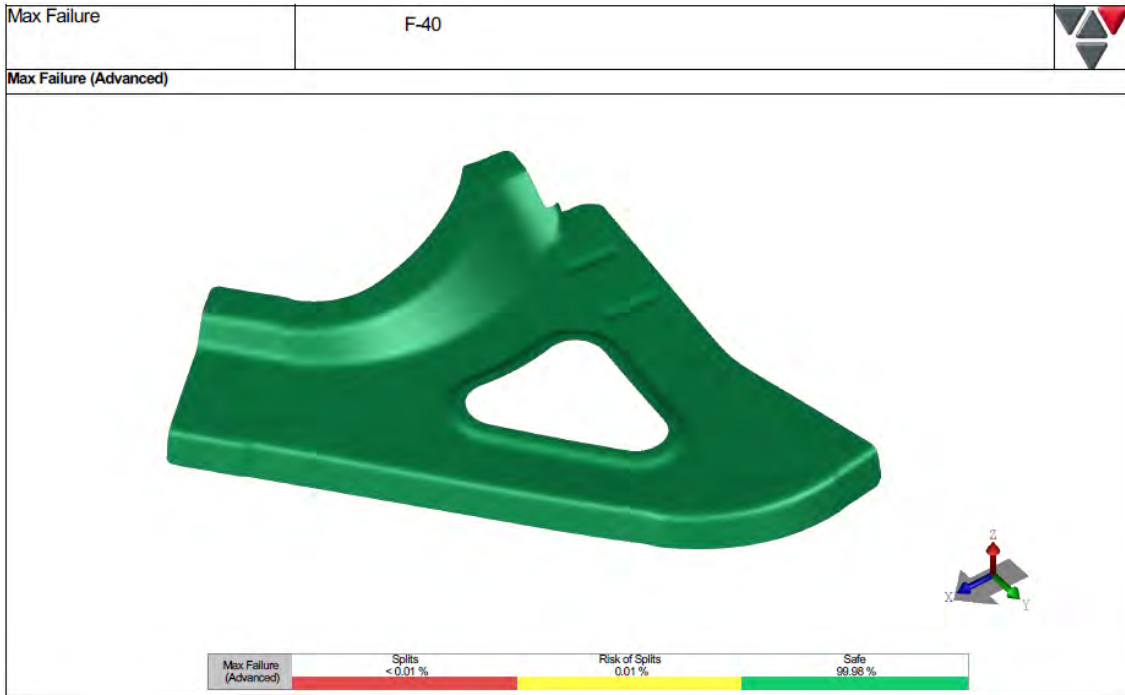
| Input Data | | D-20 | | | | Process Data | |
|--|-----------------------------|-------------------------|-----|--|-------------------------------|----------------------|--|
| Tool Info | | Process Data | | | | Friction Coefficient | |
| Meshing Tolerance | 0.05 mm | Process Type | | | | Constant 0.100 | |
| Process Type | Single Action Draw | Tool Geometry Refers to | | | | Die - Blank - | |
| Tool Geometry Refers to | Lower Side of Initial Blank | Tools | | | | Punch - Blank - | |
| Tools | Contact Side | Type | Gap | | Binder - Blank - | | |
| Die | Upper Side of Blank | Rigid | | | Binderforce | | |
| Punch | Lower Side of Blank | Rigid | | | RAM 184.5 tf | | |
| Binder | Lower Side of Blank | Force Controlled | | | Binderforce/-pressure 66.6 tf | | |
| Tool Geometry 1st opp | | | | | | | |
|   | | | | | | | |

| | | |
|-------------|------|--|
| Formability | F-40 | |
|-------------|------|--|

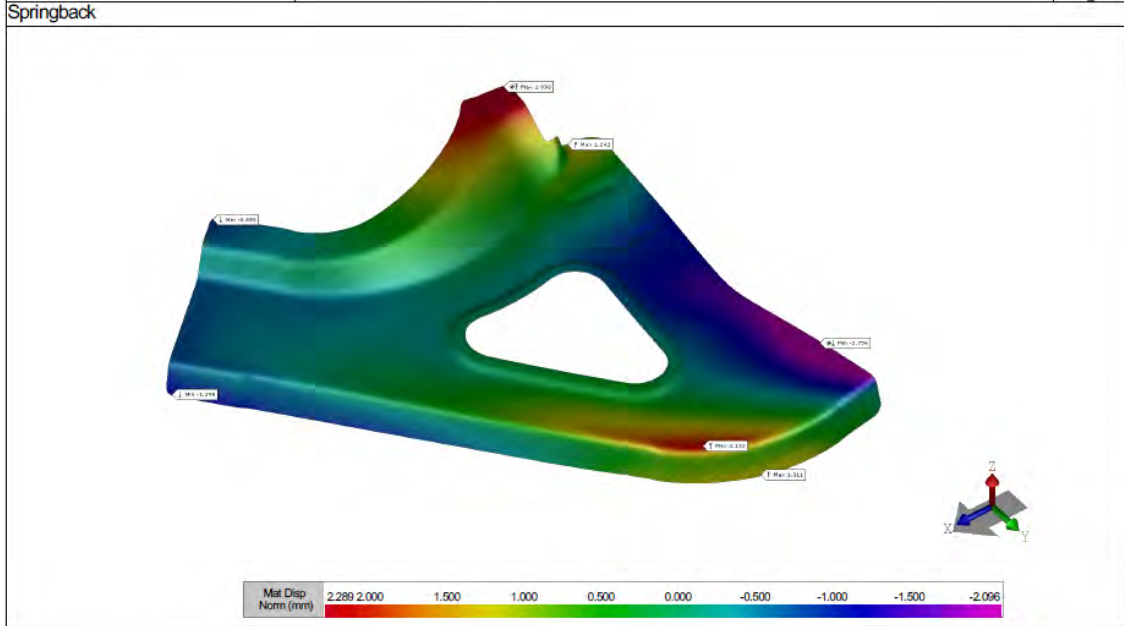


| | | |
|----------|------|--|
| Wrinkles | F-40 | |
|----------|------|--|





| | | |
|------------|------|--|
| Springback | T-50 | |
|------------|------|--|



Front rail angled outer

| Overview and Summary | | | | | | |
|--|--------------|------------------|------|-------------------------------------|--------------------------|---------------|
| Part Info | | Criterion | | OK | n OK | Status |
| Designation: 03506010 FRONT RAIL ANGLED OUTER LH | Type: | FLD | 5.2 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part No.: | Drawing No.: | Flanging | 5.24 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Material: Dual_Phase_980_HY | | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Sheet Thickness: 2.000 mm | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Info | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Plan No.: | | Thinning | 5.6 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Drawing No.: | Rev.: | Strain | 5.7 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part | | Wrinkles | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Springback | 5.9 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Simulation Info: | | | | | | |
| Filename: ARRK_03506010_Frt_Rail_Angled_Outer_NMS_15-8-22_it4 - EXTENSION MODS 2 - AutoForm | | | | | | |
| AutoForm Forming Solver R10.0.0 | | | | | Memory: 262.89 MB | |
| Process - Blank Die / Crash & Flange / Form | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

| Input Data | | Material & Blank | | | | Blank Info | |
|---------------------|-------------------|-----------------------|----------|----------|--|---|--|
| Calculated Material | Dual_Phase_980_HV | Calc. Sheet Thickness | 2.000 mm | | <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | | |
| Yield Stress | 745.58 MPa | r0 | 0.93 | r90 | 1.04 | Meshing Roll angle: 0.00 ° Initial Element Size: 20.00 mm Refinement Level: 6 Max Element Angle: 22.50 ° | |
| n-Value | 0.128 | r45 | 0.95 | E-Module | 2.10E+05 MPa | | |

Yield Curve

MU - Part to Blank
100%

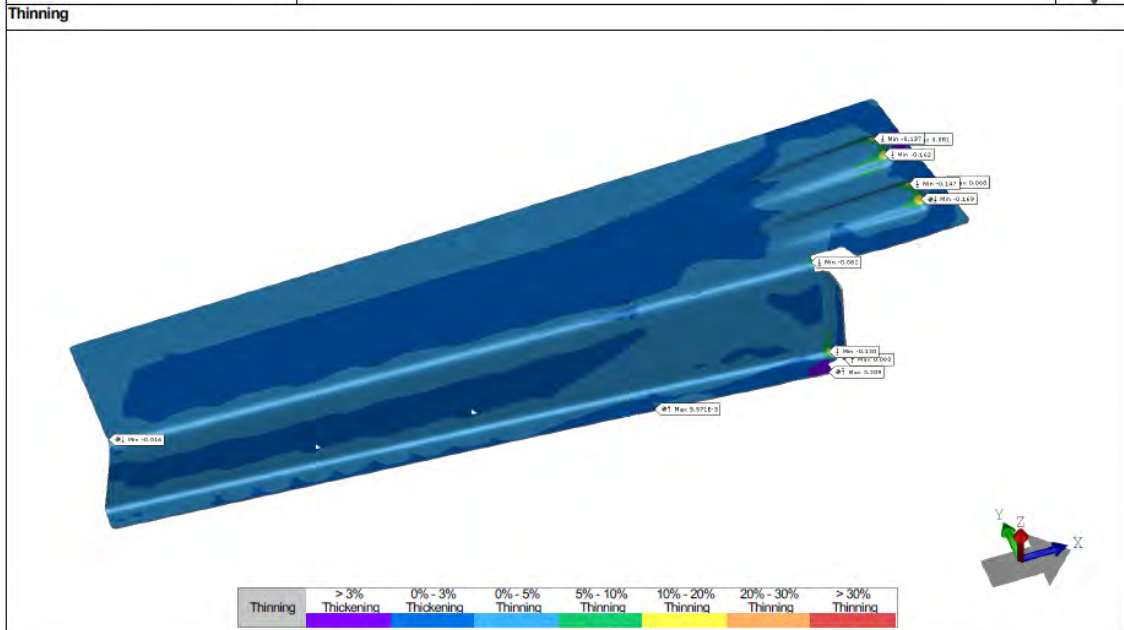
Yield Surface

Forming Limit Curve

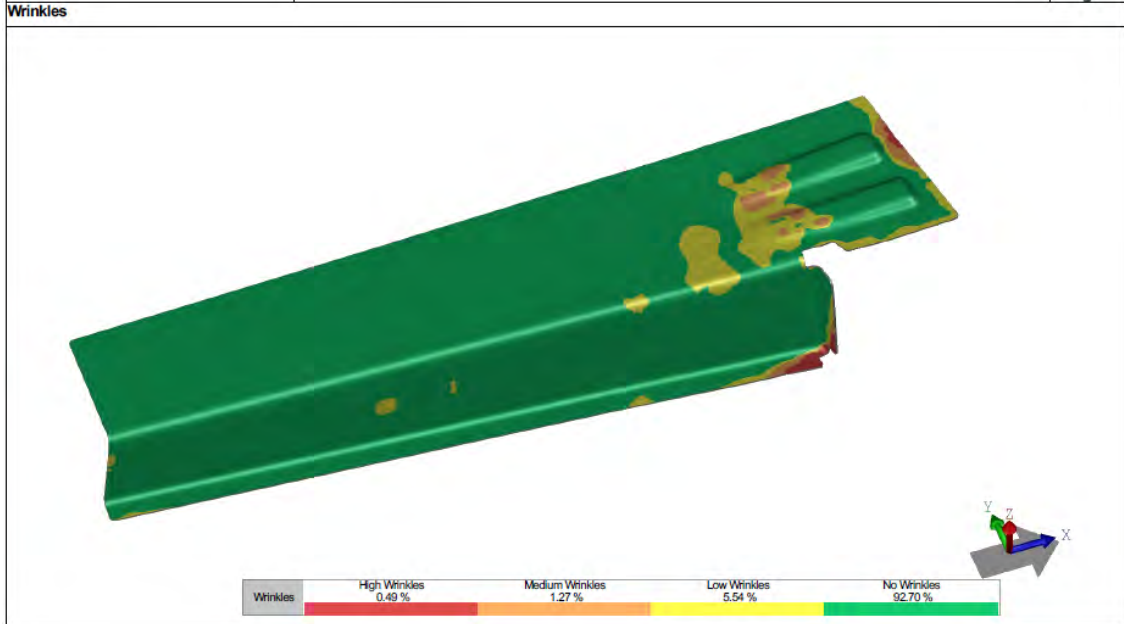
Dual_Phase_980_HV(2.000 mm) Dual_Phase_780(1.800 mm)

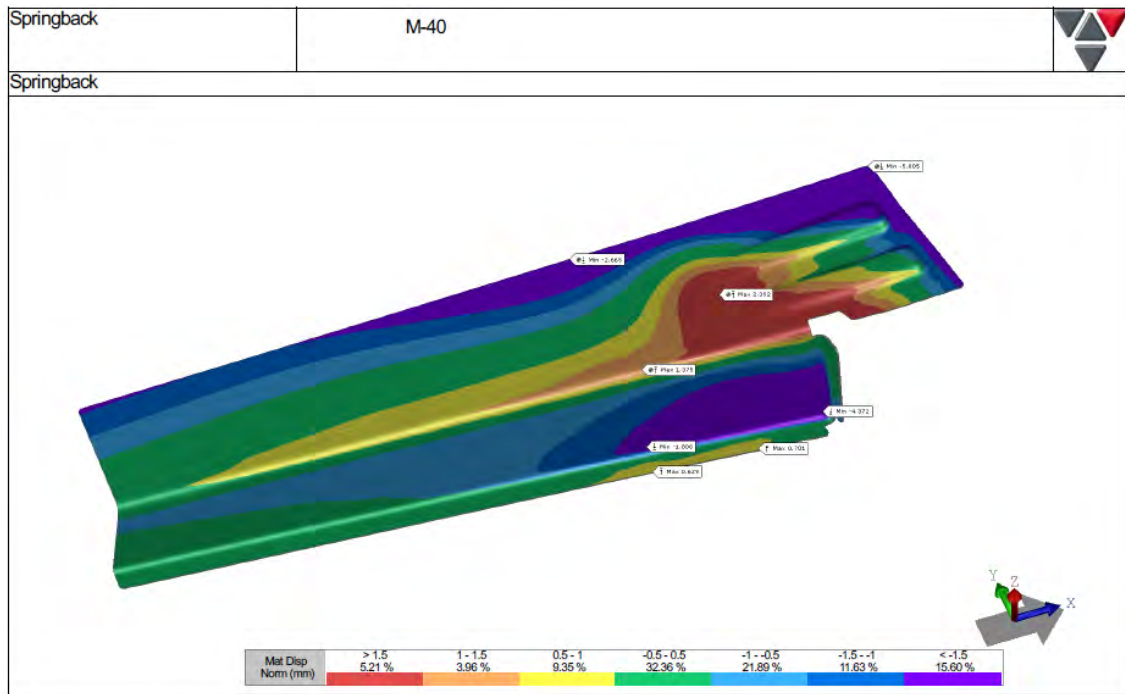
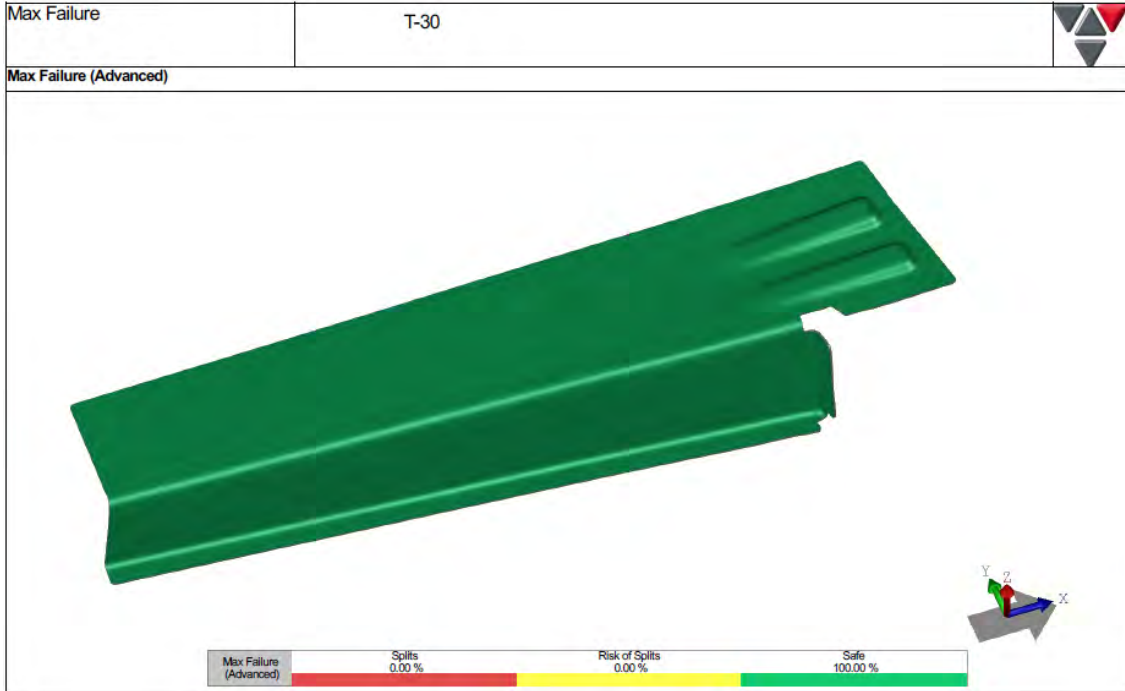
| Formability | T-30 | | | | | | | | |
|--|-------------------|------------------|-------------------|-----------------|--------------------------|-----------------|--------------------------|-----------------|------------------|
| Advanced Formability | | | | | | | | | |
| | | | | | | | | | |
| <table border="1" style="width: 100%; text-align: center; font-size: small;"> <tr> <td>Adv. Formability</td> <td>Thickening 2.56 %</td> <td>Compress 1.12 %</td> <td>Insuff. Stretch</td> <td>Safe 2.53 %</td> <td>Nonlinear Risk of Splits</td> <td>Excess Thinning</td> <td>Nonlinear Splits</td> </tr> </table> | | Adv. Formability | Thickening 2.56 % | Compress 1.12 % | Insuff. Stretch | Safe 2.53 % | Nonlinear Risk of Splits | Excess Thinning | Nonlinear Splits |
| Adv. Formability | Thickening 2.56 % | Compress 1.12 % | Insuff. Stretch | Safe 2.53 % | Nonlinear Risk of Splits | Excess Thinning | Nonlinear Splits | | |

| | | |
|----------|------|---|
| Thinning | T-30 |  |
|----------|------|---|




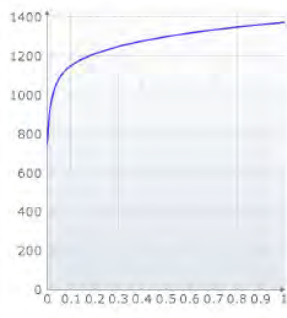


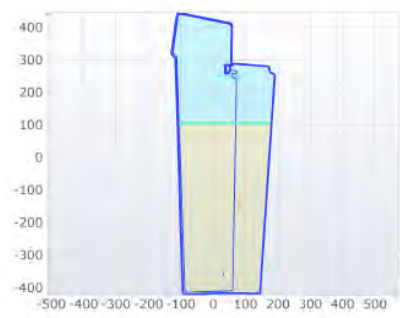
| | | |
|----------|------|---|
| Wrinkles | T-30 |  |
|----------|------|---|



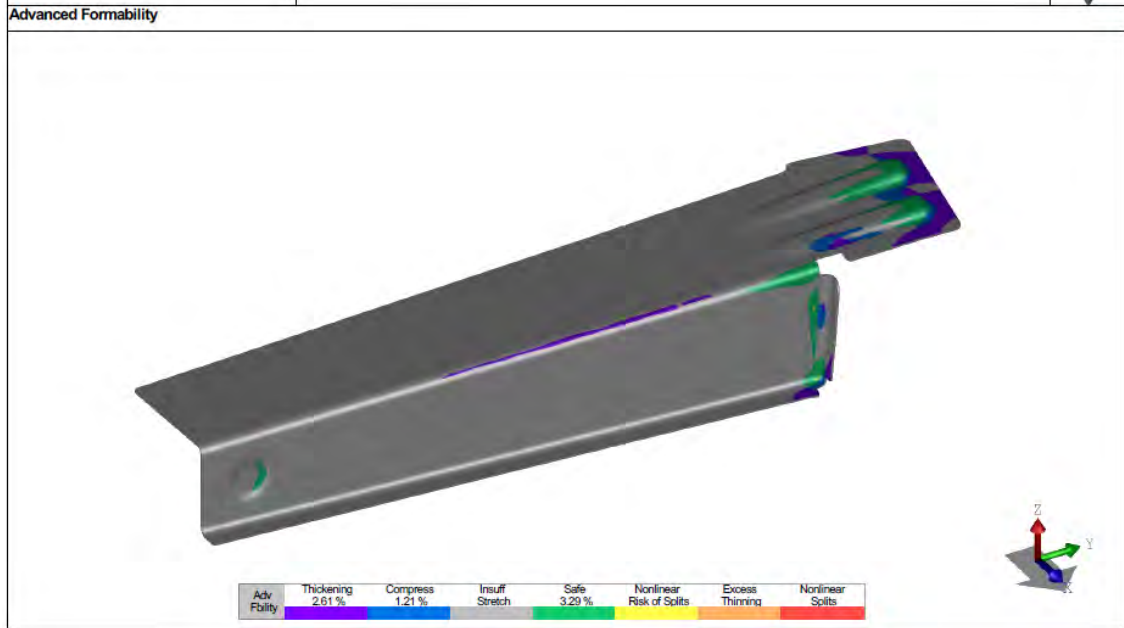


Front longitudinal rail inner

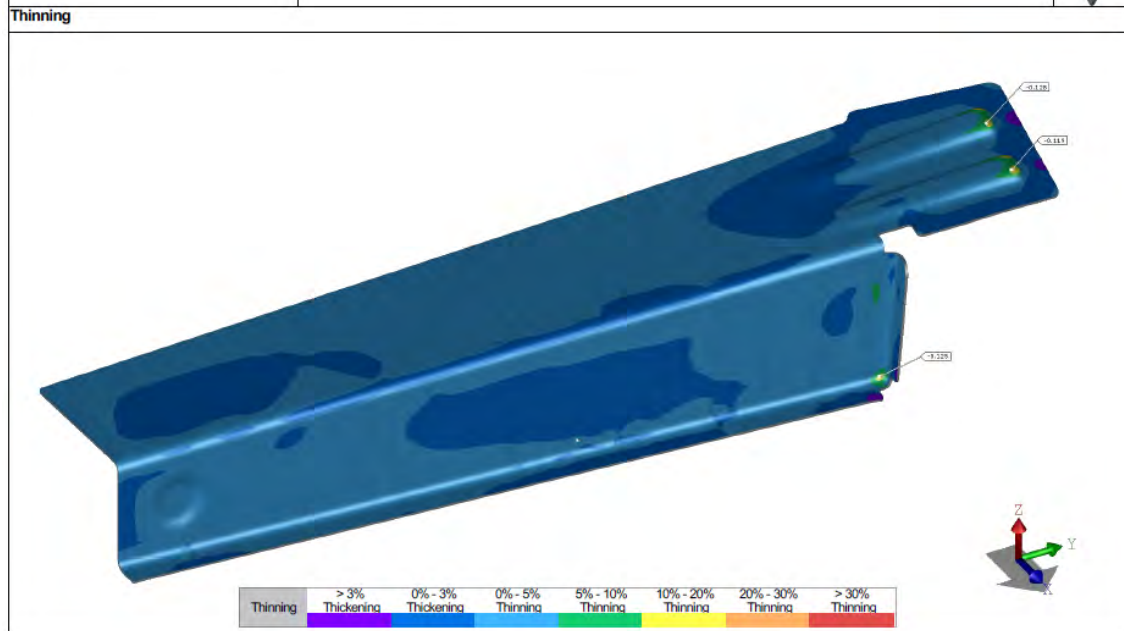
| Overview and Summary | | | | | |
|--|--------------|---|-----------|-------------------------------------|--------------------------|
| Part Info | | Criterion | OK | n OK | Status |
| Designation: 03506011 FRONT RAIL ANGLED INNER LH | Type: | FLD | 5.2 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Part No.: | Drawing No.: | Flanging | 5.24 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Nom. / Calculated Material: Dual_Phase_980_HY | | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Nom. / Calculated Sheet Thickness: 2.000 mm | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Method Info | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Method Plan No.: | | Thinning | 5.6 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Drawing No.: | Rev.: | Strain | 5.7 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Part | | Wrinkles | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
|  | | Springback | 5.9 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| | | Simulation Info: Filename: ARRK_03506011_Longit_Mid_Rail_Inr_Frt_NMS_14-8-22_it3 - EXTENSION MODS 1 - AutoForm AutoForm Forming Solver R10.0.0 Memory: 227.53 MB | | | |
| Process - Blank Die / Crash & Flange / Form / CAM form & CAM Pierce | | | | | |

| Input Data | | Material & Blank | | | |
|--|-------------------|---|----------|---|--------------|
| Calculated Material | Dual_Phase_980_HY | Calc. Sheet Thickness | 2.000 mm | | |
| Yield Stress | 745.58 MPa | r0 | 0.93 | r90 | 1.04 |
| n-Value | 0.128 | r45 | 0.95 | E-Module | 2.10E+05 MPa |
| Yield Curve | | Yield Surface | | Blank Info | |
|  | |  | | <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| MU - Part to Blank 100% | | Forming Limit Curve  | | Meshing Roll angle: 0.00 ° Initial Element Size: 20.00 mm Refinement Level: 6 Max Element Angle: 22.50 ° | |
|  | | | | | |

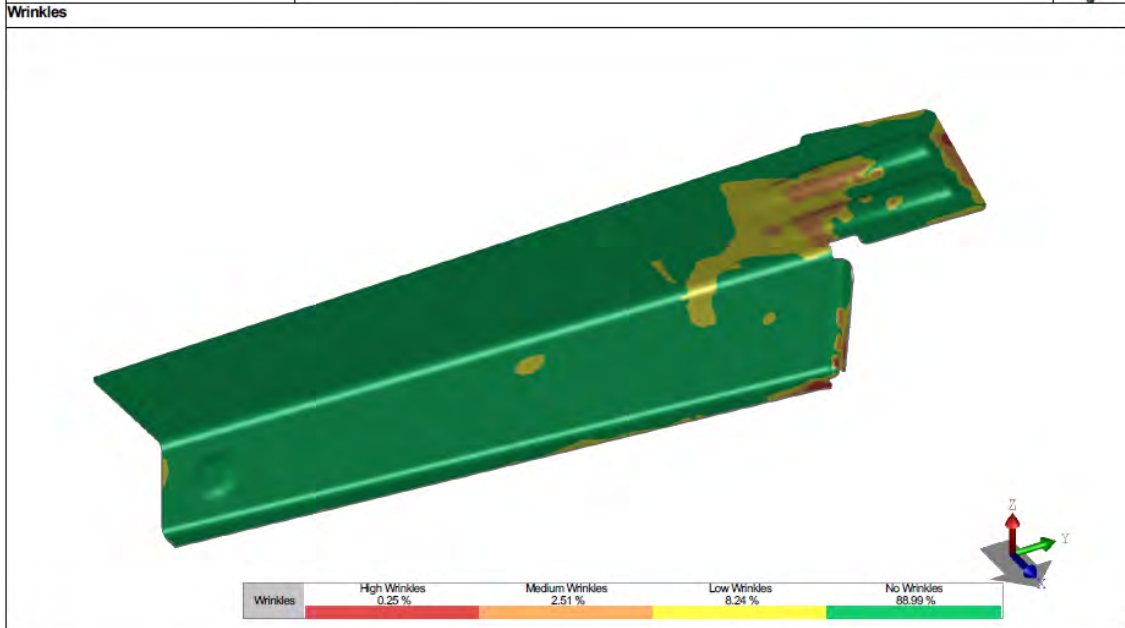
| | | |
|-------------|------|--|
| Formability | F-40 | |
|-------------|------|--|



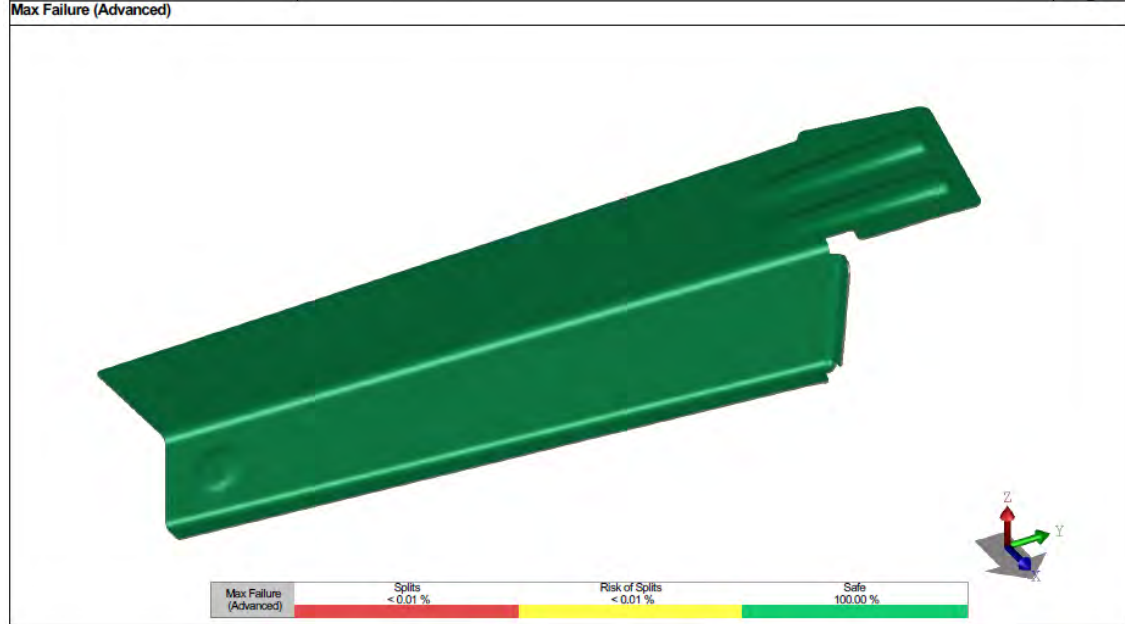
| | | |
|----------|------|--|
| Thinning | F-40 | |
|----------|------|--|

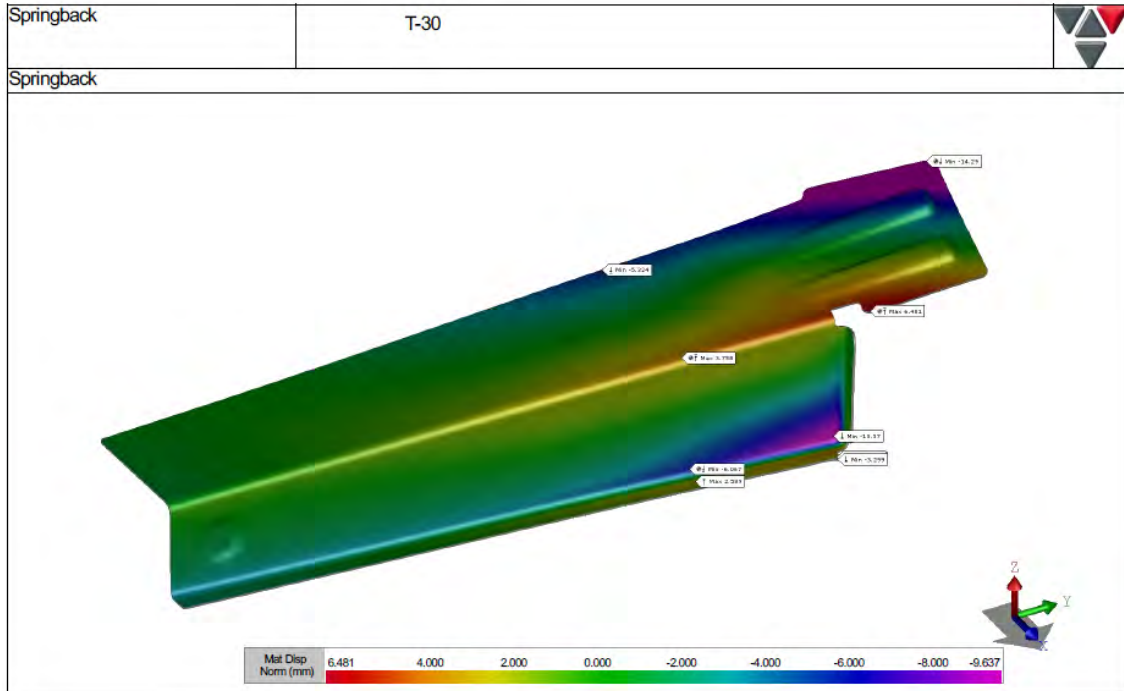


| | | |
|----------|------|--|
| Wrinkles | F-40 | |
|----------|------|--|



| | | |
|-------------|------|--|
| Max Failure | F-40 | |
|-------------|------|--|






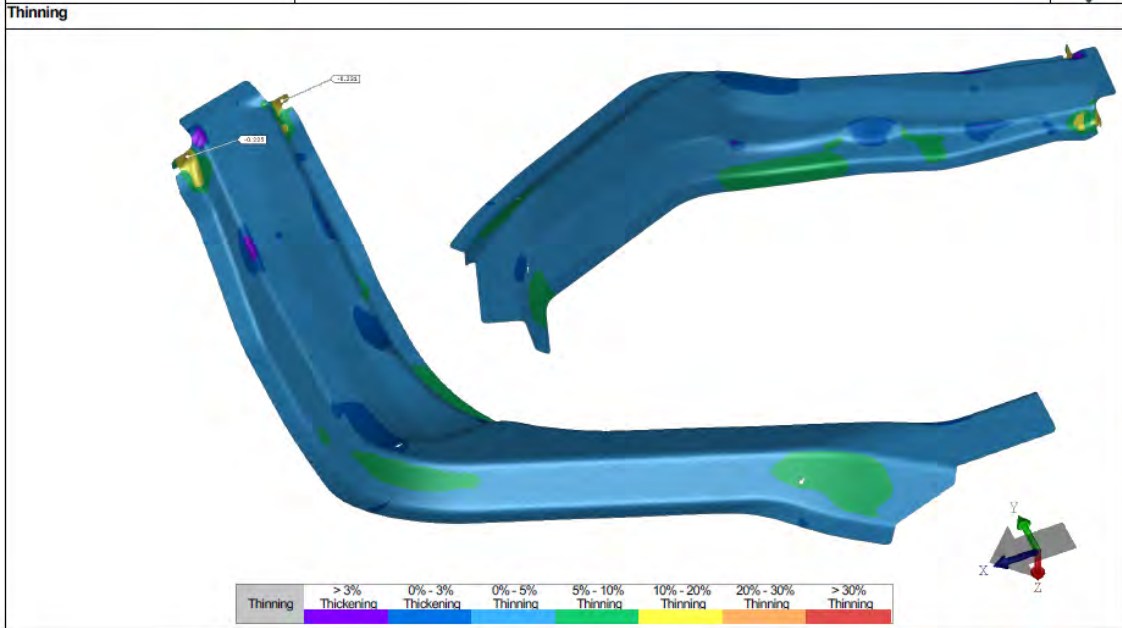
Glance beam inner

| Overview and Summary | | | | | |
|--|------------------------|--|-----------|-------------------------------------|--------------------------|
| Part Info | | Criterion | OK | n OK | Status |
| Designation: 03585862-Body.1 | Type: Form Trim Pierce | FLD | 5.2 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Part No.: | Drawing No.: | Flanging | 5.24 | <input type="checkbox"/> | <input type="checkbox"/> |
| Norm. / Calculated Material: 22MnB5 | | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Norm. / Calculated Sheet Thickness: 1.000 mm | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Method Info | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Method Plan No.: | | Thinning | 5.6 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Drawing No.: | Rev.: | Martensite | 5.7 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Part | | Temperature | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| | | Hardness | | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| | | Simulation Info: | | | |
| | | Filename: ARRK_03585862_Glance_Beam_Inr_LH_NMS_17-8-22_it9 - EXTENSION MODS 4 - AutoForm Memory: 674.20 MB AutoForm Forming Solver Thermo R10.0.0 | | | |
| | | Remarks: Wrinkles are now all under control by modifying the process but there is still slightly high thinning on the two end tabs (23%). I believe this is OK for Green status for prototype stage. | | | |
| | | Process - Blank Die / Heating / Draw / Quenching / Laser Trim | | | |

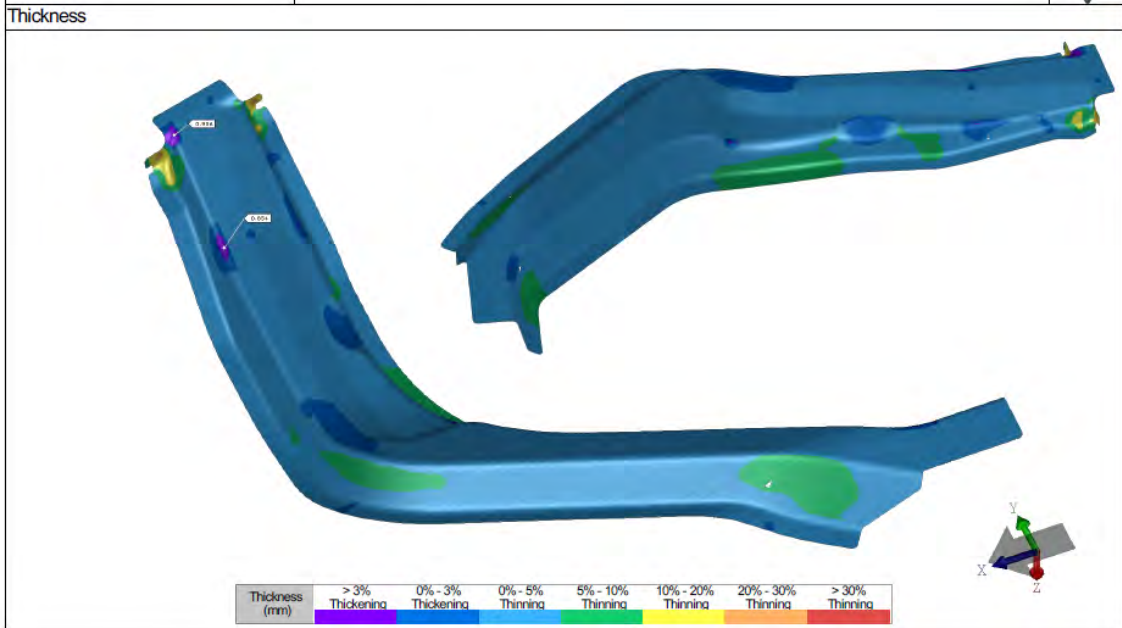
| | | | | | | | |
|-------------------------------|--------|------------------------|------|----------|------|--|--|
| Input Data | | Material & Blank | | | | | |
| Calculated Material | 22MnB5 | Calc. Sheet Thickness | | 1.000 mm | | Blank Info | |
| Yield Stress | | r0 | 1.00 | r90 | 1.00 | <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| n-Value | | r45 | 1.00 | E-Module | | Meshing | |
| Yield Curve | | Yield Surface | | | | Roll angle | |
| | | | | | | 0.00 ° | |
| | | | | | | Initial Element Size | |
| | | | | | | 40.00 mm | |
| | | | | | | Refinement Level | |
| | | | | | | 7 | |
| | | | | | | Max Element Angle | |
| | | | | | | 30.00 ° | |
| | | | | | | Blank Size - 1158.31 mm X 1497.64 mm | |
| | | | | | | | |
| | | | | | | -400 -200 0 200 400 600 800 1000 1200 1400 22MnB5/1.000 mm | |
| MU - Part to Blank 73.85 % | | RAM Tonnage - 153.0 tf | | | | | |

| | | | | | | | | | | | | | | | | | | | | | | |
|---|------------|----------|----------------|---------|----------------|-----------------|-------------|------------|----------|----------------|------|----------------|-----------------|--------|--|--------|---------|--|---------|--|--|--------|
| Formability | T-40 | | | | | | | | | | | | | | | | | | | | | |
| Advanced Formability | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | |
| <table border="1"> <tr> <td>Formability</td> <td>Thickening</td> <td>Compress</td> <td>Insuff Stretch</td> <td>Safe</td> <td>Risk of Splits</td> <td>Excess Thinning</td> <td>Splits</td> </tr> <tr> <td></td> <td>3.58 %</td> <td>17.04 %</td> <td></td> <td>32.61 %</td> <td></td> <td></td> <td>0.00 %</td> </tr> </table> | | | | | | | Formability | Thickening | Compress | Insuff Stretch | Safe | Risk of Splits | Excess Thinning | Splits | | 3.58 % | 17.04 % | | 32.61 % | | | 0.00 % |
| Formability | Thickening | Compress | Insuff Stretch | Safe | Risk of Splits | Excess Thinning | Splits | | | | | | | | | | | | | | | |
| | 3.58 % | 17.04 % | | 32.61 % | | | 0.00 % | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | |

| | | |
|----------|------|---|
| Thinning | T-40 |  |
|----------|------|---|



| | | |
|-----------|------|---|
| Wrinkling | T-40 |  |
|-----------|------|---|



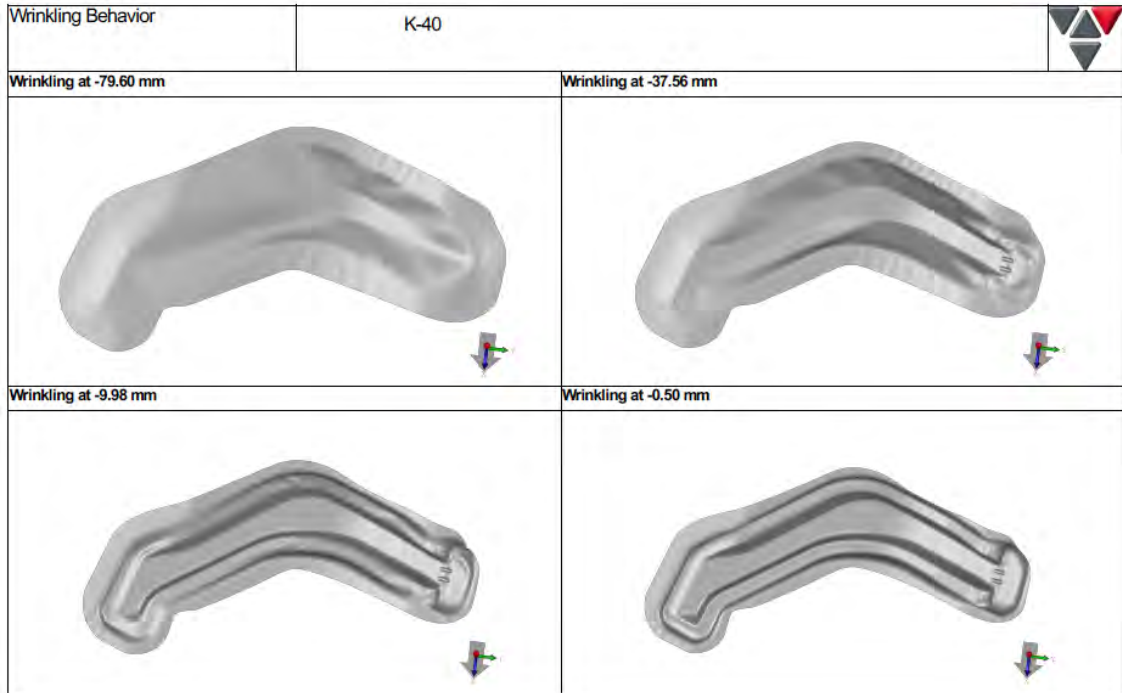
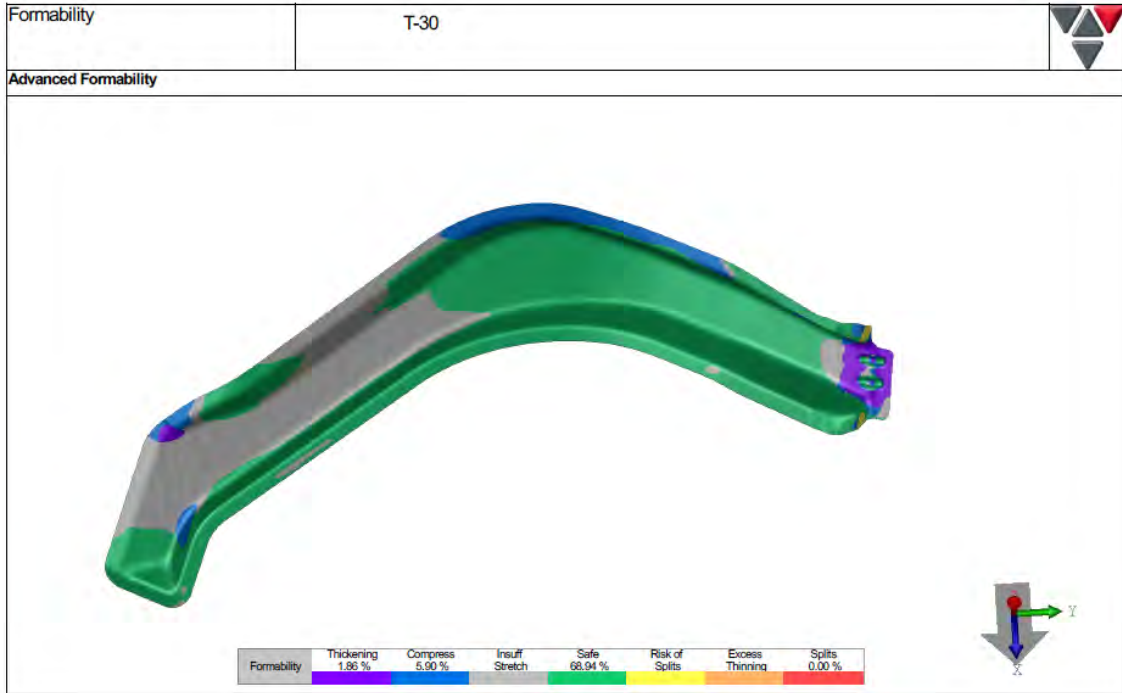
| | | | |
|--------------------|--|--------------|--|
| Wrinkling Behavior | | H-10 | |
| Wrinkling at | | Wrinkling at | |
| | | | |
| Wrinkling at | | Wrinkling at | |
| | | | |

Glance beam outer


| Overview and Summary | | | | | |
|---|--------------------------|--|-----------|-------------------------------------|--------------------------|
| Part Info | | Criterion | OK | n OK | Status |
| Designation: 03585867-Body.2 | Type: Single Action Draw | FLD | 5.2 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Part No.: | Drawing No.: | Flanging | 5.24 | <input type="checkbox"/> | <input type="checkbox"/> |
| Nom. / Calculated Material: Usibor1500_200mm_700C | | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Nom. / Calculated Sheet Thickness: 1.500 mm | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Method Info | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Method Plan No.: | | Thinning | 5.6 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Drawing No.: | Rev.: | Martensite | 5.7 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Part | | Temperature | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| | | Hardness | | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| | | Simulation Info: | | | |
| | | Filename: ARRK_03585867_Glance_Beam_Otr_LH_NMS_8-9-22_it12 - EXTENSION MODS 8 - AutoForm | | | |
| | | AutoForm Forming Solver Thermo R10.0.0 | | | |
| | | Memory: 492.67 MB | | | |
| | | m | | | |
| | | Process - Blank Die / Heating / Draw / Quenching / Laser Trim | | | |
| | | | | | |
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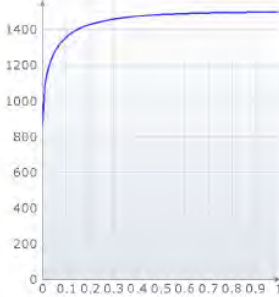
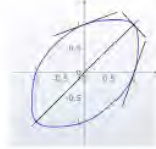
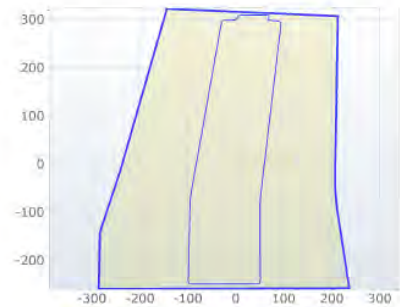
| Input Data | | Material & Blank | | | | | |
|---------------------|------------------|-----------------------|----------|------------------------|-------------------|--|----------|
| Calculated Material | Usibor1500_200mm | Calc. Sheet Thickness | 1.500 mm | | Blank Info | | |
| Yield Stress | | r0 | 1.00 | r90 | 1.00 | <input type="checkbox"/> Rectangular Blank | |
| n-Value | | r45 | 1.00 | E-Module | | <input checked="" type="checkbox"/> Shaped Blank | |
| Yield Curve | | | | Yield Surface | | Meshing | |
| | | | | | | Roll angle | 0.00 ° |
| MU - Part to Blank | | | | RAM Tonnage - 300.0 tf | | Initial Element Size | 20.00 mm |
| 52.12 % | | | | | | Refinement Level | 6 |
| | | | | | | Max Element Angle | 30.00 ° |
| | | | | | | Blank Size - 1310.15 mm X 719.70 mm | |
| | | | | | | | |
| | | | | | | Usibor1500_200mm_700C/1.500 mm | |

| Input Data | | D-20 | | D-20 | | | |
|------------------------------|-----------------------------|------------------|-----|-----------------------|----------|--|--|
| Tool Info | | | | Process Data | | | |
| Meshing Tolerance | 0.05 mm | | | Friction Coefficient | | | |
| Process Type | Single Action Draw | | | Constant | 0.400 | | |
| Tool Geometry Refers to | Lower Side of Initial Blank | | | Die - Blank | - | | |
| Tools | Contact Side | Type | Gap | Punch - Blank | - | | |
| Die | Upper Side of Blank | Rigid | | Binder - Blank | - | | |
| Pad | Upper Side of Blank | Force Controlled | | Binderforce | | | |
| Punch | Lower Side of Blank | Rigid | | RAM | 300.0 tf | | |
| Tool Geometry 1st opp | | | | Binderforce/-pressure | 3,8 tf | | |
| | | | | | | | |



Front Vertical Dash Brace

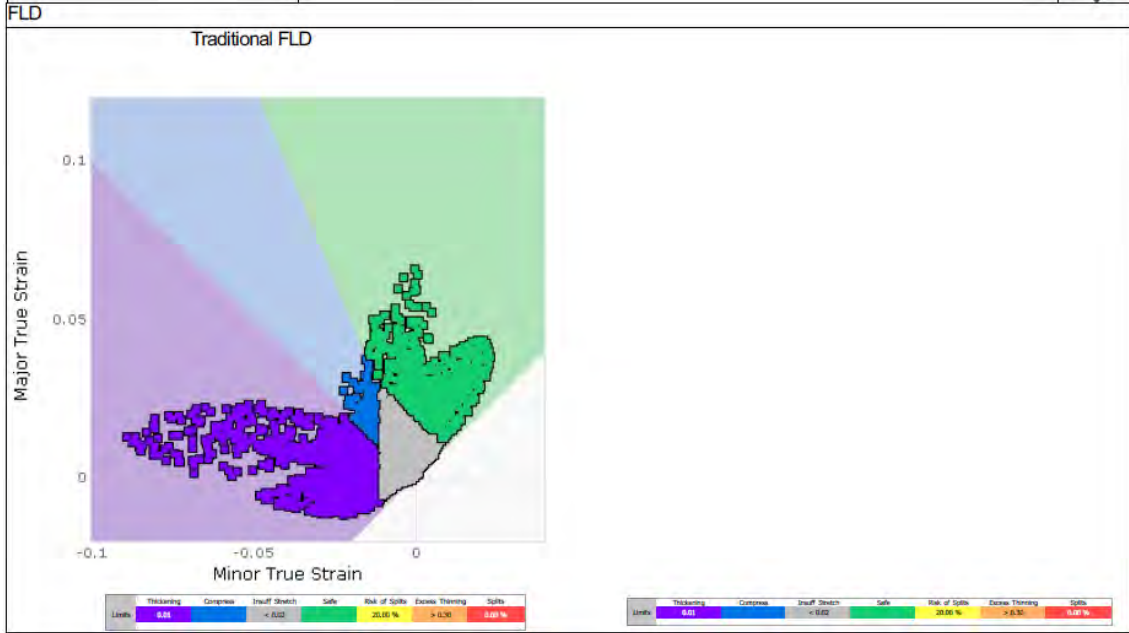
| Overview and Summary | | | |
|---|--------------|--|--|
| Part Info | | Criterion | Status |
| Designation: 03593060-Body.1 | Type: | FLD 5.2 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
| Part No.: | Drawing No.: | Flanging 5.24 | <input type="checkbox"/> OK <input type="checkbox"/> n OK |
| Nom. / Calculated Material: CR820Y1180T_RA_CE+ | | Gravity 5.3 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
| Nom. / Calculated Sheet Thickness: 1.600 mm | | Closing 5.4 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
| Method Info | | Forming 5.5 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
| Method Plan No.: | | Thinning 5.6 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
| Drawing No.: | Rev: | Strain 5.7 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
| Part | | Wrinkles 5.8 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
|  | | Springback 5.9 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
| | | Simulation Info: Filename: ARRK_03593060_Vertical_Dash_Brace_Upr_LH_NMS_8-9-22_It8 - EXTENSION MODS AutoForm Memory: 213.46 MB AutoForm Forming Solver R10.0.0 | |
| Process - Blank / Form / Trim | | | |

| Input Data | | Material & Blank | |
|---|----------------|---|--------------|
| Calculated Material | CR820Y1180T_RA | Calc. Sheet Thickness | 1.600 mm |
| Yield Stress | 869.85 MPa | r0 | 0.56 |
| n-Value | 0.119 | r45 | 0.77 |
| | | r90 | 0.61 |
| | | E-Module | 2.10E+05 MPa |
| Yield Curve | | Yield Surface | |
|  | |  | |
| MU - Part to Blank 72.90 % | | Forming Limit Curve | |
| | | Blank Info <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| | | Meshing | |
| | | Roll angle | 0.00 ° |
| | | Initial Element Size | 20.00 mm |
| | | Refinement Level | 6 |
| | | Max Element Angle | 22.50 ° |
| | | Blank size 521.93 X 581.17  | |
| | | CR820Y1180T_RA_CE+/1.600 mm | |

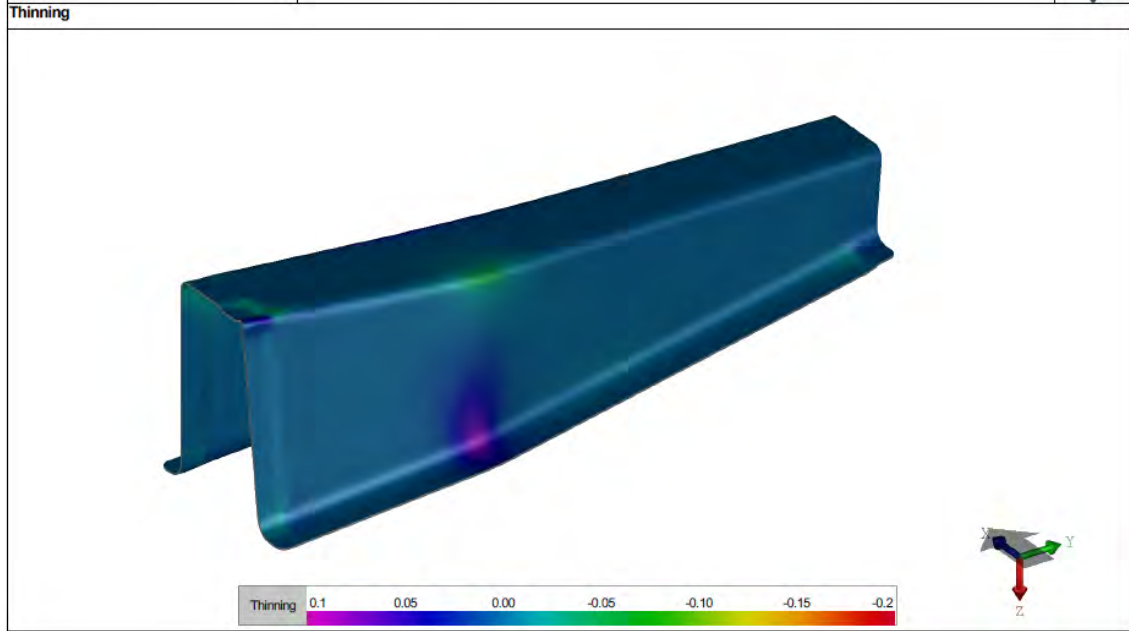
| | | | | | |
|------------------------------|-----------------------------|------------------|-----|----------------------|---------|
| Input Data | | F-10 | | | |
| Tool Info | | | | | |
| Meshing Tolerance | 0.05 mm | | | Friction Coefficient | |
| Process Type | Form Trim Pierce | | | Constant | 0.150 |
| Tool Geometry Refers to | Upper Side of Initial Blank | | | Die - Blank | - |
| Tools | Contact Side | Type | Gap | Punch - Blank | - |
| Pad | Upper Side of Blank | Rigid | | Binder - Blank | - |
| Post | Lower Side of Blank | Force Controlled | | Binderforce | |
| Steel | Lower Side of Blank | Rigid | | RAM | 98.1 tf |
| Tool Geometry 1st opp | | | | Binderforce/pressure | 31.3 tf |
| | | | | | |

| | | | | | | | | | | | | | | | | | | | | | |
|---|------------|----------|---------------|--------|----------------|-----------------|------------|----------|---------------|------|----------------|-----------------|--------|--|--------|--------|--|--------|--|--|--------|
| Formability | | T-20 | | | | | | | | | | | | | | | | | | | |
| Advanced Formability | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | |
| <table border="1" style="width: 100%; text-align: center;"> <tr> <td>Formability</td> <td>Thickening</td> <td>Compress</td> <td>Inuff Stretch</td> <td>Safe</td> <td>Risk of Splits</td> <td>Excess Thinning</td> <td>Splits</td> </tr> <tr> <td></td> <td>7.19 %</td> <td>1.23 %</td> <td></td> <td>2.27 %</td> <td></td> <td></td> <td>0.00 %</td> </tr> </table> | | | | | | Formability | Thickening | Compress | Inuff Stretch | Safe | Risk of Splits | Excess Thinning | Splits | | 7.19 % | 1.23 % | | 2.27 % | | | 0.00 % |
| Formability | Thickening | Compress | Inuff Stretch | Safe | Risk of Splits | Excess Thinning | Splits | | | | | | | | | | | | | | |
| | 7.19 % | 1.23 % | | 2.27 % | | | 0.00 % | | | | | | | | | | | | | | |

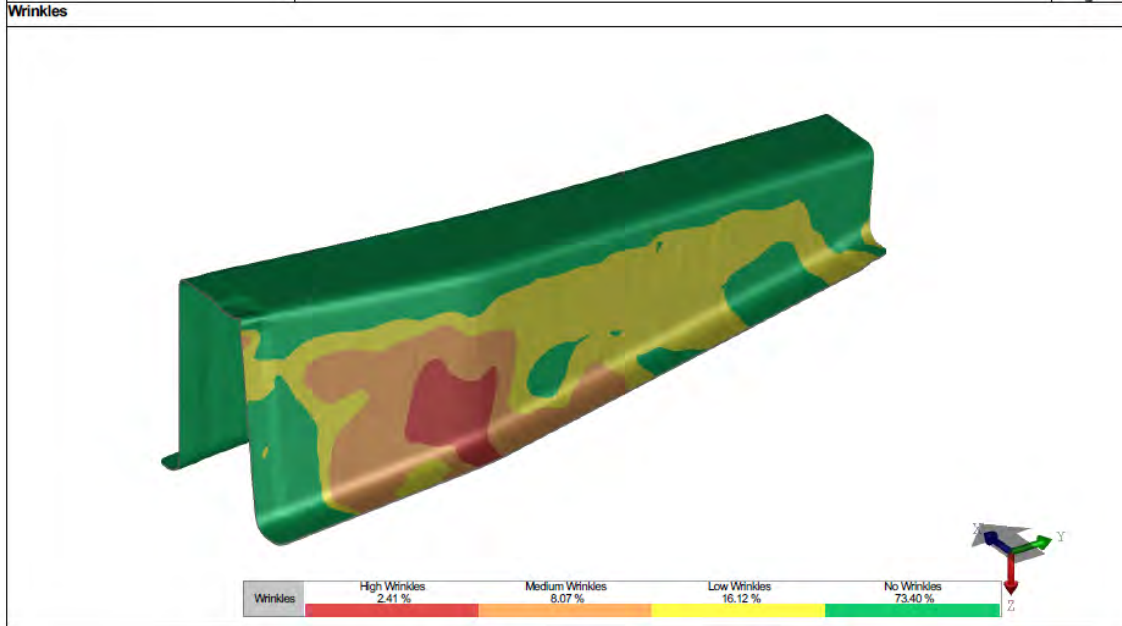
| | | |
|-------------|------|--|
| Formability | F-10 | |
|-------------|------|--|



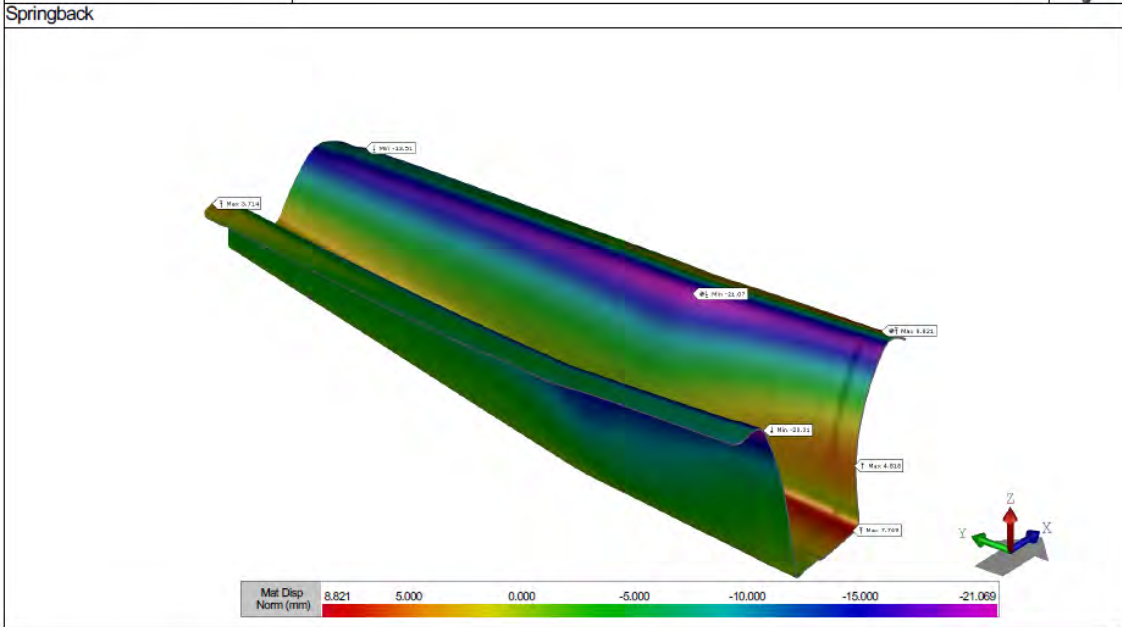
| | | |
|----------|------|--|
| Thinning | T-20 | |
|----------|------|--|



| | | |
|----------|------|---|
| Wrinkles | T-20 |  |
|----------|------|---|



| | | |
|------------|--|---|
| Springback | |  |
|------------|--|---|



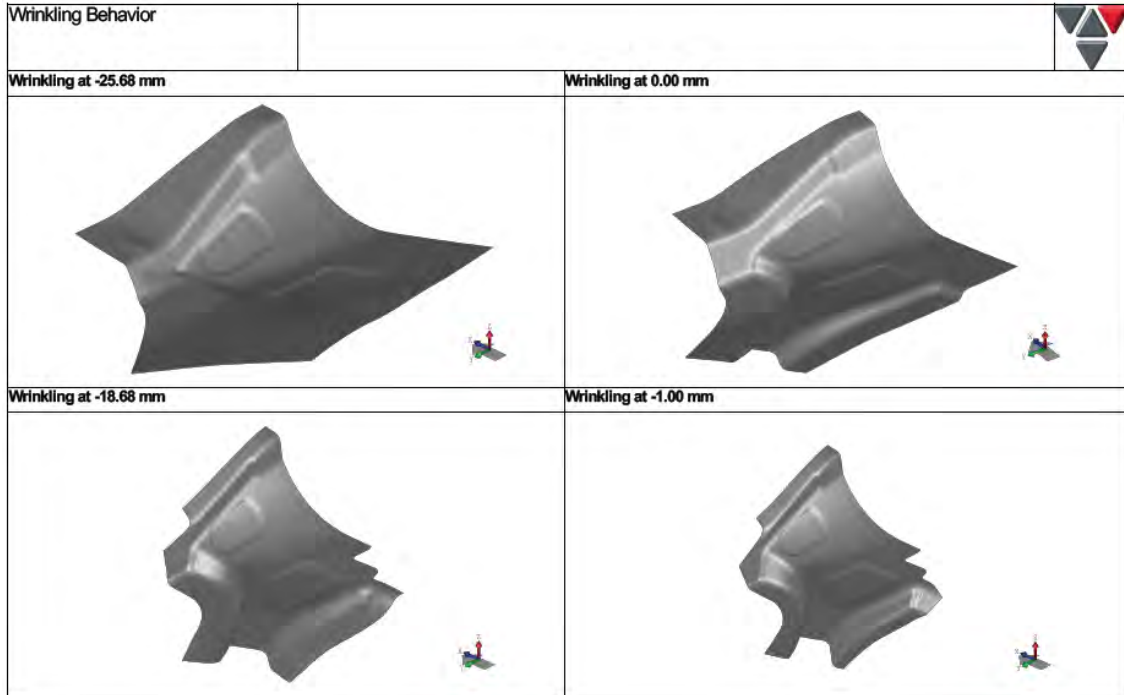
Rear inner roof header gusset

| Overview and Summary | | | | | |
|---|--|--|-----------|-------------------------------------|-------------------------------------|
| Part Info | | Criterion | OK | n OK | Status |
| Designation: 03599233 Rear Inr Roof Hdr Gst Type:Form Trim Pierce | | FLD | 5.2 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Part No.: Drawing No.: | | Flanging | 5.24 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Nom. / Calculated Material: DC04 | | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Nom. / Calculated Sheet Thickness: 0.800 mm | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Method Info | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Method Plan No.: | | Thinning | 5.6 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |
| Drawing No.: Rev.: | | Strain | 5.7 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |
| Part | | Wrinkles | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| | | Springback | 5.9 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| | | Simulation Info: Filename: ARRK_03599233_Rear_Inr_Roof_Header_Gusset_Mount_NMS_21-9-22_it4 - AutoForm AutoForm Forming Solver R10.0.0 Memory: 123.37 MB | | | |
| Process - Blank / Form / Laser Trim / Flange / Laser Trim | | | | | |

| Input Data | | Material & Blank | | | |
|------------------------------|------------|----------------------------|----------|-----------------------|--|
| Calculated Material | DC04 | Calc. Sheet Thickness | 0.800 mm | | |
| Yield Stress | 167.85 MPa | r0 | 1.87 | r902.14 | |
| n-Value | 0.211 | r45 | 1.30 | E-Module 2.10E+05 MPa | |
| Yield Curve | | Yield Surface | | | |
| | | | | | |
| MU - Part to Blank 0.00 % | | Forming Limit Curve | | | |
| | | | | | |
| | | Meshing | | | |
| | | Roll angle | 0.00 ° | | |
| | | Initial Element Size | 40.00 mm | | |
| | | Refinement Level | 7 | | |
| | | Max Element Angle | 30.00 ° | | |
| | | | | | |
| | | DC04(0.800 mm) | | | |

| | | | | | | | |
|------------------------------|-----------------------------|------|------------------|------------------------------|----------------|--|--|
| Input Data | | F-10 | | F-10 | | | |
| Tool Info | | | | Process Data | | | |
| Meshing Tolerance | 0.05 mm | | | Friction Coefficient | Constant 0.080 | | |
| Process Type | Form Trim Pierce | | | Die - Blank | - | | |
| Tool Geometry Refers to | Upper Side of Initial Blank | | | Punch - Blank | - | | |
| Tools | Contact Side | Type | Gap | Binder - Blank | - | | |
| Pad | Upper Side of Blank | | Force Controlled | Binderforce | | | |
| Steel | Upper Side of Blank | | Rigid | RAM | | | |
| Post | Lower Side of Blank | | Rigid | RAM | 45.7 tf | | |
| Tool Geometry 1st opp | | | | Tool Geometry 2nd opp | | | |
| | | | | | | | |

| | | | | | |
|-----------------------------|--|------|--|--|--|
| Formability | | T-40 | | | |
| Advanced Formability | | | | | |
| | | | | | |




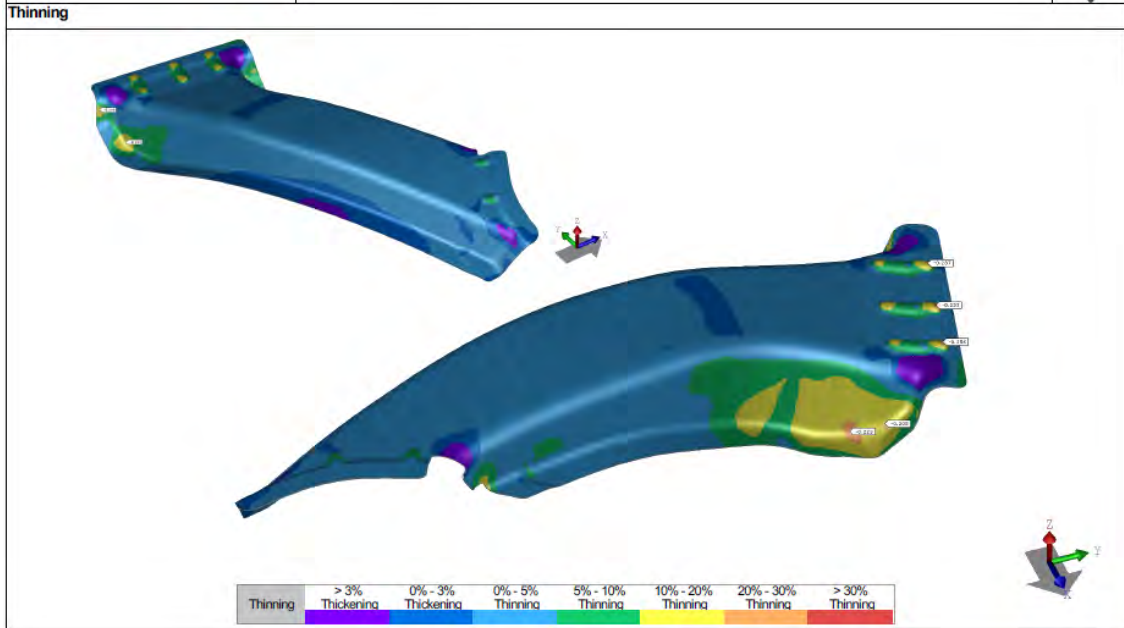
Glance Beam Upper Triangulation Outer

| Overview and Summary | | | | | |
|---|------------------------|---|-----------|-------------------------------------|--------------------------|
| Part Info | | Criterion | OK | n OK | Status |
| Designation: 03601006-Body.1 | Type: Form Trim Pierce | FLD | 5.2 | <input type="checkbox"/> | <input type="checkbox"/> |
| Part No.: | Drawing No.: | Thickness | 5.24 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Nom. / Calculated Material: 22MnB5 | | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Nom. / Calculated Sheet Thickness: 1.000 mm | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Method Info | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Method Plan No.: | | Thinning | 5.6 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Drawing No.: | Rev.: | Martensite | 5.7 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Part | | Temperature | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| | | Hardness | | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| | | Simulation Info: Filename: ARRK_03601006_Glance_Beam_Upr_Triangulation_Otr_LH_NMS_1-9-22_it5 - AutoForm AutoForm Forming Solver Thermo R10.0.0 Memory: 343.38 MB | | | |
| | | Process - Blank Die / Heating / Form / Quenching / Laser Trim | | | |
| | | | | | |
| | | | | | |
| | | | | | |

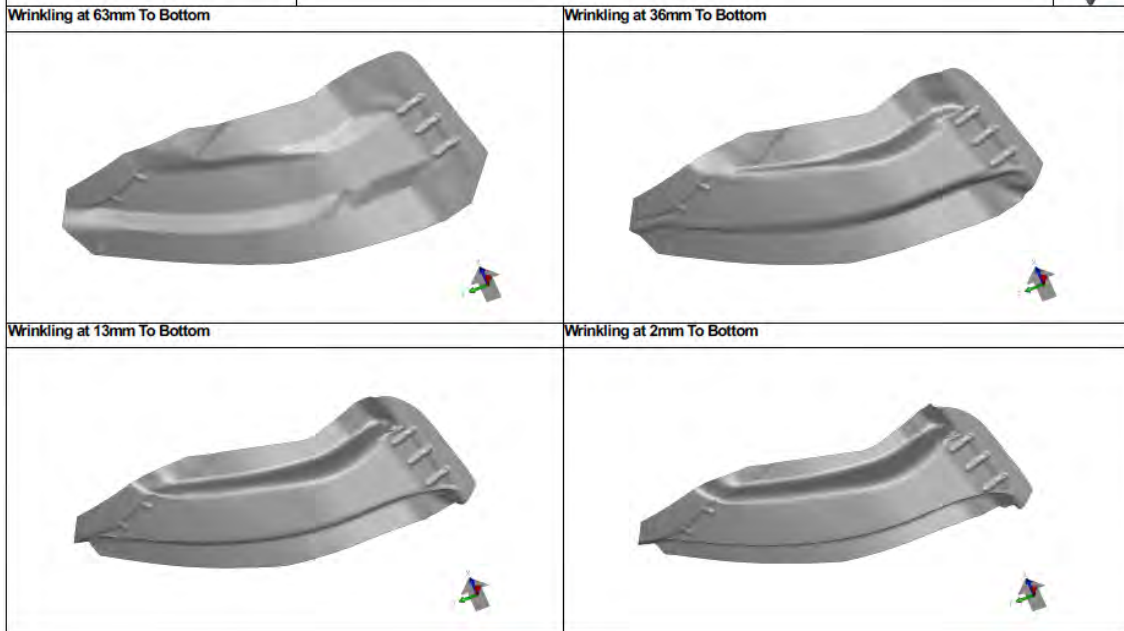
| Input Data | | Material & Blank | | | | | |
|---------------------------------------|--------|-------------------------------|----------|----------|-------------------|--|--|
| Calculated Material | 22MnB5 | Calc. Sheet Thickness | 1.000 mm | | Blank Info | | |
| Yield Stress | | r0 | 1.00 | r90 | 1.00 | <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| n-Value | | r45 | 1.00 | E-Module | | Meshing | |
| Yield Curve | | Yield Surface | | | | Roll angle | |
| | | | | | | 0.00 ° | |
| <p>MU - Part to Blank 87.46 %</p> | | <p>RAM Tonnage - 153.0 tf</p> | | | | Initial Element Size | |
| | | | | | | 20.00 mm | |
| | | | | | | Refinement Level | |
| | | | | | | 5 | |
| | | | | | | Max Element Angle | |
| | | | | | | 22.50 ° | |
| | | | | | | Blank Size - 663.12 mm X 352.75 mm | |
| | | | | | | | |
| | | | | | | 22MnB5 (1.000 mm) | |

| Formability | | T-40 | | | | | | | | | | | | | | | | | | | | | |
|--|------------|----------|----------------|---------|----------------|-----------------|--------|-------------|------------|----------|----------------|------|----------------|-----------------|--------|--|---------|---------|--|---------|--|--|--------|
| Advanced Formability | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | |
| <table border="1"> <thead> <tr> <th>Formability</th> <th>Thickening</th> <th>Compress</th> <th>Insuff Stretch</th> <th>Safe</th> <th>Risk of Splits</th> <th>Excess Thinning</th> <th>Splits</th> </tr> </thead> <tbody> <tr> <td></td> <td>11.39 %</td> <td>22.86 %</td> <td></td> <td>22.51 %</td> <td></td> <td></td> <td>0.00 %</td> </tr> </tbody> </table> | | | | | | | | Formability | Thickening | Compress | Insuff Stretch | Safe | Risk of Splits | Excess Thinning | Splits | | 11.39 % | 22.86 % | | 22.51 % | | | 0.00 % |
| Formability | Thickening | Compress | Insuff Stretch | Safe | Risk of Splits | Excess Thinning | Splits | | | | | | | | | | | | | | | | |
| | 11.39 % | 22.86 % | | 22.51 % | | | 0.00 % | | | | | | | | | | | | | | | | |

| | | |
|----------|------|---|
| Thinning | T-40 |  |
|----------|------|---|



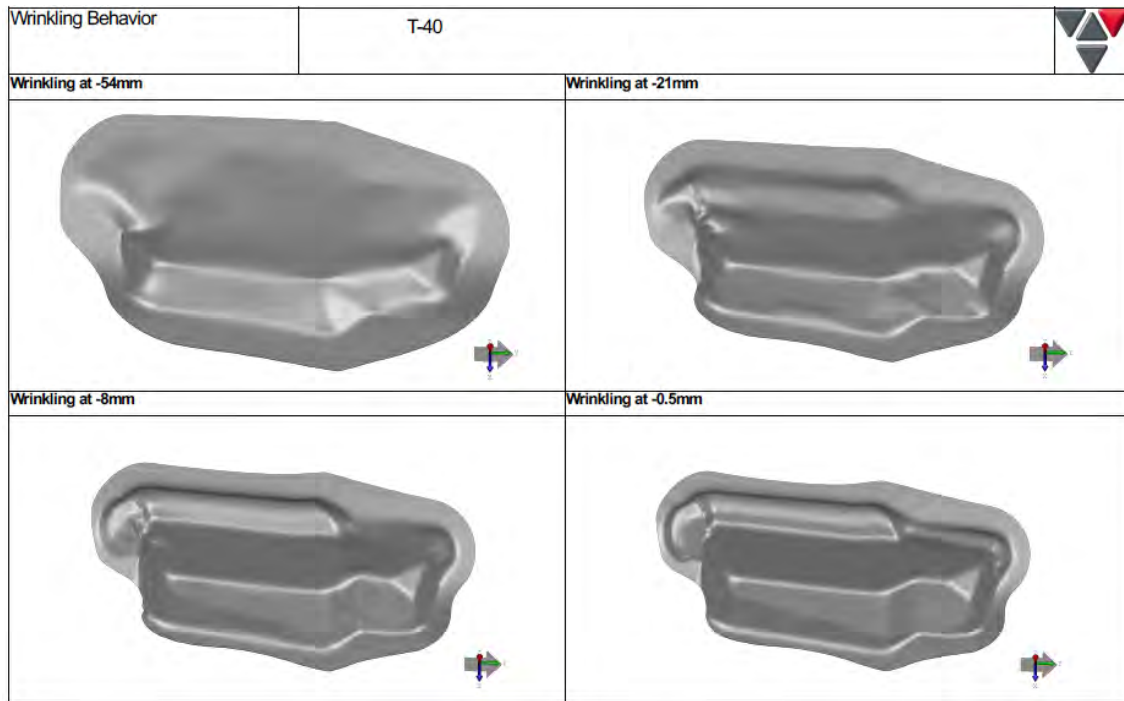
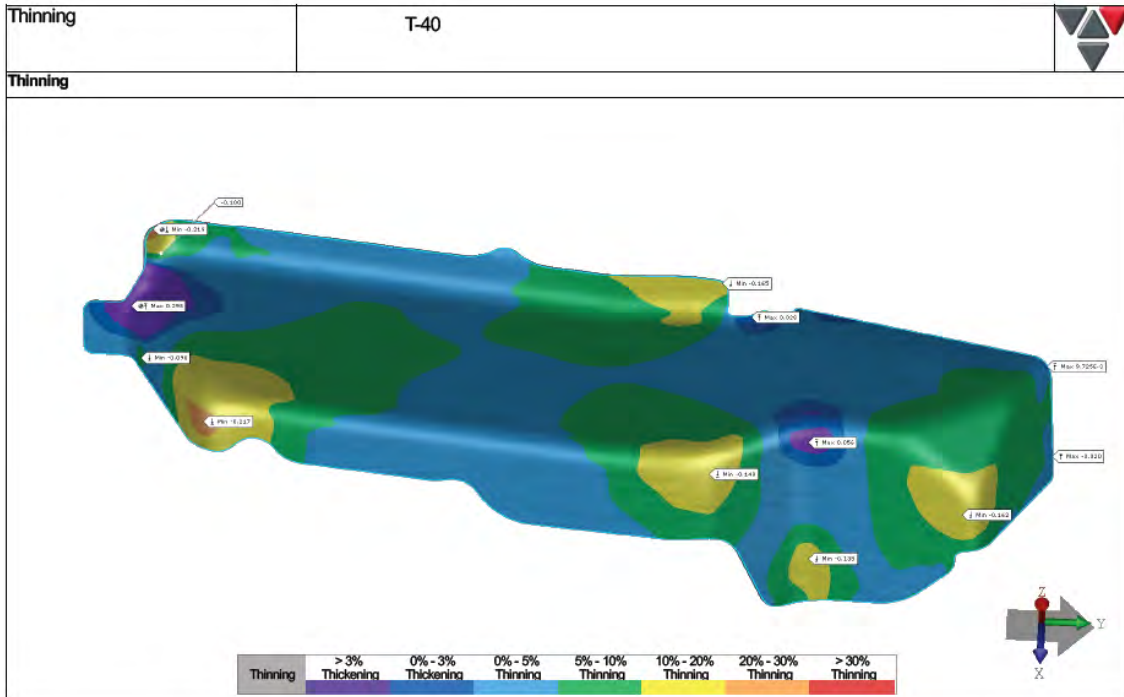
| | | |
|--------------------|------|---|
| Wrinkling Behavior | K-30 |  |
|--------------------|------|---|



Front Vertical Dash Brace Lower

| Overview and Summary | | | | | |
|---|--------------------------|--|-------------------------------------|--------------------------|---------------|
| Part Info | | Criterion | OK | n OK | Status |
| Designation: 03630344 VERTICAL DASH BRACE LOWER | Type: Single Action Draw | FLD | <input type="checkbox"/> | <input type="checkbox"/> | |
| Part No.: | Drawing No.: | Flanging | <input type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Material: Usibor1500_100mm_600C | | Gravity | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Sheet Thickness: 2.000 mm | | Closing | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Info | | Forming | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Plan No.: | | Thinning | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Drawing No.: | Rev.: | Martensite | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part | | Temperature | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Hardness | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Simulation Info: | | | |
| | | Filename: ARRK_03630344_Vertical_Dash_Brace_Lower_Inr_LH_NMS_3-9-22_r4 - EXTENSION | | | |
| | | AutoForm Memory: 771.96 MB | | | |
| | | AutoForm Forming Solver Thermo R10.0.0 | | | |
| | | Process - Blank Die / Heating / Draw / Quenching / Laser Trim | | | |

| Input Data | | Material & Blank | | | |
|-------------------------------|------------------|------------------------|----------|---|--|
| Calculated Material | Usibor1500_100mm | Calc. Sheet Thickness | 2.000 mm | | Blank Info |
| Yield Stress | r0 1.00 | r90 | 1.00 | | <input type="checkbox"/> Rectangular Blank |
| n-Value | r45 1.00 | E-Module | | | <input checked="" type="checkbox"/> Shaped Blank |
| Yield Curve | | Yield Surface | | Meshing | |
| | | | | Roll angle: 0.00 ° Initial Element Size: 20.00 mm Refinement Level: 5 Max Element Angle: 20.00 ° | |
| MU - Part to Blank 45.96 % | | RAM Tonnage - 130.7 tf | | Blank Size - 724.59 mm X 443.70 mm | |



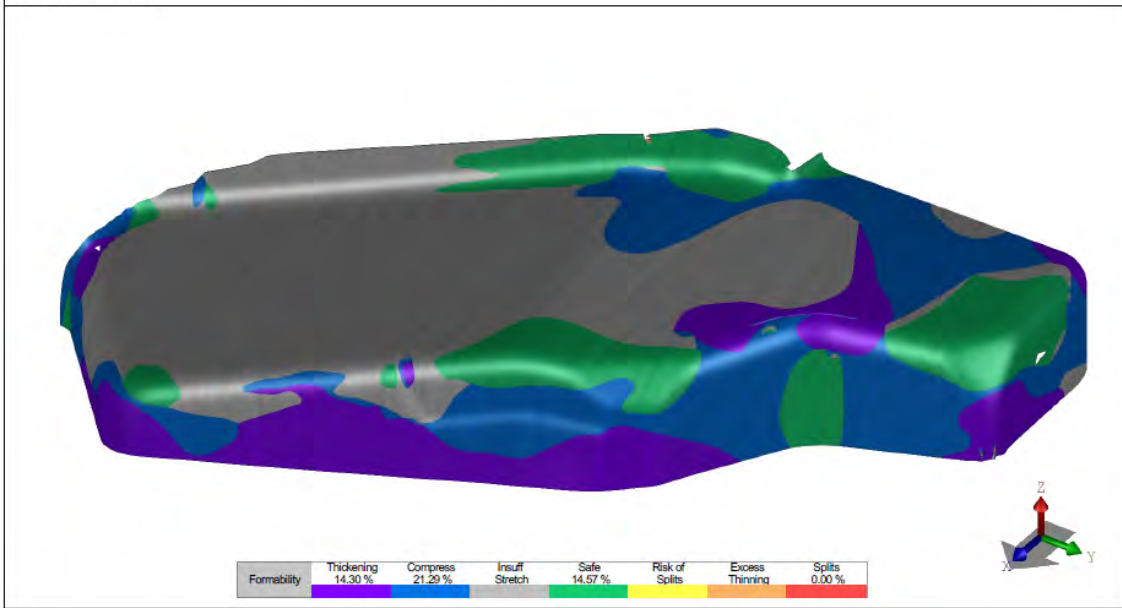
Rear Dash Brace Lower

| Overview and Summary | | | | | |
|--|--------------|---|-------------------------------------|-------------------------------------|---------------|
| Part Info | | Criterion | OK | n OK | Status |
| Designation: 03630350 - Rear Dash Brace | Type: | FLD | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part No.: | Drawing No.: | Flanging | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Material: CR820Y1180T_RA_CE+ | | Gravity | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Sheet Thickness: 1.000 mm | | Closing | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Info | | Forming | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Plan No.: | | Thinning | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Drawing No.: | Rev: | Strain | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part | | Wrinkles | <input type="checkbox"/> | <input checked="" type="checkbox"/> | |
| | | Springback | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Simulation Info: | | | |
| | | Filename: ARRK_03630350_Rear_Dash_Brace_A_LH_NMS_20-9-22_it9 - EXTENSION MODS 7 - | | | |
| | | AutoForm | | Memory: 227.44 MB | |
| | | AutoForm Forming Solver R10.0.0 | | | |
| | | Remarks: After many modifications and many simulations we have a result which is good enough for prototype stage. | | | |

| Input Data | | Material & Blank | |
|---------------------|----------------|---|--------------|
| Calculated Material | CR820Y1180T_RA | Calc. Sheet Thickness | 1.000 mm |
| Yield Stress | 869.85 MPa | r0 | 0.56 |
| n-Value | 0.119 | r45 | 0.77 |
| | | r90 | 0.61 |
| | | E-Module | 2.10E+05 MPa |
| Yield Curve | | Yield Surface | |
| | | | |
| | | Forming Limit Curve | |
| | | | |
| | | Blank Info | |
| | | <input checked="" type="checkbox"/> Rectangular Blank | |
| | | <input type="checkbox"/> Shaped Blank | |
| | | Meshing | |
| | | Roll angle | 0.00 ° |
| | | Initial Element Size | 40.00 mm |
| | | Refinement Level | 7 |
| | | Max Element Angle | 30.00 ° |
| | | | |

| | | | | | | | |
|------------------------------|-----------------------------|------------------|------------------------------|----------------|--|-----------------------|----------|
| Input Data | | | D-20 | | | | |
| Tool Info | | | Process Data | | | | |
| Meshing Tolerance | 0.05 mm | | Friction Coefficient | | | | |
| Process Type | Single Action Draw | | Constant | | | 0.100 | |
| Tool Geometry Refers to | Lower Side of Initial Blank | | Die - Blank | | | - | |
| Tools | Contact Side | Type | Gap | Punch - Blank | | | - |
| Die | Upper Side of Blank | Rigid | | Binder - Blank | | | - |
| Punch | Lower Side of Blank | Rigid | | Binderforce | | | |
| Binder | Lower Side of Blank | Force Controlled | | RAM | | | 117.0 tf |
| Tool Geometry 1st opp | | | Tool Geometry 2nd opp | | | Binderforce/-pressure | |
| | | | | | | 21.2 tf | |

| | | |
|-----------------------------|------|--|
| Formability | D-20 | |
| Advanced Formability | | |



| | | | |
|--------------------|--|---------------------|--|
| Wrinkling Behavior | | D-20 | |
| Wrinkling at -45mm | | Wrinkling at -20mm | |
| | | | |
| Wrinkling at -5mm | | Wrinkling at -0.5mm | |
| | | | |


Front Strut Top

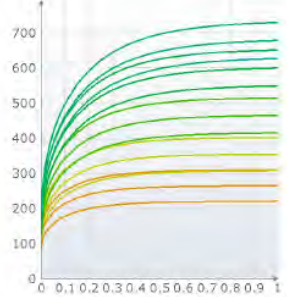
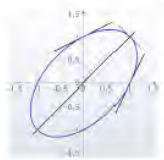
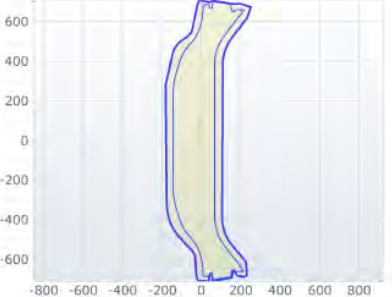
| | | | | | | |
|---|--------------|---|-----------|-------------------------------------|--------------------------|--|
| | | Overview and Summary | | | | |
| Part Info | | Criterion | OK | n OK | Status | |
| Designation: 03603910-Body.1 | Type: | FLD | 5.2 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part No.: | Drawing No.: | Flanging | 5.24 | <input type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Material: CR_1180DP_AF_RevA | | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Sheet Thickness: 2.400 mm | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Info | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Plan No.: | | Thinning | 5.6 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Drawing No.: | Rev: | Strain | 5.7 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part | | Wrinkles | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Springback | 5.9 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Simulation Info: | | | | |
| | | Filename:ARRK_03633910_Strut_Top_Front_LH_NMS_10-6-22_it2 - MOD TIP.afd | | | | |
| | | AutoForm | | Memory: 164.93 MB | | |
| | | AutoForm Forming Solver R10.0.0 | | | | |
| | | Proces - Blank Die / Draw / CAM Trim & Pierce / CAM Trim / | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

| Input Data | | Material & Blank | | Blank Info | |
|-------------------------------|-----------------|-------------------------|----------|---|--------------|
| Calculated Material | CR_1180DP_AF_Re | Calc. Sheet Thickness | 2.400 mm | <input type="checkbox"/> Rectangular Blank | |
| Yield Stress | 927.64 MPa | r0 | 0.80 | <input checked="" type="checkbox"/> Shaped Blank | |
| n-Value | 0.095 | r45 | 0.74 | E-Module | 2.10E+05 MPa |
| Yield Curve | | Yield Surface | | Meshing | |
| | | | | Roll angle: 0.00 ° Initial Element Size: 40.00 mm Refinement Level: 7 Max Element Angle: 30.00 ° | |
| MU - Part to Blank 48.71 % | | Forming Limit Curve | | Blank Size - 630.81 mm X 443.46 mm | |

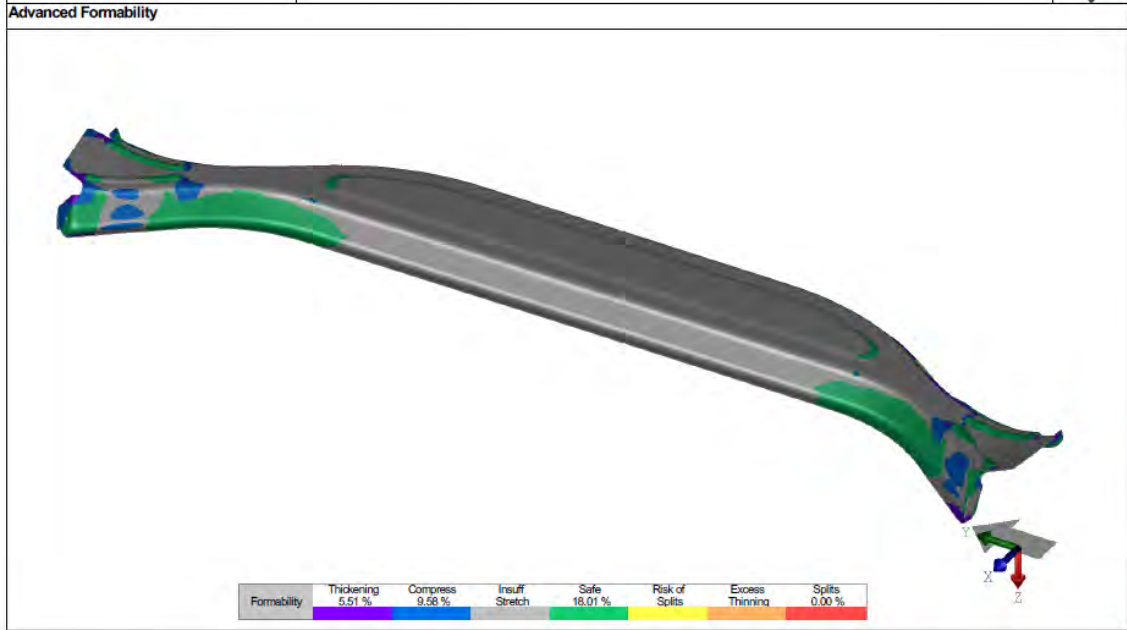
| Wrinkling Behavior | | D-20 | |
|------------------------|--|------------------------|--|
| Wrinkling at -54.95 mm | | Wrinkling at -34.74 mm | |
| | | | |
| Wrinkling at -8.56 mm | | Wrinkling at -1.00 mm | |
| | | | |

Front Strut Cross Member

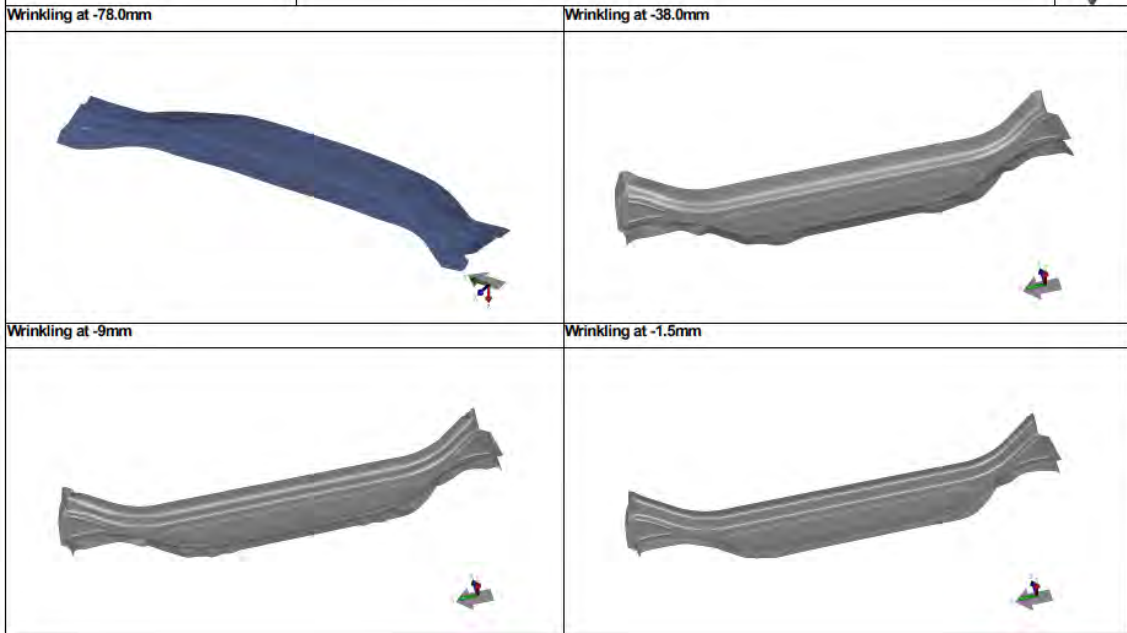
| Overview and Summary | | | |
|---|------------------------|---|--|
| Part Info | | Criterion | OK n OK Status |
| Designation: 03640758-Body.1 | Type: Form Trim Pierce | FLD | 5.2 <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Part No.: | Drawing No.: | Flanging | 5.24 <input type="checkbox"/> <input type="checkbox"/> |
| Nom. / Calculated Material: Usibor2000UFG_200mm_700C | | Gravity | 5.3 <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Nom. / Calculated Sheet Thickness: 1.000 mm | | Closing | 5.4 <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Method Info | | Forming | 5.5 <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Method Plan No.: | | Thinning | 5.6 <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Drawing No.: | Rev.: | Martensite | 5.7 <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Part | | Temperature | 5.8 <input checked="" type="checkbox"/> <input type="checkbox"/> |
|  | | Hardness | <input checked="" type="checkbox"/> <input type="checkbox"/> |
| | | Simulation Info: | |
| | | Filename: ARRK_03640758_Strut_X_Mbr_Frt_NMS_6-9-22_it1 - EXTENSION MODS 2 - NEW | |
| | | AutoForm AutoForm Forming Solver Thermo R10.0.0 Memory: 673.94 MB | |
| | | Process - Blank Die / Heating / Form / Quenching / Laser Trim | |

| Input Data | | Material & Blank | |
|---|-------------------|--|----------|
| Calculated Material | Usibor2000UFG_200 | Calc. Sheet Thickness | 1.000 mm |
| Yield Stress | r0 1.00 r90 1.00 | Blank Info | |
| n-Value | r45 1.00 E-Module | <input type="checkbox"/> Rectangular Blank | |
| Yield Curve | | <input checked="" type="checkbox"/> Shaped Blank | |
|  | | Meshing | |
| Yield Surface | | Roll angle | |
|  | | 0.00 ° | |
| MU - Part to Blank | | Initial Element Size | |
| 92.90 % | | 40.00 mm | |
| RAM Tonnage - 300.0 tf | | Refinement Level | |
| | | 5 | |
| | | Max Element Angle | |
| | | 22.50 ° | |
| | | Blank Size - 1416.97 mm X 432.08 mm | |
| | |  | |
| | | Usibor2000UFG_200mm_700C(1.000 mm) | |


| | | |
|-------------|------|--|
| Formability | T-40 | |
|-------------|------|--|

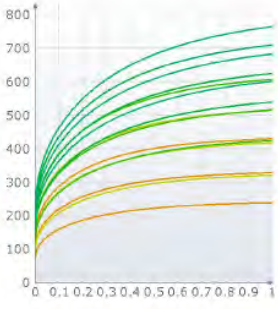

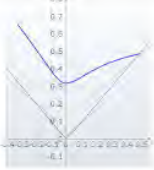



| | | |
|--------------------|------|--|
| Wrinkling Behavior | T-40 | |
|--------------------|------|--|



Glance Beam Upper Reaction


| Overview and Summary | | | |
|---|--------------|--|---|
| Part Info | | Criterion | OK n OK Status |
| Designation: 03640760-Body.1 | Type: | FLD | 5.2 <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Part : | Drawing No.: | Flanging | 5.24 <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Nom. / Calculated Material: Usibor1500_200mm_700C | | Gravity | 5.3 <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Nom. / Calculated Sheet Thickness: 0.800 mm | | Closing | 5.4 <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Method Info | | Forming | 5.5 <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Method Plan No.: | | Thinning | 5.6 <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Drawing No.: | Rev: | Strain | 5.7 <input checked="" type="checkbox"/> <input type="checkbox"/> |
| Part | | Wrinkles | 5.8 <input checked="" type="checkbox"/> <input type="checkbox"/> |
|  | | Springback | 5.9 <input checked="" type="checkbox"/> <input type="checkbox"/> |
| | | Simulation Info: | |
| | | Filename: ARRK_03640760_Glance_Beam_Upr_Reaction_LH_NMS_7-9-22_it9 - EXTENSION | |
| | | AutoForm Memory: 389.41 MB | |
| | | AutoForm Forming Solver Thermo R10.0.0 | |
| Process - Blank / Heating / Draw / Cooling / Trim | | | |

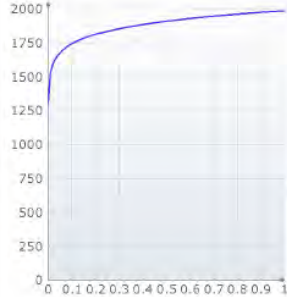
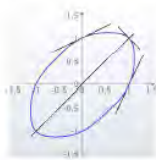
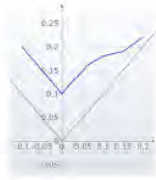

| Input Data | | Material & Blank | |
|---|------------------|--|----------|
| Calculated Material | Usibor1500_200mm | Calc. Sheet Thickness | 0.800 mm |
| Yield Stress | | r0 | 1.00 |
| n-Value | | r45 | 1.00 |
| | | r90 | 1.00 |
| | | E-Module | |
| Yield Curve | | Yield Surface | |
|  | |  | |
| <p>MU - Part to Blank 41.31 %</p> | | Forming Limit Curve | |
| | |  | |
| | | Blank Info | |
| | | <input type="checkbox"/> Rectangular Blank | |
| | | <input checked="" type="checkbox"/> Shaped Blank | |
| | | Meshing | |
| | | Roll angle | 0.00 ° |
| | | Initial Element Size | 40.00 mm |
| | | Refinement Level | 6 |
| | | Max Element Angle | 22.50 ° |
| | | Blank Size - 565.99 mm x 326.44 mm | |
| | |  | |
| | | Usibor1500_200mm_700C(0.800 mm) | |

| | | | | | |
|------------------------------|-----------------------------|----------------|-----|----------------------|----------|
| Input Data | | D-20 | | | |
| Tool Info | | | | | |
| Meshing Tolerance | 0.05 mm | | | Friction Coefficient | |
| Process Type | Single Action Draw | | | Constant | 0.450 |
| Tool Geometry Refers to | Lower Side of Initial Blank | | | Die - Blank | - |
| Tools | Contact Side | Type | Gap | Punch - Blank | - |
| Die | Upper Side of Blank | Rigid | | Binder - Blank | - |
| Punch | Lower Side of Blank | Rigid | | Binderforce | |
| Binder | Lower Side of Blank | Gap Controlled | | RAM | 200.0 tf |
| Tool Geometry 1st opp | | | | Binderforce/pressure | 0.8 tf |
| | | | | | |

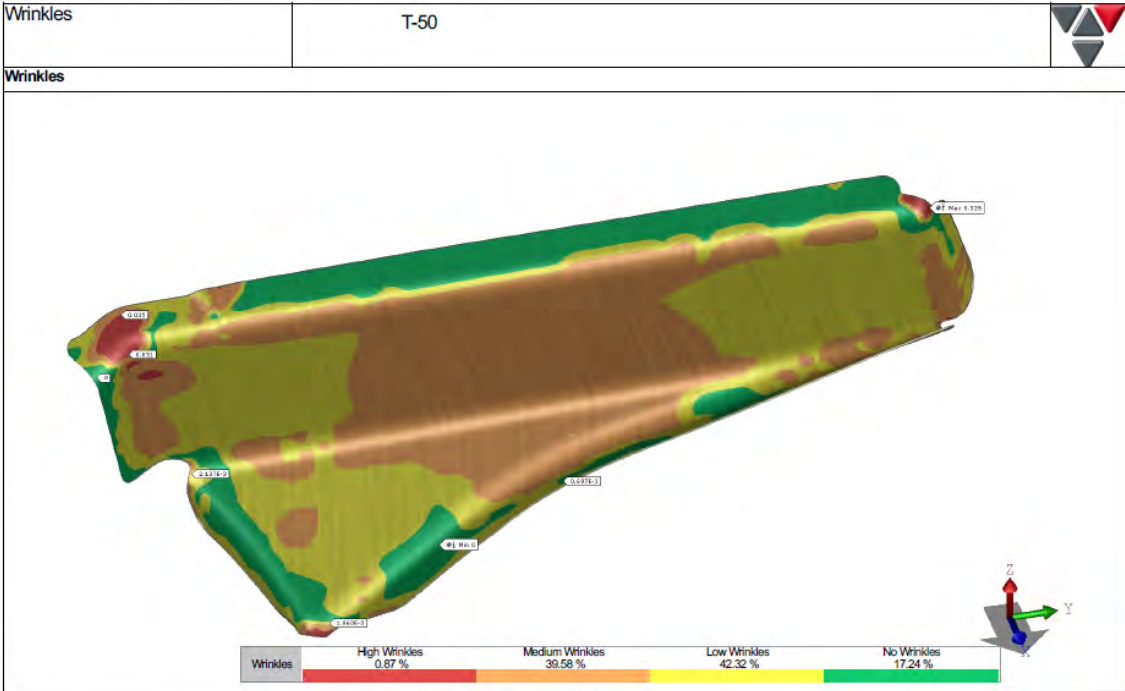
| | | | | | |
|--|--|------|--|---|--|
| Wrinkling Behavior | | D-20 | | | |
| Wrinkling at 10mm To Bottom 1st stage | | | | | |
| | | | | | |
| Wrinkling at 11mm To Bottom 2nd stage | | | | Wrinkling at 1.5mm To Bottom 2nd stage | |
| | | | | | |

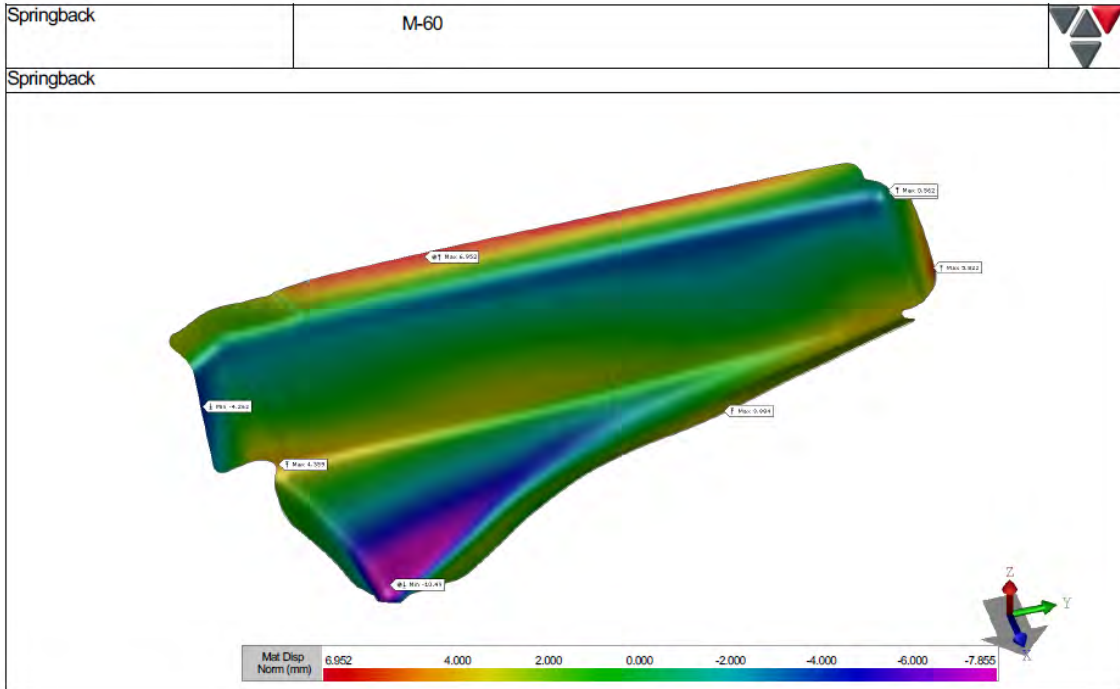
Glance Beam Lower Reaction

| Overview and Summary | | | | | |
|---|--------------|---|-----------|-------------------------------------|--------------------------|
| Part Info | | Criterion | OK | n OK | Status |
| Designation: 03642244-Body.1 | Type: | FLD | 5.2 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Part : | Drawing No.: | Flanging | 5.24 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Nom. / Calculated Material: SSAB_CR1220Y1500T_MS | | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Nom. / Calculated Sheet Thickness: 0.800 mm | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Method Info | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Method Plan No.: | | Thinning | 5.6 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Drawing No.: | Rev.: | Strain | 5.7 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Part | | Wrinkles | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
|  | | Springback | 5.9 | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| | | Simulation Info: Filename: ARRK_03642244_Glance_Beam_Lwr_Reaction_LH_NMS_31-8-22_it3 - EXTENSION AutoForm AutoForm Forming Solver R10.0.0 | | | |
| | | Process - Blank / Crash / Flange Up / Form / Laser Trim | | | |

| Input Data | | Material & Blank | |
|---|------------------|---|--------------|
| Calculated Material | SSAB_CR1220Y1500 | Calc. Sheet Thickness | 0.800 mm |
| Yield Stress | 1296.54 MPa | r0 | 0.93 |
| n-Value | 0.084 | r45 | 0.94 |
| | | r90 | 0.96 |
| | | E-Module | 2.00E+05 MPa |
| Yield Curve | | Yield Surface | |
|  | |  | |
| MU - Part to Blank 98.70 % | | Forming Limit Curve | |
| | |  | |
| | | Blank Info <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| | | Meshing | |
| | | Roll angle | 0.00 ° |
| | | Initial Element Size | 40.00 mm |
| | | Refinement Level | 6 |
| | | Max Element Angle | 22.50 ° |
| | | Blank Size - 451.50 mm x 228.35 mm | |
| | |  | |
| | | SSAB_CR1220Y1500T_MS/0.800 mm | |

| | | | | | |
|------------------------------|-----------------------------|------------------------------|----------------------|------------------------------|-------|
| Input Data | | C-20 | | | |
| Tool Info | | Process Data | | | |
| Meshing Tolerance | 0.05 mm | | Friction Coefficient | | |
| Process Type | Crashform Up | | Constant | | 0.100 |
| Tool Geometry Refers to | Lower Side of Initial Blank | | Die - Blank | | - |
| Tools | Contact Side | Type | Gap | Punch - Blank | - |
| Die | Upper Side of Blank | Rigid | | Binder - Blank | - |
| Punch | Lower Side of Blank | Rigid | | Binderforce | |
| | | RAM | | 39.6 tf | |
| Tool Geometry 1st opp | | Binderforce/-pressure | | 4.70 N | |
| | | Tool Geometry 2nd opp | | Tool Geometry 3rd opp | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |



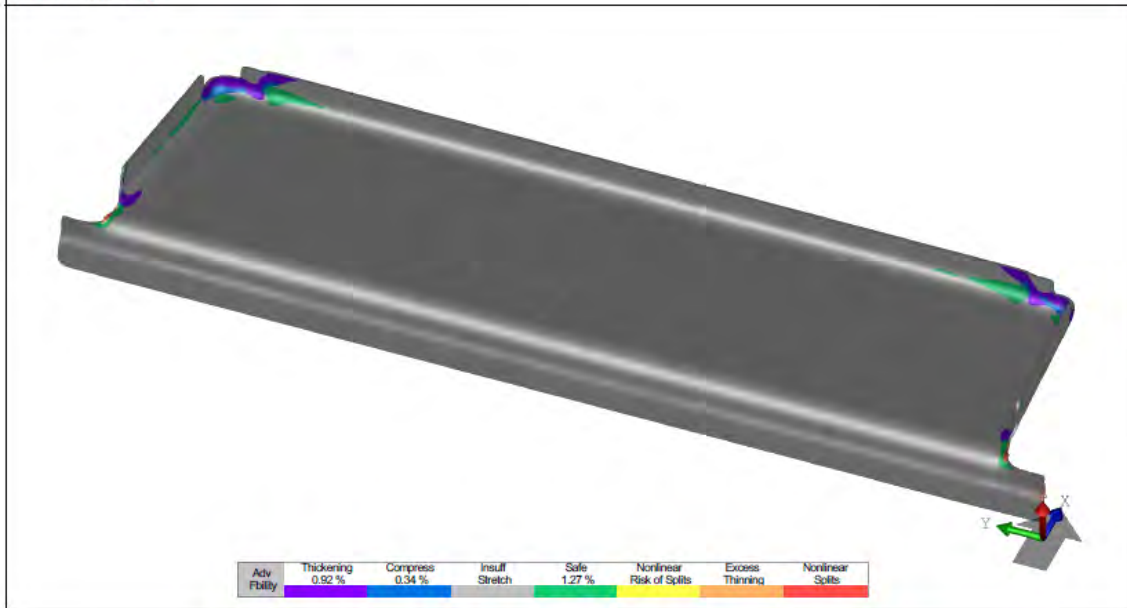


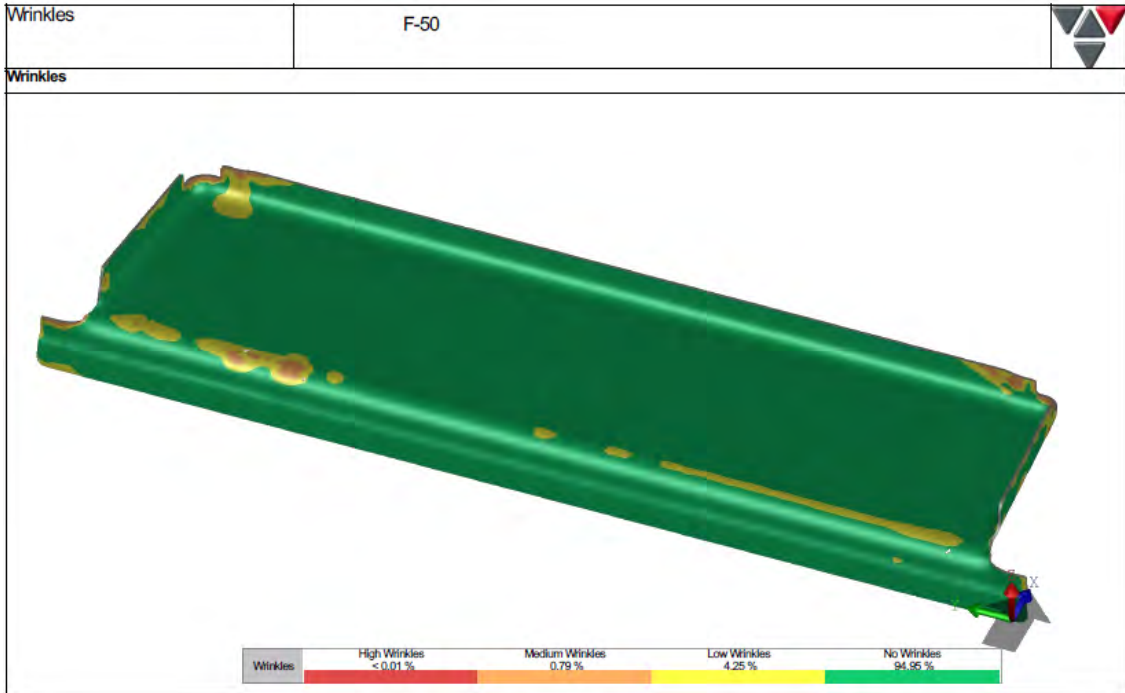
One bar outer upper

| Overview and Summary | | | | | |
|--|--------------|--|-------------------------------------|--------------------------|---------------|
| Part Info | | Criterion | OK | n OK | Status |
| Designation: 03670457 One_Bar_Outer_Upper | Type: | FLD | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part No.: | Drawing No.: | Flanging | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Material: SSAB_CR1220Y1500T_MS | | Gravity | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Sheet Thickness: 2.000 mm | | Closing | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Info | | Forming | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Plan No.: | | Thinning | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Drawing No.: | Rev: | Strain | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part | | Wrinkles | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Springback | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Simulation Info: | | | |
| | | Filename: ARRK_03670457_One_Bar_Outer_Upr_NMS_5-9-22_it2 - EXTENSION MODS 2 - | | | |
| | | AutoForm AutoForm Forming Solver R10.0.0 | | | |
| | | Memory: 207.26 MB | | | |
| | | Process - Blank Die / Crash / Flange / Form / Re-strike | | | |
| | | | | | |
| | | | | | |
| | | | | | |

| Input Data | | Material & Blank | | | | | |
|--|------------------|-----------------------|----------|----------|--------------|--|--|
| Calculated Material | SSAB_CR1220Y1500 | Calc. Sheet Thickness | 2.000 mm | | Blank Info | | |
| Yield Stress | 1296.54 MPa | r0 | 0.93 | r90 | 0.96 | <input type="checkbox"/> Rectangular Blank | |
| n-Value | 0.084 | r45 | 0.94 | E-Module | 2.00E+05 MPa | <input checked="" type="checkbox"/> Shaped Blank | |
| Yield Curve | | | | | | Meshing | |
| Yield Surface | | | | | | Roll angle | |
| Forming Limit Curve | | | | | | Initial Element Size | |
| Blank size - 710.55 mm X 231.68 mm | | | | | | Refinement Level | |
| | | | | | | Max Element Angle | |
| | | | | | | | |
| | | | | | | | |
| <p>MU - Part to Blank 102.26 %</p> | | | | | | <p>SSAB_CR1220Y1500T_M5/2,000 mm</p> | |

| Formability | F-50 | |
|----------------------|------|--|
| Advanced Formability | | |



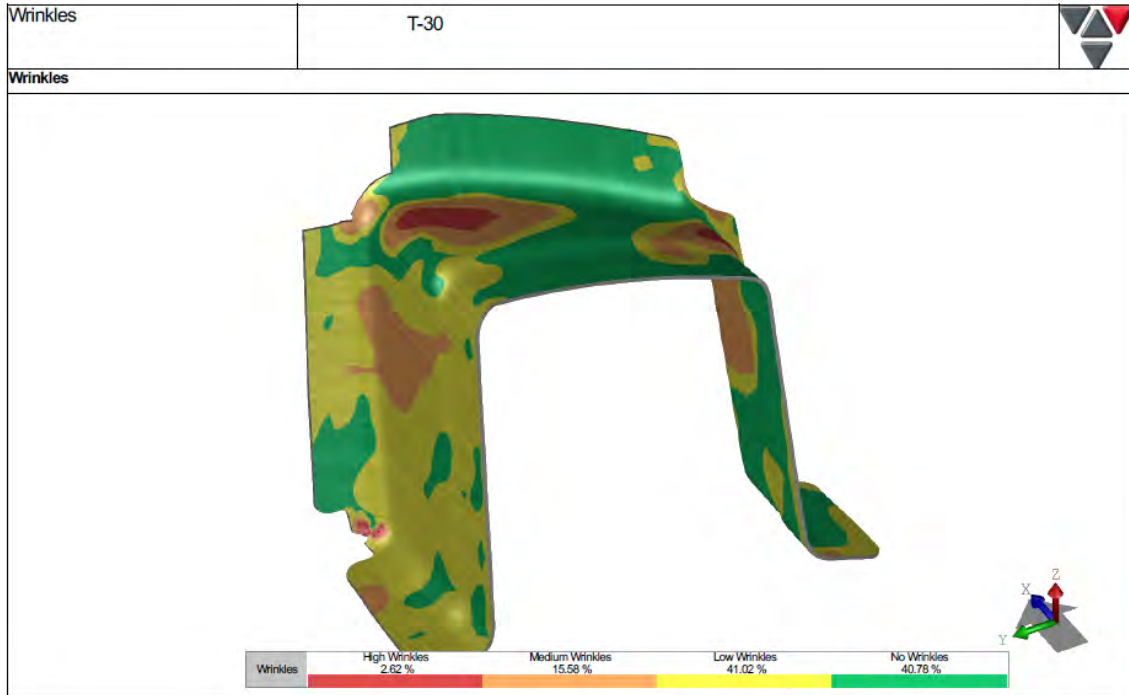


Front Vertical Dash Brace Upper

| | | | | | | |
|--|-----------------------------|--|------|-------------------------------------|--------------------------|---------------|
| | | Overview and Summary | | | | |
| Part Info | | Criterion | | OK | n OK | Status |
| Designation: | Type: Single Action Draw | FLD | 5.2 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part No.: | Drawing No.: | Flanging | 5.24 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Material: USS_CAL_MS1500_AF_RevB | | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Sheet Thickness: 1.600 mm | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Info | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Plan No.: | | Thinning | 5.6 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Drawing No.: | Rev.: | Strain | 5.7 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part | | Wrinkles | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Springback | 5.9 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Simulation Info: | | | | |
| | | Filename: ARRK_03671385_Vertical_Dash_Brace_Upr_Frt_NMS_21-9-22_it1 - EXTENSION | | | | |
| | | AutoForm | | Memory: 73.36 MB | | |
| | | AutoForm Forming Solver R10.0.0 | | | | |
| | | Process - Blank / Form / Laser trim / Form / Laser Trim | | | | |

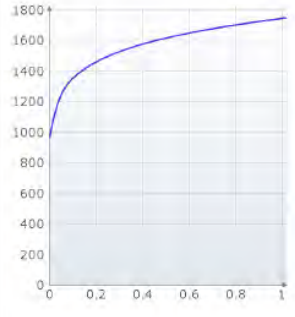
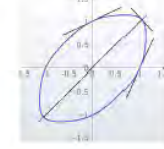
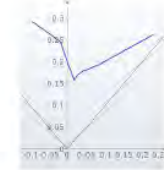

| Input Data | | Material & Blank | | | | Blank Info | |
|------------------------|----------------|--------------------------------|----------|------------------------|--|---|--|
| Calculated Material | USS_CAL_MS1500 | Calc. Sheet Thickness | 1.600 mm | | | <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| Yield Stress | 1359.15 MPa | r0 | 1.24 | r90 0.83 | | Meshing Roll angle: 0.00 ° Initial Element Size: 40.00 mm Refinement Level: 7 Max Element Angle: 30.00 ° | |
| n-Value | 0.061 | r45 | 0.50 | E-Module: 2.10E+05 MPa | | | |
| Yield Curve | | Yield Surface | | | | | |
| | | Forming Limit Curve | | | | | |

| Formability | | T-30 | | | | | | | | | |
|--|--------------------|-----------------|-----------------|------------------|--------------------------|-----------------|------------------|-------------|--------------------------|-----------------|------------------|
| Advanced Formability | | | | | | | | | | | |
| | | | | | | | | | | | |
| <table border="1"> <tr> <td>Adv. Formability</td> <td>Thickening 11.30 %</td> <td>Compress 1.15 %</td> <td>Insuff. Stretch</td> <td>Safe 2.57 %</td> <td>Nonlinear Risk of Splits</td> <td>Excess Thinning</td> <td>Nonlinear Splits</td> </tr> </table> | | | | Adv. Formability | Thickening 11.30 % | Compress 1.15 % | Insuff. Stretch | Safe 2.57 % | Nonlinear Risk of Splits | Excess Thinning | Nonlinear Splits |
| Adv. Formability | Thickening 11.30 % | Compress 1.15 % | Insuff. Stretch | Safe 2.57 % | Nonlinear Risk of Splits | Excess Thinning | Nonlinear Splits | | | | |

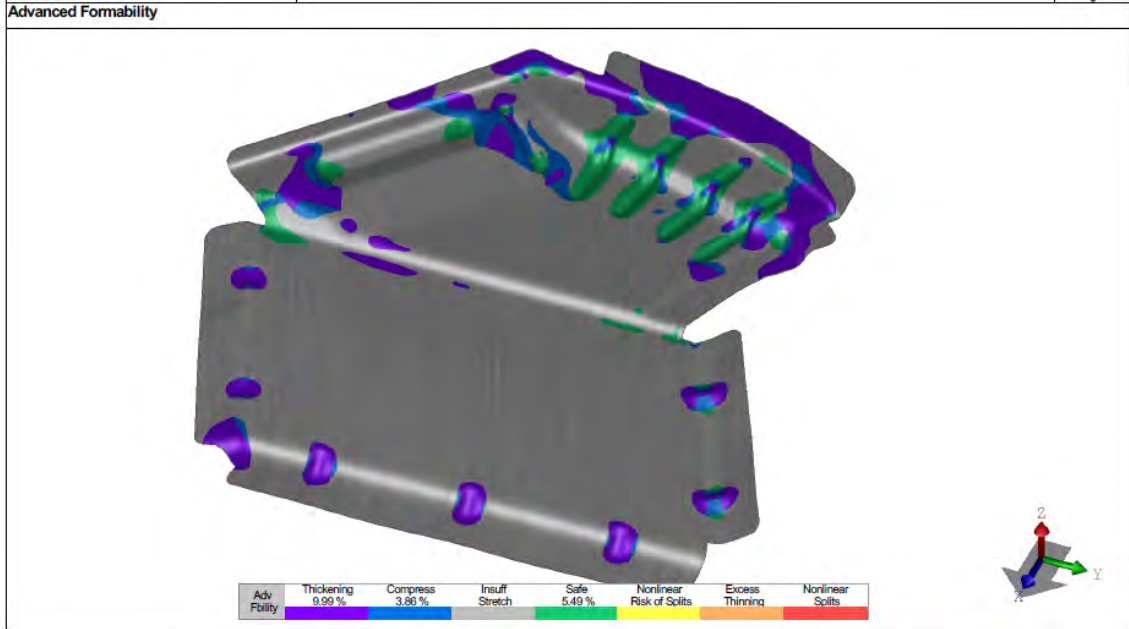


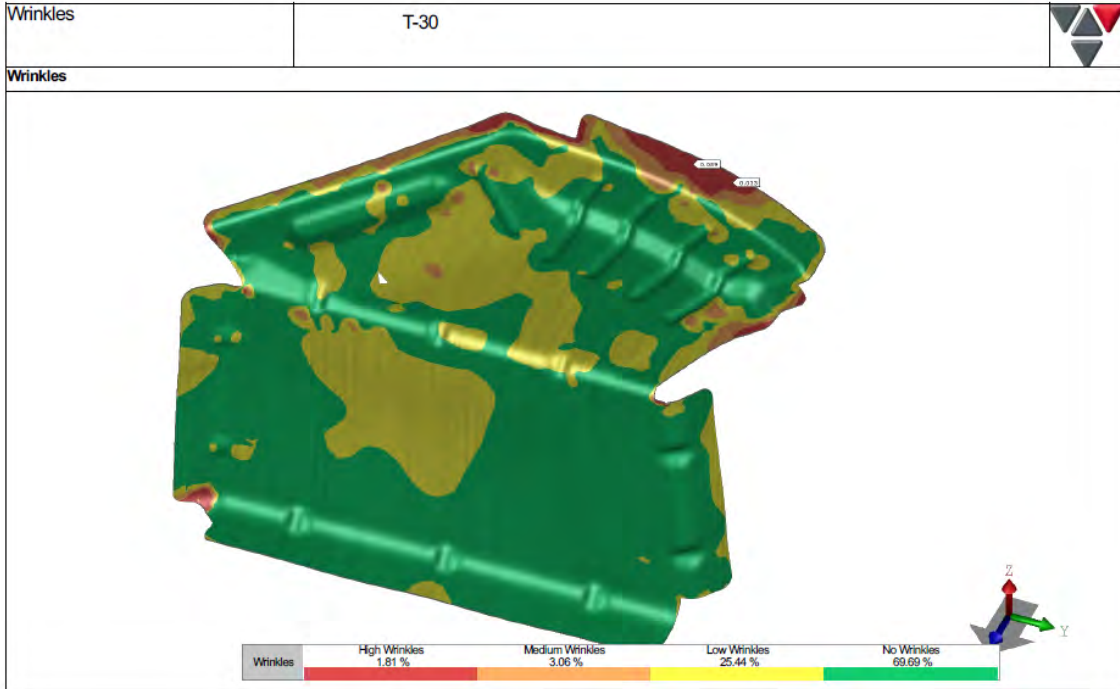
Front torque box outer

| | | | | | | |
|---|--|---|-----------|-------------------------------------|--------------------------|--|
| | | Overview and Summary | | | | |
| Part Info | | Criterion | OK | n OK | Status | |
| Designation: 03691527-Body.1 | | FLD | 5.2 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Type: | | Flanging | 5.24 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part No.: | | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Drawing No.: | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Material: | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Sheet Thickness: 1.000 mm | | Thinning | 5.6 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Info | | Strain | 5.7 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Plan No.: | | Wrinkles | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Drawing No.: | | Springback | 5.9 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Rev.: | | Simulation Info: | | | | |
| Part | | Filename: | | | | |
| | | ARRK_03691527_Torque_Box_NMS_14-8-22_it3 - EXTENSION MODS 1 - NEW CAD | | | | |
| | | AutoForm | | Memory: 242.03 MB | | |
| | | AutoForm Forming Solver R10.0.0 | | | | |
| | | Process - Blank Die / Crash & Flange / Form / | | | | |
| | | | | | | |
| | | | | | | |

| Input Data | | Material & Blank | | | | Blank Info | |
|---|------------------------------|---|------|---|--------------|---|--|
| Calculated Material | CR850Y1180T-DH-UC-EG DP1200- | Calc. Sheet Thickness | | 1.000 mm | | <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| Yield Stress | 957.78 MPa | r0 | 0.85 | r90 | 0.94 | Meshing Roll angle: 0.00 ° Initial Element Size: 20.00 mm Refinement Level: 6 Max Element Angle: 22.50 ° | |
| n-Value | 0.132 | r45 | 1.04 | E-Module | 2.10E+05 MPa | | |
| Yield Curve  <p>MU - Part to Blank 94.60 %</p> | | Yield Surface  | |  | | | |
| | | | |  <p>CR850Y1180T-DH-UC-EG_DP1200-HD_Rev2(1.000 mm)</p> | | | |

| Formability | T-30 |
|-----------------------------|------|
| Advanced Formability | |





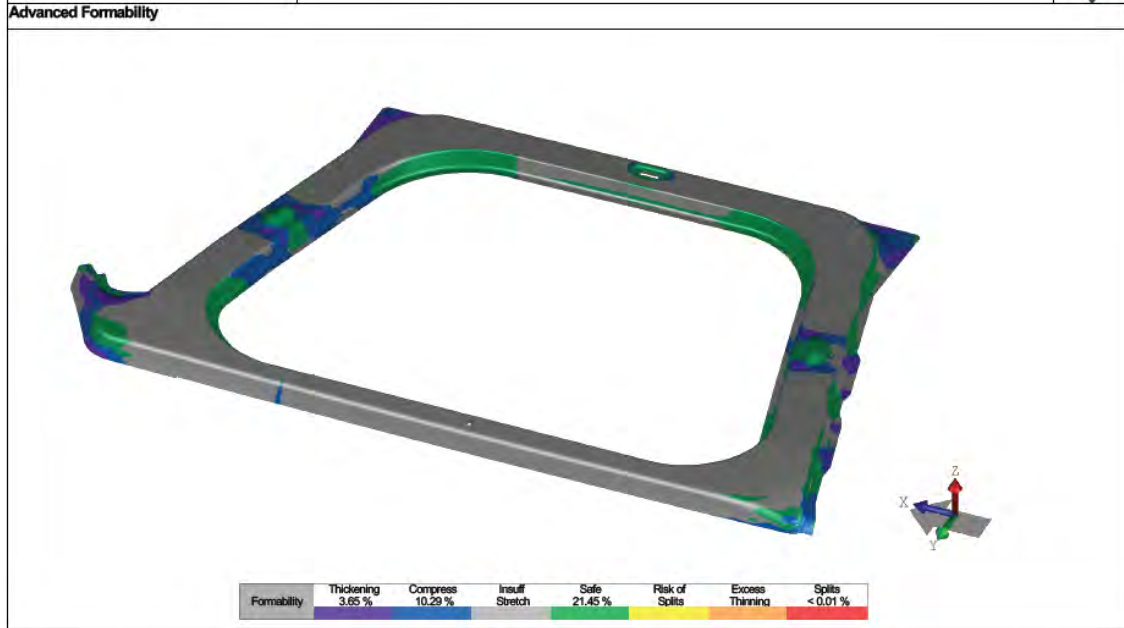
Door Ring Outer (TWB)

| Overview and Summary | | | | | |
|---|--------------|--|-----------|-------------------------------------|---------------|
| Part Info | | Criterion | OK | n OK | Status |
| Designation: 03694699-Body.1 | | FLD | 5.2 | <input type="checkbox"/> | |
| Type: Heating | | Thickness | 5.24 | <input checked="" type="checkbox"/> | |
| Part No.: | Drawing No.: | Gravity | 5.3 | <input checked="" type="checkbox"/> | |
| Nom. / Calculated Material: Usibor 2000 / Usibor 1500 / Ductibor 1000 | | Closing | 5.4 | <input checked="" type="checkbox"/> | |
| Nom. / Calculated Sheet Thickness: 1.2mm / 1.5mm / 0.8mm | | Forming | 5.5 | <input checked="" type="checkbox"/> | |
| Method Info | | Thinning | 5.6 | <input checked="" type="checkbox"/> | |
| Method Plan No.: | | Martensite | 5.7 | <input type="checkbox"/> | |
| Drawing No.: | Rev.: | Temperature | 5.8 | <input checked="" type="checkbox"/> | |
| Part | | Hardness | | <input type="checkbox"/> | |
| | | Simulation Info: | | | |
| | | Filename: ARRK_03694699_Outer_Ring_TWb_NMS_7-9-22_it3 - EXTENSION MODS 8 - MOD | | | |
| | | AutoForm Memory: 2068.16 MB | | | |
| | | AutoForm Forming Solver Thermo R10.0.0 | | | |
| | | Process - TWB blank manufacture / Heating / Draw / Quenching / Laser Trim | | | |

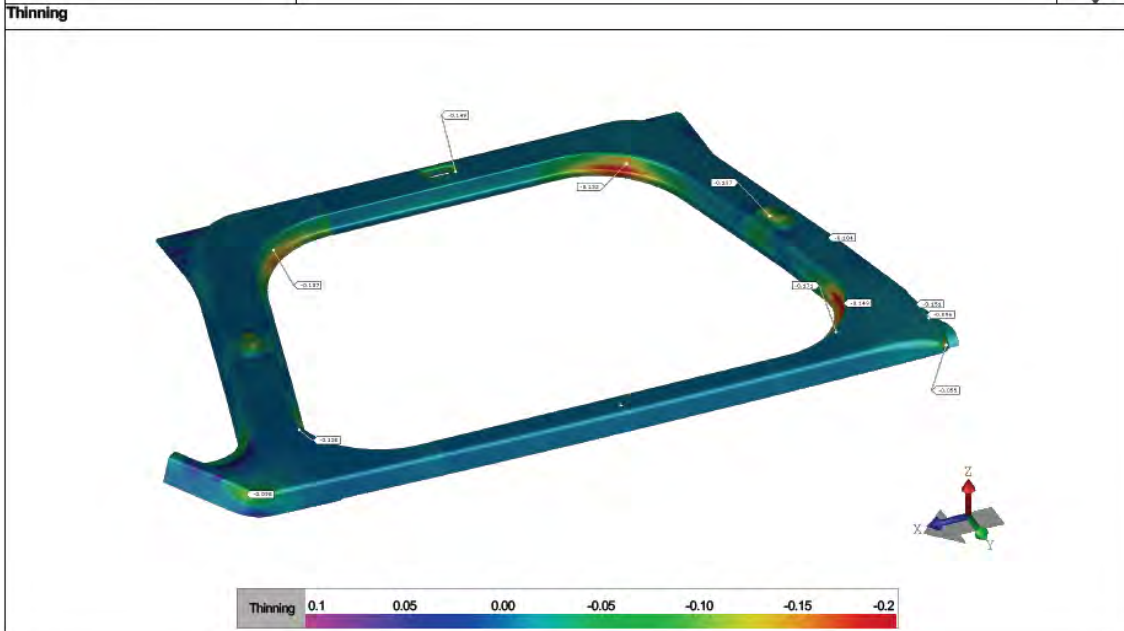
| Input Data | | Material & Blank | | | |
|--------------------------------------|-------------------|-------------------------------|----------|--|----------|
| Calculated Material | Usibor2000UFG_100 | Calc. Sheet Thickness | 1.200 mm | Blank Info | |
| Yield Stress | | r0 | 1.00 | <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| n-Value | | r45 | 1.00 | Meshing | |
| Yield Curve | | Yield Surface | | Roll angle | 0.00 ° |
| | | | | Initial Element Size | 20.00 mm |
| <p>MU - Part to Blank 0.00 %</p> | | <p>RAM Tonnage - 691.0 tf</p> | | Refinement Level | 6 |
| | | | | Max Element Angle | 30.00 ° |
| | | | | <p>Blank Size - 2980.00 mm X 1942.98 mm</p> | |
| | | | | | |

| Formability | | T-30 | | | | | | | | | | | | | | | | | | | |
|--|------------|----------|----------------|---------|----------------|-----------------|------------|----------|----------------|------|----------------|-----------------|--------|--|--------|---------|--|---------|--|--|----------|
| Advanced Formability | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | |
| <table border="1"> <thead> <tr> <th>Formability</th> <th>Thickening</th> <th>Compress</th> <th>Insuff Stretch</th> <th>Safe</th> <th>Risk of Splits</th> <th>Excess Thinning</th> <th>Splits</th> </tr> </thead> <tbody> <tr> <td></td> <td>3.65 %</td> <td>10.29 %</td> <td></td> <td>21.45 %</td> <td></td> <td></td> <td>< 0.01 %</td> </tr> </tbody> </table> | | | | | | Formability | Thickening | Compress | Insuff Stretch | Safe | Risk of Splits | Excess Thinning | Splits | | 3.65 % | 10.29 % | | 21.45 % | | | < 0.01 % |
| Formability | Thickening | Compress | Insuff Stretch | Safe | Risk of Splits | Excess Thinning | Splits | | | | | | | | | | | | | | |
| | 3.65 % | 10.29 % | | 21.45 % | | | < 0.01 % | | | | | | | | | | | | | | |

| | | |
|-------------|------|---|
| Formability | T-30 |  |
|-------------|------|---|



| | | |
|----------|------|---|
| Thinning | T-30 |  |
|----------|------|---|



| | | | |
|--------------------|--|--------------------|--|
| Wrinkling Behavior | | H-10 | |
| Wrinkling at -34mm | | Wrinkling at -22mm | |
| | | | |
| Wrinkling at | | Wrinkling at | |
| | | | |

Rear Torque Box

| Overview and Summary | | | | | | |
|---|--------------------------|---|------|--|--------------------------|---------------|
| Part Info | | Criterion | | OK | n OK | Status |
| Designation: 03750809 Rear Torque Box | Type: Single Action Draw | FLD | 5.2 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part No.: | Drawing No.: | Flanging | 5.24 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Material: RA780 - CE | | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Sheet Thickness: 1.600 mm | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Info | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Plan No.: | | Thinning | 5.6 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Drawing No.: | Rev.: | Strain | 5.7 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part | | Wrinkles | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Springback | 5.9 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Simulation Info: | | | | |
| | | Filename: | | ARRK_03750809_Rear_Torque_Box_NMS_20-9-22_It9 - EXTENSION MODS 6 - CAD | | |
| | | AutoForm | | Memory: 142.44 MB | | |
| | | AutoForm Forming Solver R10.0.0 | | | | |
| | | R | | | | |
| | | ut | | | | |
| | | in | | | | |
| | | si | | | | |
| | | Process - Blank / Form / Laser Trim / Form / Laser Trim | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

| Input Data | | Material & Blank | | | | Blank Info | |
|---------------------|------------|-----------------------|------|-----------------------|--|---|--|
| Calculated Material | RA780 - CE | Calc. Sheet Thickness | | 1.600 mm | | <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| Yield Stress | 509.85 MPa | r0 | 1.00 | r90 1.00 | | Meshing Roll angle: 0.00 ° Initial Element Size: 40.00 mm Refinement Level: 7 Max Element Angle: 30.00 ° | |
| n-Value | 0.186 | r45 | 1.00 | E-Module 2.10E+05 MPa | | | |

Yield Curve

Yield Surface

Forming Limit Curve

RA780 - CE/1.600 mm

| Formability | F-40 | | | | | | | | |
|---|--------------------|------------------|--------------------|------------------|--------------------------|-----------------|--------------------------|-----------------|------------------|
| Advanced Formability | | | | | | | | | |
| | | | | | | | | | |
| <table border="1"> <tr> <td>Adv Formity</td> <td>Thickening 22.17 %</td> <td>Compress 11.21 %</td> <td>Insurf Stretch</td> <td>Safe 9.14 %</td> <td>Nonlinear Risk of Splits</td> <td>Excess Thinning</td> <td>Nonlinear Splits</td> </tr> </table> | | Adv Formity | Thickening 22.17 % | Compress 11.21 % | Insurf Stretch | Safe 9.14 % | Nonlinear Risk of Splits | Excess Thinning | Nonlinear Splits |
| Adv Formity | Thickening 22.17 % | Compress 11.21 % | Insurf Stretch | Safe 9.14 % | Nonlinear Risk of Splits | Excess Thinning | Nonlinear Splits | | |

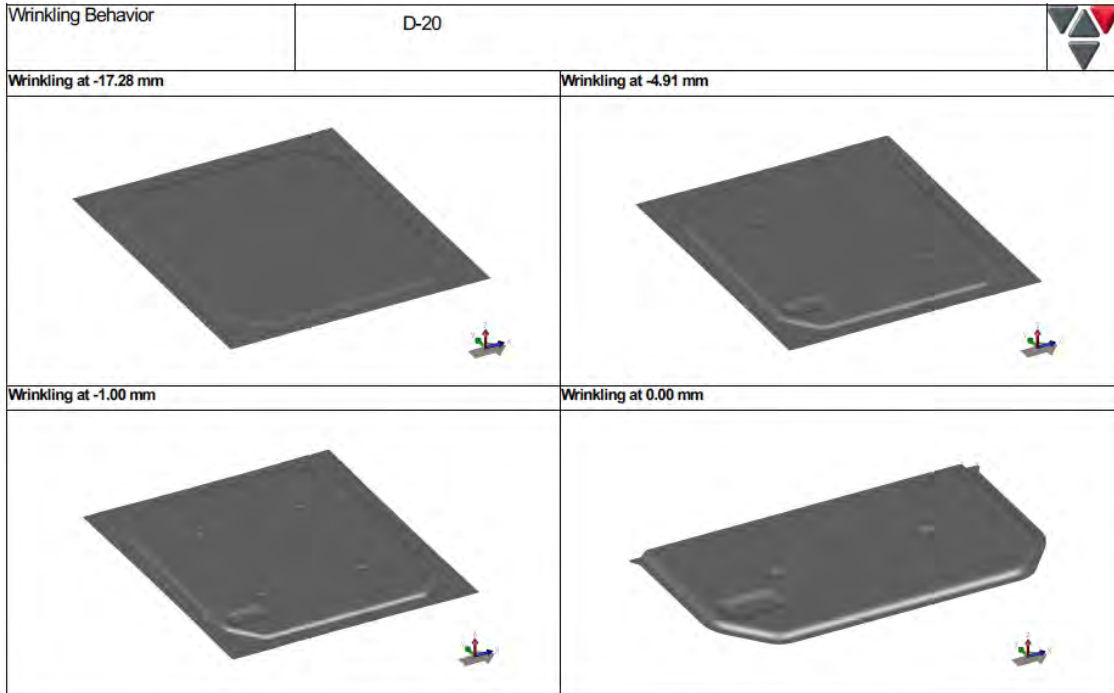
| | | | |
|-------------------------|--|------------------------|--|
| Wrinkling Behavior | | D-20 | |
| Wrinkling at -234.98 mm | | Wrinkling at -94.21 mm | |
| | | | |
| Wrinkling at -13.10 mm | | Wrinkling at -1.00 mm | |
| | | | |

Battery Tray Lower

| | | | | | | |
|--|--|--|-----------|-------------------------------------|--------------------------|--|
| | | Overview and Summary | | | | |
| Part Info | | Criterion | OK | n OK | Status | |
| Designation: 03647933 - Battery Tray Side | | FLD | 5.2 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Type: | | Flanging | 5.24 | <input type="checkbox"/> | <input type="checkbox"/> | |
| Part No.: | | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Drawing No.: | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Material: SDSTEEL_CR420-780DP_1.2mm(1) | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Sheet Thickness: 0.700 mm | | Thinning | 5.6 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Info | | Strain | 5.7 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Plan No.: | | Wrinkles | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Drawing No.: | | Springback | 5.9 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Rev.: | | Simulation Info: | | | | |
| Part | | Filename: ARRK_03647933_Battery_Tray_Lower_NMS_19-9-22_it5 - EXTENSION MODS 4 - AutoForm | | | | |
| | | AutoForm Forming Solver R10.0.0 | | | | |
| | | Memory: 810.42 MB | | | | |
| | | n | | | | |
| | | Process - Blank / Draw / Laser Trim | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

| Input Data | | Material & Blank | | | | | |
|---------------------|-----------------|----------------------------|------|-----------------------|--|---|--|
| Calculated Material | SDSTEEL_CR420-7 | Calc. Sheet Thickness | | 0.700 mm | | Blank Info | |
| Yield Stress | 452.85 MPa | r0 | 0.91 | r90 0.82 | | <input checked="" type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| n-Value | 0.186 | r45 | 0.81 | E-Module 2.10E+05 MPa | | Meshing | |
| Yield Curve | | Yield Surface | | Roll angle | | 0.00 ° | |
| | | | | Initial Element Size | | 40.00 mm | |
| | | | | Refinement Level | | 6 | |
| | | | | Max Element Angle | | 22.50 ° | |
| | | Forming Limit Curve | | Blank Size | | 1680.00 X 1480.00 | |
| | | | | | | | |
| | | | | | | SDSTEEL_CR420-780UP_L2mm(1)0.700mm | |

| Input Data | | D-20 | | | | | |
|------------------------------|-----------------------------|------------------|-----|-----------------------|----------|----------------------------|--|
| Tool Info | | | | Process Data | | | |
| Meshing Tolerance | 0.05 mm | | | Friction Coefficient | | | |
| Process Type | Single Action Draw | | | Constant | 0.100 | | |
| Tool Geometry Refers to | Lower Side of Initial Blank | | | Die - Blank | - | | |
| Tools | Contact Side | Type | Gap | Punch - Blank | - | | |
| Die | Upper Side of Blank | Rigid | | Binder - Blank | - | | |
| Punch | Lower Side of Blank | Rigid | | Binderforce | | | |
| Binder | Lower Side of Blank | Force Controlled | | TOTAL TONNAGE | 378.5 tf | Half blank so total is x 2 | |
| Tool Geometry 1st opp | | | | Binderforce/-pressure | 250.0 tf | | |
| | | | | | | | |

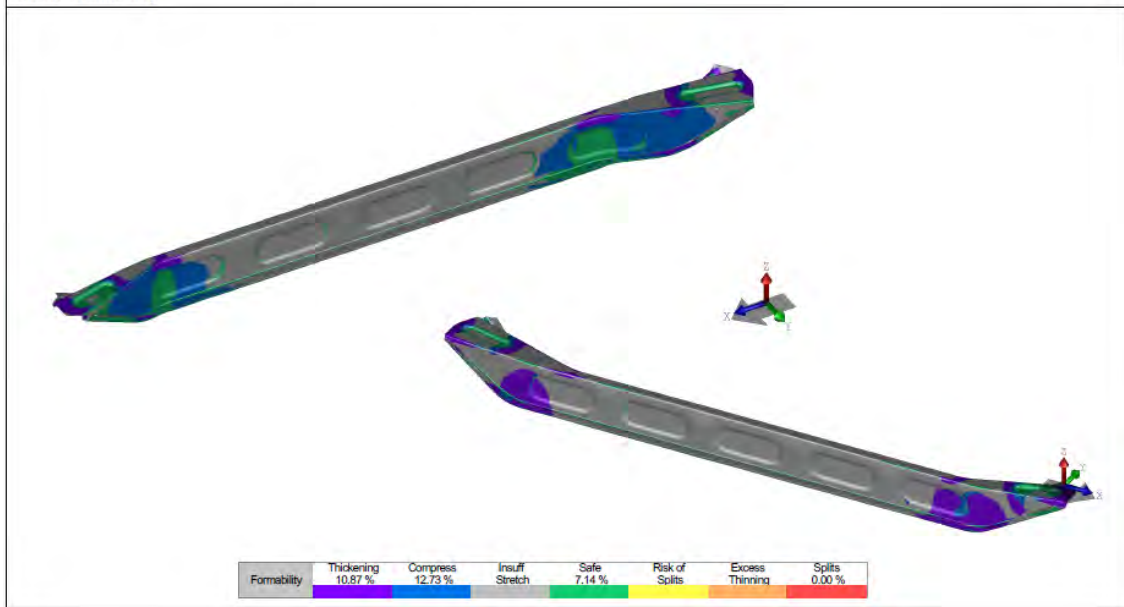


Battery Frame Longitudinal

| Overview and Summary | | | | | | |
|--|--------------------|--|------|-------------------------------------|--------------------------|---------------|
| Part Info | | Criterion | | OK | n OK | Status |
| Designation: 03702273_Battery_Longit-LONGITUDIONAL | Type: Crashform Up | FLD | 5.2 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part No.: | Drawing No.: | Flanging | 5.24 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Material: Dual_Phase_450 | | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Sheet Thickness: 1.800 mm | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Info | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Plan No.: | | Thinning | 5.6 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Drawing No.: | Rev: | Strain | 5.7 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part | | Wrinkles | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Springback | 5.9 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Simulation Info: | | | | |
| | | Filename: ARRK_03702273_Longit_Munich_Left_NMS_14-9-22_it12 - EXTENSION MODS 3 - AutoForm | | Memory: 1326.47 MB | | |
| | | AutoForm Forming Solver R10.0.0 | | | | |
| | | F u a c t i a | | | | |
| | | Process - Blank Die / Crash / Flange / CAM flange / CAM Flange / Flange Up / CAM Form / CAM Trlm | | | | |
| | | | | | | |
| | | | | | | |

| Input Data | | Material & Blank | | | | | |
|----------------------------|----------------|-----------------------|----------|-----------------------|--|--|--|
| Calculated Material | Dual_Phase_450 | Calc. Sheet Thickness | 1.800 mm | | | Blank Info | |
| Yield Stress | 271.84 MPa | r0 | 1.04 | r90 1.32 | | <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| n-Value | 0.220 | r45 | 0.88 | E-Module 2.10E+05 MPa | | Meshing | |
| Yield Curve | | Yield Surface | | | | Roll angle | |
| | | | | | | 0.00 ° | |
| MU - Part to Blank 88.46 % | | Forming Limit Curve | | | | Initial Element Size | |
| | | | | | | 40.00 mm | |
| | | | | | | Refinement Level | |
| | | | | | | 7 | |
| | | | | | | Max Element Angle | |
| | | | | | | 30.00 ° | |
| | | | | | | Blank Size - 1782.59 mm X 367.29 mm | |
| | | | | | | | |
| | | | | | | -1000 -800 -600 -400 -200 0 200 400 600 800 1000 | |
| | | | | | | Dual_Phase_450/1.800 mm | |

| Formability | F-60 | |
|-----------------------------|------|--|
| Advanced Formability | | |




| | | | |
|-----------------------|--|-----------------------|--|
| Wrinkling Behavior | | F-30 | |
| Wrinkling at -1.81 mm | | Wrinkling at -2.11 mm | |
| | | | |
| Wrinkling at -1.00 mm | | | |
| | | | |

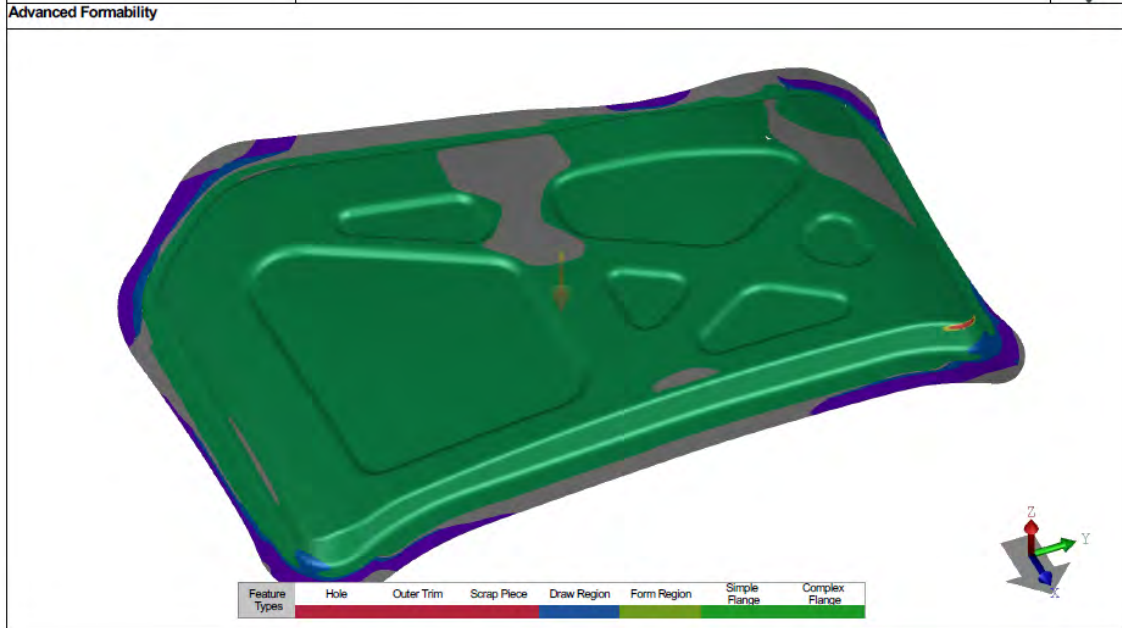
Side (scissor) door rear outer

| | | | | | | |
|--|-----------------------------|-----------------------------|------|-------------------------------------|--------------------------|---------------|
| | | Overview and Summary | | | | |
| Part Info | | Criterion | | OK | n OK | Status |
| Designation | Type: Single Action Draw | FLD | 5.2 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part No.:03750084 Rear Side Door Otr | Drawing No.: | Flanging | 5.24 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Material: BH280_HD_AF | | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Sheet Thickness: 0.700 mm | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Info | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Plan No.: | | Thinning | 5.6 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Drawing No.: | Rev: | Strain | 5.7 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part | | Wrinkles | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Springback | 5.9 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Simulation Info: | | | | | | |
| Filename: ARRK_03750084_Side_Rear_Door_Otr_NMS_20-9-22_it1 - EXTENSION MODS 1 - | | | | | | |
| AutoForm | | | | | Memory: 4017.68 MB | |
| AutoForm Forming Solver R10.0.0 | | | | | | |
| Process - Blank / Draw / Laser Trim / Flange / Flange | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

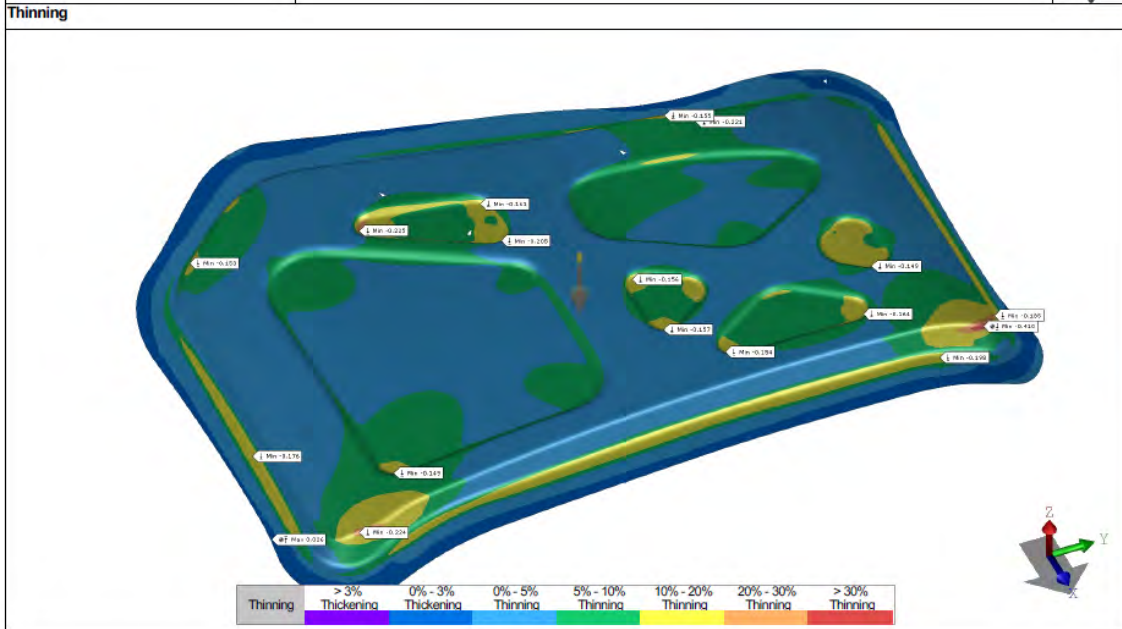
| Input Data | | Material & Blank | | | | | |
|---------------------|-------------|----------------------------|----------|----------|--------------|--|--|
| Calculated Material | BH280_HD_AF | Calc. Sheet Thickness | 0.700 mm | | | Blank Info | |
| Yield Stress | 294.74 MPa | r0 | 1.12 | r90 | 1.35 | <input type="checkbox"/> Rectangular Blank | |
| n-Value | 0.159 | r45 | 1.34 | E-Module | 2.10E+05 MPa | <input checked="" type="checkbox"/> Shaped Blank | |
| Yield Curve | | Yield Surface | | | | Meshing | |
| | | | | | | Roll angle | |
| | | | | | | Initial Element Size | |
| | | | | | | Refinement Level | |
| | | | | | | Max Element Angle | |
| | | Forming Limit Curve | | | | | |
| | | | | | | | |
| | | | | | | BH280_HD_AF/0.700 mm | |


| Input Data | | D-20 | | D-20 | | | |
|------------------------------|-----------------------------|------------------|-----|-----------------------|----------|--|--|
| Tool Info | | | | Process Data | | | |
| Meshing Tolerance | 0.05 mm | | | Friction Coefficient | | | |
| Process Type | Single Action Draw | | | Constant | 0.110 | | |
| Tool Geometry Refers to | Upper Side of Initial Blank | | | Die - Blank | - | | |
| Tools | Contact Side | Type | Gap | Punch - Blank | - | | |
| Die | Upper Side of Blank | Rigid | | Binder - Blank | - | | |
| Punch | Lower Side of Blank | Rigid | | Binderforce | | | |
| Binder | Lower Side of Blank | Force Controlled | | RAM | 606.5 tf | | |
| Tool Geometry 1st opp | | | | Binderforce/-pressure | 280.0 tf | | |
| | | | | | | | |

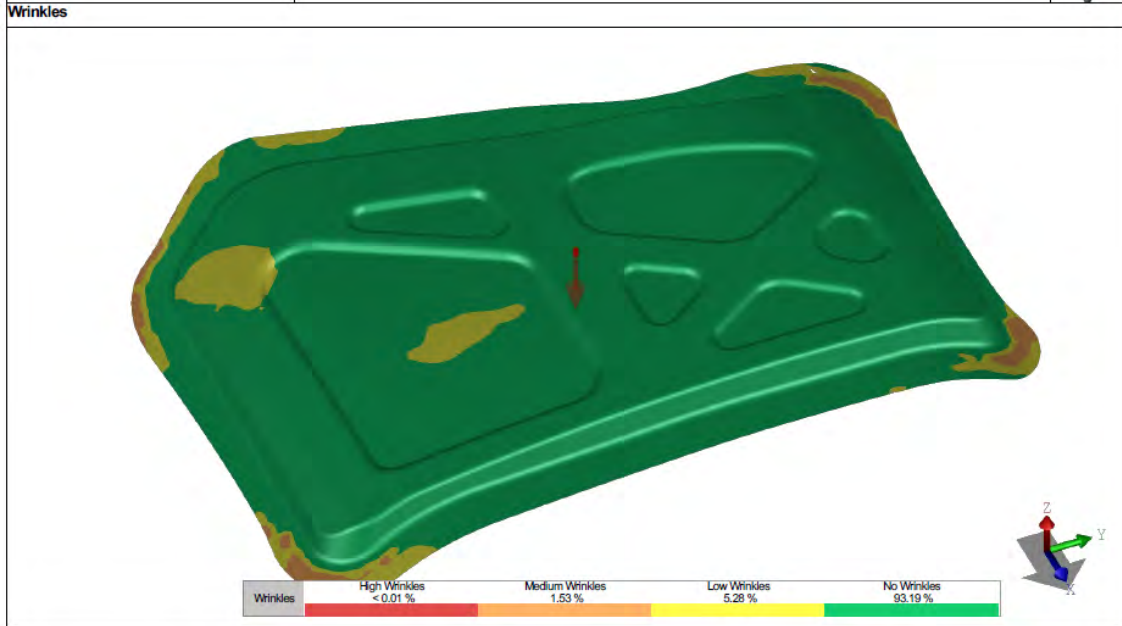
| | | |
|-------------|------|---|
| Formability | D-20 |  |
|-------------|------|---|




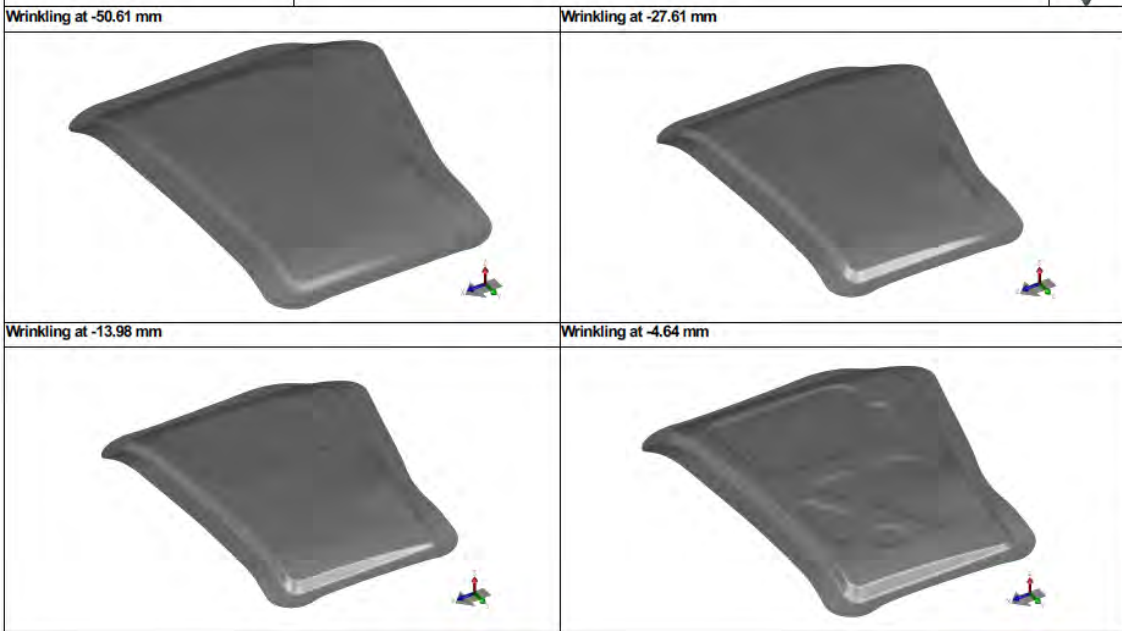
| | | |
|----------|------|---|
| Thinning | D-20 |  |
|----------|------|---|




| | | |
|----------|------|---|
| Wrinkles | D-20 |  |
|----------|------|---|

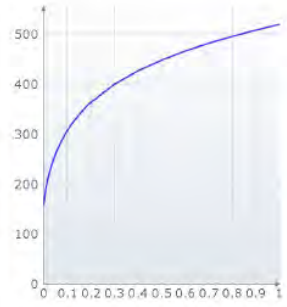
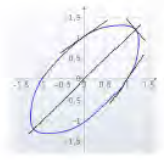
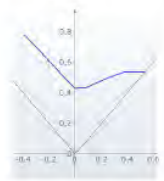
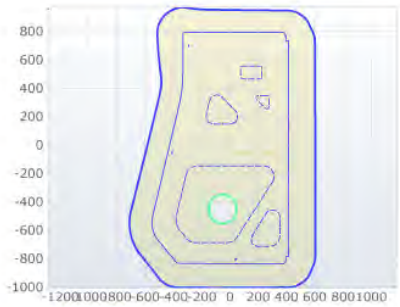


| | | |
|--------------------|------|---|
| Wrinkling Behavior | D-20 |  |
|--------------------|------|---|



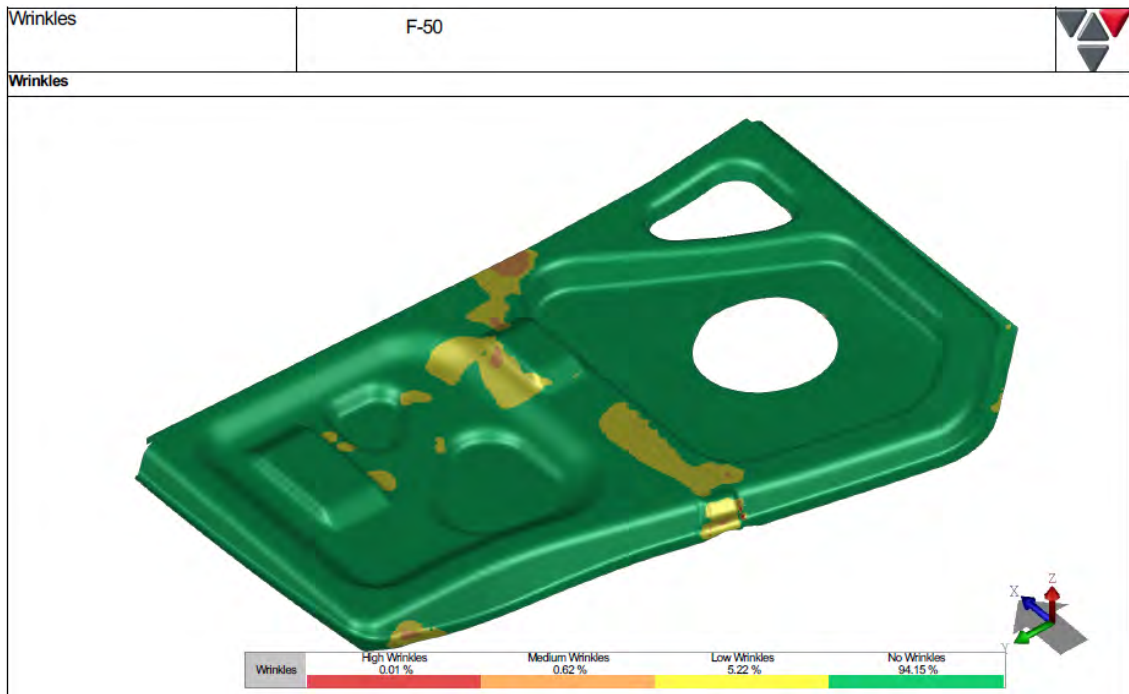
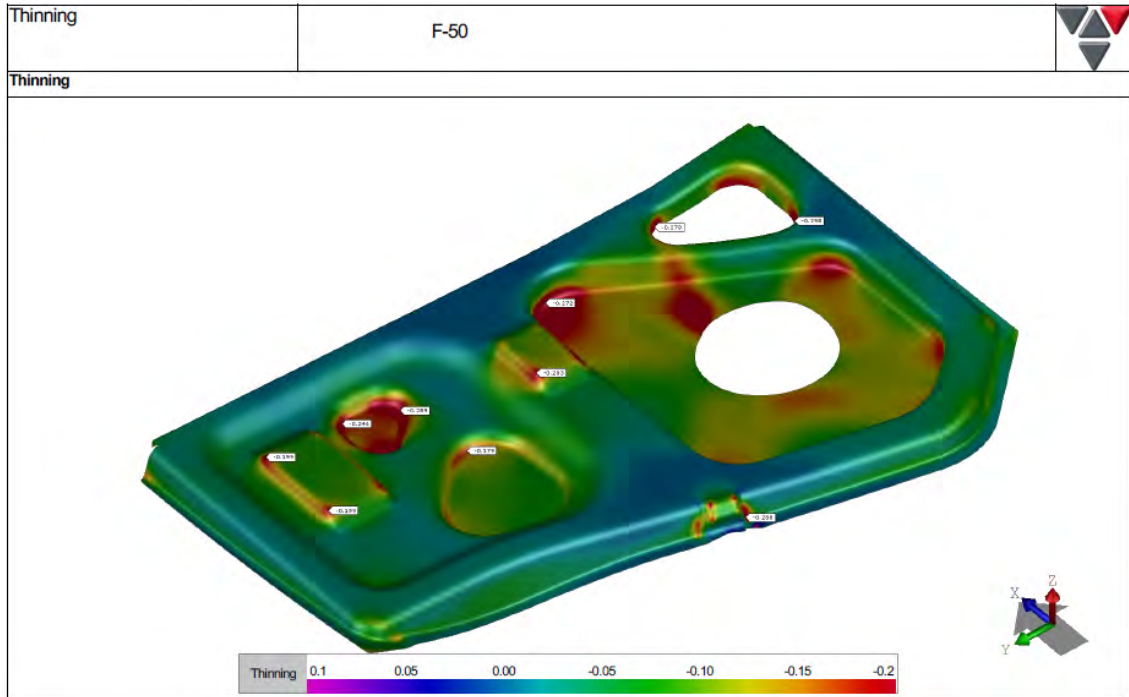
Side (scissor) door rear inner

| Overview and Summary | | | |
|---|-----------------------------|--|---|
| Part Info | | Criterion | Status |
| Designation: 30082022_DS-WAS-1430_SCISSOR DOOR | Type: Single Action Draw | FLD 5.2 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
| Part No.: | Drawing No.: | Flanging 5.24 | <input type="checkbox"/> OK <input checked="" type="checkbox"/> n OK |
| Nom. / Calculated Material: DX56D | | Gravity 5.3 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
| Nom. / Calculated Sheet Thickness: 1.200 mm | | Closing 5.4 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
| Method Info | | Forming 5.5 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
| Method Plan No.: | | Thinning 5.6 | <input checked="" type="checkbox"/> OK <input checked="" type="checkbox"/> n OK |
| Drawing No.: | Rev.: | Strain 5.7 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
| Part | | Wrinkles 5.8 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
|  | | Springback 5.9 | <input checked="" type="checkbox"/> OK <input type="checkbox"/> n OK |
| | | Simulation Info: Filename: ARRK_03750471_Side_Frt_Door_Inr_NMS_2-9-22_it2 - EXTENSION MODS 2 - AutoForm AutoForm Forming Solver R10.0.0 | |
| | | Memory: 1322.95 MB Process - Draw / Laser Trim / Flange / CAM Form | |

| Input Data | | Material & Blank | |
|--|------------|---|--------------|
| Calculated Material | DX56D | Calc. Sheet Thickness | 1.200 mm |
| Yield Stress | 157.05 MPa | r0 | 2.05 |
| n-Value | 0.226 | r45 | 1.73 |
| | | E-Module | 2.10E+05 MPa |
| Yield Curve | | Yield Surface | |
|  | |  | |
| MU - Part to Blank 58.26 % | | Forming Limit Curve | |
| | |  | |
| | | Blank Info <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| | | Meshing | |
| | | Roll angle | 0.00 ° |
| | | Initial Element Size | 40.00 mm |
| | | Refinement Level | 6 |
| | | Max Element Angle | 22.50 ° |
|  | | | |

| | | | | | | | |
|------------------------------|-----------------------------|------------------|-----|------------------------------|--|------------------------------|--|
| Input Data | | D-20 | | D-20 | | | |
| Tool Info | | | | Process Data | | | |
| Meshing Tolerance | 0.05 mm | | | Friction Coefficient | | | |
| Process Type | Single Action Draw | | | Constant 0.100 | | | |
| Tool Geometry Refers to | Lower Side of Initial Blank | | | Die - Blank | | | |
| Tools | Contact Side | Type | Gap | Punch - Blank | | | |
| Die | Upper Side of Blank | Rigid | | Binder - Blank | | | |
| Punch | Lower Side of Blank | Rigid | | Binderforce | | | |
| Binder | Lower Side of Blank | Force Controlled | | RAM | | 661.2 tf | |
| Tool Geometry 1st opp | | | | Binderforce/-pressure | | 201.3 tf | |
| | | | | Tool Geometry 2nd opp | | Tool Geometry 3rd opp | |
| | | | | | | | |

| | | | | | |
|-----------------------------|--|------|--|--|--|
| Formability | | F-50 | | | |
| Advanced Formability | | | | | |
| | | | | | |




| | | | |
|------------------------|--|------------------------|--|
| Wrinkling Behavior | | D-20 | |
| Wrinkling at -58.73 mm | | Wrinkling at -28.03 mm | |
| | | | |
| Wrinkling at -11.07 mm | | Wrinkling at -1.00 mm | |
| | | | |

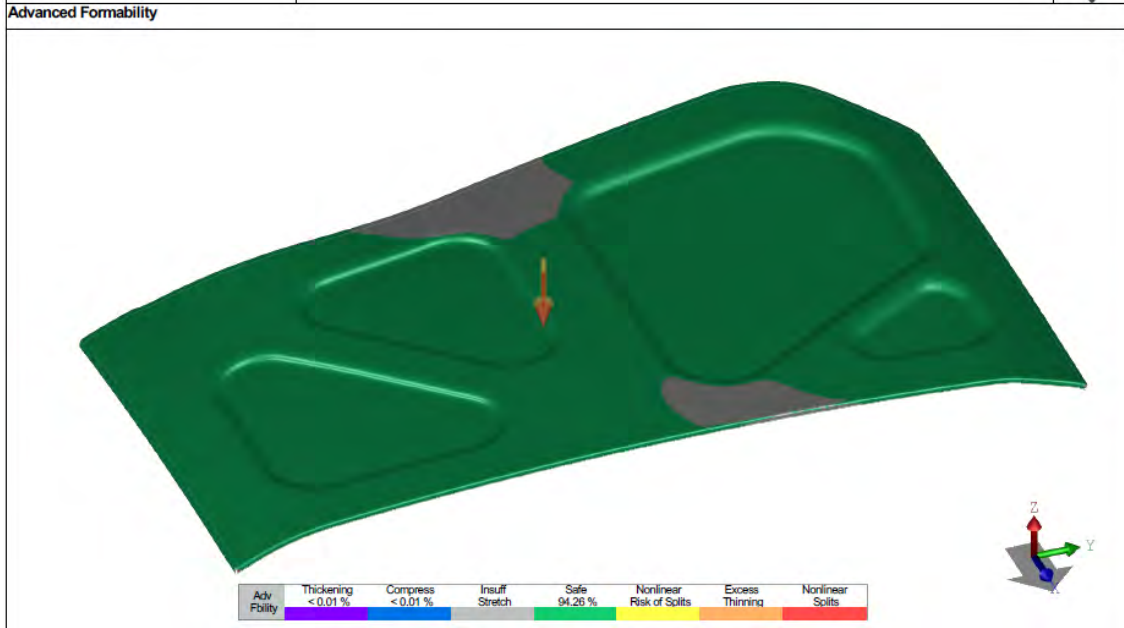
Side (scissor) door outer front

| | | | | | | |
|---|--------------------|---|------|-------------------------------------|--------------------------|--|
| | | Overview and Summary | | | | |
| Part Info | | Criterion | OK | n OK | Status | |
| Designation: | Type: | FLD | 5.2 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| 30082022_DS-WAS-1430_SCISSOR DOOR | Single Action Draw | Flanging | 5.24 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part No.: | Drawing No.: | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Material: BH280_HD_AF | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Sheet Thickness: 0.700 mm | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Info | | Thinning | 5.6 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Plan No.: | | Strain | 5.7 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Drawing No.: | Rev.: | Wrinkles | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part | | Springback | 5.9 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Simulation Info: | | | | |
| | | Filename: | | | | |
| | | ARRK_03750465_Side_Frt_Door_Otr_NMS_6-9-22_it2 - EXTENSION MODS 3 - | | | | |
| | | AutoForm | | Memory: 3901.13 MB | | |
| | | AutoForm Forming Solver R10.0.0 | | | | |
| | | Process - Blank / Draw / Laser Trim / Flange / Flange | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

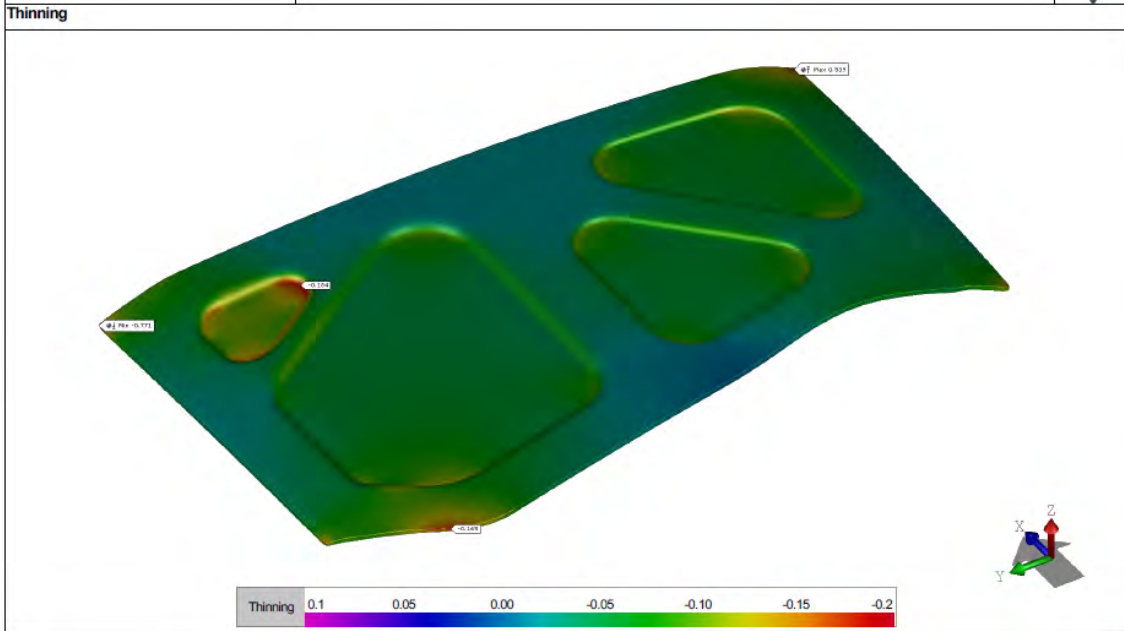
| Input Data | | Material & Blank | | | | | |
|---------------------------------------|-------------|----------------------------|------|---|--------------|--|--|
| Calculated Material | BH280_HD_AF | Calc. Sheet Thickness | | 0.700 mm | | Blank Info | |
| Yield Stress | 294.74 MPa | r0 | 1.12 | r90 | 1.35 | <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| n-Value | 0.159 | r45 | 1.34 | E-Module | 2.10E+05 MPa | Meshing | |
| Yield Curve | | Yield Surface | | Roll angle: 0.00 ° Initial Element Size: 40.00 mm Refinement Level: 6 Max Element Angle: 22.50 ° | | | |
| <p>MU - Part to Blank 50.50 %</p> | | | | | | | |
| | | Forming Limit Curve | | | | | |
| | | | | | | | |

| Input Data | | D-20 | | D-20 | | | |
|------------------------------|-----------------------------|------------------|-----|--------------------------------|--|--|--|
| Tool Info | | | | Process Data | | | |
| Meshing Tolerance | 0.05 mm | | | Friction Coefficient | | | |
| Process Type | Single Action Draw | | | Constant: 0.110 | | | |
| Tool Geometry Refers to | Upper Side of Initial Blank | | | Die - Blank: - | | | |
| Tools | Contact Side | Type | Gap | Punch - Blank: - | | | |
| Die | Upper Side of Blank | Rigid | | Binder - Blank: - | | | |
| Punch | Lower Side of Blank | Rigid | | Binderforce | | | |
| Binder | Lower Side of Blank | Force Controlled | | RAM: 619.6 tf | | | |
| Tool Geometry 1st opp | | | | Binderforce/pressure: 280.0 tf | | | |
| | | | | | | | |

| | | |
|-------------|------|---|
| Formability | F-50 |  |
|-------------|------|---|



| | | |
|----------|------|---|
| Thinning | F-50 |  |
|----------|------|---|



| | | | |
|------------------------|--|------------------------|--|
| Wrinkling Behavior | | D-20 | |
| Wrinkling at -50.24 mm | | Wrinkling at -18.13 mm | |
| | | | |
| Wrinkling at -5.32 mm | | Wrinkling at -0.50 mm | |
| | | | |

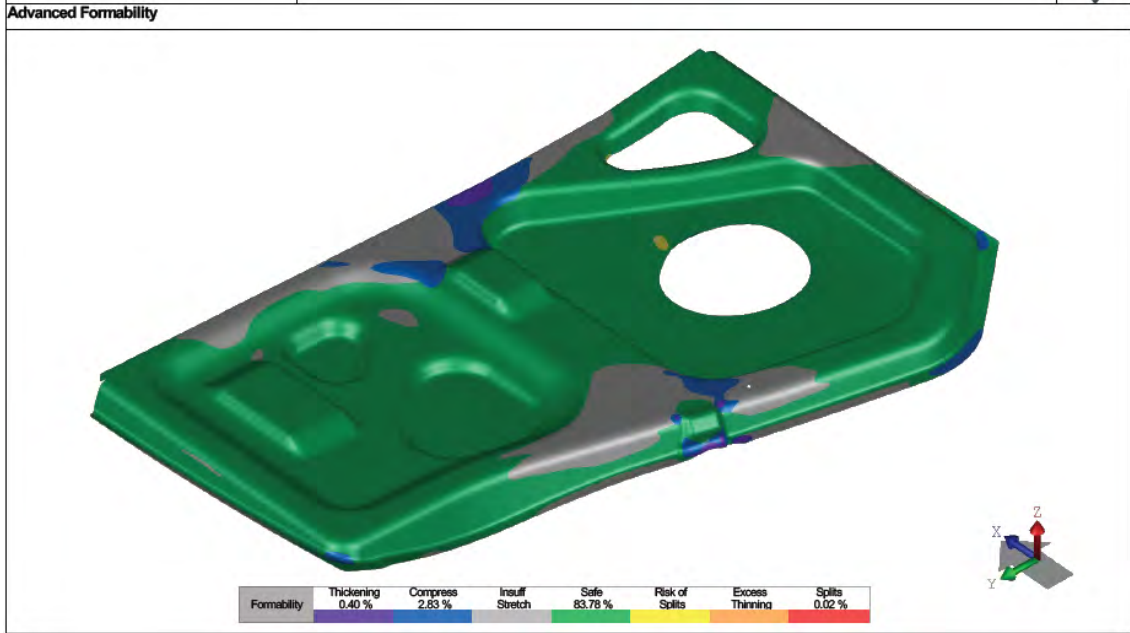
Side (scissor) door front inner

| | | | | | | |
|--|--------------------------|---|------|-------------------------------------|-------------------------------------|---------------|
| | | Overview and Summary | | | | |
| Part Info | | Criterion | | OK | n OK | Status |
| Designation: 30082022_DS-WAS-1430_SCISSOR DOOR | Type: Single Action Draw | FLD | 5.2 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part No.: | Drawing No.: | Flanging | 5.24 | <input type="checkbox"/> | <input checked="" type="checkbox"/> | |
| Nom. / Calculated Material: DX56D | | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Sheet Thickness: 1.200 mm | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Info | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Plan No.: | | Thinning | 5.6 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | |
| Drawing No.: | Rev.: | Strain | 5.7 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part | | Wrinkles | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Springback | 5.9 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Simulation Info: | | | | |
| | | Filename: ARRK_03750471_Side_Frt_Door_Inr_NMS_2-9-22_it2 - EXTENSION MODS 2 - | | | | |
| | | AutoForm Memory: 1322.95 MB | | | | |
| | | AutoForm Forming Solver R10.0.0 | | | | |
| | | Process - Draw / Laser Trim / Flange / CAM Form | | | | |
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| | | | | | | |
| | | | | | | |

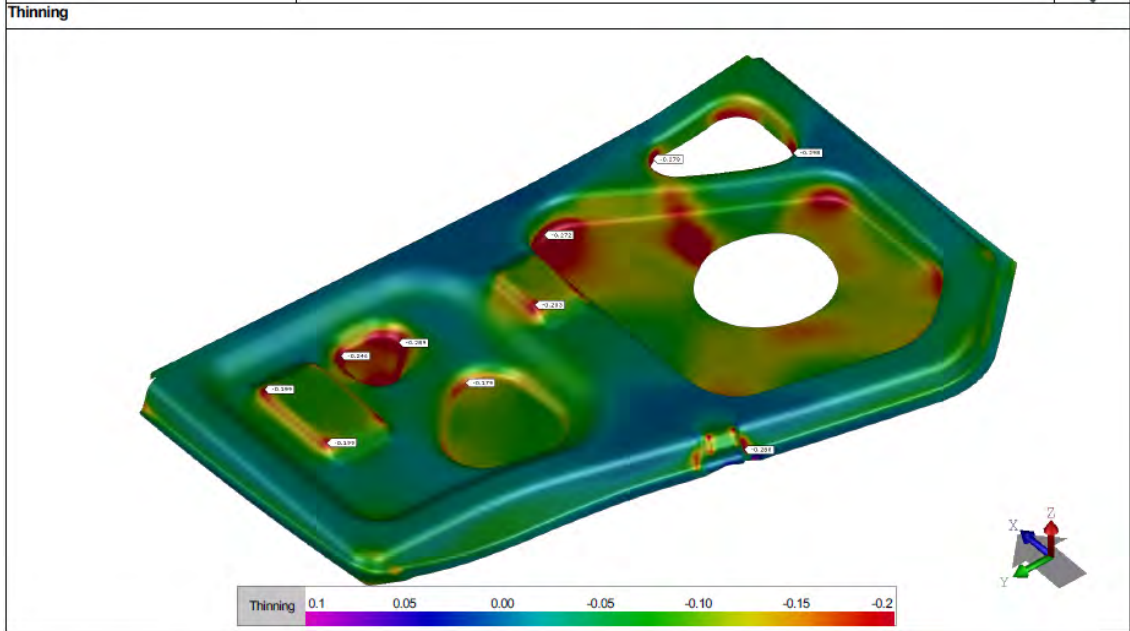
| Input Data | | Material & Blank | | | | | |
|--|------------|----------------------------|----------|----------|--------------|--|--|
| Calculated Material | DX56D | Calc. Sheet Thickness | 1.200 mm | | | Blank Info | |
| Yield Stress | 157.05 MPa | r0 | 2.05 | r902.50 | | <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| n-Value | 0.226 | r45 | 1.73 | E-Module | 2.10E+05 MPa | Meshing | |
| Yield Curve | | Yield Surface | | | | Roll angle | |
| | | | | | | 0.00 ° | |
| | | Forming Limit Curve | | | | Initial Element Size | |
| | | | | | | 40.00 mm | |
| | | | | | | Refinement Level | |
| | | | | | | 6 | |
| | | | | | | Max Element Angle | |
| | | | | | | 22.50 ° | |
| <p>MU - Part to Blank</p> <p>58.26 %</p> | | | | | | | |

| Input Data | | D-20 | | D-20 | | | |
|------------------------------|-----------------------------|------------------|-----|------------------------------|--|------------------------------|--|
| Tool Info | | | | Process Data | | | |
| Meshing Tolerance | 0.05 mm | | | Friction Coefficient | | | |
| Process Type | Single Action Draw | | | Constant | | | |
| Tool Geometry Refers to | Lower Side of Initial Blank | | | 0.100 | | | |
| Tools | Contact Side | Type | Gap | Die - Blank | | | |
| Die | Upper Side of Blank | Rigid | | Punch - Blank | | | |
| Punch | Lower Side of Blank | Rigid | | Binder - Blank | | | |
| Binder | Lower Side of Blank | Force Controlled | | Binderforce | | | |
| | | | | RAM | | 661.2 tf | |
| | | | | Binderforce/-pressure | | 201.3 tf | |
| Tool Geometry 1st opp | | | | Tool Geometry 2nd opp | | Tool Geometry 3rd opp | |
| | | | | | | | |

| | | |
|-------------|------|---|
| Formability | F-50 |  |
|-------------|------|---|



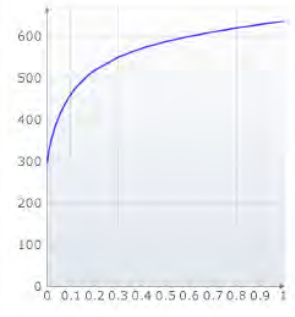
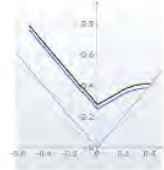
| | | |
|----------|------|---|
| Thinning | F-50 |  |
|----------|------|---|

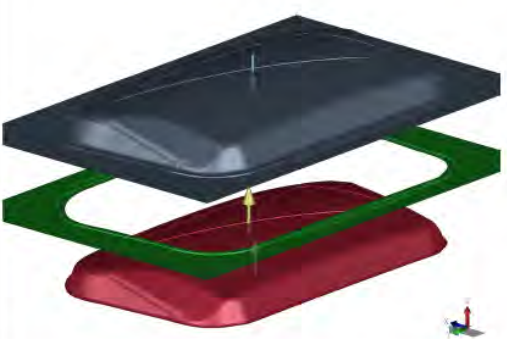



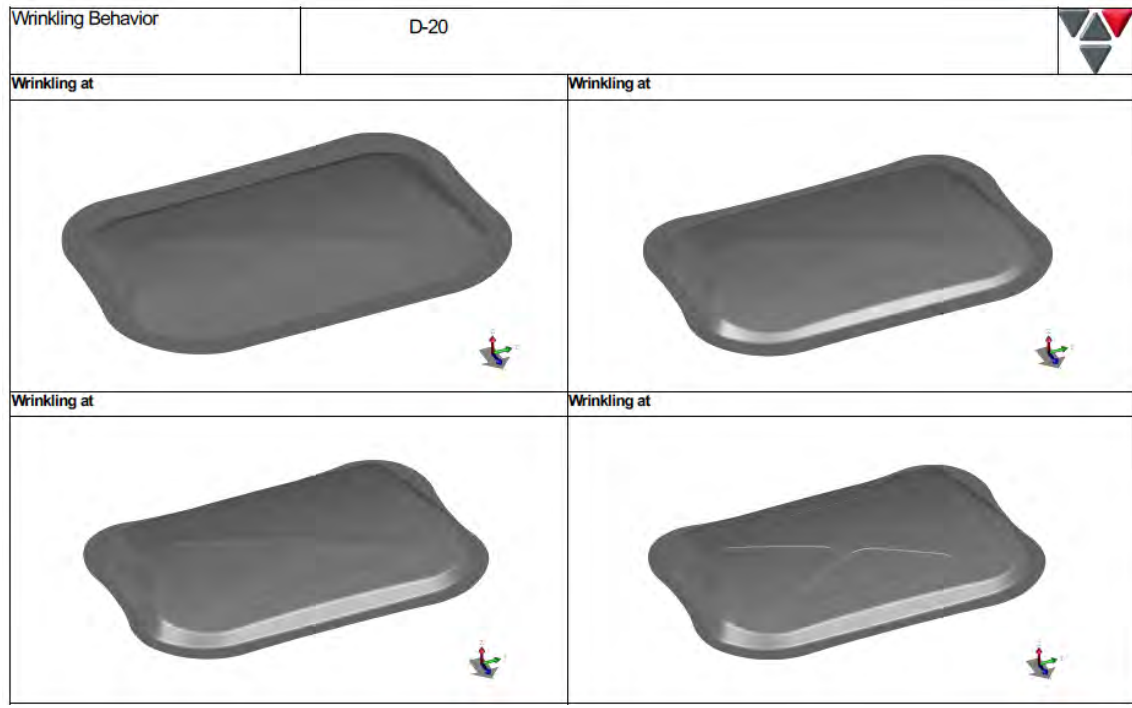
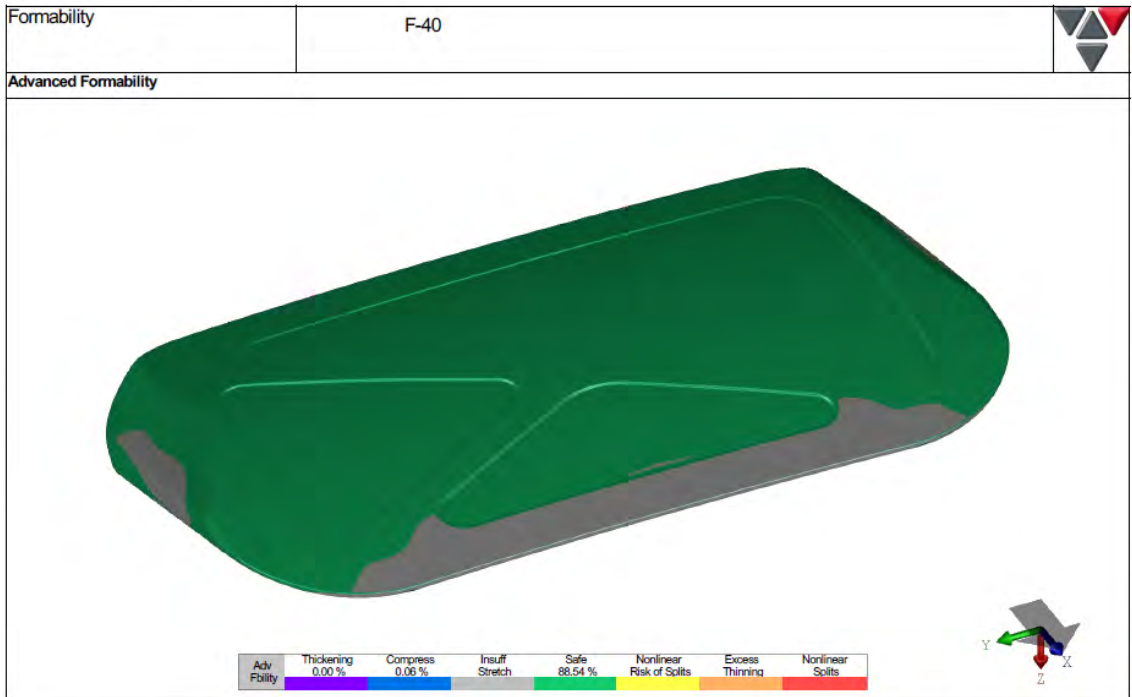
| | | | |
|------------------------|--|------------------------|--|
| Wrinkling Behavior | | D-20 | |
| Wrinkling at -58.73 mm | | Wrinkling at -28.03 mm | |
| | | | |
| Wrinkling at -11.07 mm | | Wrinkling at -1.00 mm | |
| | | | |

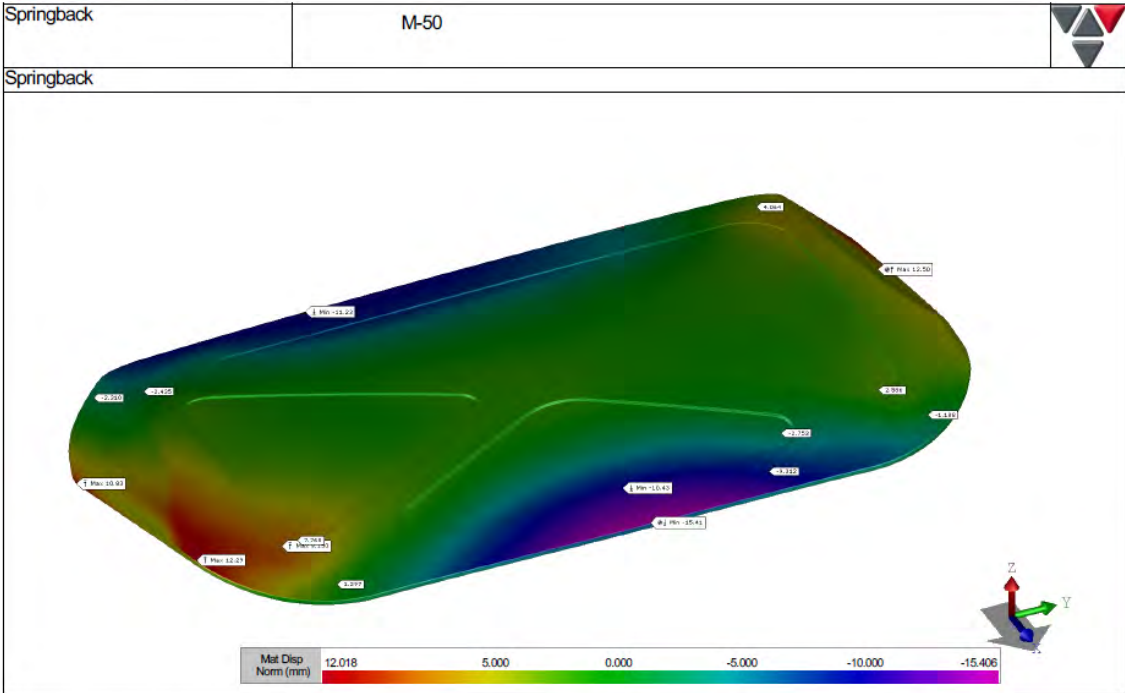
Coach Door Outer

| Overview and Summary | | | | | | |
|---|--------------|---|-----------|---|-------------------------------------|--|
| Part Info | | Criterion | OK | n OK | Status | |
| Designation: 03777906-A-Surface Coach Door Sheet | Type: | FLD | 5.2 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part No.: | Drawing No.: | Flanging | 5.24 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Material: BH280_HD_AF | | Gravity | 5.3 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Sheet Thickness: 0.700 mm | | Closing | 5.4 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Info | | Forming | 5.5 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Plan No.: | | Thinning | 5.6 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Drawing No.: | Rev.: | Strain | 5.7 | <input type="checkbox"/> | <input checked="" type="checkbox"/> | |
| Part | | Wrinkles | 5.8 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Springback | 5.9 | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Simulation Info: | | | | |
| | | Filename: | | ARRK_03777906_Coach_Door_Outer_NMS_19-8-22_it2 - EXTENSION MODS 2 - INC | | |
| | | AutoForm | | Memory: 4434.52 MB | | |
| | | AutoForm Forming Solver R10.0.0 | | | | |
| | | Process - Blank Die / Draw / Laser Trim / Flange | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

| Input Data | | Material & Blank | | | | Blank Info | |
|---|-------------|---|----------|---|--------------|---|--|
| Calculated Material | BH280_HD_AF | Calc. Sheet Thickness | 0.700 mm | | | <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| Yield Stress | 294.74 MPa | r0 | 1.12 | r90 | 1.35 | Meshing Roll angle: 0.04 ° Initial Element Size: 20.00 mm Refinement Level: 6 Max Element Angle: 22.50 ° | |
| n-Value | 0.159 | r45 | 1.34 | E-Module | 2.10E+05 MPa | | |
| Yield Curve  <p>MU - Part to Blank 59.20 %</p> | | Yield Surface  | | Forming Limit Curve  | | | |
| | | Blank size: 1312.80 X 1939.59  | | | | | |

| Input Data | | D-20 | | | | Tool Info | | Process Data | |
|------------|--|---|--|------------------|--|--|--|-----------------------|--|
| | | | | | | Meshing Tolerance | | Friction Coefficient | |
| | | | | | | 0.05 mm | | Constant: 0.100 | |
| | | | | | | Process Type | | Die - Blank | |
| | | | | | | Single Action Draw | | Punch - Blank | |
| | | | | | | Tool Geometry Refers to | | Binder - Blank | |
| | | | | | | Upper Side of Initial Blank | | Binderforce | |
| | | Tools | | Type | | Gap | | RAM | |
| | | Contact Side | | Rigid | | | | 599.3 tf | |
| | | Upper Side of Blank | | Rigid | | | | Binderforce/-pressure | |
| | | Lower Side of Blank | | | | | | 300.0 tf | |
| | | Lower Side of Blank | | Force Controlled | | | | | |
| | | Tool Geometry 1st opp  | | | | Tool Geometry 2nd opp  | | | |





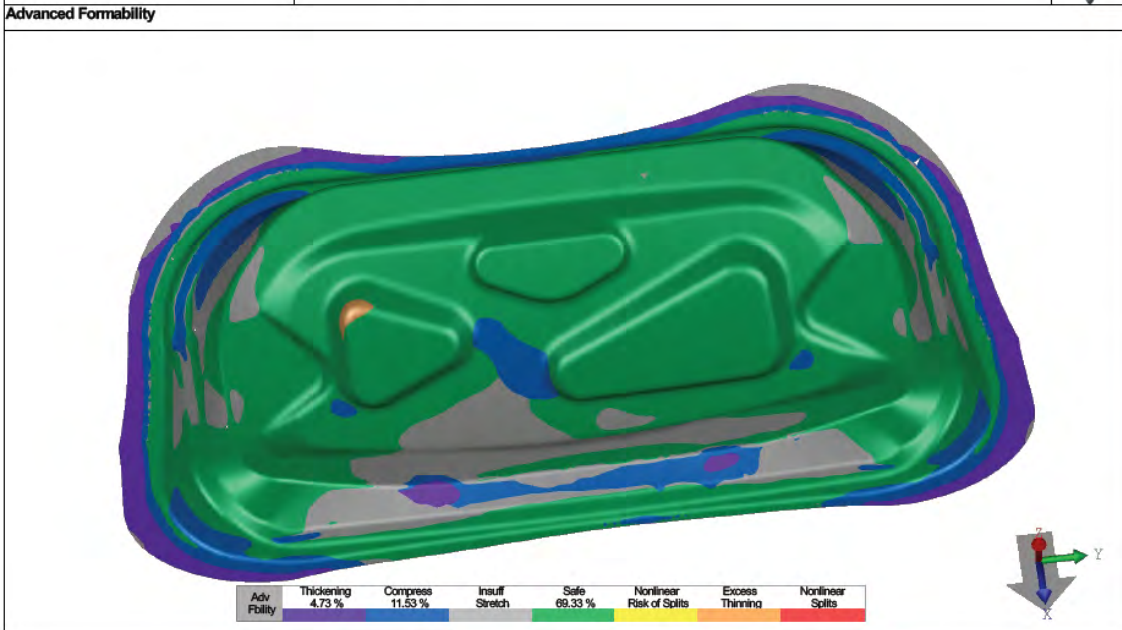
Coach door inner

| Overview and Summary | | | | | |
|---|--------------|------------------|-------------------------------------|--------------------------|---------------|
| Part Info | | Criterion | OK | n OK | Status |
| Designation: | Type: | FLD | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part No.: | Drawing No.: | Flanging | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Material: DX56D | | Gravity | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Nom. / Calculated Sheet Thickness: 1.200 mm | | Closing | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Info | | Forming | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Method Plan No.: | | Thinning | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Drawing No.: | Rev.: | Strain | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Part | | Winkles | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| | | Springback | <input checked="" type="checkbox"/> | <input type="checkbox"/> | |
| Simulation Info: | | | | | |
| Filename: ARRK_03777910_Coach_Door_Inner_NMS_19-9-22_it5 - EXTENSION MODS 5 - CAD | | | | | |
| AutoForm | | | Memory: 1160.17 MB | | |
| AutoForm Forming Solver R10.0.0 | | | | | |
| Remarks: Changes implemented worked well. | | | | | |
| Process - Blank / Draw / Laser Trim / Form Up | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

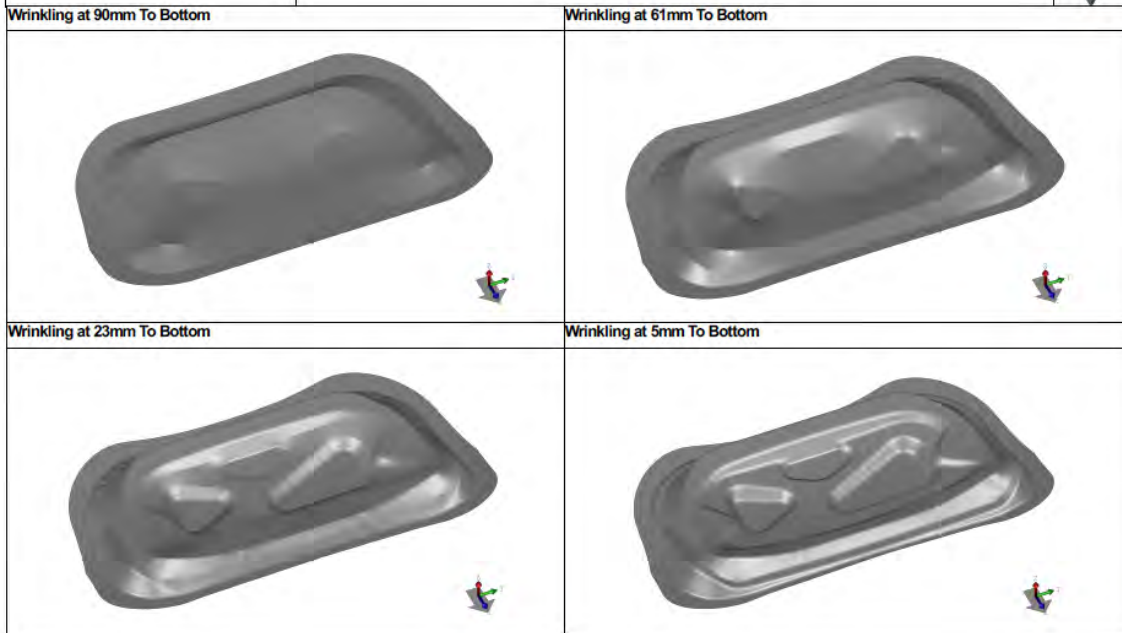
| Input Data | | Material & Blank | | | | | |
|---------------------|------------|-----------------------|----------|---|-------------------|--|--|
| Calculated Material | DX56D | Calc. Sheet Thickness | 1.200 mm | | Blank Info | | |
| Yield Stress | 157.05 MPa | r0 | 2.05 | r90 | 2.50 | <input type="checkbox"/> Rectangular Blank <input checked="" type="checkbox"/> Shaped Blank | |
| n-Value | 0.226 | r45 | 1.73 | E-Module | 2.10E+05 MPa | Meshing | |
| Yield Curve | | Yield Surface | | Roll angle: 0.00 ° Initial Element Size: 40.00 mm Refinement Level: 6 Max Element Angle: 22.50 ° | | | |
| | | | | Blank size: 1131.64 X 2031.05 | | | |
| | | | | | | | |

| Input Data | | D-20 | | | | | |
|------------------------------|-----------------------------|----------------------|-----|----------------------|--|----------|--|
| Tool Info | | Process Data | | | | | |
| Meshing Tolerance | 0.05 mm | Friction Coefficient | | Constant | | 0.100 | |
| Process Type | Single Action Draw | Die - Blank | | Punch - Blank | | - | |
| Tool Geometry Refers to | Lower Side of Initial Blank | Binder - Blank | | Binderforce | | - | |
| Tools | Contact Side | Type | Gap | RAM | | 581.0 tf | |
| Die | Upper Side of Blank | Rigid | | Binderforce/pressure | | 218.9 tf | |
| Punch | Lower Side of Blank | Rigid | | | | | |
| Binder | Lower Side of Blank | Force Controlled | | | | | |
| Tool Geometry 1st opp | | | | | | | |
| | | | | | | | |

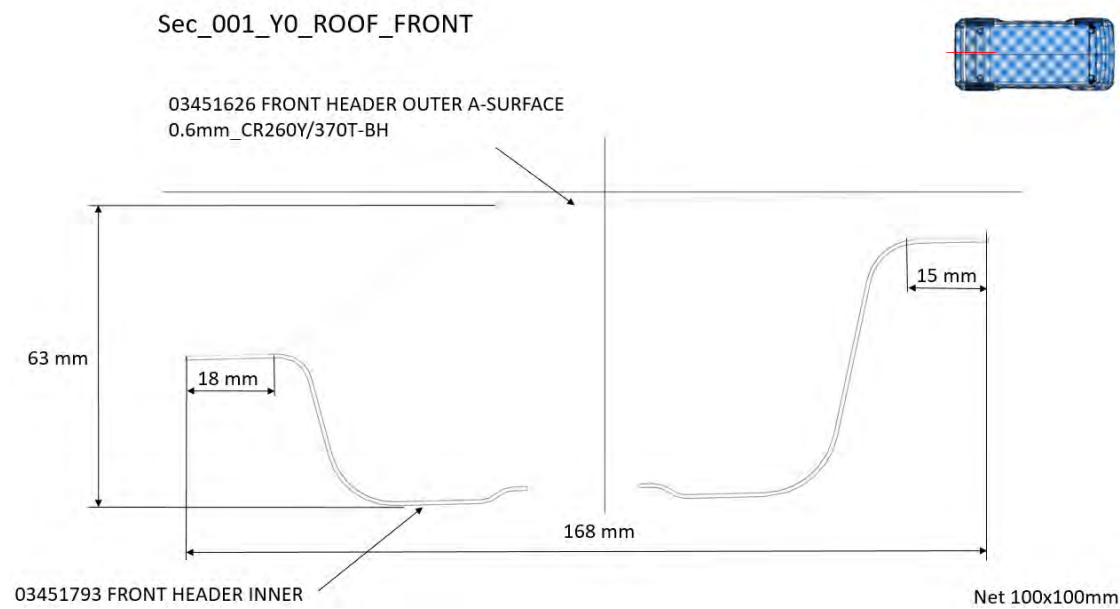
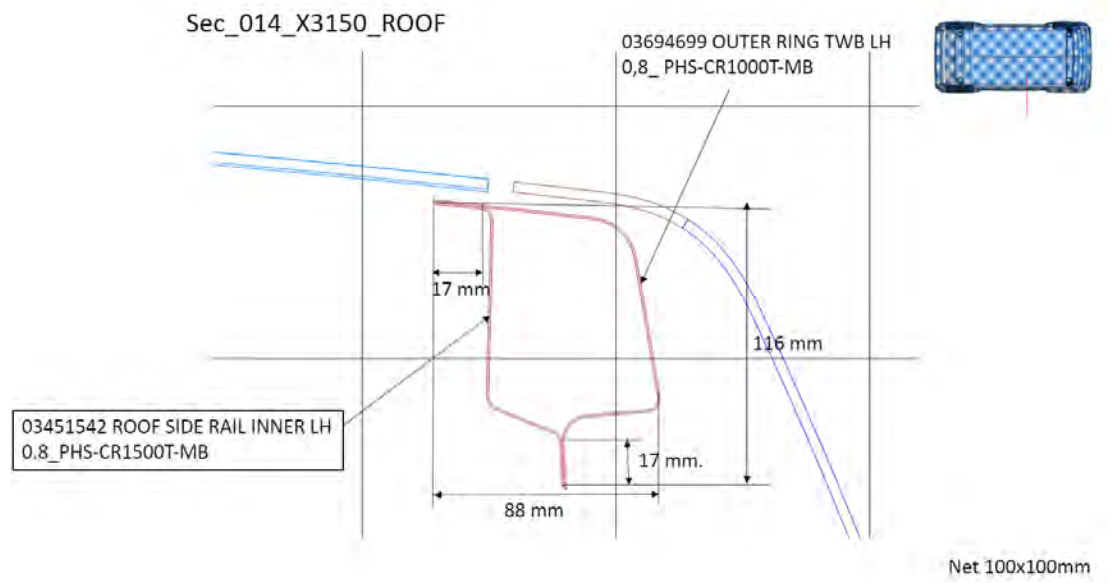
| | | |
|-------------|------|--|
| Formability | D-20 | |
|-------------|------|--|



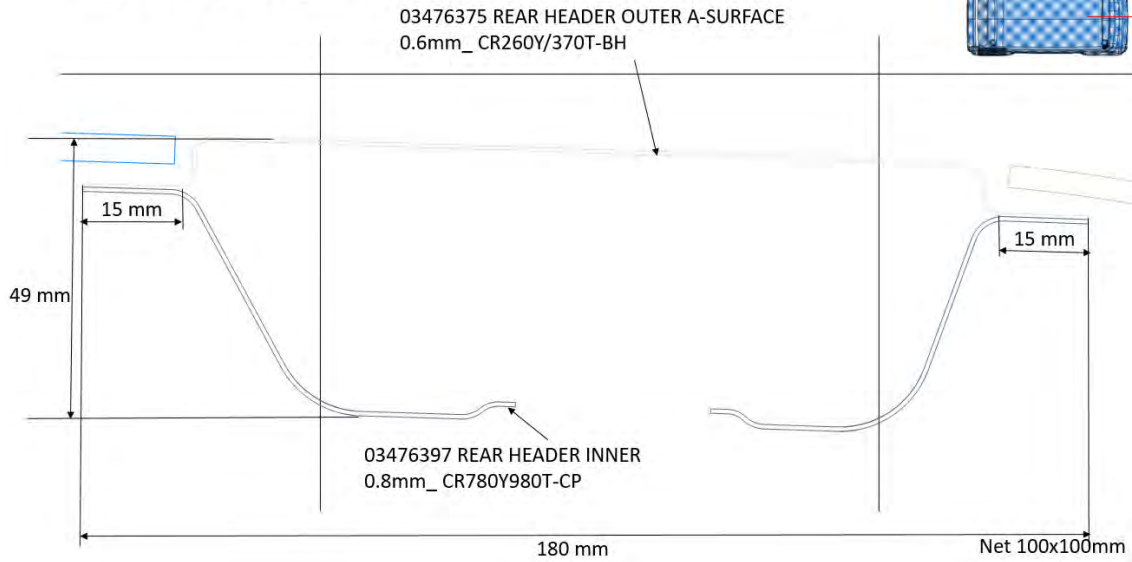
| | | |
|--------------------|------|--|
| Wrinkling Behavior | D-20 | |
|--------------------|------|--|



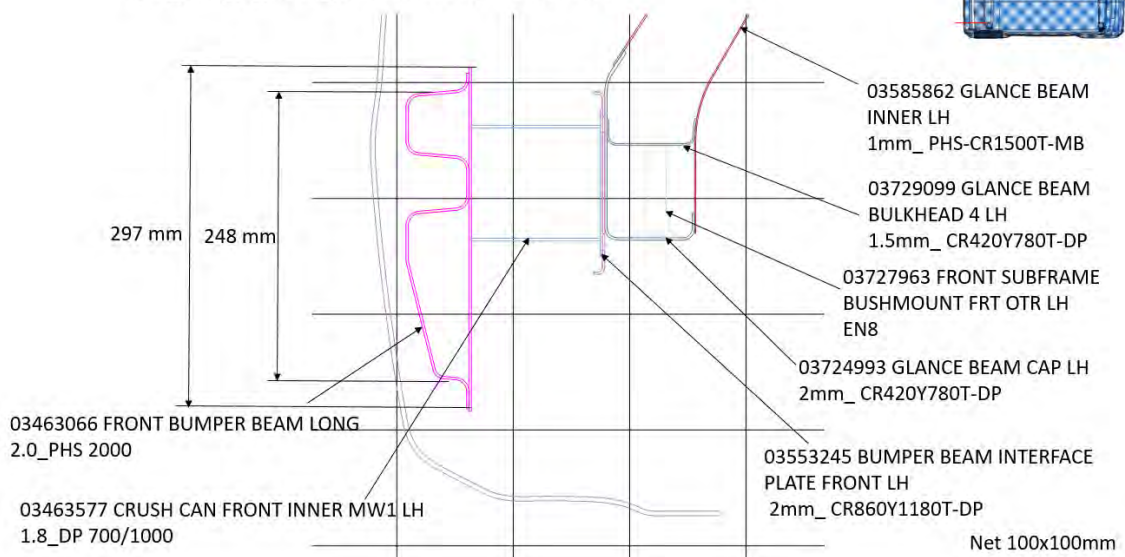
Appendix 2.2 SEM1 BIW section profiles



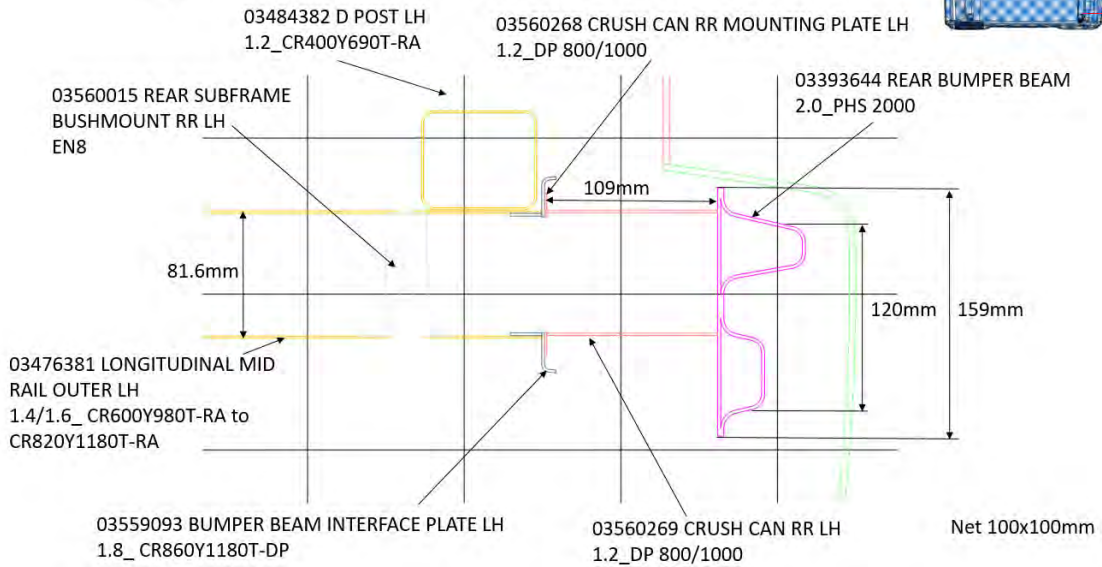
Sec_001_Y0_ROOF_REAR



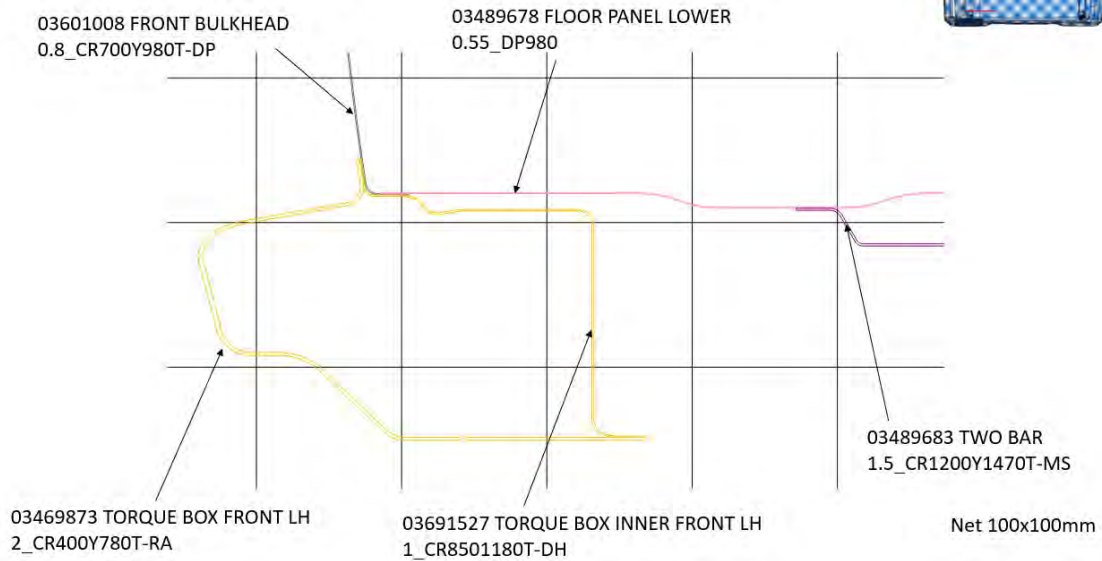
Sec_003_Y_-505_SECTION FRONT CRASH



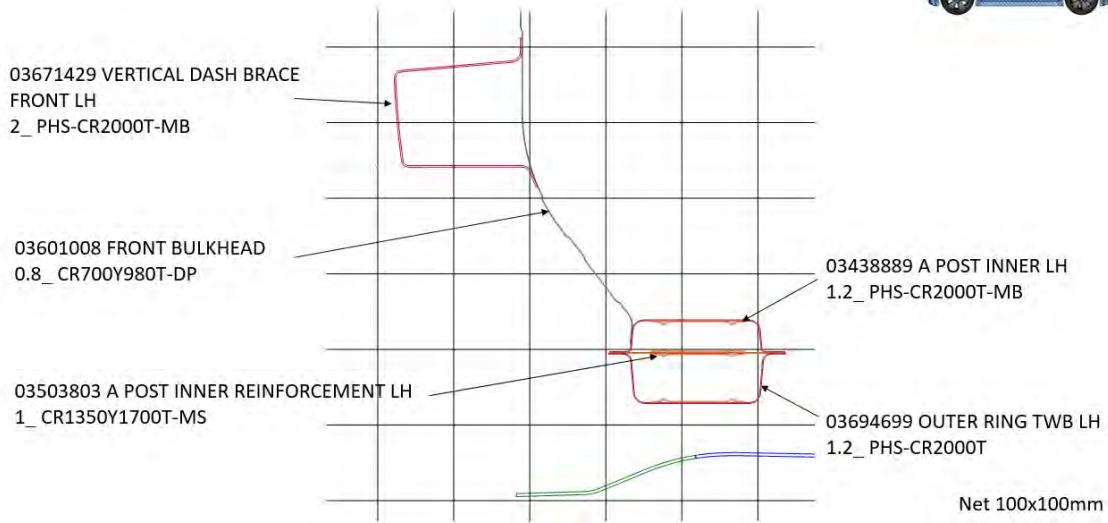
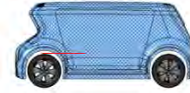
Sec_004_Y_-405_SECTION REAR CRASH



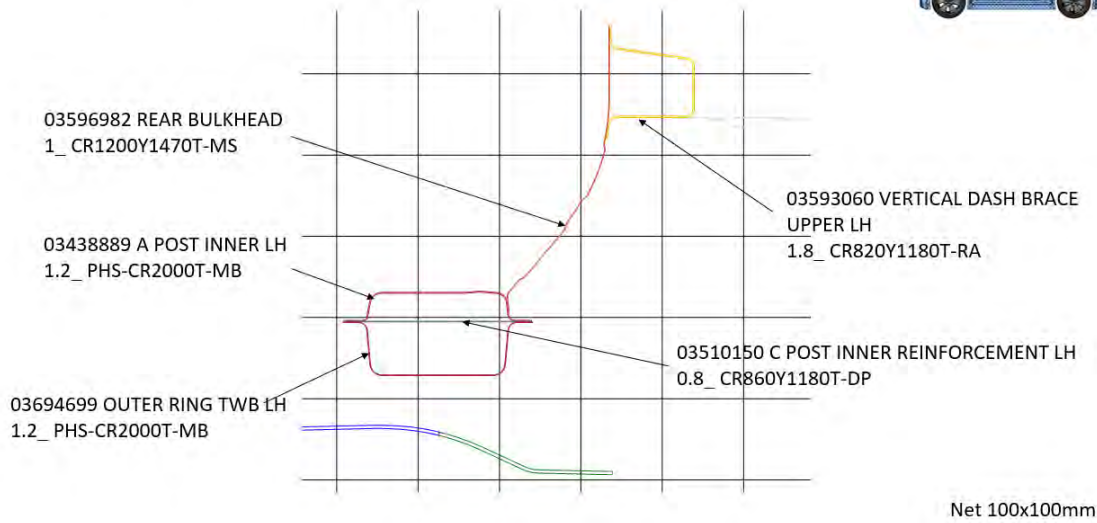
Sec_005_Y_-505_SECTION BATTERY FRONT



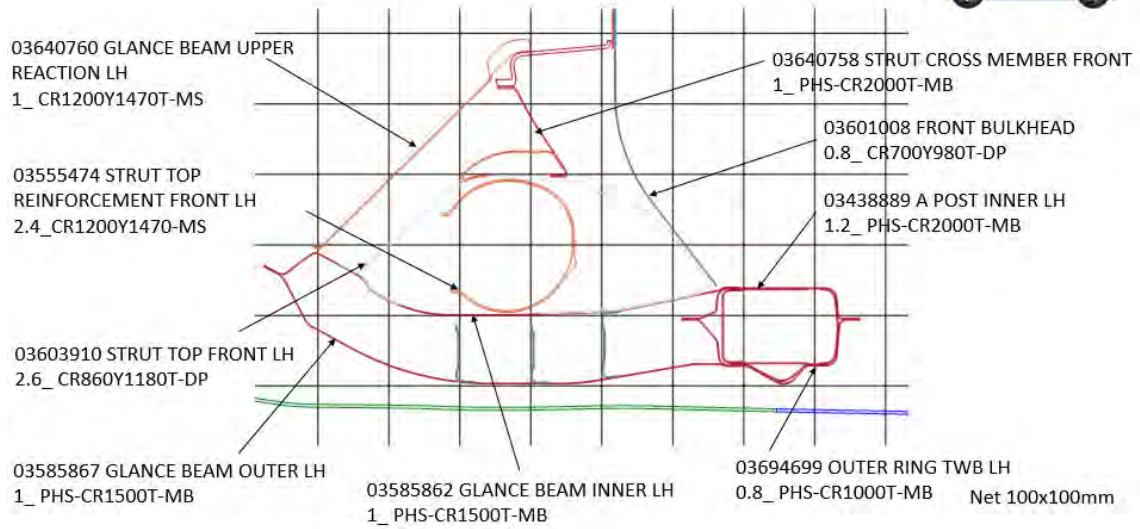
Sec_028_Z1341.7_LOWER_HINGE



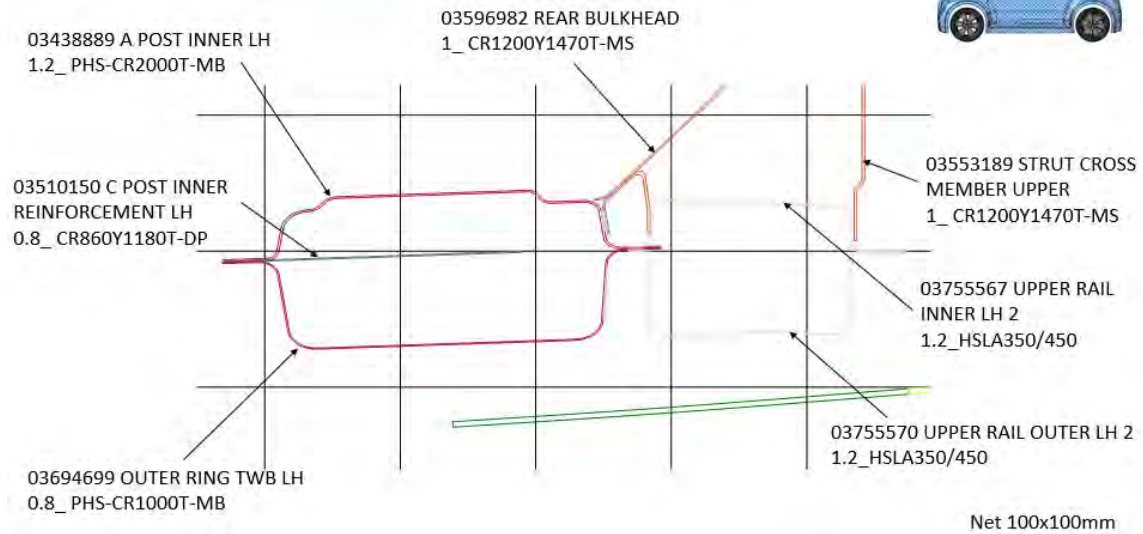
Sec_028_Z1341.7_LOWER_HINGE_REAR



Sec_026_Z1641.7_UPPER_HINGE_FRONT

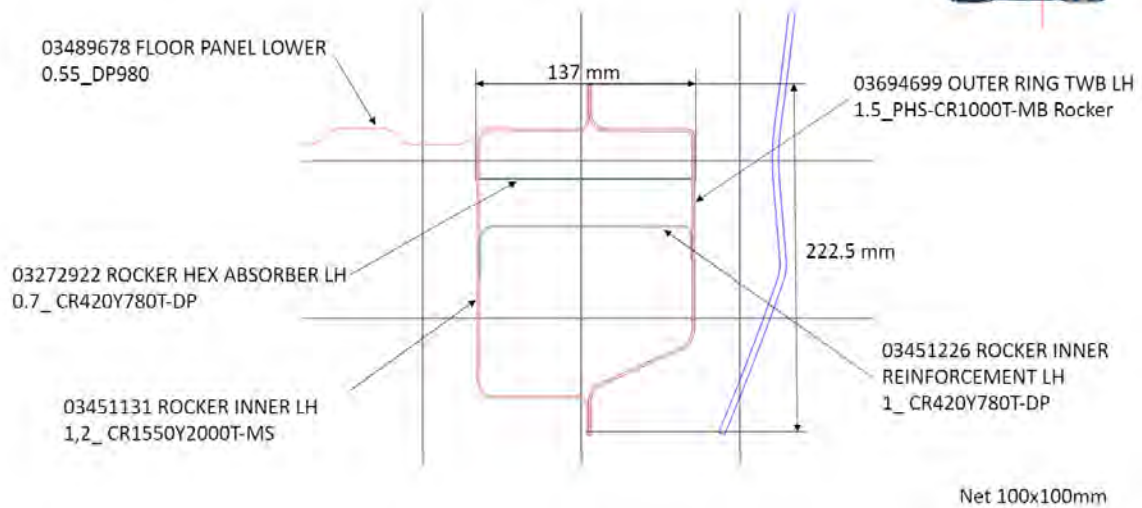


Radial_Section_D-Pillar

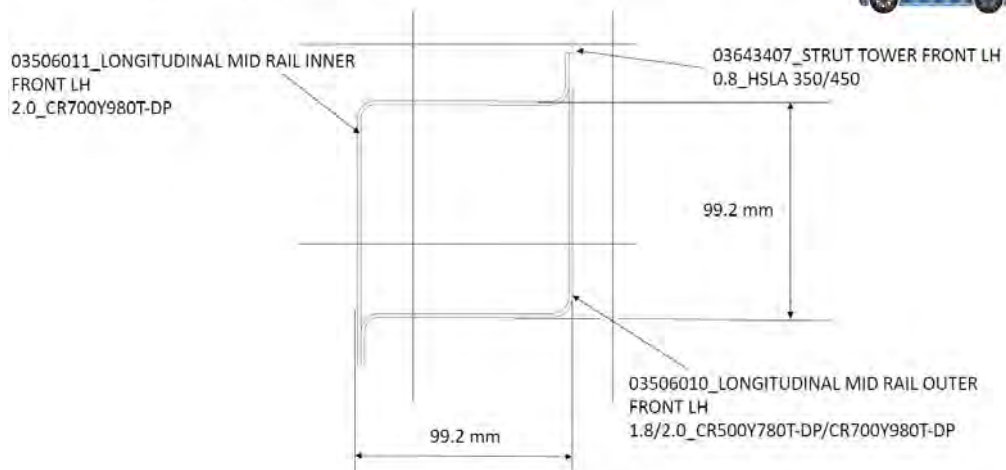


Sec_014_X3150_ROCKER

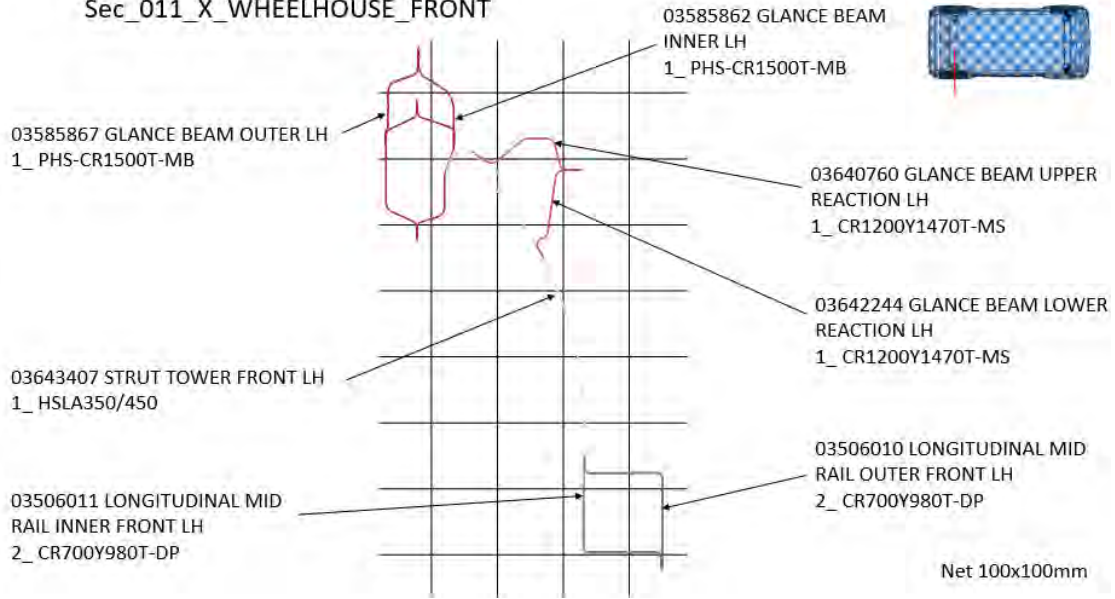
03470047 SIDEFAME LH MW 0,7mm



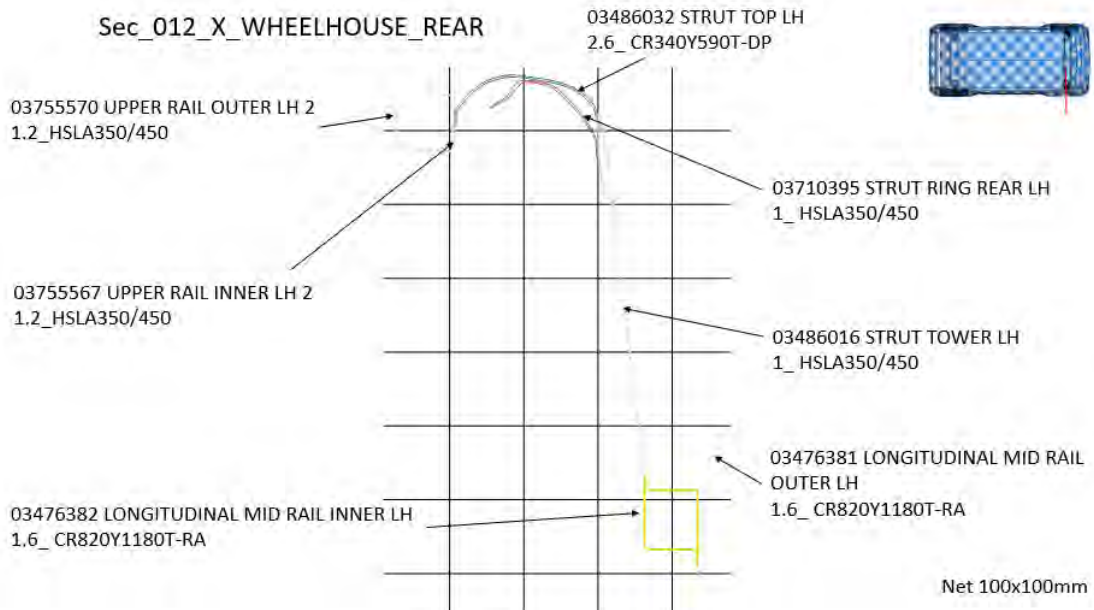
SEC_008_SECTION LONGITUDINAL MID RAIL



Sec_011_X_WHEELHOUSE_FRONT



Sec_012_X_WHEELHOUSE_REAR



Appendix 3 Body in White Assemblies

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Underbody Front Zone



| | |
|---|--|
|  | Part Number: 0104070 |
| | Part Name: VERTICAL DASH-BRACE LOWER OUTER |
| | Material designation: PHS-DR2007-40B |
| | Material thickness: 2.0 mm |
| | Manufacturing process: Deep drawing |
| | Connection technology: Spot Welding |
| | Weight: 2.049 kg |
| | Coating: |

| | |
|---|--|
|  | Part Number: 0103244 |
| | Part Name: VERTICAL DASH-BRACE LOWER INNER |
| | Material designation: PHS-DR2007-40B |
| | Material thickness: 2.0 mm |
| | Manufacturing process: Deep drawing |
| | Connection technology: Spot Welding |
| | Weight: 3.024 kg |
| | Coating: |

| | |
|---|--|
|  | Part Number: 0103943 |
| | Part Name: FRONT SUBFRAME BRUSHBACK REAR |
| | Material designation: PHS |
| | Material thickness: 4.0 mm |
| | Manufacturing process: Spot Welding / Seam Shielding |
| | Weight: 0.354 kg |
| | Coating: |

| | |
|---|--|
|  | Part Number: 0103943 |
| | Part Name: FRONT SUBFRAME BRUSHBACK REAR |
| | Material designation: PHS |
| | Material thickness: 4.0 mm |
| | Manufacturing process: Spot Welding |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |



„Engineering support for Future Steel Mobility“

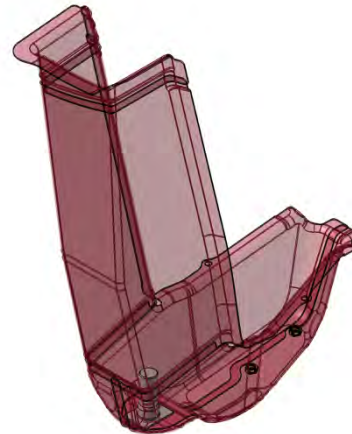
Underbody Front Zone



| | |
|--|--|
|  | Part Number: 0103943 |
| | Part Name: FRONT SUBFRAME BRUSHBACK REAR |
| | Material designation: PHS |
| | Material thickness: 4.0 mm |
| | Manufacturing process: Spot Welding |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|---|--|
|  | Part Number: 0103943 |
| | Part Name: FRONT SUBFRAME BRUSHBACK REAR |
| | Material designation: PHS |
| | Material thickness: 4.0 mm |
| | Manufacturing process: Spot Welding |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|---|--|
|  | Part Number: 0103943 |
| | Part Name: FRONT SUBFRAME BRUSHBACK REAR |
| | Material designation: PHS |
| | Material thickness: 4.0 mm |
| | Manufacturing process: Spot Welding |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

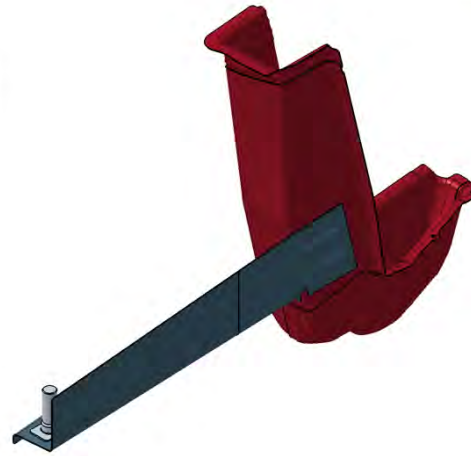


Underbody Front Zone

| | |
|--|--|
| | Part Number: VERTICAL DASH BRACE ASSEMBLY LH |
| | Part Name: VERTICAL DASH BRACE ASSEMBLY LH |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|--|
| | Part Number: LONGITUDINAL MID RAIL COVER FRONT LH - R500000002 |
| | Part Name: LONGITUDINAL MID RAIL COVER FRONT LH - R500000002 |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|---|
| | Part Number: UPPER DASH BRACE ASSEMBLY LH |
| | Part Name: UPPER DASH BRACE ASSEMBLY LH |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

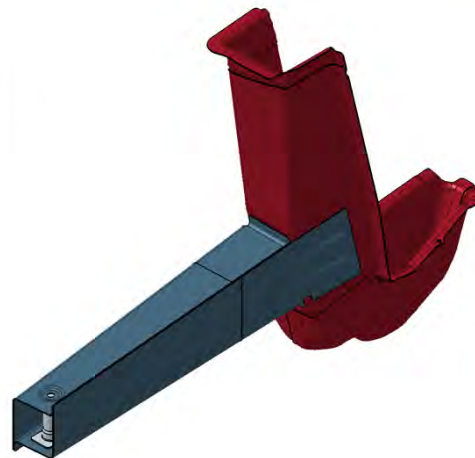


Underbody Front Zone

| | |
|--|---|
| | Part Number: REAR RAIL DASH BRACE ASSEMBLY LH |
| | Part Name: REAR RAIL DASH BRACE ASSEMBLY LH |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|--|
| | Part Number: LONGITUDINAL MID RAIL INNER PIECE LH |
| | Part Name: LONGITUDINAL MID RAIL INNER PIECE LH |
| | Material description: LONGITUDINAL MID RAIL INNER PIECE LH |
| | Material thickness: 3.8 to 3.0 mm |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: 3.322 kg |
| | Coating: |

| | |
|--|--|
| | Part Number: FRONT RAIL DASH BRACE ASSEMBLY LH |
| | Part Name: FRONT RAIL DASH BRACE ASSEMBLY LH |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

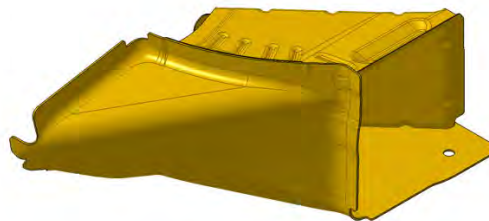


Underbody Front Zone

| | |
|--|-------------------------------------|
| | Part Number: 03406703 |
| | Part Name: TONGUE BOX FRONT LH |
| | Material description: 03406703T 03 |
| | Material thickness: 2 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 2.249 kg |
| | Coating: |

| | |
|--|--|
| | Part Number: 03472255 |
| | Part Name: TONGUE BOX INNER UPPER FRONT LH |
| | Material description: 03472255T 02 |
| | Material thickness: 2 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 0.77 kg |
| | Coating: |

| | |
|--|-------------------------------------|
| | Part Number: TONGUE BOX ASSEMBLY LH |
| | Part Name: TONGUE BOX ASSEMBLY LH |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

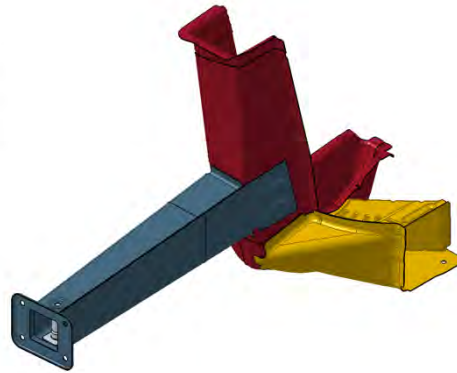


Underbody Front Zone

| | |
|--|---|
| | Part Number: 49421 B&B END CAP ASSEMBLY (P) - 202510000 |
| | Part Name: 49421 B&B END CAP ASSEMBLY (P) - 202510000 |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding + Seam Welding |
| | Weight: |
| | Coating: |

| | |
|--|---------------------------------------|
| | Part Number: TORSION BAR ASSEMBLY PIN |
| | Part Name: TORSION BAR ASSEMBLY PIN |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|--|
| | Part Number: FRONT RAIL + SHOCK BRACE + TORSION BAR ASSEMBLY (P) |
| | Part Name: FRONT RAIL + SHOCK BRACE + TORSION BAR ASSEMBLY (P) |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |



Underbody Front Zone

| | |
|--|--------------------------------------|
| | Part Number: 03623007 |
| | Part Name: ONE RAIL OUTER UPPER |
| | Material description: CR600/1300T-0P |
| | Material thickness: 2.0 mm |
| | Manufacturing process: Sheet Draping |
| | Connection technology: Spot Welding |
| | Weight: 0.72 kg |
| | Coating: |

| | |
|--|--------------------------------------|
| | Part Number: 03623008 |
| | Part Name: ONE RAIL OUTER LOWER |
| | Material description: CR600/1300T-0P |
| | Material thickness: 2.0 mm |
| | Manufacturing process: Sheet Draping |
| | Connection technology: Spot Welding |
| | Weight: 0.72 kg |
| | Coating: |

| | |
|--|--------------------------------------|
| | Part Number: ONE RAIL OUTER ASSEMBLY |
| | Part Name: ONE RAIL OUTER ASSEMBLY |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |



Underbody Front Zone

| | |
|--|-------------------------------------|
| | Part Number: 03623007 |
| | Part Name: ONE RAIL OUTER ASSEMBLY |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|--------------------------------------|
| | Part Number: 03623008 |
| | Part Name: ONE RAIL INNER |
| | Material description: CR600/1300T-0P |
| | Material thickness: 1.0 mm |
| | Manufacturing process: Sheet Draping |
| | Connection technology: Spot Welding |
| | Weight: 1.272 kg |
| | Coating: |

| | |
|--|-------------------------------------|
| | Part Number: ONE RAIL ASSEMBLY |
| | Part Name: ONE RAIL ASSEMBLY |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |



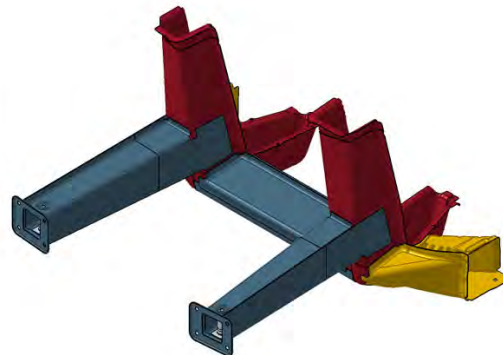
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Underbody Front Zone

| | |
|--|--|
| | Part Number: FRONT END - CAP BRACE - TORQUE JOINT ASSEMBLY L&R |
| | Part Name: FRONT END - CAP BRACE - TORQUE JOINT ASSEMBLY L&R |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|--|
| | Part Number: FRONT END - CAP BRACE - TORQUE JOINT ASSEMBLY L&R |
| | Part Name: FRONT END - CAP BRACE - TORQUE JOINT ASSEMBLY L&R |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |



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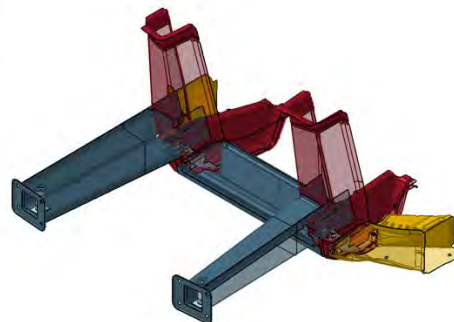
Underbody Front Zone

| | |
|--|--|
| | Part Number: FRONT END - CAP BRACE - TORQUE JOINT ASSEMBLY L&R |
| | Part Name: FRONT END - CAP BRACE - TORQUE JOINT ASSEMBLY L&R |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|---|
| | Part Number: COVER CAP BRACE ASSEMBLY L&R |
| | Part Name: COVER CAP BRACE ASSEMBLY L&R |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Seam-Welding |
| | Weight: |
| | Coating: |

| | |
|--|--|
| | Part Number: 0303200 |
| | Part Name: BULKHEAD - SUBFRAME B Side LH |
| | Material description: HSLA 550/500 |
| | Material thickness: 2 mm |
| | Manufacturing process: Deep drawing |
| | Connection technology: Seam-Welding |
| | Weight: 0.388 kg |
| | Coating: |

| | |
|--|--|
| | Part Number: 0303201 |
| | Part Name: BULKHEAD - SUBFRAME B Side RH |
| | Material description: HSLA 550/500 |
| | Material thickness: 2 mm |
| | Manufacturing process: Deep drawing |
| | Connection technology: Seam-Welding |
| | Weight: 0.388 kg |
| | Coating: |



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Underbody Front Zone

| | |
|--|---------------------------------------|
| | Part Number: 0303002 |
| | Part Name: FRONT TOP FRONT LH |
| | Material description: 0303002-001-001 |
| | Material thickness: 2.6 mm |
| | Manufacturing process: Deep drawing |
| | Connection technology: Spot Welding |
| | Weight: 2.295 kg |
| | Coating: |

| | |
|--|--------------------------------------|
| | Part Number: STRUT TOWER ASSEMBLY LH |
| | Part Name: STRUT TOWER ASSEMBLY LH |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot welding |
| | Weight: |
| | Coating: |

| | |
|--|-------------------------------------|
| | Part Number: 0303007 |
| | Part Name: FRONT TOP FRONT RH |
| | Material description: HSLA 550/500 |
| | Material thickness: 3 mm |
| | Manufacturing process: Deep drawing |
| | Connection technology: Spot Welding |
| | Weight: 2.826 kg |
| | Coating: |



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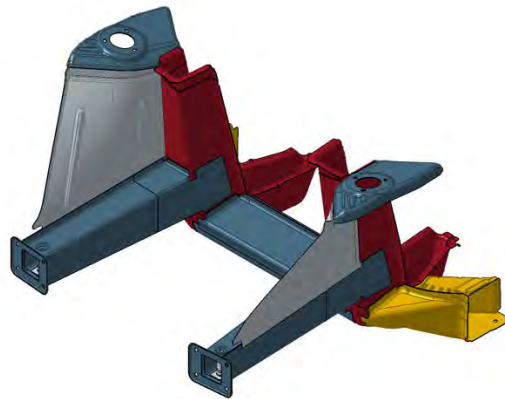
Underbody Front Zone

| | | |
|--|-----------------------|---|
| | Part Number | FRONT RAIL + DASH BRACE + TORQUE BOX + ONE BAR + STRUT TOWER ASSEMBLY |
| | Part Name | |
| | Material designation | |
| | Material thickness | |
| | Manufacturing process | |
| | Connection technology | |
| | Weight | |
| | Coating | |

| | | |
|--|-----------------------|----------------------|
| | Part Number | STRUT TOWER ASSEMBLY |
| | Part Name | |
| | Material designation | |
| | Material thickness | |
| | Manufacturing process | |
| | Connection technology | |
| | Weight | |
| | Coating | |

| | | |
|--|-----------------------|----------------------|
| | Part Number | STRUT TOWER ASSEMBLY |
| | Part Name | |
| | Material designation | |
| | Material thickness | |
| | Manufacturing process | |
| | Connection technology | |
| | Weight | |
| | Coating | |

| | | |
|--|-----------------------|---|
| | Part Number | FRONT RAIL + DASH BRACE + TORQUE BOX + ONE BAR + STRUT TOWER ASSEMBLY |
| | Part Name | |
| | Material designation | |
| | Material thickness | |
| | Manufacturing process | |
| | Connection technology | Spot welding |
| | Weight | |
| | Coating | |



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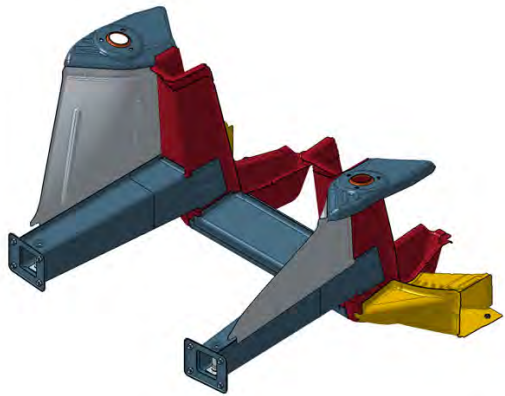
Underbody Front Zone

| | | |
|--|-----------------------|---|
| | Part Number | FRONT RAIL + DASH BRACE + TORQUE BOX + ONE BAR + STRUT TOWER ASSEMBLY |
| | Part Name | |
| | Material designation | |
| | Material thickness | |
| | Manufacturing process | |
| | Connection technology | Spot welding |
| | Weight | |
| | Coating | |

| | | |
|--|-----------------------|---------------------|
| | Part Number | STRUT RING FRONT LH |
| | Part Name | |
| | Material designation | CX12025410-MS |
| | Material thickness | 2 mm |
| | Manufacturing process | Deep Drawing |
| | Connection technology | Spot Welding |
| | Weight | 0.239 kg |
| | Coating | |

| | | |
|--|-----------------------|---------------------|
| | Part Number | STRUT RING FRONT RH |
| | Part Name | |
| | Material designation | CX12025410-MS |
| | Material thickness | 2 mm |
| | Manufacturing process | Deep Drawing |
| | Connection technology | Spot Welding |
| | Weight | 0.239 kg |
| | Coating | |

| | | |
|--|-----------------------|---|
| | Part Number | FRONT RAIL + DASH BRACE + TORQUE BOX + ONE BAR + STRUT TOWER ASSEMBLY |
| | Part Name | |
| | Material designation | |
| | Material thickness | |
| | Manufacturing process | |
| | Connection technology | Spot welding |
| | Weight | |
| | Coating | |



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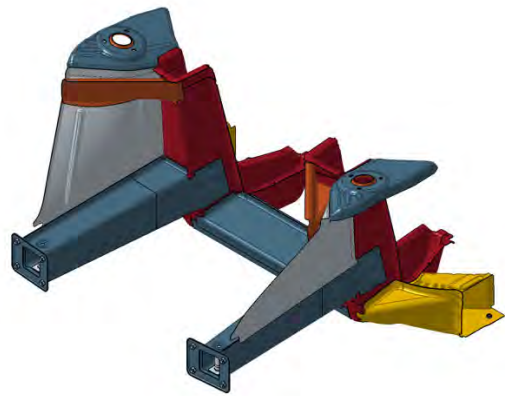
Underbody Front Zone

| | | |
|--|-----------------------|---|
| | Part Number | FRONT RAIL + DASH BRACE + TORQUE BOX + ONE BAR + STRUT TOWER ASSEMBLY |
| | Part Name | |
| | Material designation | |
| | Material thickness | |
| | Manufacturing process | |
| | Connection technology | Spot Welding |
| | Weight | |
| | Coating | |

| | | |
|--|-----------------------|-------------------------------|
| | Part Number | GLANCE BEAM LOWER REACTION LH |
| | Part Name | |
| | Material designation | CX12025410-MS |
| | Material thickness | 1.0 mm |
| | Manufacturing process | |
| | Connection technology | Spot Welding |
| | Weight | 0.027 kg |
| | Coating | |

| | | |
|--|-----------------------|-------------------------------|
| | Part Number | GLANCE BEAM LOWER REACTION RH |
| | Part Name | |
| | Material designation | CX12025410-MS |
| | Material thickness | 1.0 mm |
| | Manufacturing process | |
| | Connection technology | Spot welding |
| | Weight | 0.027 kg |
| | Coating | |

| | | |
|--|-----------------------|---|
| | Part Number | FRONT RAIL + DASH BRACE + TORQUE BOX + ONE BAR + STRUT TOWER + GLANCE REACTION ASSEMBLY |
| | Part Name | |
| | Material designation | |
| | Material thickness | |
| | Manufacturing process | |
| | Connection technology | Spot welding |
| | Weight | |
| | Coating | |



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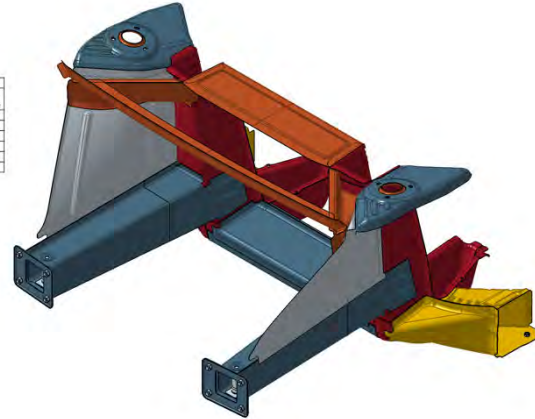
Underbody Front Zone

| | |
|--|---|
| | Part Number: 0804205 Part Name: FRONT END - DASH BRACE + TORQUE BOX + ONE BAR + STRUT TOWER + GLANCE REACTION ASSEMBLY |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot welding |
| | Weight: |
| | Coating: |

| | |
|--|---|
| | Part Number: 0804207 Part Name: STRUT CROSS MEMBER CLOSING PLATE |
| | Material description: 0810000001 MS |
| | Material thickness: 2.0 mm |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: 2.380 kg |
| | Coating: |

| | |
|--|---|
| | Part Number: 0804300 Part Name: GLANCE REAR LATERAL CROSS MEMBER STRUT |
| | Material description: 0810000001 MS |
| | Material thickness: 2.0 mm |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: 2.240 kg |
| | Coating: |

| | |
|--|---|
| | Part Number: 0804205 Part Name: FRONT END - DASH BRACE + TORQUE BOX + ONE BAR + STRUT TOWER + GLANCE REACTION LATERAL ASSEMBLY |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |



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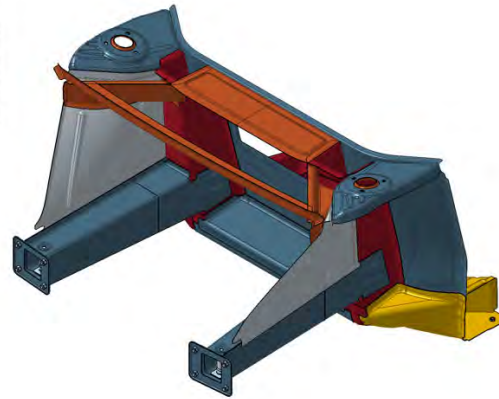


Underbody Front Zone

| | |
|--|---|
| | Part Number: 0804205 Part Name: FRONT END - DASH BRACE + TORQUE BOX + ONE BAR + STRUT TOWER + GLANCE REACTION LATERAL ASSEMBLY |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|--|
| | Part Number: 0804208 Part Name: FRONT BUSH HEAD |
| | Material description: 0810000001 SP |
| | Material thickness: 2.0 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 2.467 kg |
| | Coating: |

| | |
|--|---|
| | Part Number: 0804205 Part Name: FRONT END - DASH BRACE + TORQUE BOX + ONE BAR + STRUT TOWER + GLANCE REACTION LATERAL ASSEMBLY |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot welding |
| | Weight: |
| | Coating: |



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Underbody Front Zone

| | |
|--|---|
| | Part Number: 0804708 Part Name: STRUT CROSS MEMBER FRONT |
| | Material description: 0810000001 MS |
| | Material thickness: 3 mm |
| | Manufacturing process: Hot-chamber die casting |
| | Connection technology: Spot Welding |
| | Weight: 2.876 kg |
| | Coating: |

| | |
|--|--|
| | Part Number: 0804707 Part Name: GLANCE REAR LATERAL REACTION MS |
| | Material description: 0810000001 MS |
| | Material thickness: 2.0 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 0.51 kg |
| | Coating: |

| | |
|--|--|
| | Part Number: 0804705 Part Name: GLANCE REAR LATERAL REACTION MS |
| | Material description: 0810000001 MS |
| | Material thickness: 2.0 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 0.51 kg |
| | Coating: |

| | |
|--|---|
| | Part Number: 0804300 Part Name: GLANCE REAR LATERAL CROSS MEMBER STRUT |
| | Material description: 0810000001 MS |
| | Material thickness: 2.0 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 1.472 kg |
| | Coating: |

| | |
|--|---|
| | Part Number: 0804708 Part Name: STRUT CROSS MEMBER FRONT |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot welding |
| | Weight: |
| | Coating: |



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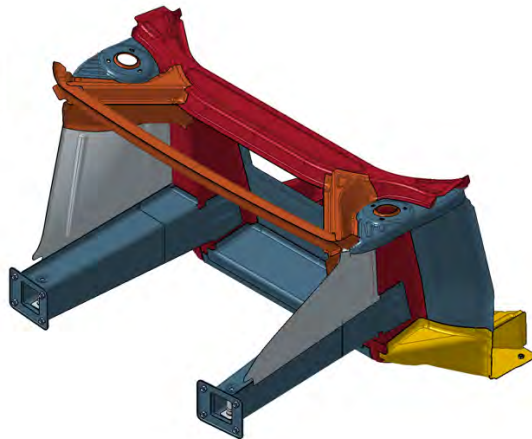


Underbody Front Zone

| | |
|-----------------------|---|
| Part Number | FRONT FLOOR + DRIVE SHAFT + TORQUE ARM + ONE SIDE OF STEEL TUBES + GLANCE REAR ASSEMBLY |
| Part Name | |
| Material description | |
| Material thickness | |
| Manufacturing process | |
| Connection technology | Spot welding |
| Weight | |
| Coating | |

| | |
|-----------------------|----------------------|
| Part Number | GLANCE REAR ASSEMBLY |
| Part Name | |
| Material description | |
| Material thickness | |
| Manufacturing process | |
| Connection technology | Spot welding |
| Weight | |
| Coating | |

| | |
|-----------------------|---------------------|
| Part Number | |
| Part Name | FRONT ZONE ASSEMBLY |
| Material description | |
| Material thickness | |
| Manufacturing process | |
| Connection technology | Spot welding |
| Weight | |
| Coating | |



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Underbody Front Zone

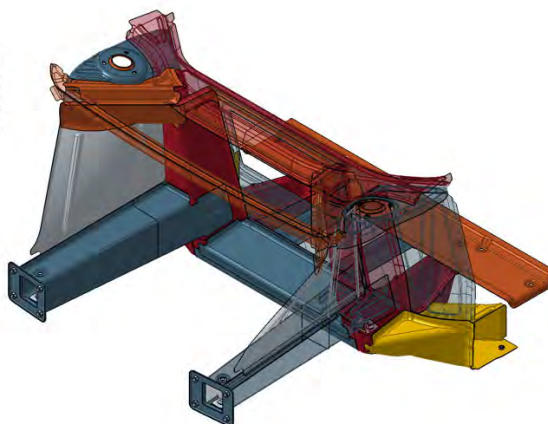
| | |
|-----------------------|---------------------|
| Part Number | FRONT ZONE ASSEMBLY |
| Part Name | |
| Material description | |
| Material thickness | |
| Manufacturing process | |
| Connection technology | Spot welding |
| Weight | |
| Coating | |

| | |
|-----------------------|-----------------|
| Part Number | DRIVE SHAFT |
| Part Name | TRUCK SHAFT |
| Material description | CR1200Y1101 AHS |
| Material thickness | 3.0 mm |
| Manufacturing process | Blank Drawing |
| Connection technology | Spot welding |
| Weight | 4.053kg |
| Coating | |

| | |
|-----------------------|-------------------------|
| Part Number | DRIVE SHAFT |
| Part Name | TRUCK SHAFT TORQUE LEFT |
| Material description | CR1200Y1101 AHS |
| Material thickness | 3.0 mm |
| Manufacturing process | Blank Drawing |
| Connection technology | Spot welding |
| Weight | 3.008kg |
| Coating | |

| | |
|-----------------------|--------------------------|
| Part Number | DRIVE SHAFT |
| Part Name | TRUCK SHAFT TORQUE RIGHT |
| Material description | CR1200Y1101 AHS |
| Material thickness | 3.0 mm |
| Manufacturing process | Blank Drawing |
| Connection technology | Spot welding |
| Weight | 3.008kg |
| Coating | |

| | |
|-----------------------|---------------------------------|
| Part Number | |
| Part Name | FRONT ZONE FLOOR PARTS ASSEMBLY |
| Material description | |
| Material thickness | |
| Manufacturing process | |
| Connection technology | Spot welding / Seam welding |
| Weight | |
| Coating | |



Mid Zone Floor Assembly

„Engineering support for Future Steel Mobility“



Underbody Middle area

| | |
|-----------------------|-----------------|
| Part Number | DRIVE SHAFT |
| Part Name | TRUCK SHAFT |
| Material description | CR1200Y1101 AHS |
| Material thickness | 3.0 mm |
| Manufacturing process | Blank Drawing |
| Connection technology | Spot welding |
| Weight | 4.053kg |
| Coating | |

| | |
|-----------------------|-------------------|
| Part Number | DRIVE SHAFT |
| Part Name | FLOOR PANEL COVER |
| Material description | CR1200Y1101 AHS |
| Material thickness | 0.55 mm |
| Manufacturing process | Blank Drawing |
| Connection technology | Spot welding |
| Weight | 14.882kg |
| Coating | |

| | |
|-----------------------|-----------------------|
| Part Number | |
| Part Name | FLOOR ASSEMBLY FINISH |
| Material description | |
| Material thickness | |
| Manufacturing process | |
| Connection technology | Spot welding |
| Weight | |



Rear Zone Assembly

„Engineering support for Future Steel Mobility“

Underbody Rear Zone



| | |
|--|--|
| | Part Number: 0183010 |
| | Part Name: VERTICAL DASH-BRACE LOWER CENTER LH |
| | Material designation: CR02111007-BA |
| | Material thickness: 1,8 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 1,652 kg |
| | Coating: |

| | |
|--|--|
| | Part Number: 0183011 |
| | Part Name: VERTICAL DASH-BRACE LOWER ASSY LH |
| | Material designation: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|--|
| | Part Number: 0183012 |
| | Part Name: REAR SUBFRAME BUMPER BRK LH |
| | Material designation: CR02111007-BA |
| | Material thickness: 1,8 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 2,854 kg |
| | Coating: |

| | |
|--|--|
| | Part Number: 0183013 |
| | Part Name: REAR SUBFRAME BUMPER MOUNT BRK LH |
| | Material designation: EN8 |
| | Material thickness: N/A |
| | Manufacturing process: N/A |
| | Connection technology: Spot Welding / Term Welding |
| | Weight: 0,394 kg |
| | Coating: |



„Engineering support for Future Steel Mobility“

Underbody Front Zone



| | |
|--|--|
| | Part Number: 03716555 |
| | Part Name: VERTICAL DASH-BRACE UPPER REAR LH |
| | Material designation: CR02111007-BA |
| | Material thickness: 1,8 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 0,218 kg |
| | Coating: |

| | |
|--|---|
| | Part Number: 03716556 |
| | Part Name: UPPER DASH-BRACE REAR LOWER MNT LH |
| | Material designation: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|---|
| | Part Number: 03531000 |
| | Part Name: VERTICAL DASH-BRACE UPPER LH |
| | Material designation: CR02111007-BA |
| | Material thickness: 1,8 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 1,652 kg |
| | Coating: |



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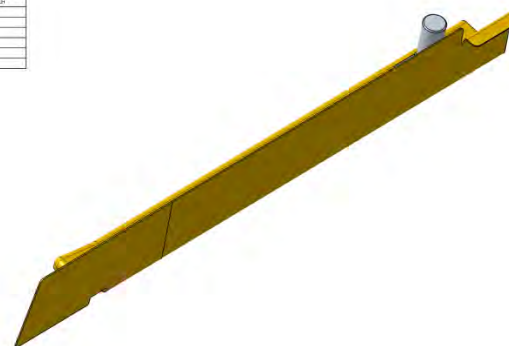
Underbody Rear Zone



| | |
|--|---|
| | Part Number: 0183015 |
| | Part Name: LONGITUDINAL RAIL CENTER LH |
| | Material designation: TRN CR02111007-BA/CR02111007-BA |
| | Material thickness: 2,1 / 2,6 mm |
| | Manufacturing process: Deep Drawing / Simple Bending |
| | Connection technology: Spot Welding |
| | Weight: 1,096 kg |
| | Coating: |

| | |
|--|---|
| | Part Number: 0183016 |
| | Part Name: REAR RAIL CENTER ASSEMBLY LH |
| | Material designation: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

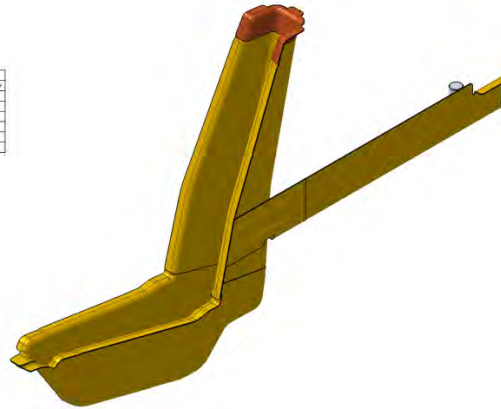
| | |
|--|--|
| | Part Number: 0183017 |
| | Part Name: REAR SUBFRAME BUMPER MOUNT BRK RH |
| | Material designation: EN8 |
| | Material thickness: N/A |
| | Manufacturing process: N/A |
| | Connection technology: Spot Welding |
| | Weight: 0,394 kg |
| | Coating: |



Underbody Rear Zone

| | | |
|--|---|-----------------------------|
| | Part Number Part Name Material designation Material thickness Manufacturing process Connection technology Weight Coating | VERTICAL DASH BRACE ASSY LH |
| | Part Number Part Name Material designation Material thickness Manufacturing process Connection technology Weight Coating | REAR RAIL OUTER ASSEMBLY LH |

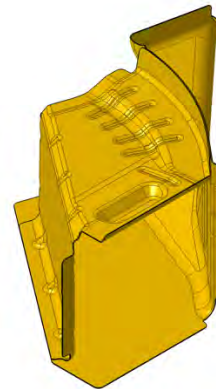
| | | |
|--|---|--|
| | Part Number Part Name Material designation Material thickness Manufacturing process Connection technology Weight Coating | VERTICAL DASH BRACE OUTER LONGIST ASSY |
|--|---|--|



Underbody Rear Zone

| | | |
|--|---|--------------------------------------|
| | Part Number Part Name Material designation Material thickness Manufacturing process Connection technology Weight Coating | 0310008 TORQUE BOX REAR LH |
| | Part Number Part Name Material designation Material thickness Manufacturing process Connection technology Weight Coating | 0353333 TORQUE BOX INNER UPPER LH |

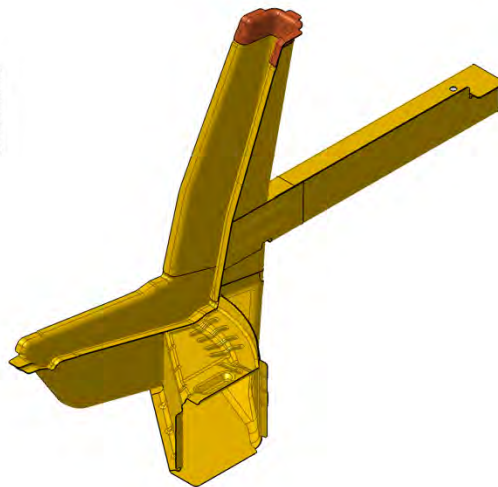
| | | |
|--|---|-------------------------|
| | Part Number Part Name Material designation Manufacturing process Connection technology Weight Coating | REAR TORQUE BOX ASSY LH |
|--|---|-------------------------|



Underbody Rear Zone

| | | |
|--|---|----------------------------------|
| | Part Number Part Name Material designation Material thickness Manufacturing process Connection technology Weight Coating | REAR RAIL DASH BRACE ASSEMBLY LH |
| | Part Number Part Name Material designation Material thickness Manufacturing process Connection technology Weight Coating | REAR TORQUE BOX ASSY LH |

| | | |
|--|---|----------------------------------|
| | Part Number Part Name Material designation Material thickness Manufacturing process Connection technology Weight Coating | REAR RAIL DASH BRACE ASSEMBLY LH |
|--|---|----------------------------------|



Underbody Rear Zone

| | |
|--|--------------------------------------|
| | Part Number: 0007016 |
| | Part Name: FIVE BAR PARTS |
| | Material designation: S19200-TRIP-20 |
| | Material thickness: 1.2 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 0.824 Kg |
| | Coating: |

| | |
|--|--|
| | Part Number: 0000008 |
| | Part Name: FIVE BAR BRACE |
| | Material designation: S19200-TRIP-20 |
| | Material thickness: 0.8 mm |
| | Manufacturing process: Deep Drawing / Cold-Forming |
| | Connection technology: Spot Welding |
| | Weight: 0.903 Kg |
| | Coating: |

| | |
|--|---------------------------------------|
| | Part Number: 0000009 |
| | Part Name: REAR COMPARTMENT FAN COVER |
| | Material designation: HSLA 350/500 |
| | Material thickness: 0.5 mm |
| | Manufacturing process: Sheet Drawing |
| | Connection technology: Spot Welding |
| | Weight: 2.09 Kg |
| | Coating: |

| | |
|--|--|
| | Part Number: 0000010 |
| | Part Name: FIVE BAR - REAR COMPARTMENT FAN BOX |
| | Material designation: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |



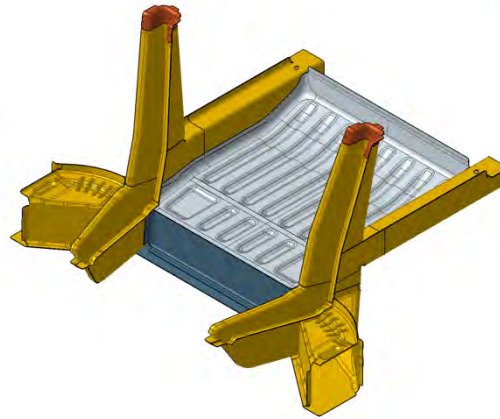
Underbody Rear Zone

| | |
|--|---|
| | Part Number: 0000011 |
| | Part Name: WHEELHOUSE REAR RAKE CRASH BRACE |
| | Material designation: HSLA 350/500 |
| | Material thickness: |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|---|
| | Part Number: 0000012 |
| | Part Name: WHEELHOUSE REAR RAKE CRASH BRACE |
| | Material designation: HSLA 350/500 |
| | Material thickness: |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|--|
| | Part Number: 0000013 |
| | Part Name: FIVE BAR - REAR COMPARTMENT FAN BOX |
| | Material designation: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|--|
| | Part Number: 0000014 |
| | Part Name: FIVE BAR - COMPARTMENT FAN - BOX-BRACE ASSEMBLY |
| | Material designation: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |



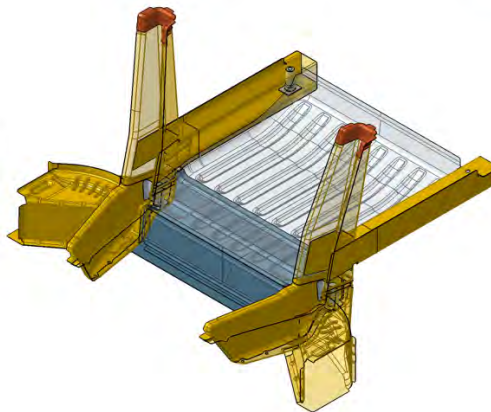
Underbody Rear Zone

| | |
|--|--|
| | Part Number: 0000015 |
| | Part Name: FIVE BAR - COMPARTMENT FAN - CRASH BRACE - REAR WHEELHOUSE ASSEMBLY |
| | Material designation: |
| | Material thickness: |
| | Manufacturing process: Spot Welding |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|-------------------------------------|
| | Part Number: 0000016 |
| | Part Name: BRACKET SURFRAME BRACE |
| | Material designation: HSLA 350/500 |
| | Material thickness: 1.0 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 0.09 kg |
| | Coating: |

| | |
|--|-------------------------------------|
| | Part Number: 0000017 |
| | Part Name: BRACKET SURFRAME BRACE |
| | Material designation: HSLA 350/500 |
| | Material thickness: 1.0 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 0.09 kg |
| | Coating: |

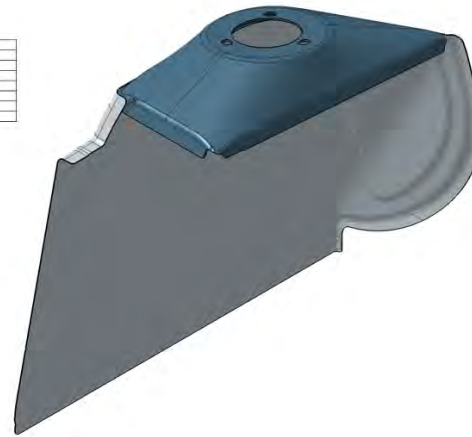
| | |
|--|--|
| | Part Number: 0000018 |
| | Part Name: FIVE BAR - COMPARTMENT FAN - BOX-BRACE ASSEMBLY |
| | Material designation: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |



Underbody Front Zone

| | |
|--|-------------------------------------|
| | Part Number: 0388020 |
| | Part Name: STRUT TOWER LP |
| | Material description: CR140V50T 0P |
| | Material thickness: 2.6 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 1.705 Kg |
| | Coating: |

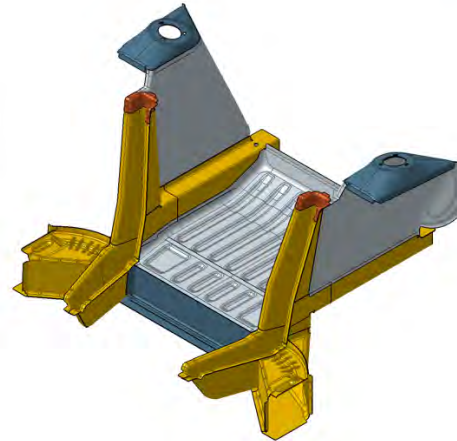
| | |
|--|-------------------------------------|
| | Part Number: 0388020 |
| | Part Name: STRUT TOWER LP |
| | Material description: CR140V50T 0P |
| | Material thickness: 2.6 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 1.705 Kg |
| | Coating: |



Underbody Rear Zone

| | |
|--|---|
| | Part Number: FILE BAR - WHEELWELL REAR SIDE - DISK BRACE ASSEMBLY |
| | Material description: CR140V50T 0P |
| | Material thickness: 2.6 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|--|
| | Part Number: FILE BAR - COMPARTMENT PAN + DISK BRACE - REAR WHEELWELL ASSEMBLY |
| | Material description: CR140V50T 0P |
| | Material thickness: 2.6 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |



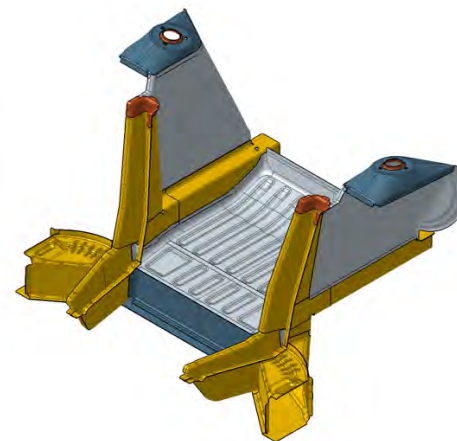
| | |
|--|---|
| | Part Number: STRUT TOWER REAR IN ASSEMBLY |
| | Material description: CR140V50T 0P |
| | Material thickness: 2.6 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|---|
| | Part Number: STRUT TOWER REAR IN ASSEMBLY |
| | Material description: CR140V50T 0P |
| | Material thickness: 2.6 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

Underbody Rear Zone

| | |
|--|--|
| | Part Number: FILE BAR - COMPARTMENT PAN + DISK BRACE - REAR WHEELWELL ASSEMBLY |
| | Material description: CR140V50T 0P |
| | Material thickness: 2.6 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|--|
| | Part Number: FILE BAR - COMPARTMENT PAN + DISK BRACE - REAR WHEELWELL ASSEMBLY |
| | Material description: CR140V50T 0P |
| | Material thickness: 2.6 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |



| | |
|--|-------------------------------------|
| | Part Number: 03779007 |
| | Part Name: STRUT RING REAR LP |
| | Material description: CR140V50T 0P |
| | Material thickness: 2.6 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 0.233 Kg |
| | Coating: |

| | |
|--|-------------------------------------|
| | Part Number: 03779008 |
| | Part Name: STRUT RING REAR RP |
| | Material description: CR140V50T 0P |
| | Material thickness: 2.6 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 0.233 Kg |
| | Coating: |

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Underbody Rear Zone

| | |
|--|---|
| | Part Number: 0359943 |
| | Part Name: REAR BULKHEAD |
| | Material designation: TRIP 420DP140T140K300007420 |
| | Material thickness: 1.2 (0.8 mm) |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 4.27 kg |
| | Coating: |

| | |
|--|---------------------------------------|
| | Part Number: 0355148 |
| | Part Name: STRUT CROSS MEMBER MEMBER |
| | Material designation: CR 220TP140T140 |
| | Material thickness: 1.5 (1 mm) |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 2.23 kg |
| | Coating: |

| | |
|--|---|
| | Part Number: |
| | Part Name: REAR BULKHEAD TURBRET BRACE LOWER ASSEMBLY |
| | Material designation: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |



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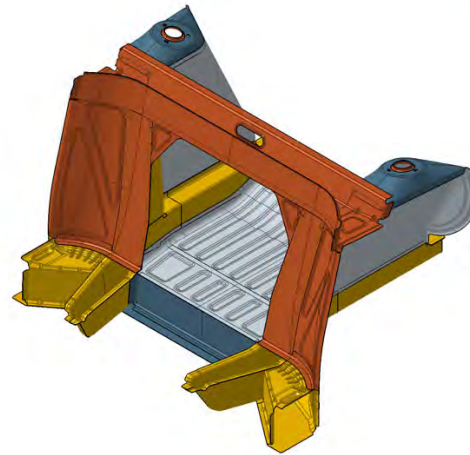


Underbody Rear Zone

| | |
|--|---|
| | Part Number: 0359943 |
| | Part Name: REAR BULKHEAD TURBRET BRACE LOWER ASSEMBLY |
| | Material designation: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|---|
| | Part Number: 0355148 |
| | Part Name: REAR BULKHEAD TURBRET BRACE LOWER ASSEMBLY |
| | Material designation: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|---|
| | Part Number: |
| | Part Name: REAR BULKHEAD TURBRET BRACE LOWER ASSEMBLY |
| | Material designation: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |



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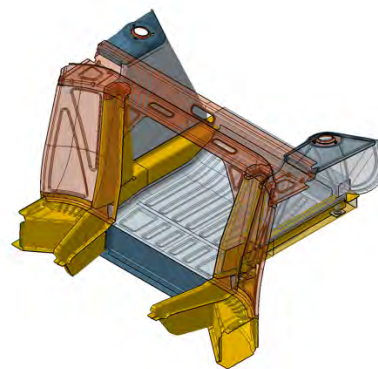


Underbody Rear Zone

| | |
|--|---|
| | Part Number: 0359943 |
| | Part Name: REAR BULKHEAD TURBRET BRACE LOWER ASSEMBLY |
| | Material designation: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|---|
| | Part Number: 0355148 |
| | Part Name: REAR BULKHEAD TURBRET BRACE LOWER ASSEMBLY |
| | Material designation: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|---|
| | Part Number: |
| | Part Name: REAR BULKHEAD TURBRET BRACE LOWER ASSEMBLY |
| | Material designation: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |



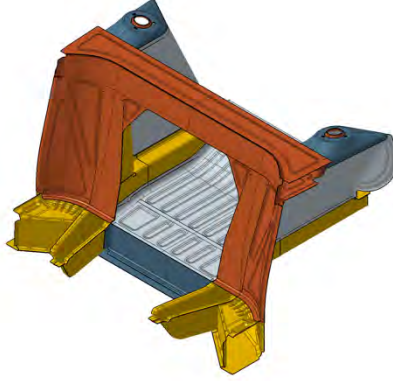
Underbody Rear Zone



| | |
|-----------------------|-----------------------------|
| Part Number | 0301300 |
| Part Name | FRONT CROSS-MEMBER ASSEMBLY |
| Material description | FRONT CROSS-MEMBER ASSEMBLY |
| Material thickness | 4.0 mm |
| Manufacturing process | Stamping |
| Connection technology | Spot Welding |
| Weight | 1.03 kg |
| Coating | |



| | |
|-----------------------|-----------------------------|
| Part Number | 0301300 |
| Part Name | FRONT CROSS-MEMBER ASSEMBLY |
| Material description | FRONT CROSS-MEMBER ASSEMBLY |
| Material thickness | 4.0 mm |
| Manufacturing process | Stamping |
| Connection technology | Spot Welding |
| Weight | 1.03 kg |
| Coating | |



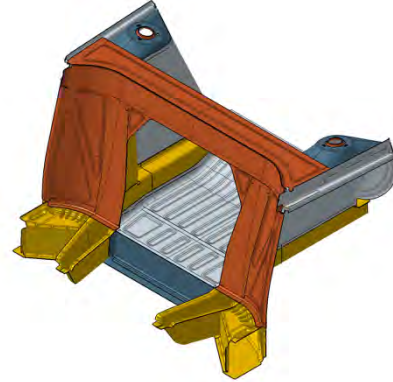
Underbody Rear Zone



| | |
|-----------------------|-----------------------------|
| Part Number | 0301300 |
| Part Name | FRONT CROSS-MEMBER ASSEMBLY |
| Material description | FRONT CROSS-MEMBER ASSEMBLY |
| Material thickness | 4.0 mm |
| Manufacturing process | Stamping |
| Connection technology | Spot Welding |
| Weight | 1.03 kg |
| Coating | |



| | |
|-----------------------|-----------------------------|
| Part Number | 0301300 |
| Part Name | FRONT CROSS-MEMBER ASSEMBLY |
| Material description | FRONT CROSS-MEMBER ASSEMBLY |
| Material thickness | 4.0 mm |
| Manufacturing process | Stamping |
| Connection technology | Spot Welding |
| Weight | 1.03 kg |
| Coating | |



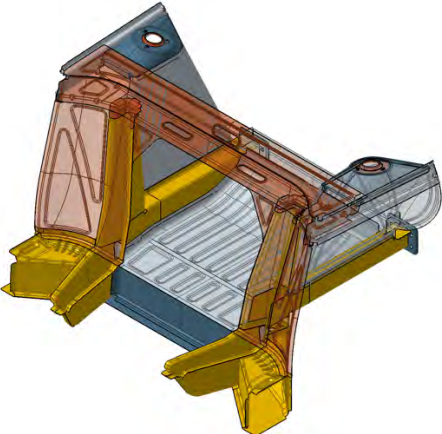
Underbody Rear Zone



| | |
|-----------------------|-----------------------------|
| Part Number | 0301300 |
| Part Name | FRONT CROSS-MEMBER ASSEMBLY |
| Material description | FRONT CROSS-MEMBER ASSEMBLY |
| Material thickness | 4.0 mm |
| Manufacturing process | Stamping |
| Connection technology | Spot Welding |
| Weight | 1.03 kg |
| Coating | |



| | |
|-----------------------|-----------------------------|
| Part Number | 0301300 |
| Part Name | FRONT CROSS-MEMBER ASSEMBLY |
| Material description | FRONT CROSS-MEMBER ASSEMBLY |
| Material thickness | 4.0 mm |
| Manufacturing process | Stamping |
| Connection technology | Spot Welding |
| Weight | 1.03 kg |
| Coating | |



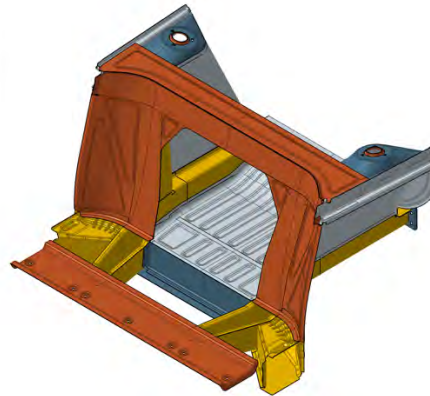
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Underbody Rear Zone

| | |
|--|---|
| | Part Number: 01840400 Part Name: REAR ZONE ASSEMBLY Material description: 01840400-01 Material thickness: 2.0 mm Manufacturing process: Spot Welding / Seam Welding Connection technology: Spot Welding / Seam Welding Weight: 4.002 kg Coating: |
| | Part Number: 01840401 Part Name: REAR ZONE BAR Material description: 01840401-01 Material thickness: 2.0 mm Manufacturing process: Deep Drawing Connection technology: Spot Welding Weight: 4.002 kg Coating: |

| | |
|--|---|
| | Part Number: 01840401 Part Name: REAR ZONE + FOUR BAR ASSEMBLY Material description: 01840401-01 Material thickness: 2.0 mm Manufacturing process: Spot Welding Connection technology: Spot Welding Weight: Coating: |
|--|---|



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Underbody Rear Zone

| | |
|--|--|
| | Part Number: 01840402 Part Name: D FOOT (L) Material description: 01840402-01 Material thickness: 2.2 mm Manufacturing process: Spot Welding Connection technology: Seam Welding Weight: 0.208 kg Coating: |
| | Part Number: 01840402 Part Name: D FOOT ASSEMBLY (L) Material description: 01840402-01 Material thickness: 2.2 mm Manufacturing process: Spot Welding / Seam Welding Connection technology: Seam Welding / Spot Welding Weight: 0.208 kg Coating: |

| | |
|--|---|
| | Part Number: 01840402 Part Name: D FOOT ASSEMBLY (L) Material description: 01840402-01 Material thickness: 2.2 mm Manufacturing process: Spot Welding / Seam Welding Connection technology: Seam Welding / Spot Welding Weight: Coating: |
|--|---|



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Underbody Rear Zone

| | |
|--|--|
| | Part Number: 01840403 Part Name: COACH DOOR LATERAL BAR Material description: 01840403-01 Material thickness: 0.8 mm Manufacturing process: Deep Drawing Connection technology: Seam Welding / Spot Welding Weight: 0.311 kg Coating: |
| | Part Number: 01840404 Part Name: BRACKET COACH DOOR REINER LP Material description: 01840404-01 Material thickness: 1.5 mm Manufacturing process: Spot Welding Connection technology: Spot Welding Weight: 0.206 kg Coating: |

| | |
|--|--|
| | Part Number: 01840403 Part Name: COACH DOOR OUTER REINFORCEMENT ASSEMBLY (L) Material description: 01840403-01 Material thickness: 0.8 mm Manufacturing process: Deep Drawing Connection technology: Seam Welding / Spot Welding Weight: Coating: |
|--|--|



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Underbody Rear Zone

| | |
|--|--------------------------------------|
| | Part Number: 00751710 |
| | Part Name: COACH DOOR LATERAL BAR |
| | Material designation: HPS450D20 |
| | Material thickness: 0.7 mm |
| | Manufacturing process: Laser Welding |
| | Connection technology: Seam Welding |
| | Weight: 1.535 Kg |
| | Coating: |

| | |
|--|--|
| | Part Number: 00751710 |
| | Part Name: COACH DOOR OUTER REINFORCEMENT ASSEMBLY (L) |
| | Material designation: HPS450D20 |
| | Material thickness: 0.7 mm |
| | Manufacturing process: Laser Welding |
| | Connection technology: Seam Welding / Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|--|
| | Part Number: 00751710 |
| | Part Name: COACH DOOR OUTER REINFORCEMENT ASSEMBLY (R) |
| | Material designation: HPS450D20 |
| | Material thickness: 0.7 mm |
| | Manufacturing process: Laser Welding |
| | Connection technology: Seam Welding / Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|--|
| | Part Number: 00751710 |
| | Part Name: COACH DOOR OUTER REINFORCEMENT ASSEMBLY (L) |
| | Material designation: HPS450D20 |
| | Material thickness: 0.7 mm |
| | Manufacturing process: Laser Welding |
| | Connection technology: Seam Welding / Spot Welding |
| | Weight: |
| | Coating: |



Side Assembly

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Side ASSEMBLY

| | |
|--|-------------------------------------|
| | Part Number: 00461553 |
| | Part Name: INNER ROLLER LIP |
| | Material designation: HPS450D20-40S |
| | Material thickness: 1.2 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 0.328 Kg |
| | Coating: |

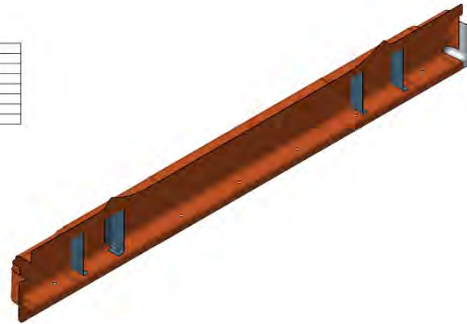
| | |
|--|-------------------------------------|
| | Part Number: 00022146 |
| | Part Name: INNER ROLLER BEARING (L) |
| | Material designation: CR2007001-016 |
| | Material thickness: 1.0 mm |
| | Manufacturing process: Bending |
| | Connection technology: Spot Welding |
| | Weight: 0.297 Kg |
| | Coating: |

| | |
|--|-------------------------------------|
| | Part Number: 00022146 |
| | Part Name: INNER ROLLER BEARING (R) |
| | Material designation: CR2007001-016 |
| | Material thickness: 1.0 mm |
| | Manufacturing process: Bending |
| | Connection technology: Spot Welding |
| | Weight: 0.297 Kg |
| | Coating: |

| | |
|--|--------------------------------------|
| | Part Number: 00262623 |
| | Part Name: ROLLER BEAM CAP INNER (L) |
| | Material designation: HPS450D20 |
| | Material thickness: 1.0 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 0.292 Kg |
| | Coating: |

| | |
|--|--------------------------------------|
| | Part Number: 00262623 |
| | Part Name: ROLLER BEAM CAP INNER (R) |
| | Material designation: HPS450D20 |
| | Material thickness: 1.0 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 0.292 Kg |
| | Coating: |

| | |
|--|--------------------------------------|
| | Part Number: 00461553 |
| | Part Name: INNER ROLLER LIP ASSEMBLY |
| | Material designation: HPS450D20-40S |
| | Material thickness: 1.2 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |



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Side ASSEMBLY

| | |
|--|---|
| | Part Number: 02680053 |
| | Part Name: GLANCE REAR UPPER TRIMMAGATION |
| | Material designation: HPS450D20 |
| | Material thickness: 1.0 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 0.893 Kg |
| | Coating: |

| | |
|--|-------------------------------------|
| | Part Number: 02680052 |
| | Part Name: GLANCE REAR INNER (L) |
| | Material designation: HPS450D20-016 |
| | Material thickness: 1.0 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 1.183 Kg |
| | Coating: |

| | |
|--|-------------------------------------|
| | Part Number: 00724993 |
| | Part Name: GLANCE REAR CAP (L) |
| | Material designation: CR2007001-016 |
| | Material thickness: 1.0 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 0.178 Kg |
| | Coating: |

| | |
|--|-------------------------------------|
| | Part Number: 02680052 |
| | Part Name: GLANCE REAR INNER (R) |
| | Material designation: HPS450D20-016 |
| | Material thickness: 1.0 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |



Side ASSEMBLY



| | |
|--|---|
| | Part Number: 0303004 |
| | Part Name: FRONT OUTER ROOF HEADER GUSSET |
| | Material description: MCR02112 |
| | Material thickness: 0.8 mm |
| | Material description: CR700M021 EP |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 0.220 kg |
| | Coating: |

| | |
|--|--|
| | Part Number: |
| | Part Name: FRONT ROOF HEADER GUSSET MOUNT ASSEMBLY |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

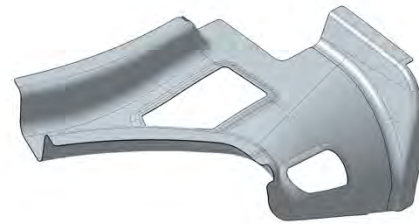


Side ASSEMBLY



| | |
|--|--|
| | Part Number: 0303005 |
| | Part Name: REAR OUTER ROOF HEADER GUSSET |
| | Material description: MCR02112 |
| | Material thickness: 0.8 mm |
| | Material description: CR700M021 EP |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 0.145 kg |
| | Coating: |

| | |
|--|---|
| | Part Number: |
| | Part Name: REAR ROOF HEADER GUSSET MOUNT ASSEMBLY |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |



Side ASSEMBLY



| | |
|--|---------------------------------------|
| | Part Number: 0303042 |
| | Part Name: ROOF SIDE RAIL INNER LINER |
| | Material description: PMS-CL-00071 AB |
| | Material thickness: 0.8 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 2.244 kg |
| | Coating: |

| | |
|--|--|
| | Part Number: 0303041 |
| | Part Name: C-POD INNER REINFORCEMENT UPPER |
| | Material description: 1.180011L011 EP |
| | Material thickness: 1.5 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 1.224 kg |
| | Coating: |

| | |
|--|--|
| | Part Number: |
| | Part Name: ROOF SIDE RAIL INNER ASSEMBLY KIT |
| | Material description: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|--|
| | Part Number: 0303040 |
| | Part Name: C-POD INNER REINFORCEMENT UPPER |
| | Material description: 1.180011L011 EP |
| | Material thickness: 1.5 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding |
| | Weight: 1.227 kg |
| | Coating: |



Side ASSEMBLY

| | | |
|--|-----------------------|------------------------------|
| | Part Number | 0075815 |
| | Part Name | REINFORCEMENT LATCH COVER LH |
| | Material description | FRS-CL0007 AM |
| | Material thickness | 1.5 mm |
| | Manufacturing process | Deep Drawing |
| | Connection technology | Spot Welding |
| | Weight | 0.022 Kg |
| | Coating | |

| | | |
|--|-----------------------|----------------------------|
| | Part Number | 0075830 |
| | Part Name | A FOOT BLEND HEAD COVER LH |
| | Material description | FRS-CL0007 AM |
| | Material thickness | 1.5 mm |
| | Manufacturing process | Bending |
| | Connection technology | Spot Welding |
| | Weight | 0.179 Kg |
| | Coating | |

| | | |
|--|-----------------------|-----------------------------|
| | Part Number | 0075843 |
| | Part Name | REINFORCEMENT DOOR LATCH LH |
| | Material description | FRS-CL0007 AM |
| | Material thickness | 1.5 mm |
| | Manufacturing process | Deep Drawing |
| | Connection technology | Spot Welding |
| | Weight | 0.148 Kg |
| | Coating | |

| | | |
|--|-----------------------|------------------------|
| | Part Number | |
| | Part Name | DOOR LATCH ASSEMBLY LH |
| | Material description | |
| | Material thickness | |
| | Manufacturing process | |
| | Connection technology | Spot Welding |
| | Weight | |
| | Coating | |



Side ASSEMBLY

| | | |
|--|-----------------------|-------------------------------|
| | Part Number | 0076003 |
| | Part Name | A FOOT INNER REINFORCEMENT LH |
| | Material description | FRS-CL0007 AM |
| | Material thickness | 1.5 mm |
| | Manufacturing process | Deep Drawing |
| | Connection technology | Spot Welding |
| | Weight | 1.791 Kg |
| | Coating | |

| | | |
|--|-----------------------|---------------------------------------|
| | Part Number | 0076071 |
| | Part Name | B BLEND A FOOT REINFORCEMENT COVER LH |
| | Material description | FRS-CL0007 AM |
| | Material thickness | 1.5 mm |
| | Manufacturing process | Deep Drawing |
| | Connection technology | Spot Welding |
| | Weight | 0.042 Kg |
| | Coating | |

| | | |
|--|-----------------------|---------------------------------------|
| | Part Number | 0076063 |
| | Part Name | B BLEND A FOOT REINFORCEMENT COVER LH |
| | Material description | FRS-CL0007 AM |
| | Material thickness | 1.5 mm |
| | Manufacturing process | Deep Drawing |
| | Connection technology | Spot Welding |
| | Weight | 0.044 Kg |
| | Coating | |

| | | |
|--|-----------------------|------------------------|
| | Part Number | |
| | Part Name | DOOR LATCH ASSEMBLY LH |
| | Material description | |
| | Material thickness | |
| | Manufacturing process | |
| | Connection technology | Spot Welding |
| | Weight | |
| | Coating | |

| | | |
|--|-----------------------|--|
| | Part Number | |
| | Part Name | A FOOT INNER REINFORCEMENT ASSEMBLY LH |
| | Material description | |
| | Material thickness | |
| | Manufacturing process | |
| | Connection technology | Spot Welding |
| | Weight | |
| | Coating | |



Side ASSEMBLY

| | | |
|--|-----------------------|-----------------------------|
| | Part Number | 0046099 |
| | Part Name | C FOOT INNER LH |
| | Material description | FRS-CL0007 AM |
| | Material thickness | 1.2 mm |
| | Manufacturing process | Deep Drawing |
| | Connection technology | Spot Welding / Seam Welding |
| | Weight | 4.817 Kg |
| | Coating | |

| | | |
|--|-----------------------|-----------------|
| | Part Number | 0046099 |
| | Part Name | D FOOT INNER LH |
| | Material description | FRS-CL0007 AM |
| | Material thickness | 0.8 mm |
| | Manufacturing process | Deep Drawing |
| | Connection technology | Spot Welding |
| | Weight | 0.432 Kg |
| | Coating | |

| | | |
|--|-----------------------|---------------------------------------|
| | Part Number | 0076043 |
| | Part Name | B BLEND A FOOT REINFORCEMENT COVER LH |
| | Material description | FRS-CL0007 AM |
| | Material thickness | 1.5 mm |
| | Manufacturing process | Deep Drawing |
| | Connection technology | Spot Welding |
| | Weight | 0.034 Kg |
| | Coating | |

| | | |
|--|-----------------------|--------------------|
| | Part Number | |
| | Part Name | C FOOT ASSEMBLY LH |
| | Material description | |
| | Material thickness | |
| | Manufacturing process | |
| | Connection technology | Spot Welding |
| | Weight | |
| | Coating | |



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Side ASSEMBLY

| | |
|--|---|
| | Part Number: INNER ROCKER L11 ASSEMBLY Material description: 22MnCr5 Material thickness: 2.2 mm Manufacturing process: Laser Driveline Connection technology: Spot Welding Weight: 5.056 kg Coating: - |
| | Part Number: A1021 INNER L11 Material description: 22MnCr5 Material thickness: 2.2 mm Manufacturing process: Laser Driveline Connection technology: Spot Welding / Seam Welding Weight: 5.056 kg Coating: - |
| | Part Number: C1021 ASSEMBLY L11 Material description: 22MnCr5 Material thickness: 2.2 mm Manufacturing process: Laser Driveline Connection technology: Spot Welding Weight: - Coating: - |
| | Part Number: ROOF SIDE RAIL INNER ASSEMBLY L11 Material description: 22MnCr5 Material thickness: 2.2 mm Manufacturing process: Laser Driveline Connection technology: Spot Welding Weight: - Coating: - |

| | |
|--|---|
| | Part Number: INNER SIDE FRAME ASSEMBLY L11 Material description: 22MnCr5 Material thickness: 2.2 mm Manufacturing process: Laser Driveline Connection technology: Spot Welding Weight: - Coating: - |
|--|---|



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Side ASSEMBLY

| | |
|--|--|
| | Part Number: INNER SIDE FRAME ASSEMBLY L11 Material description: 22MnCr5 Material thickness: 2.2 mm Manufacturing process: Laser Driveline Connection technology: Spot Welding Weight: - Coating: - |
| | Part Number: INNER GLANCE BEAM ASSEMBLY L11 Material description: 22MnCr5 Material thickness: 2.2 mm Manufacturing process: Laser Driveline Connection technology: Spot Welding Weight: - Coating: - |

| | |
|--|---|
| | Part Number: INNER SIDE ASSEMBLY L11 Material description: 22MnCr5 Material thickness: 2.2 mm Manufacturing process: Laser Driveline Connection technology: Spot Welding Weight: - Coating: - |
|--|---|



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Side ASSEMBLY

| | |
|--|--|
| | Part Number: 0000000 Part Name: INNER SIDE ASSEMBLY LP Material designation: S275SR Material thickness: 1.5 mm Manufacturing process: Deep Drawing Connection technology: Spot Welding / Seam Welding Weight: 0.24 kg Coating: Galvalume |
| | Part Number: 0000000 Part Name: FRONT ROOF RIBS/DOOR RIBS/REAR ASSEMBLY LP Material designation: S275SR Material thickness: 1.5 mm Manufacturing process: Deep Drawing Connection technology: Spot Welding Weight: 0.24 kg Coating: Galvalume |
| | Part Number: 0000000 Part Name: REAR ROOF RIBS/DOOR RIBS/REAR ASSEMBLY LP Material designation: S275SR Material thickness: 1.5 mm Manufacturing process: Deep Drawing Connection technology: Spot Welding Weight: 0.24 kg Coating: Galvalume |
| | Part Number: 0000000 Part Name: WIND ROOF BEAM MOUNT LP Material designation: S275SR Material thickness: 1.5 mm Manufacturing process: Deep Drawing Connection technology: Spot Welding / Seam Welding Weight: 0.24 kg Coating: Galvalume |
| | Part Number: 0000000 Part Name: A-POST INNER ASSEMBLY LP Material designation: S275SR Material thickness: 1.5 mm Manufacturing process: Deep Drawing Connection technology: Spot Welding / Seam Welding Weight: 0.24 kg Coating: Galvalume |
| | Part Number: 0000000 Part Name: C-POST INNER REINFORCEMENT LP Material designation: S275SR Material thickness: 1.5 mm Manufacturing process: Deep Drawing Connection technology: Spot Welding Weight: 0.24 kg Coating: Galvalume |

| | |
|--|--|
| | Part Number: 0000000 Part Name: WIND ROOF BEAM MOUNT LP Material designation: S275SR Material thickness: 1.5 mm Manufacturing process: Deep Drawing Connection technology: Spot Welding / Seam Welding Weight: 0.24 kg Coating: Galvalume |
|--|--|



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Side ASSEMBLY

| | |
|--|--|
| | Part Number: 0000000 Part Name: WIND ROOF BEAM MOUNT LP Material designation: S275SR Material thickness: 1.5 mm Manufacturing process: Deep Drawing Connection technology: Spot Welding / Seam Welding Weight: 0.24 kg Coating: Galvalume |
| | Part Number: 0000000 Part Name: BUSH ROD C. PULLER MIDDLE LP Material designation: S275SR Material thickness: 1.5 mm Manufacturing process: Deep Drawing Connection technology: Spot Welding Weight: 0.24 kg Coating: Galvalume |
| | Part Number: 0000000 Part Name: BUSH ROD C. PULLER END LP Material designation: S275SR Material thickness: 1.5 mm Manufacturing process: Deep Drawing Connection technology: Spot Welding Weight: 0.24 kg Coating: Galvalume |
| | Part Number: 0000000 Part Name: SLANG BEAM BUSH ROD 431 Material designation: S275SR Material thickness: 1.5 mm Manufacturing process: Deep Drawing Connection technology: Spot Welding / Seam Welding Weight: 0.24 kg Coating: Galvalume |
| | Part Number: 0000000 Part Name: BUSH ROD BUSH ROD 431 Material designation: S275SR Material thickness: 1.5 mm Manufacturing process: Deep Drawing Connection technology: Spot Welding Weight: 0.24 kg Coating: Galvalume |

| | |
|--|---|
| | Part Number: 0000000 Part Name: WIND ROOF BEAM MOUNT LP Material designation: S275SR Material thickness: 1.5 mm Manufacturing process: Deep Drawing Connection technology: Spot Welding Weight: 0.24 kg Coating: Galvalume |
|--|---|



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Side ASSEMBLY

| | |
|--|--|
| | Part Number: 0000000 Part Name: ROOF RIBS/DOOR RIBS/REAR ASSEMBLY LP Material designation: S275SR Material thickness: 1.5 mm Manufacturing process: Deep Drawing Connection technology: Spot Welding Weight: 0.24 kg Coating: Galvalume |
| | Part Number: 0000000 Part Name: WIND ROOF BEAM MOUNT LP Material designation: S275SR Material thickness: 1.5 mm Manufacturing process: Deep Drawing Connection technology: Spot Welding / Seam Welding Weight: 0.24 kg Coating: Galvalume |

| | |
|--|--|
| | Part Number: 0000000 Part Name: ROOF RIBS/DOOR RIBS/REAR ASSEMBLY LP Material designation: S275SR Material thickness: 1.5 mm Manufacturing process: Deep Drawing Connection technology: Spot Welding Weight: 0.24 kg Coating: Galvalume |
|--|--|



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Side ASSEMBLY



| | |
|--|---|
| | Part Number: FRONT BLOCK INNER BEAM ASSEMBLY Part Name: FRONT BLOCK INNER BEAM ASSEMBLY Material description: FR Material thickness: 2.0mm Manufacturing process: Spot Welding Connection technology: Spot Weight: 1.200 Kg Coating: |
| | Part Number: MAIN SIDE UPPER CROSSMEMBER & SIDE ASSEMBLY - REINFORCEMENT L/R Part Name: MAIN SIDE UPPER CROSSMEMBER & SIDE ASSEMBLY - REINFORCEMENT L/R Material description: FR Material thickness: 2.0mm Manufacturing process: Spot Welding Connection technology: Spot Welding / Glue Weight: Coating: |

| | |
|--|--|
| | Part Number: MAIN SIDE UPPER CROSSMEMBER & SIDE ASSEMBLY - REINFORCEMENT L/R Part Name: MAIN SIDE UPPER CROSSMEMBER & SIDE ASSEMBLY - REINFORCEMENT L/R Material description: FR Material thickness: 2.0mm Manufacturing process: Spot Welding / Glue Connection technology: Spot Welding / Glue Weight: Coating: |
|--|--|



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Side ASSEMBLY



| | |
|--|---|
| | Part Number: Q80005 Part Name: QUANCE BEAM UPPER REINFORCEMENT Material description: FR 0.500 Material thickness: 2.0mm Manufacturing process: Deep Drawing Connection technology: Spot Welding Weight: 1.200 Kg Coating: |
| | Part Number: Q80007 Part Name: QUANCE BEAM REINFORCEMENT Material description: FR 0.500 and FR0500 Material thickness: 2.0mm Manufacturing process: Deep Drawing Connection technology: Spot Welding Weight: 2.250 Kg Coating: |
| | Part Number: Q87003 Part Name: QUANCE BEAM REINFORCEMENT L/R Material description: Q8A207007 GP Material thickness: 2.0mm Manufacturing process: Deep Drawing Connection technology: Spot Welding Weight: 0.200 Kg Coating: |
| | Part Number: Q87004 Part Name: QUANCE BEAM REINFORCEMENT L/R Material description: Q8A207007 GP Material thickness: 2.0mm Manufacturing process: Deep Drawing Connection technology: Spot Welding Weight: 0.240 Kg Coating: |
| | Part Number: Q87005 Part Name: QUANCE BEAM REINFORCEMENT L/R Material description: Q8A207007 GP Material thickness: 2.0mm Manufacturing process: Deep Drawing Connection technology: Spot Welding Weight: 0.200 Kg Coating: |

| | |
|--|--|
| | Part Number: Q87006 Part Name: OUTER QUANCE BEAM ASSEMBLY L/R Material description: Material thickness: Manufacturing process: Connection technology: Spot Welding Weight: Coating: |
|--|--|

| | |
|--|--|
| | Part Number: Q87008 Part Name: QUANCE BEAM REINFORCEMENT L/R Material description: Q8A207007 GP Material thickness: 2.0mm Manufacturing process: Deep Drawing Connection technology: Spot Welding Weight: 0.200 Kg Coating: |
|--|--|

| | |
|--|--|
| | Part Number: Q87009 Part Name: QUANCE BEAM REINFORCEMENT L/R Material description: Q8A207007 GP Material thickness: 2.0mm Manufacturing process: Deep Drawing Connection technology: Spot Welding Weight: 0.240 Kg Coating: |
|--|--|

| | |
|--|--|
| | Part Number: Q87010 Part Name: QUANCE BEAM REINFORCEMENT L/R Material description: Q8A207007 GP Material thickness: 2.0mm Manufacturing process: Deep Drawing Connection technology: Spot Welding Weight: 0.200 Kg Coating: |
|--|--|



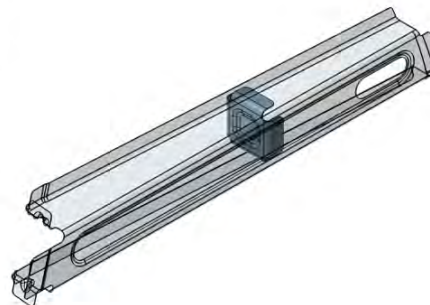
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Side ASSEMBLY



| | |
|--|---|
| | Part Number: Q07000 Part Name: UPPER RAIL OUTER REF Material description: FR0400000 Material thickness: 1.2 mm Manufacturing process: Deep Drawing / Bending Connection technology: Spot Welding Weight: 1.000 Kg Coating: |
| | Part Number: Q07001 Part Name: UPPER RAIL OUTER REF ASSEMBLY L/R Material description: Q8A207007 GP Material thickness: 2.0mm Manufacturing process: Deep Drawing / Bending Connection technology: Glue / Spot Welding Weight: 0.200 Kg Coating: |

| | |
|--|---|
| | Part Number: Q07001 Part Name: UPPER RAIL OUTER REF ASSEMBLY L/R Material description: Material thickness: Manufacturing process: Connection technology: Spot Welding Weight: Coating: |
|--|---|



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Side ASSEMBLY

| | |
|--|--|
| | Part Number: 0308499 |
| | Part Name: CUTTER RING PART 01 |
| | Material designation: TUB PRO 2002 / EP 802/2180 |
| | Material thickness: 2.0mm / 2.1mm / 2.0mm |
| | Manufacturing process: Sheet Drawing |
| | Connection technology: Glue / Spot Welding |
| | Weight: 26.27kg |
| | Coating: |

| | |
|--|---|
| | Part Number: |
| | Part Name: CUTTER GLANCE BEAM ASSEMBLY 01 |
| | Material designation: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|---|
| | Part Number: |
| | Part Name: UPPER RAIL CUTTER BEAM ASSEMBLY 01 |
| | Material designation: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|---------------------------------------|
| | Part Number: 0314265 |
| | Part Name: CUTTER FRAME BEAM PLATE 01 |
| | Material designation: C235/C275/EP |
| | Material thickness: 2 mm |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: 6.075 kg |
| | Coating: |

| | |
|--|--|
| | Part Number: |
| | Part Name: SIDE CUTTER ASSEMBLY 01 |
| | Material designation: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding / Seam Welding |
| | Weight: |
| | Coating: |



Roof Assembly

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Roof ASSEMBLY

| | |
|--|--|
| | Part Number: 0308114 |
| | Part Name: DIAGONAL INNER PANEL REAR 01 |
| | Material designation: HSA 510/500 |
| | Material thickness: 0.8 mm |
| | Manufacturing process: Sheet Drawing |
| | Connection technology: Spot Welding / Seam Welding |
| | Weight: 1.376 kg |
| | Coating: |

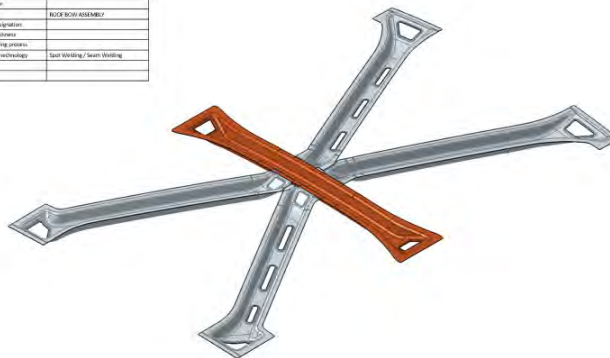
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|--|--|
| | Part Number: 0308173 |
| | Part Name: DIAGONAL INNER PANEL FRONT 01 |
| | Material designation: HSA 510/500 |
| | Material thickness: 0.8 mm |
| | Manufacturing process: Sheet Drawing |
| | Connection technology: Spot Welding / Seam Welding |
| | Weight: 1.472 kg |
| | Coating: |

| | |
|--|--|
| | Part Number: 0311588 |
| | Part Name: DIAGONAL INNER PANEL REAR 01 |
| | Material designation: HSA 510/500 |
| | Material thickness: 0.8 mm |
| | Manufacturing process: Sheet Drawing |
| | Connection technology: Spot Welding / Seam Welding |
| | Weight: 1.376 kg |
| | Coating: |

| | |
|--|--|
| | Part Number: 0311895 |
| | Part Name: DIAGONAL INNER PANEL FRONT 01 |
| | Material designation: HSA 510/500 |
| | Material thickness: 0.8 mm |
| | Manufacturing process: Sheet Drawing |
| | Connection technology: Spot Welding / Seam Welding |
| | Weight: 1.472 kg |
| | Coating: |

| | |
|--|--|
| | Part Number: 0302778 |
| | Part Name: RIB RAIL BEAM |
| | Material designation: CR420/1.187-AS |
| | Material thickness: 0.8 mm |
| | Manufacturing process: Sheet Drawing |
| | Connection technology: Spot Welding / Seam Welding |
| | Weight: 1.765 kg |
| | Coating: |

| | |
|--|--|
| | Part Number: |
| | Part Name: ROOF BEAM ASSEMBLY |
| | Material designation: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding / Seam Welding |
| | Weight: |
| | Coating: |



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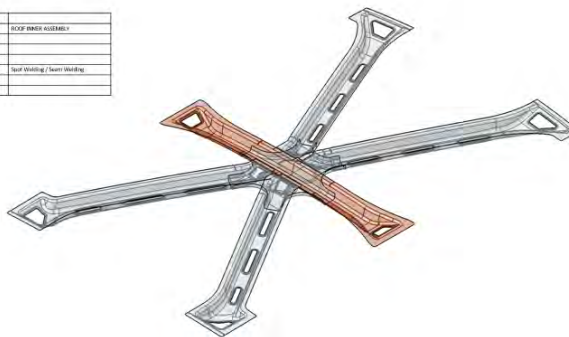


Roof ASSEMBLY

| | |
|--|--|
| | Part Number: 0301234 |
| | Part Name: ROOF REAR SECTION INNER PANEL |
| | Material designation: HSA 510/500 |
| | Material thickness: 0.8 mm |
| | Manufacturing process: Sheet Drawing |
| | Connection technology: Spot Welding |
| | Weight: 1.039 kg |
| | Coating: |

| | |
|--|-------------------------------------|
| | Part Number: |
| | Part Name: ROOF BEAM ASSEMBLY |
| | Material designation: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding |
| | Weight: |
| | Coating: |

| | |
|--|--|
| | Part Number: |
| | Part Name: ROOF BEAM ASSEMBLY |
| | Material designation: |
| | Material thickness: |
| | Manufacturing process: |
| | Connection technology: Spot Welding / Seam Welding |
| | Weight: |
| | Coating: |



Roof ASSEMBLY

| | |
|-----------------------|-----------------------------|
| Part Number | 0167000 |
| Part Name | ROOF RIBBED ASSEMBLY |
| Material designation | |
| Material thickness | |
| Manufacturing process | |
| Connection technology | Spot Welding / Seam Welding |
| Weight | |
| Coating | |

| | |
|-----------------------|-----------------------------|
| Part Number | 0167000 |
| Part Name | REAR HEADER INNER LIFT |
| Material designation | CP 300M087 CP |
| Material thickness | 0.8 mm |
| Manufacturing process | Deep Drawing |
| Connection technology | Spot Welding / Seam Welding |
| Weight | 1.045 kg |
| Coating | |

| | |
|-----------------------|-----------------------------|
| Part Number | 0167000 |
| Part Name | FRONT HEADER INNER RIB |
| Material designation | CP 300M087 CP |
| Material thickness | 0.8 mm |
| Manufacturing process | Deep Drawing |
| Connection technology | Spot Welding / Seam Welding |
| Weight | 1.075 kg |
| Coating | |

| | |
|-----------------------|-----------------------------|
| Part Number | |
| Part Name | ROOF INNER RIBS ASSEMBLY |
| Material designation | |
| Material thickness | |
| Manufacturing process | |
| Connection technology | Spot Welding / Seam Welding |
| Weight | |
| Coating | |



Roof ASSEMBLY

| | |
|-----------------------|--------------------------------------|
| Part Number | 0167000 |
| Part Name | FRONTAL OUTER SURFACE PANEL FRONT LH |
| Material designation | CA300/170T 80 |
| Material thickness | 0.6 mm |
| Manufacturing process | |
| Connection technology | Spot Welding / Seam Welding |
| Weight | 0.785 kg |
| Coating | |

| | |
|-----------------------|-------------------------------------|
| Part Number | 0167000 |
| Part Name | FRONTAL OUTER SURFACE PANEL REAR LH |
| Material designation | CA300/170T 80 |
| Material thickness | 0.6 mm |
| Manufacturing process | |
| Connection technology | Spot Welding / Seam Welding |
| Weight | 0.805 kg |
| Coating | |

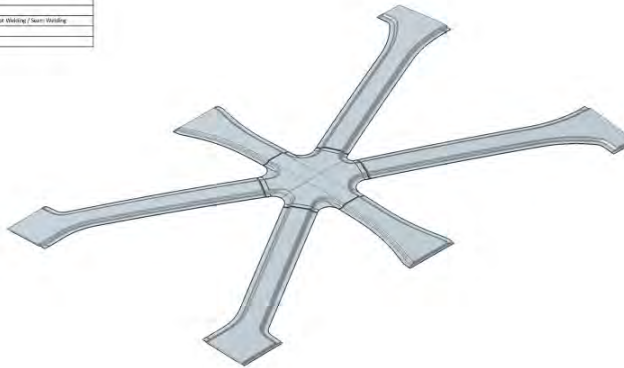
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|-----------------------|--|
| Part Number | 0167000 |
| Part Name | RHD INTERSECTION OUTER A SURFACE PANEL |
| Material designation | CA300/170T 80 |
| Material thickness | 0.6 mm |
| Manufacturing process | |
| Connection technology | Spot Welding / Seam Welding |
| Weight | 0.834 kg |
| Coating | |

| | |
|-----------------------|-------------------------------------|
| Part Number | 0167000 |
| Part Name | FRONTAL OUTER SURFACE PANEL REAR RH |
| Material designation | CA300/170T 80 |
| Material thickness | 0.6 mm |
| Manufacturing process | |
| Connection technology | Spot Welding / Seam Welding |
| Weight | 0.829 kg |
| Coating | |

| | |
|-----------------------|--------------------------------------|
| Part Number | 0167000 |
| Part Name | FRONTAL OUTER SURFACE PANEL FRONT RH |
| Material designation | CA300/170T 80 |
| Material thickness | 0.6 mm |
| Manufacturing process | |
| Connection technology | Spot Welding / Seam Welding |
| Weight | 0.795 kg |
| Coating | |

| | |
|-----------------------|------------------------------------|
| Part Number | 0167000 |
| Part Name | FRONT HEADER OUTER A SURFACE PANEL |
| Material designation | CA300/170T 80 |
| Material thickness | 0.6 mm |
| Manufacturing process | |
| Connection technology | Spot Welding / Seam Welding |
| Weight | 1.045 kg |
| Coating | |

| | |
|-----------------------|-----------------------------|
| Part Number | |
| Part Name | ROOF OUTER ASSEMBLY |
| Material designation | |
| Material thickness | |
| Manufacturing process | |
| Connection technology | Spot Welding / Seam Welding |
| Weight | |
| Coating | |



Roof ASSEMBLY

| | |
|---|--|
|  | Part Number: 03476550 |
| | Part Name: FRONT HEADER EXTERIOR SURFACE |
| | Material description: EN20D/1.03F 40L |
| | Material thickness: 0.8 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding / Seam Welding |
| | Weight: 1.25 kg |
| | Cloning: |

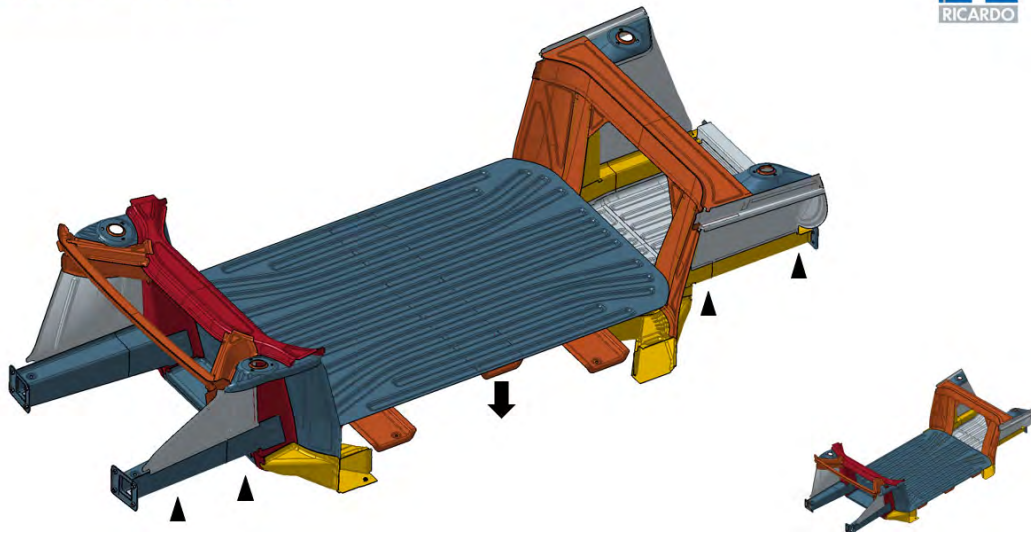


| | |
|---|--|
|  | Part Number: 03476570 |
| | Part Name: REAR HEADER EXTERIOR SURFACE |
| | Material description: EN20D/1.03F 40L |
| | Material thickness: 0.8 mm |
| | Manufacturing process: Deep Drawing |
| | Connection technology: Spot Welding / Seam Welding |
| | Weight: 1.20 kg |
| | Cloning: |

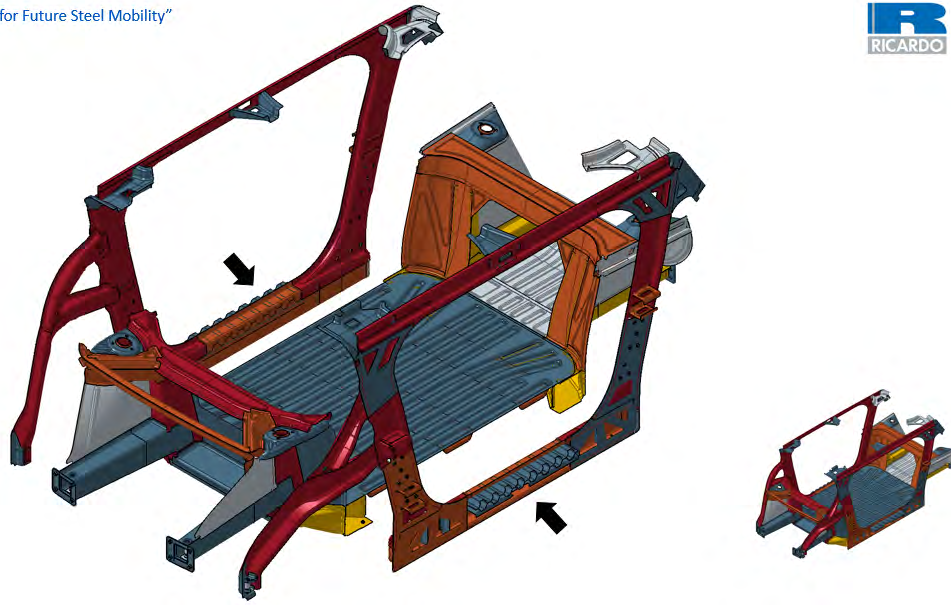


General Assembly

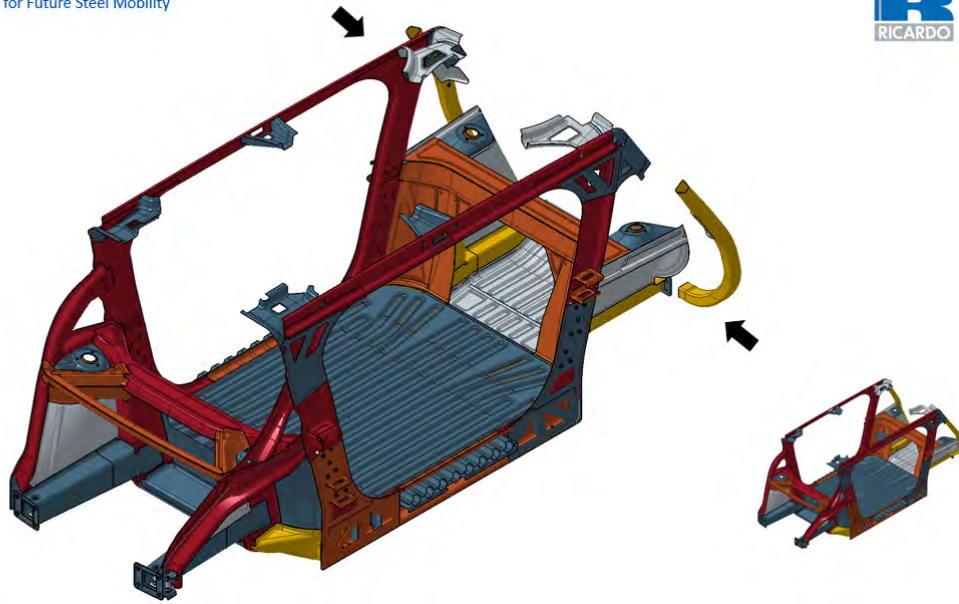
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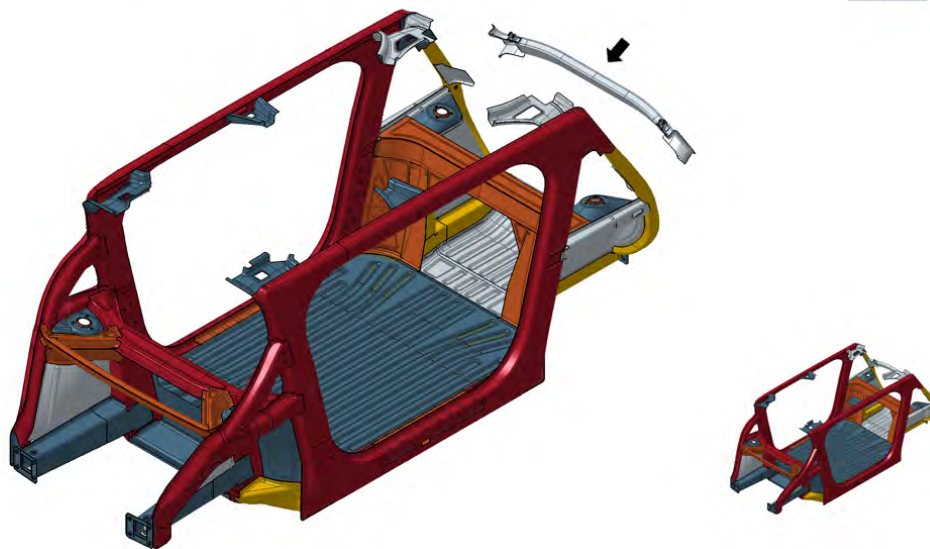
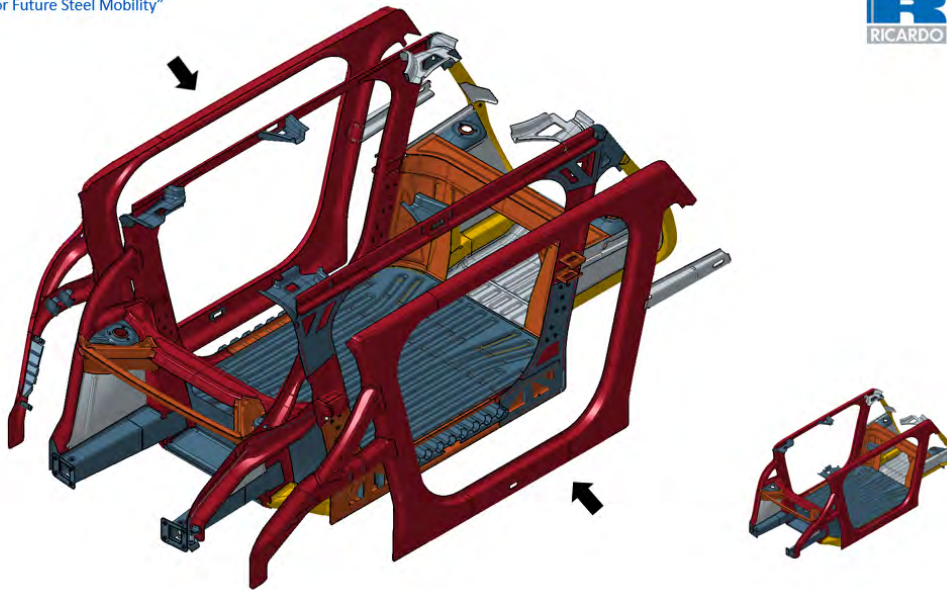


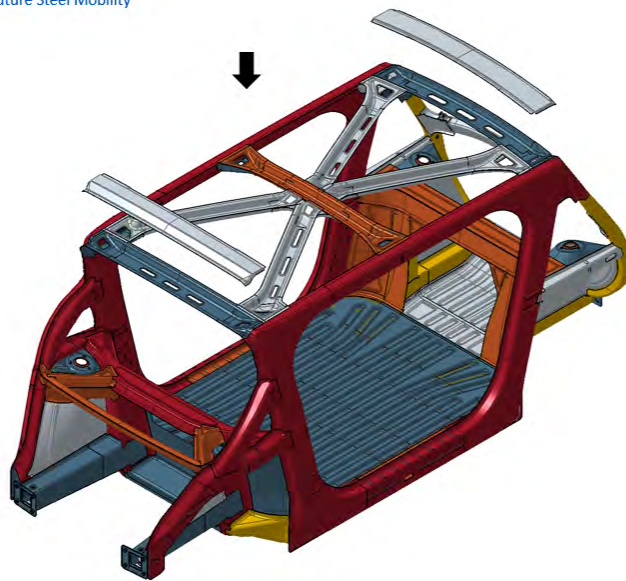
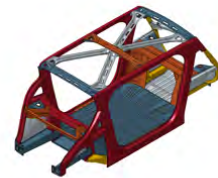
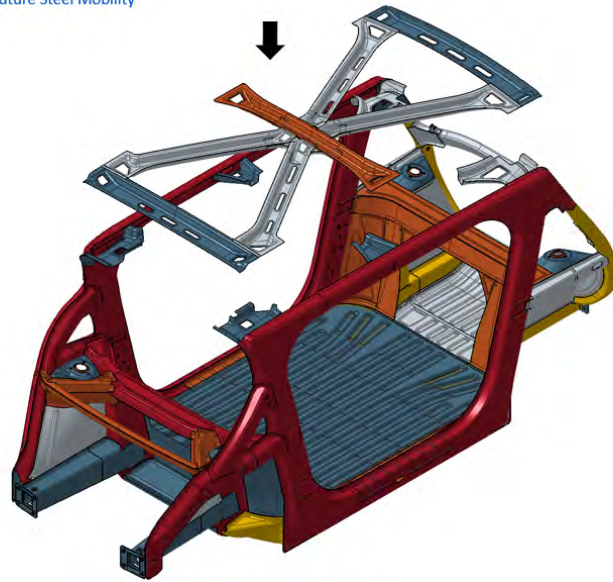
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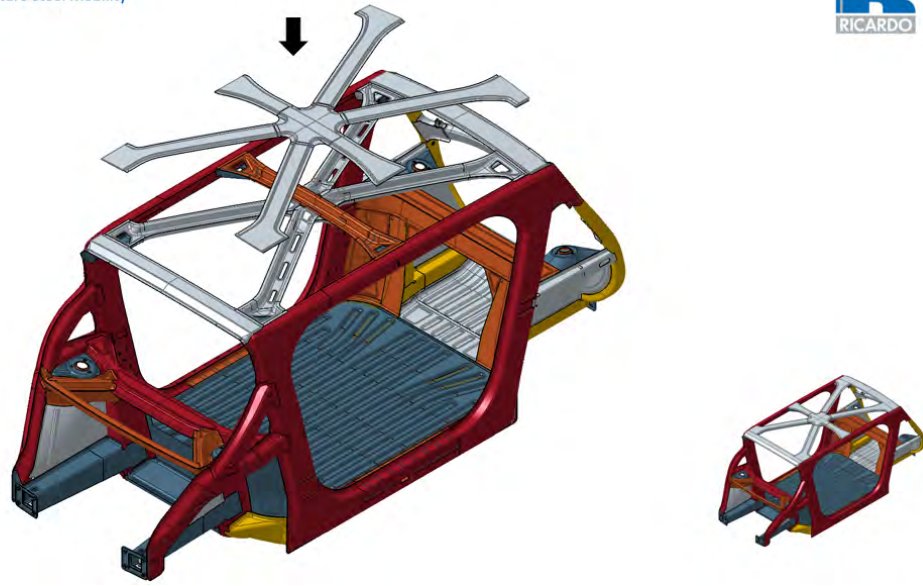
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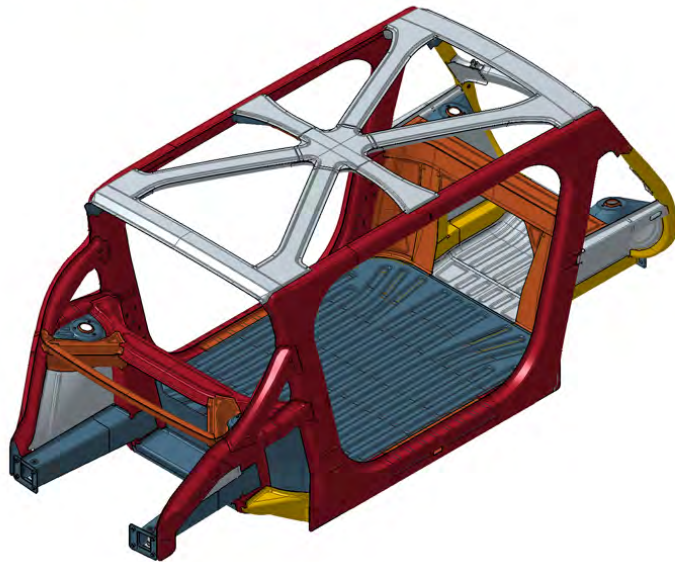




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Appendix 4 Full size images and figures

Figure 3.4.1 Autonomous vehicle and Mobility as a Service roadmap

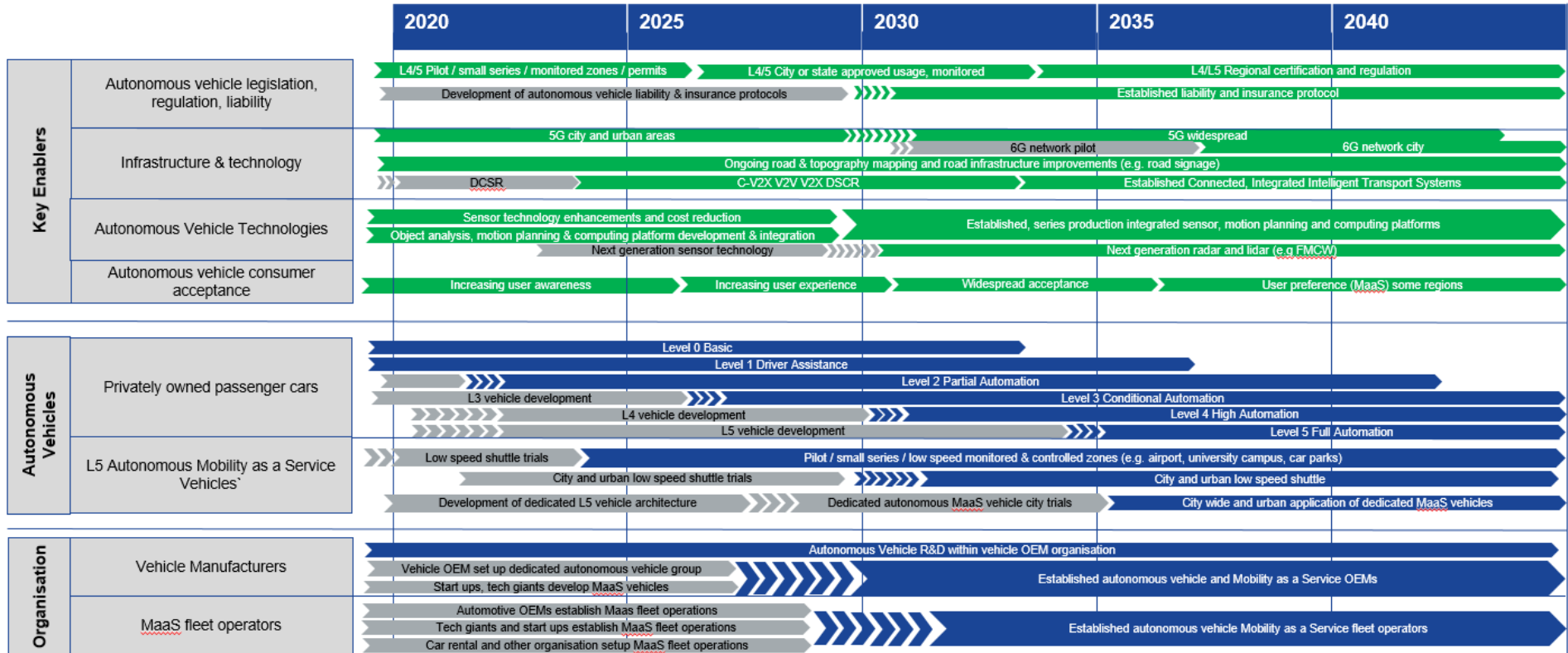


Figure 6.2.5.1.1 Extracts from creative design poll questions and response

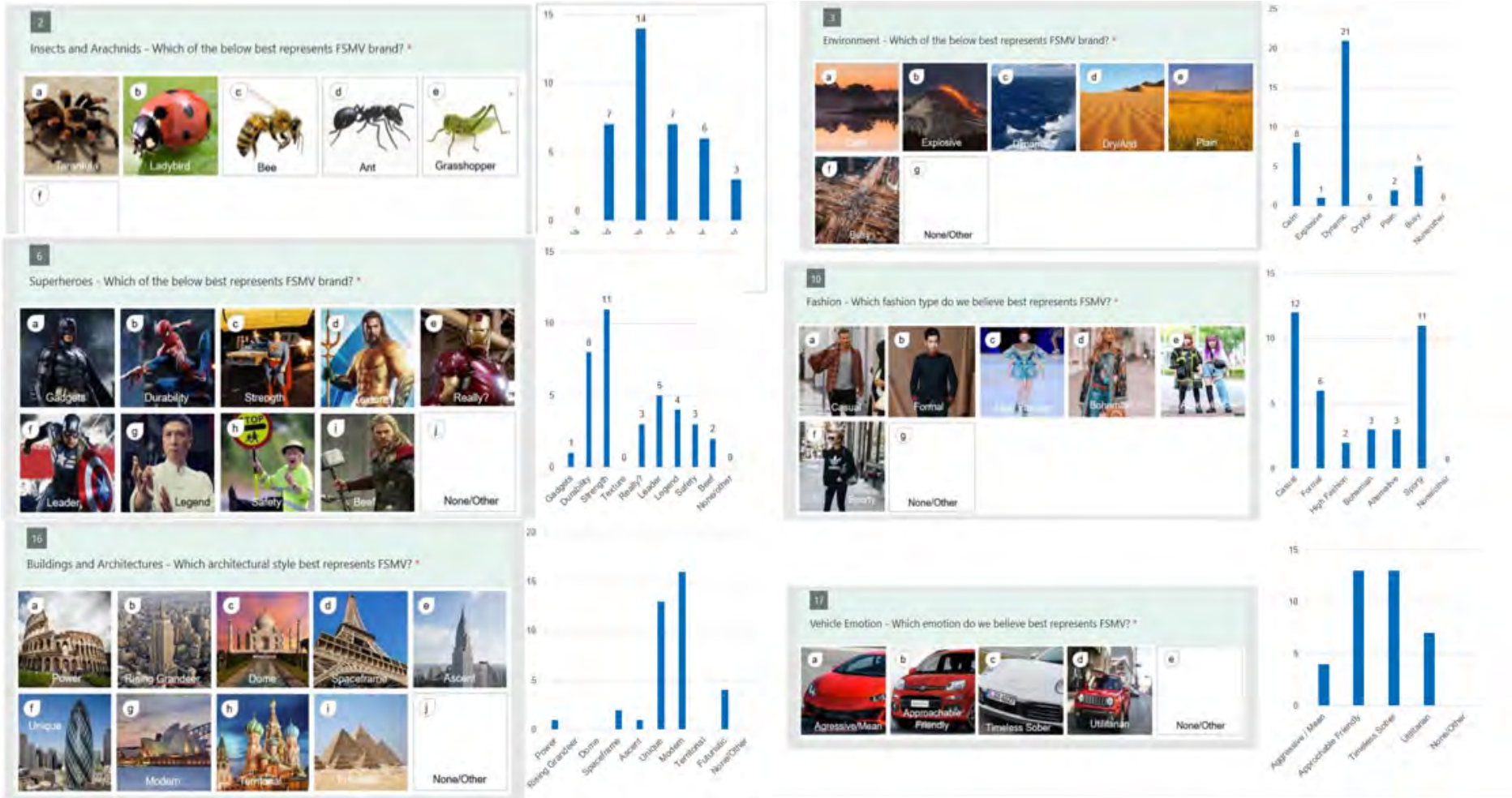


Figure 6.2.5.1.6 Engineering appraisal of 3 selected concepts

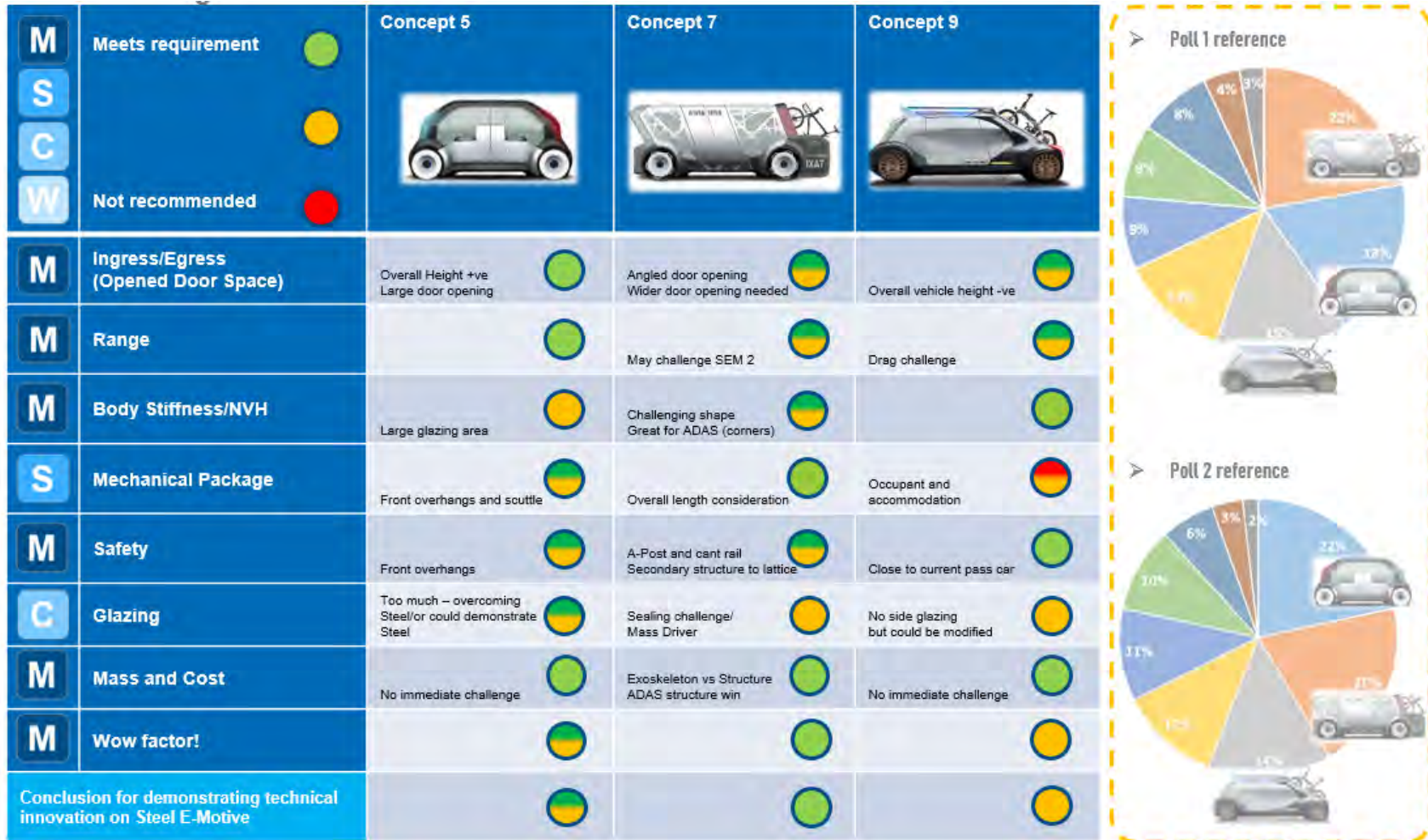


Figure 6.3.3.3 Front crash structure FEA concept design studies evaluating longitudinal crush rail and front subframe configurations

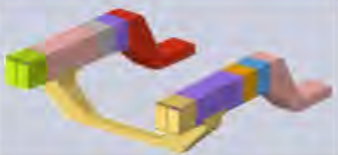

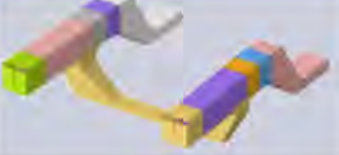


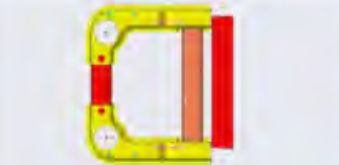

| | | | Concept 1 | Concept 3a | Concept 3b | Concept 3c |
|--------------------------------------|------------------------|--------|---|--|---|---|
| Front Longitudinal Crush Rail Design | | |  |  |  |  |
| Chassis/subframe design | | |  |  |  | (no subframe) |
| Metric | CAE Target (interim) | | | | | |
| FFB | Acceleration | <48G | 43 | 51 | 56 | 54 |
| | Intrusion | - [mm] | 363 | 398 | 375 | 400 |
| | Max longitudinal force | <350kN | 265 | 261 | 334 | 256 |
| ODB | Acceleration | <40G | 39 | 36 | X | 37 |
| | Intrusion | - [mm] | 893 | 820 | X | 777 |
| | Max longitudinal force | <350kN | 293 | 253 | X | 268 |
| Mass - longitudinal | - [kg] | 13.6 | 10.2 | 13.6 | 12 | |
| Mass - subframe | - [kg] | 15.6 | 14 | 7.2 | X | |
| Overall performance status | | | | | | |

Figure 6.3.3.5 Rear crash structure FEA concept design studies


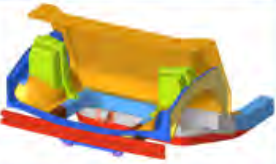
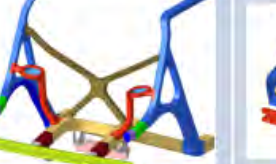


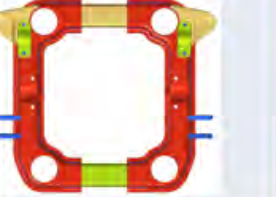
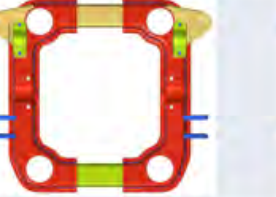
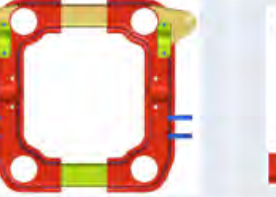
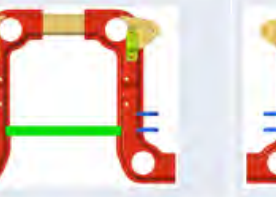
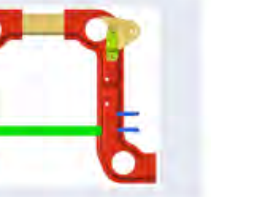
| | | Concept 1a | Concept 1b | Concept 2 | Concept 3a | Concept 3b |
|----------------------------|--|---|--|---|---|---|
| Body structure design | |  |  |  |  |  |
| Rear subframe design | |  |  |  |  |  |
| Metric | CAE Target (subsystem/ interim) | | | | | |
| Accelerations | <20G | 30G | 42G | 30G | 41G | 49G |
| Battery Forces | <70kN | 88kN | 103kN | 79kN | 85kN | 147kN |
| Door Intrusion | <40mm | 127mm | 69mm | 48mm | 79mm | 15mm |
| Longitudinal Efficiency | - | 37% | 36% | 51% | 36% | 44% |
| Body Mass | - | 148kg | 161kg | 132kg | 148kg | 129kg |
| Subframe Mass | | 18.4kg | 18.4kg | 18.4kg | 21.1kg | 21.1kg |
| Overall performance status | | | | | | |

Figure 6.3.3.8 Preliminary rocker concept FEA studies, including aluminium extrusion benchmark

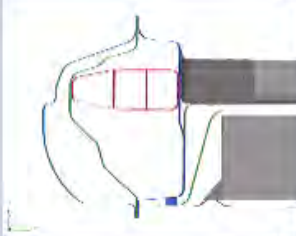
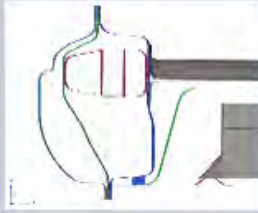


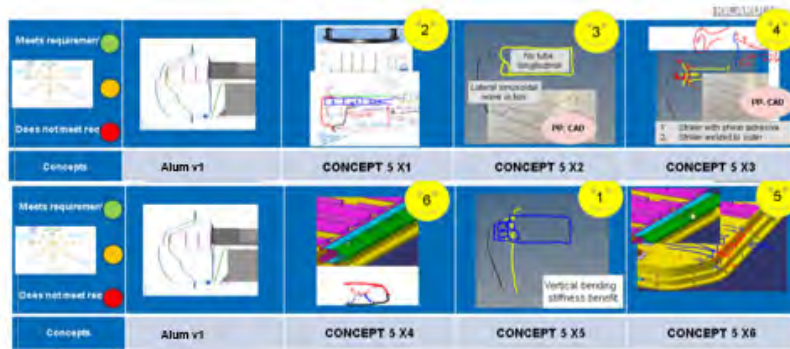
| | | (Benchmark study) | Concept 2 | Concept 5 | Concept 7.3.2 |
|---|------------------------------|---|--|---|---|
| Mid-Zone Design (cross section profile) | |  |  |  |  |
| Design concept | | Extruded aluminium crush element, <u>AHSS</u> protection | Fabricated Advanced High Strength Steel crush element | Coverless battery pack. Body floor & crossmembers provide top cover. | Sliding door concept Re-profiled reinforcement sections, with stabilisers. Swages added to crossmembers. Sill inner increased thickness. |
| Metric | CAE Target (subsystem model) | | | | |
| Rebound | - | 35ms | 43ms | 33ms | 29ms |
| Pole Force | - | 625kN | 560kN | 552kN | 544kN |
| Floor crush | <25mm | 15mm | 80mm | 11mm | 40mm |
| Rocker energy | >80% | 82% | 53% | 95% | 77% |
| Rocker Mass | <18kg/m | 19.8kg/m | 14.9kg/m | - | 21.9kg/m |

Figure 6.3.3.9 Development and assessment of rocker crush element designs



| Base 4 | Concept-5 X1 | Concept-5 X2 | Concept-5 X3 | Concept-5 X4 | Concept-5 X5 | Concept-5 X7 |
|--|--|----------------------------------|-------------------------------------|---|--|---|
| | | | | | | |
| Base model 3-part pusher Model 5444 | D50mm Crashcans & stiff armature | Sine beam crush | Plunge & crush mechanism | Clamshell 2-Part pusher | D25mm crush tubes | Crush planes |
| Developed for Concept-5 mid-zone | Difficult to make work between crossmembers Armature heavy | Works well & very mass efficient | (Not evaluated) | Works well, comparable with base 3-part M5444 | Tubes need to be joined to container & upper/lower surfaces along length | Stable crush of planes difficult to achieve |
| 9.2kg/m | 11kg to 14kg estimate | 5.7kg/m | | 7.9kg/m | 8.0kg/m | 9.0kg/m |
| MS1700 | Cans DP1180 Armature MS1700 | DP1180 | | MS1700 | MS1700 | DP1180 |

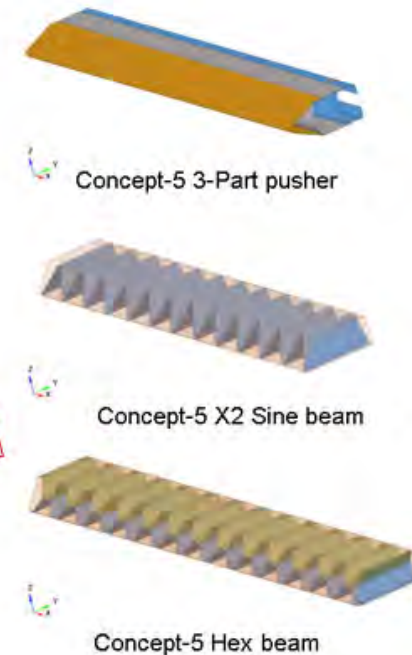


Figure 6.3.4.4 Battery concept #8 assembly process (battery into vehicle only)

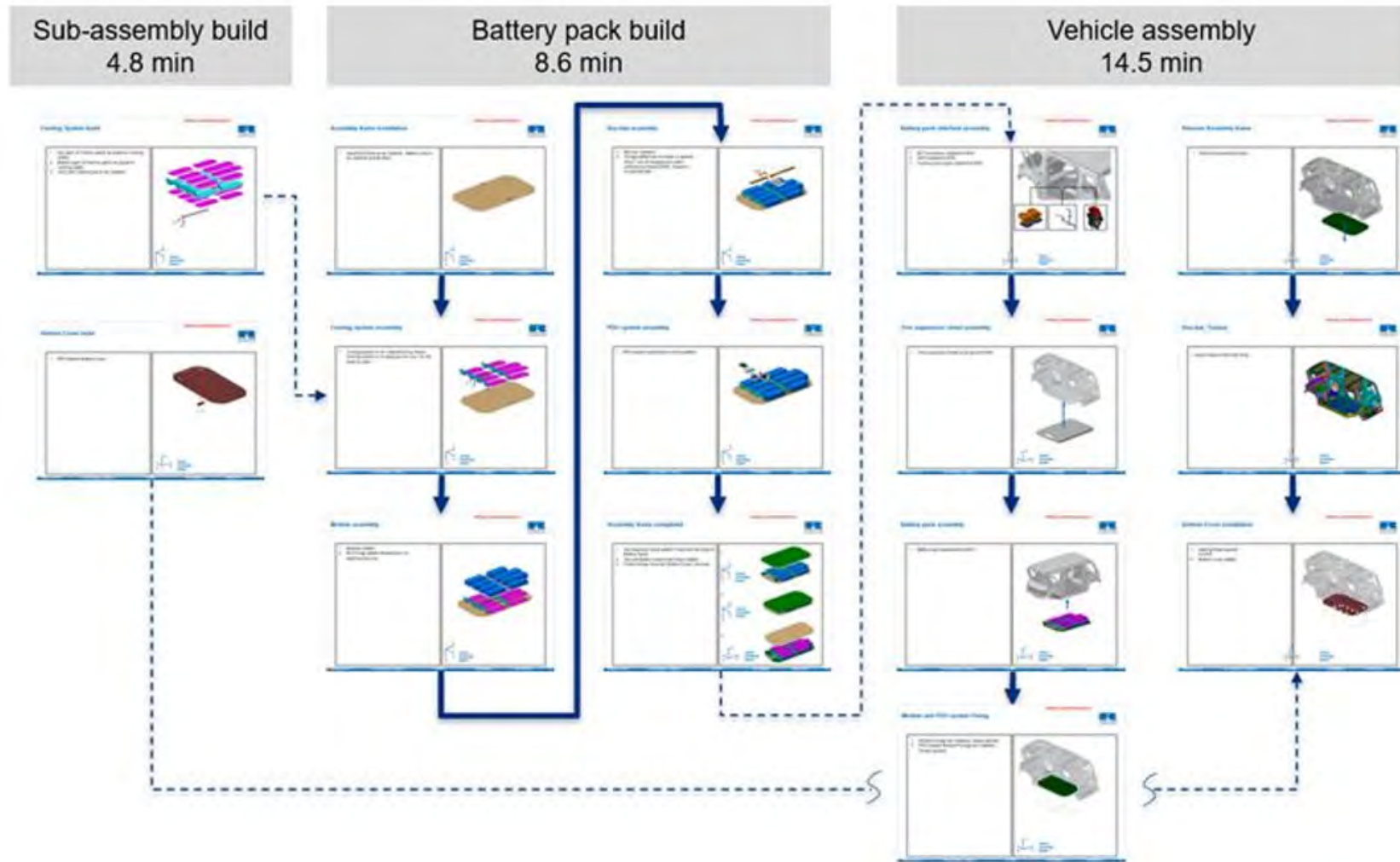


Figure 6.3.4.7 Battery concept #11

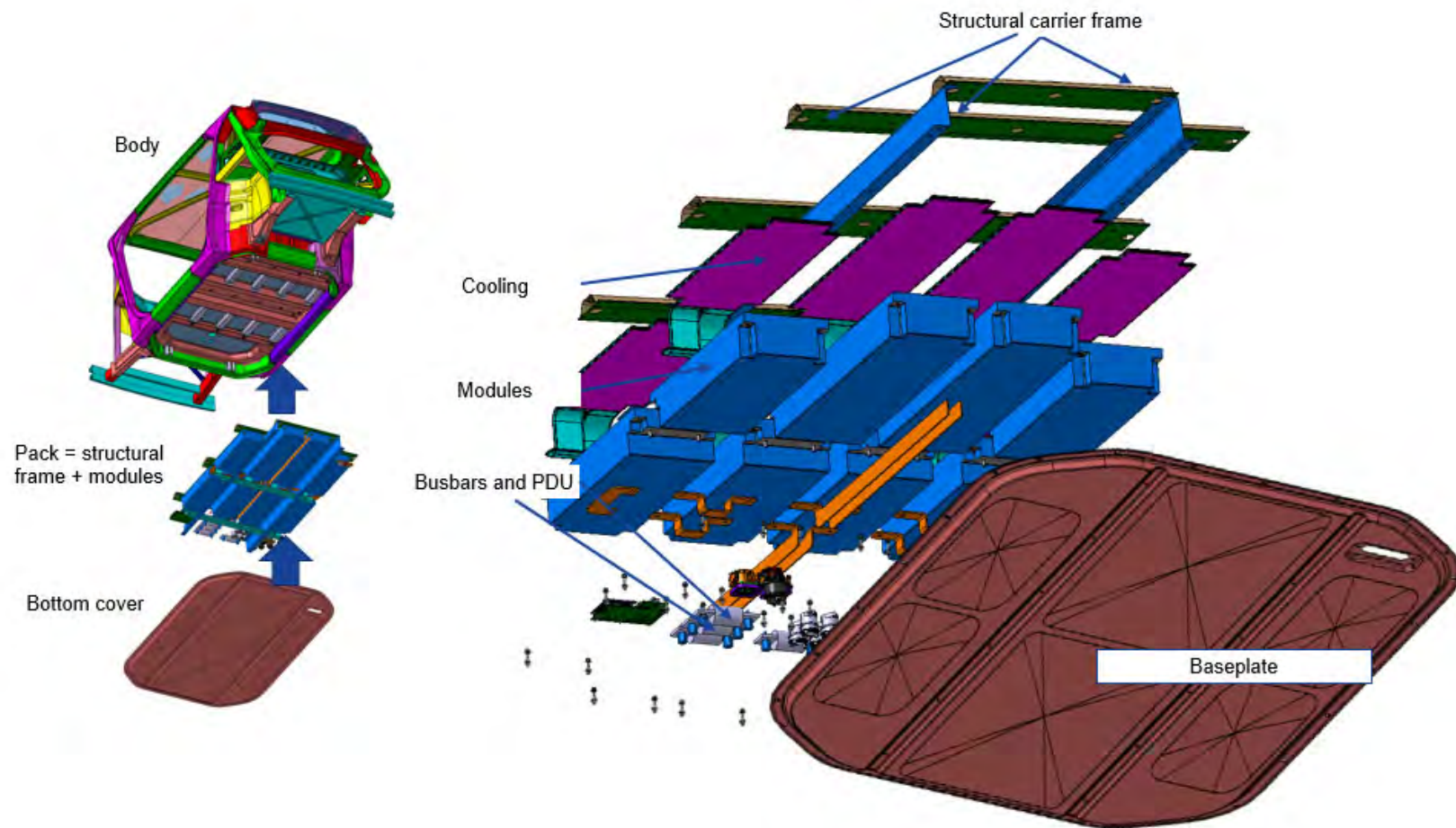


Figure 6.3.5.3.2 Rear closures concept selection matrix

| Attribute | BASELINE | | | | SELECTED | | | |
|---|---|--|---|--|--|---|---|---|
| | Concept 1 – Conventional Liftgate | Concept 2 – Club Door | Concept 3.1 – Half Liftgate with Exposed Hinge | Concept 3.3 – Half Liftgate with Fiat 500 Hinge | Concept 4.1 – Coach Door | Concept 4.5 – Coach Door Revision | Concept 5 – Double Link Hinge | Concept 6 – Split Liftgate |
| Tailgate Opening (mm) | 1431 | 449 | 449 | 610 | 688 | 690 | 462 | 1431 |
| Interior Intrusion | N/A | N/A | N/A | N/A | 235mm (x) from back of closest passenger | Crank of looped arms currently sits 352mm (x) from back of closest passenger | N/A | N/A |
| Mechanical Package | Simple hinge design with powered strut mounted to BIW | Connecting arm must be exposed to allow for secondary hinge axis to be outside the vehicle Requires A-Surface to move | Hinges must be exposed to allow for correct sweep that doesn't clash with glazing | Full hinge assembly with base/door plates packages well into BIW | Large connecting arms difficult to package Hinge axis can be changed to allow for more efficient package and eliminate some current clashes | Needs consideration for driving mechanism (Stabilus Powerise or motor) Connecting arms package more efficiently than previous concept 4.1 due to reduced crank throw | Concept needs to be further developed to efficiently package hinge design without BIW clashes | Concept needs to be further developed to efficiently package hinge design without BIW clashes |
| Kerbside Ingress (mm) | N/A | 635 | N/A | N/A | N/A | N/A | N/A | N/A |
| Vehicle Height Impact (m) | 1.99 (+0.11) | N/A | N/A | N/A | 2.03 (+0.15) | 2.03 (+0.15) | 1.98 (+0.10) | 2.02 (+0.14) |
| Rear Overhang (mm) | 646 | 695 | 363 | 447 | 185 | 197 | 113 | 296 |
| Overhang at Open Position (mm) (measured from bumper A-Surface) | 653 | -114 | / | 258* | / | -66 | -40 | 296 |
| Fixed Glazing | N | Y | Y | Y | Y | Y | Y | N |
| Rear Box Section Potential (global stiffness contribution) | N | Y | Y | Y | Y | Y | Y | N |
| Door Panel Mass Estimate (kg) | 19.62 | 7.47 | / | 10.6 | / | 11.8 | 10.6 | 19.2 |
| Cost Estimate | WIP | | | | | | | |

Figure 6.3.6.2.4 SEM1 IIHS 64kph SORB front crash strategy

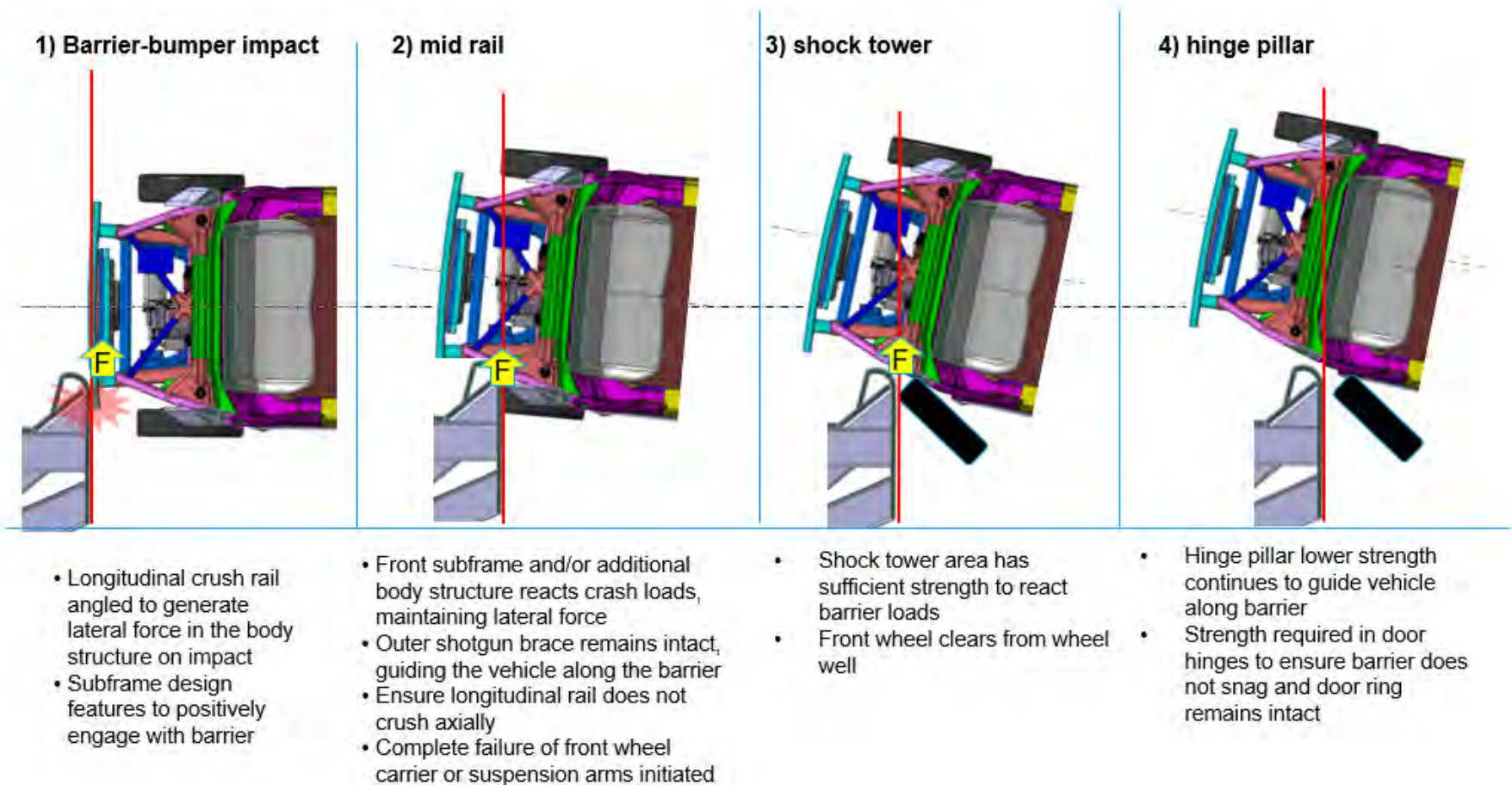


Figure 6.3.6.5.1 Considerations and approach for protection of the rear facing front occupants in a frontal collision

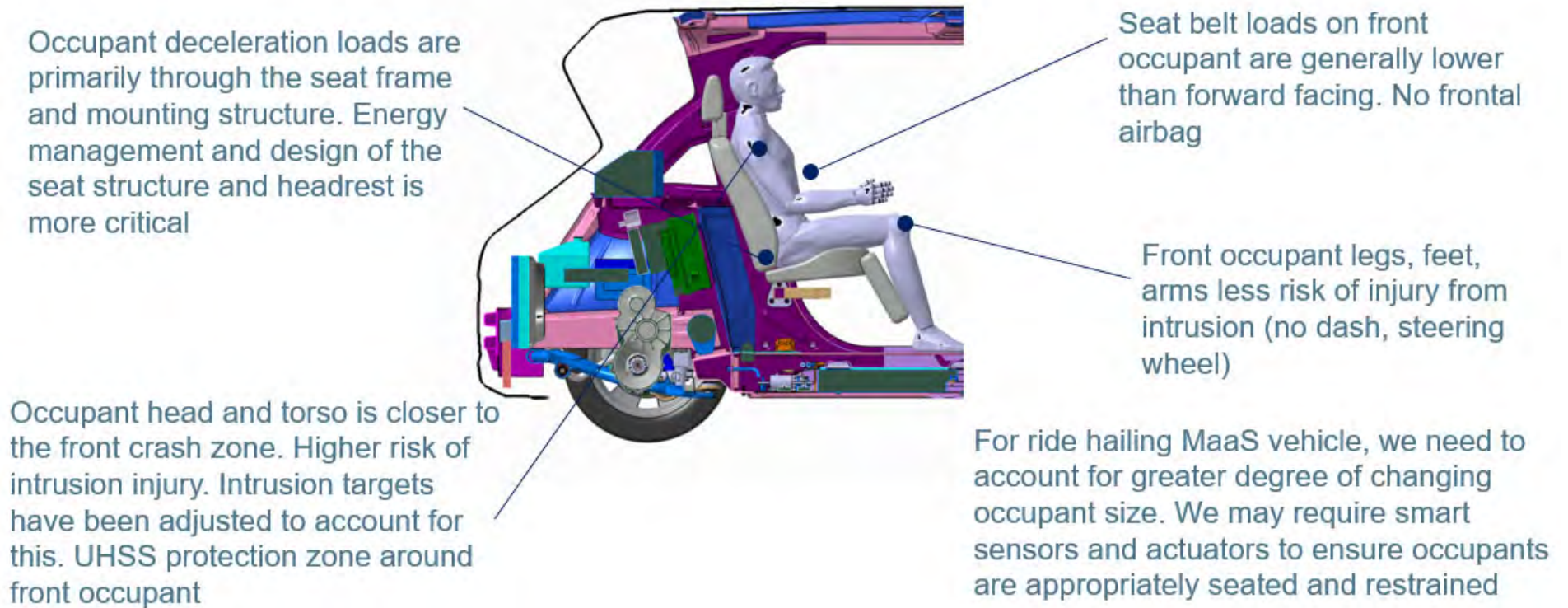


Figure 7.1.1 Engineering 3D CAD image of SEM1 vehicle. Key design features and achievements

SAE Level 5 autonomous driving:

- Fully autonomous, SAE level 5
- Deletion of direct driver controls (steering wheel, pedals, dashboard)
- Package accommodation of autonomous vehicle sensors
- Suitable for deployment on existing highway networks, operating alongside Level 1 to 4 vehicles

Advanced High Strength Steel Body Structure:

- Achieves high speed vehicle crashworthiness standards. Predicted to achieve IIHS “good” rating
- High stiffness and strength body structure. Good levels of comfort and NVH
- Lightweight steel design
- Significant reduction in lifecycle greenhouse gas emissions comparing 2035 operation to 2020 conventional battery electric vehicle



Spacious, comfortable cabin interior

- Inward facing seating configuration
- Scissor doors with wide door aperture providing improved entry and egress for passengers
- Glazing surfaces maximised, enabling light and airy cabin space environment
- Steel E-Motive frame mounted integrated battery solution results in a flat floor interior and low step in height
- Vehicle systems packaged and positioned to provide maximum interior space

Optimised propulsion system

- 75kWh battery electric powerunit. Front electric drive unit. Potential for 12 hour operation on a single charge
- Potential for conversion to hydrogen fuel cell powertrain
- All wheel steer, enabling 7.4m turning circle

Figure 7.1.5.2 Vehicle curb weight versus box volume comparison. Reference vehicle data source www.a2mac1.com

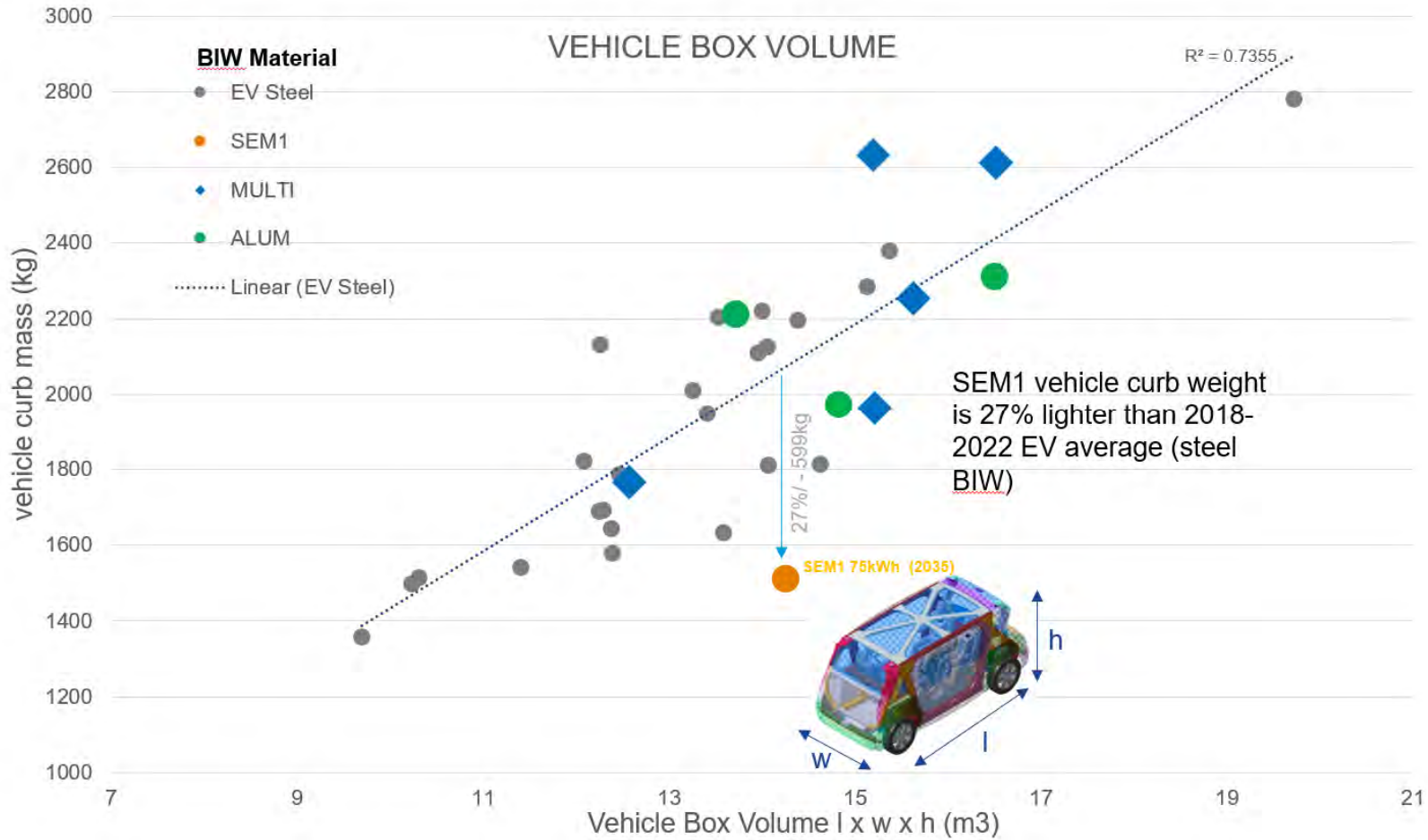


Figure 7.2.1.1 Steel E-Motive SEM1 BIW design and distribution of AHSS



Figure 7.2.1.2 Steel E-Motive BIW AHSS grade allocation

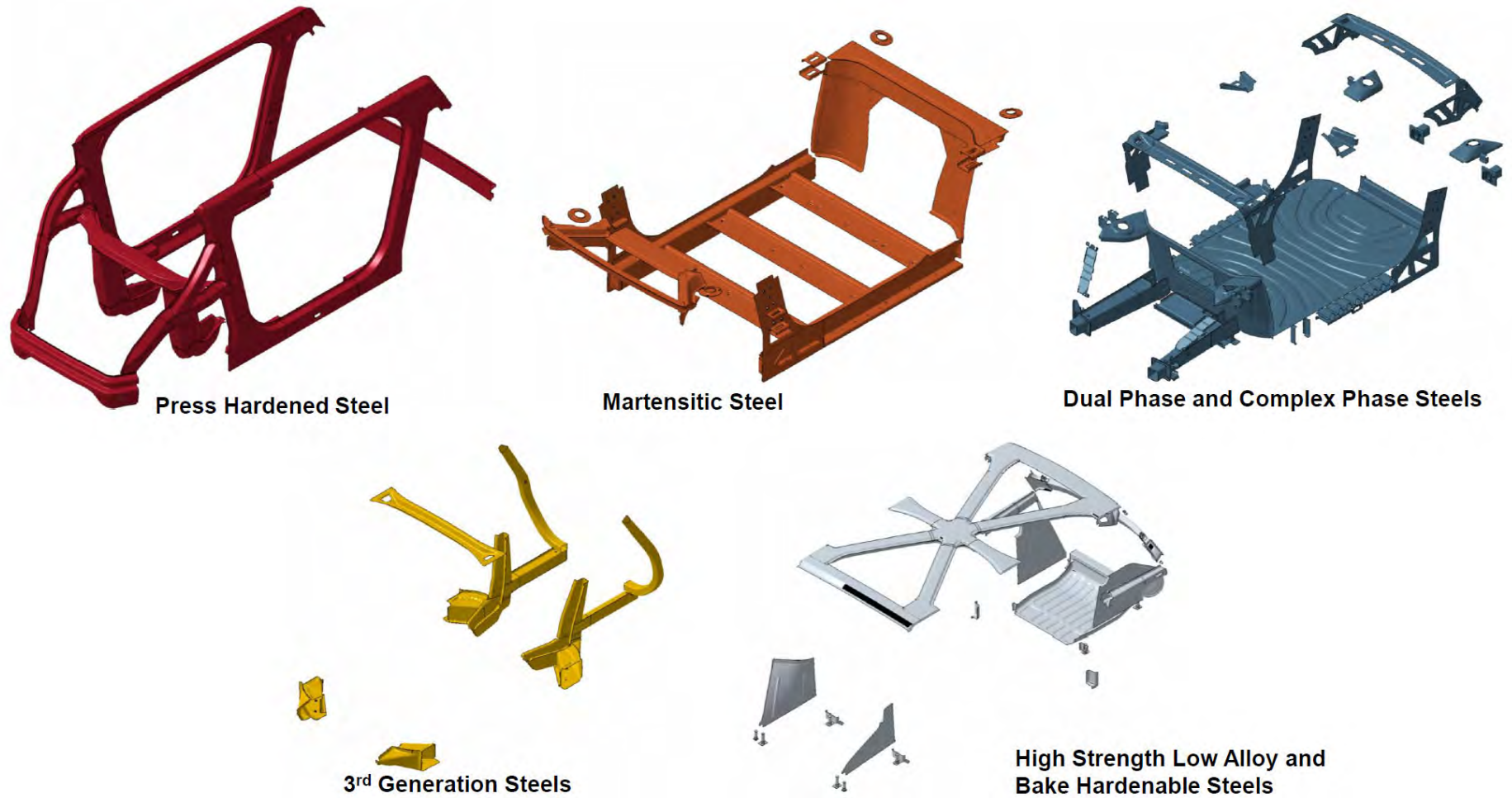


Figure 7.2.1.3 Steel E-Motive BIW AHSS grade distribution

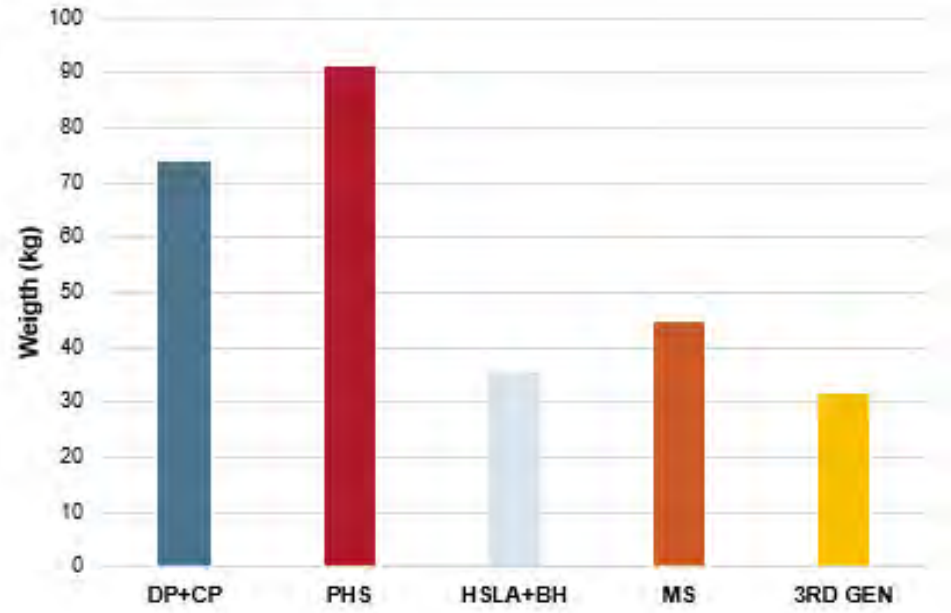
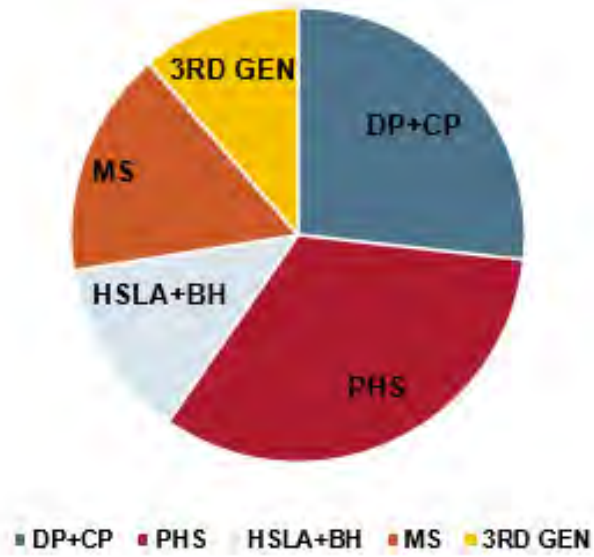


Figure 7.2.1.4 Steel E-Motive SEM1 BIW AHSS grades (exploded view)



Figure 7.2.2.2 Body In White weight regression analysis

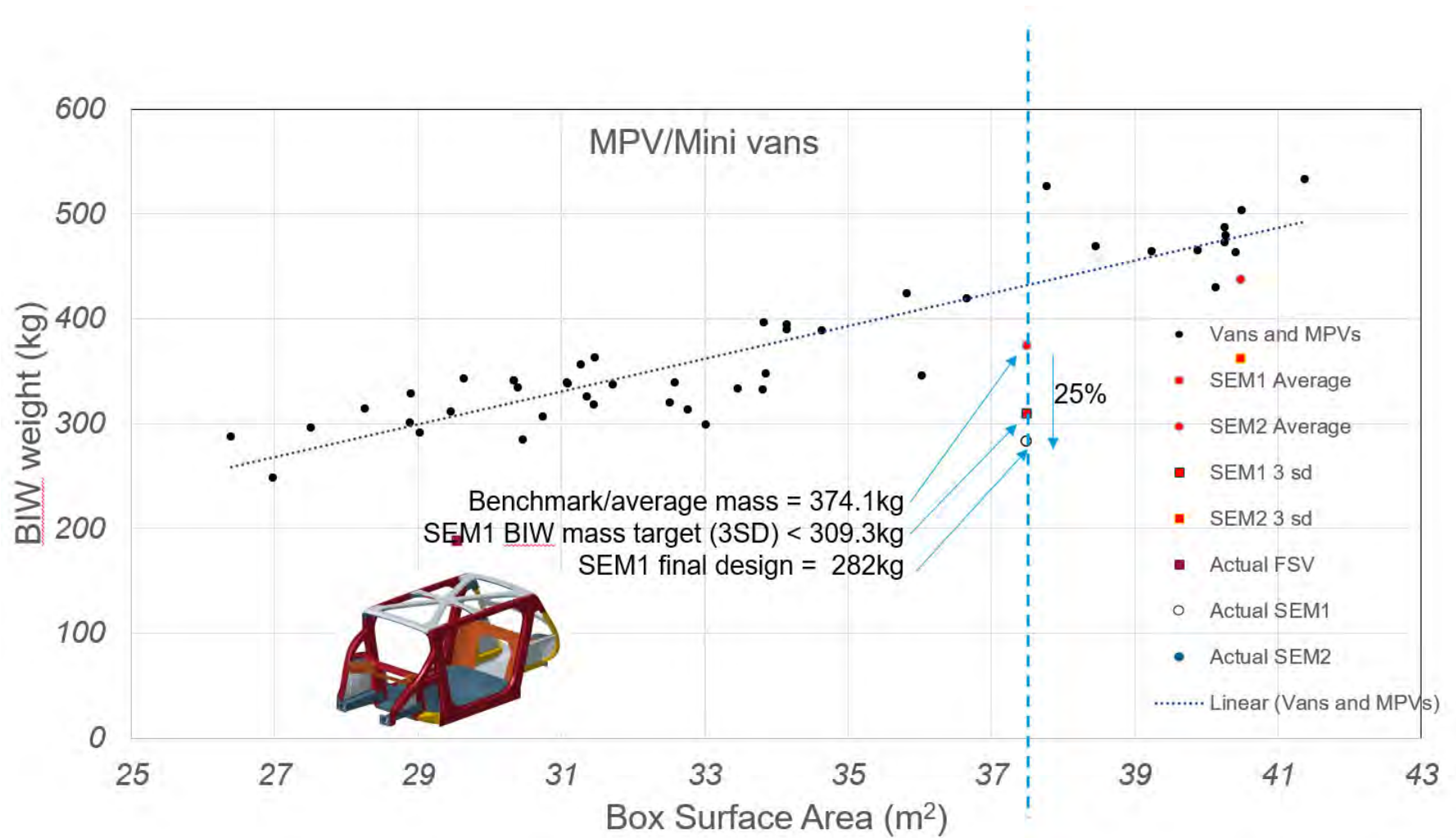


Figure 7.2.2.4 SEM1 body structure key loadpaths

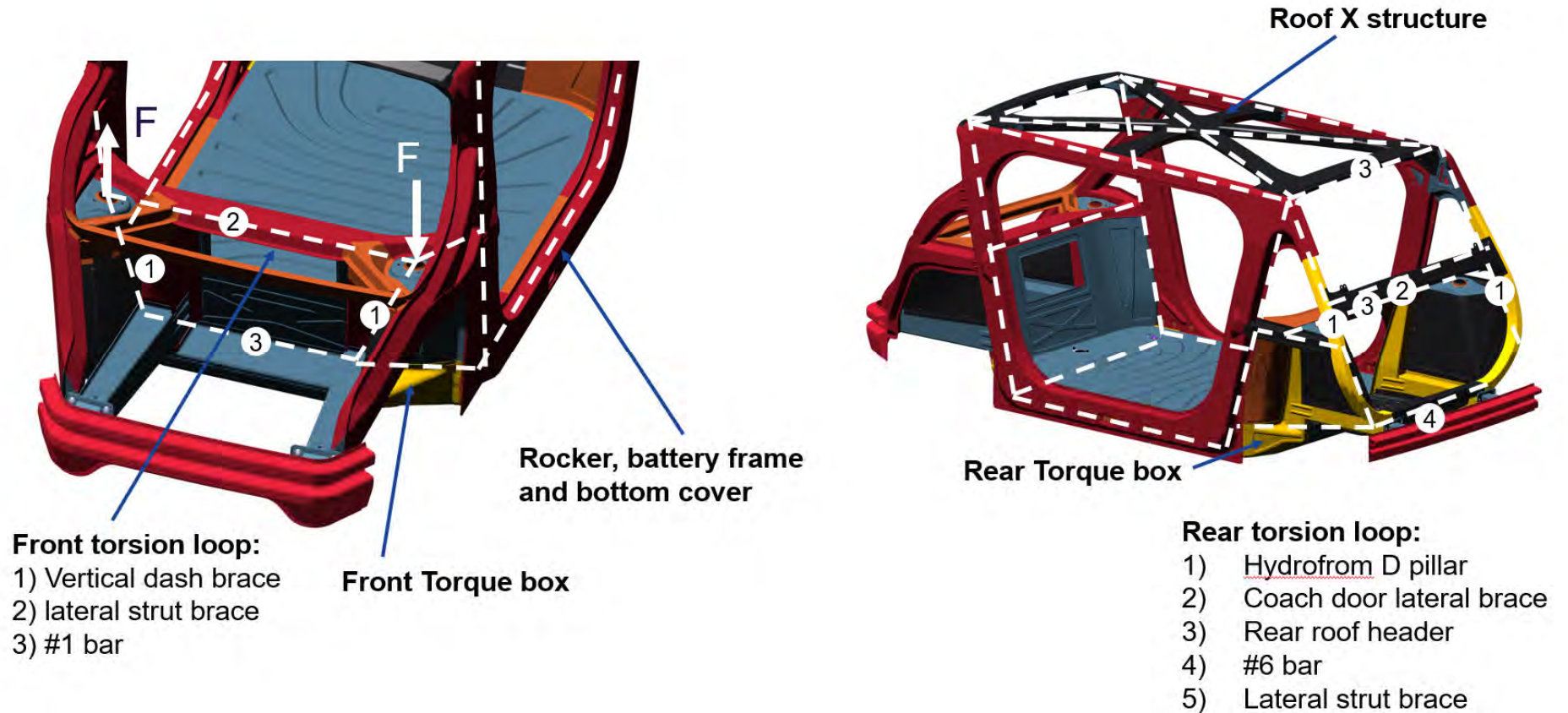


Figure 7.2.2.5 BIW section in X-X through front strut top mounts

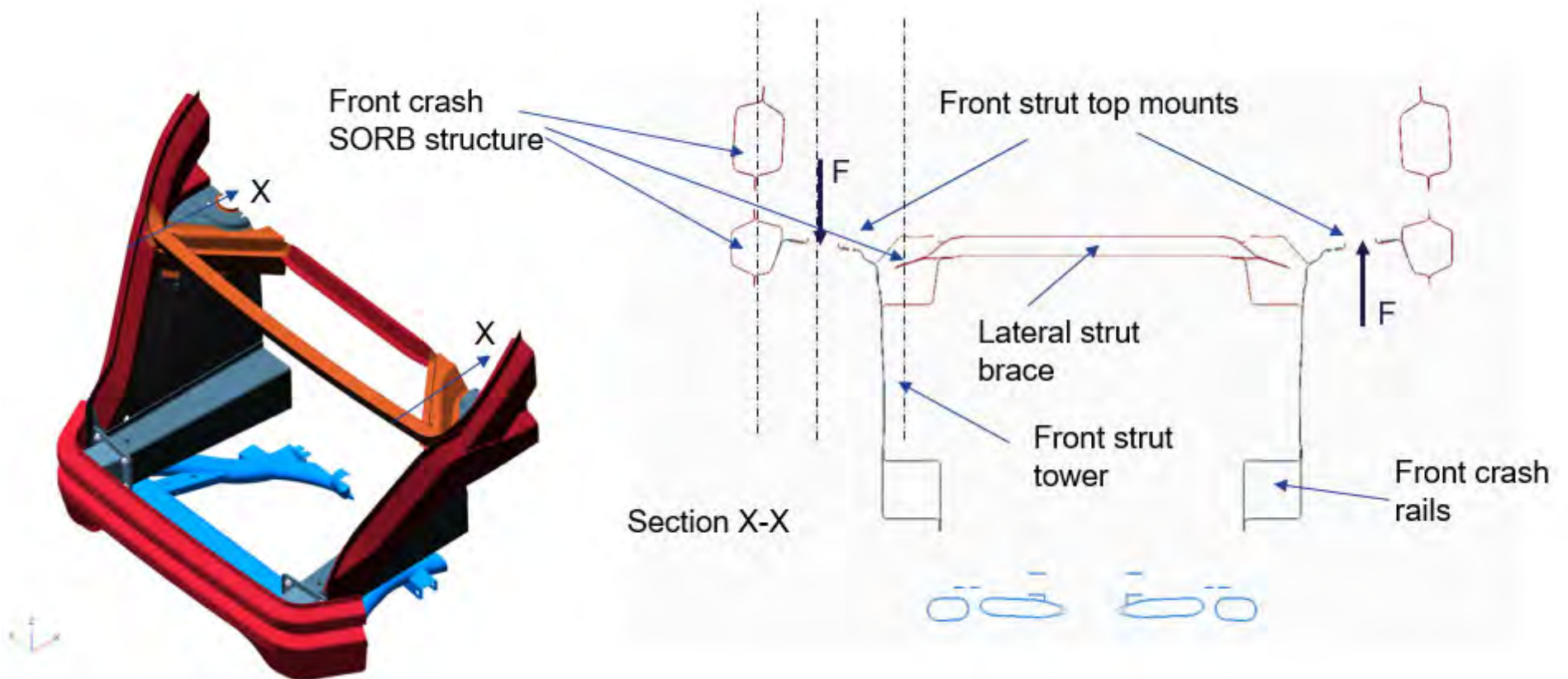


Figure 7.2.2.8 Battery carrier frame fixings to body in white

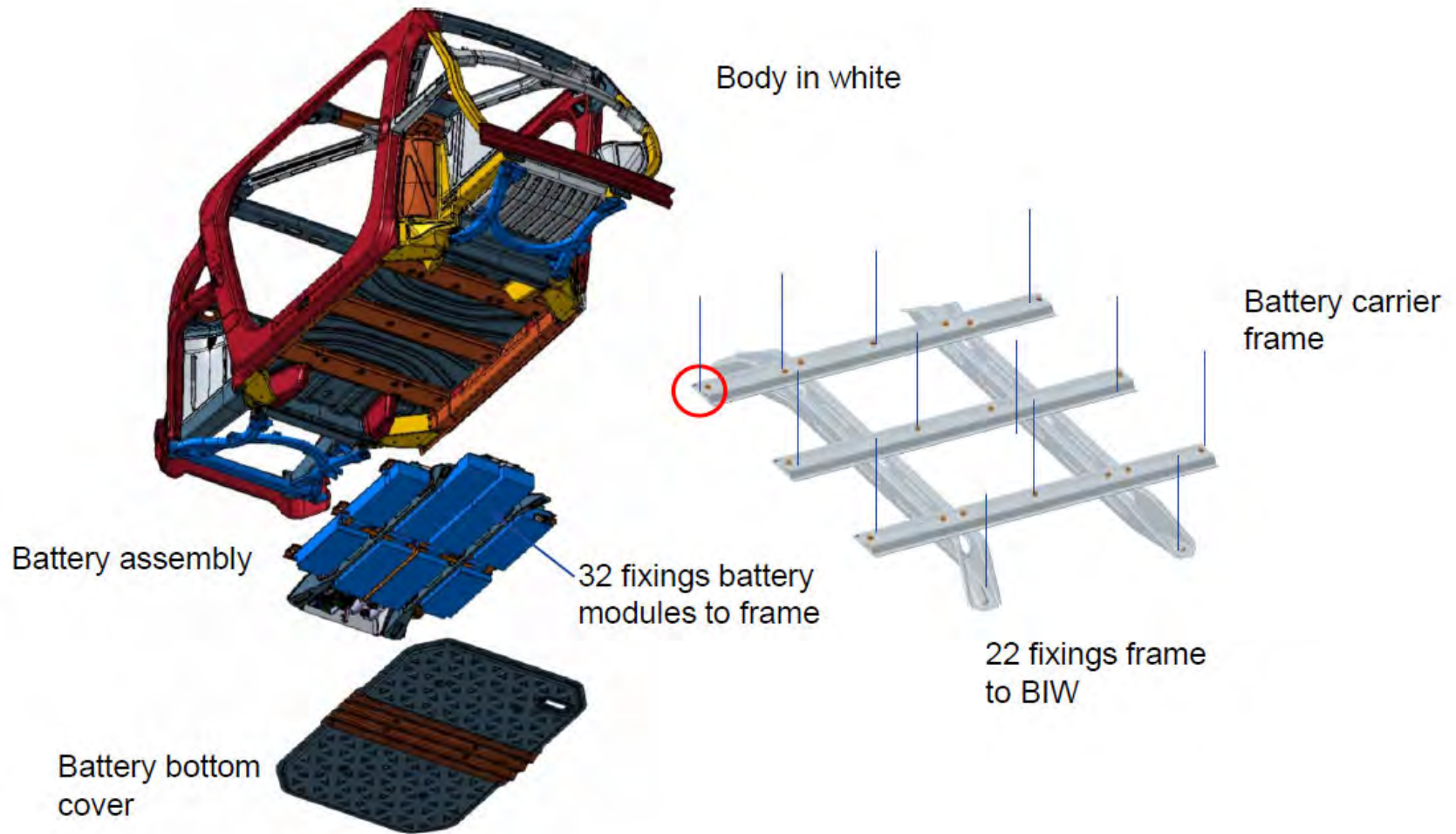


Figure 7.2.2.10 Localised gusset reinforcements adding efficient stiffness and strength improvements

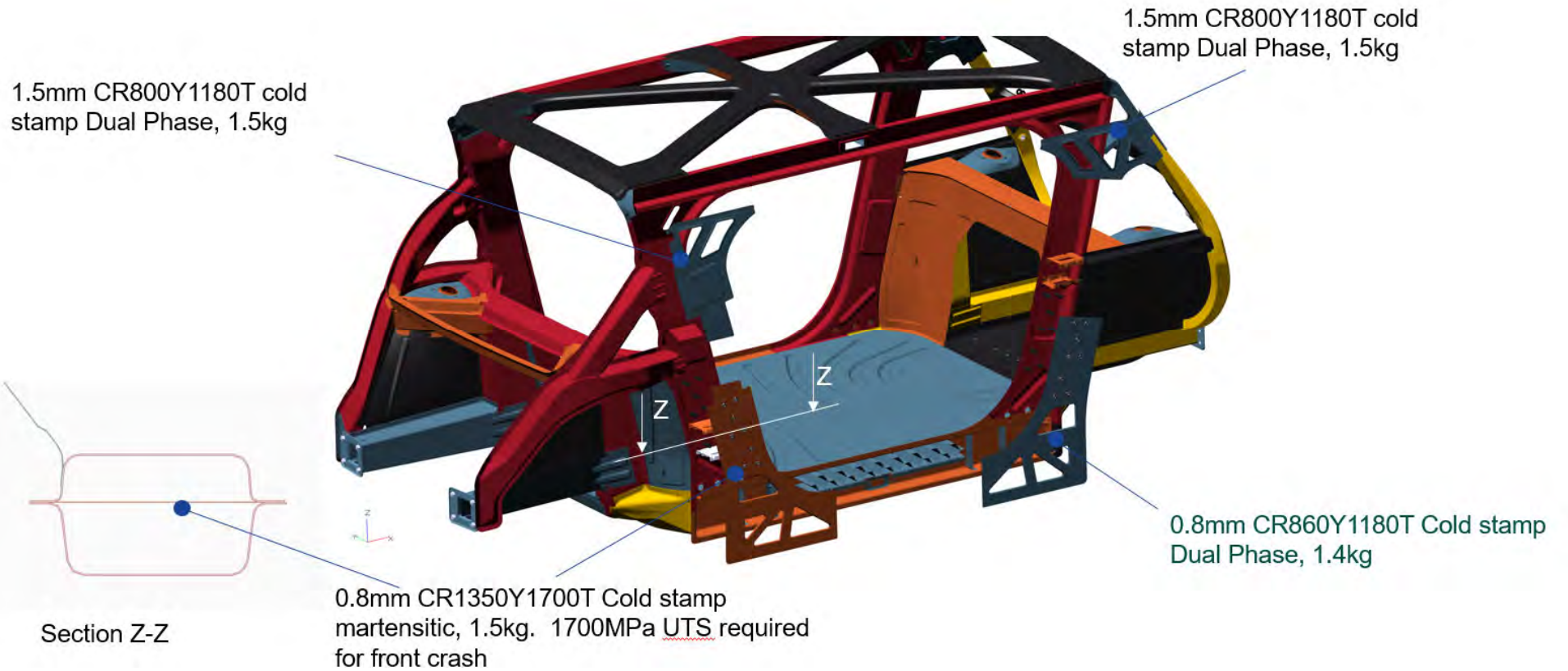


Figure 7.2.2.14 Gauge thickness assignment in SEM1 BIW (exploded view)

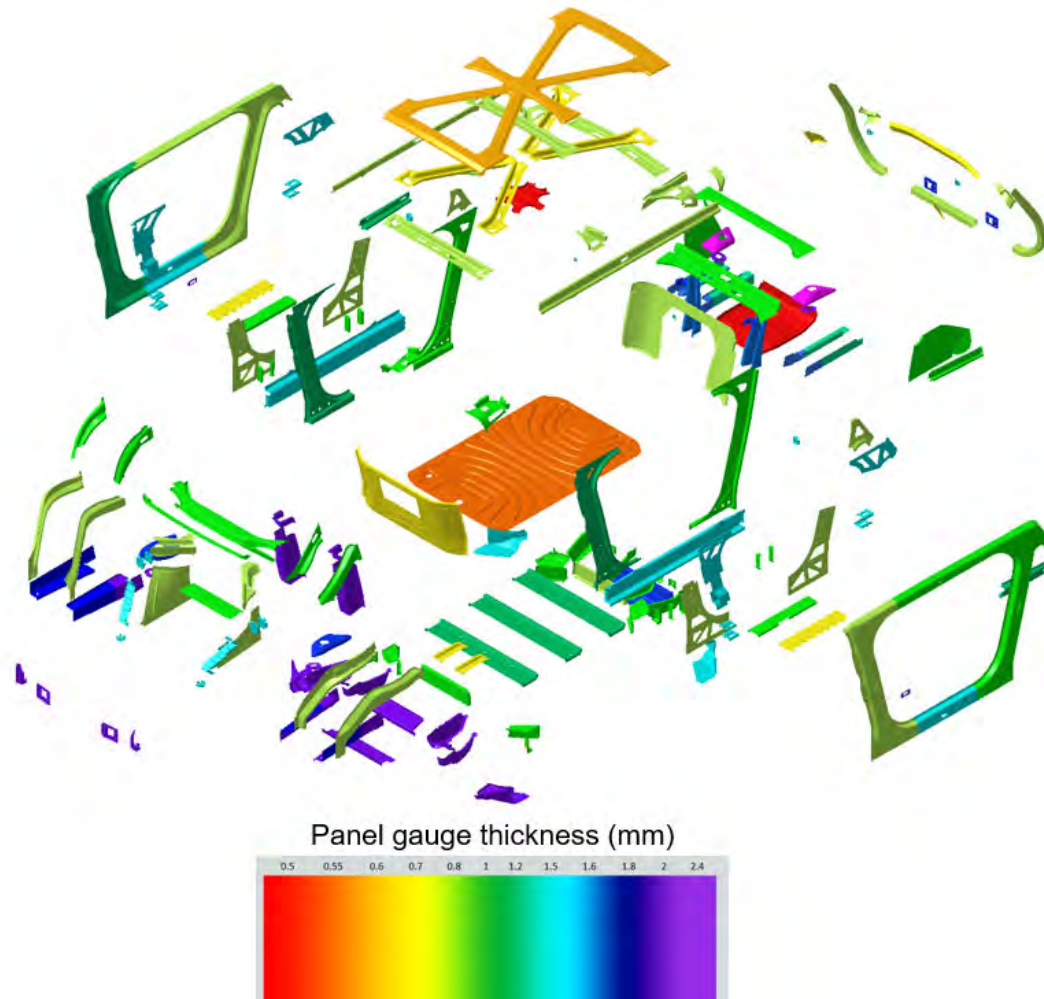



Figure 7.2.2.14 Body in White joining methods

Welding

-  • 2 sheet spot Weld 3219
-  • 3 sheet spot Weld 777
-  • 4 sheet spot Weld 38
-  • One side spot Weld 34


Glue

-  • Structural adhesive 8276 mm

Seam Welding

-  • Seam/MIG Weld 15394 mm

Seam Welding

-  • Laser Weld 1686 mm

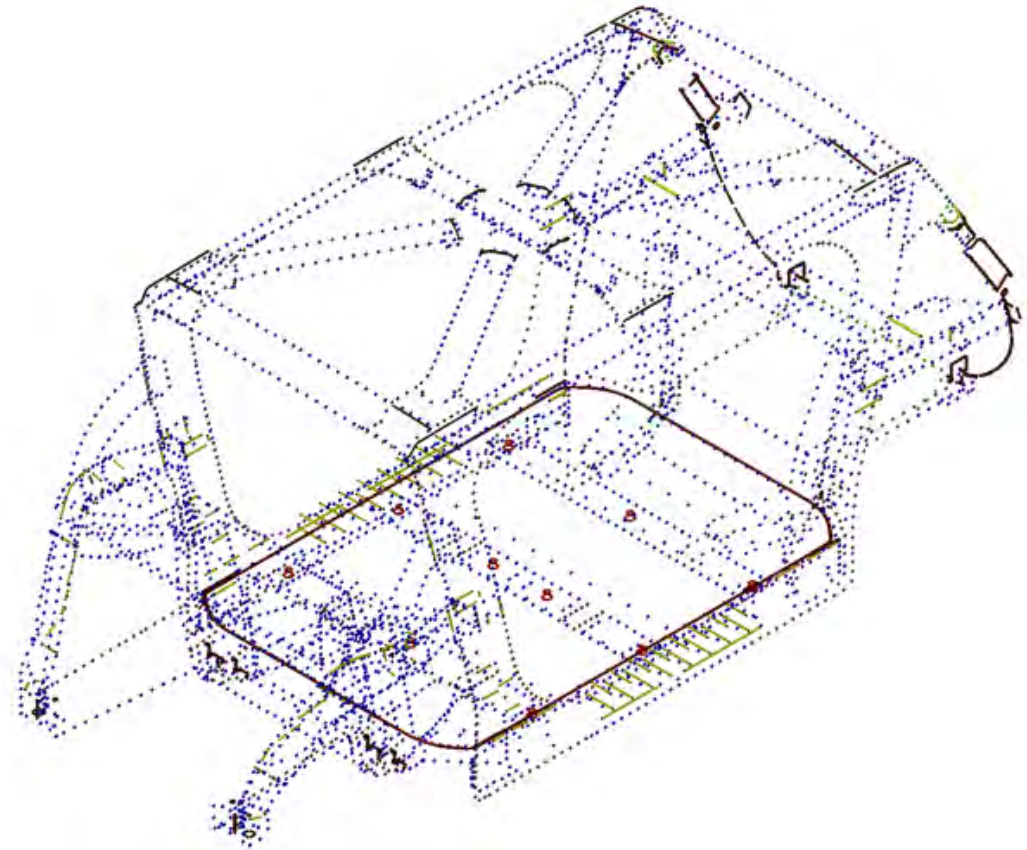


Figure 7.2.2.24 SEM1 Vehicle NVH modal map

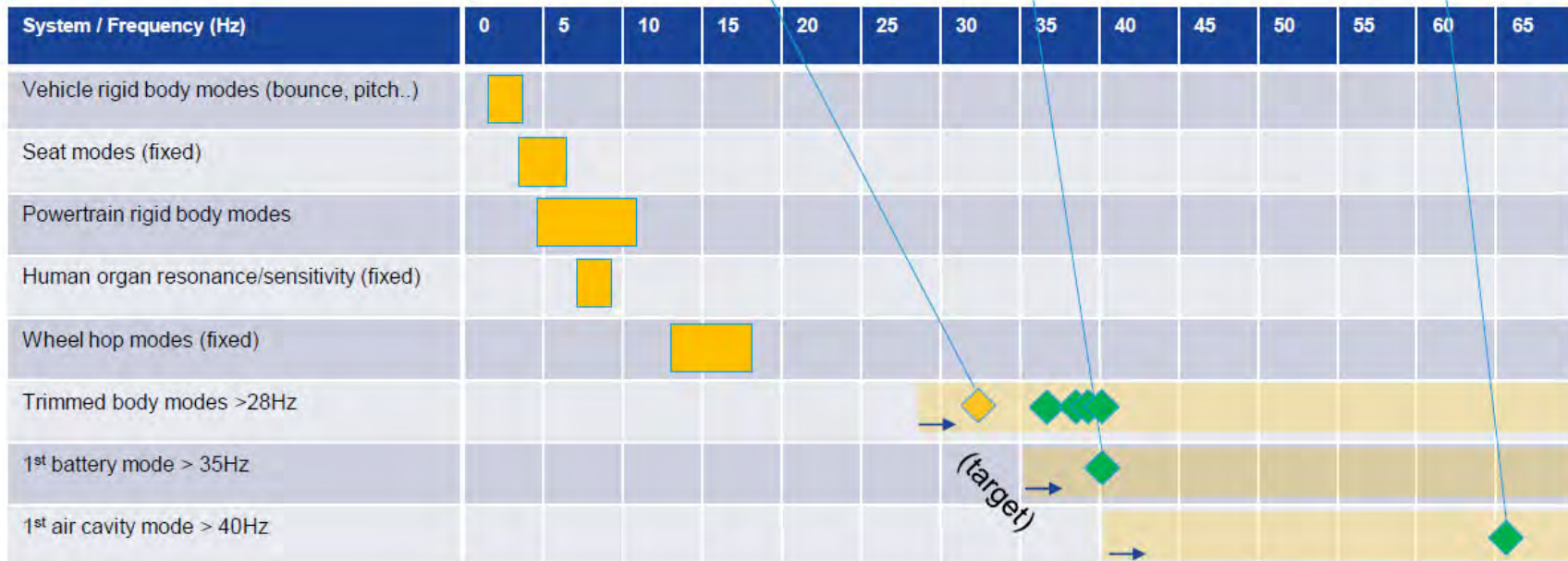
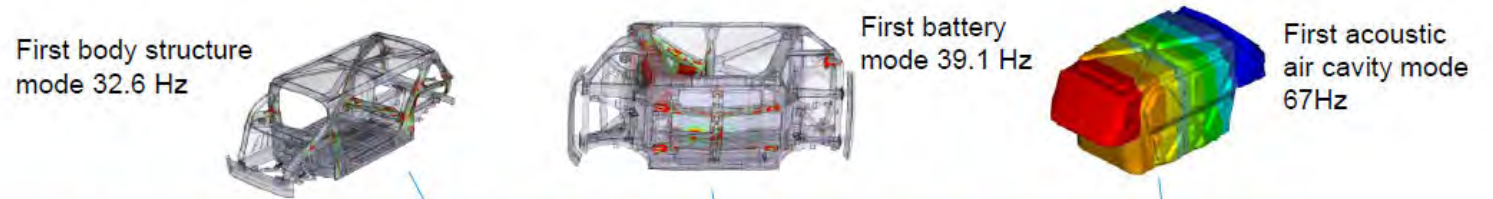


Figure 7.2.3.1 Primary subassemblies in SEM1 front crash structure

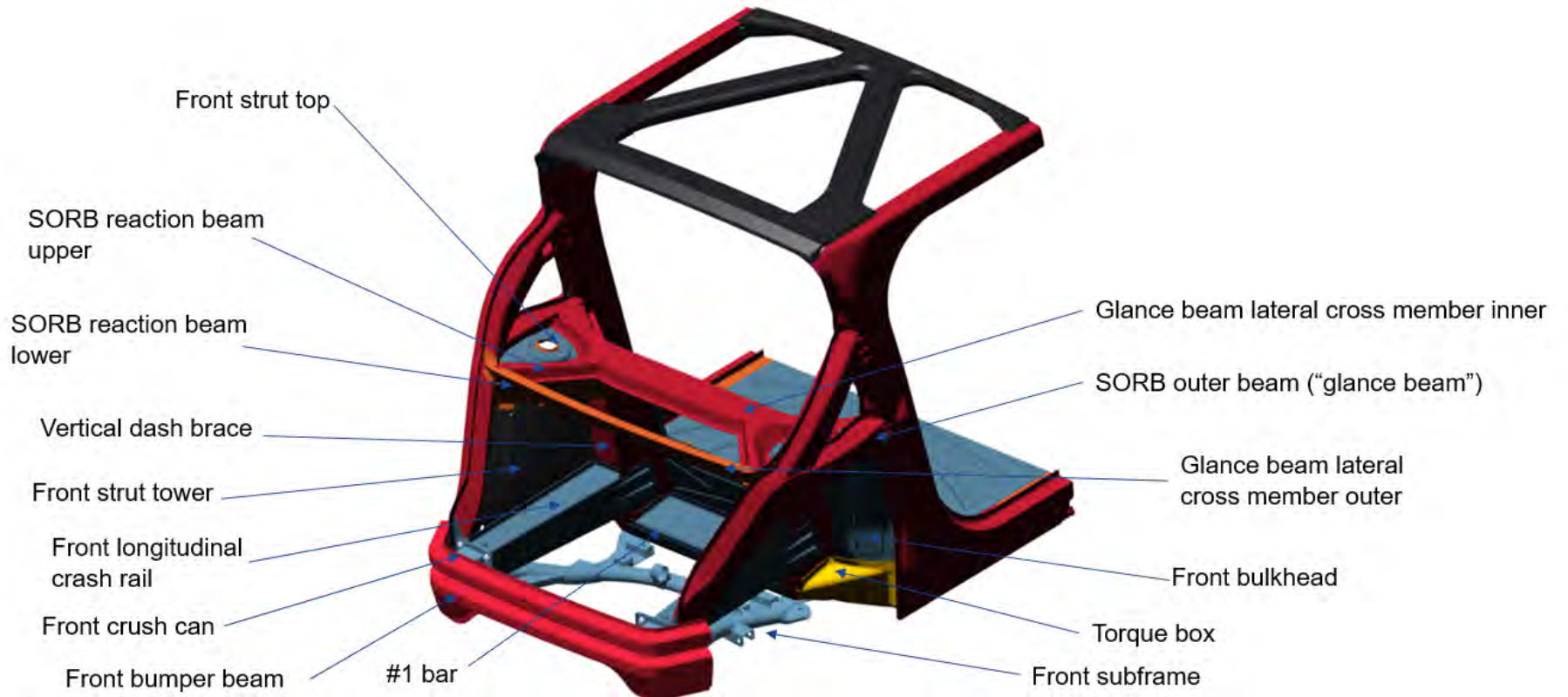


Figure 7.2.3.2 USNCAP 56kph FFB crash test. Vehicle CAE simulation showing the front crush zone deformation behaviour (some parts removed for clarity)

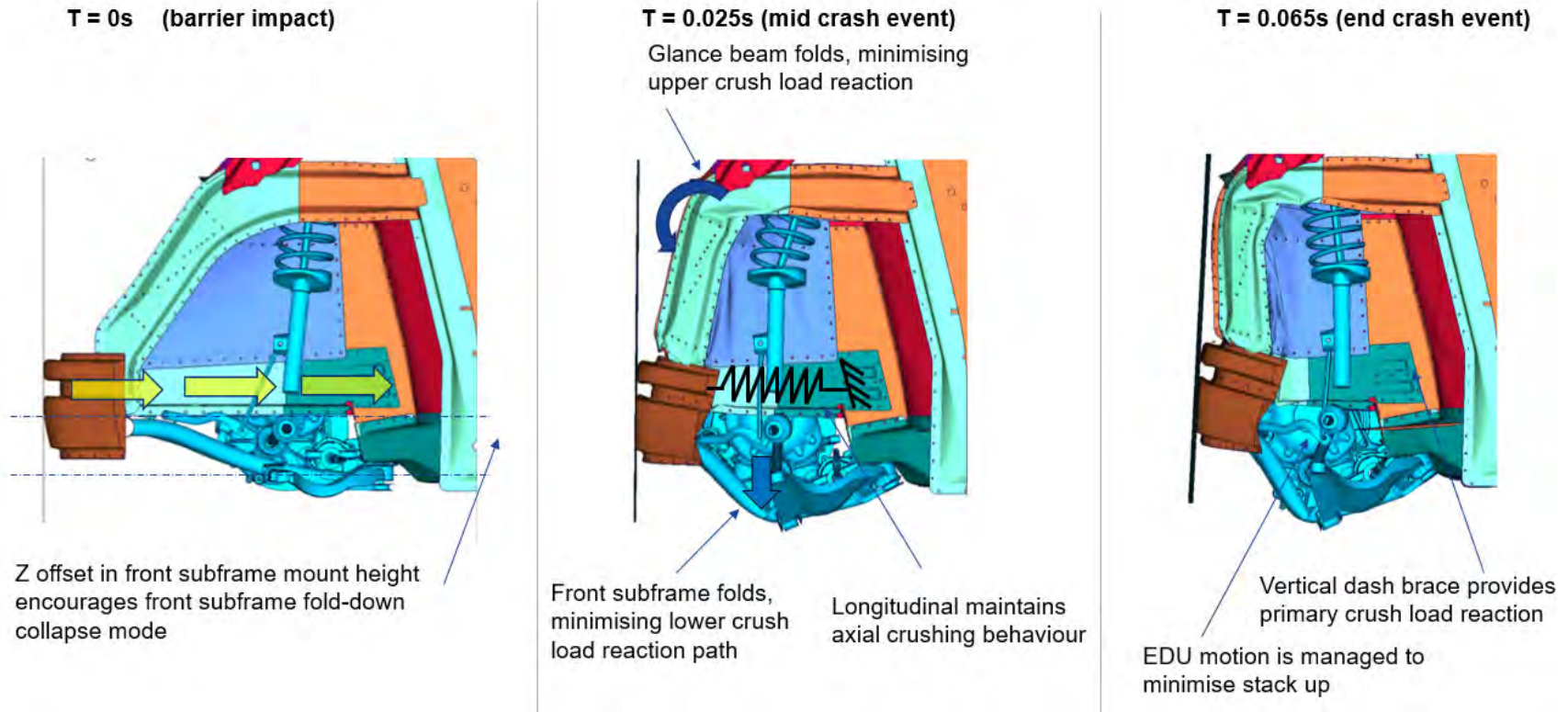
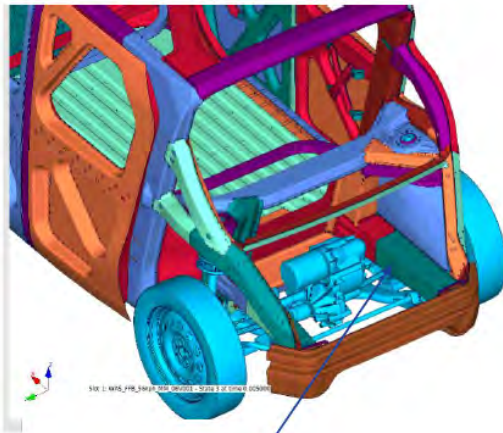


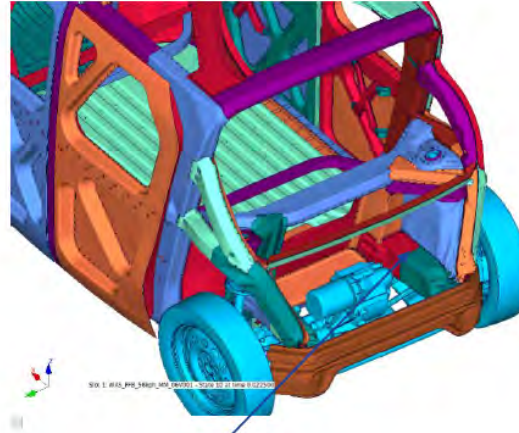
Figure 7.2.3.2b USNCAP 56kph FFB crash test. Vehicle CAE simulation showing the front crush zone deformation behaviour (some parts removed for clarity)

T = 0s (barrier impact)



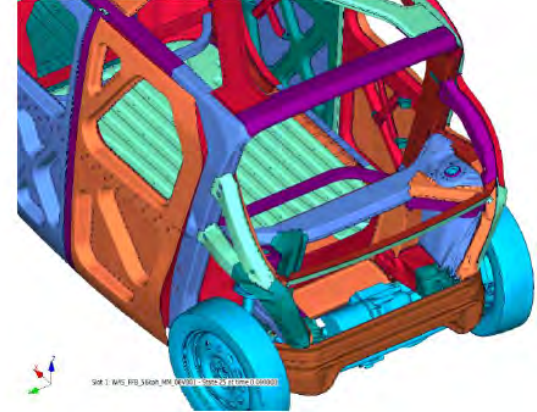
Tailor Welded Blank Dual
Phase front crush longitudinals
Front
2.0mm CR700Y980T-DP ■
1.8mm CR500Y780T-DP ■

T = 0.0225s (mid crash event)



Majority of crush energy absorbed in
crush cans and front part of
longitudinal crush rails. Rear portion
remains stable

T = 0.060s (end crash event)



Crush rail deformation mainly axial
EDU contact to #1 bar and bulkhead is
minimised

Figure 7.2.3.5 Front crash FFB and ODB key components and AHSS grades & gauges

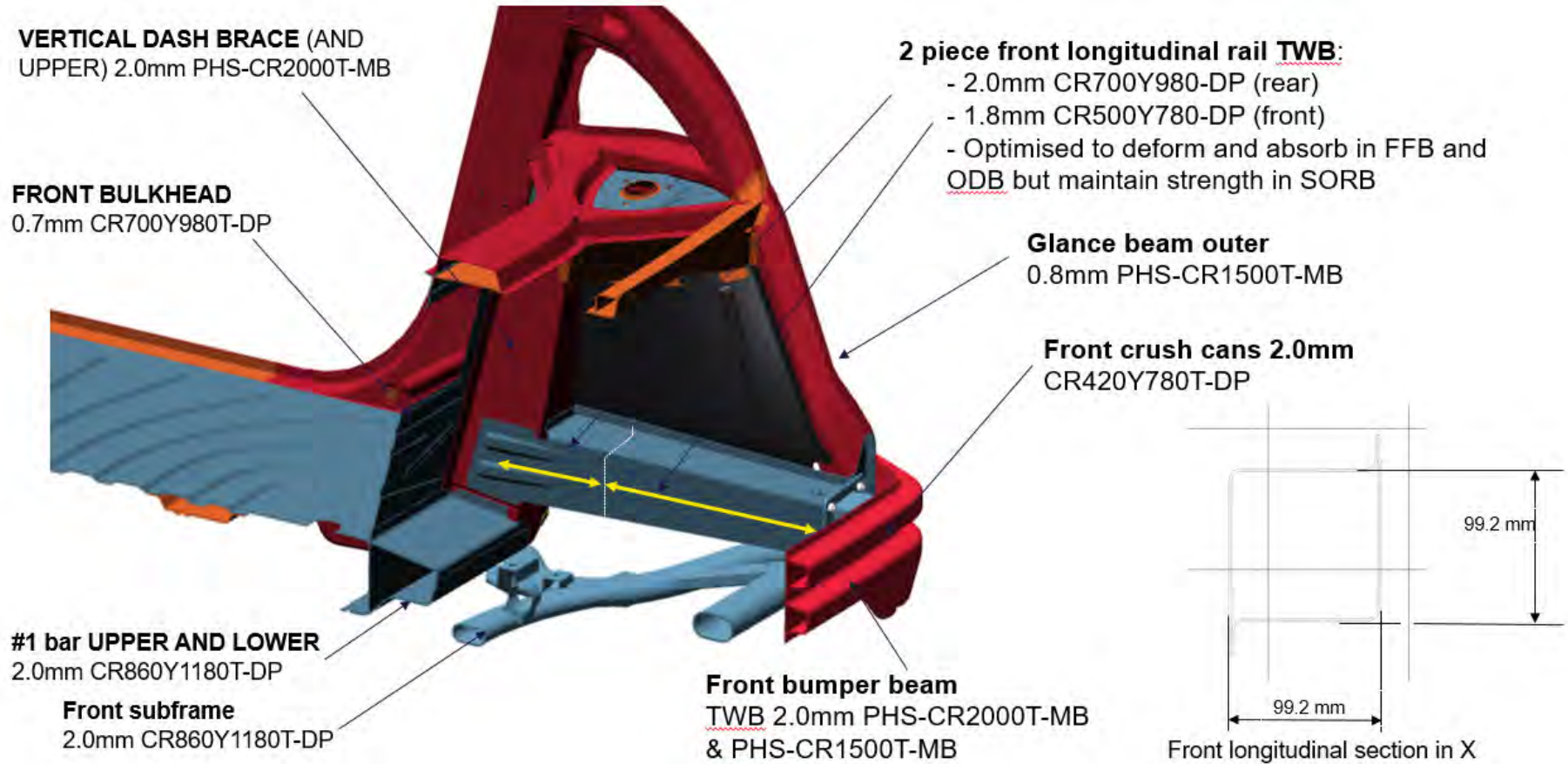


Figure 7.2.3.14 Front bumper beam AHSS grades

| Front Bumper Beam | |
|-----------------------------------|---|
| Geometry/design | Bumper beam outer faces angled and oriented to align with IIHS SORB barrier impact location. In early stage of SORB crash event the bumper beam deforms to contact with front subframe providing lateral force loadpath to initiate glance off motion |
| Part 1: front bumper panel | 2.0mm PHS-CR2000T-MB / Hot form |
| Part 2: rear bumper panel | 2.0mm PHS-CR1500T-MB/ Hot form |
| Part 3: front crush cans | 2.0 mm CR420Y780T-DP / Cold Stamp |
| Part 4: interface panel | 1.2mm CR780Y980T-CP / Cold Stamp |

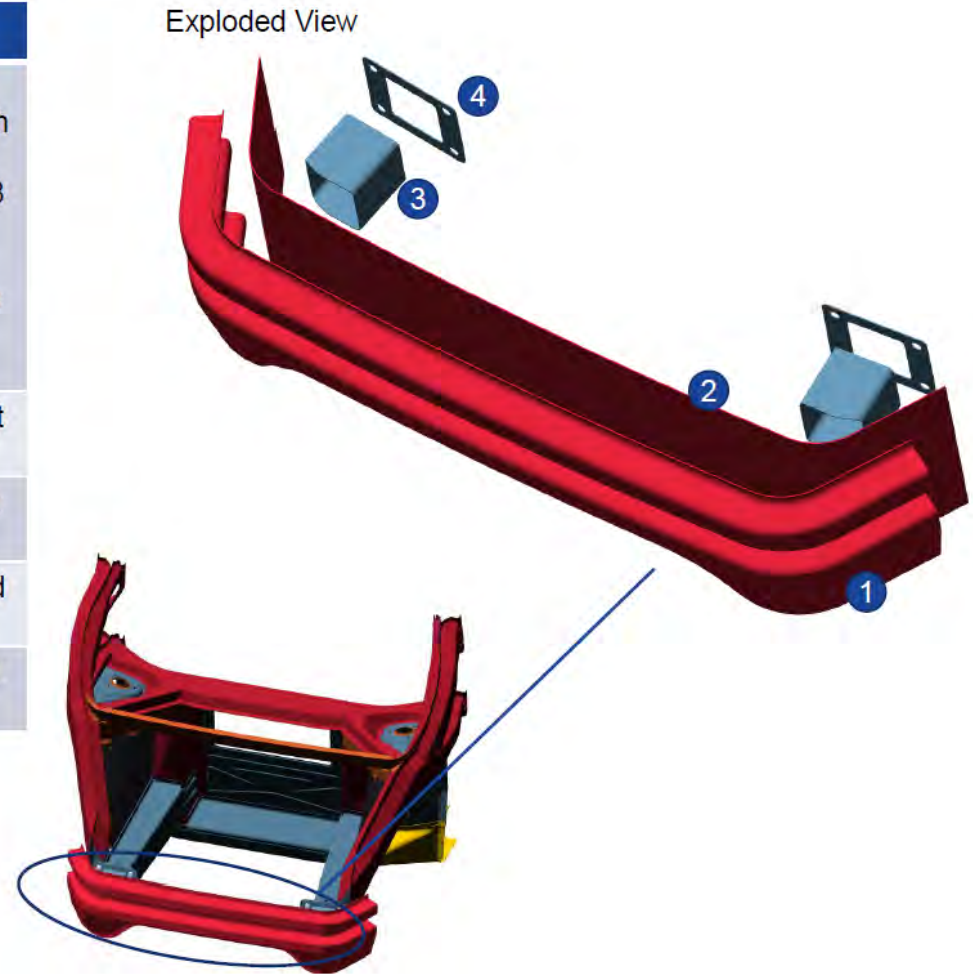


Figure 7.2.3.15 Front crush zone AHSS grades

| Front crush zone | |
|--|---|
| Geometry/design | Longitudinal crush rails 1 and 2 provide primary crush absorption for FFB, ODB and MPDB tests. Tailor Welded blank parts enable uniform axial crush performance and vehicle deceleration. Vertical dash brace parts 4,5, 6 and 7 provide crush load reaction and limits intrusion. One bar parts 8,9 & 10 limit lower intrusion and protect battery |
| Part 1: LONGITUDINAL MID RAIL INNER FRONT RH | TWB 1.8/2.0_CR500Y780T-DP/CR700Y980T-DP / Cold stamp |
| Part 2: LONGITUDINAL MID RAIL OUTER FRONT RH | TWB 1.8/2.0_CR500Y780T-DP/CR700Y980T-DP / Cold stamp |
| Part 3: BUMPER BEAM INTERFACE PLATE FRONT RH | 2.0mm CR860Y1180T-DP / Cold stamp |
| Part 4: VERTICAL DASH BRACE FRONT LH | 2.0mm PHS-CR2000T-MB / Hot form |
| Part 5: VERTICAL DASH BRACE UPPER FRONT | 2.0mm PHS-CR2000T-MB / Hot form |
| Part 6 & 7: VERTICAL DASH BRACE LOWER INNER & OUTER | 2.0mm PHS-CR2000T-MB / Hot form |
| Part 8 & 9: ONE BAR UPPER AND LOWER | 1.0mm CR860Y1180T-DP / Cold stamp |
| Part 10: ONE BAR INNER | 2.0mm CR8501180T-DH / Cold stamp |
| Part 11: STRUT TOWER FRONT RH | 0.8mm CR350Y450T-LA / Cold stamp |
| Part 12: STRUT TOP FRONT RH | 1.8mm CR860Y1180T-DP / Cold stamp |
| Part 13: STRUT RING FRONT | 2.0mm CR1200Y1470-MS / Cold stamp |

Exploded View

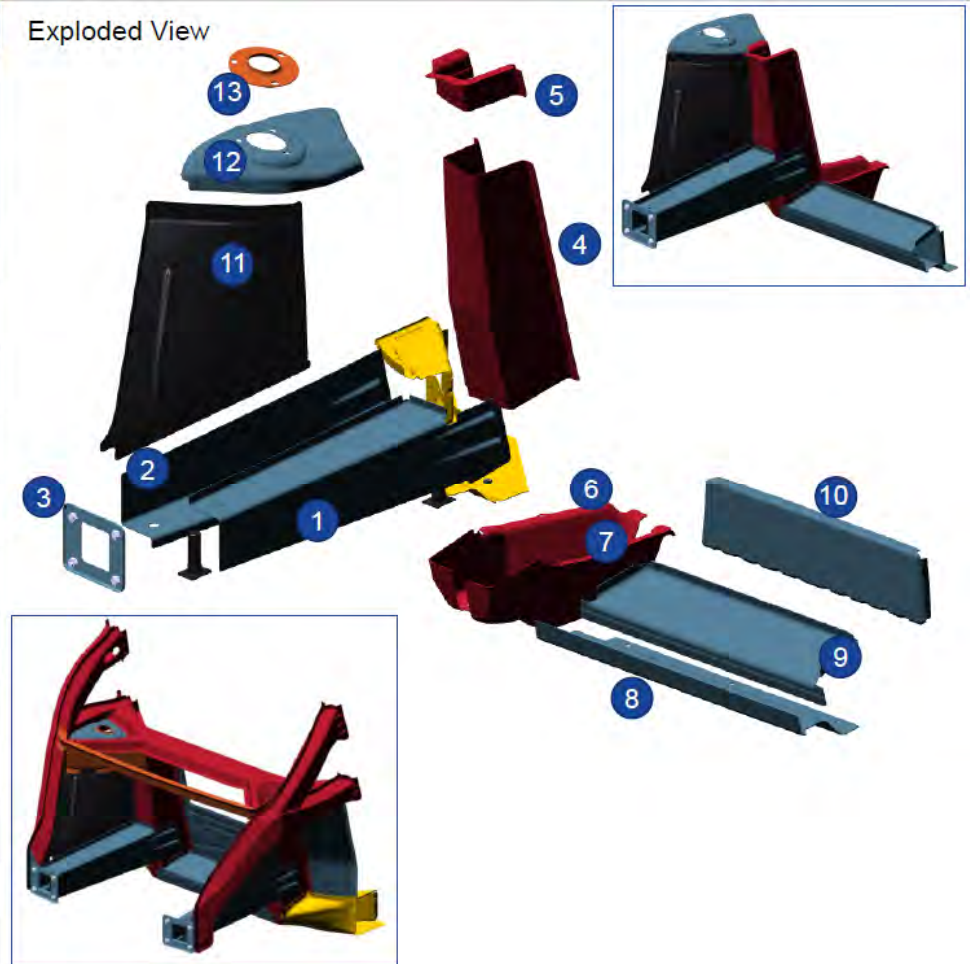


Figure 7.2.3.16 Glance beam AHSS grades

| Glance Beam | |
|---|--|
| Geometry/design | Plan view profile optimised to guide vehicle along desired SORB barrier trajectory. Design and grades optimised to enable fold in FFB and no rupture in SORB |
| Part 1: GLANCE BEAM OUTER LH | 0.8mm PHS-CR1500T-MB / Hot form |
| Part 2: GLANCE BEAM INNER LH | 0.8mm PHS-CR1500T-MB / Hot form |
| Part 3: GLANCE BEAM UPPER TRIANGULATION OUTER LH | 2.0 mm CR420Y780T-DP / Cold Stamp |
| Part 4: GLANCE BEAM UPPER TRIANGULATION INNER LH | 1.2mm CR780Y980T-CP / Cold Stamp |
| Part 5: GLANCE BEAM BULKHEADS | 1.5mm CR420Y780T-DP CR780Y980T-CP / Cold Stamp |
| Part 6: GLANCE BEAM BULKHEADS | 1.5mm CR420Y780T-DP CR780Y980T-CP / Cold Stamp |
| Part 7: GLANCE BEAM CAP (and subframe bolt) | 2.0mm CR420Y780T-DP / Cold stamp |

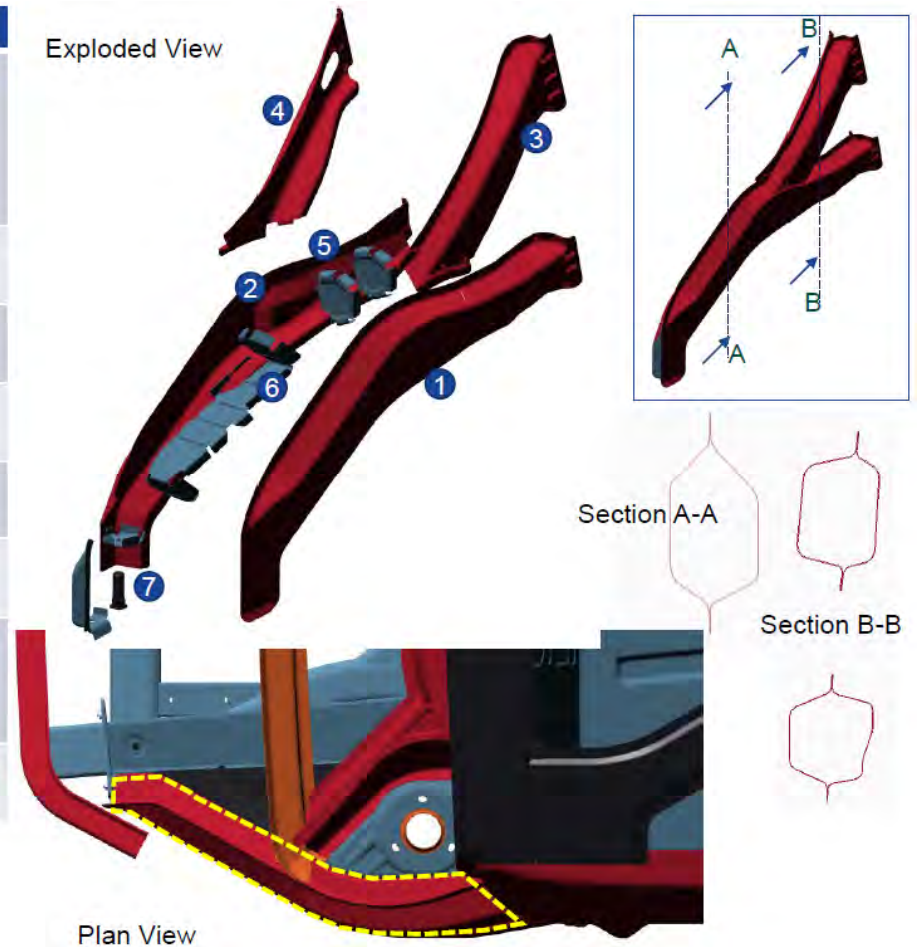


Figure 7.2.3.17 SORB glance reaction beam and damper strut top AHSS grades

| SORB Glance Reaction Beams and Damper Strut Top | |
|---|---|
| Geometry/design | Grades and geometry enable SORB lateral loadpath for glance behaviour |
| Part 1: GLANCE BEAM UPPER REACTION LH | 0.8mm PHS-CR1500T-MB / Hot form |
| Part 2: GLANCE BEAM LOWER REACTION LH | 0.8mm CR1200Y1470T-MS / Cold stamp |
| Part 3: GLANCE BEAM LATERAL CROSS MEMBER OUTER | 1.0mm CR1200Y1470T-MS / Cold stamp |
| Part 4: GLANCE BEAM LATERAL CROSS MEMBER INNER | 1.0mm CR1200Y1470T-MS / Cold stamp |
| Part 5: STRUT CROSS MEMBER FRONT | 1.0mm PHS-CR2000T-MB / Hot form |
| Part 6: STRUT CROSS MEMBER CLOSING PLATE | 1.0mm CR1550Y2000T-MS / Cold stamp |
| Part 7: STRUT TOP FRONT | 1.8mm CR860Y1180T-DP / Cold stamp |
| Part 8: STRUT RING FRONT | 2.0 mm CR1200Y1470-MS / Cold stamp |
| Part 9: VERTICAL DASH BRACE UPPER FRONT | 2.0mm PHS-CR2000T-MB / Hot form |
| Part 10: VERTICAL DASH BRACE FRONT LH | 2.0mm PHS-CR2000T-MB / Hot form |
| Part 11: STRUT TOWER FRONT LH | 0.8mm CR350Y/450T-LA / Cold stamp |

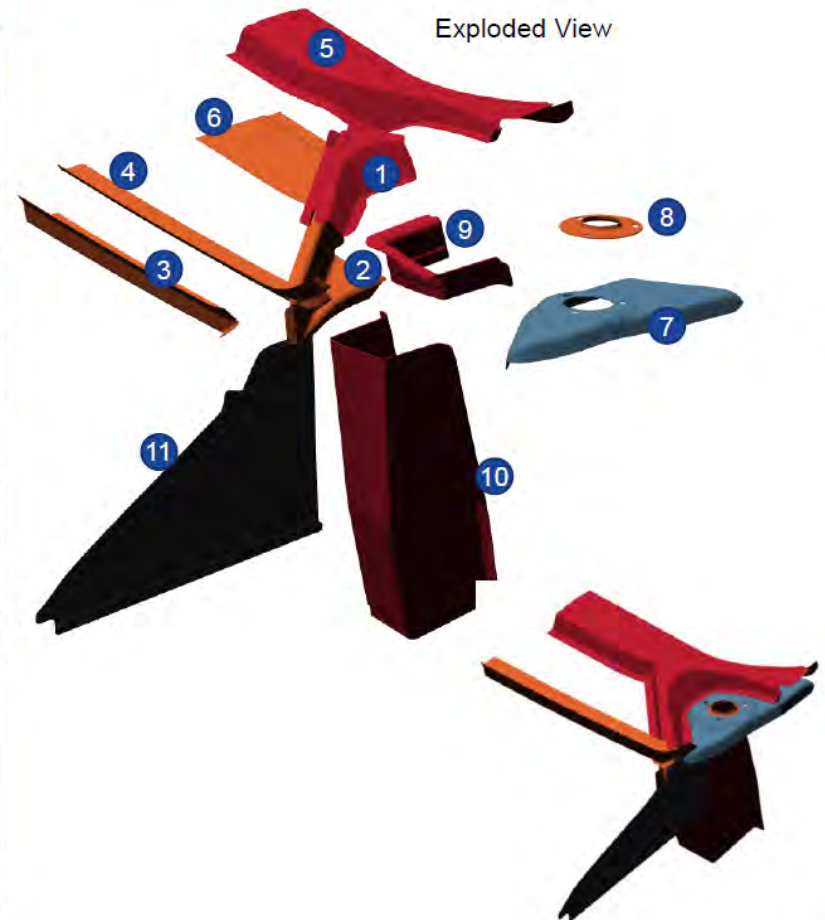


Figure 7.2.3.18 Front subframe AHSS grades

| Front Subframe | |
|---|--|
| Geometry/design | <p>Rigidly connected to BIW at points A (front longitudinal crush rails) B (glance beam), C (Vertical dash brace lower). Provides global body stiffness contribution and crash loadpaths. Front lateral beam (1) provides SORB lateral loadpath</p> <p>Z offset (D) promotes subframe folding collapse mechanism in front FFB, ODB and MPDB loadcases</p> <p>2.0mm gauge selected as standard for corrosion resistance for chassis parts</p> |
| Part 1:FRONT SUBFRAME LATERAL BEAM (FRONT) | 2.0mm CR860Y1180T-DP / Cold rolled tube |
| Part 2:FRONT SUBFRAME LONGITUDINAL LH | 2.0mm CR860Y1180T-DP / Cold rolled tube |
| Part 3: FRONT SUBFRAME LATERAL BEAM (REAR) | 2.0mm CR860Y1180T-DP / Cold rolled tube |
| Part 4: MISC. BRACKETS | 2.0mm CR860Y1180T-DP / Cold stamp |

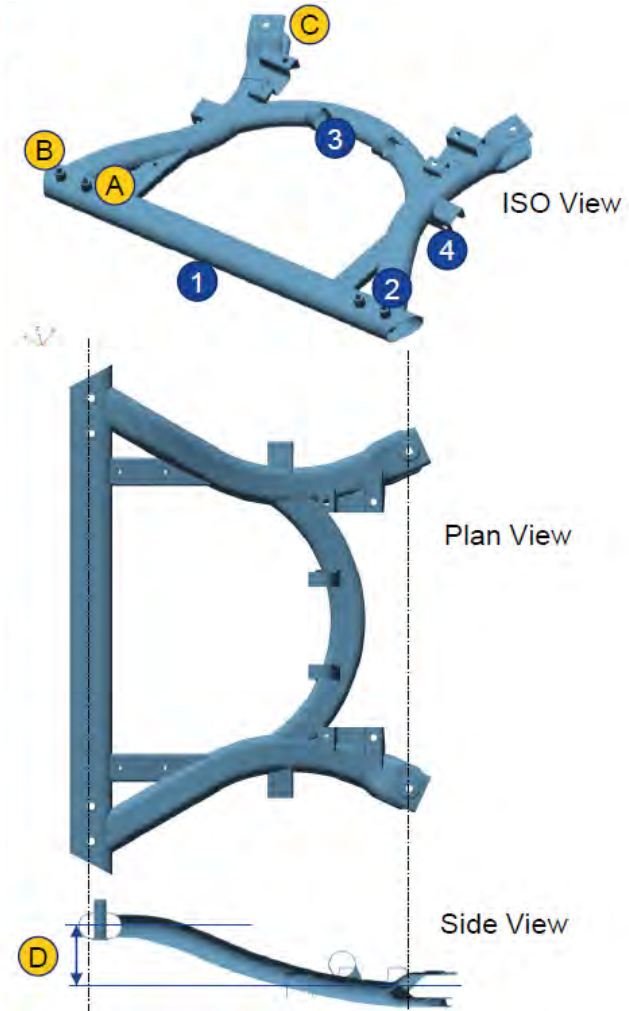


Figure 7.2.3.19 Front crash protection / intrusion prevention zone AHSS grades

| Front Crash Protection / Intrusion Zone | |
|--|--|
| Geometry/design | |
| Part 1: VERTICAL DASH BRACE FRONT LH | 2.0mm PHS-CR2000T-MB / Hot form |
| Part 2: VERTICAL DASH BRACE UPPER FRONT LH | 2.0mm PHS-CR2000T-MB / Hot form |
| Part 3: VERTICAL DASH BRACE LOWER INNER & OUTER | 2.0mm PHS-CR2000T-MB / Hot form |
| Part 4: ONE BAR UPPER AND LOWER | 1.0mm CR860Y1180T-DP / Cold stamp |
| Part 5: ONE BAR INNER | 2.0mm CR8501180T-DH / Cold stamp |
| Part 6: FRONT BULKHEAD | 2.0mm CR860Y1180T-DP / Cold stamp |
| Part 7: TORQUE BOX OUTER AND INNER | 2.0mm CR400Y780T-RA (outer), 1.0mm INNER / Cold stamp |
| Part 8: STRUT CROSS MEMBER FRONT | 1.0mm PHS-CR2000T-MB / Hot form |
| Part 9: STRUT CROSS MEMBER CLOSING PLATE | 1.0mm CR1550Y2000T-MS / Cold stamp |
| Part 10: A PILLAR OUTER | 1.2mm PHS-CR2000T-MB / Hot form (part of TWB OUTER RING) |
| Part 11: A PILLAR INNER | 1.2mm PHS-CR2000T-MB / Hot form |

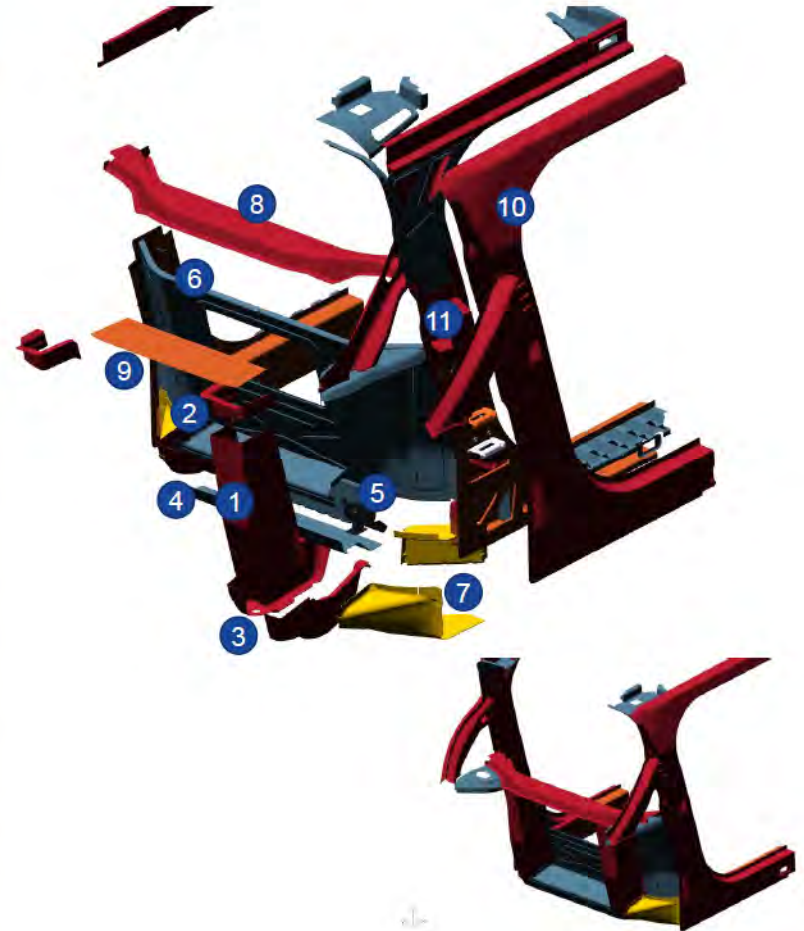
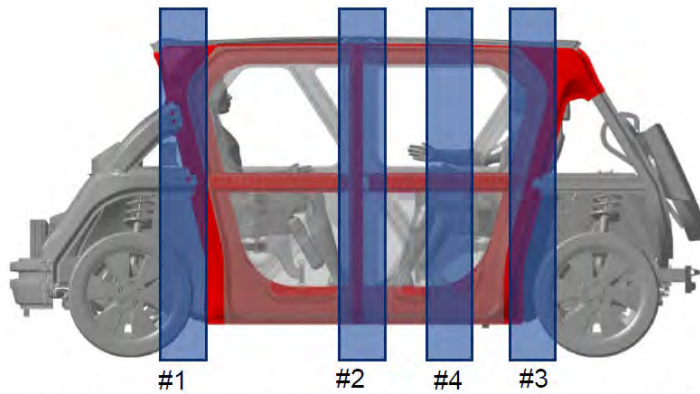
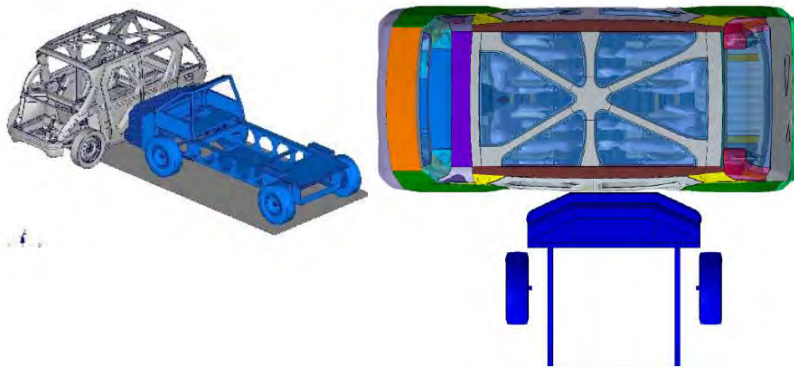
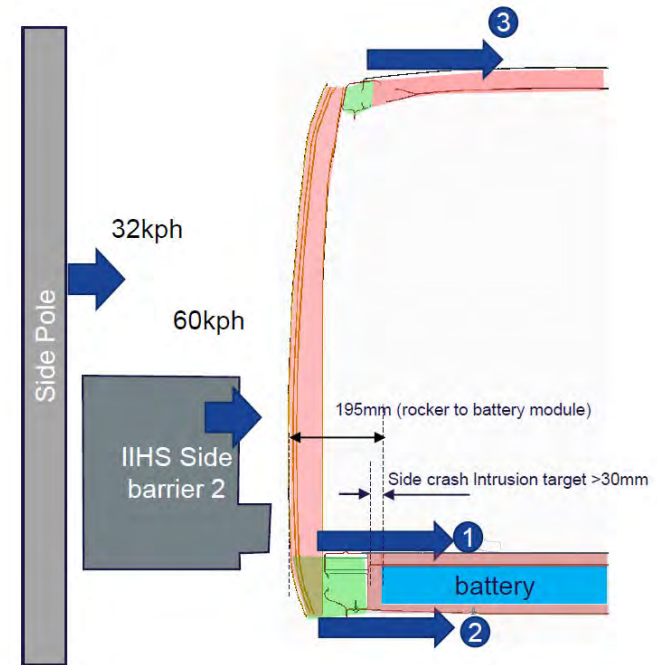


Figure 7.2.5.2 SEM1 side crash barrier alignment and strategy for loadpath and intrusion management

IIHS 60kph side barrier alignment to SEM1



USNCAP 32kph side pole impact crash locations SEM1



- Crush zones in rocker and cantrail to absorb side pole energy. High strength door, floor and roof structure intrusion zones
- Side pole crash loadpaths 1) Upper lateral cross members 2) Structural battery cover 3) roof structure
- Ensure >30mm crush intrusion target to protect battery modules

Figure 7.2.5.4 Crash CAE simulation of IIHS 60kph side barrier. Predicted intrusion values are in the IIHS "good" zone

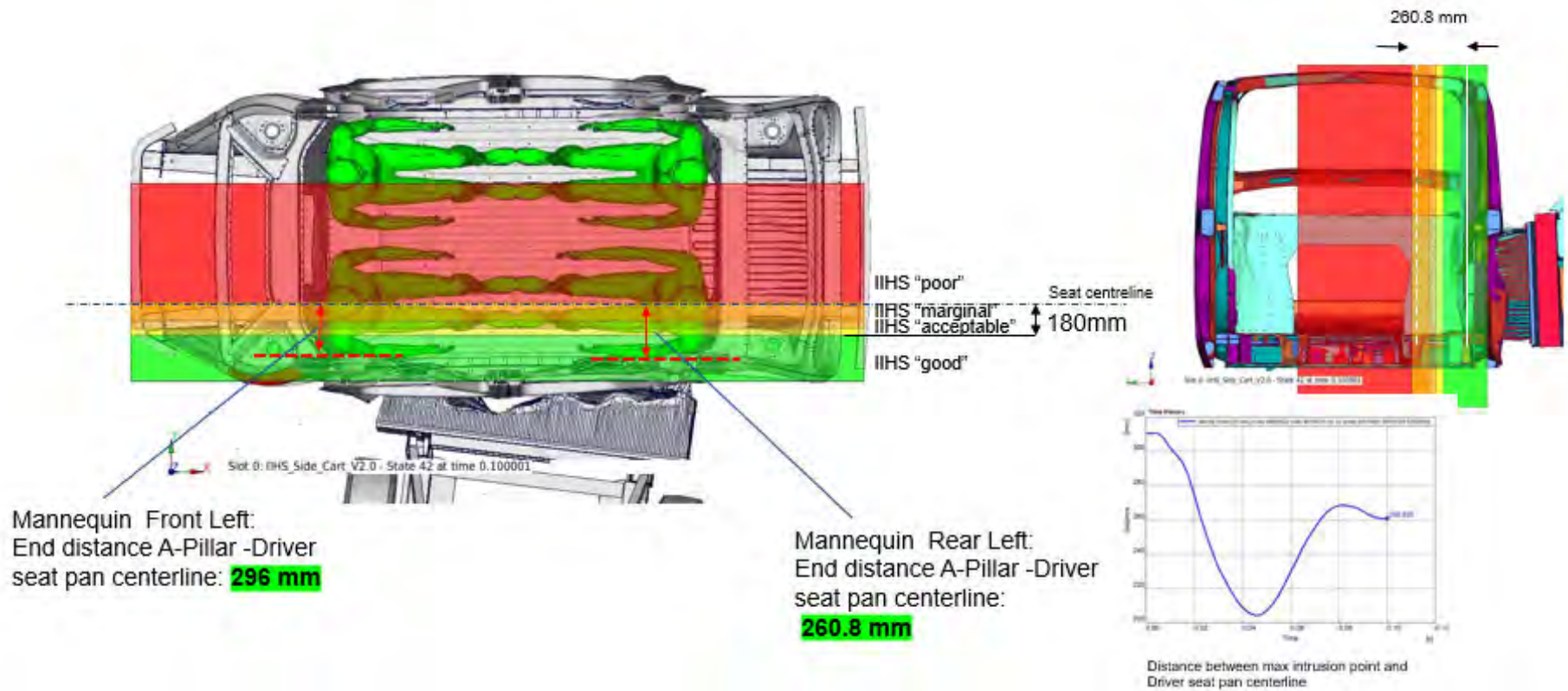


Figure 7.2.5.6 USNCAP 32kph side pole, predicted intrusion values for 4 test locations

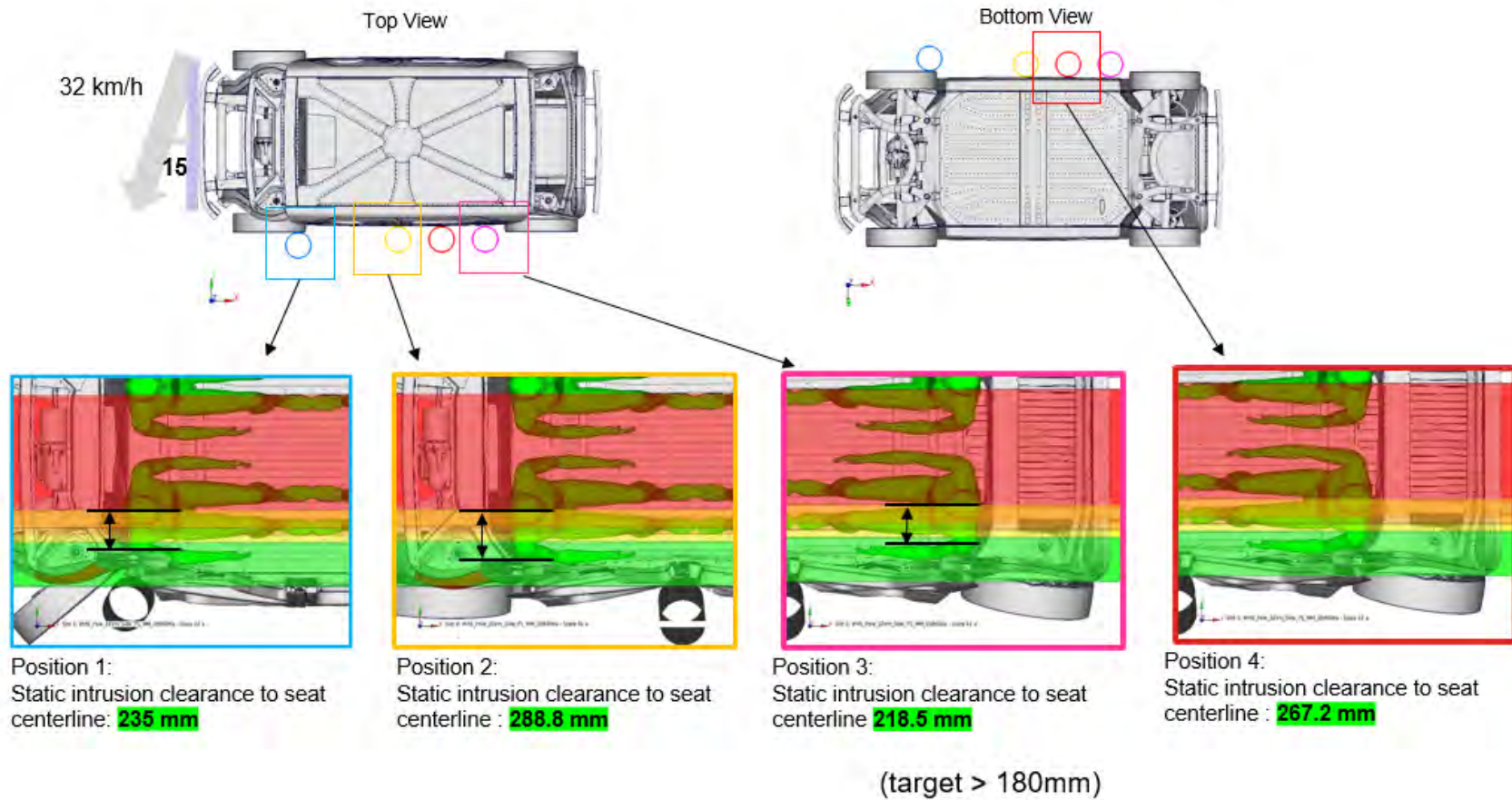


Figure 7.2.5.7 predicted intrusion values for the USNCAP 32kph side pole test (4 locations)

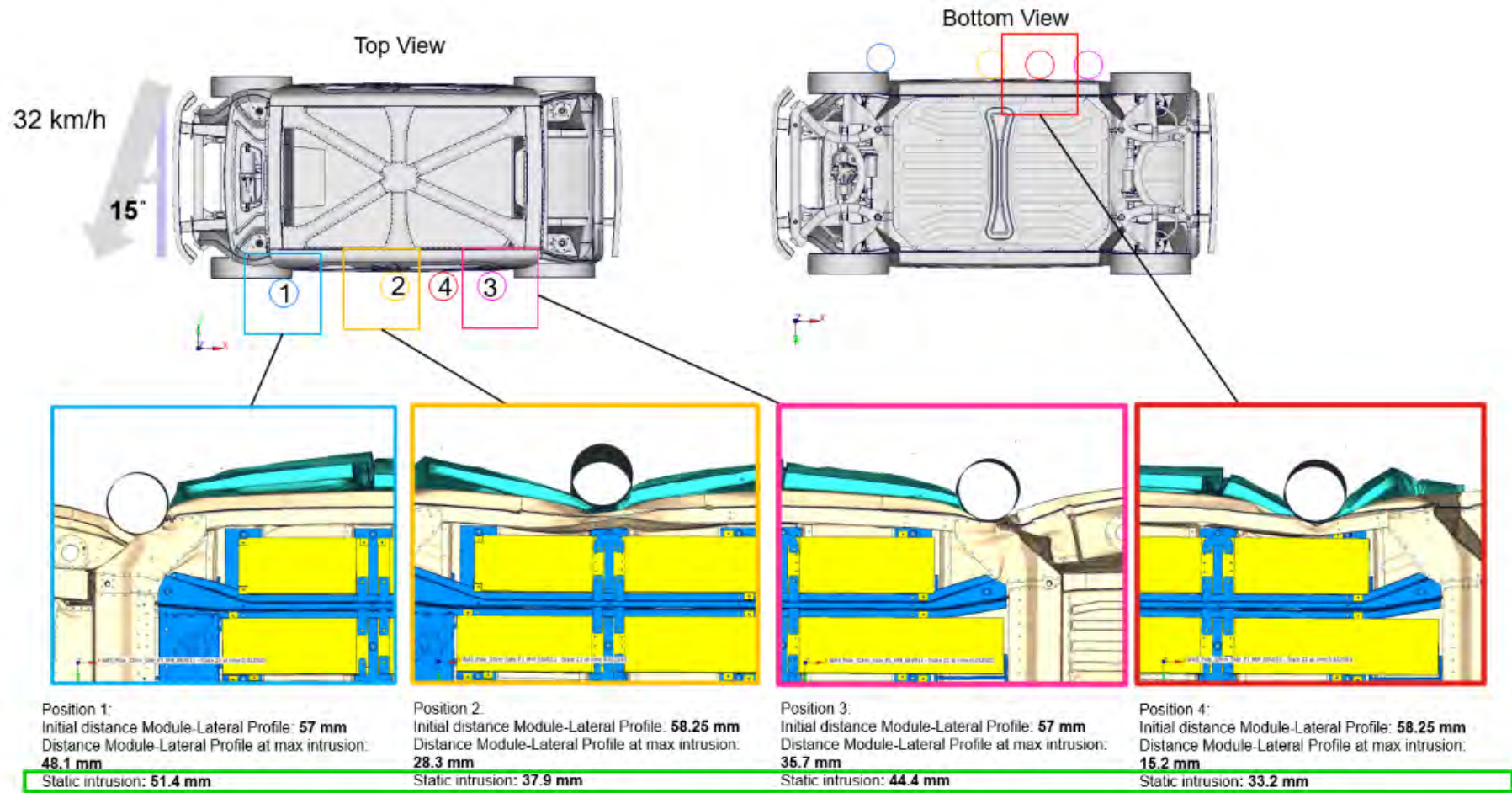


Figure 7.2.5.8a Door structural members and loadpaths into body structure for the IIHS side barrier loadcase (body structure shown for clarity)

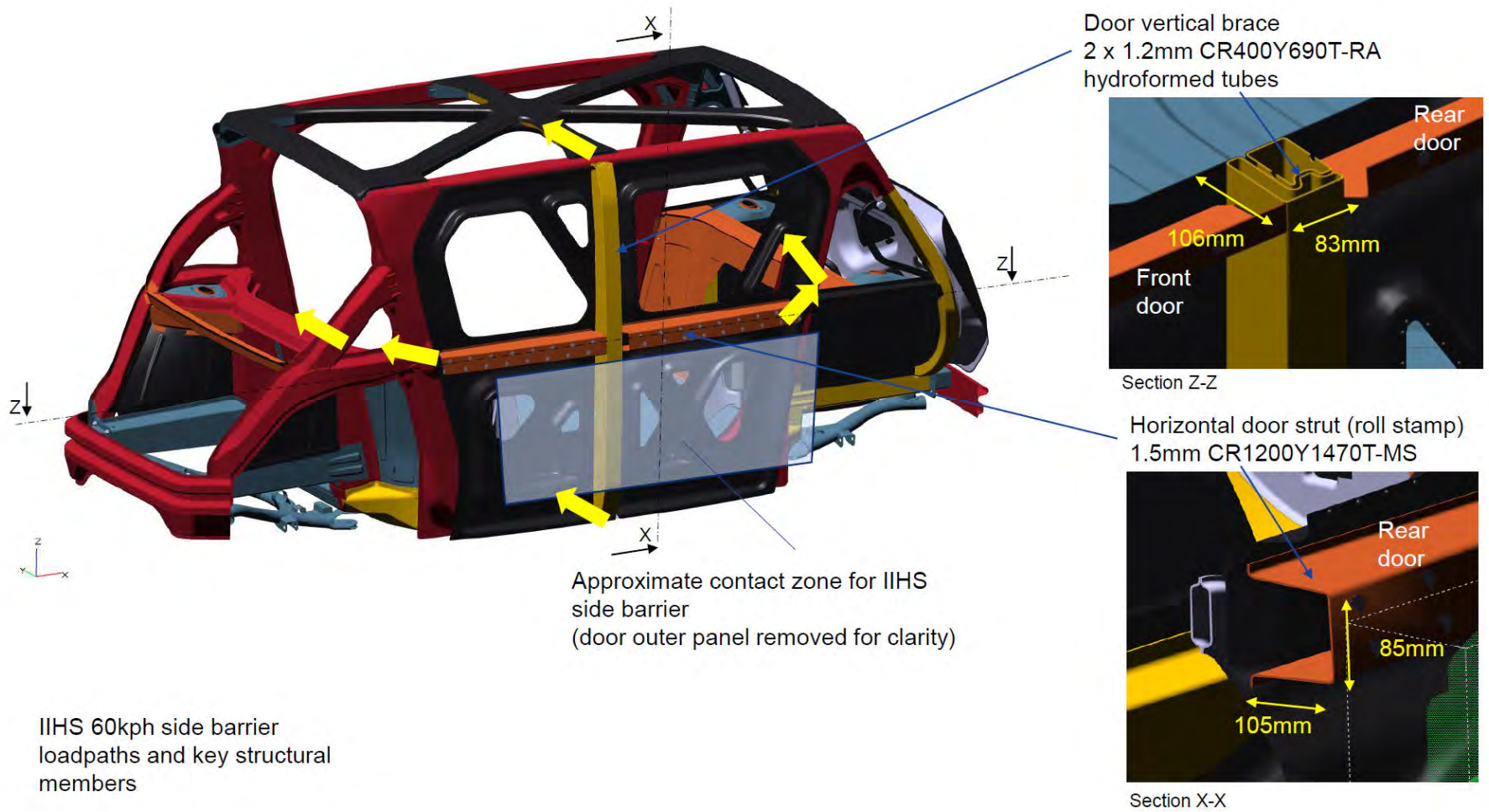


Figure 7.2.5.8b Door structural members and loadpaths into body structure for the IIHS side barrier loadcase (body structure shown for clarity)

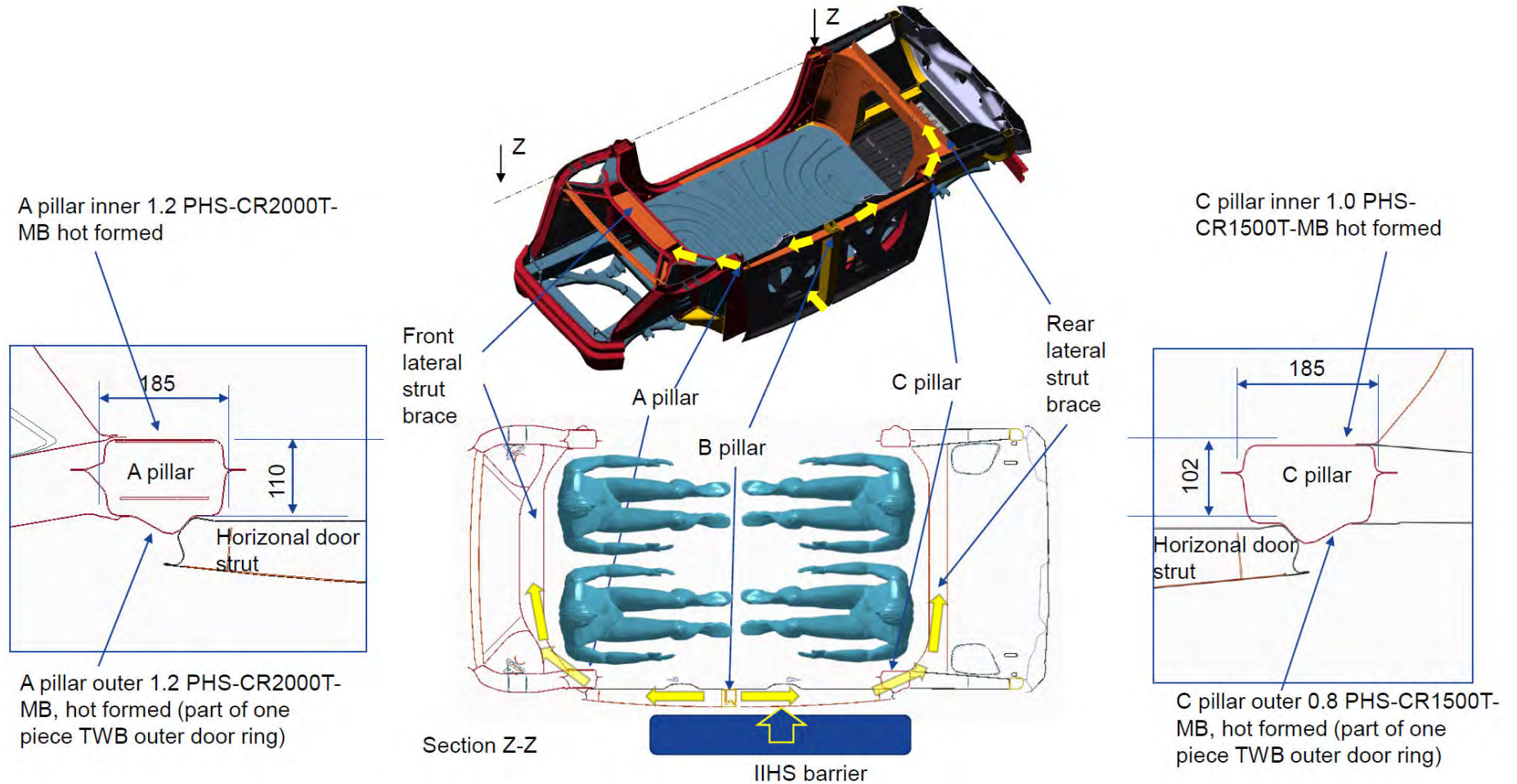
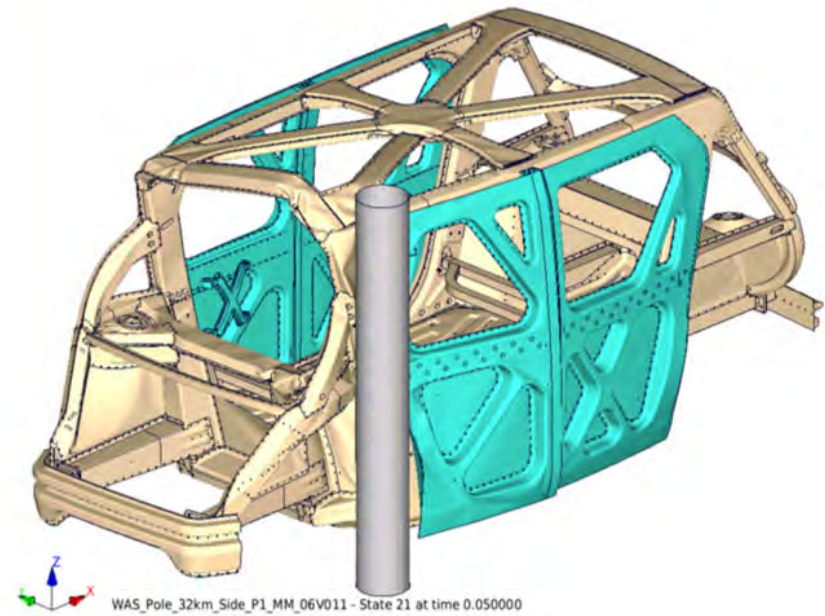
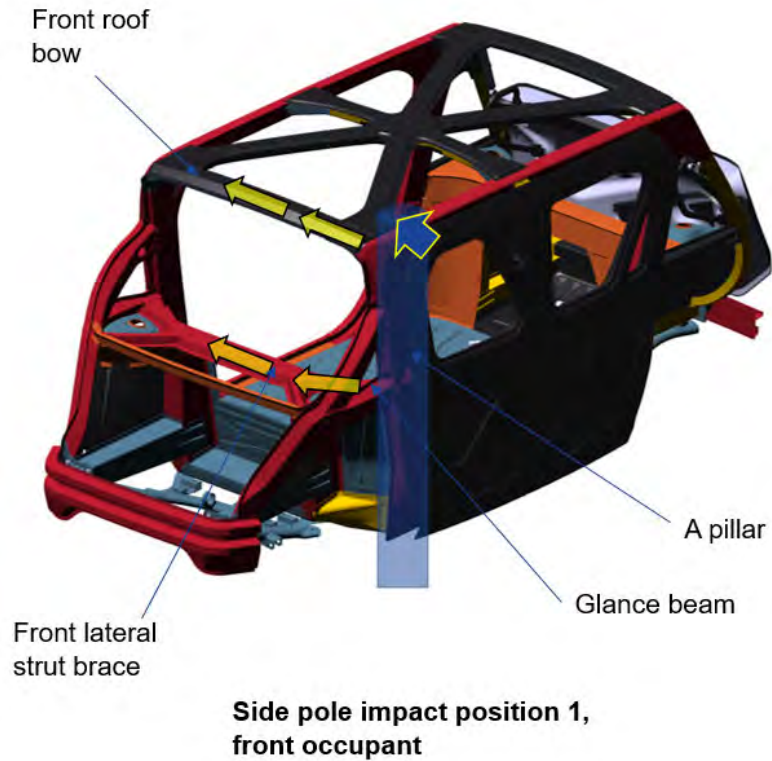


Figure 7.2.5.11 USCAP 32kph side pole crash loadcase, position 1. Loadpaths and crash simulation result



Side pole crash simulation, 50ms

Figure 7.2.5.12 USCAP 32kph side pole crash loadcase, position 3. Loadpaths and crash simulation result

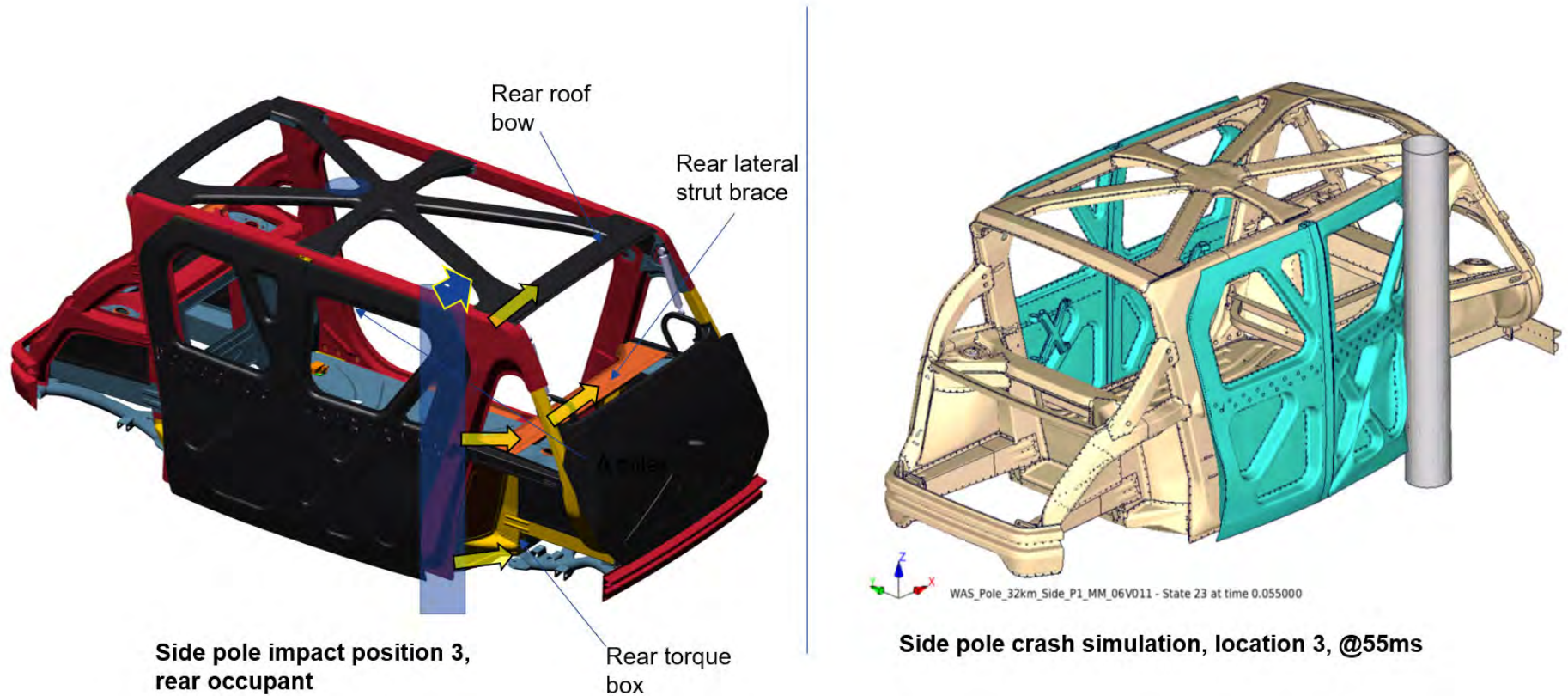


Figure 7.2.5.14 body structure cross section in X at door split point, side pole position 2. (battery modules, cooling plates, interconnects removed for clarity)

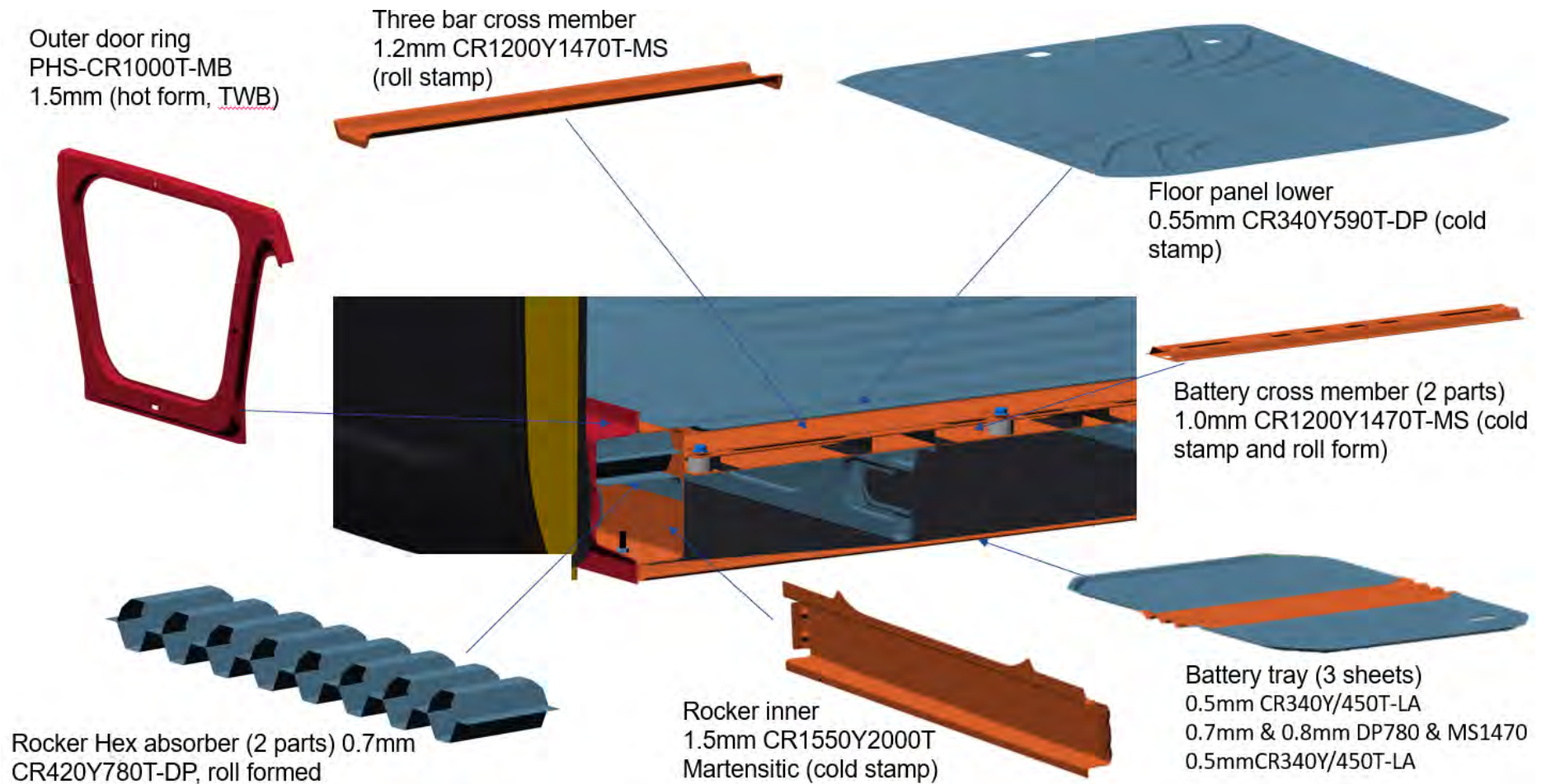


Figure 7.2.5.15 body structure cross section in X showing side pole crash intrusion prevention measures and upper & lower loadpaths

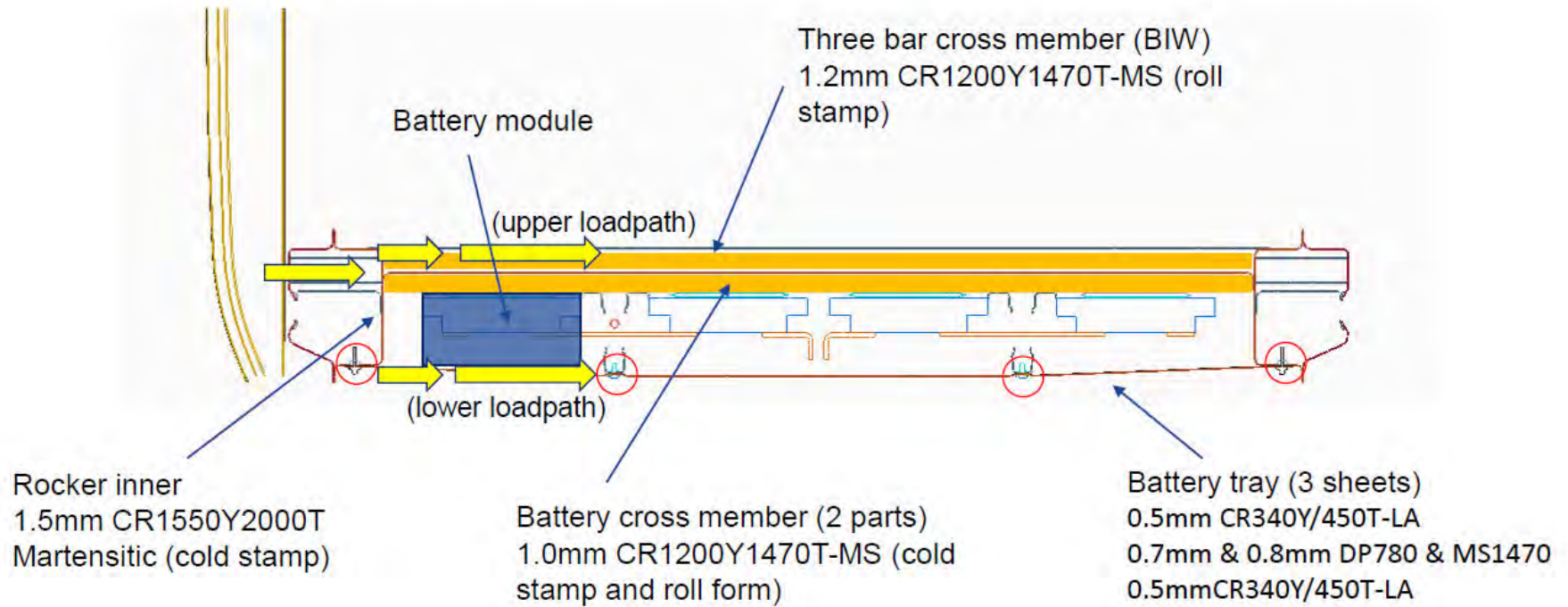


Figure 7.2.5.16 Body structure (floor panel removed) showing body cross members (two, three and four bar) and battery cross members (upper loadpaths)

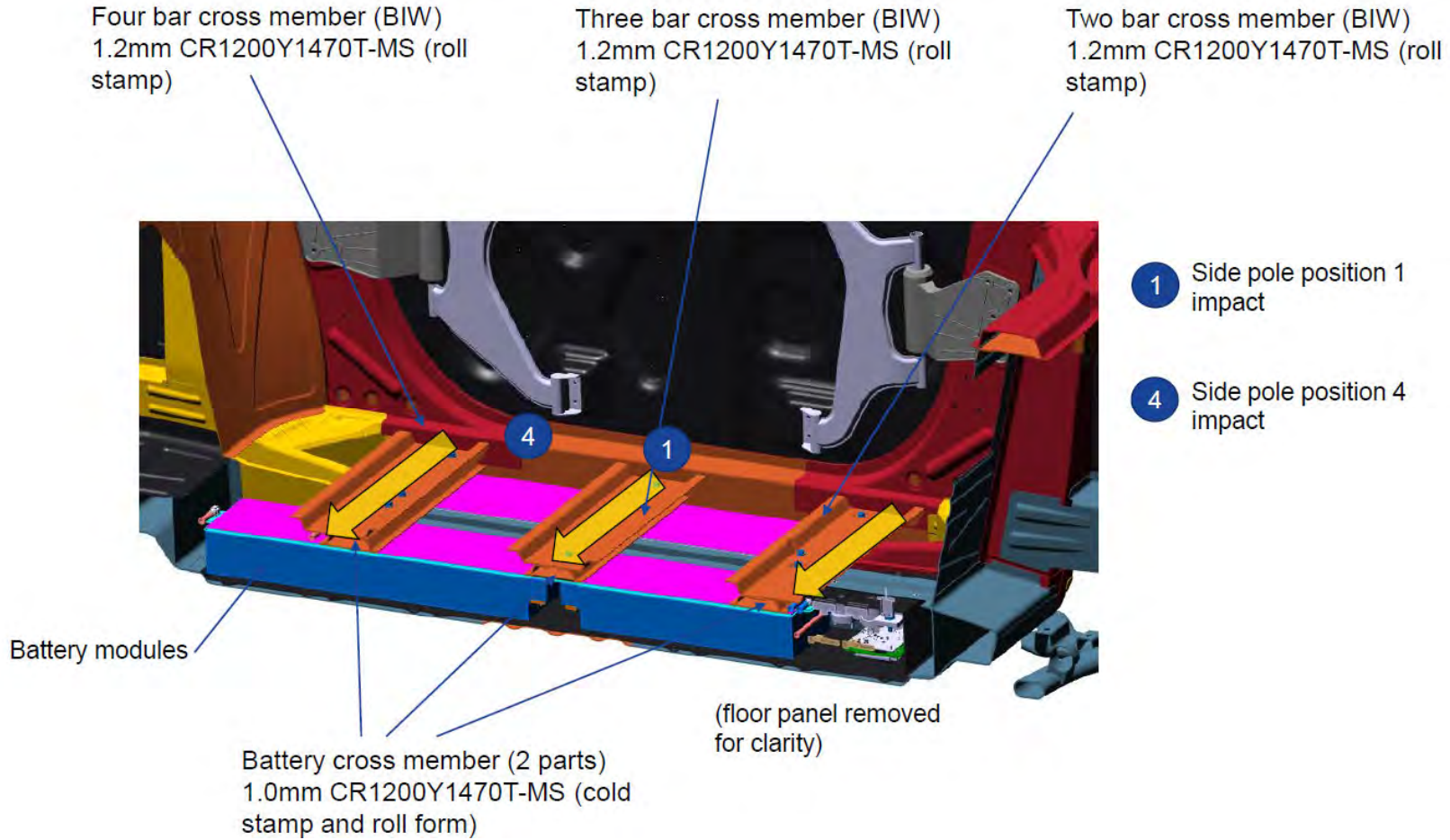
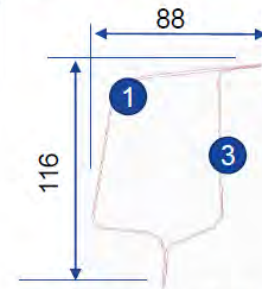
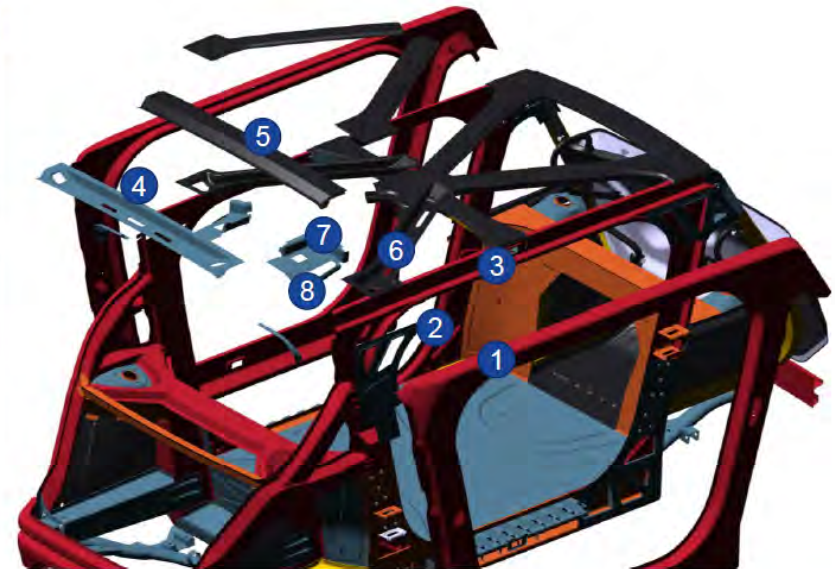


Figure 7.2.5.18 SEM1 mid zone upper structure AHSS grades

| Roof structure (front) | |
|---|---|
| Part 1: OUTER RING TWB LH | TWB (A PILLAR PHS-CR2000T-MB 1.2mm, C PILLAR PHS-CR1500T-MB 0.8mm, Cantrail/roof outer PHS-CR1000T-MB 1.5mm, Rocker PHS-CR1000T-MB 1.5mm) |
| Part 2: A POST INNER REINFORCEMENT UPPER | 1.5mm CR800Y1180T-DP / Cold stamp |
| Part 3: ROOF SIDE RAIL INNER LH | 0.8mm PHS-CR1500T-MB / Hot form |
| Part 4: FRONT HEADER INNER | 0.8mm CR780Y980T-CP / Cold stamp |
| Part 5: FRONT HEADER OUTER A-SURFACE | 0.6mm CR260Y/370T-BH / Cold stamp |
| Part 6: DIAGONAL INNER PANEL FRONT | 0.7mm CR550Y/620T-LA/ Cold stamp |
| Part 7: FRONT INNER ROOF HEADER GUSSET MOUNT | 1.0mm CR700Y980T-DP / Cold stamp |
| Part 8: FRONT OUTER ROOF HEADER GUSSET MOUNT | 1.0mm CR700Y980T-DP / Cold stamp |



Section XX Cantrail section

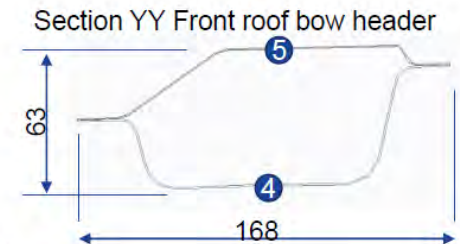
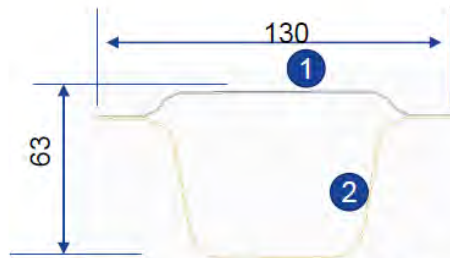


Figure 7.2.5.19 SEM1 mid zone roof structure and AHHS grades

| Roof structure (middle) | |
|--|-----------------------------------|
| Geometry/design | |
| Part 1: MID ROOF BOW OUTER A-SURFACE | 0.6mm CR260Y/370T-BH / Cold stamp |
| Part 2: MID ROOF BOW INNER | 0.8mm CR820Y1180T-RA / Cold stamp |
| Part 3: MID INTERSECTION OUTER A-SURFACE PANEL | 0.6mm CR260Y/370T-BH / Cold stamp |
| Part 4: MID INTERSECTION INNER PANEL | 0.5_CR260Y/370T-BH / Cold stamp |
| Parts 5, 7 8 & 9 : DIAGONAL OUTER A SURFACE | 0.6mm CR260Y/370T-BH / Cold stamp |
| Parts 10, 11, 12, 13 : DIAGONAL INNER PANEL | 0.7mm CR550Y/620T-LA/ Cold stamp |



Section YY Middle roof bow



Figure 7.2.5.20 SEM1 outer ring and approach for A surfaces

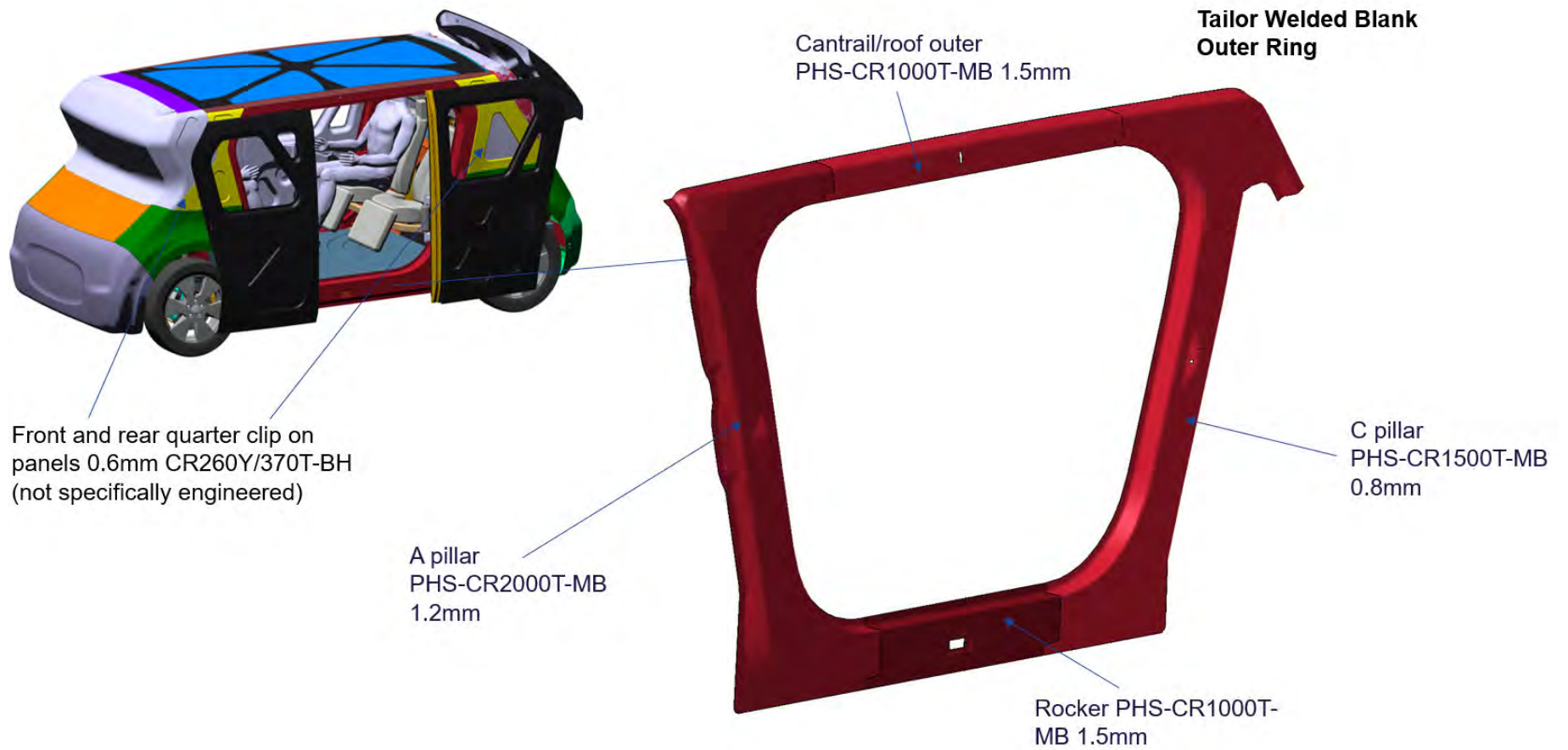


Figure 7.2.5.1 IHS Roof Crush Strength Evaluation 1 and SEM1 CAE calculation

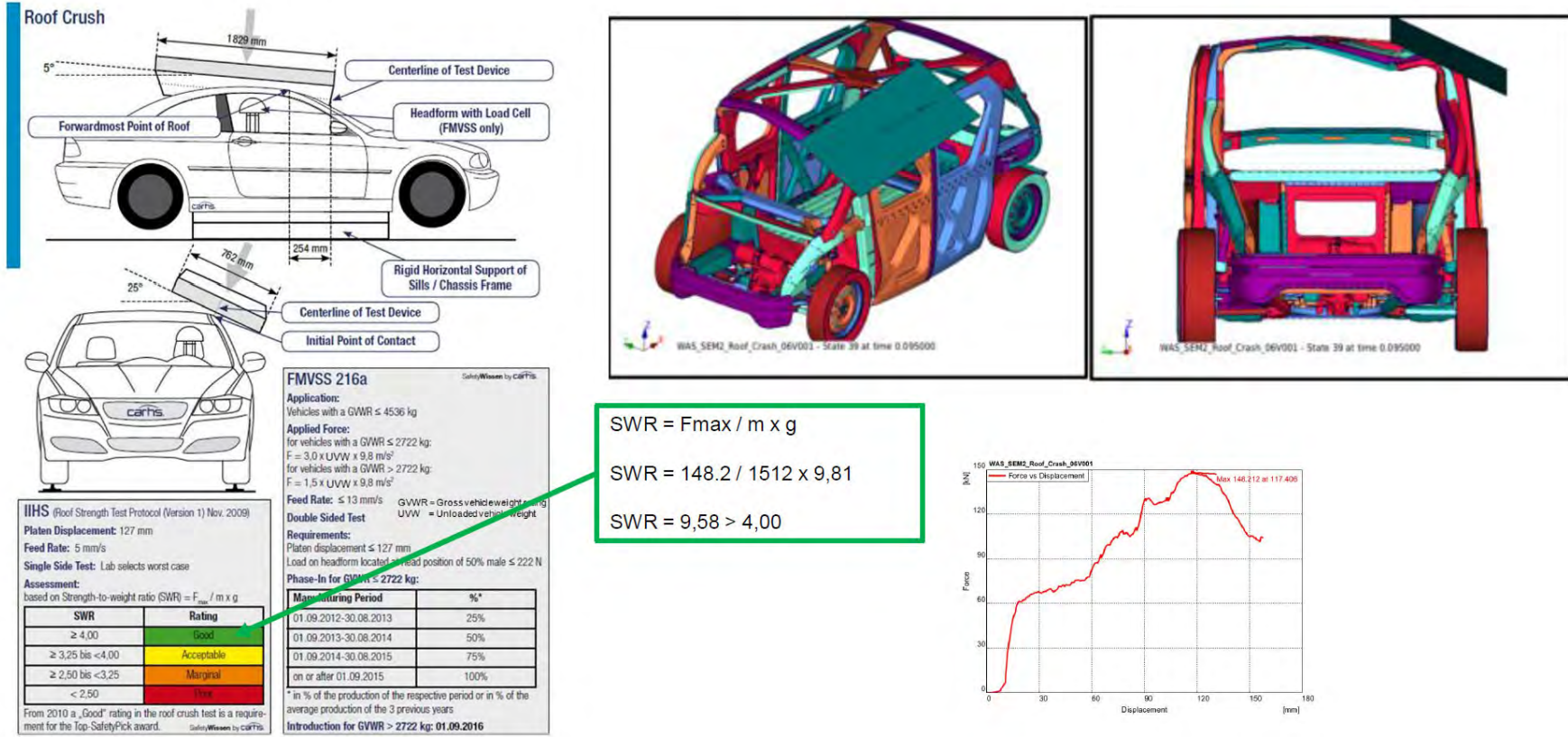


Figure 7.2.6.1 Rear zone subassemblies

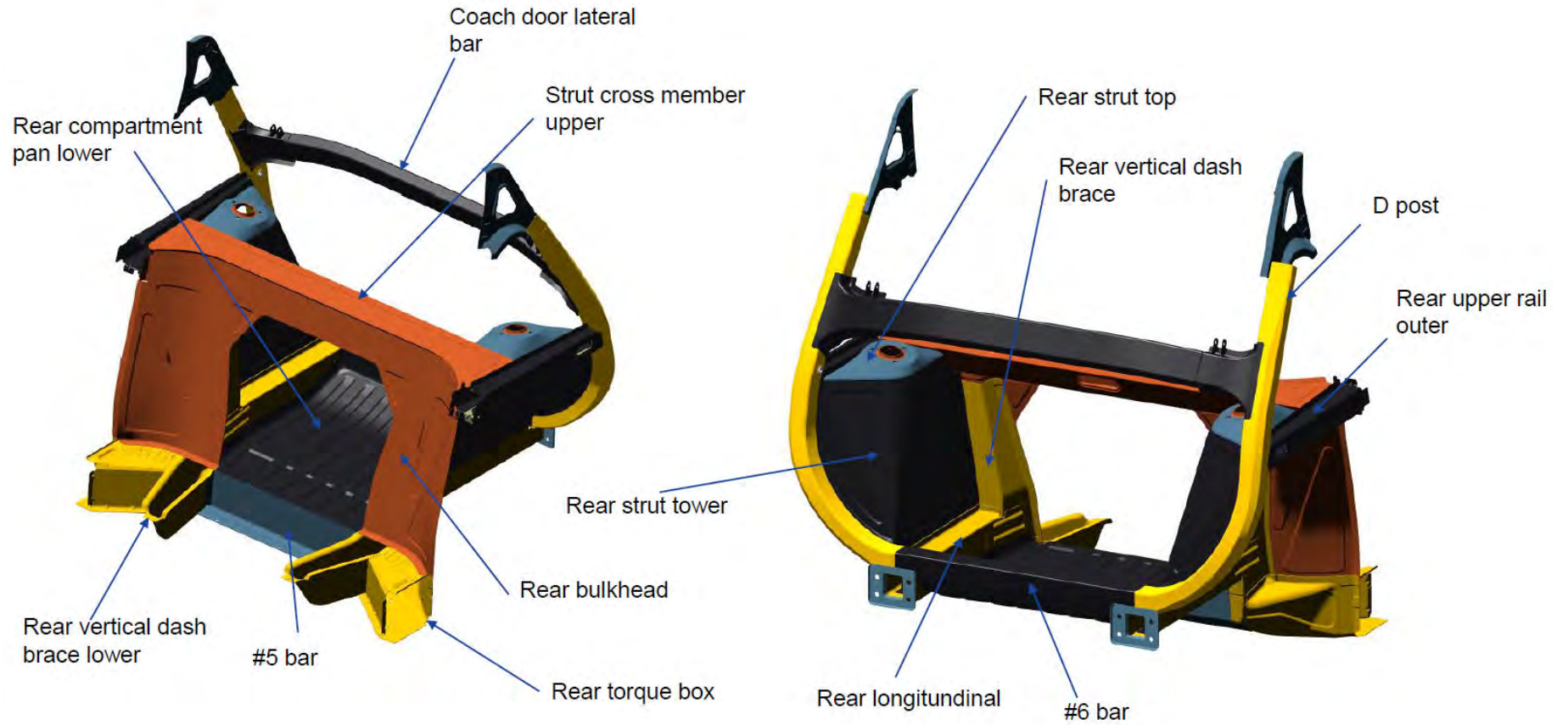


Figure 7.2.6.4 SEM1 Body structure rear zone

| Rear body structure (crush zone) | |
|---|---|
| Geometry/design | Crush cans (2) and longitudinal rails (3) tuned to crush axially under FMVSS305 EV loadcase. Longitudinals are 2 grade TWB. Rear subframe is rigidly bolted to BIW and engineered to fold in rear crash |
| Part 1: REAR BUMPER BEAM | 2.0mm PHS-CR2000T-MB / hot formed |
| Part 2: REAR CRUSH CAN | 1.5mm CR350Y600T DP / cold formed |
| Parts 3: REAR LONGITUDINAL RAILS (2 PARTS) | TWB: (A) 1.6mm CR820Y1180T-RA (B) 1.4mm CR600Y980T-RA / cold formed |
| Part 4: REAR SUBFRAME | 2.0mm CR860Y1180T-DP / hydroformed tubes |
| Part 5: REAR COMPARTMENT PAN LOWER | 0.5mm CR350Y/450T-LA / cold formed |

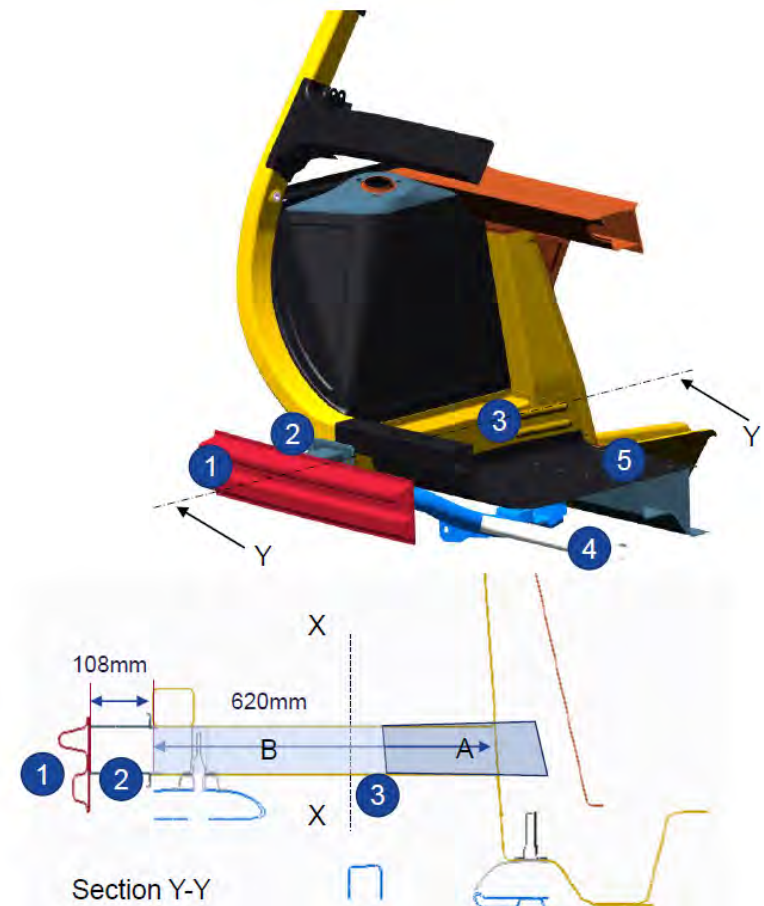
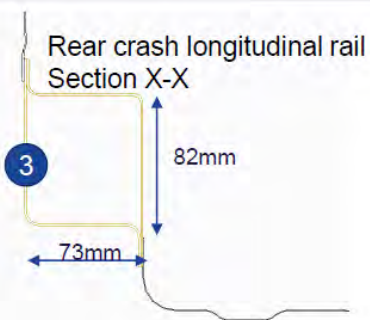


Figure 7.2.6.5 SEM1 Body structure rear zone

| Rear body structure (intrusion zone) | |
|---|---|
| Geometry/design | Vertical dash braces provides primary crash load reaction in rear crash. Five bar provides intrusion protection for battery. Rear strut cross member and rear bulkhead provide crush load reaction and intrusion strength |
| Part 1: REAR VERTICAL DASH BRACE | 1.6mm CR820Y1180T-RA / cold formed |
| Parts 2 & 3: FIVE BAR (INNER & OUTER) | 0.8mm CR900Y1180T-CP & 1.8mm CR420Y780T-DP / cold formed |
| Parts 4 & 5: REAR STRUT CROSS MEMBER (UPPER AND LOWER) | 1.0mm CR1200Y1470T-MS |
| Part 6: REAR BULKHEAD | TWB (A) 1.0mm CR1200Y1470T-MS & (B) 0.8mm CR1000Y1470T-MS |
| | |

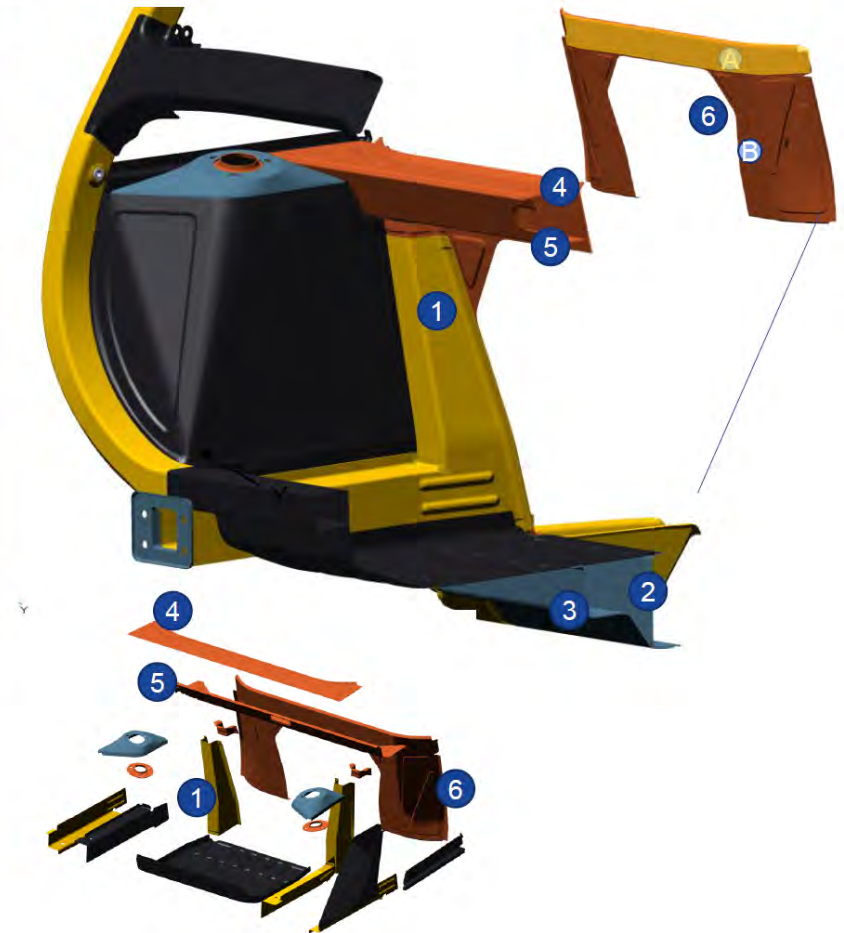


Figure 7.2.6.6 Rear torque box and five bar assembly

| Rear body structure (torque box, five bar, lower vertical dash brace) | |
|--|---|
| Geometry/design | Rear torque box and five bar assembly forms the lower part of the rear crash intrusion zone. The assembly also provides contribution to global body stiffness |
| Parts 1 & 2: REAR VERTICAL DASH BRACE LOWER (INNER & OUTER) | 1.0mm CR820Y1180T-RA / cold formed |
| Parts 3 & 4: TORQUE BOX REAR (INNER & OUTER) | 1.5mm CR400Y780T-RA / cold formed |
| Part 5: FIVE BAR OUTER | 0.8mm CR900Y1180T-CP / cold formed |
| Part 6: FIVE BAR INNER | 0.8mm CR900Y1180T-CP / cold formed |

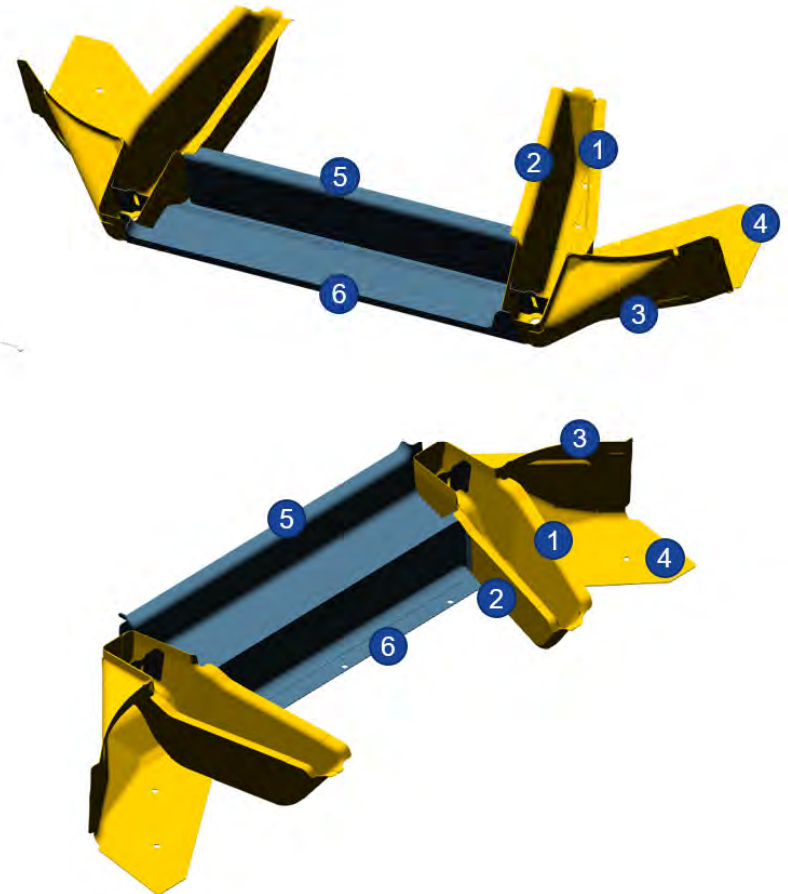
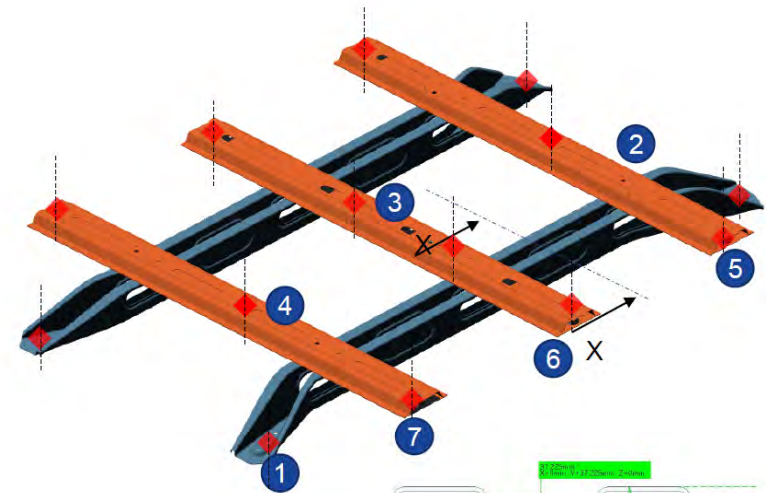


Figure 7.3.2.1 SEM1 battery carrier frame design and AHSS grades

| Battery carrier frame | |
|---|------------------------------------|
| Part 1 : CARRIER FRAME LONGITUDINAL (LEFT & RIGHT) | 1.8mm CR260Y450T-DP / cold formed |
| Part 2: UPPER CROSS MEMBER #3 | 1.0mm CR1200Y1470T-MS / roll stamp |
| Parts 3 & 4: UPPER CROSS MEMBER #2 & 3 | 1.0mm CR1200Y1470T-MS / roll form |
| Parts 5,6 & 7: LOWER CROSS MEMBERS #3, #2, #1 | 1.0mm CR1200Y1470T-MS / roll form |



◆ Fixing position to body structure

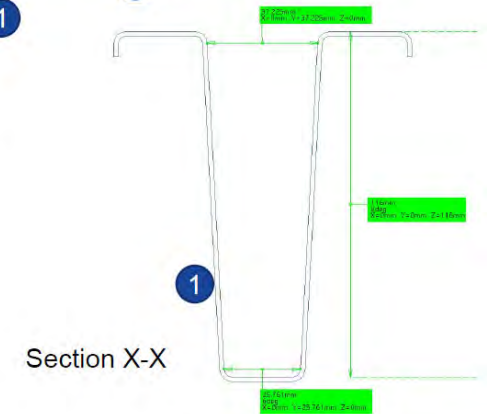


Figure 7.3.3.1 Battery tray design and AHSS grades

| Battery tray (bottom cover) | |
|---|--|
| Geometry/design | <p>3 sheet steel sandwich cover combines to provide high stiffness and strength. Triangular stamping in 2 provides section depth for stiffness and strength</p> <p>Use of 0.5mm and 0.7mm gauge helps achieve total weight 33.2kg</p> <p>Joining methods: spotweld, laser weld, adhesive</p> |
| Part 1: BATTERY TRAY UPPER | 0.5mm CR340Y/450T-LA / cold formed |
| Part 2 : BATTERY TRAY TRIANGLECOMB FRONT & REAR | 0.5mm CR340Y/450T-LA / cold formed |
| Part 3: BATTERY TRAY LOWER | <p>TWB</p> <p>(A) 0.7mm CR420Y780T-DP</p> <p>(B) 1.0mm CR1200Y1470T-MS / cold formed</p> |

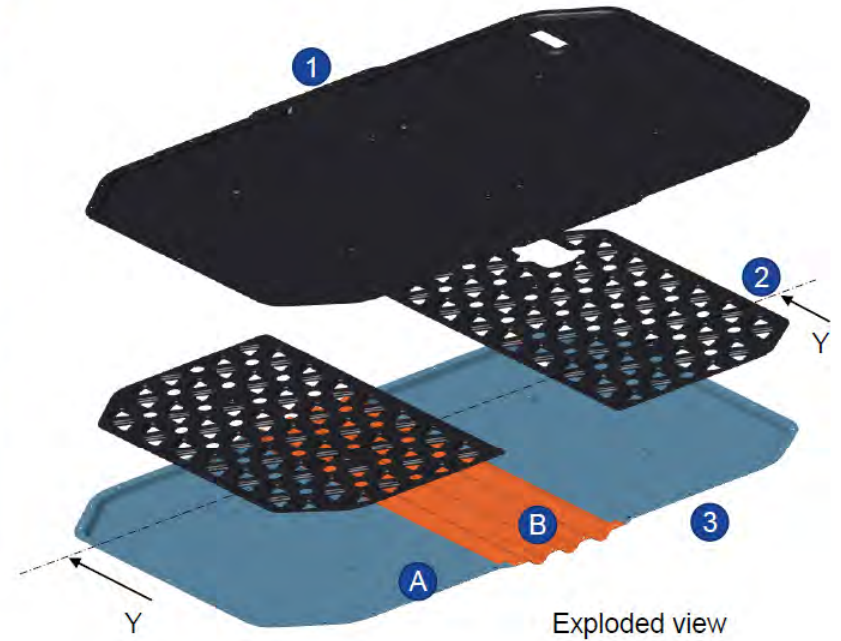


Figure 7.3.3.2 CAE results of battery tray debris and jacking loadcases

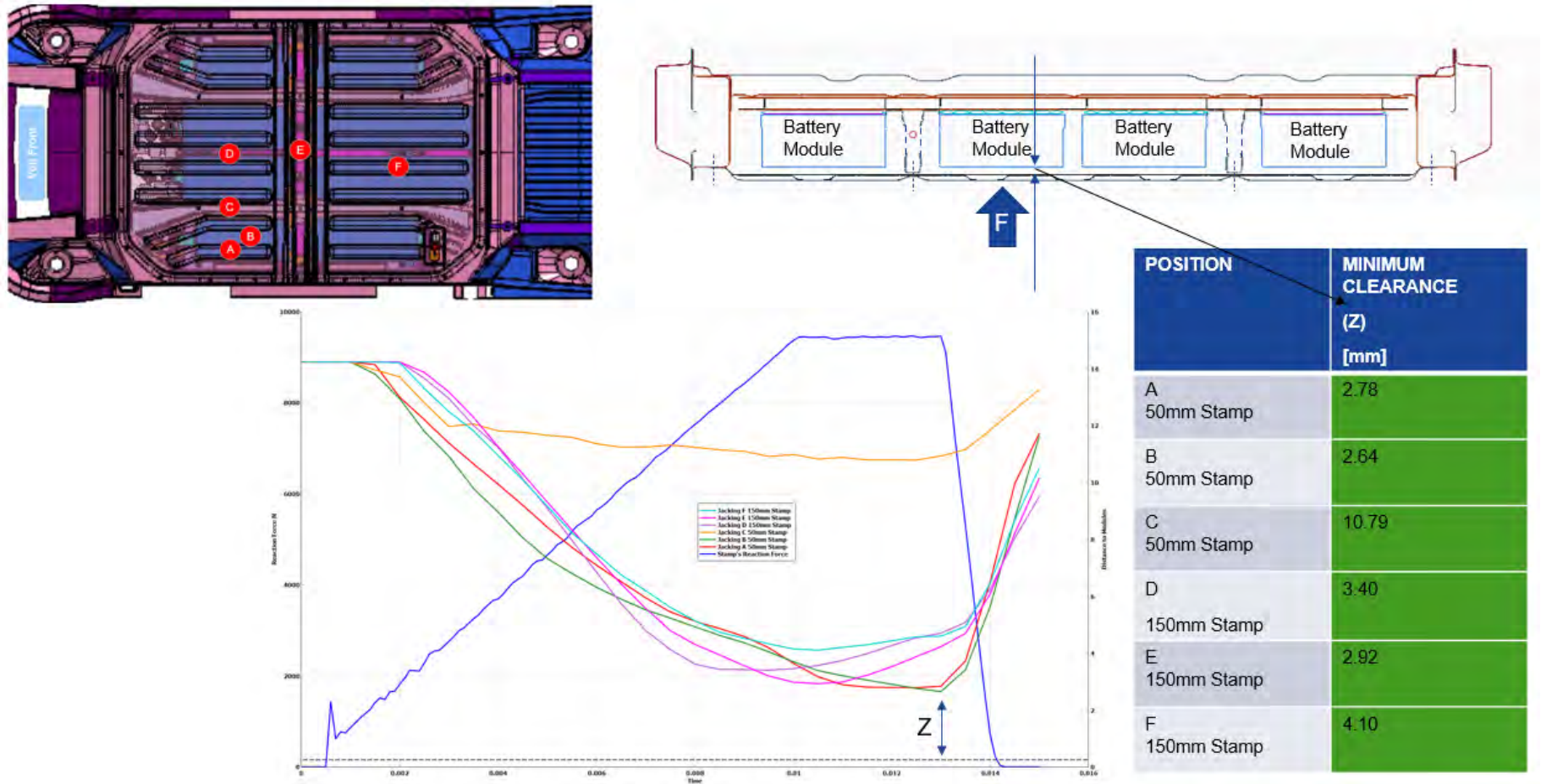


Figure 7.3.3.4 Battery durability FEA. Predicted Von-Mises stresses (Root Mean Square)

Battery Durability FEA. Predicted PSD Analysis Root Mean Square Von-Mises stress

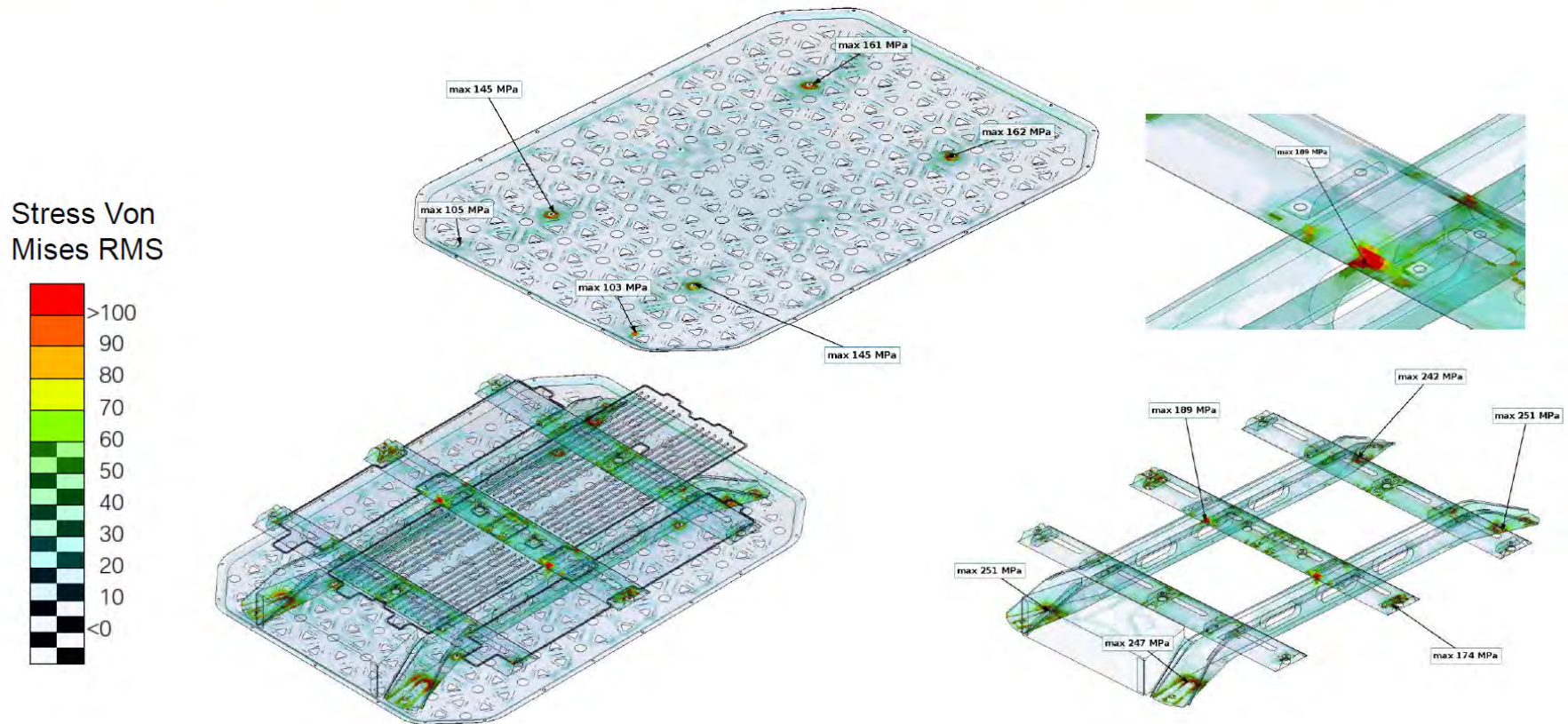


Figure 7.3.3.6 Steel E-Motive battery tray sealing configuration

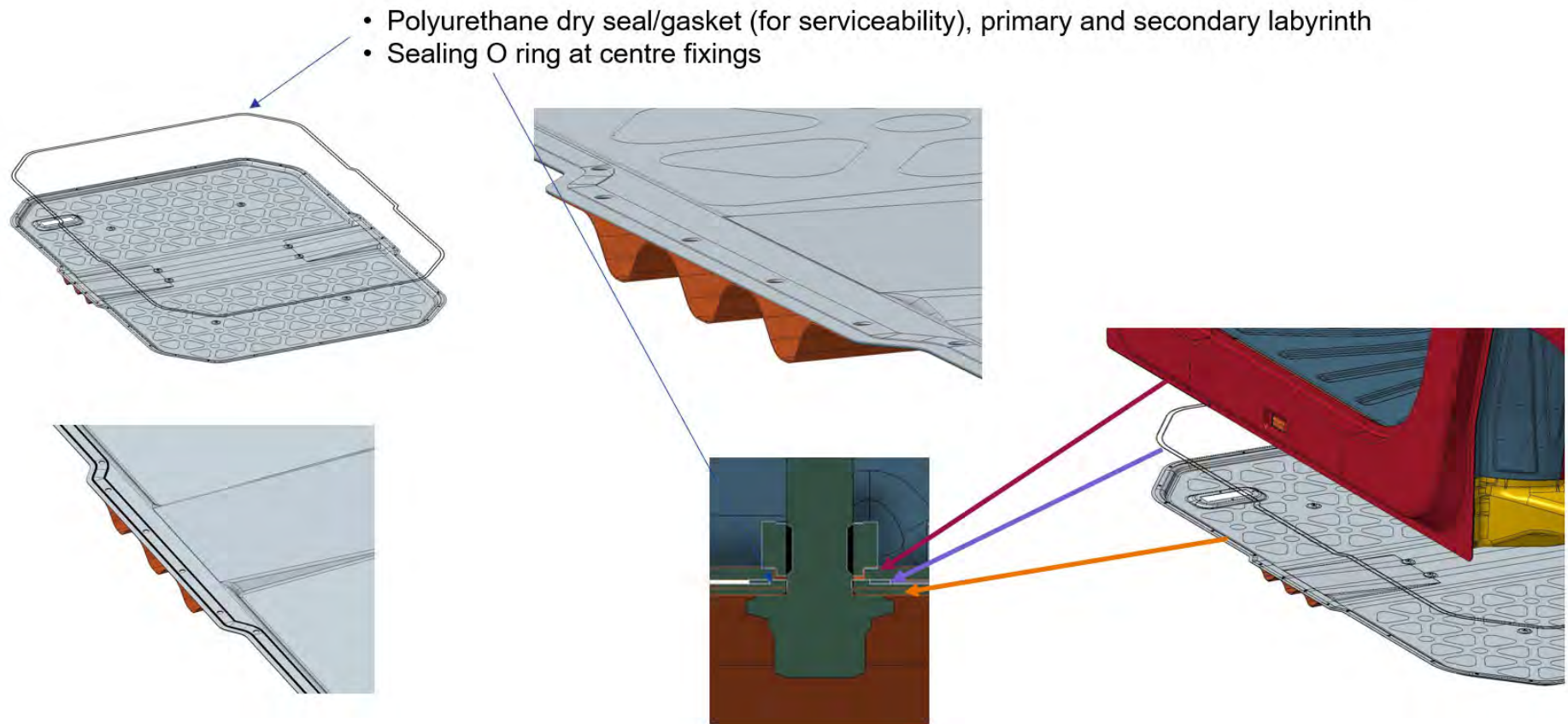
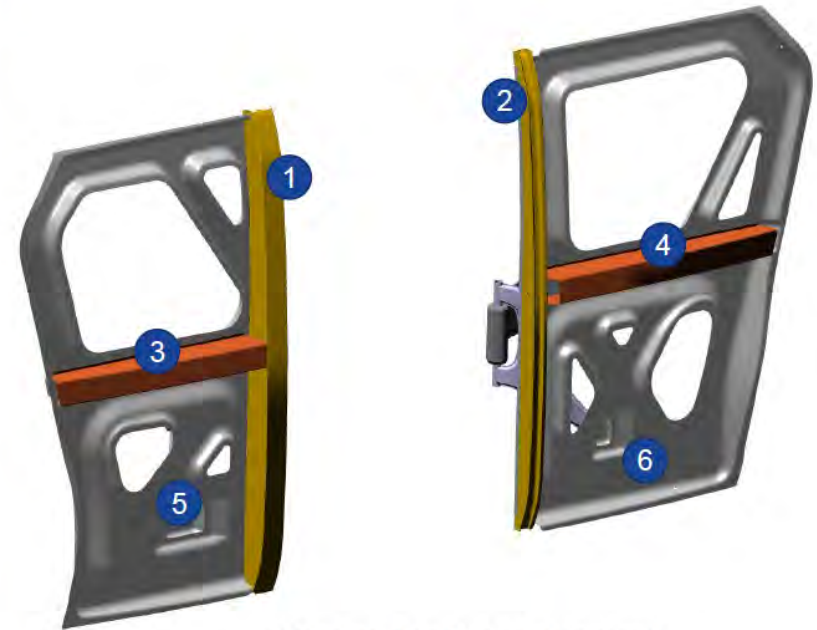


Figure 7.4.1.2.4 AHSS grades in SEM1 scissor doors

| Scissor Door Structure | |
|--|---|
| Geometry/design | B pillars (1 & 2) and horizontal door struts (3 & 4) provide main crash loadpaths for IIHS side barrier. B pillars overlap the cantrail (top) and rocker sections (bottom) to provide crash loadpath into BIW structure. Mild steel door inner panels and bake hardenable outer panels. Lattice features provide some |
| Parts 1 & 2: B PILLAR (FRONT AND REAR) | 1.2mm CR400Y690T-RA / Hydroformed |
| Parts 3 & 4: HORIZONTAL DOOR STRUTS (FRONT AND REAR) | 1.5mm CR1200Y1470T-MS / roll stamp |
| Parts 5 & 6: DOOR INNER PANEL (FRONT AND REAR) | 1.2mm Mild140/270 / cold stamp |
| Parts 7 & 8: DOOR OUTER PANEL(not shown) (FRONT AND REAR) | 0.7mm CR280Y/400T-BH / cold stamp |



(door outer A surface panel removed)

Figure 7.6.2.3 Pareto of the highest 45 part costs in the SEM1 BIW

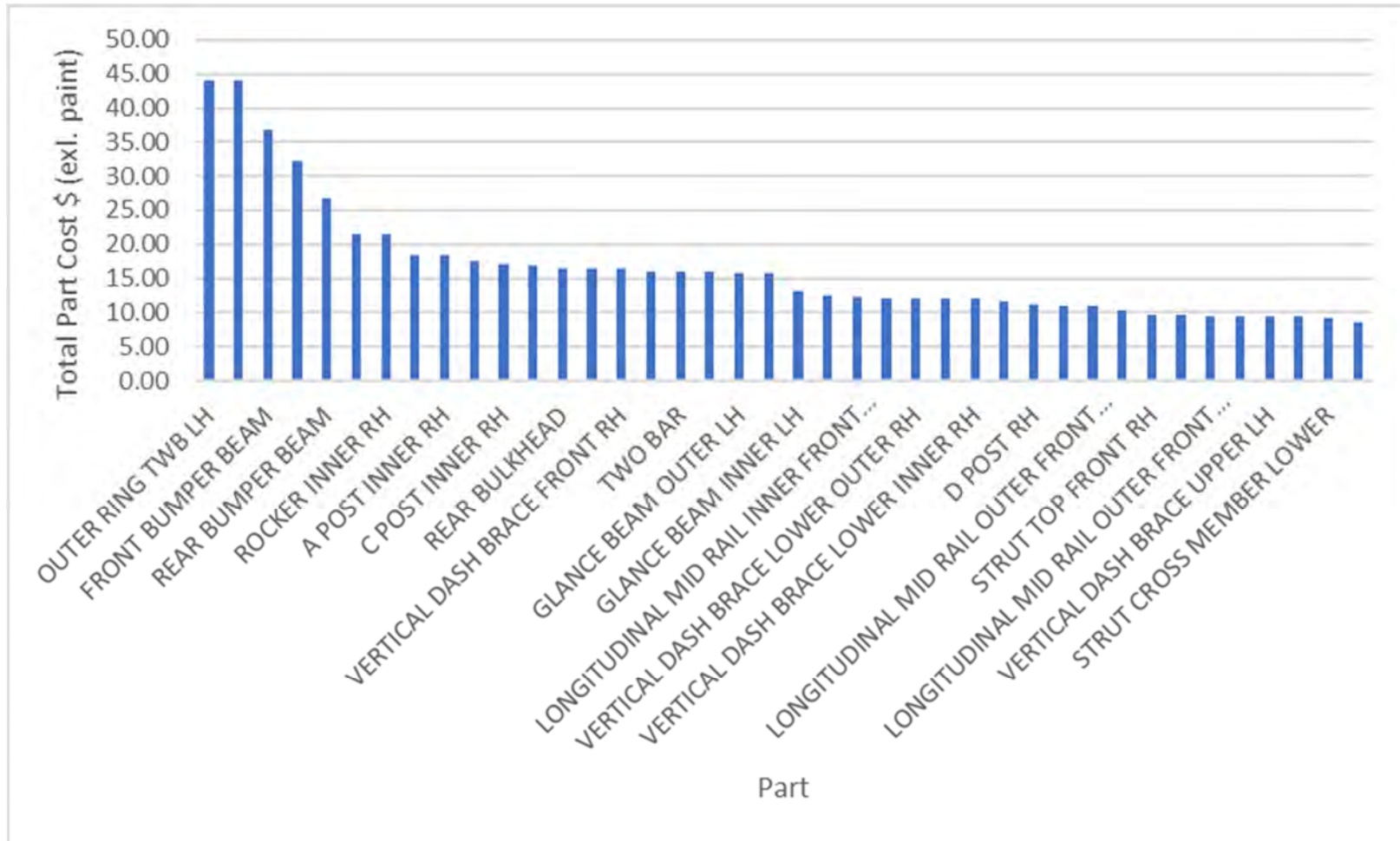
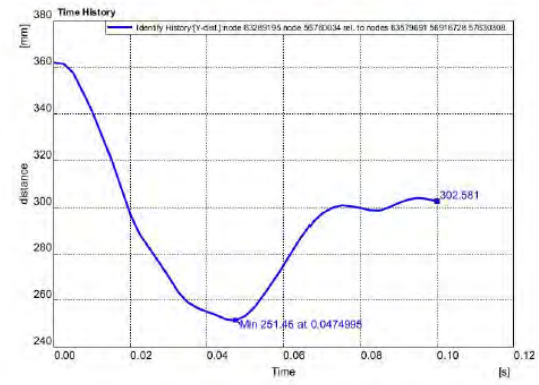
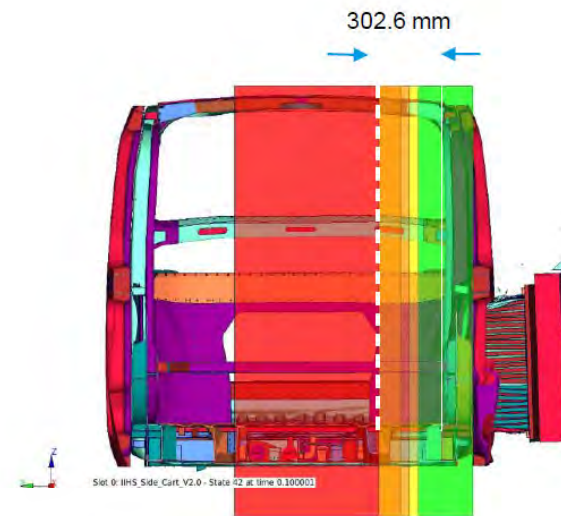
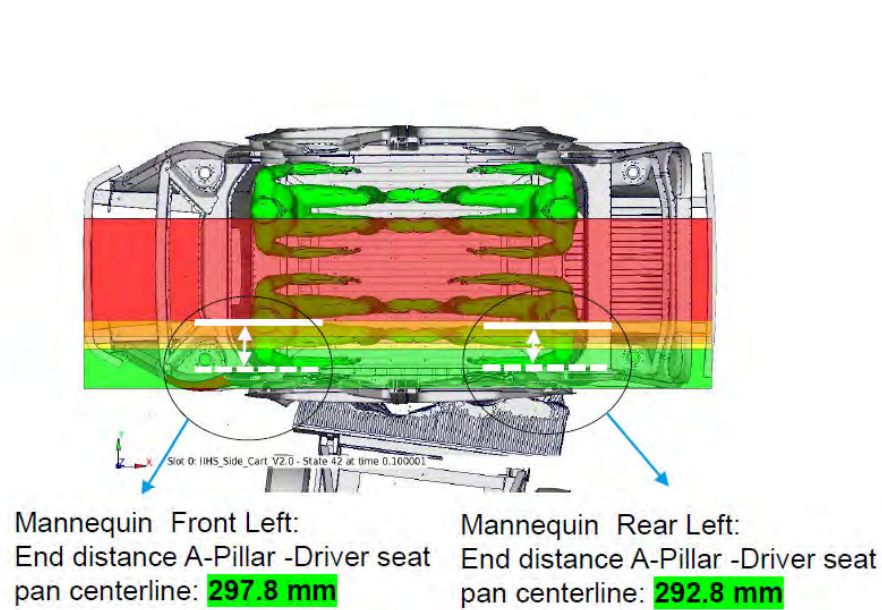


Figure 8.2.1 SEM1 front crashworthiness results (from full vehicle simulation)

| Vehicle Crashworthiness | | | | | |
|--|--|--|----------------------------|---|--|
| | Loadcase | Target Value | Result Value | Comments | |
| Front (core loadcases) | US - NCAP 56 km/h FFB | <35 G Deceleration | 33.1 | - progressive, controlled collapse of crush rail - front subframe collapse encourages EDU ride down, reducing impact to front bulkhead - see Figure 8.2.2 | |
| | | < 40 mm bulkhead intrusion | 2.5 | | |
| | IIHS 64 km/h 40% ODB | <35 G Deceleration | 20.5 | Targets described in Figure 4.2.3. | |
| | | Footwell intrusion (1,2,3) < 150mm | 1) 2.4 2) 4.1 3) 1.4 | Intrusion values are within IIHS "good" rating | |
| | | Bulkhead Intrusion (4,5) < 50mm | 4) 3.4 5) 5.2 | - see Figure 8.2.3 | |
| | | A pillar Y intrusion (6,7) >180mm clearance to seat centreline | 6) >180mm 7) >180mm | | |
| | | No contact body structure to battery | (no contact observed) | | |
| | IIHS 64 km/h 25% SORB | <35 G Deceleration | 19.9 | - IIHS "good" rating achieved. Vehicle exhibits "glance off" motion with 420mm lateral deflection | |
| | | Footwell intrusion (1,2,3) < 150mm | 1) 2.0 2) 2.4 3) 4.2 | - intrusion levels close to target but within 75mm IIHS "good" target - very stable A pillar and door ring | |
| | | Bulkhead Intrusion (4,5) < 75mm | 4) 53.8 5) 48.9 | - see Figure 8.2.4 | |
| A pillar Y intrusion (6,7) >180mm clearance to seat centreline | | 6) >180 7) >180 | | | |
| No contact body structure to battery | | (no contact observed) | | | |
| Front (reference loadcase) | OEM Centre Rigid Pole 64km/h, 253mm Pole | <40 G Deceleration | 39 | <40g pulse for all loadcases | |
| | | < 80 mm bulkhead intrusion | 1.6 | < 70mm dash intrusions Passenger cell integrity remains good | |
| | NHTSA 90kph 35% 15 degree oblique | <40g | 31.9 | - see Figure 8.2.5 to 8.2.7 | |
| | | <80mm intrusion | 70 | | |
| | NCAP - MPDB | <40 G Deceleration | 33.3 | | |
| < 80 mm bulkhead intrusion | | 1.3 | | | |

Figure 8.3.2 IIHS 60KPH side barrier (II) crash simulation results



Distance between max intrusion point and Driver seat pan centerline

Figure 8.3.3 USNCAP 32kph side pole crash simulation results, battery protection

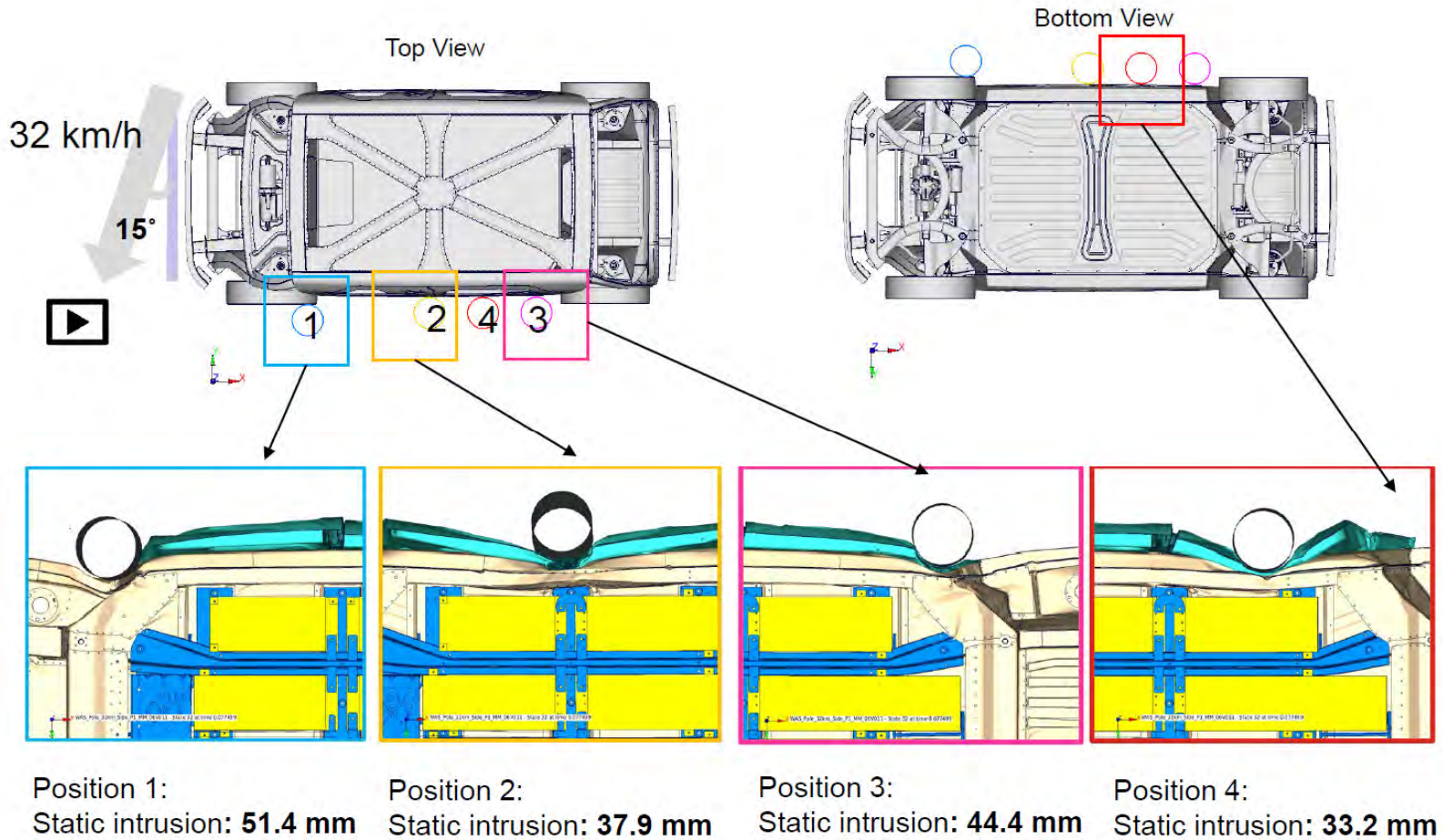


Figure 8.3.4 USNCAP 32kph side pole crash simulation results, occupant protection

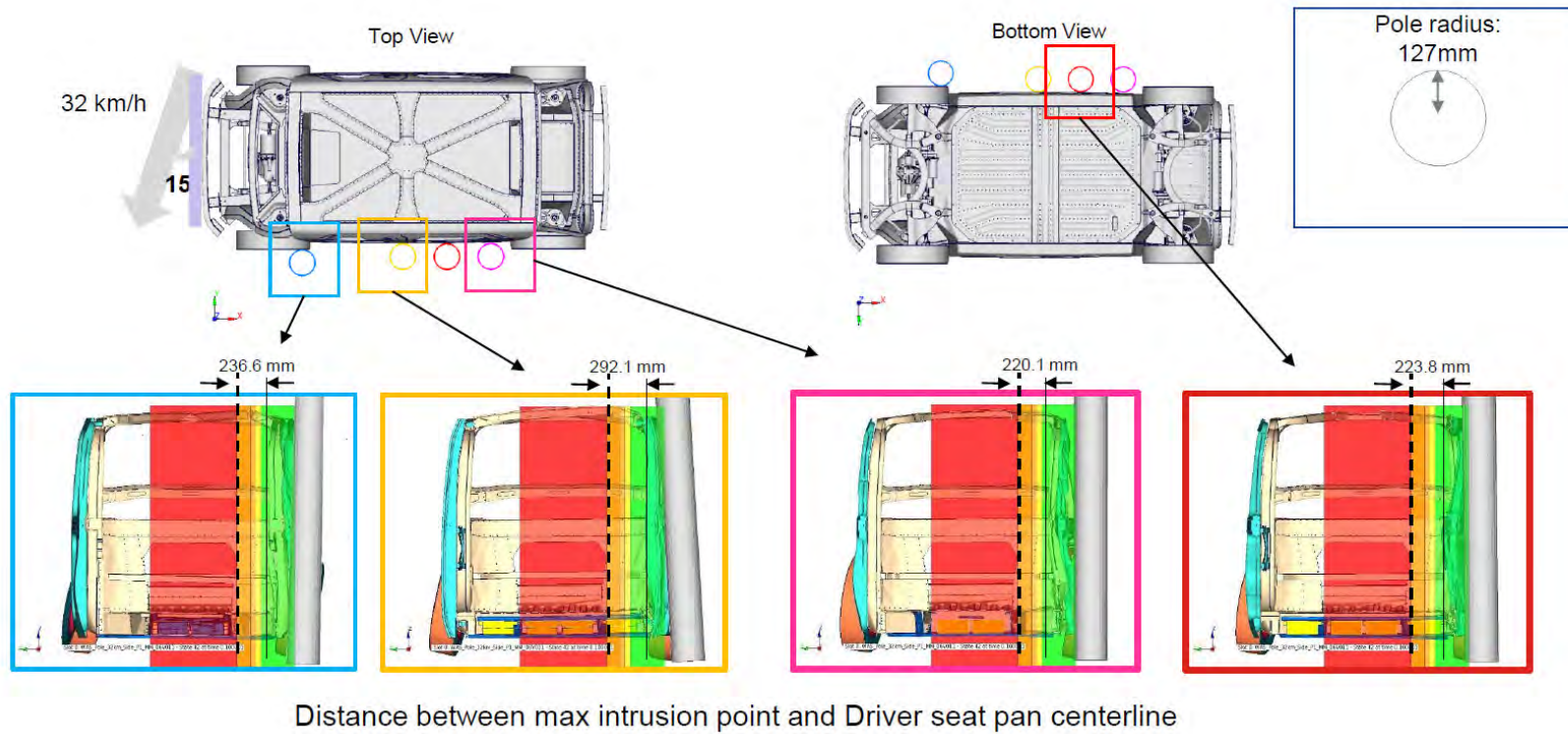


Figure 8.3.5 USNCAP 32kph side pole crash simulation results, occupant protection

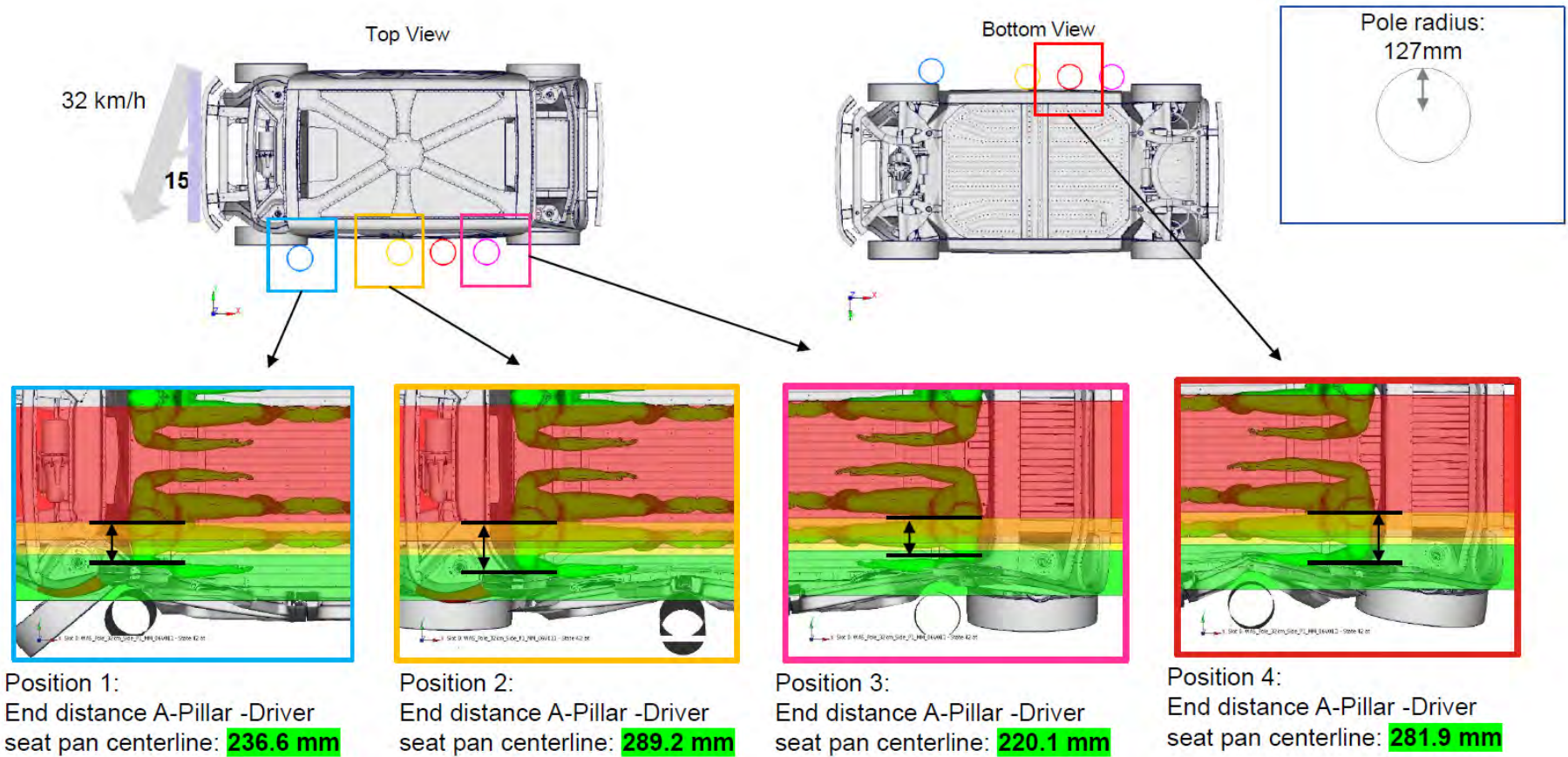


Figure 9.2.1 UCSB Life Cycle Analysis tool data flow

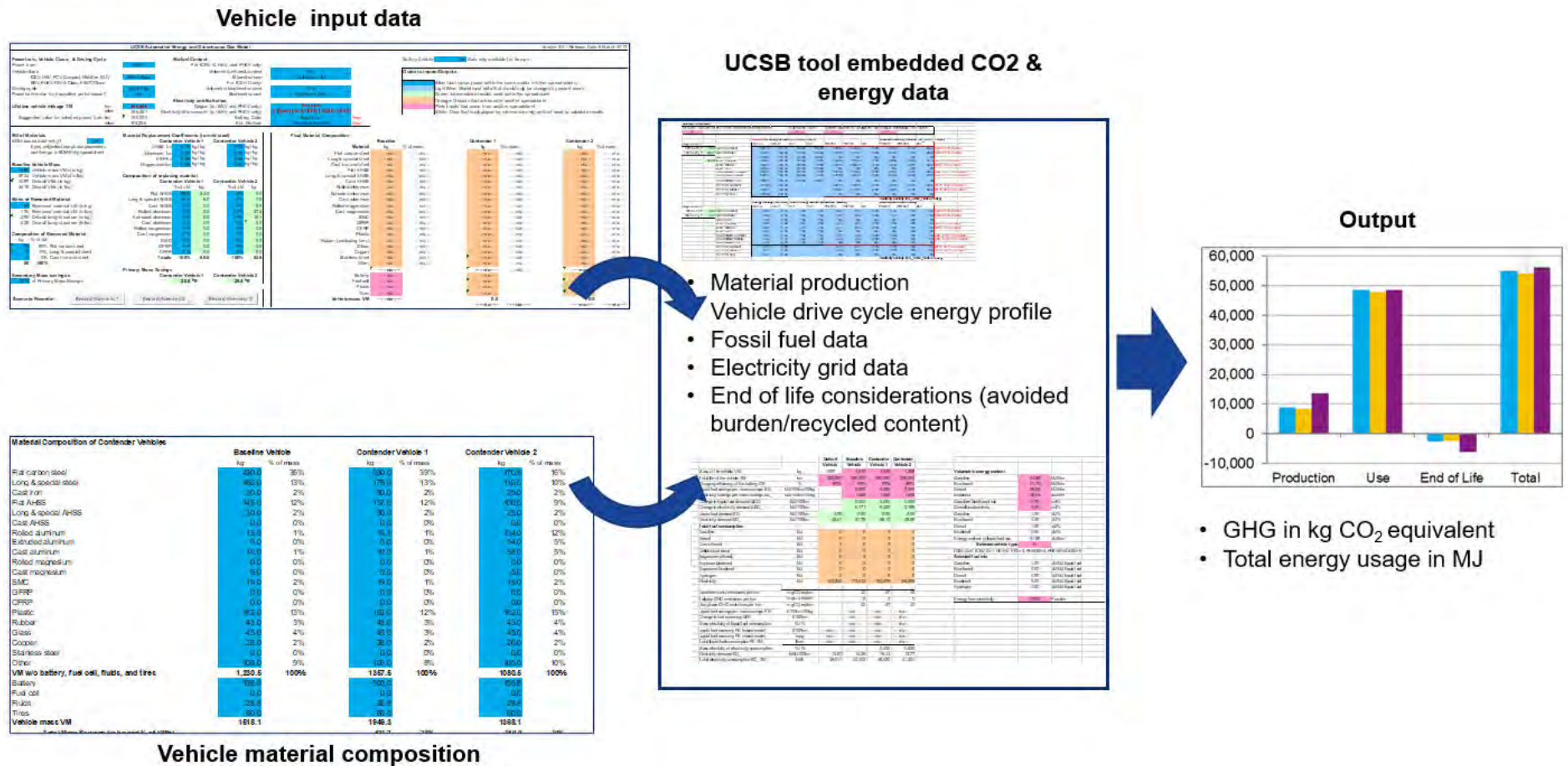
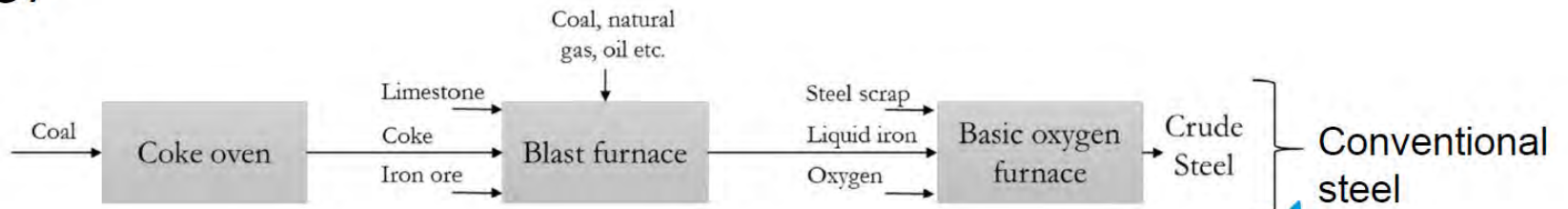


Figure 9.2.2 LCA model input parameters

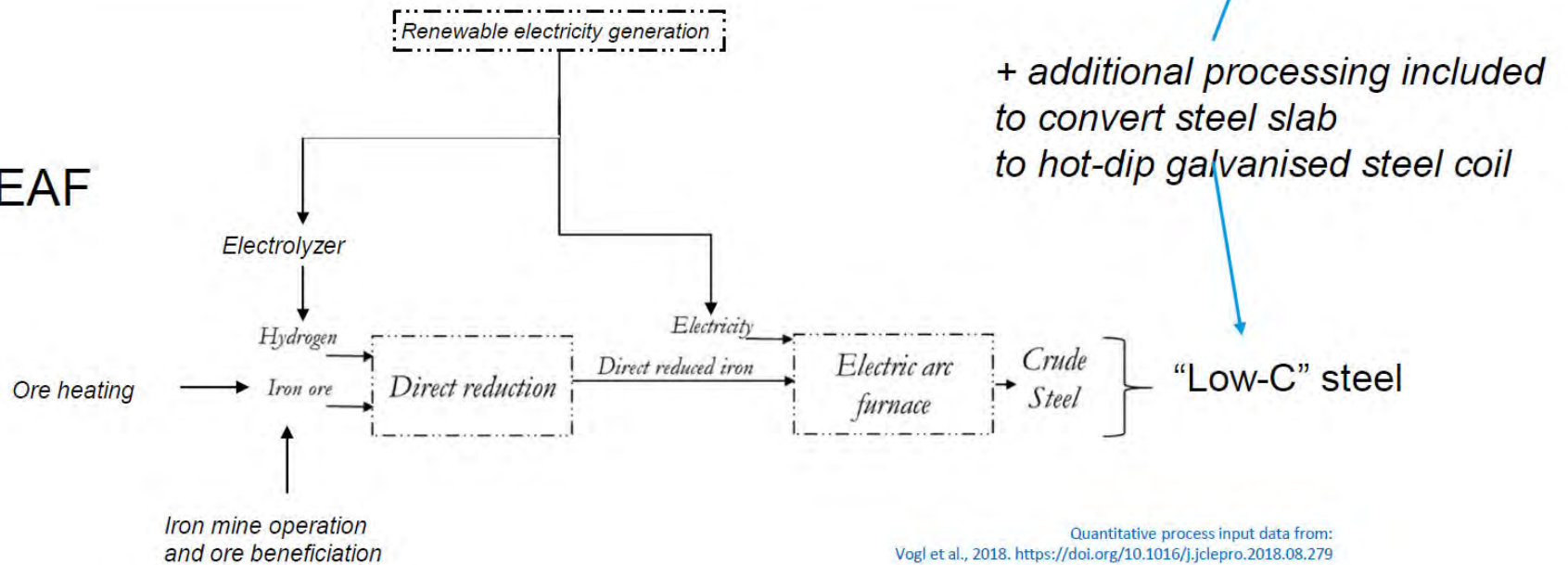
| LCA parameter | Value |
|---|---|
| description | Text description of the LCA model (e.g. "reference", "Steel E-Motive baseline") |
| Su-title Level 1 | Further model description (e.g. "drivecycle smoothing" study) |
| power train | (is Battery Electric for all vehicles in the LCA study) |
| % ethanol | (=0% for all (BEV) vehicles in the LCA study) |
| Vehicle class | (= "FSV A class" for all vehicles in the LCA study. This is standard option in UCSB tool) |
| Driving cycle | Standard test drive cycle used for use phase calculation (e.g. WLTP) |
| Driving cycle smoothing reduction | % reduction in drive cycle energy, based on autonomous vehicle speed and throttle control potential |
| Lifetime km | Total expected life of vehicle (kilometers) |
| Battery lifetime (km) | Total expected life of propulsion battery (kilometers) |
| pyrometall. LIB recycling share | Propulsion battery recycling approach |
| Grid mix (both SDS and STEPS for future scenarios) | Electricity grid supply timeline (data from IEA) |
| Region | Vehicle operation (grid supply) location (Europe, US, Japan, China, India) |
| EoL method | LCA End of life methodology (avoided burden, recycled content) |
| "green" steel share | % steel of reduced carbon production steel used (100% = all steel used in vehicle is manufactured using decarbonised process) |
| "green" Al share | % of reduced carbon production aluminium used (100% = all aluminium used in vehicle is manufactured using decarbonised process) |
| Vehicle occupancy (ride sharing) | Number of vehicle occupants in LCA calculations |

Figure 9.3.2.1.2 Life Cycle Analysis modelling considerations for BF-BOF and DRI-EAF steel production methods

BF-BOF



DRI - EAF



Quantitative process input data from:
Vogl et al., 2018. <https://doi.org/10.1016/j.jclepro.2018.08.279>

Figure 9.3.2.1.3 GaBi modelling of DRI-EAF steel production

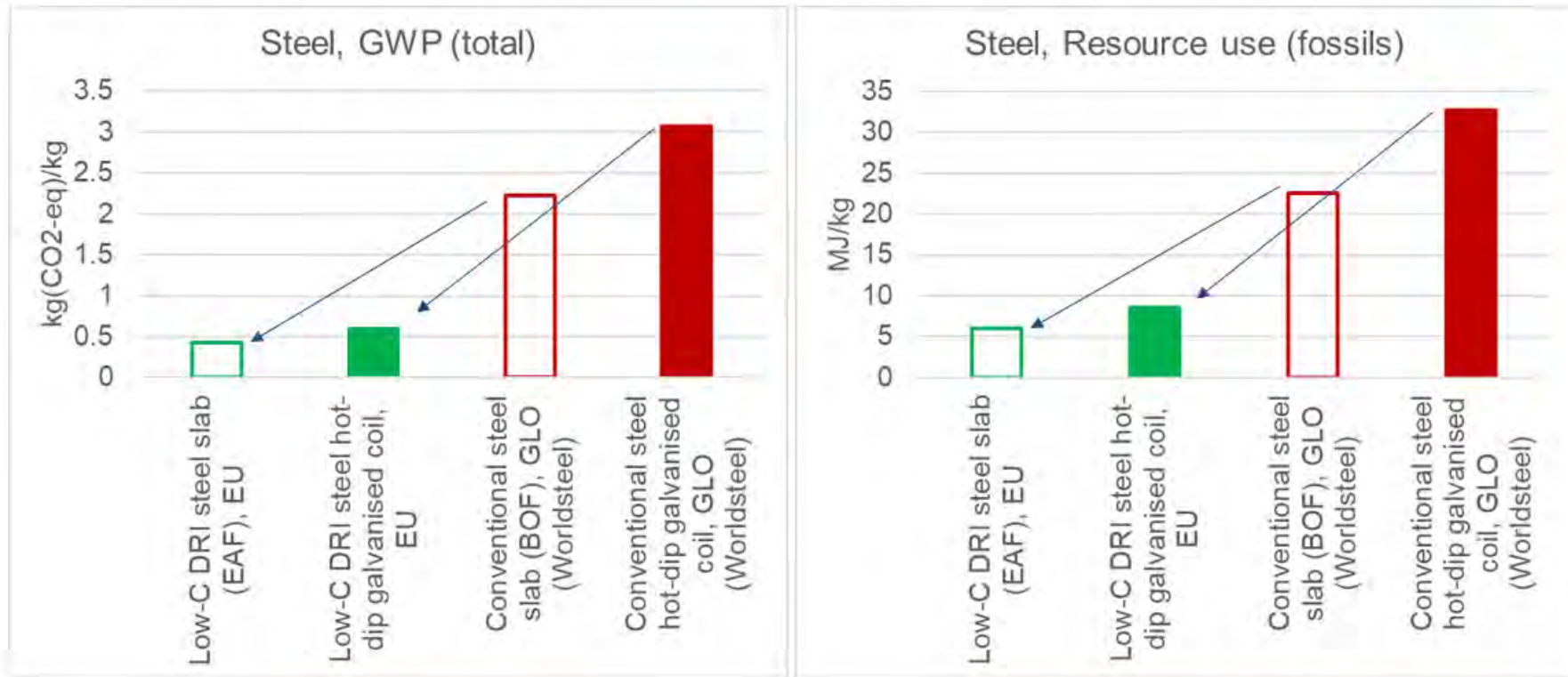
Low-C DRI steel slab
 Process plant: Max (Dg)
 The names of the basic processes are shown.



• RE source assumed = 100% on-shore Wind (Sweden)

+ additional processing included to convert steel slab to hot-dip galvanised steel coil

Figure 9.3.2.1.4 Predicted GHG emissions and fossil fuel primary energy demand effects of “green” steel production. (BF-BOF data provided by WorldSteel association).



• 5.2x reduction in GWP

• 3.8x reduction in fossil resource use

Figure 9.3.2.5.2 1D IGNITE vehicle energy simulation model schematic

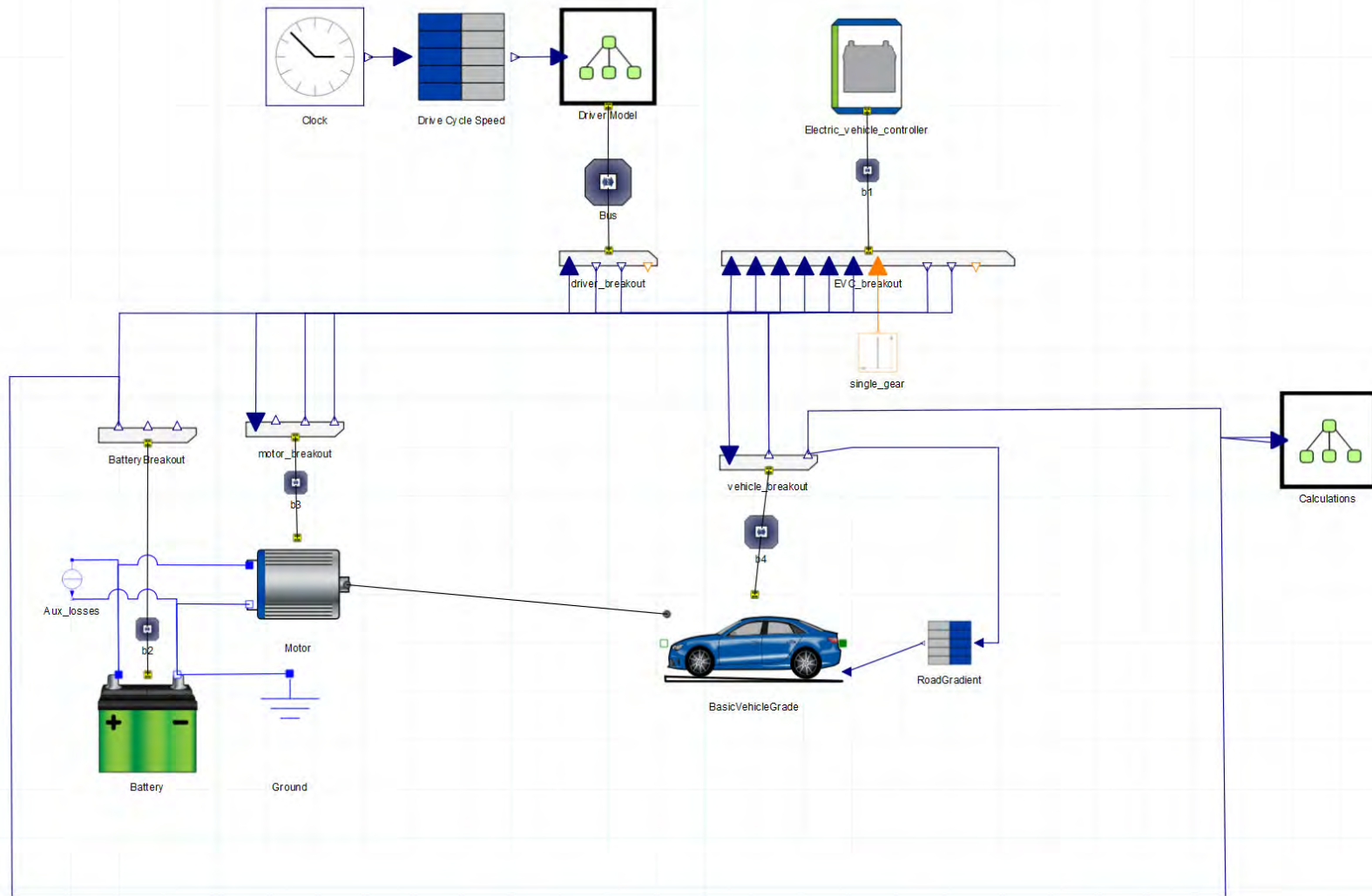


Figure 9.3.2.5.3 Traffic & drive cycle generation, vehicle energy simulation, Life Cycle Analysis process flow applied in Steel E-Motive

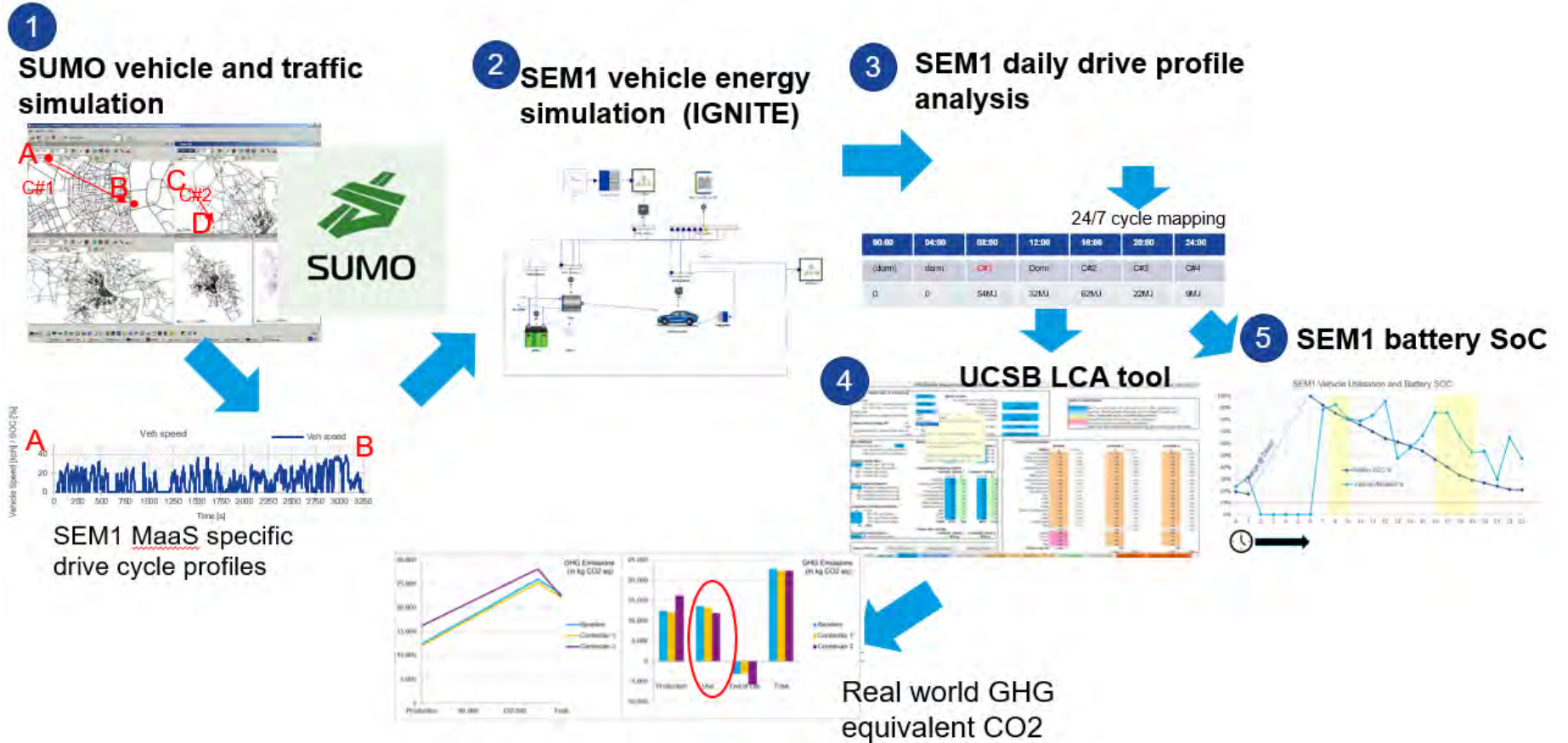


Figure 9.3.2.5.4 Map of SEM1 SUMO model mission routes

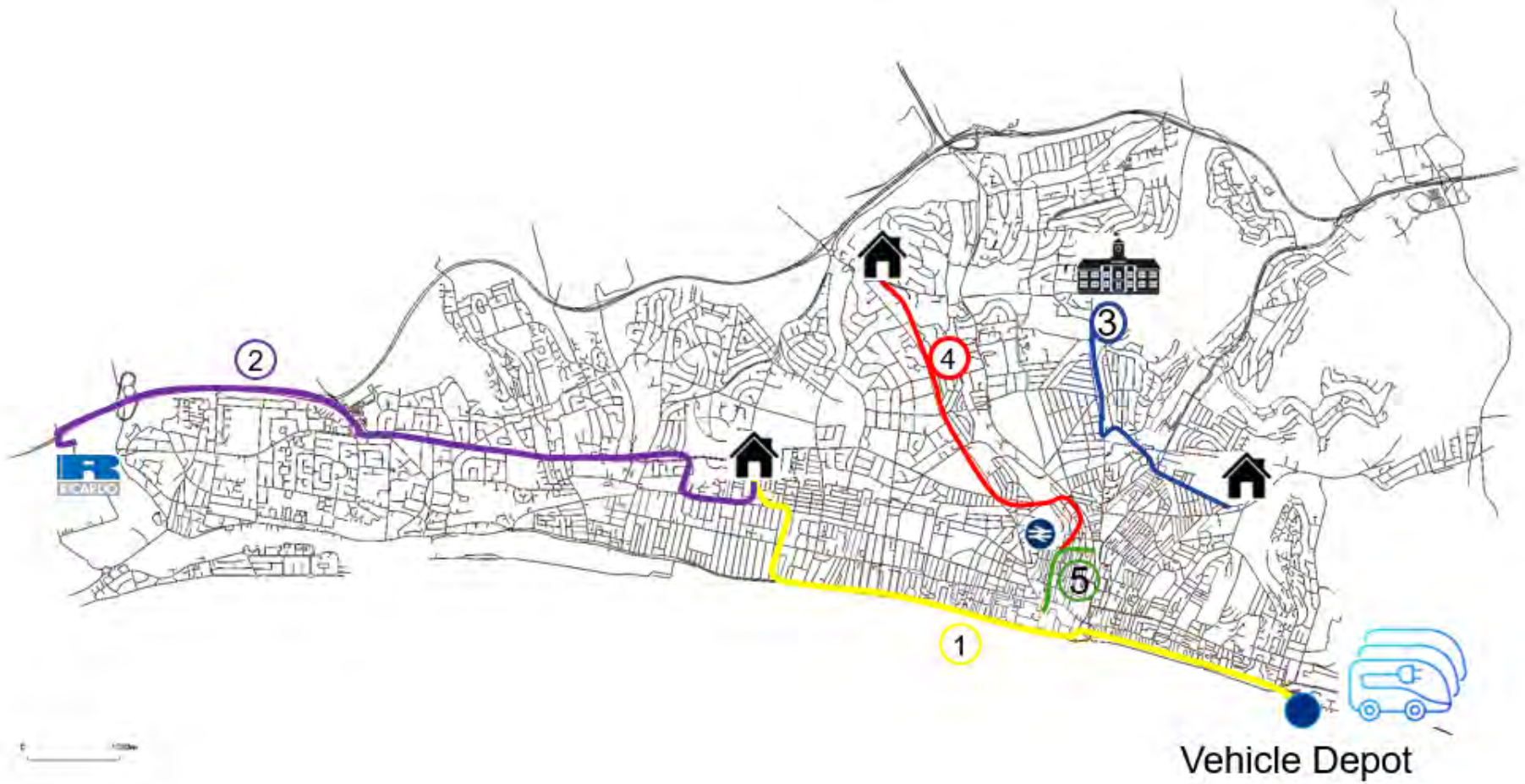
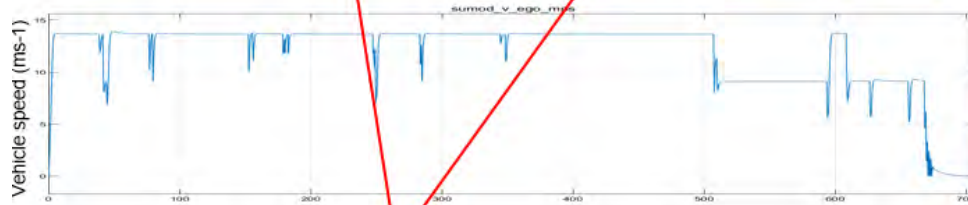
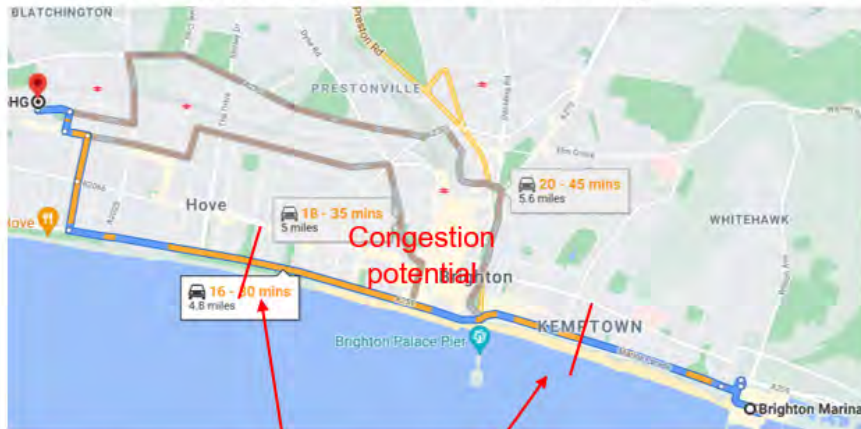


Table 9.3.2.5.5 SUMO traffic modelling output for SEM1 missions

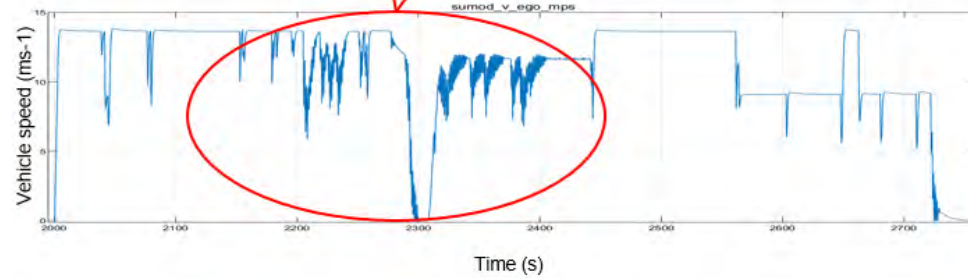
| Mission number | Description | Journey distance (km) | Journey type | Journey time (minutes) (low traffic/off peak) | Average vehicle speed (km/h) (low traffic/off peak) | Journey time (minutes) (high traffic/peak) | Average vehicle speed (km/h) (high traffic/peak) |
|----------------|-----------------------------------|-----------------------|----------------------|---|---|--|--|
| 1 | Depot to home collection | 8.37 | Suburban to suburban | 11.9 | 41.7 | 13 | 37.6 |
| 2 | Home to office | 9.11 | Suburban to rural | 10.0 | 53.8 | 10.0 | 53.8 |
| 3 | Home to school | 3.22 | Suburban to suburban | 6.2 | 30.4 | 6.2 | 30.4 |
| 4 | Home to city centre train station | 4.08 | Suburban to city | 7.1 | 33.9 | 7.1 | 33.9 |
| 5 | City centre journey | 1.67 | City centre | 3.6 | 27.1 | 9.2 | 11.5 |

Figure 9.3.2.5.7 SUMO traffic modelling drive cycle profiles for low and high traffic scenarios

Mission #1 Depot to home pick up



Off peak /
Low traffic



Peak / High
traffic

Mission #5 City centre "hop"

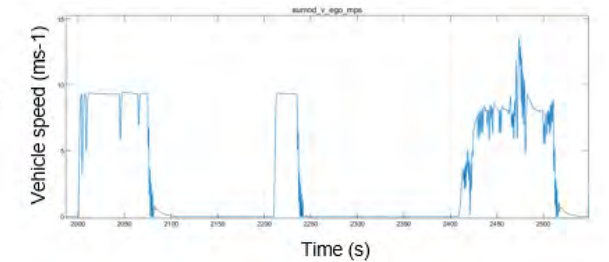
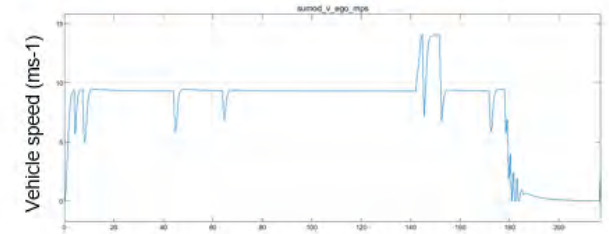
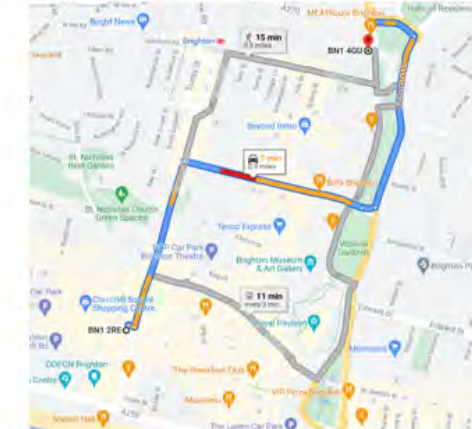


Figure 9.3.2.5.8 24-hour SEM1 vehicle mission profile, combining mission segments #1 to #5, at low/high traffic and low/high weight

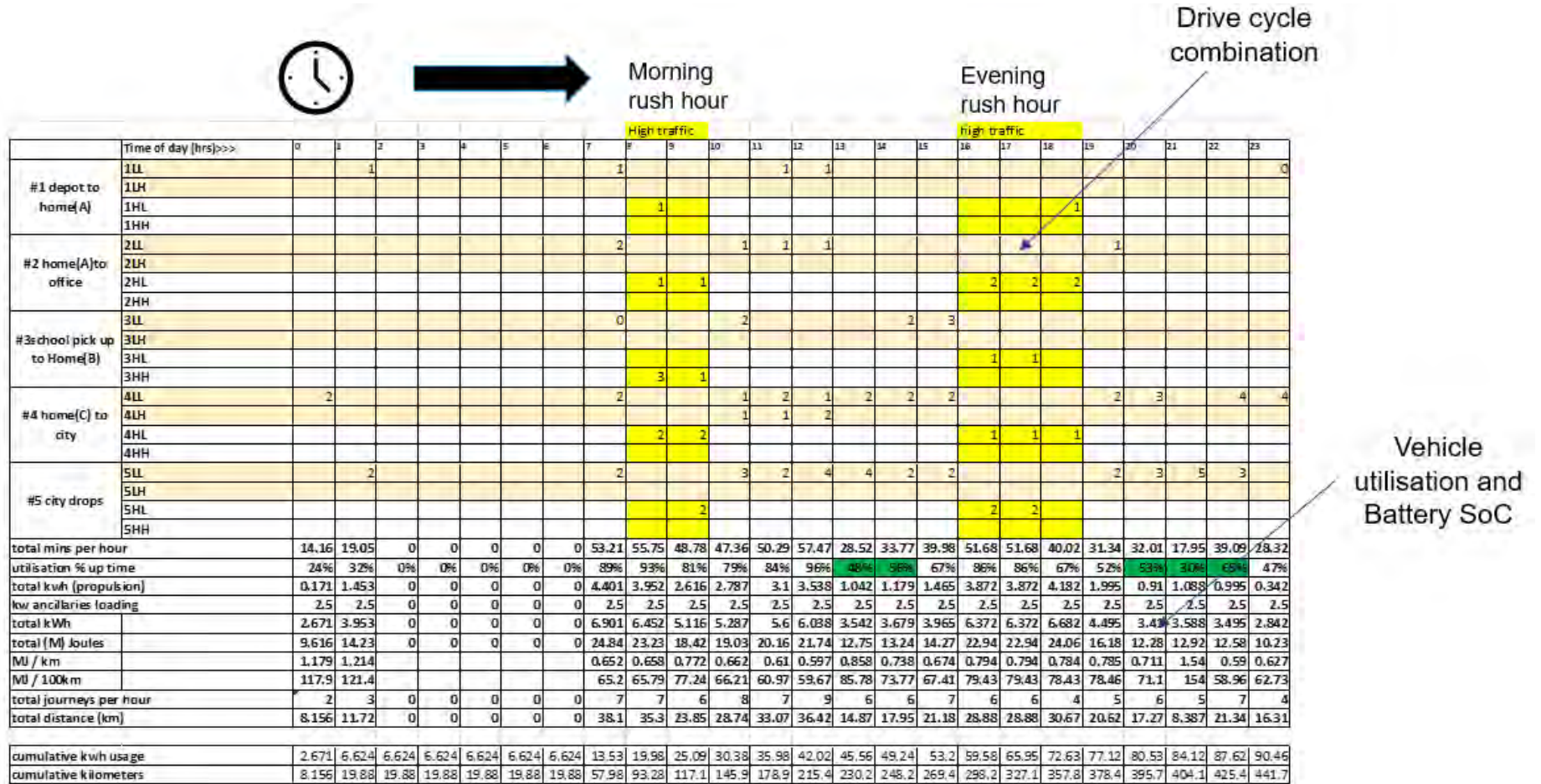


Figure 9.4.1 Lifecycle analysis studies and model boundary conditions

| Scenario n. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|--|---|--|--|--|---|---|--|--|--|---|--|
| <i>description</i> | <i>BASELINE: 2018-2030 grid mix, private/taxi, EU</i> | <i>Future grid mix, private/taxi, EU</i> | <i>Future grid mix, private/taxi, EU, recycled content EoL</i> | <i>Future grid mix, 100% low-C steel, private/taxi, EU</i> | <i>Future grid mix, extended life, 2 batt, private/taxi, EU</i> | <i>Future grid mix, extended life, 1 batt, private/taxi, EU</i> | <i>Future grid mix, private/taxi, "real world" cycle, EU</i> | <i>Future grid mix, autonomous, private/taxi, "real world" cycle, EU</i> | <i>Future grid mix, ride sharing low, EU</i> | <i>Future grid mix, ride sharing high, EU</i> | <i>Future grid mix, extended life, 100% low-C steel, autonomous, ride sharing high, EU</i> |
| <i>Title Level 1</i> | <i>Baseline vehicle</i> | | | | | | | | <i>Increased</i> | | |
| <i>Title Level 2</i> | <i>2018</i> | <i>Steel e-Motive;</i> | | | | | | | | | |
| <i>Title Level 3</i> | <i>Baseline</i> | <i>Default</i> | <i>Recycled</i> | <i>Low-C steel</i> | <i>Extended life, 2</i> | <i>Extended life, 1</i> | <i>"Real-World"</i> | <i>"Real-World"</i> | <i>Ride sharing low</i> | <i>Ride sharing</i> | <i>Extended life,</i> |
| power train | BEV | BEV | BEV | BEV | BEV | BEV | BEV | BEV | BEV | BEV | BEV |
| % ethanol | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Vehicle class | FSV A-class | FSV A-class | FSV A-class | FSV A-class | FSV A-class | FSV A-class | FSV A-class | FSV A-class | FSV A-class | FSV A-class | FSV A-class |
| Driving cycle | WLTP | WLTP | WLTP | WLTP | WLTP | WLTP | <i>real-world cycle</i> | <i>real-world cycle</i> | WLTP | WLTP | WLTP |
| Driving cycle smoothing reduction | 0% | 0% | 0% | 0% | 0% | 0% | 0% | -15% | 0% | 0% | 0% |
| Lifetime km | 300,000 | 300,000 | 300,000 | 300,000 | 600,000 | 600,000 | 300,000 | 300,000 | 300,000 | 300,000 | 600,000 |
| Battery lifetime (km) | 300,000 | 300,000 | 300,000 | 300,000 | 300,000 | 600,000 | 300,000 | 300,000 | 300,000 | 300,000 | 600,000 |
| pyrometall. LIB recycling share | 50% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Grid mix (both SDS and STEPS for future scenarios) | 2018 | 2030-2040 | 2030-2040 | 2030-2040 | 2030-2040 | 2030-2040 | 2030-2040 | 2030-2040 | 2030-2040 | 2030-2040 | 2030-2040 |
| Region | Europe | Europe | Europe | Europe | Europe | Europe | Europe | Europe | Europe | Europe | Europe |
| EoL method | Av.Burden | Av.Burden | <i>Recycled content</i> | Av.Burden | Av.Burden | Av.Burden | Av.Burden | Av.Burden | Av.Burden | Av.Burden | Av.Burden |
| "green" steel share | 0% | 0% | 0% | 100% | 0% | 0% | 0% | 0% | 0% | 0% | 100% |
| "green" Al share | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Vehicle occupancy (ride sharing) | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 2 | 3 | 3 |

Figure 9.4.2 lifecycle analysis GHG CO₂ calculations (CO₂ equivalent per passenger-kilometers)

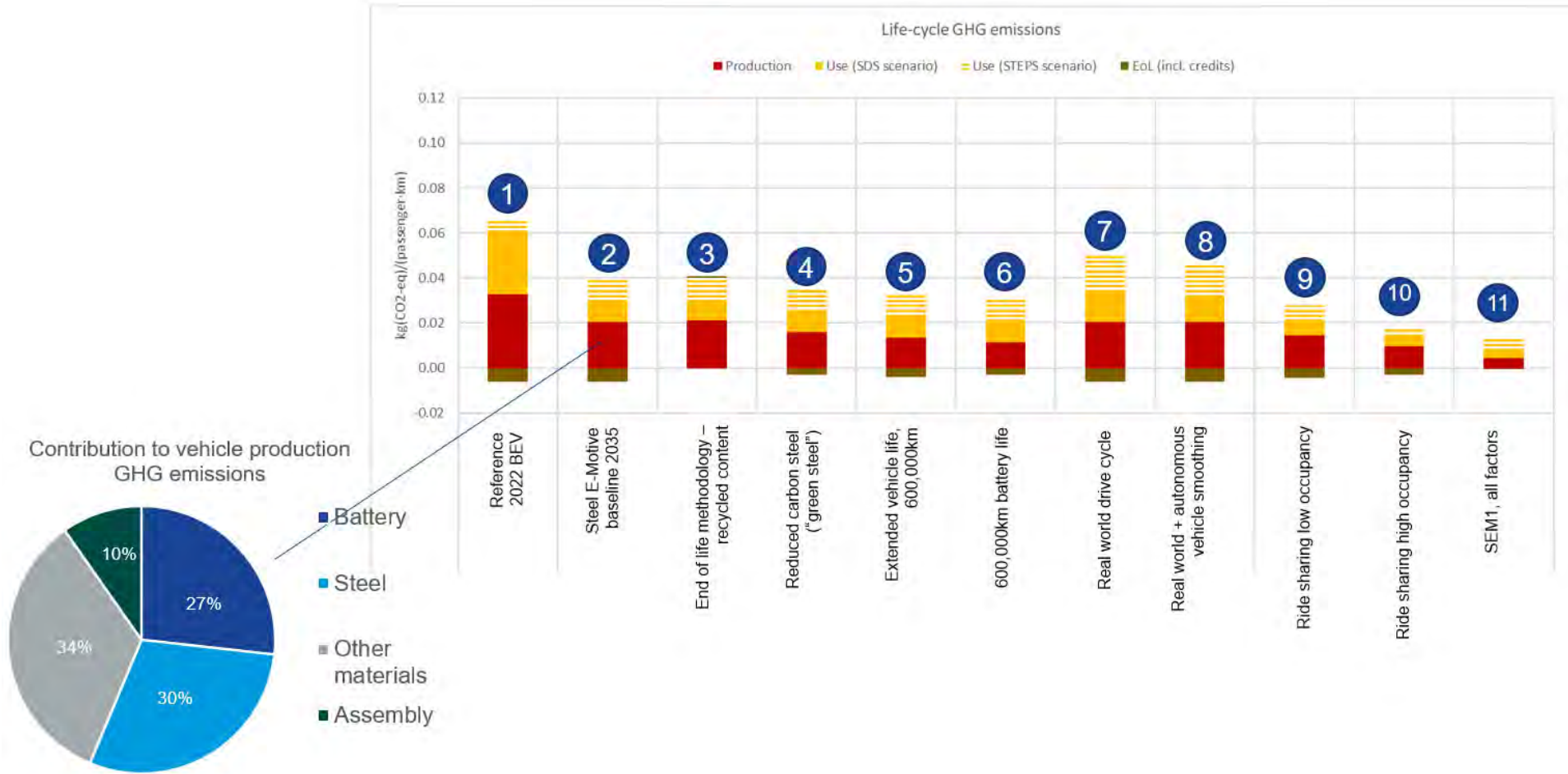


Figure 9.4.3 lifecycle analysis GHG CO₂ calculations, expressed as % of reference 2022 BEV

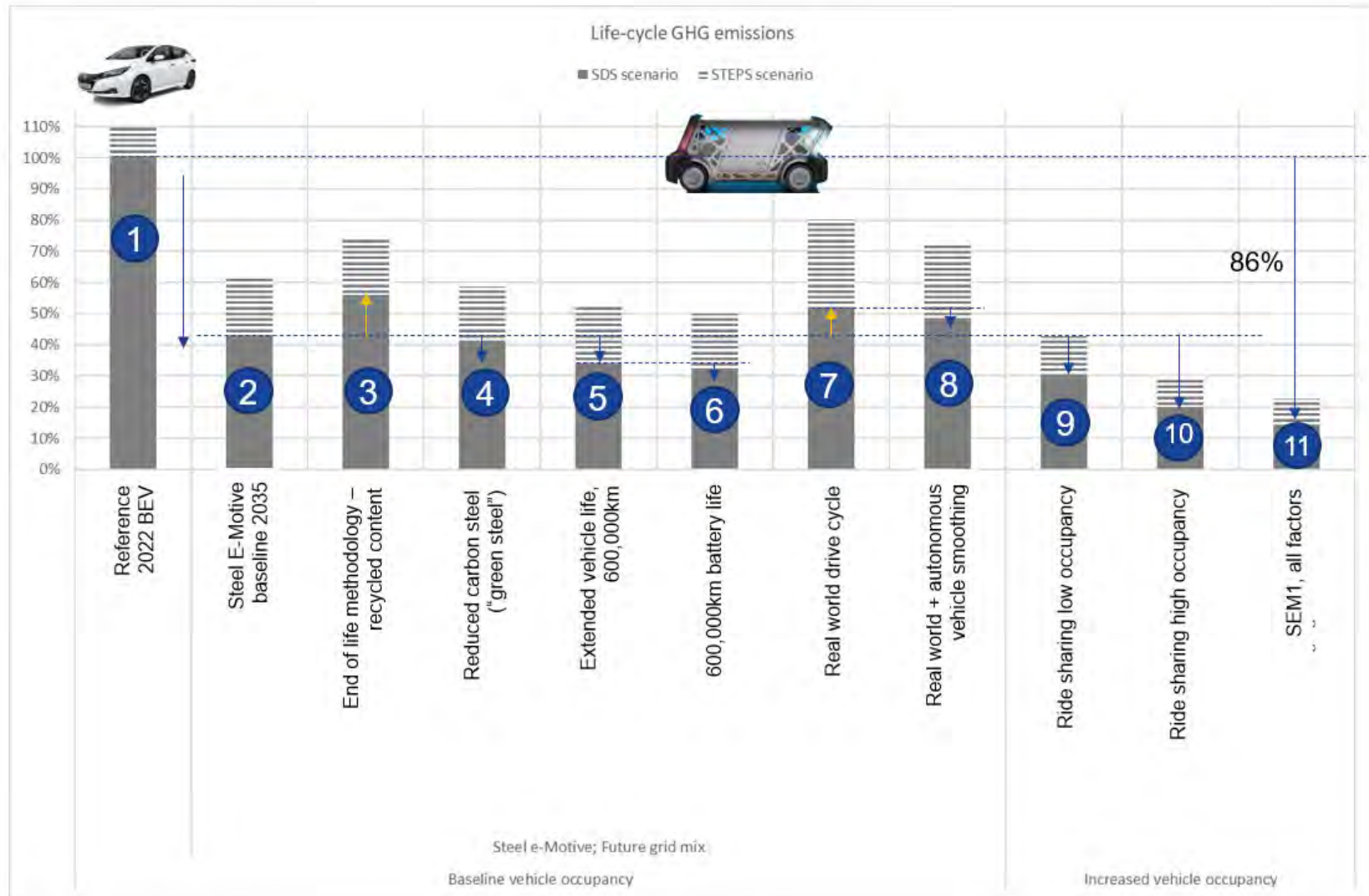


Figure 9.4.4 LCA results narrative

| Model/result number | Description | Key Result |
|---------------------|--|--|
| 1 | Reference BEV, 2022 | Used as datum/reference for SEM |
| 2 | Baseline Steel E-Motive. 25% vehicle weight reduction versus (1), 2030-2040 electricity grid mix | 57% life cycle GHG reduction compared to (1) |
| 3 | Steel E-Motive. As (2) with End of Life methodology changed from <i>avoided burden</i> method to <i>recycled content</i> | Recycled content EOL methodology results in a 13% increase in lifecycle GHG |
| 4 | Steel E-Motive. As (2) with all AHSS in the vehicle substituted with decarbonised steel production | 22% reduction in vehicle production GHG emissions. 3% decrease in GHG over vehicle lifecycle. Note, the effect is diluted due to the GHG contribution in the use phase |
| 5 | Steel E-Motive. As (2), with vehicle lifetime kilometers increased from 300,000km (2) to 600,000km (5) | 20% reduction in vehicle lifecycle GHG |
| 6 | Steel E-Motive. As (5), with battery lifetime increased from 300,000km to 600,000km | A further 7% reduction in lifecycle GHG emissions compared to (5) |
| 7 | Steel E-Motive. As (2) with real-world driving cycle. (all other models assume a standard WLTP drive cycle) | Real world drive cycle results in overall 21% increase in lifecycle GHG emissions |
| 8 | Steel E-Motive. As (7) with effect of autonomous vehicle drive cycle smoothing | 7% reduction in lifecycle GHG emissions compared to (7) |
| 9 | Steel E-Motive. As (2) with vehicle occupancy passenger increased from 1.4 to 2.0 | 30% reduction in lifecycle GHG emissions compared to (2) |
| 10 | Steel E-Motive. As (2) with vehicle occupancy passenger increased from 1.4 to 3.0 | 53% reduction in lifecycle GHG emissions compared to (2) |
| 11 | Steel E-Motive. As (2), with combined effects of (4), (5), (6), (10) | 86% reduction in lifecycle GHG emissions compared to reference 2022 BEV vehicle (1)) |

Figure 9.4.5 Lifecycle calculations for Eu, US, China and Japan regions

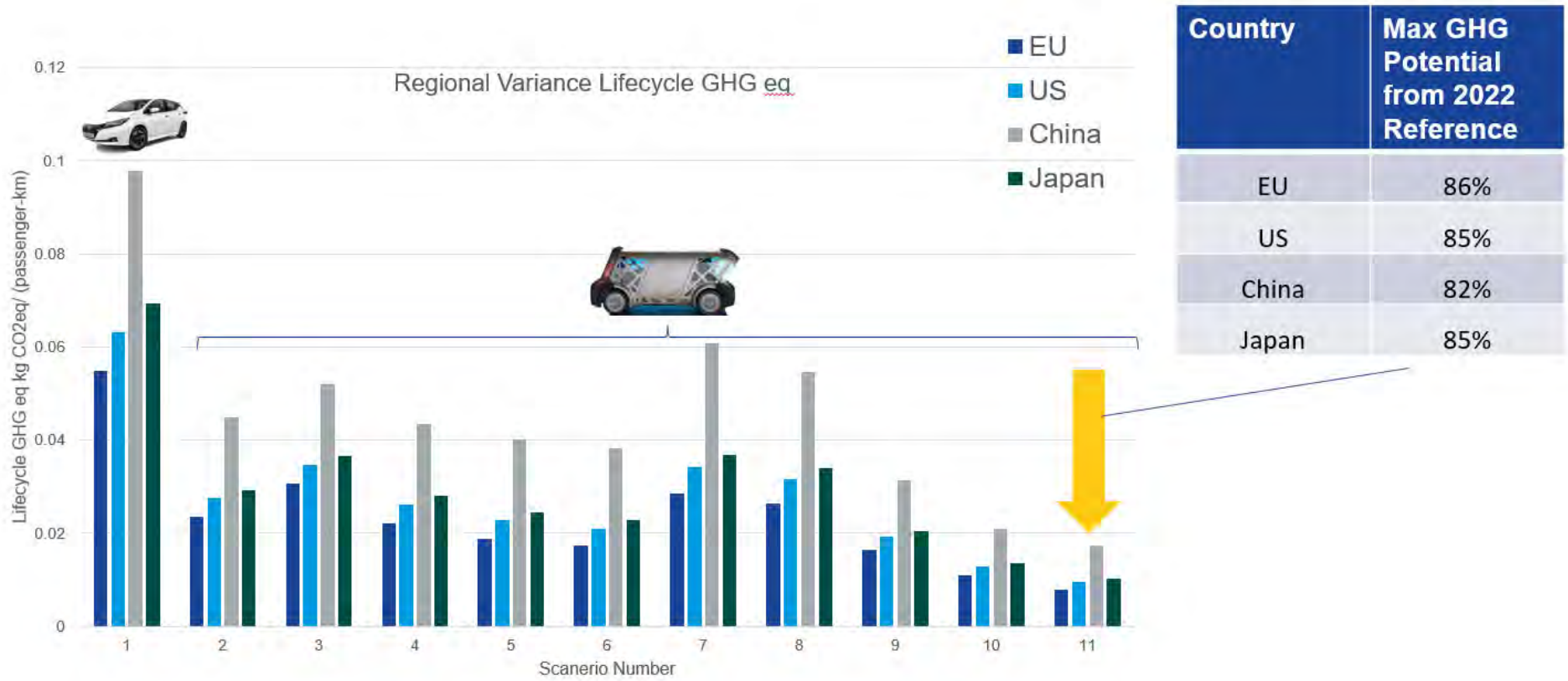
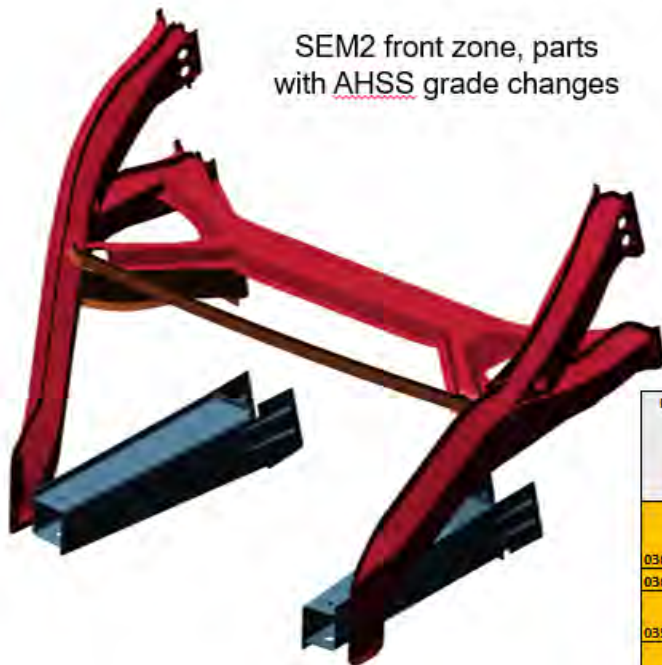


Figure 11.4.2.2 Unique SEM2 BIW parts: front zone



SEM2 front zone, parts with AHSS grade changes

| Part Number | Part Name | AHSS Grade | Gauge (mm) | C = Carry over SEM1 G = grade/gauge change N = New geom | Part Mass (kg) | SEM2 change |
|-------------|--|-----------------------------|------------|---|----------------|--|
| 03643418_2 | GLANCE BEAM LOWER REACTION RH | CR1200Y1470T-MS | 1.2 | G | 0.72 | change from 0.8mm to 1.2mm |
| 03640761_2 | GLANCE BEAM UPPER REACTION RH | PH5-CR1500T-IB | 1.0 | G | 0.52 | change from 0.8mm to 1.2mm |
| 03553269_2 | LONGITUDINAL MID RAIL OUTER FRONT RH | CR500Y780T-DP/CR700Y980T-DP | 2.0 | G | 3.51 | change from 1.8mm/2.0mm TWB to to 2.0mm throughout |
| 03506010_2 | LONGITUDINAL MID RAIL OUTER FRONT LH | CR500Y780T-DP/CR700Y980T-DP | 2.0 | G | 3.51 | change from 1.8mm/2.0mm TWB to to 2.0mm throughout |
| 03585863_2 | GLANCE BEAM UPPER TRIANGULATION INNER LH | PH5-CR1500T-IB | 1.2 | G | 1.12 | change from 0.8mm to 1.2mm |
| 03642244_2 | GLANCE BEAM LOWER REACTION LH | CR1200Y1470T-MS | 1.2 | G | 0.72 | change from 0.8mm to 1.2mm |
| 03553270_2 | LONGITUDINAL MID RAIL INNER FRONT RH | CR500Y780T-DP/CR700Y980T-DP | 2.0 | G | 3.79 | change from 1.8mm/2.0mm TWB to to 2.0mm throughout |
| 03618987_2 | GLANCE BEAM OUTER RH | PH5-CR1500T-IB | 1.2 | G | 2.63 | change from 0.8mm to 1.2mm |
| 03618991_2 | GLANCE BEAM UPPER TRIANGULATION OUTER RH | PH5-CR1500T-IB | 1.2 | G | 1.27 | change from 0.8mm to 1.2mm |
| 03640760_2 | GLANCE BEAM UPPER REACTION LH | CR1200Y1470T-MS | 1.2 | C | 0.42 | change from 0.8mm to 1.2mm |
| 03618990_2 | GLANCE BEAM UPPER TRIANGULATION INNER RH | PH5-CR1500T-IB | 1.2 | G | 1.12 | change from 0.8mm to 1.2mm |
| 03643340_2 | GLANCE BEAM LATERAL CROSS MEMBER OUTER | CR1200Y1470T-MS | 1.2 | G | 1.52 | change from 0.8mm to 1.2mm |
| 03601006_2 | GLANCE BEAM UPPER TRIANGULATION OUTER LH | PH5-CR1500T-IB | 1.2 | G | 1.27 | change from 0.8mm to 1.2mm |
| 03506011_2 | LONGITUDINAL MID RAIL INNER FRONT LH | CR500Y780T-DP/CR700Y980T-DP | 2.0 | G | 3.51 | change from 1.8mm/2.0mm TWB to to 2.0mm throughout |
| 03640758_2 | STRUT CROSS MEMBER FRONT | PH5-CR2000T-IB | 1.2 | G | 3.31 | change from 1.0mm to 1.2mm |
| 03618989_2 | GLANCE BEAM INNER RH | PH5-CR1500T-IB | 1.2 | G | 2.36 | change from 0.8mm to 1.2mm |
| 03585867_2 | GLANCE BEAM OUTER LH | PH5-CR1500T-IB | 1.2 | G | 2.63 | change from 0.8mm to 1.2mm |

Figure 11.4.2.2 Unique SEM2 BIW parts: rear zone

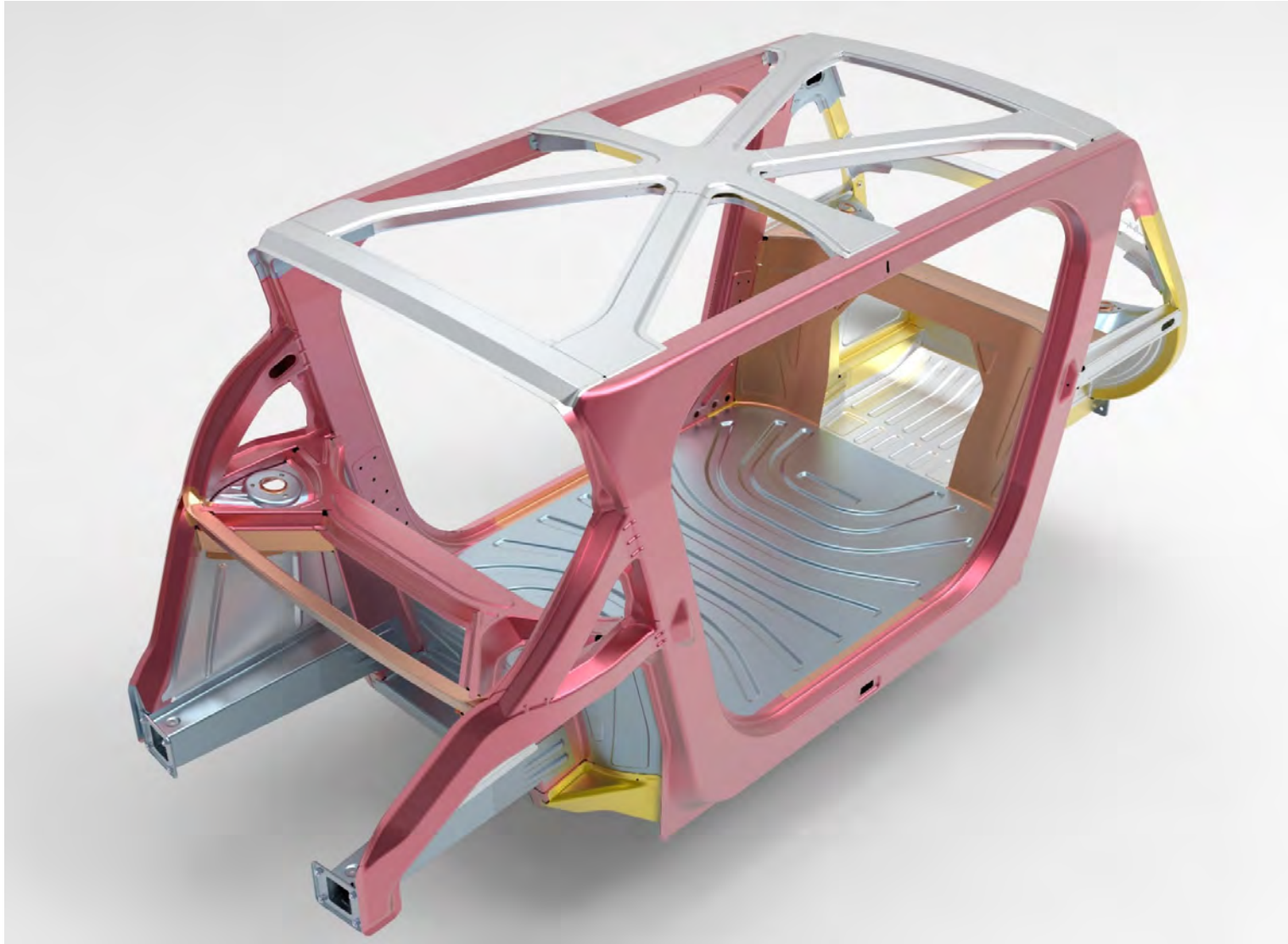
SEM2 rear zone, parts with AHSS grade changes



| Part Number | Part Name | AHSS Grade | Gauge (mm) | C = Carry over SEM1 G = grade/gauge change N = New geom | Part Mass (kg) | SEM2 change |
|-------------|---------------------------------|------------------------------|------------|---|----------------|--------------------------------------|
| 03596995_2 | REAR COMPARTMENT PAN LOWER | CR_HSLA350/450 | 0.5 | N | 2.89 | New geometry for rear EDU package |
| 03477701_2 | LONGITUDINAL REAR RAIL INNER RH | CR820Y1180T-RA_1.4_CR600Y980 | 1.8 | G | 1.90 | change from 1.4mm/1.6mm TWB to 1.6mm |
| 03476382_2 | LONGITUDINAL REAR RAIL INNER LH | CR820Y1180T-RA_1.4_CR600Y980 | 1.6 | G | 1.90 | change from 1.4mm/1.6mm TWB to 1.6mm |
| 03477703_2 | LONGITUDINAL REAR RAIL OUTER RH | CR820Y1180T-RA_1.4_CR600Y980 | 1.6 | G | 1.81 | change from 1.4mm/1.6mm TWB to 1.6mm |
| 03476381_2 | LONGITUDINAL REAR RAIL OUTER LH | CR820Y1180T-RA_1.4_CR600Y980 | 1.6 | G | 1.81 | change from 1.4mm/1.6mm TWB to 1.6mm |

Figure 11.5.1 Subjective performance evaluation for SEM2

| Attribute/Requirement | Impact of SEM1 to SEM2 | Design mitigation and countermeasures |
|---------------------------------------|---|--|
| Front crash | SEM2 higher 24% curb mass, therefore front crash will have higher energy levels to manage | Increase strength of front longitudinals to enable greater energy absorption. Increase gauge thickness of PHS2000 SORB parts |
| Side crash | IIHS side barrier. Larger side aperture. Heavier vehicle. SEM1 has very good side barrier crash performance Pole: Alignment to occupant won't change so no issue expected. Pole to HV battery potentially an issue with stretched door aperture | Additional C pillar to protect 3 rd row occupants |
| Rear crash & roof crush | Higher GVW. SEM1 performance is comfortable so no significant issue expected | None |
| Body stiffness and NVH | Stretched, longer body structure therefore modal frequencies expected to reduce, potentially below target. Higher battery mass will further reduce the batter first mode | Additional structural adhesive applied to recover NVH modal frequencies |
| Durability | Higher curb mass = higher durability loads. SEM1 has some margin on durability performance so no change is expected | None |
| BIW Mass | SEM2 BIW mass increase will be: additional/stretch mid-zone section. Impact of secondary countermeasures. There could be a -ve mass spiral effect with more mass being required due to higher curb mass. E.g. body needs to be heavier due to heavier battery | None |
| Cost | New mid-zone panels (tooling) and increased grade and gauges in front zone | Cost increases expected to be in line with other vehicle platform approach |
| Life Cycle Assessment | Higher vehicle mass, more steel. Less aggressive real world duty cycle (less city stop-start) Need to ensure high occupancy rate >2 | None |
| Manufacture & assembly | Don't expect significant manufacture issues beyond usual vehicle variant lines | |
| HV battery, jacking, China crush, PSD | Higher mass, higher jacking load. Larger battery cover area. More challenging to meet targets | None |





END OF REPORT