ULSAB-AVC

Advanced Vehicle Concepts

Overview Report

January, 2002

Safe, affordable, fuel efficient vehicle concepts for the 21st century designed in steel.

Table of Contents

ULSAB-AVC
Advanced Vehicle Concepts

ULSAB-AVC Member Companies

Following is a list of ULSAB-AVC Consortium members steel companies who sponsored the ULSAB-AVC Program:

ACERALIA Corporación Siderúrgica, S.A. - Spain
AK Steel Corporation - USA
Shanghai Baosteel Group Co. - China
Bethlehem Steel Corporation - USA
BHP Steel - Australia
China Steel Corporation - Taiwan
CorusGroup - The Netherlands
CorusGroup - United Kingdom
Dofasco Inc. - Canada
Iscor Flat Steel Products - South Africa
Ispat Inland, Inc. - USA
Kobe Steel, Ltd. - Japan
LTV Steel Company, Inc. - USA
National Steel Corporation - USA
Nippon Steel Corporation - Japan
NKK Corporation - Japan
NOVÁ HUŤ, a. s. - Czech Republic
Pohang Iron and Steel Co., Ltd (POSCO) - South Korea
Rautaruukki Oyj - Finland
Rouge Steel Company - USA
Steel Authority of India Limited (SAIL) - India
Salzgitter AG - Germany
SIDERAR S.A.I.C. - Argentina
SSAB Tunnplåt AB - Sweden
Stelco Inc. - Canada
The Tata Iron and Steel Company, Ltd. (TISCO) - India
ThyssenKrupp Stahl AG - Germany
Usinas Siderúrgicas de Minas Gerais S.A. - Brazil
USINOR Group - France
United States Steel LLC - USA
VALLOUREC GROUP - France
voestalpine STAHL GmbH - Austria
Weirton Steel Corporation - USA

Program Highlights

ULSAB-AVC demonstrates high volume, STEEL-intensive C-Class and PNGV-Class (similar to Midsize-Class) vehicle concepts. These efficient designs, made possible by the unique properties of steel, provide the foundation to achieve:

Safety Rating Potential:

	C-Class	PNGV-Class
US-NCAP	★★★★ or ★★★★★	★★★★★
US-SINCAP	★★★★★	★★★★★
Euro-NCAP	★★★★★	★★★★★

Affordable Costs:

	C-Class	PNGV-Class
Manufacturing Cost Range at 225,000 units/year	$9,200 to $10,200	

Fuel Efficiency:

	C-Class	PNGV-Class
European Driving Cycle (NEDC 2000)	4.4 L/100 km (gasoline) 3.2 L/100 km (diesel)	4.5 L/100 km (gasoline) 3.4 L/100 km (diesel)
U.S. Driving Cycle (Combined Hwy & City)	53 mpg (gasoline) 73 mpg (diesel)	52 mpg (gasoline) 68 mpg (diesel)

Vehicle curb weights ranging from 930kg to 1030kg were achieved through design optimization of components and an efficient steel body structure that is 100% high strength steels, of which 85% are the new advanced high strength steels.

Safe, Affordable, Fuel Efficient Vehicle Concepts for the 21st Century, designed in ***STEEL***—the most recycled material in the world.

ULSAB-AVC Advanced Vehicle Concepts

ULSAB-AVC (Advanced Vehicle Concepts) is the most recent addition to the global steel industry's series of initiatives offering steel solutions to the challenges facing automakers around the world today. That is, the need to increase vehicle fuel efficiency while improving safety and maintaining affordability. ULSAB-AVC concepts revolutionize the kinds of steels normally applied to vehicle architectures, as well as demonstrate cutting edge steel vehicle design. This vehicle concepts initiative, engineered by Porsche Engineering Services, Inc., Troy, Michigan, USA, brings the potential for safe, affordable, fuel efficient vehicles, which are environmentally responsible, to near-term reality.

Envisioned by the collaborative efforts of 33 international steel producers forming the ULSAB-AVC Consortium, the ULSAB-AVC Program presents advanced vehicle concepts that help automakers use steel more efficiently and provide a structural platform for achieving:

- Anticipated crash safety requirements for 2004,
- Significantly improved fuel efficiency,
- Optimized environmental performance regarding emissions, source reduction and recycling, and
- High volume manufacturability at affordable costs.

Two important program drivers were the U.S. Partnership for a New Generation of Vehicles (PNGV) and EUCAR (The European CO_2 reduction program) projects. These projects provided references for setting ULSAB-AVC targets. ULSAB-AVC focused on development of vehicle concepts for the popular European C-Class (see Figure ES1), or so-called Golf class, and the North American Midsize-Class, which is the target for the PNGV program, hereafter referred to as PNGV-Class vehicle (see Figure ES2). However, the designs were conceived with an emphasis on developing a common platform for the two vehicle classes, which as a result, share 22 percent of the vehicle components and have identical front end architectures.

Figure ES1: **ULSAB-AVC C-Class Concept**

Figure ES2: **ULSAB-AVC PNGV-Class Concept**

The ULSAB-AVC Program focused on the development of steel applications for vehicles for the year 2004 and beyond. Therefore, the vehicle body structures employ the unique advantages of advanced steel grades, which provide heightened strength with excellent part forming. ULSAB-AVC vehicle body and closure structures are comprised of 100 percent high-strength steel grades, of which over 80 percent are advanced high-strength steels. These steels are combined with the most advanced manufacturing and joining technologies, such as tailored blanks, hydroforming, and laser welding, to achieve the structurally efficient designs and safety features found in ULSAB-AVC concepts.

Key to reaching the program objectives was meeting anticipated 2004 crash requirements with steel, achieving the delicate balance of mass efficiency without compromise to safety.

Throughout the program, steel industry material experts worked closely with Porsche Engineering Services, Inc. in a simultaneous engineering process to optimize part designs in terms of steel material applications.

ULSAB-AVC vehicle concepts are not the only possibility for structurally efficient steel vehicle designs, rather they offer engineering insight into the future applications of steel for building safe and efficient automobiles.

Following is a summary of achievements:

SAFE

Star Rating Potential		
	C-Class	**PNGV-Class**
US-NCAP	★★★★ or ★★★★★	★★★★★
US-SINCAP	★★★★★	★★★★★
Euro-NCAP	★★★★★	★★★★★

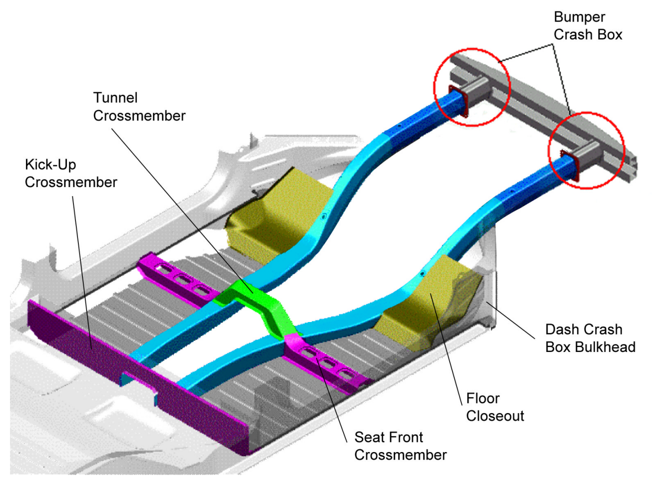
ULSAB-AVC vehicle concepts were subjected to and successfully passed the most severe crash simulations, encompassing seven different events that represent New Car Assessment Program (NCAP) requirements anticipated by the year 2004.

Further, based on a comparative assessment of current benchmark vehicles, the ULSAB-AVC C-Class vehicle could potentially achieve a 4- or 5-star rating in the US-NCAP (a full front-end collision) and a 5-star rating in the US-SINCAP (side collision). The PNGV-Class could achieve a 5-star rating for these two crash events, and both vehicles could potentially achieve a full 5-star rating according to European criteria (Euro-NCAP). The Euro-NCAP is based on a combined rating of three separate tests: an offset crash (a collision involving only 40 percent of the vehicle's front end), a side crash and a side pole crash (like hitting a tree or telephone pole).

These crash results are achieved even at this early concept phase design level through the combination of design, advanced steels and related manufacturing technologies. The body structure, which is the vehicle skeletal system and key ingredient to excellent crash performance, was carefully designed to manage the crash demands. Two steel longitudinal rails (see Figure ES3) are the backbone of the entire underbody and integral crash load-carrying structures for frontal crash energy management. These structures are hydroformed, tailored tubes made of Dual Phase (DP) steel, a member of the new advanced high-strength family of steels.

Tailored tubes and tailored blanks weld together different material grades or thicknesses. They allow for the appropriate material strength and thicknesses to be applied where most needed for part strength and efficiency for the best possible part performance. Using the hydroforming process with steel further enhances structural efficiency by promoting part integration and improving part strength through its added work hardening effects.

Figure ES3: **Front End Structure Underbody View**

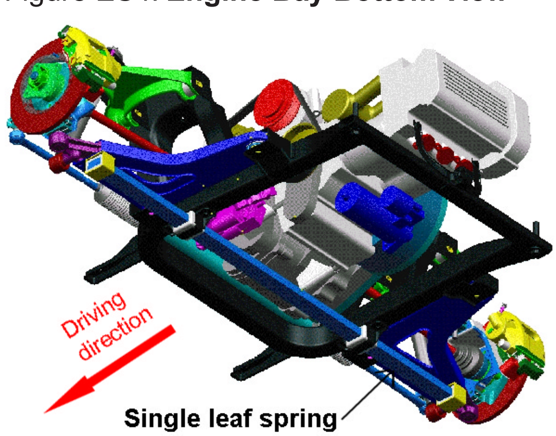


Further into the front-end structure are two pyramid-shaped structures, called dash crash boxes. Also made of varying grades and thicknesses of DP steel, these structures, working in conjunction with the DP steel front rails, ensures that crash loads are widely distributed through the vehicle, which is important to protect passengers.

DP steels have excellent attributes for these vehicle structures. Steel absorbs energy and actually becomes stronger, called the work hardening effect, when deformed in a collision. In the case of the front rails, the rails absorb the crash energy to keep it away from the passenger compartment. DP steels have a greater capacity for energy absorption, thus enabling engineers to achieve greater structural efficiency than with conventional steels.

Advanced high-strength steel cross-car beam designs provide additional safety. Made of DP and Martensitic (Mart) steels, these crossmembers carry much of the side impact crash load and therefore are key to passenger compartment integrity. With the crossmember designs, which extend all the way to just inside the side vehicle "skin", the crash energy forces are driven directly into the crossmember. This keeps the passenger compartment stable and passengers safer.

Figure ES4: **Engine Bay Bottom View**



Another way that the ULSAB-AVC vehicles have been designed for good crash performance is through a unique front-end module (see Figure ES4). This module includes a steel subframe to which most of the engine bay components, like the suspension, powertrain and radiator are attached. The subframe rear attachments break away in the event of a full front-end collision, allowing the powertrain to move rearward into a specially designed tunnel rather than intrude into the passenger compartment (see Figure ES5). For this purpose, a mass efficient, narrow VR-3 engine was specified in the design.

An added benefit of this front-end module design is that it facilitates modular assembly of the vehicle (delivery of large subassemblies directly to the final assembly line) as well as easy removal for maintenance of any of its components during the life of the car. Because of the front-end module, the hood is fixed and has a small service lid for maintaining washer, transmission and oil fluids.

Figure ES5: **C-Class US-VCAP Deformed Shape Underbody View**

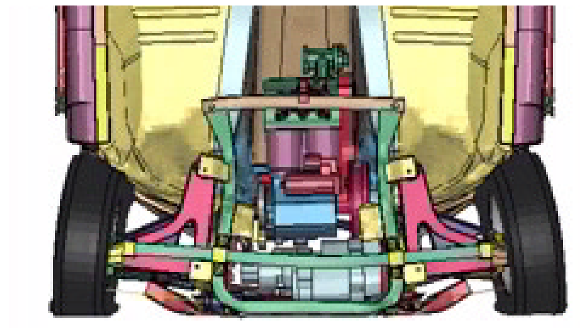
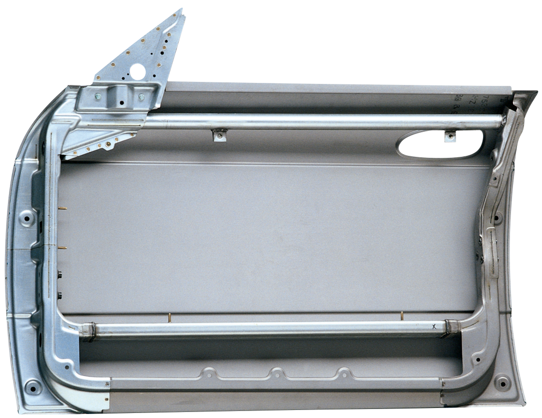


Figure ES6: **ULSAC Door**

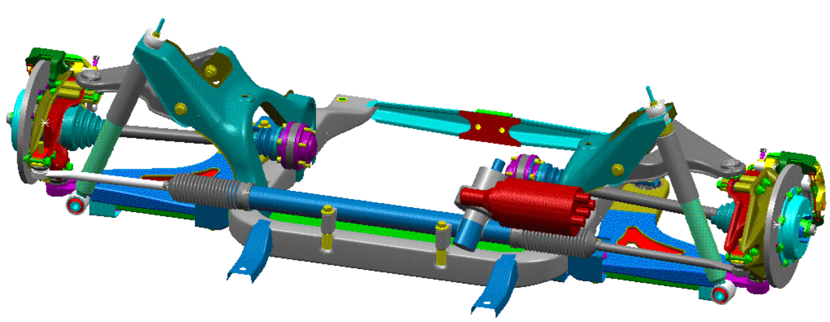


Also, unique steel door structure designs, conceived in the steel industry's UltraLight Steel Auto Closures (ULSAC) Program completed in May 2001, contribute to excellent performance in side impact crash events. The ULSAC Program successfully manufactured a door structure that uses two ultra high-strength steel tubes in a very efficient design for enhanced safety (see Figure ES6).

Though not yet a requirement anywhere in the world, ULSAB-AVC also considered pedestrian safety and offers innovative design ideas for minimizing pedestrian head injury. One of these ideas was to place the front-end module below the body structure front rails, keeping hard points away from under the hood. Also, a specific suspension design, which does not require shock towers (see Figure ES7), was selected to avoid hard points under the hood.

In addition, the ULSAB-AVC vehicles were designed to have a more equalized distribution of total vehicle mass between the front and rear axles for improved vehicle handling. This is evident in the design in the forward position of the front wheels and a powertrain arrangement (transmission in front of engine) that is radically different than conventional designs.

Figure ES7: **ULSAB-AVC Front Suspension**



ULSAB-AVC Advanced Vehicle Concepts

AFFORDABLE

	C-Class		PNGV-Class	
	Gasoline	Diesel	Gasoline	Diesel
Parts Fabrication Cost	$7,905	$8,605	$8,163	$8,863
Assembly Cost	1,284	1,284	1,375	1,375
ULSAB-AVC Manufacturing Cost	$9,190	$9,890	$9,538	$10,238

Many decisions were made during the development process to ensure that ULSAB-AVC would be affordable, both to the manufacturer and the consumer. Modular assembly (like the front-end module) fewer body-in-white parts through part integration, and use of conventional powertrain technology all contributed to keep manufacturing costs down. Key to affordability is the steel-intensive design—steel continues to be the most cost-effective structural material for automobile manufacturing.

A detailed economic analysis, performed by leading cost analysts, was conducted to assess how much it would cost an automobile manufacturer to build the ULSAB-AVC vehicles. The economic analysis included development of a detailed cost model, which provides a platform for understanding the costs of all aspects of manufacturing an entire vehicle.

The cost model tracks the costs of all parts in the vehicle, the production of subassemblies and the final assembly process. Emphasis was placed on understanding the costs of steel part fabrication and assembly processes, like stamping, tailored blanks or hydroforming, which are modeled in considerable detail. The remaining parts costs, like the electrical system or seats, which auto manufacturers normally purchase, were estimated via supplier quotes, industry information and other cost estimates. Automotive assembly plant activities, such as painting and final assembly/trim line, were modeled using industry data concerning these processes.

To account for varying opinions as to what should be included in manufacturing costs, the spreadsheet cost model was developed so that individual users can input their company-specific assumptions to arrive at their own cost conclusions.

The assessment results show that advanced steel vehicle concepts, which have the potential to achieve four or five star crash ratings, are fuel efficient, and can be built in high volume at affordable costs.

An additional study, which benchmarked the selling price of current production vehicles, revealed that ULSAB-AVC vehicles are affordable compared to benchmarks. Also, the data clearly indicates that ULSAB-AVC concept vehicles' selling price could be far below the selling price of current hybrid-engine concept vehicles, while offering substantial reduction in CO_2 emissions over conventional vehicles.

FUEL EFFICIENT

	C-Class		PNGV-Class	
	Gasoline	**Diesel**	**Gasoline**	**Diesel**
Aerodynamic Drag	0.25	0.25	0.25	0.25
European Driving Cycle				
CO_2 Emissions (NEDC 2000)*	106	86	108	89
L/100 km	4.4	3.2	4.5	3.4
U.S. Driving Cycle				
CO_2 Emissions (Combined)**	105	86	108	92
Combined (mpg)	53	73	52	68
City [mpg]	49	66	48	62
Highway [mpg]	61	84	60	78

** automatic shift mode*
***average of automatic and manual shift mode*

Vehicle Mass Results

	C-Class		PNGV-Class	
	Gasoline	Diesel	Gasoline	Diesel
Vehicle Curb Weight (kg)	933	966	998	1031

The ULSAB-AVC Program explored advanced high-strength steel applications and steel manufacturing processes, coupled with design innovations, to produce vehicle concepts that significantly improve fuel efficiency using an internal combustion engine (ICE).

Several ideas were investigated, which included selection of a VR-3 engine that offers the crash advantages mentioned previously, as well as low emissions. In addition, a manual transmission with an automatic gearshift actuator contributes to fuel efficiency. This means that it can be driven as a manual shift vehicle if the driver prefers, or for optimal fuel efficiency, as an automatic shift vehicle

A structurally efficient steel body structure, a low total vehicle mass and the latest in aerodynamic technology (e.g., rear-view cameras and enclosed underbody) were additional design steps taken to achieve ULSAB-AVC vehicles' fuel efficiency.

The CO_2 emissions assessment included evaluation procedures for both the New European Driving Cycle (NEDC 2000) and the U.S. Combined Driving Cycle. The stringent EUCAR proposed future requirement specifies CO_2 emissions for a fleet average of 140 g/km. ULSAB-AVC adopted this former figure as a single car requirement and set a target at <140 g/km. It was assumed that meeting this target would also achieve the U.S. EPA Tier 2 Requirements. ULSAB-AVC vehicles offer the potential for dramatic reduction in CO_2 emissions (see table above), and consequently, a significant increase in fuel economy with a conventional internal combustion engine.

And as the manufacturing cost results reveal, fuel efficiency no longer has to come at a premium. This could mean that CO_2 emissions reduction and better fuel efficiency for high production volume vehicles do not have to wait until the technology and infrastructure are in place to manage alternative power sources.

ENVIRONMENTALLY RESPONSIBLE

Lower CO_2 emissions and reduced fuel consumption is just one part of the ULSAB-AVC vehicle concepts' environmental advantages. Because ULSAB-AVC employs advanced and high-strength steels, designers were able to use less material without compromising the structural strength needed for good crash and structural performance. This means that the ULSAB-AVC vehicle concepts use less kilograms of steel than conventional vehicles and thus fewer natural resources to manufacture them.

And steel is one of the most recycled materials in the world. Every year steelmakers recycle nearly 385 million tons of steel. Steel's recycling rate is far higher than that of any other material, capturing more than twice as much tonnage as all other materials combined. Additionally, it takes used steel to make new steel. This means that each new steel product is made in part from recycled steel. Using recycled steel means less mining of natural resources. Recycling a single car conserves more than 2500 pounds (1134 kilograms) of virgin iron ore, 1400 pounds (635 kilograms) of coal and 120 pounds (54 kilograms) of limestone.

Further, steel's established recycling loop and the ease with which steel scrap is magnetically reclaimed helps today's designers make end-of-life total vehicle recycling a vital part of product planning.

1 Program Overview

The ULSAB-AVC (Advanced Vehicle Concepts) Program objective was to demonstrate and communicate steel's capability to help fulfill society's demands for safe, affordable and environmentally responsible vehicles for the 21st Century. By doing so, the global steel industry aims to reinforce the ongoing commitment of the automotive industry to retain steel as the material of choice for vehicle construction.

The ULSAB-AVC Program focused on the development of steel applications for vehicles for the year 2004 and beyond. To achieve this goal, a holistic design approach considered the complete vehicle, which meant that all of its subsystems and components had to be treated as a whole. Therefore optimizing any subsystem of the vehicle, e.g., body structure, was evaluated based on its interaction and contribution to the performance and efficiency of the entire vehicle with all its subsystems, rather than attempting to optimize on a component-by-component basis.

An important factor for the success of this program was the combination of an advanced vehicle design, which exploited the properties of a range of new steels, and related advanced and traditional manufacturing and assembly processes to achieve significant mass reduction in the body structure, as well as for the total vehicle.

Two important drivers were the U.S. Partnership for a New Generation of Vehicles (PNGV) and EUCAR (The European CO_2 reduction program) projects. These projects provided references for setting ULSAB-AVC targets.

Porsche Engineering Services, Inc. (PES) was contracted to develop concepts with a common platform approach for the popular European C-Class (so-called Golf-class) and the North American Midsize-Class, which is the target for the PNGV program (hereafter referred to as PNGV-Class vehicle).

In summary, ULSAB-AVC, sponsored by a consortium of 33 international steel producers, is intended to present advanced vehicle concepts that help automakers use steel more efficiently and provide a structural platform for achieving:

- Anticipated crash safety requirements for 2004,
- Significantly improved fuel efficiency,
- Optimized environmental performance regarding emissions, source reduction and recycling, and
- High volume manufacturability at affordable costs.

1.1 Benchmarking and Target Setting

Benchmarking and target setting provided the foundation and direction for the ULSAB-AVC design development. Benchmark data were collected from current production C-Class and PNGV-size vehicles, as well as vehicles with a curb weight in the 900 kg range. Additionally two vehicles, a Ford Focus (C-Class vehicle) and a Peugeot 206 (B-Class vehicle) were purchased, dismantled and evaluated.

The Ford Focus was selected for evaluation as a recent example of a production vehicle that meets current safety standards and fits into the C-Class vehicle category. The Peugeot was selected because its vehicle mass is approximately 909 kg/2000 lbs. (basic model without options). For the PNGV-Class vehicle, data from similar-sized vehicles (e.g. Audi A6 or Daimler/Chrysler E-Class) were gathered.

For the ULSAB-AVC Program, the targets have been set on the basis of program objectives outlined in Section 1.0 of this report.

All targets were set based upon PES's experience, engineering judgment and current, publicly available data, as well as benchmarking data.

The ULSAB-AVC Consortium specification of steel as the main component material reflects the program's goal to develop vehicle concepts with the lowest possible curb mass through optimized steel designs.

For the purpose of this summary report, the targets detailed here relate to the key objectives of the ULSAB-AVC program. However, a full range of target setting was completed and monitored throughout the program. For a thorough review of all targets set for this program, please refer to the ULSAB-AVC Engineering Report Section 2.0.

1.1.1 Crashworthiness Targets

The selected crash events take into account developments in crashworthiness and anticipate future requirements, as forecast in industry publications and outlined by government standards worldwide.

The ULSAB-AVC vehicle concepts were subjected to crash events, which are, in general, significantly more severe than those used for current vehicles. Noteworthy is the fact that, at the start of the target setting process in 1999, the side pole impact event was selected as an anticipated requirement. Since that time, this crash event has become a requirement in the United States.

Following are crash events selected for ULSAB-AVC vehicles, and subsequent targets.

Figure 1: **US-NCAP Front Impact Targets**

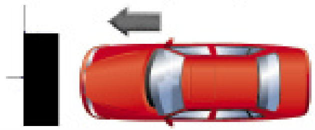
Crash Event	Crashworthiness Targets
US-NCAP Front Impact 35 mph (56 km/h) full face rigid barrier, zero degree impact 	Overall dynamic deformation _ 650 mm Steering Column displacement ≤ 80 mm in X-direction

Figure 2: **Euro-NCAP Front Impact Targets**

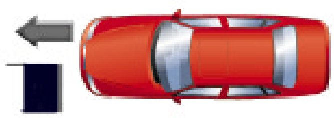
Crash Event	Crashworthiness Targets
Euro-NCAP 64 km/h (40 mph), 40% overlap offset deformable barrier, zero degree impact 	A-pillar displacement < 50 mm Footwell intrusion < 150 mm Steering column displacement ≤ 80 mm in X-direction

Figure 3: **US-SINCAP Targets**

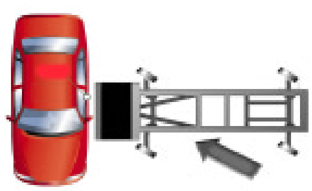
Crash Event	Crashworthiness Targets
US-SINCAP 38.5 mph (62 km/h) impact by 1370 kg trolley moving at 63 degrees to longitudinal axis of the vehicle 	Maximum intrusion velocity 6-7 m/sec

Figure 4: **Side Pole Targets**

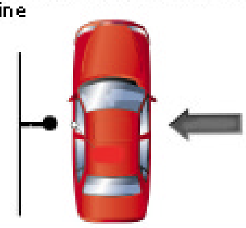
Crash Event	Crashworthiness Targets
Side Pole Impact 32 km/h impact with diameter 254 mm rigid pole aligned with the occupant head Centre of Gravity. Pole extends from 100mm above ground to above vehicle roofline 	Maximum Pole Intrusion velocity when striking occupant < 8 m/sec

Figure 5: **Rear Impact Targets**

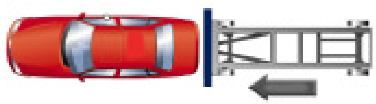
Crash Event	Crashworthiness Targets
Rear Impact 35 mph (56 km/h) rigid moving barrier 4000lb (1814 kg) impact with rear of vehicle in brakes-off condition 	Minimal deformation in region of fuel tank Movement of rear seat R-point < 50 mm

Figure 6: **Roof Crush/Rollover Targets**

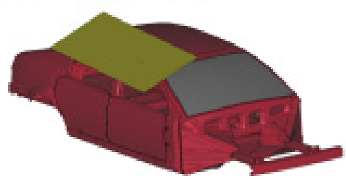
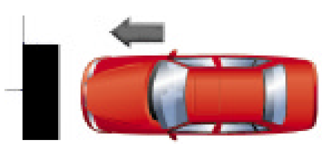
Crash Event	Crashworthiness Targets
Roof Crush / Rollover An inclined rigid loading device is forced against the A-pillar/roof side structure, quasi-statically, with a load 2.5 times the vehicle weight (test simlar to US-FMVSS216) 	Roof deformation < 127 mm

Figure 7: **Low Speed Impact Description**

Crash Event	Criteria for Crashworthiness Assessment
15 km/h impact into full-face rigid barrier at zero degrees 	Contain damage in bumper system components
Considerations	
Repairablility of the vehicle is important for cost of ownership and insurance	

1.1.2 Star Rating Assessment

The Star Rating system is a means of presenting the occupant injury results of the NCAP crash tests, which can be easily understood by consumers. In the United States, separate Star Ratings (up to five stars) are awarded to vehicles for the US-NCAP Front Impact test and the US-SINCAP test. In Europe, the EuroNCAP Star Rating is a combined rating for vehicles based on performance in the Front Impact and Side Impact tests. The EuroNCAP star rating allows a maximum of four stars with the addition of a fifth star for side pole crash safety (for vehicles with side air bags only).

The Star Rating assessments are based on occupant response, which is influenced by restraint system design. The crashworthiness targets have been defined from experience to provide a good basis for achieving a high level of overall safety. This program provides an optimized, lightweight steel structure design concept that could be further developed in normal automotive design practice for preparing a complete production vehicle. Therefore, ULSAB-AVC vehicle crashworthiness targeted criteria that would provide the opportunity for development of completed vehicles that achieve maximum Star Ratings in the EuroNCAP and US-NCAP, with the use of state-of-the-art occupant restraint system.

1.1.3 Main Component Mass

1.1.3.1 Body Structure Mass Targets

The body structure mass targets were set with assumptions made for a common platform concept, crash requirements, benchmarking data, as well as experience gathered through the mass reduction advancements made during the UltraLight Steel Auto Body (ULSAB) development.

The ULSAB-AVC targets acknowledge that the more severe crash requirements for the year 2004 will increase the body structure mass. The goal was to offset this potential mass increase using advanced steels, leading edge manufacturing and joining technologies, and further related innovations. Based on the resources described above and this goal to offset mass increases, the PNGV-Class target was set at 228 kg.

It is important to note that benchmark data indicate that the average PNGV-size vehicle body structure is 263 kg and the average C-Class is 243 kg. Since the mass difference between the two vehicle-class average benchmarks was 20 kg, it was decided to set the C-Class target at 20 kg less than the established PNGV-Class target (PNGV-Class 228 kg target – 20 kg = 208 kg C-Class target).

To put these targets into perspective, the aforementioned average benchmarks do not consider the significant increase in severity posed by the medley of events anticipated for 2004 crash requirements and the potential mass increase needed to effectively manage the increased crash demands. ULSAB-AVC vehicle targets do consider these more severe requirements.

Table 1: **Body Structure Mass**

Body Structure Mass	C-Class kg	PNGV-Class kg
ULSAB-AVC Targets	208	228
Average Benchmarks	243	263

1.1.3.2 Closure Mass Targets

Closure targets (see Tables 2 & 3) consider the difference in size between the ULSAB-AVC vehicle concepts and ULSAC. The goal was to reach the targets set in the ULSAC program, which were specified as a normalized mass (kg/m^2).

Table 2: **C-Class Closure Structures**

Closure Structure	Best-In-Class Benchmark kg	Target C-Class kg	Target C-Class kg/m^2
Door Front	31.0	26.0	15.5
Hood	13.5	16.0	8.0
Hatch	11.0	10.0	14.0
Fenders	6.0	4.0	-
Assembly Parts (e.g., hinges, brackets, springs, etc.)	17.9	15.5	
Total	79.4	71.5	

Table 3: **PNGV -Class Closure Structures**

Closure Structure	Best-In-Class Benchmark kg	Target PNGV-Class kg	Target PNGV-Class kg/m^2
Door Front	30.0	27.0	15.5
Door Rear	24.5	22.0	15.5
Hood	17.0	16.0	8.0
Deck Lid	11.0	10.0	8.0
Fenders	6.7	4.0	-
Assembly Parts (e.g., hinges, brackets, springs, etc.)	31.3	25.0	
Total	120.5	104.0	

1.1.3.3 Main Component Mass Summary

Following is a summary of all main component targets as well as the total vehicle mass targets. Additional details regarding what is included in each main component, as well as the mass of each sub-component, are available in the ULSAB-AVC Engineering Report Section 2.0.

Table 4: **Main Components Targets Summary**

Component Name	C-Class		PNGV-Class	
	Gasoline kg	Diesel kg	Gasoline kg	Diesel kg
Body Structure	208.0		228.0	
Closures Structure	71.5		104.0	
Glazing	32.1		32.8	
Chassis	198.5		198.5	
Engine	143.5	183.5	144.5	184.5
Gear Box	50.0		50.0	
Interior	173.0		192.0	
Exterior	4.5		6.5	
Electrics	41.7		41.5	
Automotive Fluid	41.0	44.0	41.0	44.0
Paint	16.0		20.0	
Total Vehicle	980	1023	1059	1102

1.1.4 Structural Performances – Body Structure

The performance targets for C-Class are set with priority to mass reduction, not for maximum stiffness. Targets for the PNGV-class vehicle reference ULSAB benchmarking data not the lower PNGV Program targets.

Table 5: **Structural Performance Targets**

	C-Class	PNGV-Class
Static Torsional Rigidity Nm/deg.	≥12000	≥13000
Static Bending Rigidity N/mm	≥11000	≥12020
First Global Mode Torsion Hz	≥35	≥40
First Global Mode Bending Hz	≥48	≥48
Front End Lateral Hz	≥55	≥55

1.1.5 Emissions

CO_2 Emissions - The CO_2 exhaust emissions are directly related to a vehicle's fuel consumption and the fuel type used (i.e. gasoline or diesel). EUCAR proposed future requirement specifies the CO_2 emissions for a fleet average of 140 g/km. For ULSAB-AVC (C-Class and PNGV-Class vehicle), the $C0_2$ EUCAR Fleet Average Target was adopted as a single vehicle target that will comply with future requirements. It was assumed that achieving the EU4 Exhaust Emissions Targets for CO_2 also would fulfill the U.S. EPA Tier 2 Requirements.

Other Emissions – No targets were set for other emissions. The ULSAB-AVC Program scope did not include development of technologies to address all EU4 emissions targets.

1.1.6 Vehicle Dimensions

Vehicle dimension targets were set, e.g., height, length, wheelbase, etc., to comply with the defined C-Class and PNGV-size vehicle classes. The vehicle dimensions were set to achieve a good basis for a platform concept that complies with the dimensions as set by PNGV. The C-Class wheelbase was not specified because the goal was to achieve maximum interior volume at a given vehicle length range.

1.1.7 Vehicle Performance

Vehicle performance targets were set based on engineering judgment to achieve primary program objectives and to reflect customer-driven trends.

Table 6: **Vehicle Performance Targets**

	C-Class	PNGV-Class
Acceleration 0-62 mph (0-100 km/h) / sec	≤14	≤14
Aerodynamic Drag coefficient	≤0.25	≤0.25
Top Speed Continuous/ mph / km/h	100 / 160	100 / 160

1.2 Program Summary

ULSAB-AVC offers concept solutions to the automotive industry's need for safe, affordable, fuel efficient vehicles. Steel is a key enabler to accomplish these demanding, and sometimes conflicting, challenges. See Figures 8 and 9 for steel grade and related manufacturing technology summaries.

Table 7: **Summary Results**

	C-Class		PNGV-Class	
	Gasoline	Diesel	Gasoline	Diesel
Safety				
Star Rating Potential – US NCAP	4 or 5	4 or 5	5	5
Star Rating Potential – US-SINCAP	5	5	5	5
Star Rating Potential – Europe	5	5	5	5
U.S.IIHS Rating Potential	good	good	good	good
Affordability				
Body Structure	$916	$916	$972	$972
Vehicle Manufacturing Cost	$9,190	$9,890	$9,538	$10,238
Fuel Efficiency				
European Driving Cycle				
CO_2 Emissions (NEDC 2000) g/km	106	86	108	89
L/100 km	4.4	3.2	4.5	3.4
U.S. Driving Cycle				
CO_2 Emissions (Combined) g/km	105	86	108	92
MPG (Combined)	53	73	52	68
MPG (City)	49	66	48	62
MPG (Highway)	61	84	60	78
Mass				
Vehicle Curb Weight (kg)	933	966	998	1031
Body Structure (kg)	202	202	218	218
Closure Structures (kg)	43	43	61	61
Driving Performance				
Acceleration (0-100 km/h)	13.5	13.4	13.9	13.9
Intermediate Accel (80-120 km/h)	17.9	16.8	18.0	17.4
Top Speed (km/h)	194	184	193	184
Structural Performance				
Static Bending Rigidity (N/mm)	17,050	17,050	17,150	17,150
Static Torsion Rigidity (Nm/deg)	14,350	14,350	17,400	17,400
First Bending Mode (Hz)	58	58	66	66
First Torsion Mode (Hz)	49	49	44	44
Front End Lateral (Hz)	> 70	> 70	>70	>70

Figure 8: **ULSAB-AVC Body Structure Steel Types**

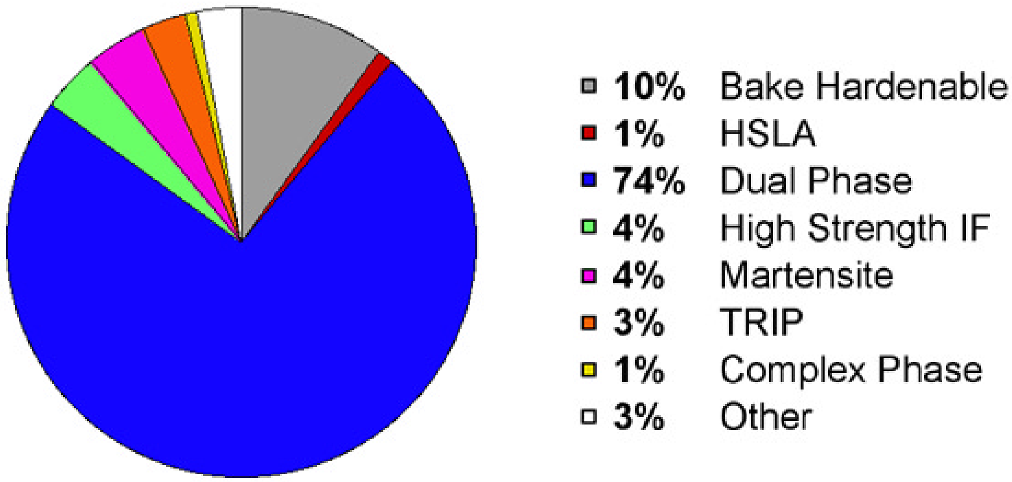
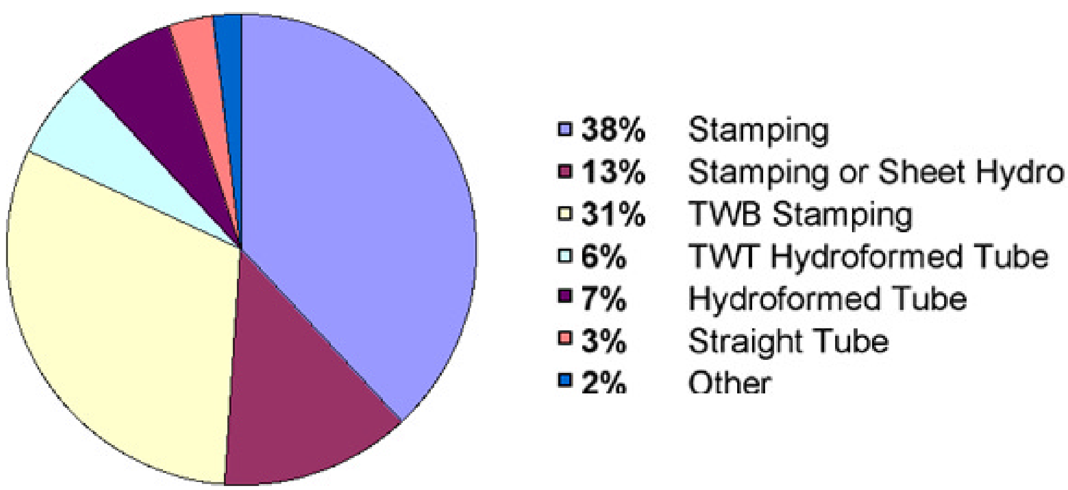


Figure 9: **ULSAB-AVC Body & Closures Maunfacturing Processes**



2.1 Design Considerations

Prior to the start of the design work, the Porsche Engineering Services, Inc. team, with appropriate input from the Consortium, defined specific elements and features that would be included in the vehicle design to achieve program targets.

In harmony with the targets for safety/crashworthiness, mass, structural performance, dimensions and component material definition, major influencing factors in package development were:

- Platform approach for both C-Class and PNGV-Class
- Safety targets for crashworthiness
- Steel-intensive vehicle at low mass
- Vehicle dimensions
- Modular design/assembly approach

2.1.1 Platform Approach

One of the first decisions made in approaching the ULSAB-AVC vehicle packaging was to consider a platform approach for the vehicle classes, also accommodating gasoline and diesel engine variants. To meet program objectives, a unique C-Class vehicle architecture and structural platform were designed with the ability to expand to a PNGV-Class vehicle. For the body-structure concept, therefore, the decision was made to develop a common front-end structure and package for both designs to share as many components as possible. The differences between classes lay mainly in the vehicle sizes and in the hatchback design for the C-Class versus the four-door sedan design of the PNGV-Class.

The ULSAB-AVC front-end architecture and engine concept are purpose-built to achieve an optimized balance of fuel efficiency and safety while optimizing modular design for ease of assembly and servicing. To achieve the safety targets, the engine was positioned behind the transmission, allowing the powertrain to move rearward into the tunnel during a crash event rather than intrude into the passenger compartment. For this purpose, a relatively large tunnel width was specified in the design.

2.1.2 Safety/Crashworthiness

The overall body structure architecture and package were designed to meet the most stringent safety requirements anticipated for the year 2004 and to provide the potential for high vehicle star ratings. The side pole crashworthiness target required a different approach to interior design, which lead to the use of fixed front seats fixed to advanced high-strength steel crossmembers to support the body structure and minimize mass increase for crashworthiness.

Pedestrian head injury protection considerations drove the selection of a common front suspension design for both vehicle classes that eliminates shock towers, and thus hard points immediately under hood and fenders. This suspension system is designed to be tuned to account for differences in total vehicle mass and for the two engine types (diesel and gasoline).

2.1.3 Materials and Processes

Primary to ULSAB-AVC's design development was the use of steel materials and manufacturing processes that reflect state-of-the-art or future trends. The need to reduce the added mass required to satisfy future safety mandates presented the opportunity to also consider the application of newer types of high-strength steels, advanced high-strength steels (AHSS), to assist in achieving the overall aims of the program. Since this is a concept program focusing on manufacturability in the year 2004 and beyond, it provides an opportunity to expand the list of candidate steels to those steels that are currently available and those under development that will become available by 2004.

The body structure analysis was run using dynamic high strain rate properties provided by the ULSAB-AVC member companies. The closure designs suggested in ULSAB-AVC utilize the designs and findings from the UltraLight Steel Auto Closures (ULSAC) program concept and validation phases completed in May 2001. For detailed review of the ULSAC Engineering Reports, please visit the website at www.ulsac.org.

Use of advanced technologies, like tailored blanks, hydroformed tubes, tailored tubes and laser assembly welding, were also basic considerations towards achieving a safe, lightweight vehicle. Proven technologies were maximized to benefit the overall vehicle goals. For example, when laser welding was needed for some applications, the use of the required laser weld station was then maximized and applied to eliminate other spot welds.

2.1.4 Vehicle Size/Dimensions/Aerodynamics

ULSAB-AVC vehicle dimensions were not downsized to meet the aggressive mass targets. Rather, in the interest of creating a design that meets with consumer acceptance in terms of size, comfort, and safety, the design maintains state-of-the-art C-Class and PNGV-Class interior space, luggage volume capacity and exterior dimensions. All package issues, such as angle of approach, defined bumper height, head position contour and passenger position, were considered.

Exterior aerodynamic drag and through-vehicle airflow were considered to reduce CO_2 emissions, which led to selection of rear-view cameras and an enclosed underbody design.

Interior design and overall packaging were driven by occupant safety and comfort considerations. Adjustable pedals and steering wheel accommodate the fixed seat approach. Maximum comfort dimensions were set for the defined exterior class sizes. A wider wheelbase helped optimize interior passenger space as well.

2.1.5 Axle Load Balance/Handling Performance

The lightweight front-end body concept, in combination with an optimized engine bay package, was a major factor contributing to front axle load reduction. The ULSAB-AVC vehicles were designed to have a more equalized distribution of total vehicle mass between the front and rear axles for improved lightweight vehicle handling. This is evident in the design in the forward position of the front wheels and the engine/transmission location that is further back than conventional designs.

2.1.6 Engine Bay Package Modular Approach

To reduce assembly cost, and therefore overall cost, the design uses modules integrating several components for assembly and servicing. The engine bay package layout is an example of this system approach, featuring a service module in which the engine/transmission, front suspension, radiator and steering rack are positioned on the sub-frame and mounted to the body structure. The complete subsystem can be assembled/disassembled as one unit from underneath the vehicle.

This design eliminated the need to give access to the engine through the hood. Consequently, the hood is fixed. A service lid in the front provides access to service oil, water and washer fluid.

Following are vital attributes of the engine bay package's final design configuration, which led to its incorporation into the vehicle concepts:

- Safety
  - No footwell intrusion of the powertrain in frontal crash, facilitated by a narrow engine concept and tunnel design.
  - Avoidance of powertrain and auxiliaries stack up to increase the dynamic frontal crash length
  - Engine/auxiliaries packaged further below the hood to increase safety for pedestrian head injury.
- Vehicle Mass Distribution
  - Short front overhang
  - Reduced front axle load contributing to an improved load distribution to the front and rear axle, compared to typical front wheel drive vehicles.
- Auxiliary Mass
  - Short exhaust system for reduced mass
  - Catalytic converter close to the exhaust manifold provides opportunity to avoid pre-heated (electric) catalytic converters for emissions reduction.
- Body Structure Mass
  - Engine packaged below the front rails to gain more opportunity for a lightweight front-end design.
- NVH
  - The opportunity to close off the engine bay above the rails for elimination of sound emissions through ducting and cable routing openings.
- Package Space
  - Space above front rails for components usually packaged inside vehicle.
  - Opportunity to increase interior space and maximize the wheelbase.

2.2 ULSAB-AVC Styling & Packaging

Since the ULSAB-AVC program focused on total vehicle development, styling was an essential part of the development process for its affects on the overall vehicle design.

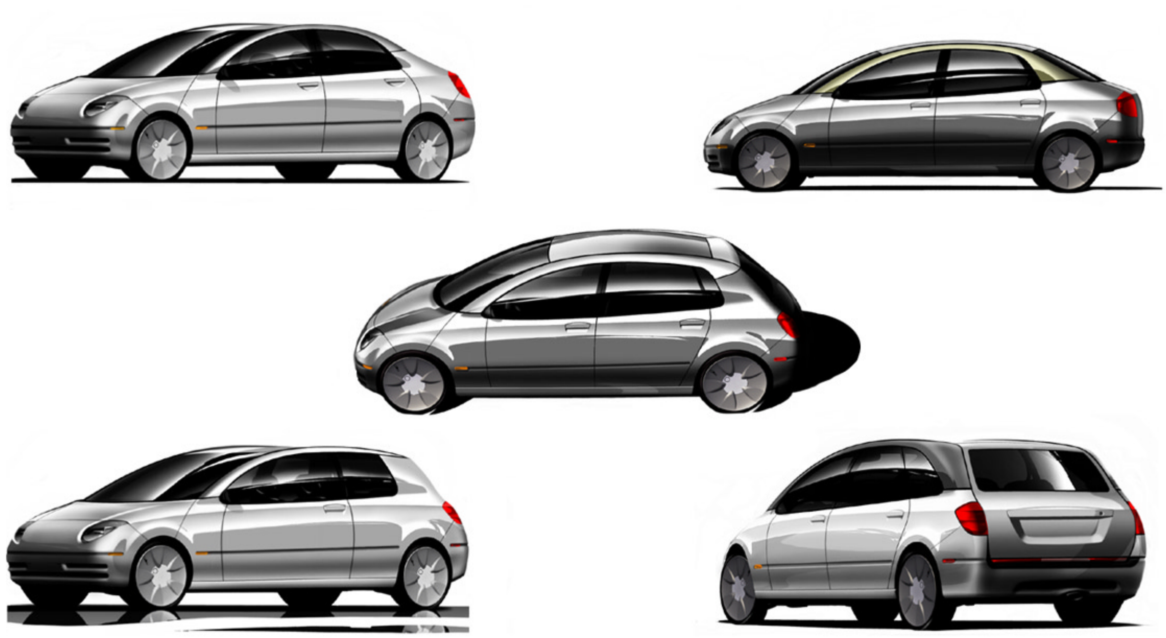
2.2.1 Exterior Styling

Styling requirements included the creation of 3D surface data for 2-door hatch-back C-Class and 4-door sedan PNGV-Class vehicles using common styling features between the two. For the C-Class derivatives, such as sedan, estate or 5-door options, only 2D sketches were required.

The overall goal was to design a family of steel vehicles that would be suitable for the year 2004 and beyond and would highlight the program focus on steel and steel-based technologies. Though the vehicles share the same front end, styling considered the longer wheelbase and sedan design of the PNGV-Class vehicle.

Figure 10 shows the 2-D sketches of the C-Class family of vehicles. Each vehicle has unique styling, yet contains substantial common parts to support the platform approach.

Figure 10: **C- Class Family Sketches**



One major characteristic that is shared among the family vehicles is the roof rail appliqués. This feature provides the opportunity for graphic distinction among the models, which could be finished with individual effects to enhance model types.

Photorealistic images of ULSAB-AVC's styling can be seen in Figures 11 through 14.

Figure 11: **C-Class 3/4 Front View**

Figure 12: **C-Class Side View**

Figure 13: **PNGV-Class 3/4 Front View**

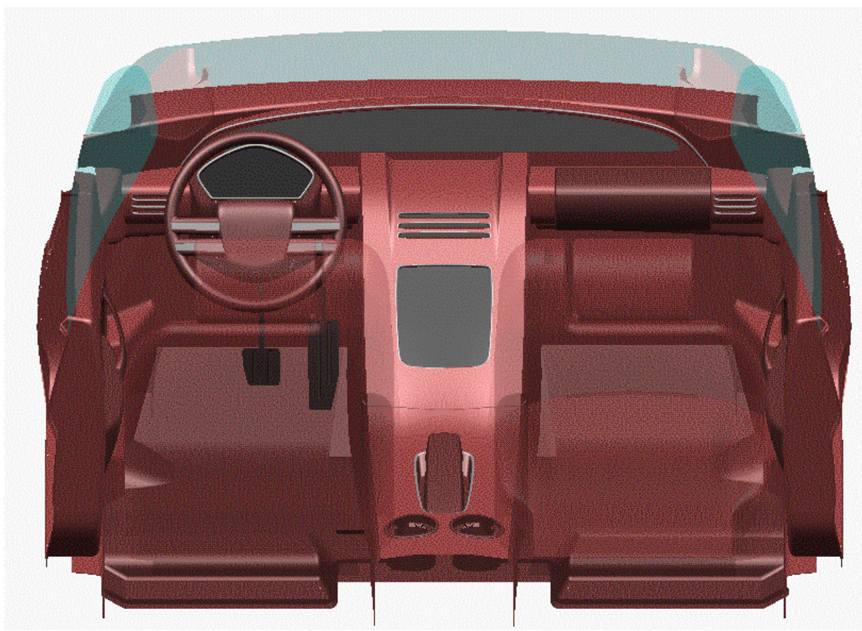
Figure 14: **PNGV-Class Side View**

2.2.2 Interior

Interior design themes were driven by a goal to expose steel and integrate these steel features into modular components that enhance the mass efficient vehicle designs.

The four main design areas were the center console, cockpit, door panel and steering wheel.

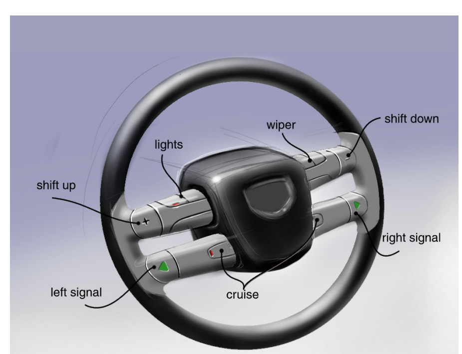
Figure 15: **Interior Styling Cockpit Concept**



The cockpit module's main theme (see Figure 15) revolves around a crossmember feature that is intersected by a large flowing center console. The cross member carries the HVAC ducting, passenger air bag and steering wheel module. Sectional surface breakups were used to overcome the visual mass of the large tunnel. The cockpit module incorporates a rear view camera display panel. More interior views can be found in Section 2.6 Subsystems and in the ULSAB-AVC Engineering Report Section 12.0.

The steering wheel module (see Figure 16) integrates the steering wheel and a flat panel display, containing vehicle information and control functions. This concept reduces parts and related costs, mass, tooling investment costs and trim line assembly costs because of the elimination of the gear shift on the tunnel or dash panel and the related levers.

Figure 16: **Steering Wheel Styling Concept**



2.2.3 Package Drawings & Dimensions

Figures 17 and 18 show package drawing side views for both vehicle classes. A full review of package drawings is available in the ULSAB-AVC Engineering Report Section 4.0.

Figure 17: **C-Class Package Drawing Side View**

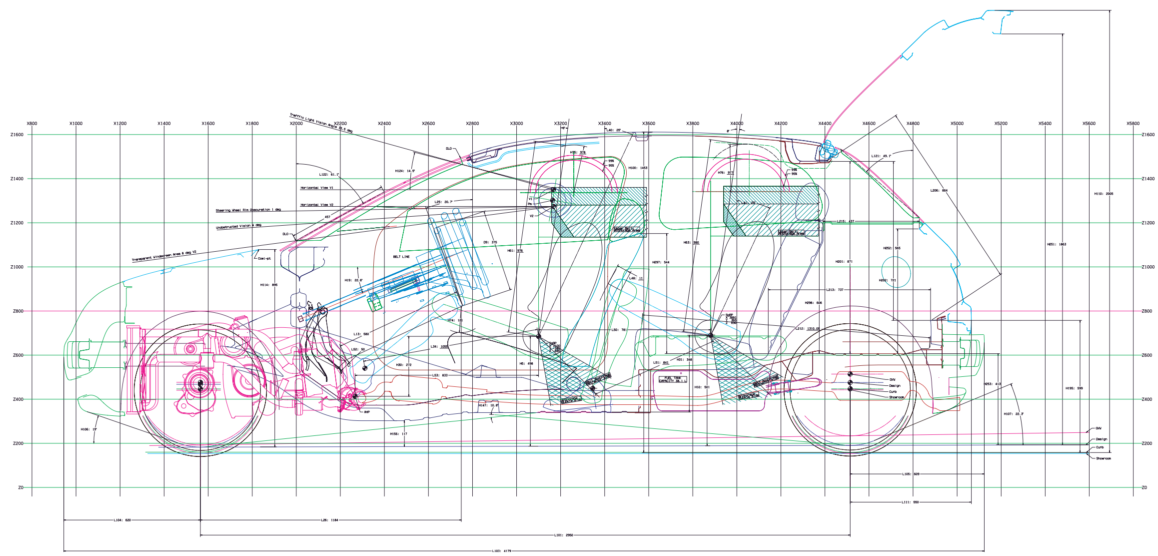
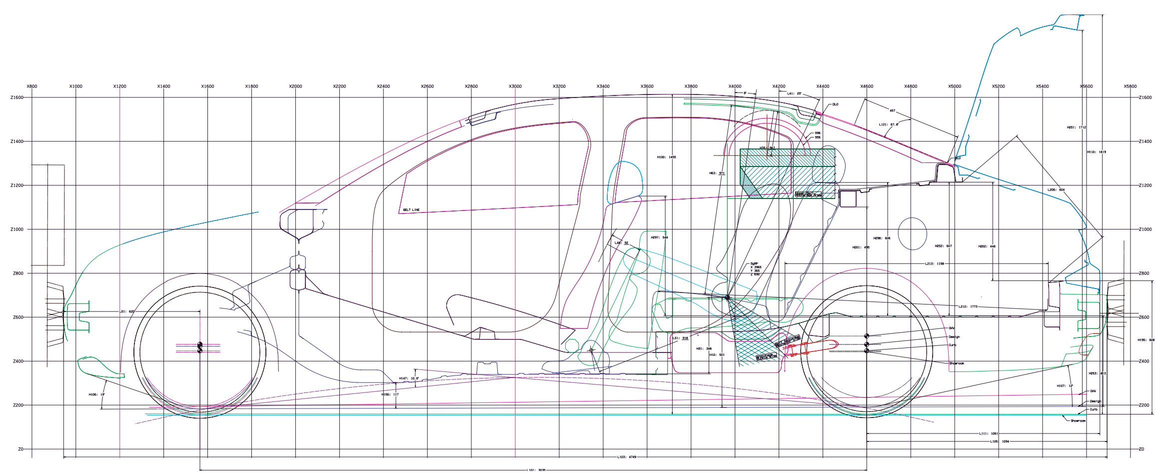


Figure 18: **PNGV-Class Package Drawing Side View**



Basic vehicle dimensions are shown in Table 8.

Table 8: **Vehicle Dimensions**

ECIE/ SAE Index	Exterior	C-Class		PNGV-Class	
		Target	Result	Target	Result
L103	Overall Length (mm)	4100+100	4179	4750	4744
W103	Overall Width (mm)	1750+50	1766	1822+50	1765
H100	Overall Height (mm)	1400+50	1455	1374	1455
W101	Track – Front (mm)	1530+20	1540	1529+20	1540
W102	Track – Rear (mm)	1530+20	1540	1529+20	1540
L101	Wheelbase (mm)	TBD	2950	>2743	3035
-	Front Area (m^2)	<2.0	2.02	<2.0	2.02
W3	Shoulder Room Front (mm)	1402	1448	1402	1448
W4	Shoulder Room Rear (mm)	>1350	1402	1389	1402
-	Interior Volume (m^3)	>Golf IV	>Golf IV	2.7	>2.7
-	Luggage Comp. Vol. (m^3)	>Golf IV	0.30/1.19*	0.44	0.57
	Passenger Capacity	5	5	5	5
	Turning Circle	<11	10.7	<11	10.9

** unfolded/folded rear seat*

2.3 Body-in-White Concept Designs

The ULSAB-AVC body-in-white is just one example of how advanced high-strength steel and advanced automobile design can be combined in a cutting edge structure to achieve the delicate balance of safety and mass efficiency, yet remain an affordable solution to mass reduction challenges.

This Section summarizes the body-in-white design, including some of its specific steel applications. To understand the steel nomenclature used to describe the steels, please refer to Section 3.2 Steel Nomenclature.

Figure 19: **C-Class Vehicle Body Structure**

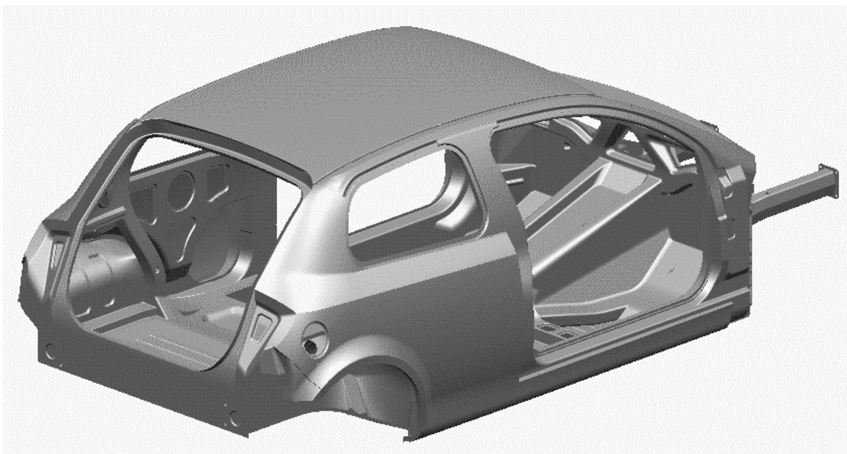
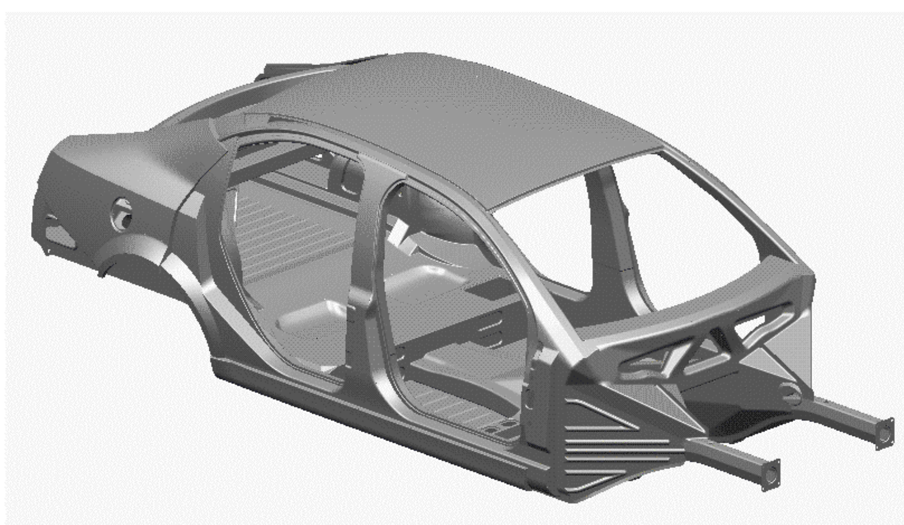


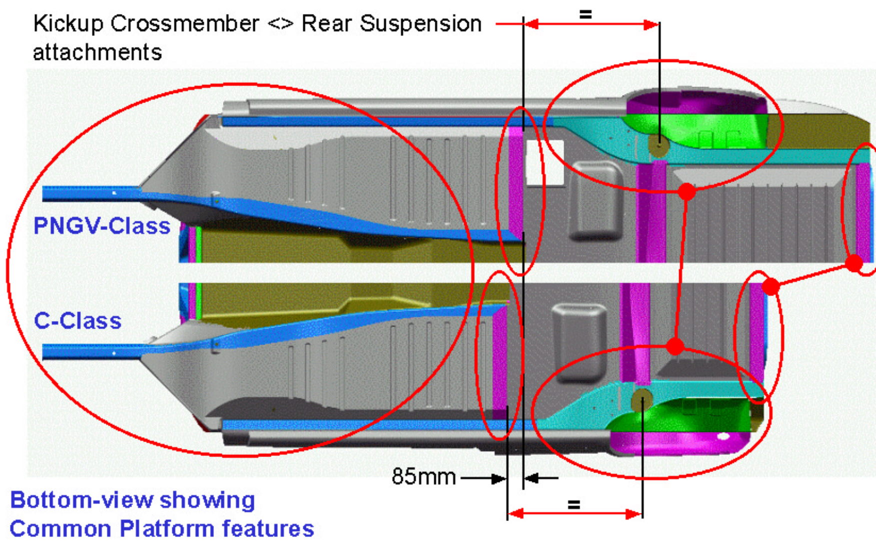
Figure 20: **PNGV-Class Vehicle Body Structure**



2.3.1 Common Platform

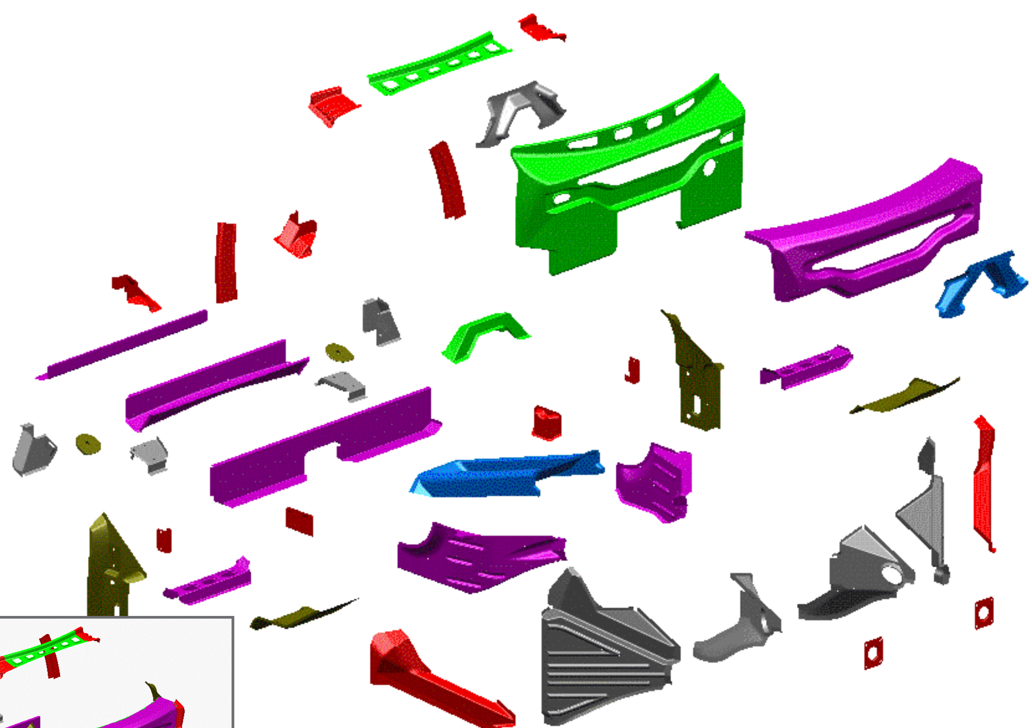
Figure 21 shows each vehicle variant, indicating the areas that are common to both vehicles, which amounts to about 22 percent of the body parts.

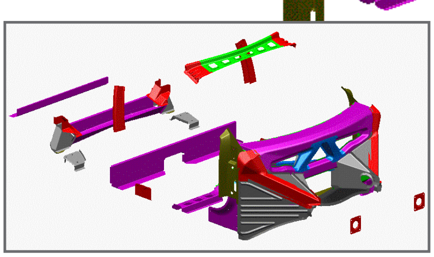
Figure 21: **Common Platform Features**



Full exploded views of both body structures and their related parts lists can be found in Appendix 1. Figure 22 illustrates the common parts as well as their location within the vehicle, using the C-Class as an example.

Figure 22: **C-Class/PNGV-Class Common Parts Exploded View**

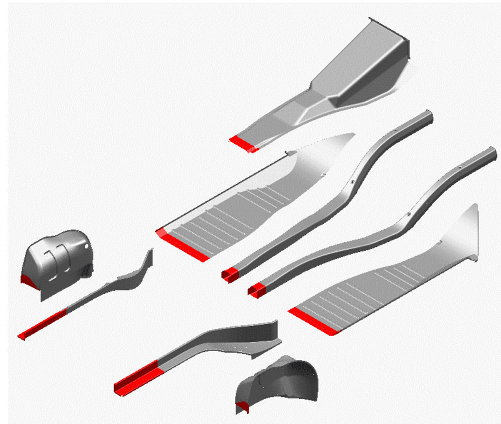




Parts shown in C-Class vehicle position

Common parts are defined as those using the same stamping or hydroformed tool followed by trim operations to size the parts for the difference in vehicle variants. Figure 23 shows parts with the potential to be manufactured using common dies, which include front-end and rear-end parts, keeping in mind that this must be verified in a detailed design phase. The trim operation area is indicated in red.

Figure 23: **C-Class and PNGV-Class Common Dies**

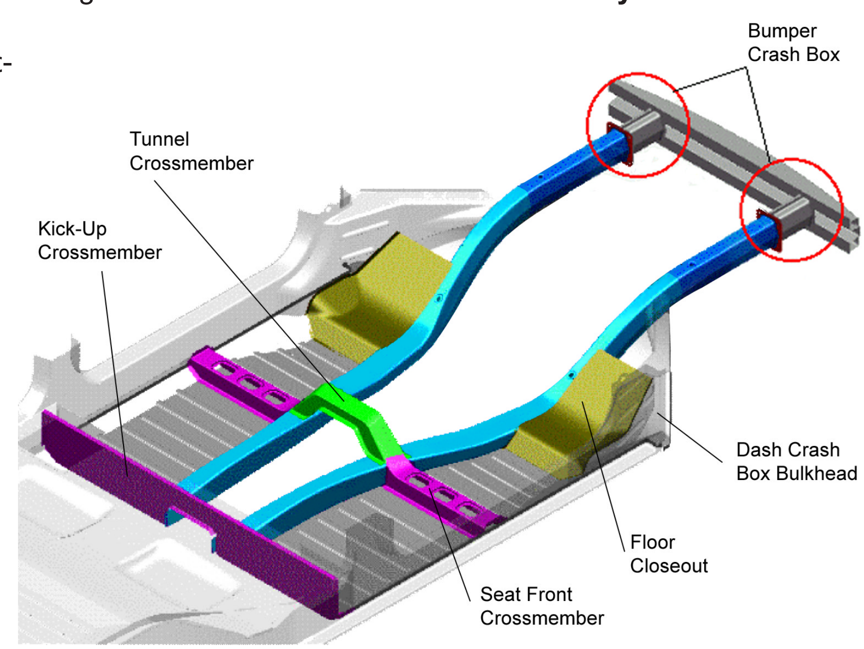


2.3.2 Front-End Structure

Two longitudinal rails (see Figure 24) are the backbone of the entire underbody and integral load-carrying structures for frontal crash energy management. These structures are made of two hydroformed 100 mm diameter DP500/800 steel tailored tubes (TWT), with front and rear tube thickness at 1.5 and 1.3 mm, respectively. TWT use in the front rails enables effective crash management at a reduced mass.

The rails extend rearwards to the kick-up crossmember box-section. The floor is laser welded to the lower outboard surface for enhanced underbody aerodynamic efficiency.

Figure 24: **Front-End Structure Underbody View**



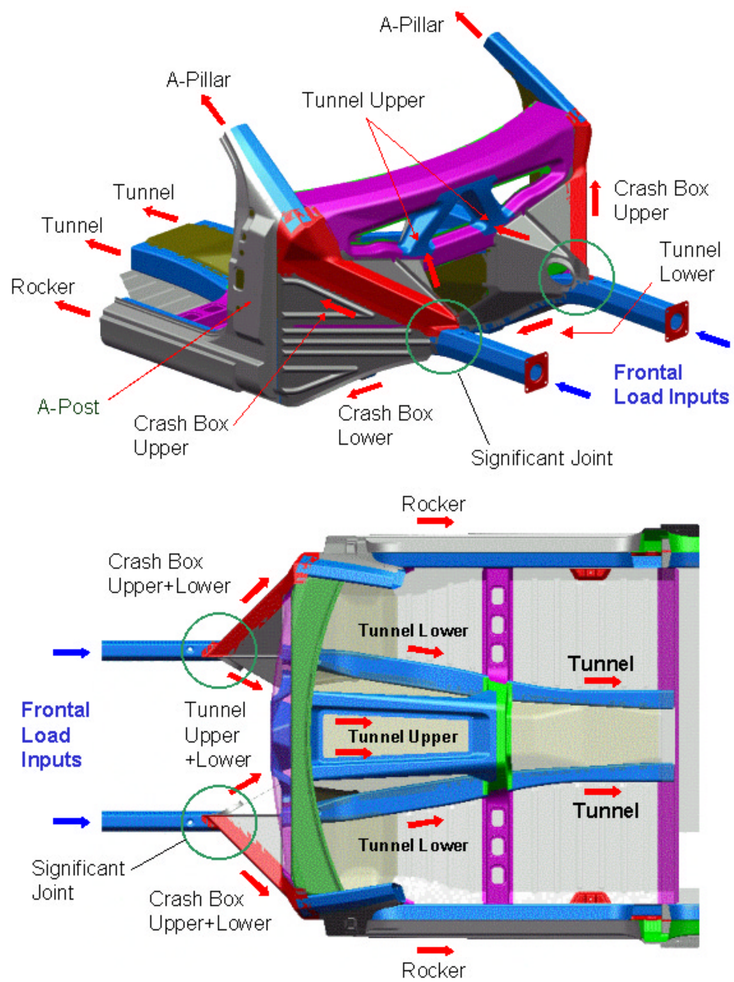
The engine/suspension subframe module eliminates the front shock towers for mass reduction and, thus, an upper longitudinal load path. Instead, frontal crash loads are transferred through the rails via the bumper beam and bumper crash boxes to the rocker, A-pillar, upper and lower tunnel. Additionally, the rear engine/suspension subframe attachments are designed to allow unrestricted engine movement rearward into the tunnel during a full frontal crash, thereby minimizing cockpit intrusion by the engine.

Forward of the A-post, a multifunctional structure, referred to as the dash crash box, was designed primarily to absorb energy in front crash and to achieve good support to manage the demands of both the full frontal and 40 percent offset crash events. The dash crash box incorporates an inner lower diagonal bulkhead and lower closeout panel that transfer loads between rail and rocker, as well as an upper diagonal reinforcement for load transfer between rail and A-pillar. Offset crash lateral loads are transferred into the dash crossmember, tunnel and cowl. Integrated into the dash and cowl structure are both upper and lower crossmembers (called the "pyramid"), connected by a two-piece stamped A-brace at the center of the vehicle. The lower crossmember and A-brace provide a good foundation for the tunnel and tunnel reinforcement joint.

Made of varying grades and thicknesses of DP steel, the dash crash box, working in conjunction with the DP steel front rails, ensures that crash loads are still widely distributed through the vehicle, even though there is a single load path through the rails. DP steel enables this to be accomplished at reduced mass, yet with excellent performance.

Figure 25 shows the common front-end structure of both vehicles in front ISO and top view, identifying the load distribution from the front rails into the structure.

Figure 25: **Front Load Paths**



2.3.3 Side Structure

The rocker structure (see Figures 26 and 27) is identical for both vehicle classes forward of the C-Class B-pillar reinforcement and PNGV-Class lower B-pillar reinforcement. There are no inner rockers, A-post reinforcements or bulkheads. These parts were eliminated through the use of tailored blanks in the rocker inner and body side outer panels. This design optimizes the rocker and A-post sections, reduces part count and eliminates unnecessary joints. The side structure also features seat (PNGV-Class) and kick-up (C-Class) crossmember extensions that are integral to side impact crash management. Their function is described in the following section.

Figure 26: **C-Class Rocker with kick-up crossmember**

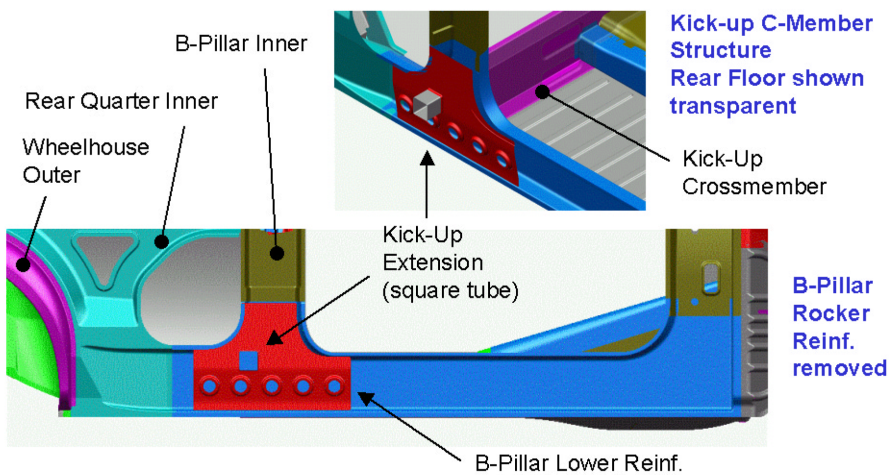
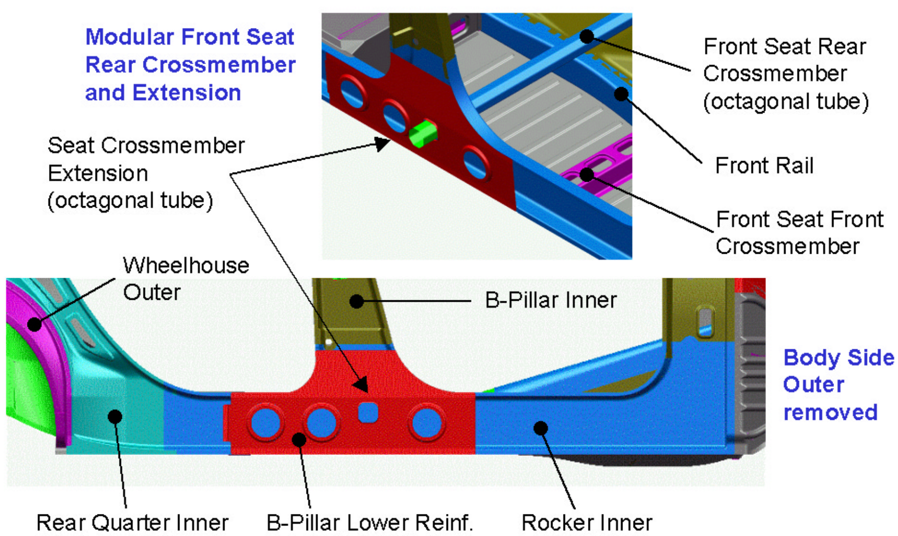


Figure 27: **PNGV-Class Rocker with kick-up crossmember**



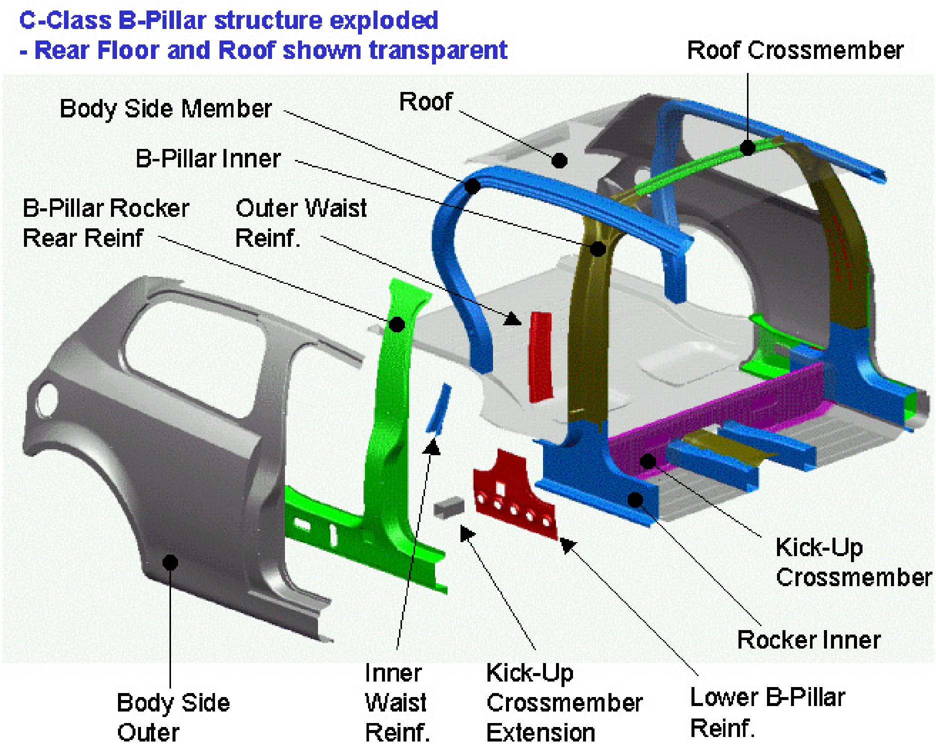
2.3.4 B-Pillar Structure

The ULSAB-AVC B-pillar design criteria included the US-SINCAP, Side Pole and Roof Crush crash events. The resulting design contributes significantly towards meeting the stringent structural demands imposed by these crash events.

2.3.4.1 C-Class B-Pillar Structure

For the C-Class design (see Figure 28), the absence of a rear door presented a specific challenge, which required a different approach than that taken for the PNGV-Class.

Figure 28: **C-Class B-Pillar Structure (Partial Exploded View)**



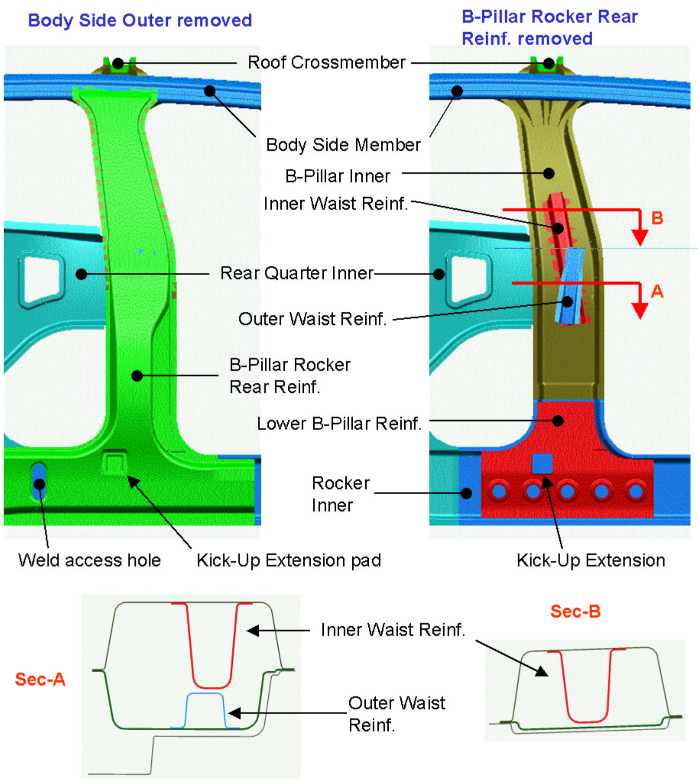
A B-pillar inner panel connects the rocker to the body side member. A full-length B-pillar inner reinforcement is incorporated into the rocker section, between the lower B-pillar joint and wheelhouse, creating a closed section. The lower joint has a reinforcement, creating a shear plane between the lower rocker weld flange and the door aperture seal attachment weld flange. The kick-up crossmember extension is welded to the reinforcement laterally.

The closed box section of the kick-up crossmember is formed by the joining of the crossmember to the rear floor. In the C-Class, the kick-up crossmember and the kick-up crossmember extension, both made of 0.7 mm DP 700/1000 steel, carry much of the side impact crash load and therefore are key to passenger compartment integrity. The extension stacks up, driving the crash energy forces directly into the crossmember. The DP steel used to build these parts contributes to crash energy management through its increased work hardening effect over conventional steels.

The seat crossmember, made of a 60 mm diameter Mart 950/1200 octagonal steel tube at 1.2 mm thickness, also supports passenger compartment integrity in side impact crash for the C-Class vehicle. See the CAE crash analysis in Section 4.1 to review how the seat and kick-up crossmembers maintain their structural integrity in the most severe side impact events.

To stabilize the B-pillar for a side impact crash (see Figure 29), the two reinforcements are positioned at the transition from lower B-pillar structure to upper B-pillar (waistline). The inner reinforcement is welded to the B-pillar inner panel, extending the length of the transition. The opposing outer reinforcement is welded to the B-pillar reinforcement, below the waist. The reinforcements are not aligned due to the door latch packaging constraints of the 2-door hatchback. At this point in the tailored blank body side outer, 0.7 mm BH 260/370 steel primarily forms a pillar closeout panel.

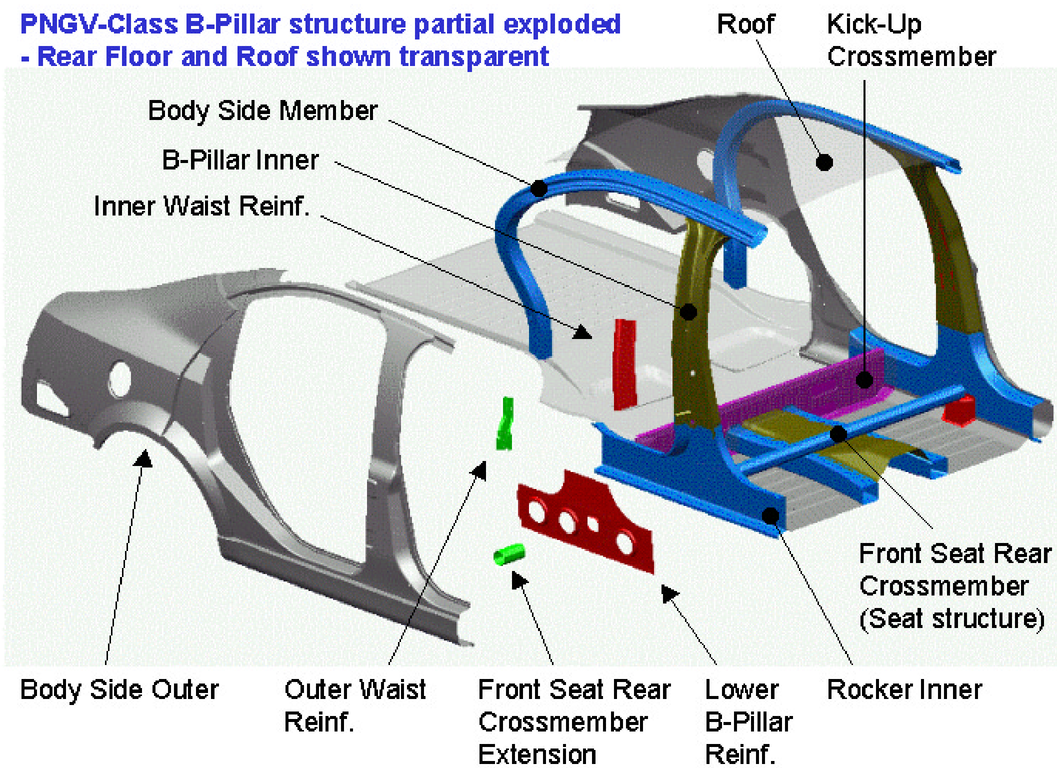
Figure 29: **C-Class B-Pillar (With Rocker Rear Reinforcement Removed)**



2.3.4.2 PNGV-Class B-Pillar Structure

As mentioned, the PNGV-Class B-pillar design (see Figure 30) differs from the C-Class because of the 4-door sedan model requirements.

Figure 30: **PNGV-Class B-Pillar Structure (Partial Exploded View)**



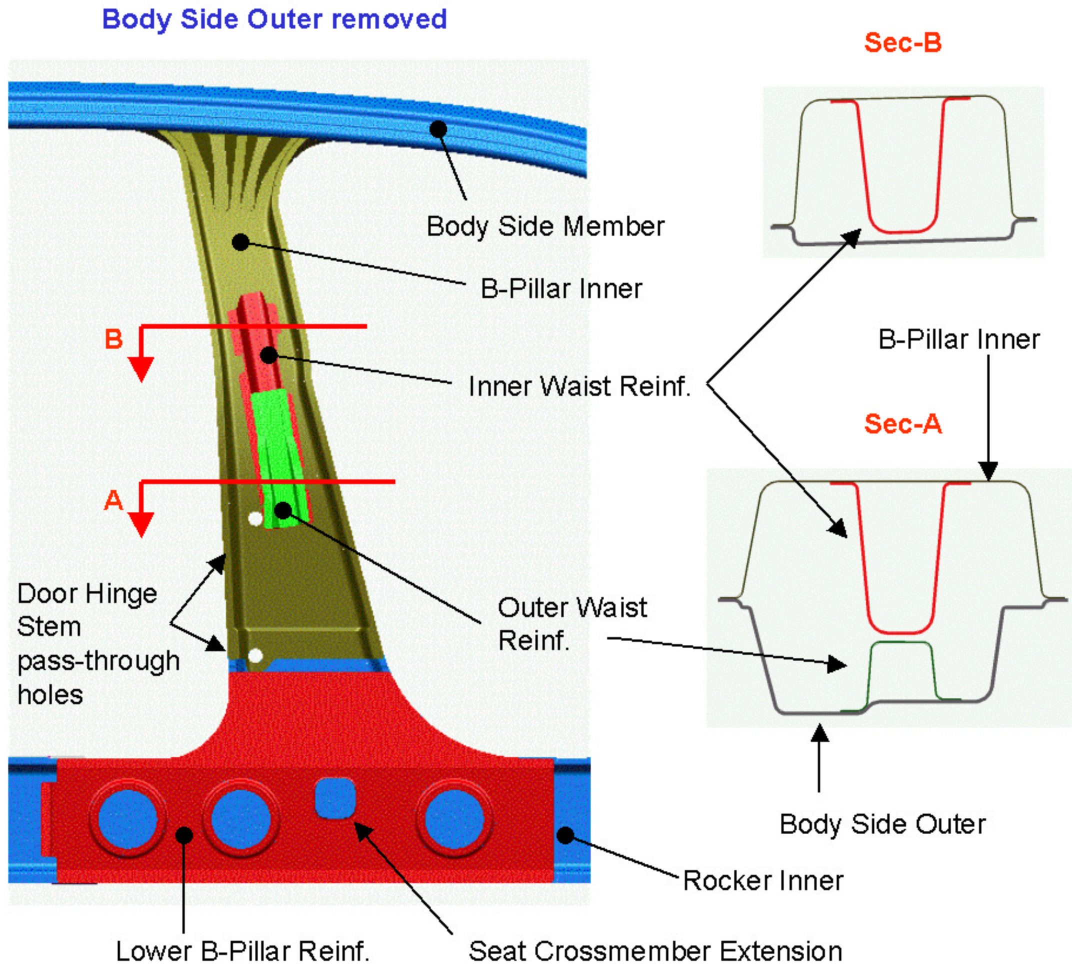
As in the C-Class, a B-pillar inner panel connects the rocker inner panel to the body side member. However, in the PNGV-Class B-pillar design, a portion of the body side outer tailored blank, made of five different steel blanks (similar to the ULSAB design), replaces the full-length B-pillar inner reinforcement. The outer B-pillar portion of the body side outer is 1.8 mm DP 700/1000 steel.

The lower joint configuration is similar in principal to the C-Class design. A major distinction in design between the two classes is that where in the C-Class an extension tube transfers loads into the kick-up crossmember, in the PNGV-Class an extension tube aligns with the seat crossmember. This has to do with the differences in door aperture between the two classes (two-door C-Class, four-door PNGV-Class). The rocker section in the PNGV-Class is larger, allowing for the extension of the seat crossmember to handle load transfers. The front seat crossmember extension matches the seat crossmember material, which is a 60 mm diameter, 1.2 mm thickness Mart 950/1200 steel octagonal tube.

The martensitic steel used in the seat crossmember and extension contributes significantly to side impact crash by providing the strength and rigidity needed for passenger compartment integrity. Also, the crossmember extension tube creates a stack up so that the crash forces go directly into the crossmember rather than allowing intrusion into the passenger compartment. Review of the CAE side impact analyses in Section 4.1 reveal that this crossmember retains its integrity even in the severe side pole test.

The PNGV-Class B-Pillar employs the same reinforcement concepts as the C-Class with a slightly different configuration. The reinforcements are incorporated as shown in Figure 31.

Figure 31: **PNGV-Class B-Pillar Structure**

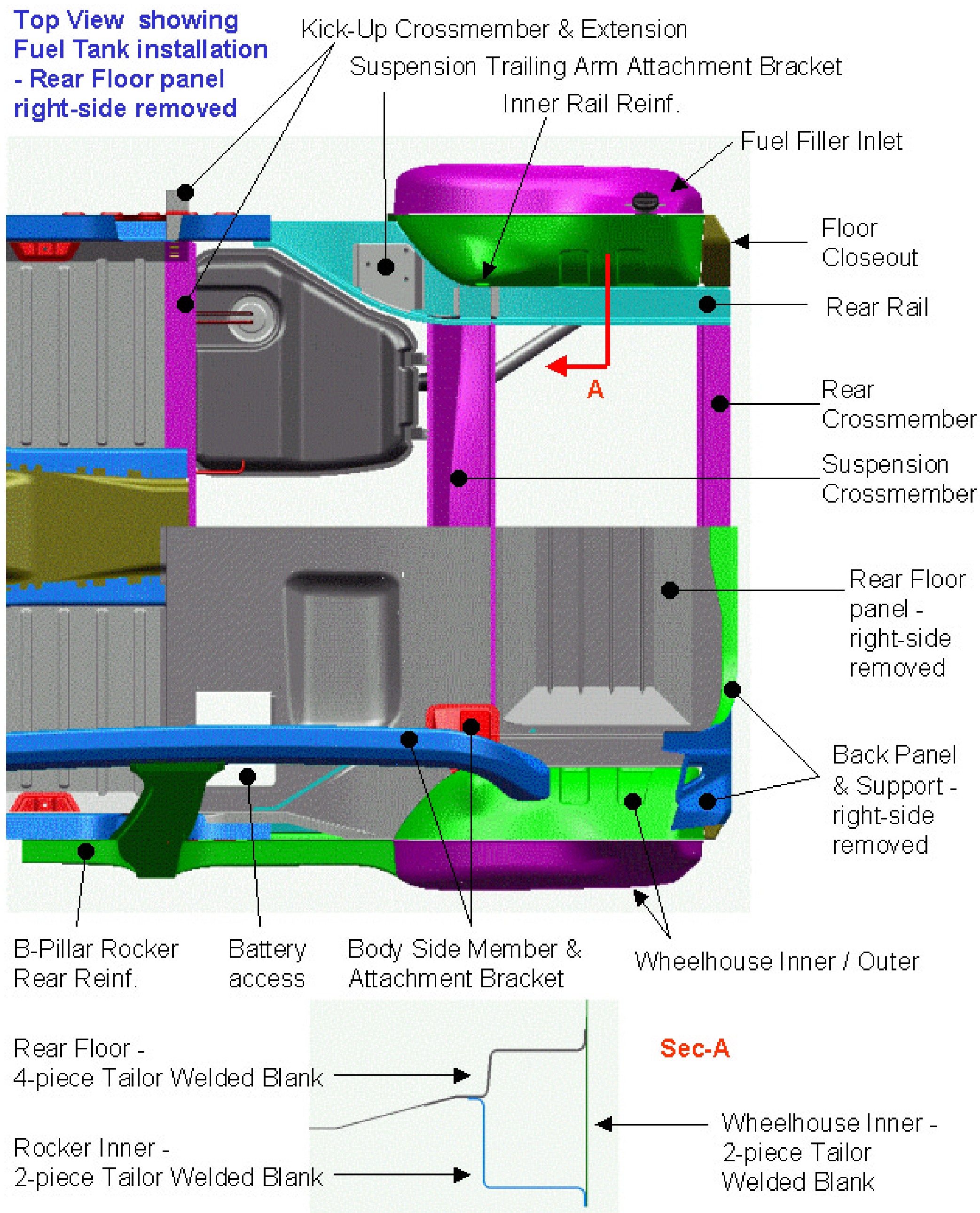


2.3.5 Rear End Structure

2.3.5.1 C-Class Rear End Structure

Figure 32 illustrates the configuration of the C-Class rear structure.
The rear longitudinal rails are created primarily of three components: the rear floor, rear rail and wheelhouse inner. All three parts are manufactured using tailored blanks to optimize body stiffness, crashworthiness and mass reduction.

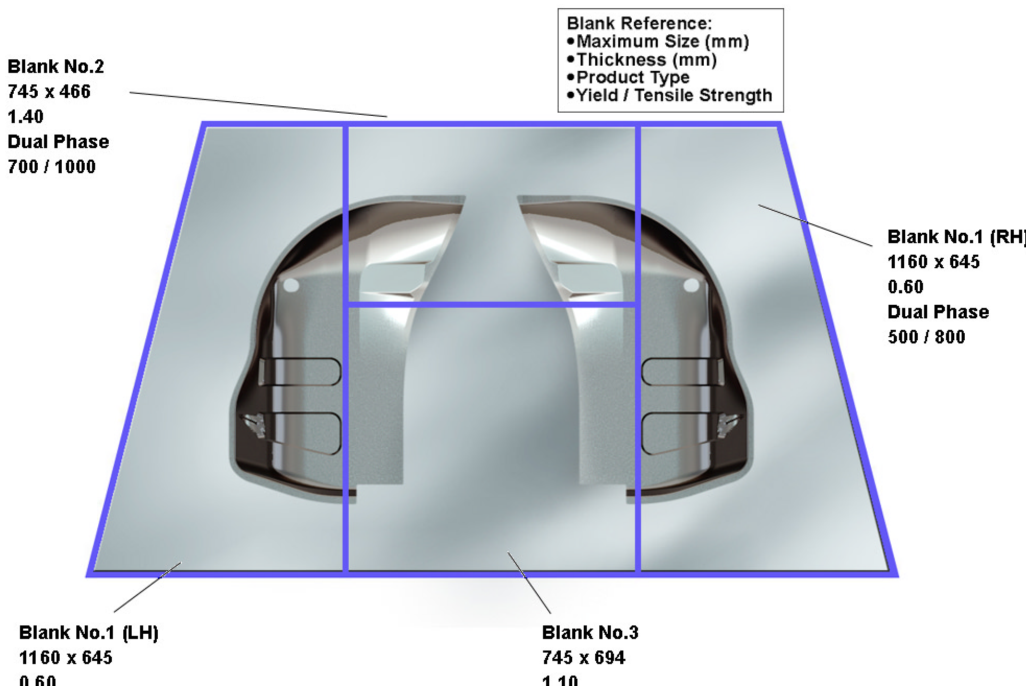
Figure 32: **C-Class Rear Structure (Top View)**



This rail design is an excellent example of how steel has enabled an optimized, efficient structure. Here tailored blanks have been used in the floor, rocker and wheelhouse panels to close out the rear rails, which add strength to the structure. (see the typical section in Figure 32).

As an example of the efficiency of this steel design, see Figure 33, which is the blank layout for the wheelhouse inner. Blank No. 2, made of 1.4 mm DP 700/1000 steel, covers the transition from the rear rail into the rocker and supports the spring reinforcement for the rear suspension. Blank No. 3, made of 1.1 mm DP 700/1000 steel, closes out the sides of the rear rail and is integral in carrying crash loads. Blank No. 1, made of 0.6 mm DP 500/800 steel, simply closes out the wheelhouse and therefore is made of a thinner gauge, lower strength material. The floor panel tailored blank serves similar functions in closing out sections of the rear rail, also placing thicker DP materials where needed. These three parts together negate the need for full rear rail tubes and other components or reinforcements necessary for creating a strong rear structure, greatly reducing part count in this area and integrating several functions into one efficient design.

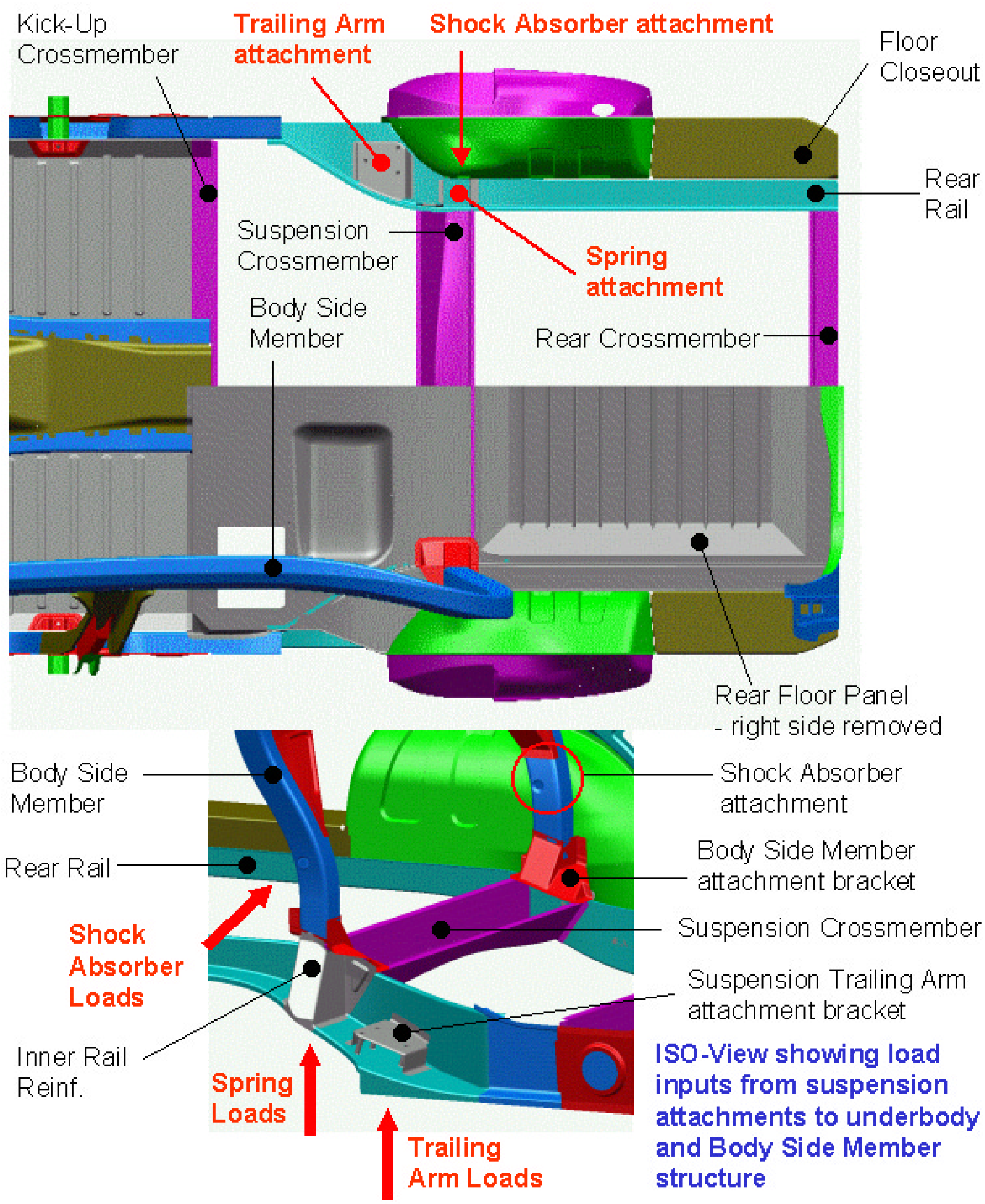
Figure 33: **Wheelhouse Inner Tailored Blank**



2.3.5.2 PNGV-Class Rear End Structure

The PNGV-Class rear body structure (see Figure 34) employs the same principles used in the C-Class structure. The rear longitudinal rails are similar to the C-Class structure except that they are extended for the longer wheelbase and increased vehicle size. This is also true for the rear floor extension, which is a tailored blank. The same steels and thicknesses used in the C-Class were carried over to the PNGV-Class as well.

Figure 34: **PNGV-Class Rear Floor Structure (top and isometric view)**



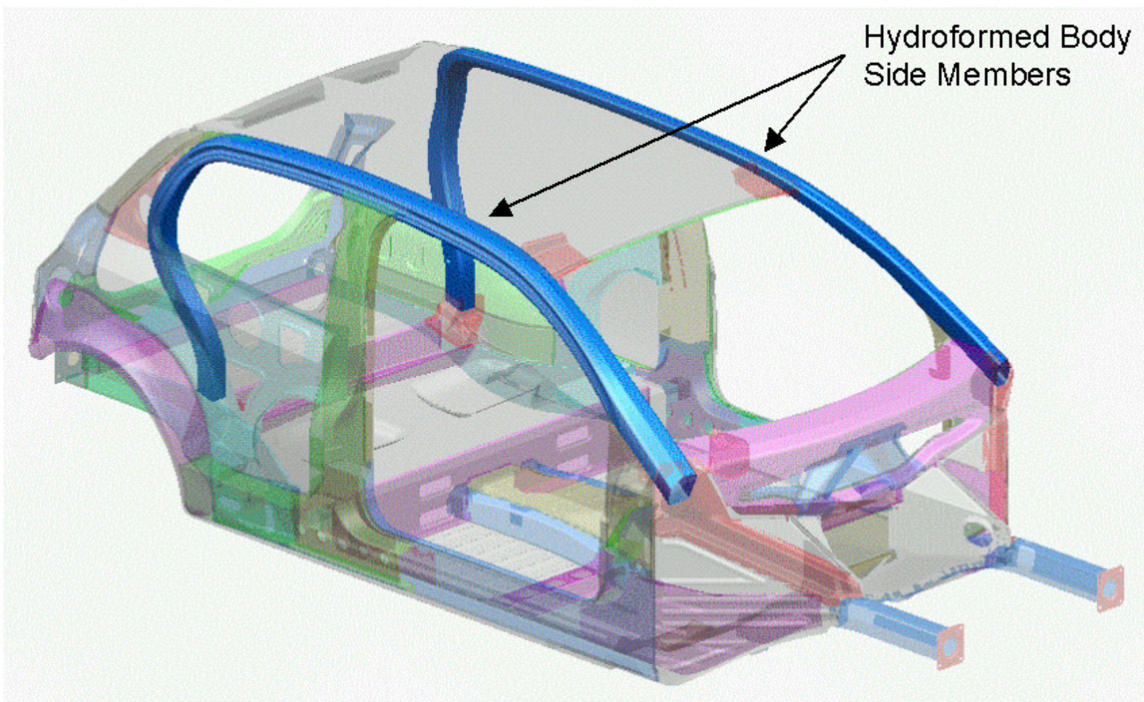
2.3.6 Upper Structure

2.3.6.1 C-Class Upper Structure

The most distinct aspects of the upper structure (see Figure 35) are the two tubular body side members, which are designed to transfer loads between the A-post and rear longitudinal rails. These tubes incorporate the A-pillar, roof side rail and partial C-pillar structure.

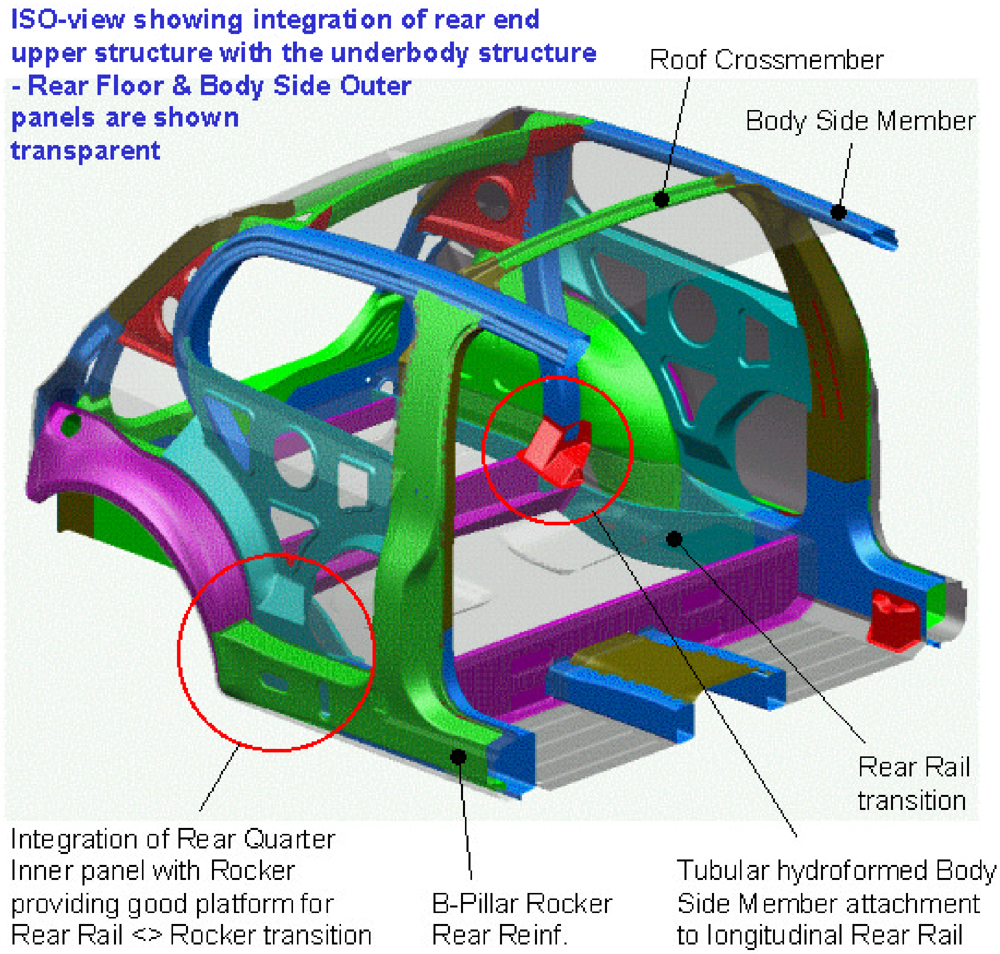
The body side members are hydroformed from an 85 mm diameter DP 500/800 steel tube at 1.0 mm thickness. The tube is expanded at the front end and the material axially fed into the hydroforming tool, creating a larger weld surface at the A-post joint.

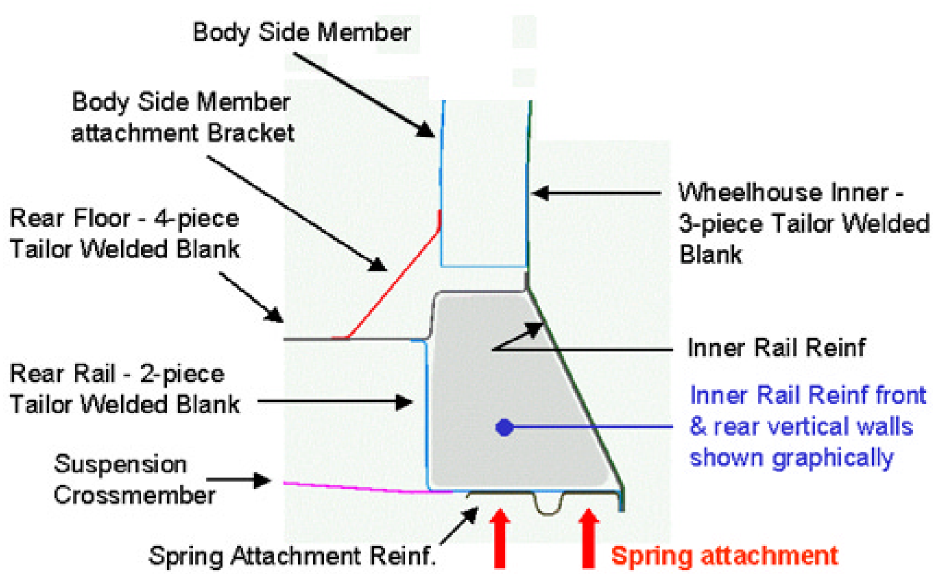
Figure 35: **C-Class Tube Hydroformed Body Side Members _ Front View**



At the rear, the body side members are attached on the top surface of the rear floor (upper part of the longitudinal rails) with a bracket connecting both longitudinal rails and rear rail upper surface. This is an important load carrying path since the body side member integrates the shock absorber attachment. The suspension spring reinforcement is positioned directly below the body side member and attached to the inner reinforcement on the rail lower surface. (see Figure 36). The shock absorber attachments are fitted from the outside to the body member. This configuration facilitates ease of rear suspension assembly. It can be installed from under the vehicle with only one person needed to connect the trailing arm and bolt the shock absorber.

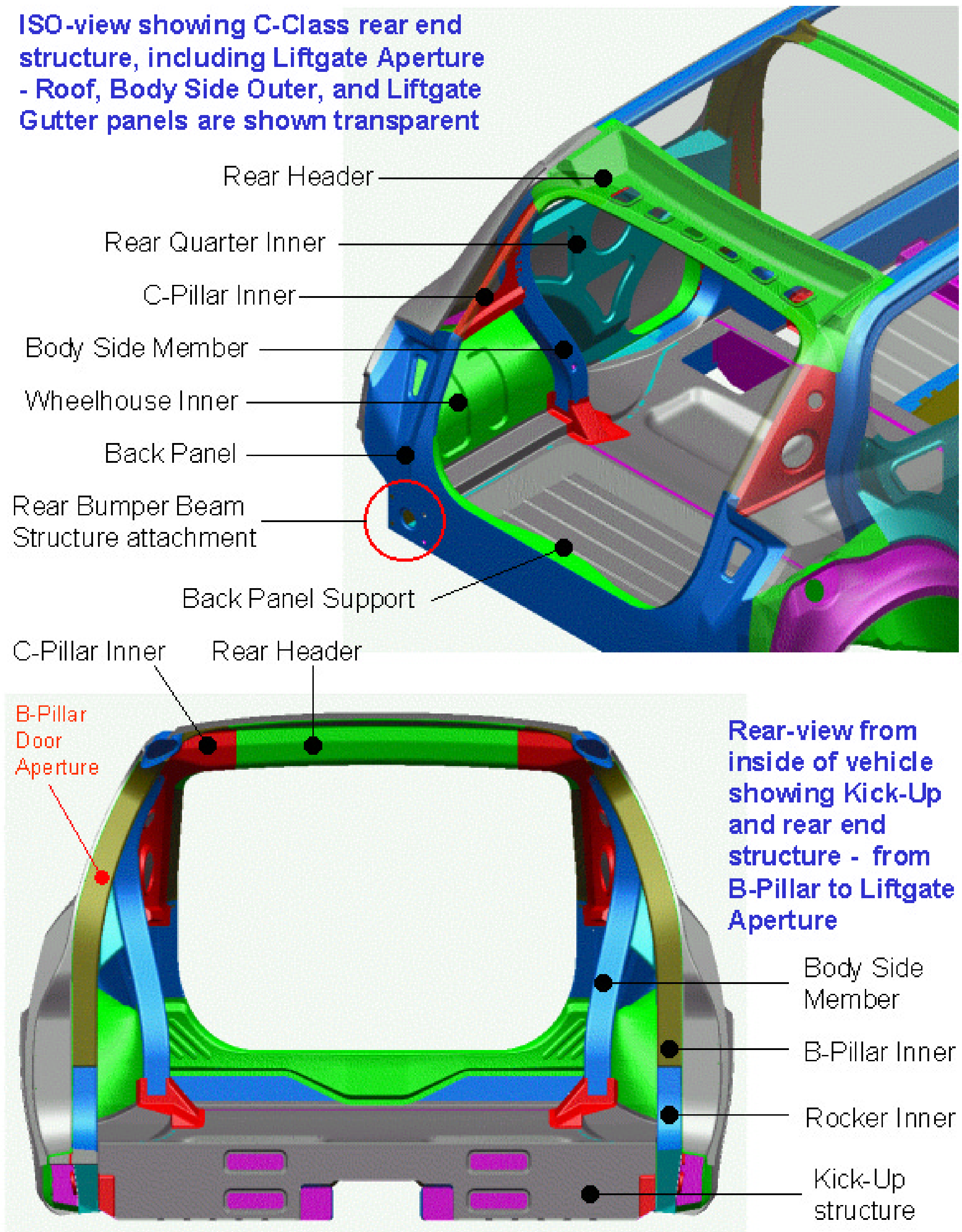
Figure 36: **C-Class Rear and Upper Structure**





Special consideration was given to the rear header and C-pillar joint (see Figure 37) to improve body stiffness and manufacturability. The header panel is adhesive bonded in the front and welded to the roof panel in the rear. The closed box section at each end not only creates a good joint, but provides a welding base for the roof panel.

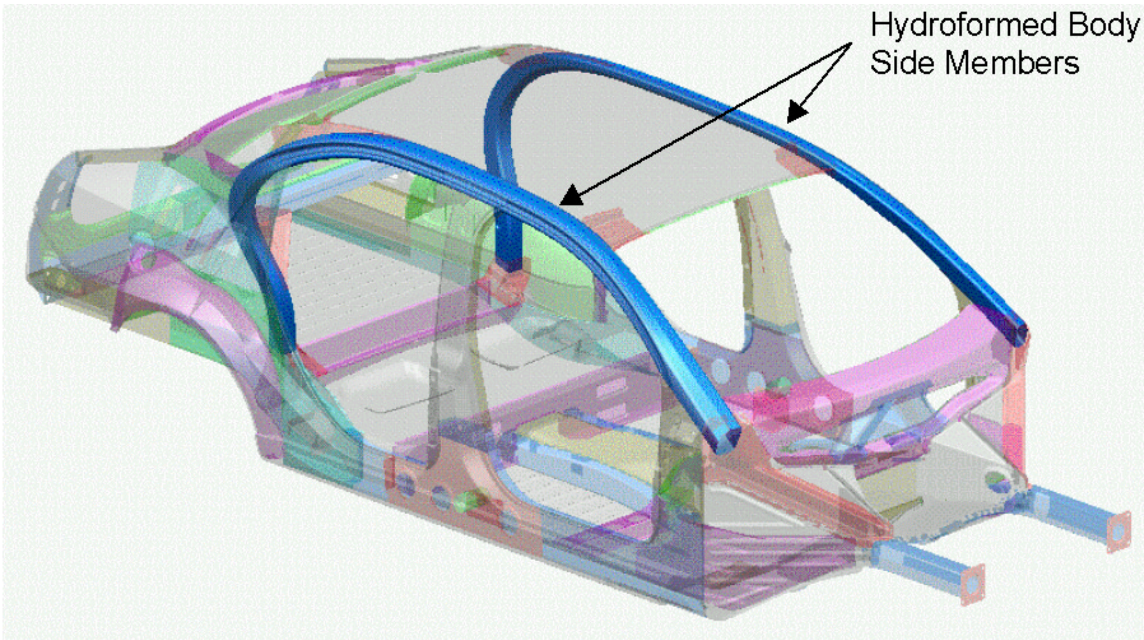
Figure 37: **C-Class Rear End Structure**



2.3.6.2 PNGV-Class Upper Structure

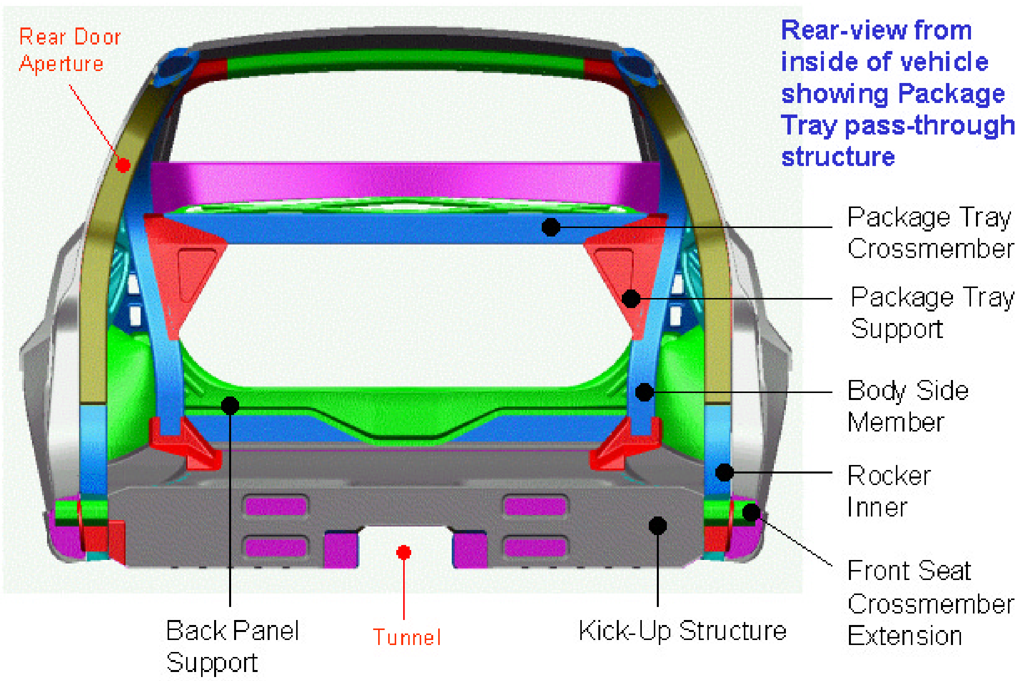
The PNGV-Class upper structure (see Figure 38) is identical in principal to the C-Class concept, using the same material type and dimensions for the bodyside members. Although the tubular side members are shaped differently at the rear end, they terminate at the rear rail in the same fashion as in the C-Class.

Figure 38: **PNGV-Class Tube Hydroformed Body Side Members**

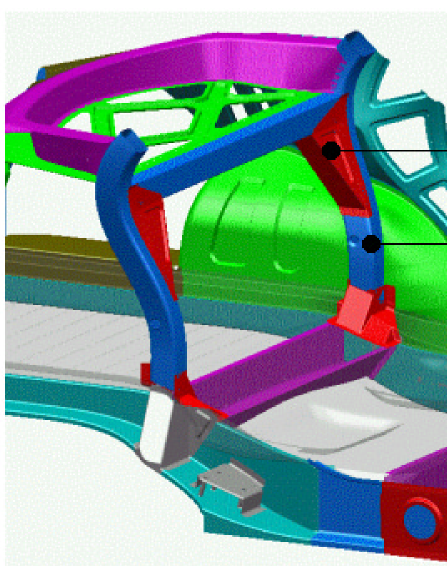


The package tray concept allows cargo access when the rear seats are in the tilt-down position. The package tray assembly is shown in Figure 39. Its crossmember is made of a 72 mm diameter DP 280/600 square tube at 1.0 mm thickness. The crossmember vertical walls are aligned with those of the side members and are supported by package tray support brackets laser welded to the side members and the crossmember. The tray upper is a stamping that provides the rear glass attachment surface. This package tray arrangement provides a cross-vehicle load path, which is important for structural torsional rigidity performance.

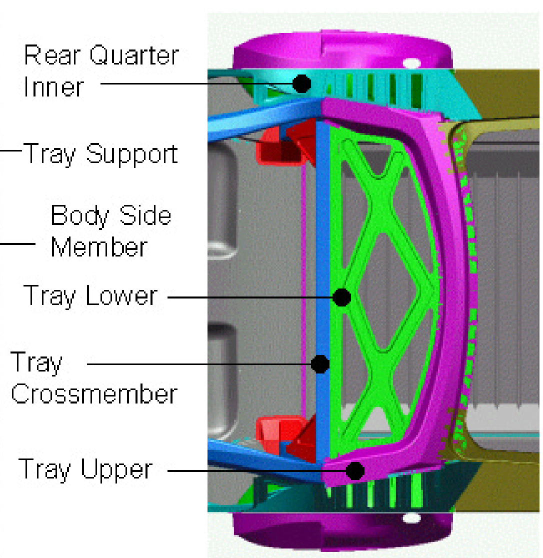
Figure 39: **PNGV-Class Package Tray**



ISO-view of Package Tray



Top-view of Package Tray



2.3.7 Body Structure Results

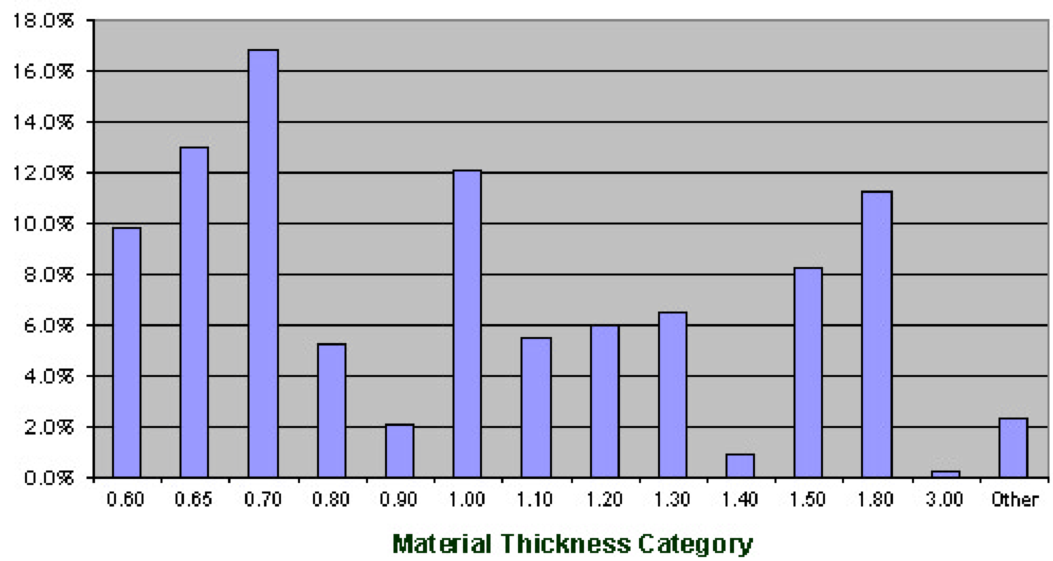
The unique properties of steel are enablers for developing innovative lightweight, safe, affordable, environmentally responsible vehicle architectures, like the ULSAB-AVC body-in-white concepts. The use of tailored blanks, tailored tubes and hydroforming and related joining technologies permit part integration for a significantly reduced part count. Additionally, the ULSAB-AVC vehicles, starting with the body-in-white, were designed to engage a balance between strength and mass, achieving the anticipated 2004 crash requirements at a minimum mass. The application of the new advanced steels fostered reduced material usage through thinner gauges, while providing the material properties (i.e., strength, energy absorption) to reach the aggressive crash and structural performance targets. Consequently, the body structure (BIW less closures) is less than 220 kg (C-Class: 202 kg, PNGV-Class: 218 kg). Comparing the body structure results to the average benchmark, the ULSAB-AVC structures are 17 percent lighter.

Table 9: **Body Structure Results**

	C-Class	PNGV-Class
Mass:		
Benchmark average	243 kg	263 kg
ULSAB-AVC body structure	202 kg	218 kg
Number of Parts:		
Stamped parts	65	65
TWB Stamped parts	11	11
Sheet Hydroformed parts	1	1
Tube Hydroformed parts	2	2
Tailored Tube Hydroformed parts	2	2
Total Body Structure Parts	81	81
Steel Types (% of mass):		
Dual Phase	74 %	74%
TRIP	4 %	2 %
Martensite	4 %	4 %
Complex Phase	1 %	1 %
Bake Hardenable	12 %	10 %
High Strength IF	3 %	4 %
HSLA	1 %	1 %
Other	2 %	4 %
Manufacturing Processes (% of mass):		
Stamping	40 %	39 %
TWB Stamping	38 %	39 %
Stamping or Sheet Hydroforming	5 %	4 %
Hydroformed Tube	8 %	6 %
Tailored Hydroformed Tube	7 %	8 %
Straight Tube	<1 %	1 %
Other	2 %	2 %

Figure 40 shows the distribution of steel thickness in the body structure as a percentage of the total body structure mass.

Figure 40: **Body Structure % Distribution of Material Thickness**

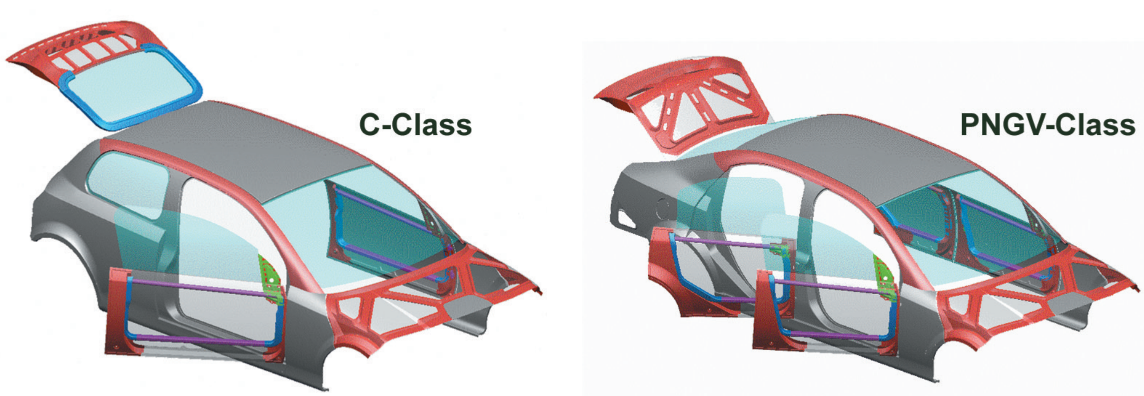


Yet ULSAB-AVC vehicle concepts do not represent the limits of steel's capabilities. A detailed design and development phase would likely reveal additional opportunities for applying thinner gauge steels.

2.3.8 Closure Structures

A comprehensive description of the design concepts included in the doors, hood, hatchback and decklid can be found in the May 2001 ULSAC Program Results, obtainable through the ULSAC website at www.ulsac.org. Figure 41 illustrates the designs as they have been incorporated into the ULSAB-AVC vehicles. A complete exploded view and parts list for all closures can be reviewed in Appendix 1.

Figure 41: **Closure structures**



A validation phase of the ULSAC program included the detailed design and build of frameless door demonstration hardware. The ULSAC door represents the development and proof of manufacture of a new generation of steel automotive closures, which are lightweight, yet safe and affordable. The ULSAC door with a stamped outer panel was 42 percent lighter than the average benchmarked frameless door. A follow-on to the ULSAC program investigated sheet hydroformed outer panels, which resulted in a 46 percent mass reduction over the average benchmarked frameless door.

For the ULSAB-AVC program, two front doors were developed, based on the same design concepts used in the ULSAC program demonstration hardware. The C-Class door is an extended version of the PNGV-Class. In keeping with the ULSAC design, both doors use high and advanced high strength steels and advanced manufacturing technologies, such as tailored blanks and tube hydroforming.

Common for both vehicle variants, the fixed hood design features a stamped or sheet hydroformed outer panel attached to a stamped inner panel. The hood is attached to the body at the rear and latched at the front in two locations to the engine cover module.

The ULSAB-AVC C-Class hatchback uses a similar hydroformed ring concept design developed during the ULSAC concept design phase. The PNGV-Class decklid design features a stamped or sheet hydroformed outer panel attached to a stamped inner panel.

2.3.9 Ancillary Closures

Due to the wrap over design of the hood that encompasses much of the wheelhouse, the front fenders (see Figure 42) are a relatively small and basic design. They can be manufactured using stamping or sheet hydroforming processes in 0.6 mm DP 350/600 steel.

Figure 42: **C-Class/PNGV-Class Fender (RH)**

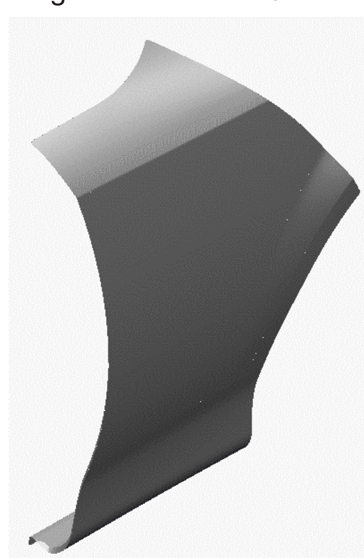


Figure 43 shows the roof side rail appliqués for the C-Class vehicle. A similar design is used for the PNGV-class vehicle. The roof side rail appliqués serve both functional and decorative purposes. Functionally, they cover the weld joints at the A-pillar and roof side rail, which are a result of the tailored blank body side outers. Decoratively, the appliqués can be finished with special paint treatments in the post body paint shop allowing for some customer flexibility in selecting exterior trim and color options.

Figure 43: **C-Class Roof Side Rail Appliqués**

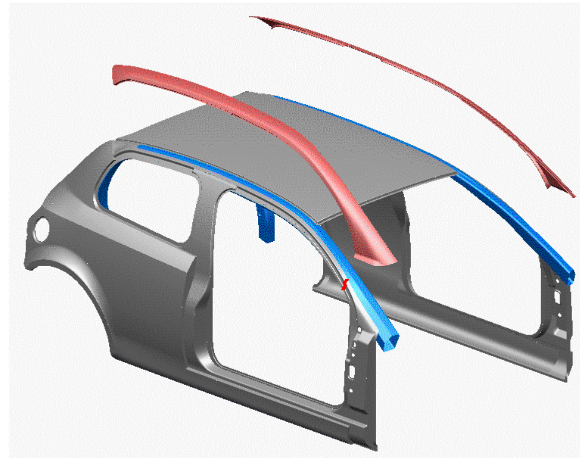
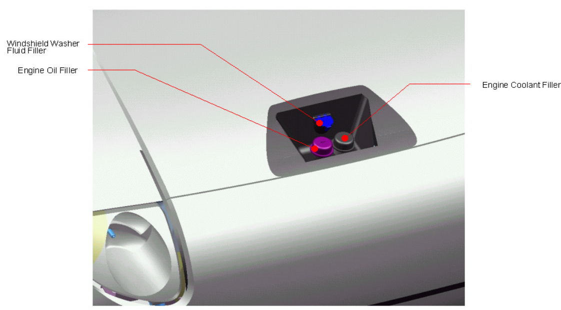


Figure 44: **Engine Service Lid (Open)**



The engine service lid (see Figure 44) provides easy access to the engine oil, engine coolant and windshield washer liquid fillers.

2.4 Chassis & Suspension Concepts

The ULSAB-AVC chassis and suspension concepts surpass the ULSAB-AVC mass targets using steel. Steel technologies such as tailored blanks for wishbones, tailored tube hydroforming for trailing arms and high-strength steel stampings where there would normally be a heavier casting (steering knuckle). Furthermore the application of high-strength steel throughout contributed to mass efficiency with excellent performance. State-of-the-art automotive technologies, such as an electrical parking brake and electro-hydraulic brake system also have contributed to the mass reduction achieved.

This Section summarizes the chassis and suspension designs, including some of their specific steel applications. To understand the steel nomenclature used to describe the steels, please refer to Section 3.2 Steel Nomenclature.

2.4.1 Approach

The main goal for development of ULSAB-AVC front and rear suspensions was to design lightweight, steel-intensive concepts. Conventional and new steel materials were applied along with innovative manufacturing and assembly technologies. As with all of ULSAB-AVC components, the intent was to achieve the lowest overall vehicle mass rather than the lowest possible mass in any one component. Therefore, the ULSAB-AVC suspension system is not necessarily the lightest system available. A lower mass, lighter weight suspension may cause mass increases in other components such as the body structure.

Because of the program objective to develop two vehicle concepts with a diesel and gasoline engine variation for each, similar suspensions were designed for both vehicle classes, with the exception of the tuning parts. These parts (springs, dampers) are unique to each class as a result of the wheel load and vehicle mass variations. Final set-up would have to be tuned on a test track. Physical load cases were defined, and components were designed to limit the resultant stresses to acceptable ranges.

The emphasis on safety was, in some respects, a principle driver of the body structure concept design particularly for pedestrian injury protection. This decision required that a significant deformable distance be achieved between the vehicle skin and the suspension component locations under the hood, which in turn influence the shock and spring location. Consequently, front suspension selection was directed by this requirement.

Furthermore, the overall approach specified that the front suspensions were to be included as part of a front-end module, which would also incorporate attachment of the engine and transmission, in a front subframe to enable module assembly and servicing. This design also influenced the type of front suspension selected.

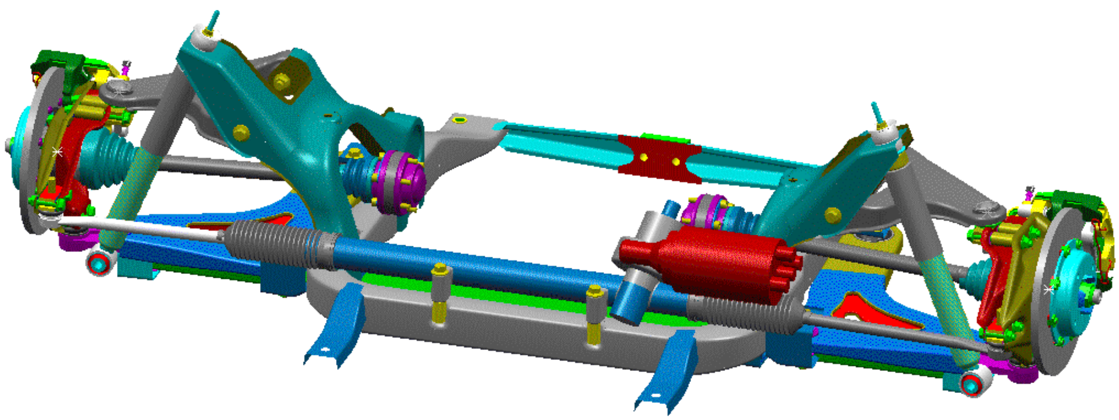
After benchmarking and target setting, vehicle curb and gross weights were calculated and used in the FE-calculation as input parameters.

2.4.2 Front Suspension

2.4.2.1 Selection – Double Wishbone with Transverse Leaf Spring

Several concepts were considered, including a McPherson suspension, as well as various configurations of a double wishbone principle: double wishbone with coil spring, with torsion bars and with a transverse leaf spring. A double wishbone with transverse leaf spring (see Figure 45) was ultimately selected because it showed the most potential for packaging while achieving overall vehicle mass targets. This system eliminates the need for the shock tower in the body structure, and thus the hard points, which would inhibit pedestrian safety. Also, with the front-end module configuration described in Section 2.4.4, this system would not require realignment each time the module is removed for servicing.

Figure 45: **Double Wishbone w/Transverse Leaf Spring**



Kinematics layout characteristics were based on existing vehicles currently on the market. To achieve a safe and stable driving behavior, the kinematics characteristics were tuned towards an understeering behavior. The kinematics layout would be validated in prototype vehicles tests and likely will be tuned at that point. Elastokinematics properties are not specified and depend on the afore-mentioned vehicle tests. However, there is enough package space in the rubber bushing locations to change their shape if necessary.

2.4.2.2 Front Suspension Components

Following are details on select front suspension components. For a complete review of the front suspension concepts, refer to the ULSAB-AVC Engineering Report Section 7.0.

Upper and Lower Wishbone Design

The upper wishbone assembly (see Figure 46) is made up of the upper wishbone stamping, the front and rear rubber bushing and the ball joint. It is designed as a single stamped tailored blank steel part made of 1.6 mm and 2.0 mm Stretch Flangeable (SF) 570/640 steel.

Figure 46: **Upper Wishbone Assembly**

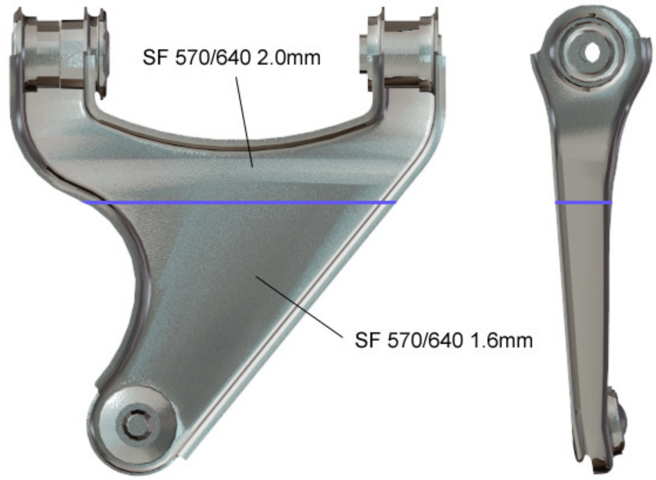
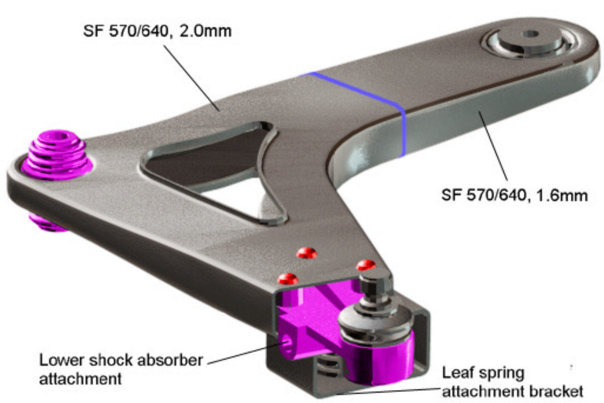


Figure 47: **Lower Wishbone Assembly**



The lower wishbone assembly (see Figure 47) is made of two tailored blank steel stampings with both wishbone halves being mirror images of each other. The lower wishbone tailored blank also used 1.6mm and 2.0mm SF 570/640. Butt- and plasma-welding were proposed joining processes for the two halves of the wishbone.

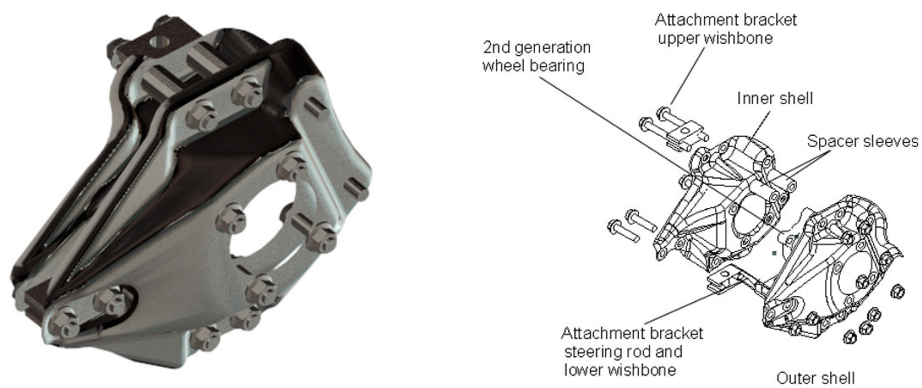
Attachment to the suspension assembly is completed with a rubber bushing and inner and outer ball joints for both sides of the vehicle. The same type inner ball joint and bushing are used for both sides and both upper and lower wishbones, potentially reducing part and tooling investment costs.

Tailored blanks were chosen for the two wishbones because FEM calculations using sheet steel at 2.0 mm thickness revealed increased stress levels from the outer and inner ball joint extending toward the rear rubber bushing, mainly in the outside radii area. Using 2.0 mm material thickness for the higher stress areas and 1.6 mm for the lower stress areas alleviated this problem.

Steering Knuckle Module

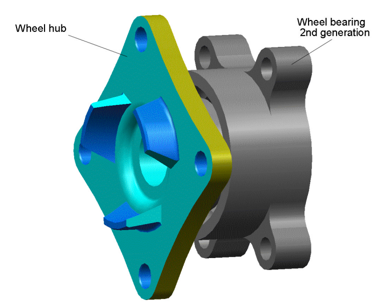
The steering knuckle module is shown in Figure 48. The main components in the assembly are two 3.0 mm DP 350/600 steel stampings. The entire module replaces what would normally be an iron casting, saving significant weight and requiring no additional machining. The mounting brackets are sandwiched between these two steel stampings, each bracket serving two attachment functions, which integrates parts for reduced part count. Several FEM-calculations and subsequent design iterations were conducted for both the steering knuckle outer and inner shell and can be viewed in the ULSAB-AVC Engineering Report Section 7.0.

Figure 48: **Steering Knuckle Module**



A 2[nd] generation wheel bearing as shown in Figure 49 includes a double row annular ball bearing, which is multiple sealing with lifetime greasing. The wheel hub is manufactured using a chromium molybdenum grade (42 Cr Mo 4) material with a tensile strength of 900 MPa and is a minimum size for reduced mass compared to conventional wheel hubs.

Figure 49: **Wheel Bearing Hub**



Other Components

In ULSAB-AVC vehicles, the transverse leaf spring has two functions, as a spring and as a stabilizer, to reduce cost and mass. Because of compliance characteristics and mounting position a fiberglass reinforced plastic leaf spring was selected.

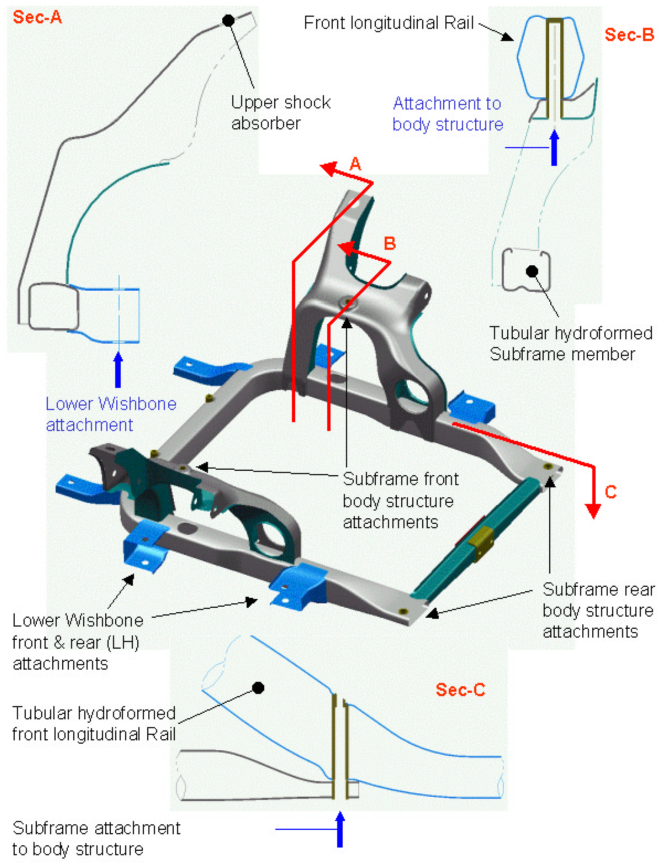
To accommodate differences in vehicle size and engine, the shock absorbers were designed as a single-tube concept with integrated wheel movement bump stop. The shock absorber tube wall thickness was minimized and a plastic coating applied to protect against stone chipping.

The drive shaft concept is a conventional design with the outer joint bolted to the wheel bearing/wheel hub and the inner joint bolted to the differential flange. The connection of the outer joint to the wheel hub depends on the philosophy of the car manufacturer.

2.4.3 Subframe and Engine Mounts

ULSAB-AVC's chassis design includes an integrated steel subframe to which the powertrain, front suspension components, steering knuckle, steering gearbox, transverse leaf spring and cooling system are attached in a front-end module. This front-end module configuration facilitates modular assembly of the vehicle as well as ease of disassembly for maintenance during the life of the car. Four attachment points, attaching the subframe to the body structure, allow for the entire subframe, and all its components, to be installed at point of manufacture or removed at point of service as one unit from below the vehicle.

Figure 50: **Subframe Part Description**



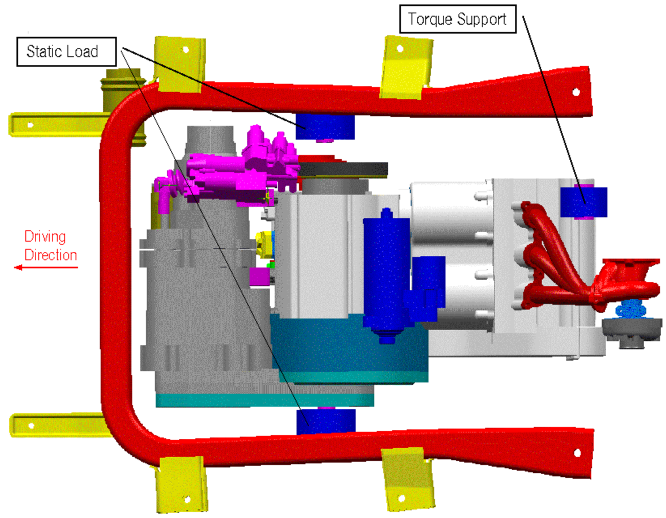
The subframe, as shown in Figure 50, is a hydroformed tube with a stamped steel sheet cross-member welded at the rear. Both subframe and crossmember are made of 2.0 mm DP 350/600 steel. DP steel was selected to support the suspension loads and the grades verified in forming simulations for manufacturability and in crash analysis for its performance. This cross member functions as an attachment for the rear torque support of the engine mount. Attachment components for systems, such as the cooling unit, steering gearbox, wishbone supports, are welded to the tube.

The subframe is designed to support the forces from the suspension to the body structure by suppressing the suspension acoustic excitation. A rigid attachment of the subframe contributes to the rigidity of the front suspension and body structure systems.

Manufacturing feasibility, function and comfort all were considered in selecting the engine mount concept, a unique design, which specifies attachments to the subframe rather than the front rails. A three-point engine mount system, connecting to the subframe, (see Figure 51) was selected because of its superior acoustic/vibration characteristics.

The front engine mount brackets are made of a 2.5 mm steel tube and two sheet steel brackets, one for attachment to the engine and one for the attachment to the subframe. The rear bracket is made of bent flat steel. All of the engine brackets are made of DP 350/600 steel. FEM calculations, which can be reviewed in the ULSAB-AVC Engineering Report Section 7.0, were performed to analyze the design's strength, and they showed acceptable performance.

Figure 51: **Three-point Engine Mount Concept Bottom View**

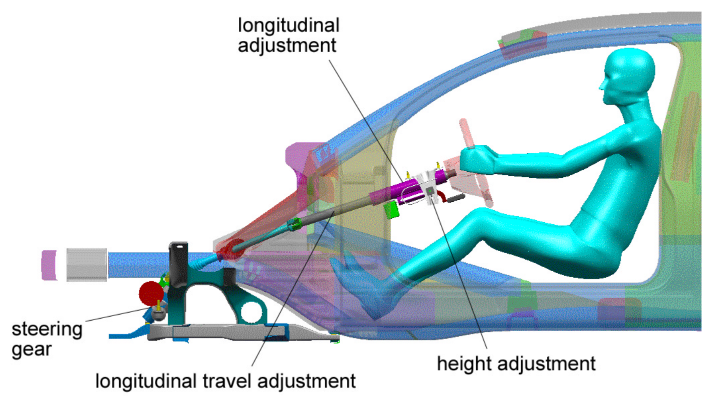


2.4.4 Steering System

To eliminate the need for a hydraulic pump and to gain the potential for speed-sensitive power assistance, a steering system with electrical power assistance was used. (see Figure 52)

ULSAB-AVC vehicles feature a multi-functional steering wheel concept with pushbutton controls, which can be reviewed in this report in Section 2.2.2.

Figure 52: **Steering System Assembly**



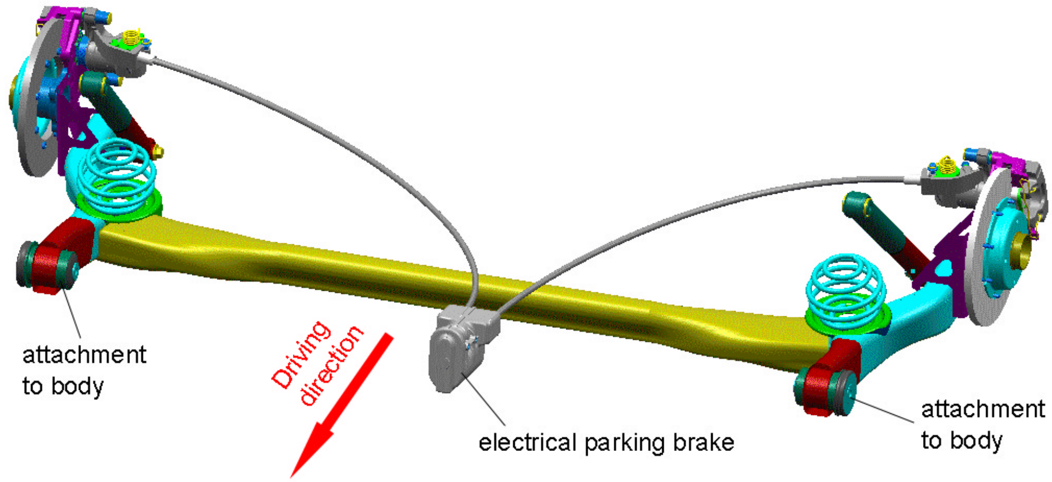
2.4.5 Rear Suspension

Benchmarking data identified the twist beam rear suspension concept as the lightest among possible alternative systems for the particular vehicle designs, like multi-link, double wishbone and de Dion, and therefore, it was selected for the ULSAB-AVC vehicles. Additionally, the twist beam has proven capabilities in many vehicle classes with respect to cornering and comfort and is popular in vehicles with similar total mass as the ULSAB-AVC concepts. Other factors that favor the twist beam concept are as follows:

- reduced part count compared to other systems
- no additional subframe needed for attachment
- can be pre-assembled off line as one unit and easily assembled to vehicle at four attachment points.

The pre-assembled rear suspension module, as delivered to the final assembly line, is shown in Figure 53 and 54, including the electrical parking brake module and the bushings for the attachment to the body.

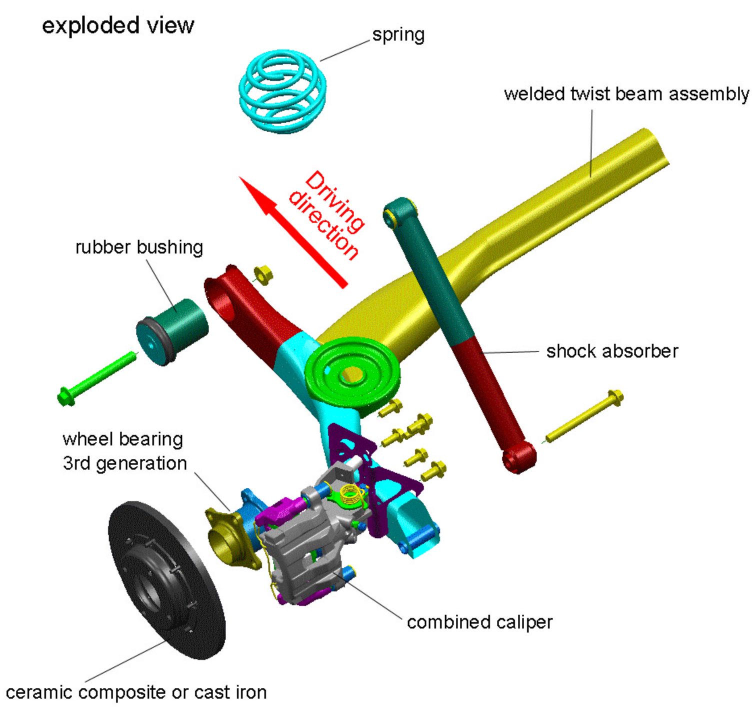
Figure 53: **Rear Suspension Module**



As with the front suspension, the basic layout has been defined, but final kinematics and elastokinematics characteristics have to be tuned in a further development phase. In that regard, the concept layout allows for hard point variations and mounting stiffness for future tuning.

2.4.5.1 Select Rear Suspension Components

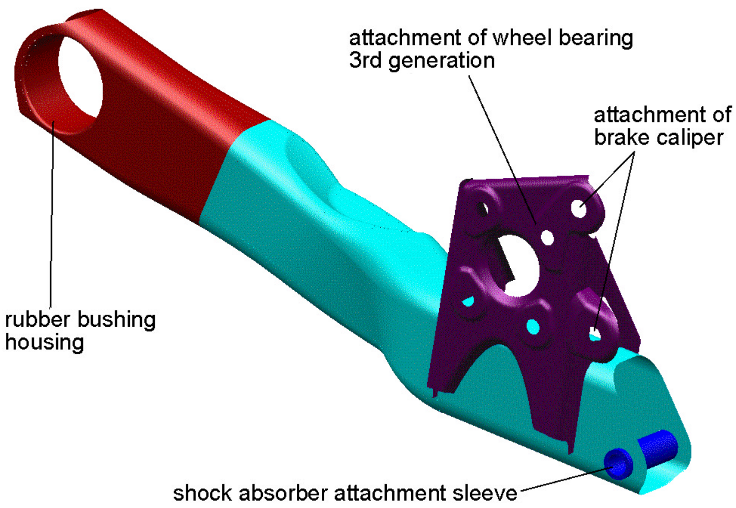
Figure 54: **Rear Suspension Exploded View**



Rear Suspension Trailing Arm

The trailing arm weld assembly as shown in Figure 55 is made up of the trailing arm, the wheel carrier and the damper attachment sleeve. The trailing arms are made of 2.2 mm and 3.0 mm DP 350/600 steel tailored tubes. During the hydroforming process, the rubber bushing housing is formed and the holes for the sleeve of the shock absorber are punched. It was important to give special attention to the longitudinal location of the weld seam for bending process feasibility.

Figure 55: **Rear Suspension Trailing Arm Weld Assembly**

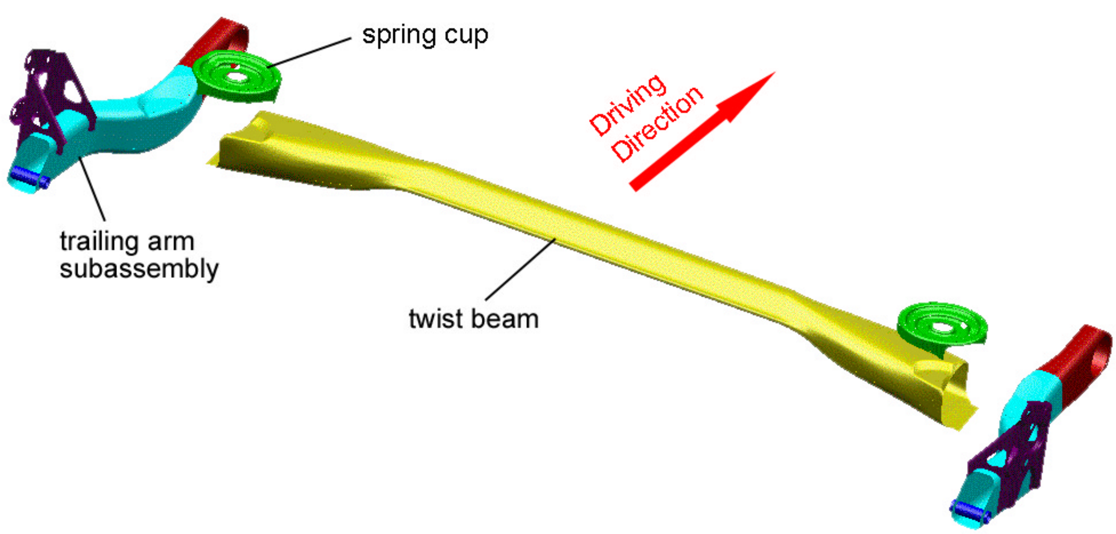


Several iterations of FEM calculations and forming simulations were conducted to optimize the design of the trailing arm assembly until acceptable stress ranges were reached. Details of these design iterations and the forming simulation can be found in the ULSAB-AVC Engineering Report Section 7.0.

Twist Beam Profile

The twist beam, made of 2.5 mm Manganese Boron (MnB) 1200/1600 steel, has a variable cross section shape, though similar to some twist beams in existing high-volume production vehicles. The main distinction is that ULSAB-AVC's twist beam (see Figure 56) is flared at the welded seam outer ends to the trailing arms. This increases the welding seam, and therefore, the support base for side forces is enlarged, which minimizes toe out behavior. MnB steel was used because it is a heat-treatable material, which offers the advantage of forming the tube and then heat-treating it to get the desired strength. The delivered flat material properties (before heat treating) are 280/450 MPa.

Figure 56: **Twist Beam Rear Suspension Assembly**



To form the tube, first it is deep drawn to obtain the spring rate of the desired torsion bar. During the second stage hydroforming process, the ends of the tube are widened using axial force-feeding to achieve a nearly constant wall thickness at the tube ends. After the forming process, the twist beam assembly is heat treated to achieve the required strength.

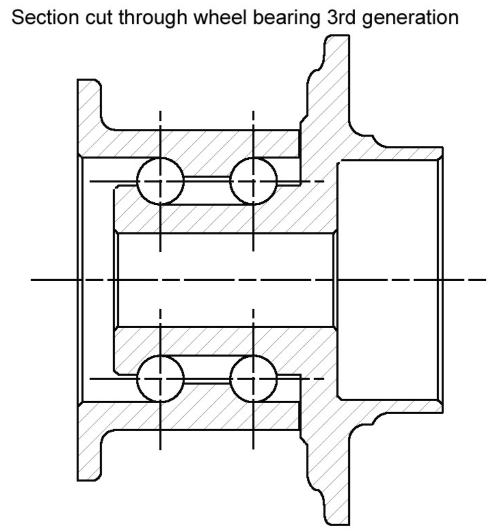
Wheel Bearing and Hub

The wheel bearing (see Figure 57) is a double row annular ball bearing that is multiple sealing with lifetime greasing. For mass reduction purposes, the wheel attachment surface shape has been reduced to a minimum.

Rear Suspension Shock Absorber

The same shock absorbers used for the front suspension were also selected for the rear suspension.

Figure 57: **Wheel Bearing and Hub**

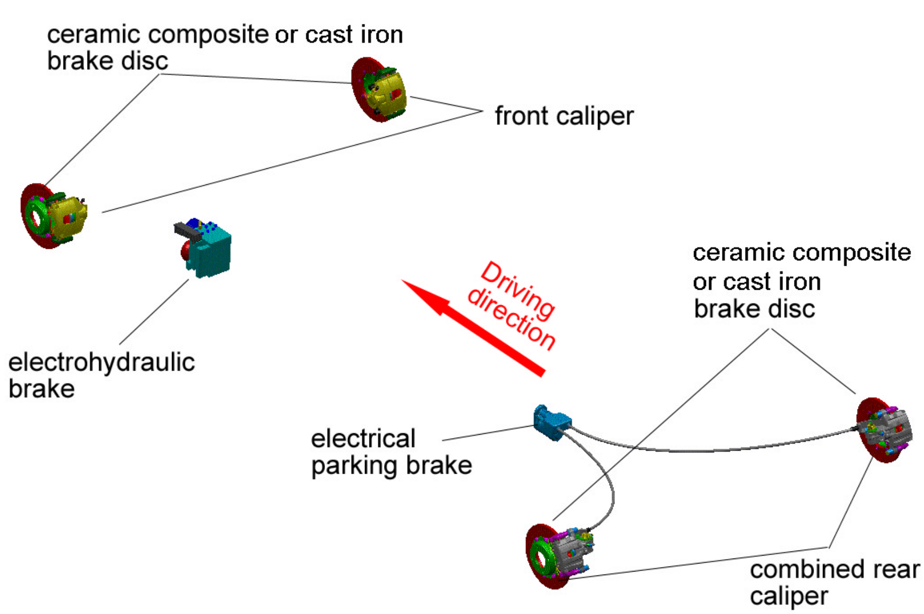


2.4.6 Brake System

The ULSAB-AVC brake system (see Figure 58) consists of the following components:

- Electro-hydraulic brake unit (EHB)
- Electrical parking brake
- Cast iron brake discs
- Front forged steel brake caliper
- Rear combined brake/parking brake caliper

Figure 58: **Brake System w/ Parking Brake**



The electro-hydraulic brake unit (EHB), an existing design, includes an electrical pump, a reservoir, valve block, pedal force simulator and control unit. The adaptation of the system is restricted by the control unit software, and must be tuned to the C-Class and PNGV-Class vehicles.

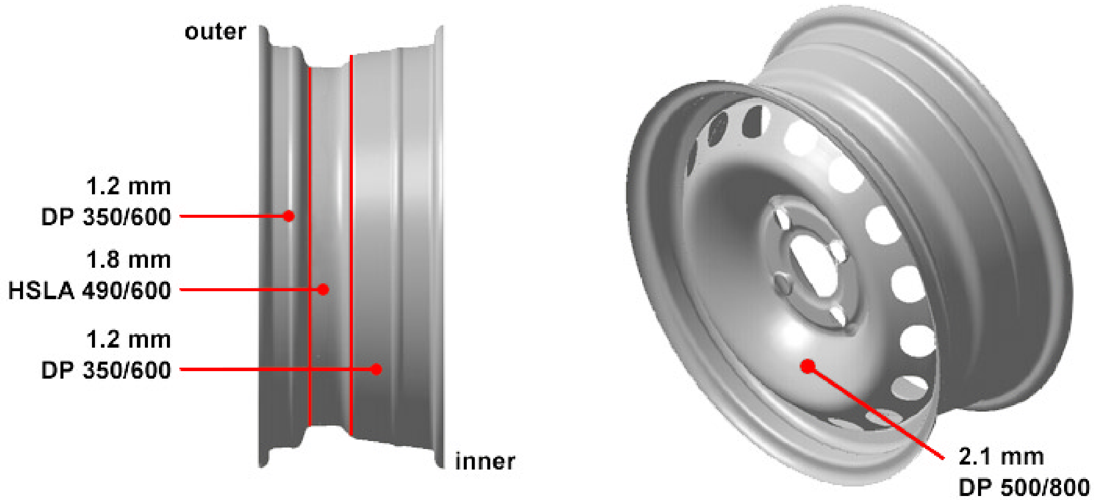
The electrical parking brake system includes an electrical actuator, which is attached to the body structure, and two bowden cables, eliminating the need for a cable extension to the cockpit hand brake lever, and thus, the routing of the cables through the body structure in final assembly.

2.4.7 Wheels and Tires

A benchmark study of competitive wheels was conducted by a Consortium member company. Based on the benchmarks, three alternative designs were optimized for ULSAB-AVC wheels using FE analysis tools. As a result of this exercise, the design selected for the ULSAB-AVC wheels (see Figure 59) features a 3-part tailor welded high-strength steel blank. The two outer portions of the wheel are made of 1.2 mm DP 350/600 steel and the inner portion is made of 1.8 mm HSLA 490/600, resulting in an optimized, lightweight steel wheel design. The disc is made of 2.1 mm DP 500/800

The vehicle concepts can be fitted with 5J x 14 wheels and 175/65 R14 tires. Or they also can use 185/60 R15 tires and 5.5J x 15 wheels, which could incorporate the same lightweight steel wheel technology concepts.

Figure 59: **Steel Wheels w/Tailored Blank Layout**



2.4.8 Vehicle Axle Load Distribution

The vehicle load distribution relative to the front and rear suspension at vehicle curb mass is 55 percent front/45 percent rear. Under fully loaded conditions the axle load distribution is even more equally balanced. This axle load distribution provides the basis for excellent handling performance.

2.5 Engine and Transmission Concept

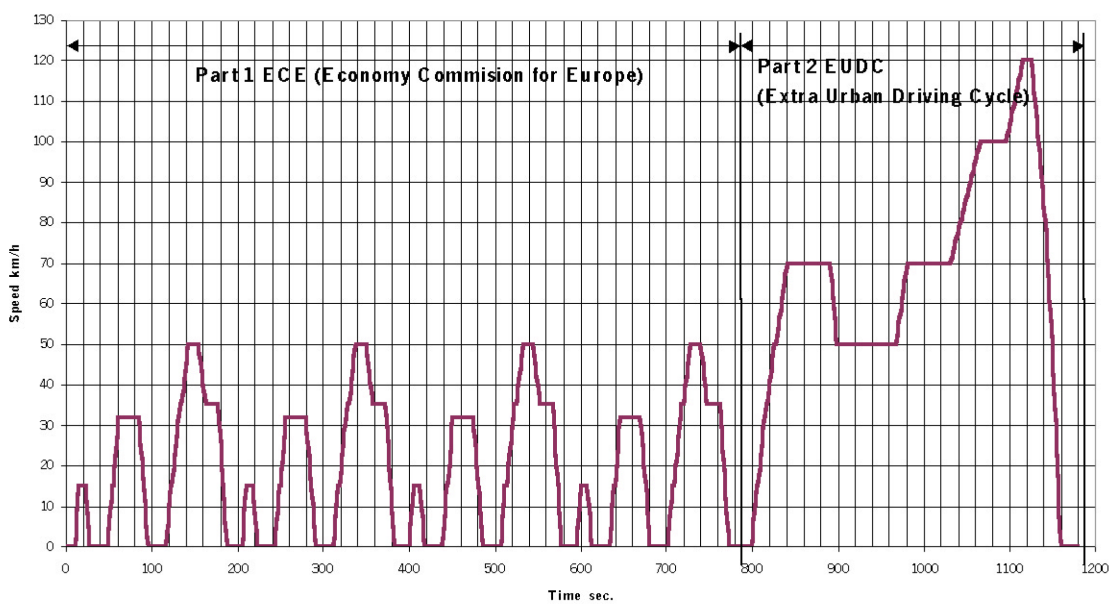
Selection of a powertrain, with both a gasoline and diesel variant was a key issue in order to achieve the program target for CO_2 emissions. The position of the powertrain behind the front axle contributes to better load distribution in ULSAB-AVC than is typically found in front-wheel drive vehicles. The powertrain position also allows for a significantly shortened (and therefore lighter weight) exhaust routing. Most importantly, the powertrain position enhances crash performance.

2.5.1 CO_2 Emissions Calculations

CO_2 emissions calculations considered driving cycles, transmission, vehicle mass, specific power/torque characteristics, and vehicle acceleration times. For this assessment, driving cycle calculations were made according to the New European Driving Cycle (NEDC) 2000 as indicated in this report in Section 4.3 CO_2 Emissions & Vehicle Performance. It was anticipated that by achieving the target of <140 g/km CO_2 under the NEDC 2000 conditions, the U.S. Combined Driving Cycle (FTP 75, Highway) also would be achieved.

Figure 60 shows the two-part applied driving cycle. Part one is prescribed by the Economy Commission for Europe (ECE) and describes a city driving cycle, which considers variation of speed in km/h over time, including stopping intervals. Part two is the Extra Urban Driving Cycle (EUDC) describing a cycle with variation of speed in km/h over a given time period without stopping intervals.

Figure 60: **NEDC Test Cycle**



Figures 61 and 62 show the power/torque curves for the diesel and gasoline engine variants. The diesel engine was calculated using the power/torque characteristic of an existing turbocharged diesel engine; the gasoline engine calculation used a normally aspirated engine characteristic.

The calculation results for each engine indicated that the target for CO_2 emissions can be met with an engine displacement of 1.2 L in combination with a 5-speed transmission.

Figure 61: **ULSAB-AVC Diesel Engine Power and Torque**

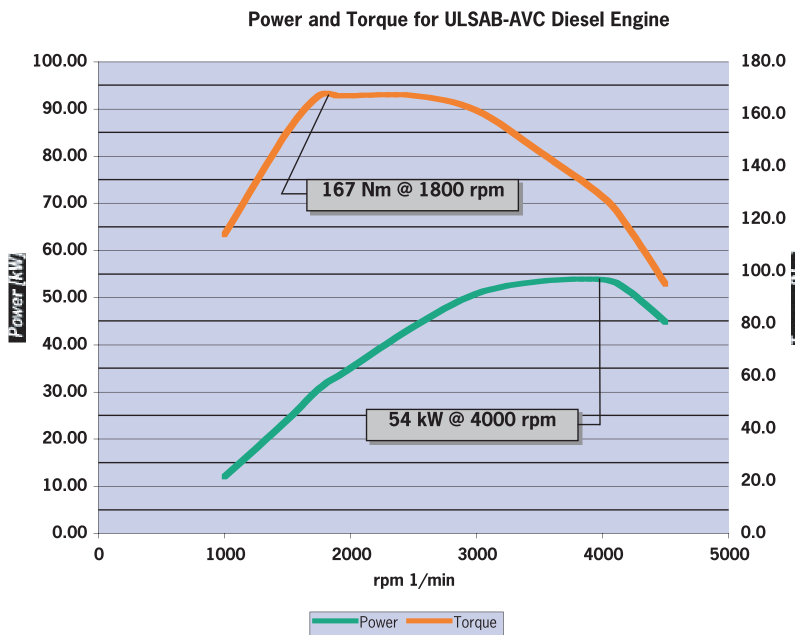
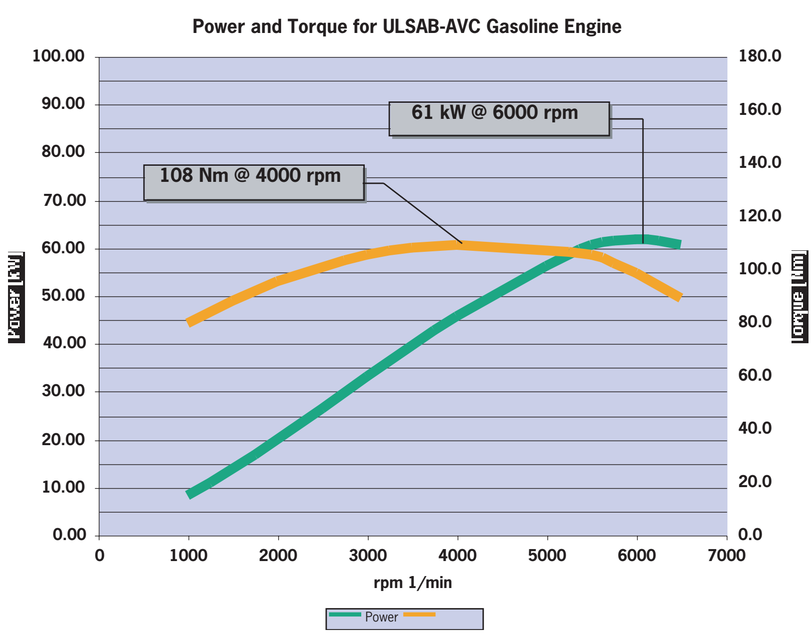


Figure 62: **ULSAB-AVC Gasoline Engine Power and Torque**



2.5.2 Engine Selection

Two engine concepts were selected from currently available state-of-the-art engine technology considering: the total vehicle target mass of the PNGV-class; the requirements for acceleration, cruising speed and CO_2 emissions; and program specifications.

A narrow, V3 cylinder engine concept was selected to allow for the engine to move into the tunnel during a front crash event. The engine specifications for both diesel and gasoline engines are shown in Table 10.

Table 10: **ULSAB-AVC Engines Specifications**

Specification	Gasoline	Diesel
Concept Type	VR-3	VR-3
No. of Valves per cylinder	4	2
Displacement [ccm]	1200	1200
Power [kW]	61 at 6000 rpm	54 at 4000 rpm
Torque [Nm]	108 at 4000 rpm	167at 1800 rpm

The diesel engine mass is 113 kg and the gasoline engines is 85 kg. For a list of all add-on parts included in the mass total, refer to ULSAB-AVC Engineering Report Section 8.0.

2.5.3 Transmission

The transmission ratio selection was based on the engine torque characteristics under the given performance requirements.

According to the calculation summary, it would be possible to reduce the fuel consumption with the use of an automatic transmission. The decision was made to use a manual transmission with an automatic gearshift actuator to achieve lower CO_2 emissions and to reduce parts. This gives the driver the ability to drive in an automatic shift mode, reducing fuel consumption over a conventional manual system. The driver may also choose to drive in a manual shift mode.

The total transmission mass, including electrical gear shifter and transmission oil, for both engine variants is 36.9 kg.

2.5.4 Powertrain Complete

Figures 63, 64, 65 and 66 illustrate the diesel and gasoline powertrain concepts.

Figure 63: **Diesel Powertrain w/Auxiliaries**

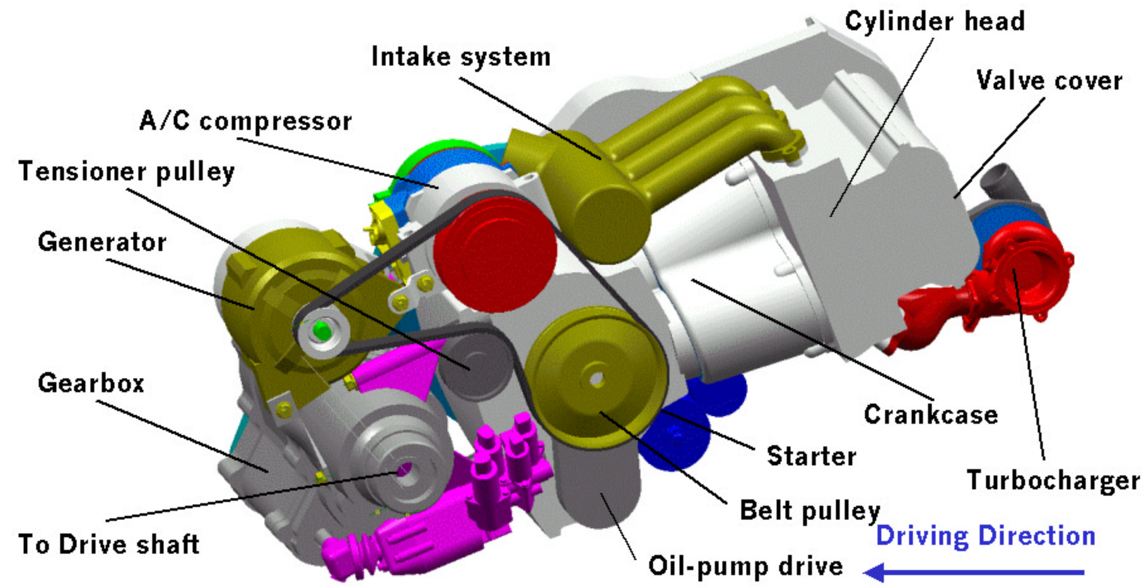


Figure 64: **Diesel Powertrain w/Auxiliaries**

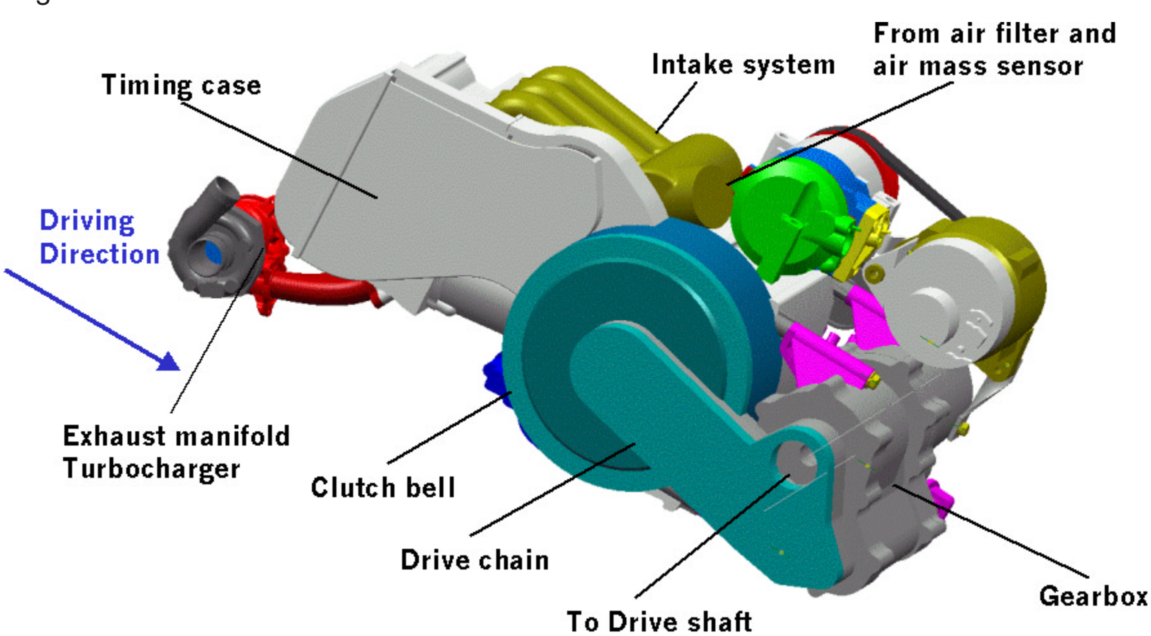


Figure 65: **Gasoline Powertrain w/Auxiliaries**

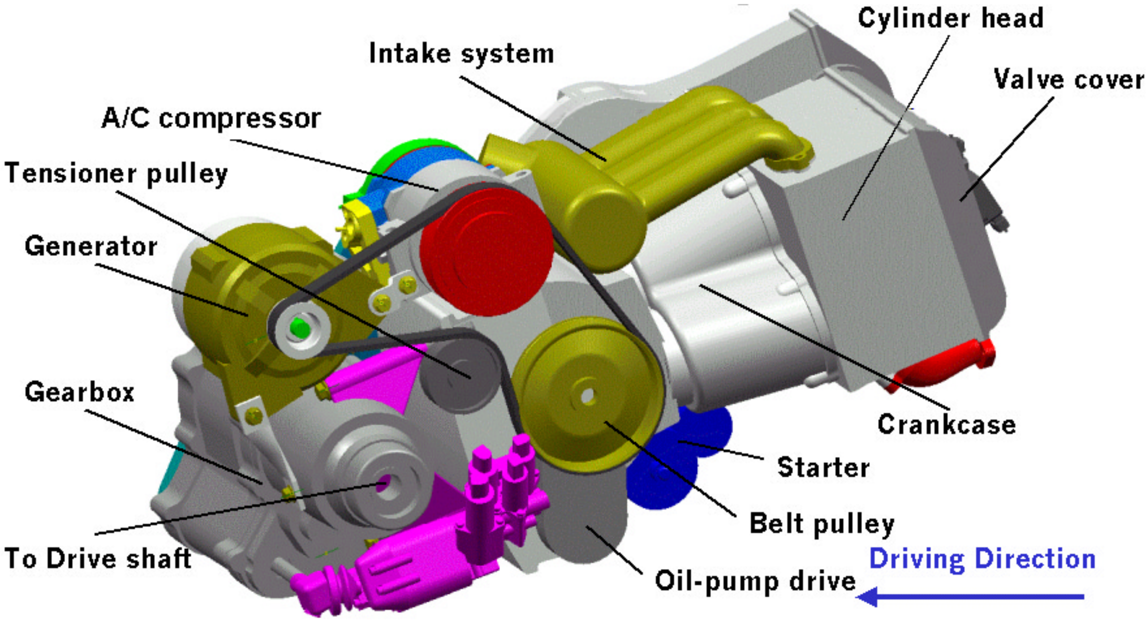
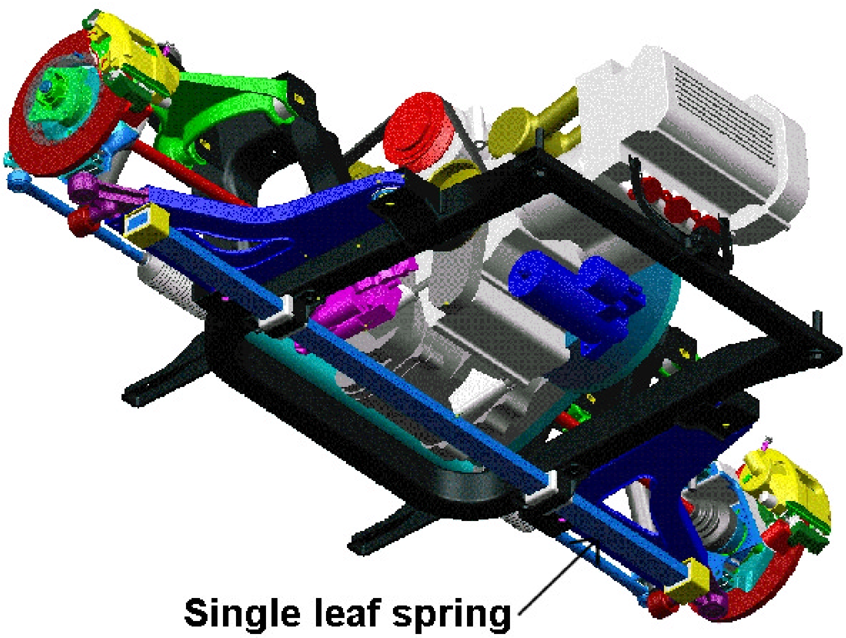


Figure 66: **Engine Bay Bottom View**



2.6 Subsystems

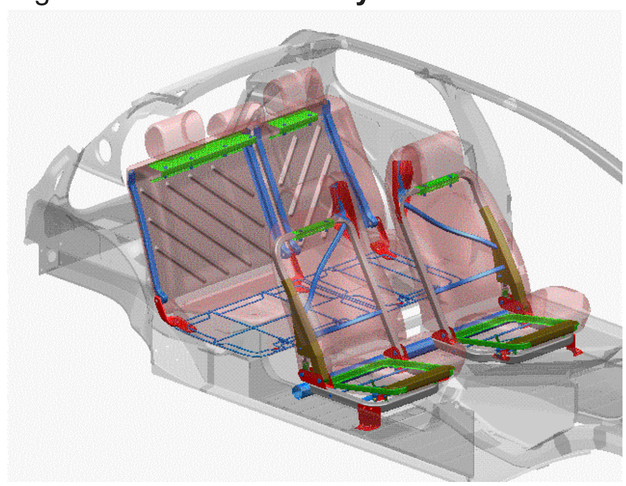
ULSAB-AVC incorporates subsystems, which have been chosen for mass reduction potential with particular attention to packaging and advanced design. A parts list, including materials and mass of each component, can be found in Appendix 1 of this report.

This Section summarizes subsystem designs, including some of its specific steel applications. To understand the steel nomenclature used to describe the steels, please refer to Section 3.2 Steel Nomenclature.

2.6.1 Seat Systems

The modular fixed-seat concept is based on a single seat crossmember to which the entire seat structure and all trim components are attached prior to vehicle installation. The seat module is mechanically attached to the body structure, by way of the crossmember, inboard of the rockers. See Section 2.3 for additional information about the function of the seat crossmember.

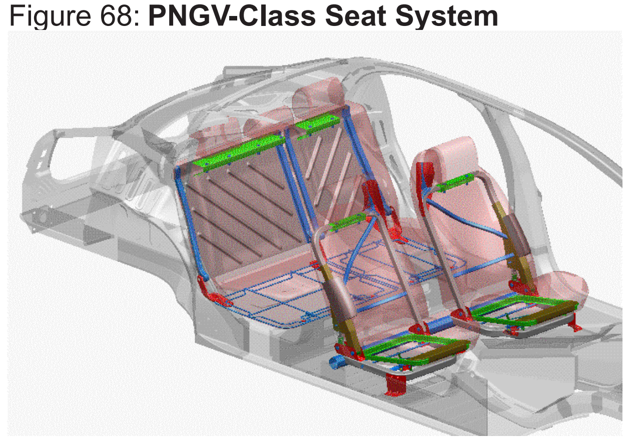
Figure 67: **C-Class Seat System**



Rear Seat and Cargo Concept

The rear seat design concept is based on a two-seat 60/40 split. The seat frame, supports and brackets are made of steel. The structure of the rear seat support is configured so as to allow for stowing in the vertical position behind the front seat.

Figure 68: **PNGV-Class Seat System**

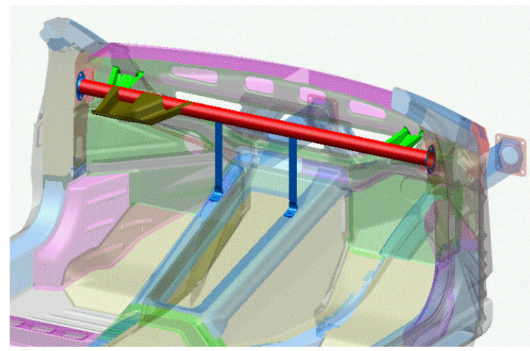


This seat arrangement determines the resulting trunk volume, which was calculated for both vehicle classes according to European Car Manufacturers Information Exchange Data (ECE) Volume definition using VDA guidelines (cubes). No spare tire was included in the package considerations since the inclusion of a repair kit is becoming more common practice in the automotive market today.

2.6.2 Instrument Panel Structure

The IP beam (see Figure 69) is made of a straight 50 mm diameter 2.0 mm DP 350/600 steel tube. It is designed for stiffness to support the steering column and the instrument panel, including the support of the passenger airbag.

Figure 69: **Instrument Panel Structure**

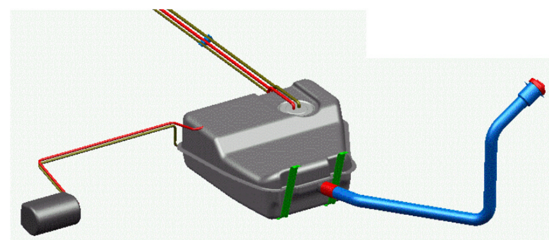


2.6.3 Fuel Tank

The fuel tank was packaged on the right side of the vehicle between the kick-up cross member and the torsion profile of the twist beam rear suspension. It is foreseen that both vehicles utilize the same fuel tank and the same fuel filler routing. The fuel filler routing had to be integrated into the body structure design for the different rear end structures (hatchback/sedan). Opposite the fuel tank, the charcoal filter was positioned behind the battery tray.

The fuel tank (see Figure 70) is a simple two-piece stamping made of 0.6 mm Mild 140/270 steel.

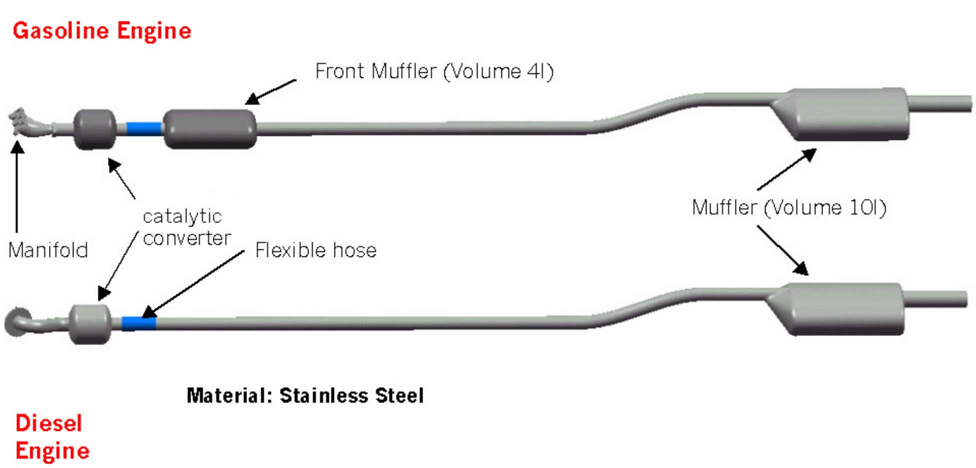
Figure 70: **Fuel Tank**



2.6.4 Exhaust System

Figure 71 illustrates the exhaust system concept for ULSAB-AVC vehicles. The stainless steel grades in the exhaust system are detailed in the ULSAB-AVC Engineering Report Section 9.0.

Figure 71: **Exhaust Systems for Gasoline and Diesel Variants**



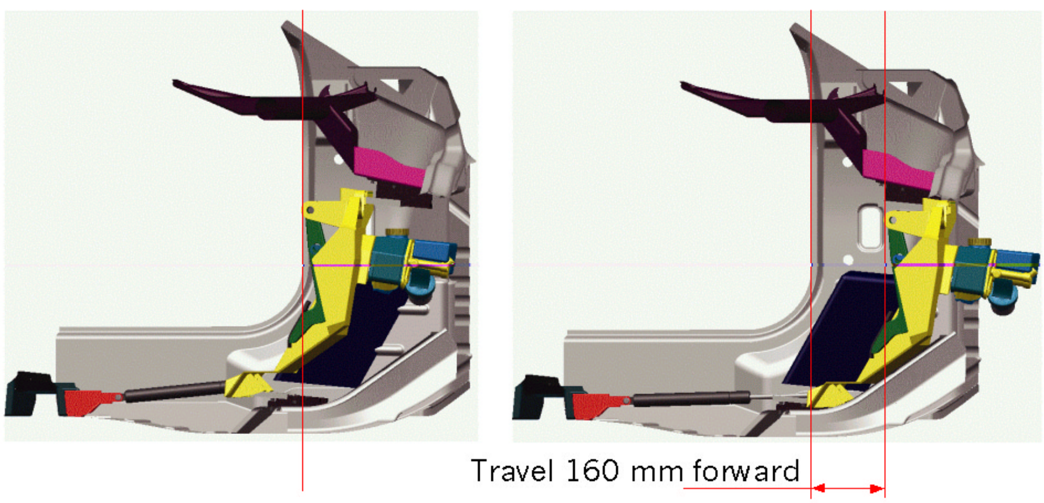
2.6.5 Adjustable Pedal System

An adjustable pedal system concept was developed for ULSAB-AVC due to the fixed seating concept. The pedal system integrates functions and combines the attachment of accelerator and brake pedal, electric hydraulic brake unit, footrest and guide rail housing. A driver can find his/her ideal pedal position by unlocking the gas strut and manually pushing the system forward or releasing to allow the system to move rearward on its own. Figure 72 illustrates the layout and positioning of the pedal system.

Due to the fixed front seat design and adjustable pedal system, the steering column was designed to have a longitudinal adjustment of 120 mm and a height adjustment of 58 mm. For mass efficiency, a mechanical adjustment with a friction locking mechanism was used rather than an electrical adjustment with a positive engagement mechanism.

Packaging space is sufficient within the vehicle to allow this system to be used on a right-hand drive vehicle as well.

Figure 72: **Adjustable Pedal Position**



2.6.6 Bumper Structure, Front Fascia Module,and Rear Fascia

Figure 73 shows the bumper beam structures both front and rear. These parts are made of dual phase, martensitic and HSLA steels for crash energy management at reduced mass. See the parts list in Appendix 1 for details.

When reviewing a vehicle design for mass reduction, the bumper beam is a good candidate for optimization. During the optimization of this component, PES reviewed manufacturability in an iterative process with material experts to come up with the highest grade steel, in this case Martensite, which would be feasible to manufacture the beam, optimizing the design for the steel. With Martensite, it is possible to keep the bumper beam stable for as long as necessary for energy absorption.

Figure 73: **Bumpers Front and Rear Exploded View**

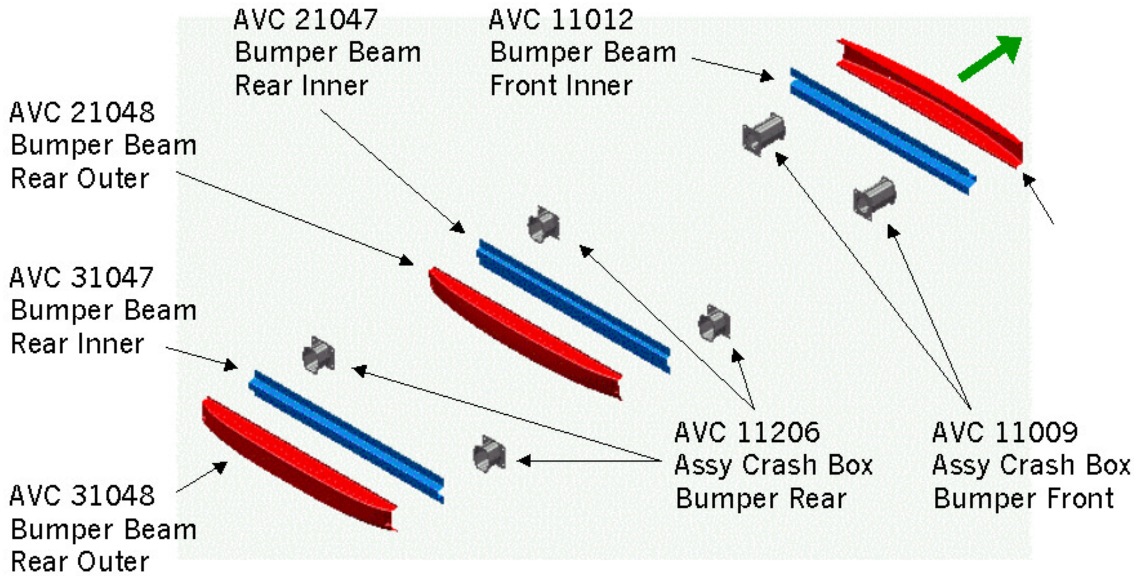
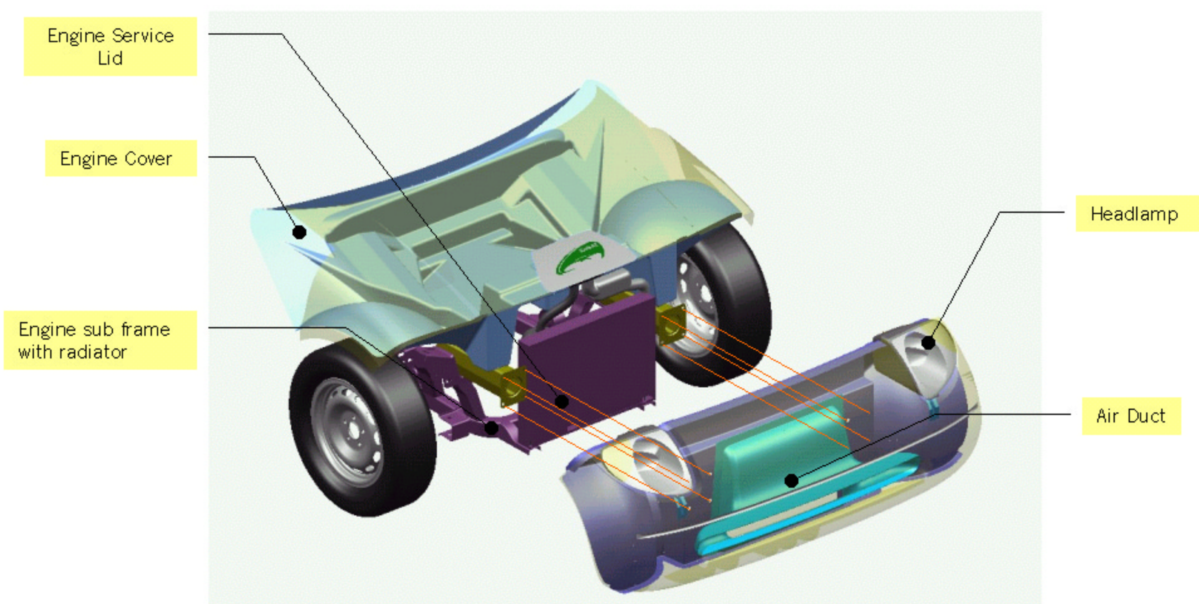


Figure 74 shows the front fascia module for the diesel variant, which is designed to arrive at the final trim line as a preassembled unit. The difference in gasoline and diesel variants has to do with the two specific radiator intakes necessary for the specific engine types.

Figure 74: **Front Fascia Module Disassembled**



Figures 75 and 76 show the rear fascia for both vehicle variants.

Figure 75: **C-Class Rear Fascia**

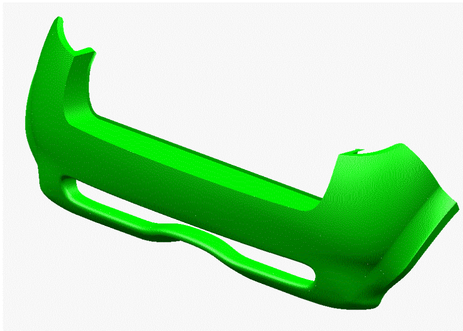
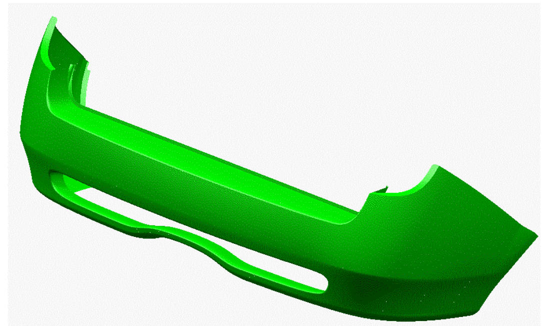


Figure 76: **PNGV-Class Rear Fascia**



2.6.7 Engine Cover Module

Because the engine subframe module is attached below the front rails, the area under the hood of the vehicle and above the front rails lends itself to a "free space" packaging area, allowing for flexibility in design packaging considerations. This area is referred to as the engine cover module, and in ULSAB-AVC, it is used to package the HVAC unit. The radiator close-out module is a hybrid design made of nylon with a steel reinforcement. It integrates the front of the wheelhouse rear and lower HVAC housing function. The engine service module with integrated HVAC system is pre-assembled prior to delivery to the final trim line. Figures 77 and 78 illustrate this concept.

Figure 77: **Engine Cover Module Top View**

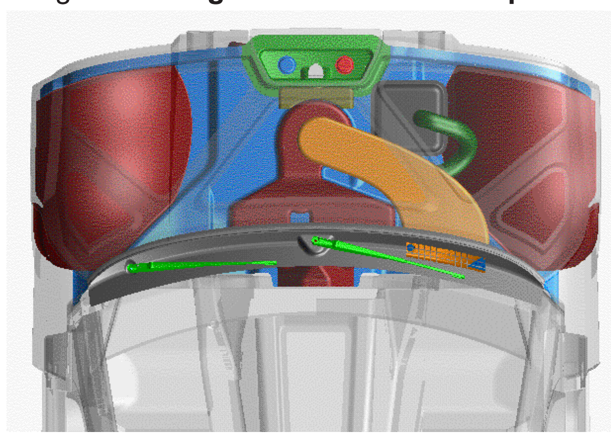
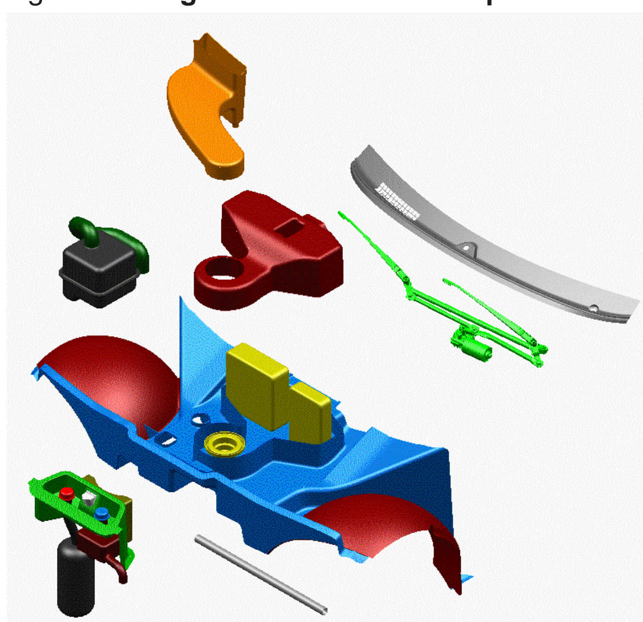


Figure 78: **Engine Cover Module Exploded View**



2.6.8 Interior

Figures 79 to 81 following show the interior concept.

Figure 79: **C-Class Interior Trim Side View**

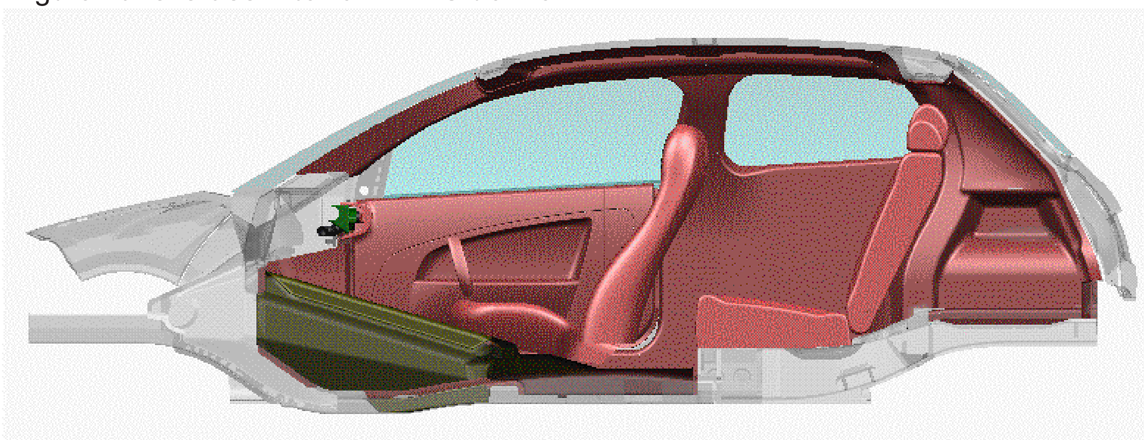


Figure 80: **PNGV-Class Interior Trim Side View**

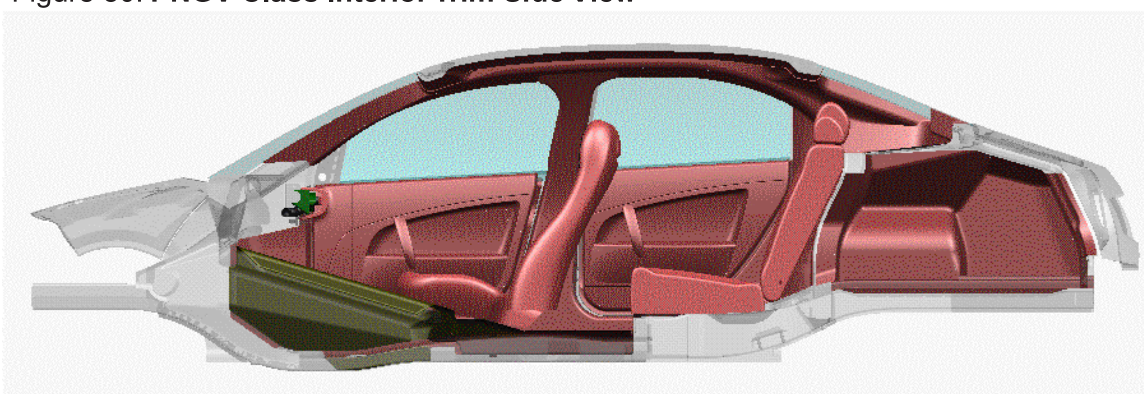
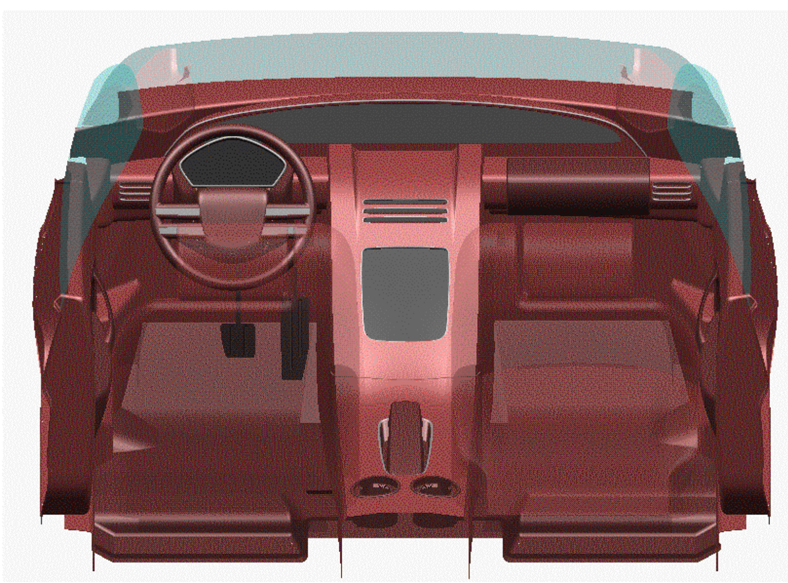


Figure 81: **Instrument Panel Styling Rear View**



2.6.9 Glazing

Figures 82 and 83 llustrate glazing between the two variants. The front glass is common for both vehicles.

Figure 82: **C-Class Glazing**

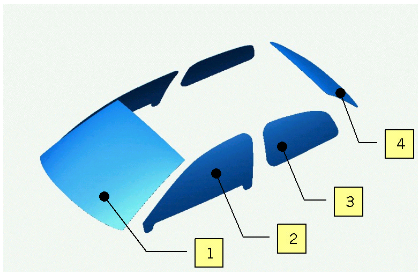
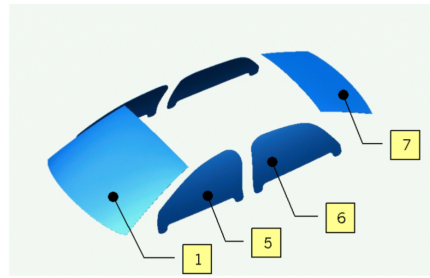


Figure 83: **PNGV-Class Glazing**



2.6.10 Electrics

ULSAB-AVC vehicles dispense with a conventional wiring system, replacing it with a Controller Area Network (CAN), use of load-free switches, electronic module switch integration, control unit smart power switches and placement of control switches near actuators and diagnostic information using CAN. The following diagrams (see Figures 84, 85, 86) show the ULSAB-AVC CAN system setup.

Package space was allocated for a conventional battery as a precaution in the case that alternative smaller and lighter batteries (e.g. lithium) were not found suitable for cost reasons. The battery is located behind the kick-up cross member on the left side of the vehicle with the battery accessible from the vehicle inside. One disadvantage could be a longer battery cable necessary for routing from the battery to the engine than in a front-end battery package. However, this concept was chosen to create more packaging freedom in the front structure and for an equalized load distribution between front and rear suspensions.

Figure 84: **CAN-Bus 3-D Wire Harness Structure**

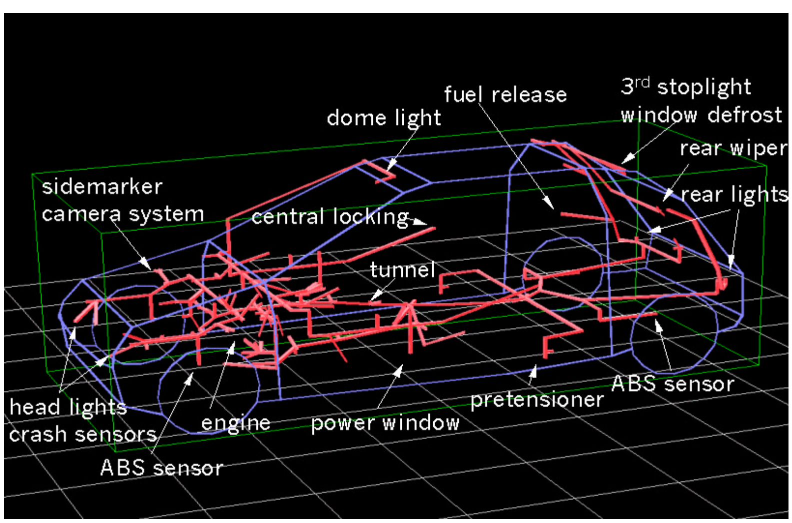
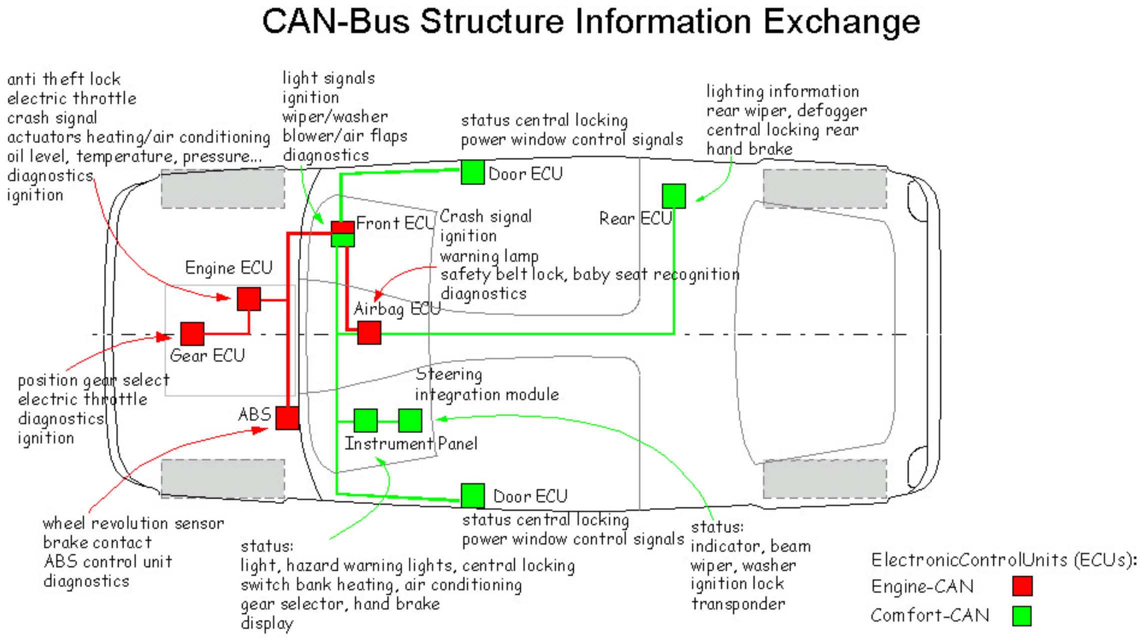
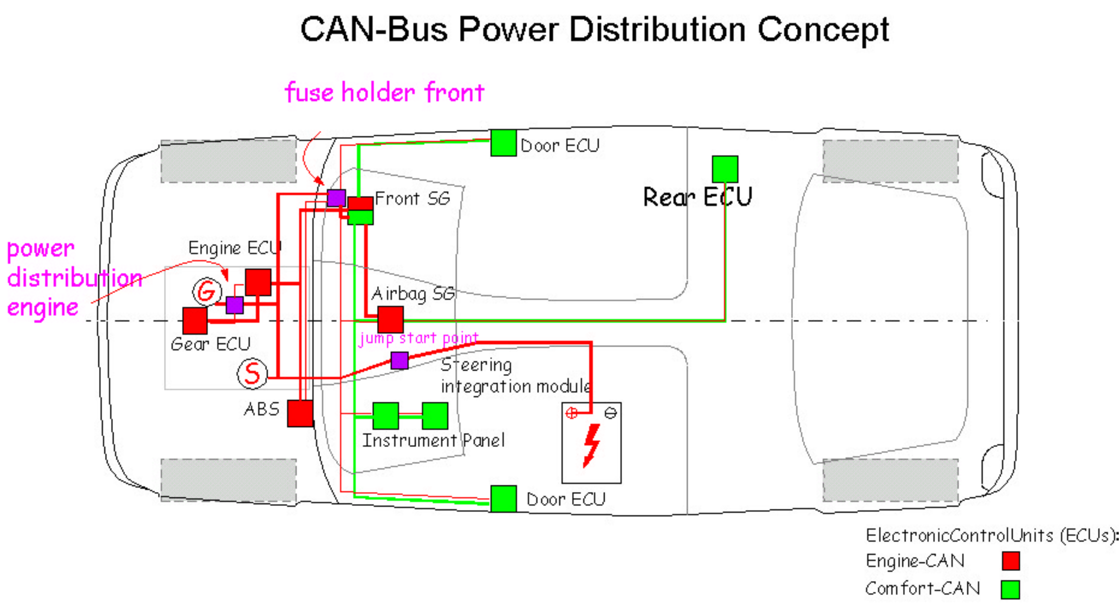


Figure 85: **CAN-Bus Structure Information Exchange**





ULSAB-AVC
Advanced Vehicle Concepts

2.7 NVH

Groundwork for good vehicle NVH characteristics was established by surpassing the global mode targets as reported in Section 4.1, CAE Analysis Results. The next step was to determine necessary measures, and their related mass, for achieving good overall NVH performance. The body structure design concepts and package were reviewed and the following areas of optimization identified:

- Airborne noise absorption
- Anti-booming measures
- Bypass noise sealing
- Interior components

The mass required for these measures is 19.2 kg for the C-Class and 19.7 kg for the PNGV-Class.

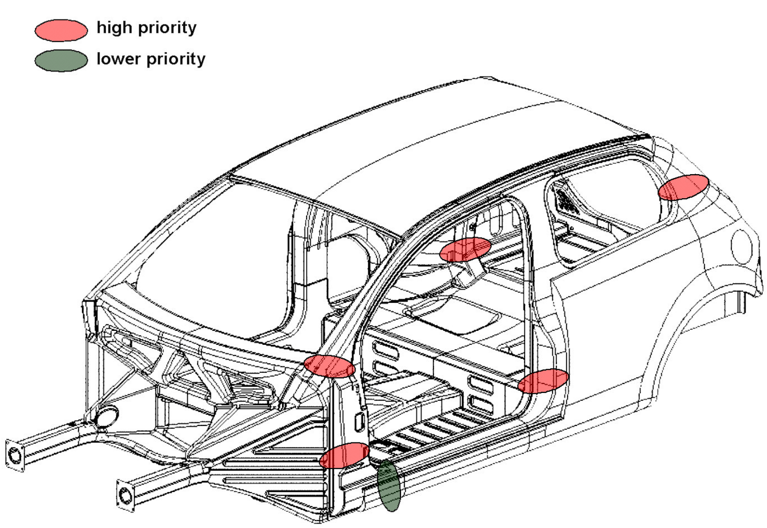
Airborne noise emitted from components (engine and transmission area, firewall, doors, etc.) were addressed with material use such as polyurethane lightweight foam with hydrophobic felt surface, polyester fiber fleece (approx. 20-30 mm) and polyurethane foam. In the interior, noise absorption materials included lightweight floor carpets and a multi-layer roofliner.

Anti-booming measures were taken using bituminous hot-melt attenuation foil for the floor, tunnel, doors, wheelhouse and firewall areas. Heat-activated expanding foam was specified for bypass sealing. Heat is applied during the paint cycle.

General sealing measures for wire harness routing, air extraction leak sealing were also projected for their mass impact, though specific details would normally come in a later development phase. The additional mass calculated into the NVH overall mass is based on experience and engineering judgment.

For full details on NVH materials and mass, refer to Section 13.0 in the ULSAB-AVC Engineering Report.

Figure 86: **Location of sound insulation foam inserts**



2.8 Trim Line Assembly Sequence

The ULSAB-AVC vehicle designs incorporate modular component subassemblies. Therefore, preassembly and trackside delivery of these modules to the manufacturing line can reduce the assembly process. Current practice is to build these subassemblies trackside, which would increase the overall time and area required for vehicle assembly.

The entire assembly process was reviewed to determine best utilization of manpower and robots, based on volume requirements. Vehicle assembly has been categorized into the following subassemblies:

- Underbody installation
- System installation
- Interior trim installation
- Miscellaneous installation (2)
- Vehicle hookup
- Closures and glazing
- Vehicle testing and preparation for shipping.

More detailed information, including a full list of components and equipment used and a description of each major assembly station, can be found in ULSAB-AVC Engineering Report Section 14.0 Final Trim Line Assembly. A view of the entire trim line assembly diagram can be found in Appendix 2.

3

Steel Materials and Processes

Engineered steels provide automotive designers and manufacturers with the unique option to combine lightweighting with the traditional steel advantages of low cost and eco-efficiency. Since the ULSAB Program, the catalog of commercial steel grades has grown to include new types of high-strength steel, called advanced high-strength steels (AHSS). As evidence of this progression, the ULSAB body structure was constructed 90 percent of high-strength steels (HSS), whereas the ULSAB-AVC body structure is 100 percent HSS, with over 80 percent of that total being AHSS steels. This is a significant steel usage advancement in automotive design since the ULSAB Program completion.

In the ULSAB-AVC Program, the need to reduce the added mass required to satisfy future safety mandates presented the opportunity to consider the application of these newer types of high-strength steels to assist in achieving the design of an efficient lightweight body structure. Because ULSAB-AVC is a concept program it opens the chance to expand the list of candidate steels by considering those steels that are currently available and those that will become available by 2004.

It must, of course, be emphasized that ULSAB-AVC is only one possible solution to achieve lightweight steel body structures. Consequently, the particular AHSS selected for each component was based on the specific designs used in ULSAB-AVC. The steels selected should be considered as useful guidelines for similar components in other automotive designs. The material selected by other automotive manufacturers will be based on a balanced consideration of their specific factors -- manufacturability, performance and cost.

Noteworthy was the collaboration of the 33 international steel producers that make up the ULSAB-AVC Consortium. Member companies supplied a list of a full range of steel materials, along with each material's dynamic behavior properties, compiling a steel catalog of international steel data for consideration in the ULSAB-AVC Program.

The ULSAB-AVC Program engaged a simultaneous engineering process between steel industry material experts and PES to ensure that part designs incorporated the best advantages of steel material applications. Forming simulation analysis was done by Consortium member companies on body structure and closure major parts to assess manufacturing feasibility. For forming analysis examples, see Technology Transfer Dispatch (TTD) #6 available through the ULSAB-AVC website at www.ulsab-avc.org.

This program provides a good example for the collaborative efforts which have been underway and are continuing between the steel industry and the automotive industry.

The selection of steels for ULSAB-AVC was made to facilitate an optimum balance between structural strength, crash resistance, formability, joinability and total economy to credibly achieve the ULSAB-AVC technical goals. Clearly, this could only be obtained through simultaneous engineering between the material suppliers and vehicle designers.

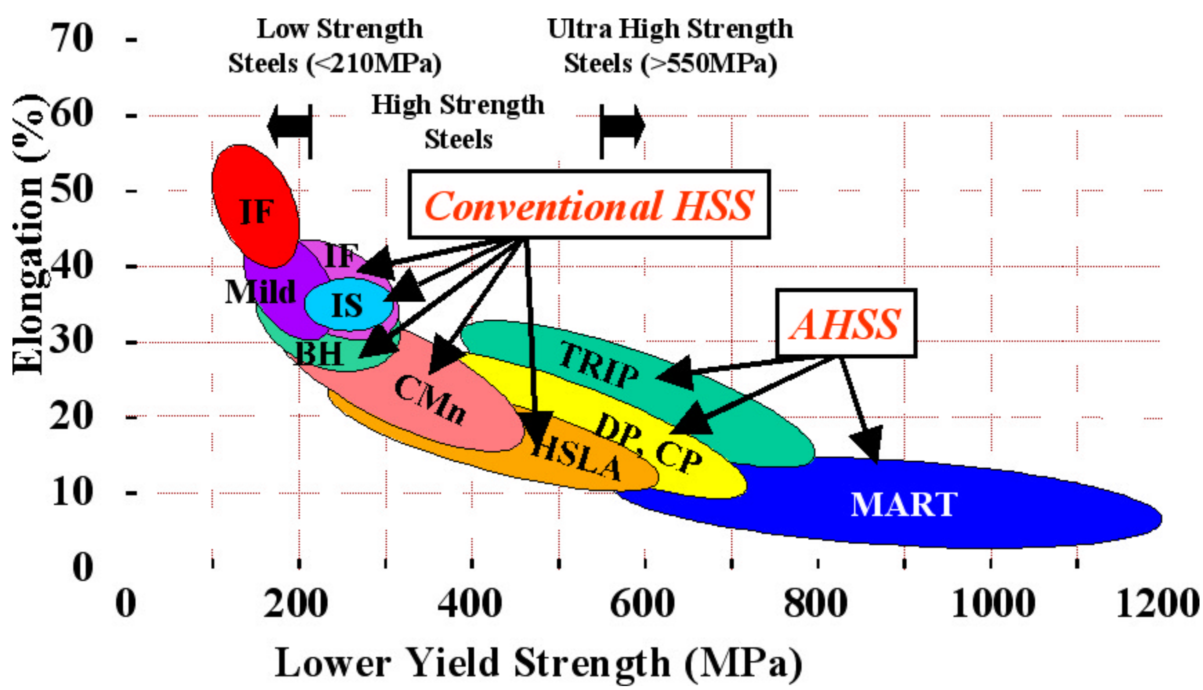
3.1 The Rationale for Advanced High-Strength Steels

Consistent with the terminology adopted for ULSAB, HSS grades are defined as those steels with yield strengths from 210–550 MPa; UHSS are defined as steels with yield strengths greater than 550 MPa. The yield strengths of grades overlap the range of strengths between HSS and UHSS, as shown in Figure 87. The principal differences between conventional HSS and AHSS are due to their microstructures. AHSS are multi-phase steels, which contain martensite, bainite, and/or retained austenite in quantities sufficient to produce unique mechanical properties. Compared to conventional micro-alloyed steels, AHSS exhibit a superior combination of high-strength with good form-ability. This combination arises primarily from their high strain hardening capacity as a result of their lower yield strength (YS) to ultimate tensile strength (UTS) ratio. Figure 87's data show the relative strengths and formability (measured by total elongation) of conventional strength steels, such as mild (Mild) and interstitial free (IF) steels; conventional HSS such as carbon-manganese (CMn), bake hardenable (BH), isotropic (IS), high-strength IF (IF), high-strength, low alloy (HSLA). Figure 87 also shows advanced high-strength steels (AHSS) such as dual phase (DP), transformation induced plasticity (TRIP), complex phase (CP), and martensite (Mart) steels.

Although not displayed in Figure 87, another category of steels, known as press hardened or hot-formed steels are also of interest, especially for those components with a complicated shape but requiring ultra high-strength levels. These grades are, essentially, martensitic grades.

To coordinate the application of AHSS steels into the ULSAB-AVC vehicles, it was first necessary to adopt a consistent nomenclature of the various grades of steels.

Figure 87: **Strength-Formability relationships**



3.2 ULSAB-AVC Steel Nomenclature

Since methods used to classify steel products vary considerably throughout the world, the ULSAB-AVC Consortium, together with PES, adopted a classification system that defines both YS and UTS for all steel grades. In this nomenclature, steels are identified as "XX aaa/bbb" where:

XX = Type of Steel
aaa = Minimum YS in MPa
bbb = Minimum UTS in MPa

The steel-type designator uses classifications shown in Table 11.

As an example of this classification system, DP 500/800 refers to dual phase steel with 500 MPa minimum yield strength and 800 MPa minimum ultimate tensile strength. An exception to this nomenclature is the material used for the exhaust system, which are stainless steel grades identified with different international designations. To review the exhaust materials used in ULSAB-AVC, see the ULSAB-AVC Engineering Report Section 9.0.

Table 11: **Steel Type Designator**

Designator	Classification	Designator	Classification
Mild	Mild Steel	DP	Dual Phase
IF	Interstitial Free	SF	Stretch Flangeable
BH	Bake Hardenable	TRIP	Transformation Induced Plasticity
CMn	Carbon Manganese	CP	Complex Phase
HSLA	High Strength Low Alloy	Mart	Martensite
IS	Isotropic	MnB	Hardenable Manganese Boron

3.3 AHSS Material Description

The fundamental metallurgy and mechanical behavior of conventional high-strength steels are generally well known. The metallurgy, processing, and mechanical behavior of AHSS reflect more recently introduced technologies. For a better understanding of these materials, see Appendix 3 of this report.

3.4 Material Selection

3.4.1 Strain Rate Dependent Material Properties

It is well known that steels display positive strain rate performance. That is, at the higher rates of strain typically associated with, for example, crash events, steels have higher strengths and consequently higher energy absorption. Preliminary studies confirmed that utilization of this phenomenon in crash analysis could assist in lightweighting. Accordingly, it was decided to use this experience in the design of the ULSAB-AVC body structure. Therefore, PES used dynamic true stress-strain curves, which describe stress-strain behavior over a wide range of strain rates, for the crash calculation model. See TTD#6, available at www.ulsab-avc.org, for a detailed description of how this was implemented in the crash analysis code

3.4.2 Steel Application Methodology

PES began the material selection process using static material data as the basis for first designs. Then an effort ensued to collect dynamic strain rate data. Then static material data were matched to the static curves of those materials where dynamic properties were also available. PES conducted a study to investigate any possible difference in results that might be achieved with dynamic strain rate properties over those already indicated in the static properties designs. Results showed that the structure had different crash deformation behavior as reported in the ULSAB-AVC Strain Rate Properties Study.

After reviewing crash behavior, PES began the design optimization process, using the Consortium's steel catalog of possible materials, as well as material application recommendations. The team experimented with different strength levels until the steel was optimized. Since most steels provided in the catalog with yield strength above 350 MPa were DP grades, the ULSAB-AVC body structure consequently contains a large percentage of DP steels.

Once the steel grades and basic thicknesses were defined, PES began the process of mass reduction through tailored blanks, hydroforming, etc. This led to significant design changes. For example, the front rails always considered tailored tubes. But the location of the seam changed over the course of the design, the goal being to position the seam as far forward as possible since the tailored tube rear portion is the lower thickness material. The redesigns reduced mass but also focused on achieving high star ratings crash results. Also during optimization, PES focused on applying different welding processes, which could result in different crash performance behavior. For example, the number of spot and laser welds in the pyramid structure was altered for improved crash results. Crash optimization considerations included material iteration, placement of TWB seams, placement of different material in the TWB, and joining specifications.

AHSS used in the ULSAB-AVC vehicle offer superior strength, formability, and crash energy absorption capacity and provide very good dent resistance and fatigue performance. These steels provide exceptional potential for increased structural strength and mass reduction by using lighter thickness than could be used with less formable conventional steel. When selecting AHSS for ULSAB-AVC, the following Consortium-recommended guidelines were considered:

- The steel selection for crash-sensitive applications should be made utilizing the area under the stress-strain curve at 10% strain, measured at strain rates from 100 to 300 s^{-1}.
- Designing components in AHSS should be performed so that the as-manufactured strength in the component was maximized by strain hardening, consistent with formability and thinning considerations.
- Strength comparisons should be made at strain rates reflected in the body structure CAE crash models.
- For constant component geometry (i.e. no structural design changes) exponentially greater increases in strength are required to maintain crash energy absorption capacity as thickness decreases, limiting the extent to which mass can be reduced by substituting higher strength, lighter gauge materials. Component design (geometry or shape) should be the primary initial focus for achieving the best result in reducing mass while maintaining or enhancing crash performance.

The design and materials teams worked closely throughout the design process to assure that design was optimized and that the steels selected, either conventional or AHSS, performed to their full potential for the particular component design.

For more information about the application of AHSS in the ULSAB-AVC design, please refer to TTD#6 at www.ulsab-avc.org.

3.5 Materials Selected for ULSAB-AVC

Table 12 contains the master materials list for ULSAB-AVC. This list gives the steel static mechanical properties of ULSAB-AVC body structure, closures, ancillary parts, suspension and wheels. Dynamic true stress-strain curves for the body structure steels can be found in TTD#6, available as indicated above.

Complete lists of the materials selected for body and closure structures are provided as Appendices 1 and 2.

Exhaust system materials are stainless grades that use international designations, as mentioned in Section 3.2. Selection mainly was driven by forming and/or heat resistance requirements for various system components.

Table 12: **Master Materials List**

Steel Grade	YS* (MPa)	UTS* (MPa)	Total EL(%)	n-value (5-15%)	r-bar	Application Code
Mild 140/270	140	270	38-44	0.23	1.8	A,C,F
BH 210/340	210	340	34-39	0.18	1.8	B
BH 260/370	260	370	29-34	0.13	1.6	B
IF 260/410	260	410	34-38	0.20	1.7	C
DP 280/600	280	600	30-34	0.21	1.0	B
IF 300/420	300	420	29-36	0.20	1.6	B
DP 300/500	300	500	30-34	0.16	1.0	B
HSLA 350/450	350	450	23-27	0.22	1.0	A,B,S
DP 350/600	350	600	24-30	0.14	1.1	A,B,C,W,S
DP 400/700	400	700	19-25	0.14	1.0	A,B
TRIP 450/800	450	800	26-32	0.24	0.9	A,B
HSLA 490/600	490	600	21-26	0.13	1.0	W
DP 500/800	500	800	14-20	0.14	1.0	A,B,C,W
SF 570/640	570	640	20-24	0.08	1.0	S
CP 700/800	700	800	10-15	0.13	1.0	B
DP 700/1000	700	1000	12-17	0.09	0.9	B
Mart 950/1200	950	1200	5-7	0.07	0.9	A,B
MnB**	1200	1600	4-5	n/a	n/a	S
Mart 1250/1520	1250	1520	4-6	0.07	0.9	A

Application Code: A=Ancillary Parts, B=Body Structure, C=Closures, F=Fuel Tank, S=Suspension/Chassis, W=Wheels

Note: Flat sheet, as shipped properties

* *YS and UTS are minimum values, others are typical values*

*** Properties in heat-treated condition; YS/UTS = 280/450, EL=21% before hardening*

It should be noted that no specific selections were made as to coatings at this design phase. Since the selection of coatings depends on individual automotive company processes and philosophies, ULSAB-AVC's general concept for steel coatings was:

- Body Structure and Closures – Coated both sides with hot-dip galvanized, galvannealed, or electrogalvanized metallic coatings. Automotive companies, for their particular system would, of course, specify coating amounts, surface treatments, and paint systems.
- Chassis Components - Coated both sides with metallic or organic coatings as specified by individual auto companies
- Fuel Tank - Coated both sides with metallic or organic coatings as specified by individual auto companies
- Exhaust System – Stainless steel, coated stainless or aluminized steel as specified by individual auto companies

Part geometry in this concept design had a significant influence on the types of steels selected. In particular, for a number of components, both DP and TRIP steels were viable candidates for selection. The choice of a DP grade was enabled since part geometry rendered the superior formability of TRIP steels redundant, based on the first-approximation one-step forming simulations.

In the case of the floor pan, TRIP 450/800 was selected rather than a DP grade. This particular component undergoes significant deformation during manufacture so that manufacturing feasibility will benefit from the additional forming capacity of the TRIP grade. In addition, practical experience on similar components has indicated that one-step forming simulations may not be completely reliable in predicting the manufacturing feasibility for such components. The selection of TRIP 450/800, therefore, provides a greater margin of manufacturing feasibility than would be the case with DP grades.

3.6 Tube Material

The ULSAB-AVC body and closures structures designs took advantage of a range of tubular steel products for hydroforming or use as straight or shaped tubes. All ULSAB-AVC tubes are made with the high frequency or laser welding process. In general the tube manufacturing process causes increased yield strength and decreased elongation, when creating round, rectangular or octagonal shapes with cold forming. These values were not taken into account for crash calculations since the high strain rate data were available only for flat sheet material at this time.

An exploded view of all tubular parts as well as a parts list is available in Appendix 1. For reference, Table 13 shows the straight tube as-shipped static mechanical properties for the body structure tubes.

Table 13: **Body Structure Tube Material**

Steel Grade	YS* (MPa)	UTS* (MPa)	Total EL (%)**	n-value (5-15%)	r-bar	Application Code
DP 280/600	450	600	27-30	0.15	1.0	B
DP 500/800	600	800	16-22	0.10	1.0	B
Mart 950/1200	1150	1200	5-7	0.02	0.9	B

Application Code: B=Body Structure
Note: Straight tube, as shipped properties
* *YS and UTS are minimum values, others are typical values*
** *Total EL % - Tubes tested with A5 method (flat sheet tested with A50 or A80)*

3.7 Material Distribution

Exploded views of the ULSAB-AVC body structure components are shown in Figures 88 and 90. The color coding used in the exploded views coordinates with the pie charts in Figures 89 and 91, which show the proportion of each grade used in the body structure. As mentioned earlier, ULSAB-AVC body structures are essentially 100 percent high-strength steels of which over 80 percent are AHSS steel grades.

Figure 88: **C-Class Body Structure Exploded View w/Steel Grade Coding**

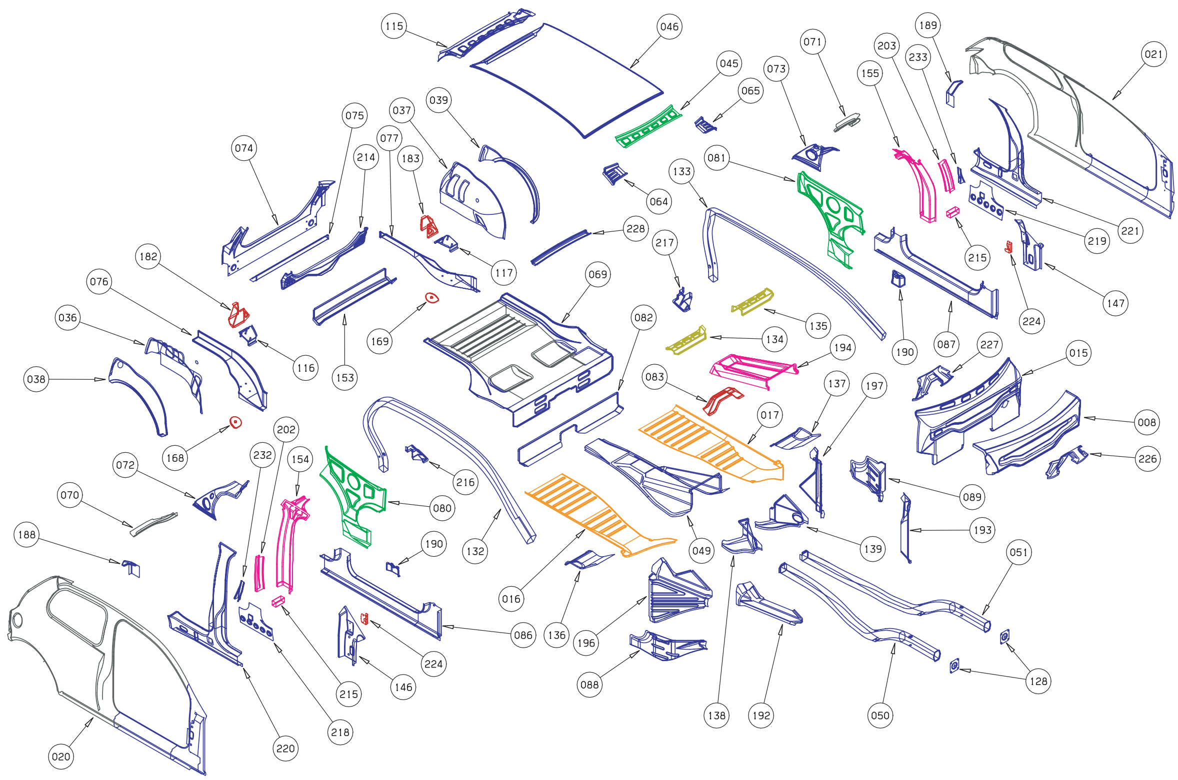
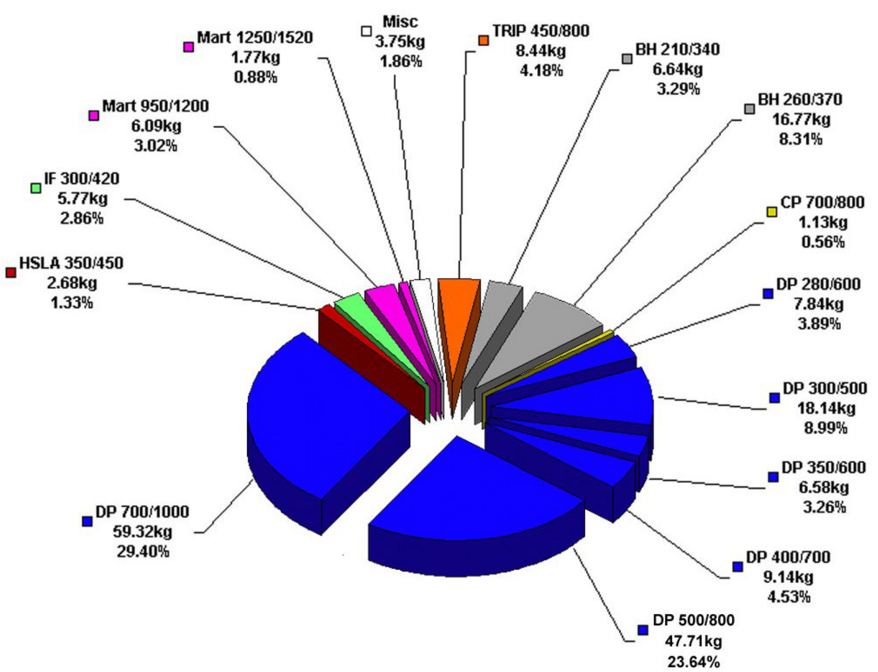


Figure 89: **C-Class Body Structure Steel/Grade Distribution**



BH	210/340
BH	260/370
CP	700/800
DP	280/600
DP	300/500
DP	350/600
DP	400/700
DP	500/800
DP	700/1000
HSLA	350/450
IF	300/420
Mart	950/1200
Mart	1250/1520
TRIP	450/800
Misc	

Material Type	Mass [kg]
BH	23.42
CP	1.13
DP	148.73
HSLA	2.68
IF	5.77
Mart	7.86
TRIP	8.44
Misc	3.75
Total	201.78

Figure 90: **PNGV-Class Body Structure Exploded View w/Steel Grade Coding**

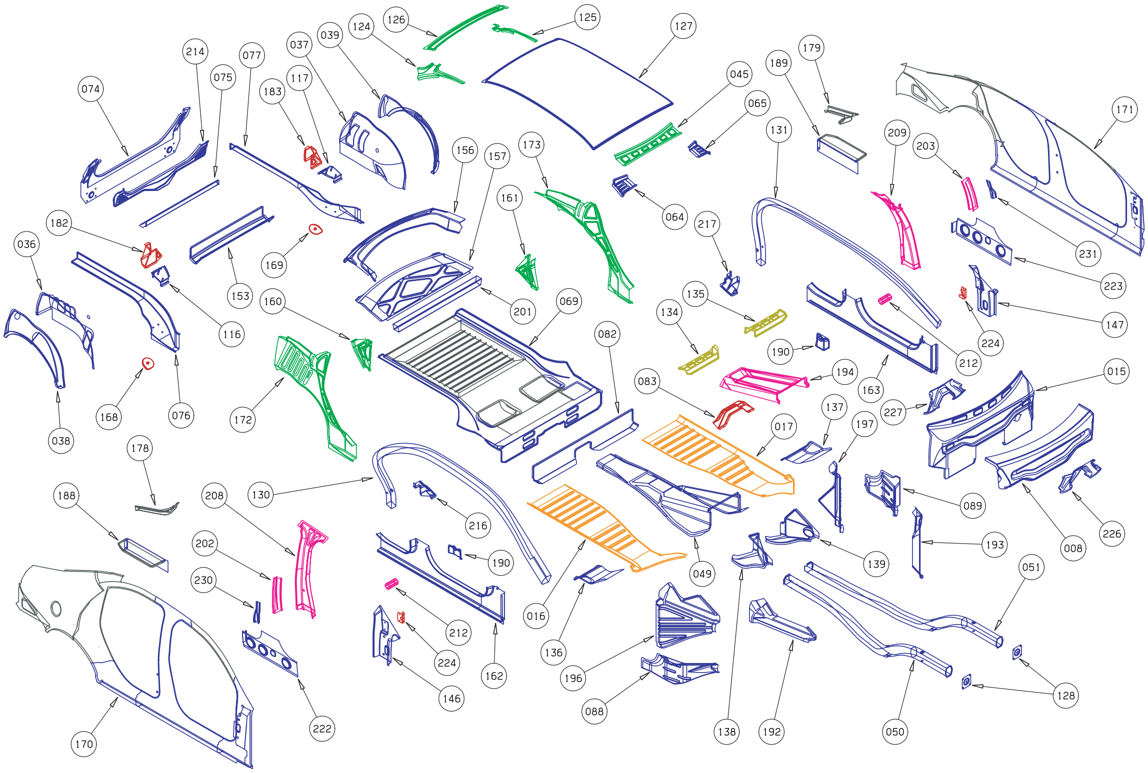
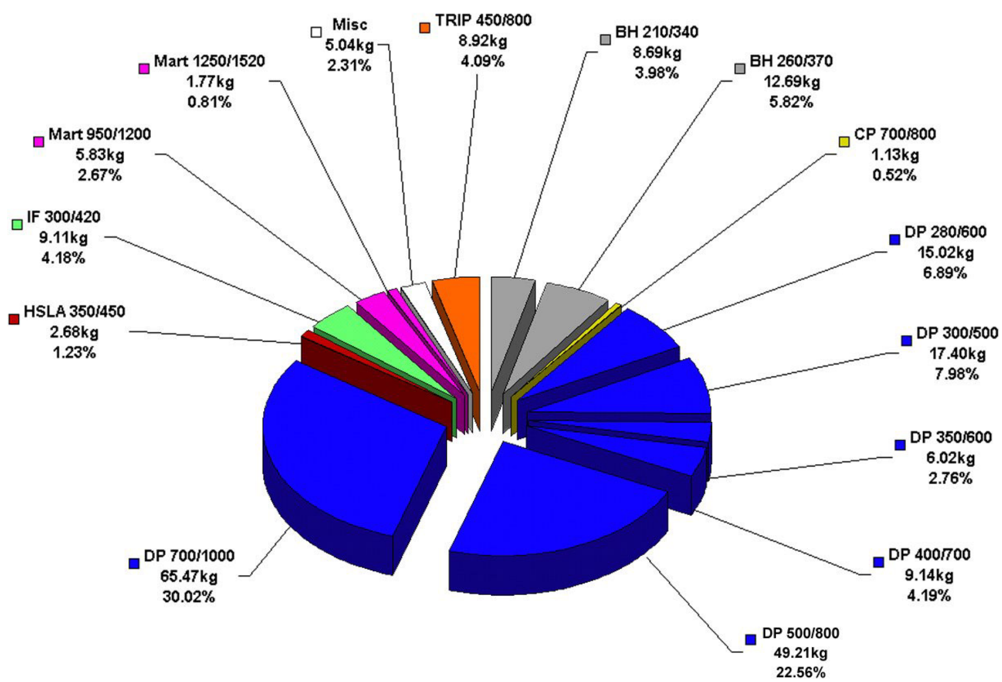


Figure 91: **PNGV-Class Body Structure Steel/Grade Distribution**



BH	210/340
BH	260/370
CP	700/800
DP	280/600
DP	300/500
DP	350/600
DP	400/700
DP	500/800
DP	700/1000
HSLA	350/450
IF	300/420
Mart	950/1200
Mart	1250/1520
TRIP	450/800
Misc	

Material Type	Mass [kg]
BH	21.38
CP	1.13
DP	162.26
HSLA	2.68
IF	9.11
Mart	7.60
TRIP	5.04
Misc	8.92
Total	218.12

ULSAB-AVC Advanced Vehicle Concepts

Exploded views for the C-Class and PNGV-Class closures are shown in Figures 92 and 94 with their respective steel grade distribution pie charts in Figures 93 and 95.

Figure 92: **C-Class Closures Exploded View w/Steel Grade Coding**

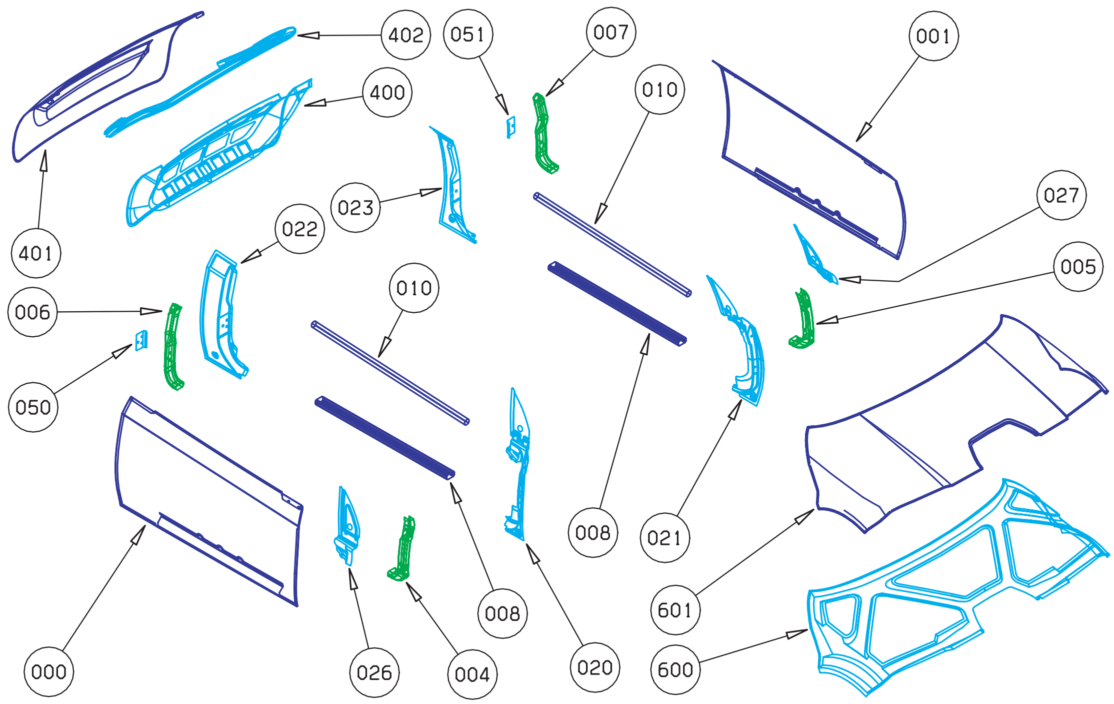
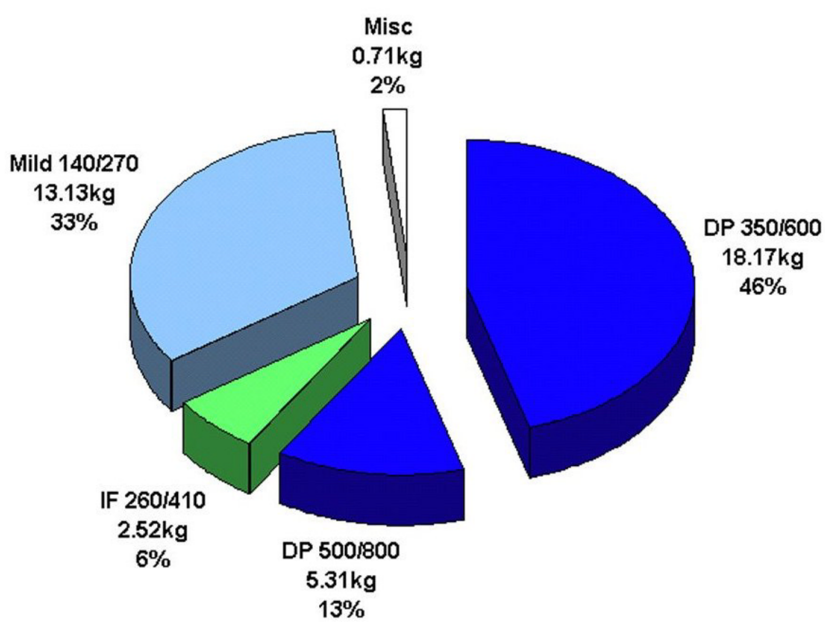


Figure 93: **C-Class Closures Steel Grade Distribution**



DP	350/600
DP	500/800
IF	260/410
Mild	140/270
Misc	

Material Type	Mass [kg]
DP	23.48
IF	2.52
Mild	13.13
Misc	0.71
Total	39.84

Figure 94: **PNGV-Class Closures Exploded View w/Steel Grade Coding**

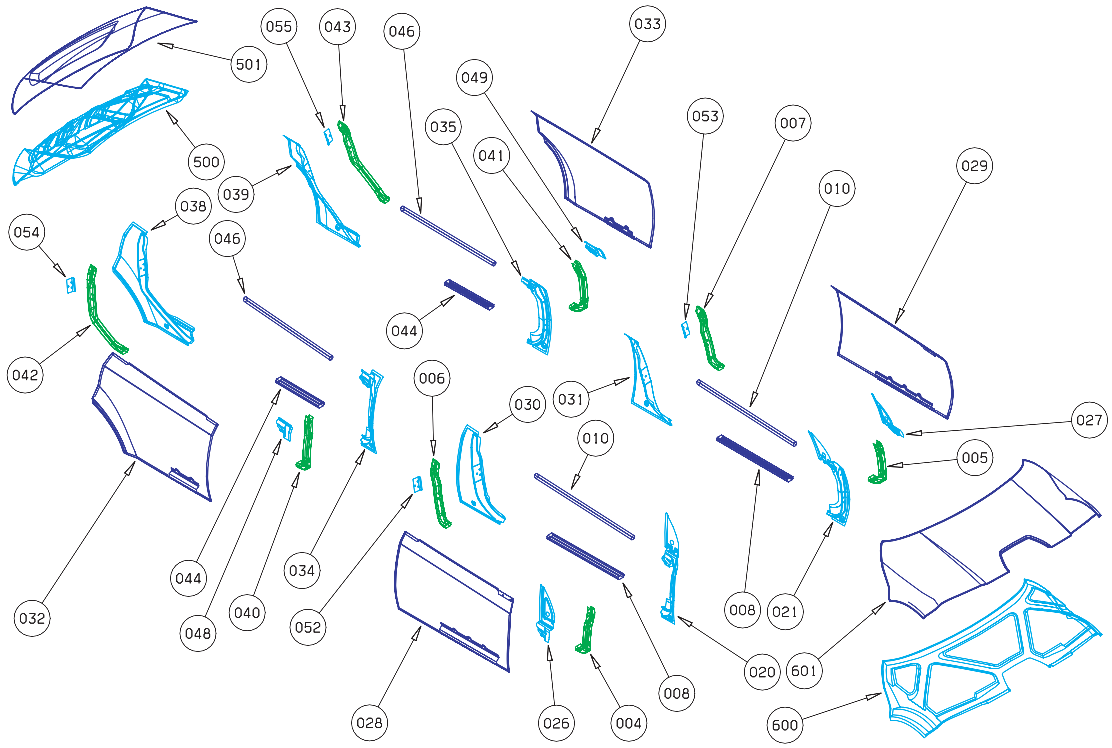
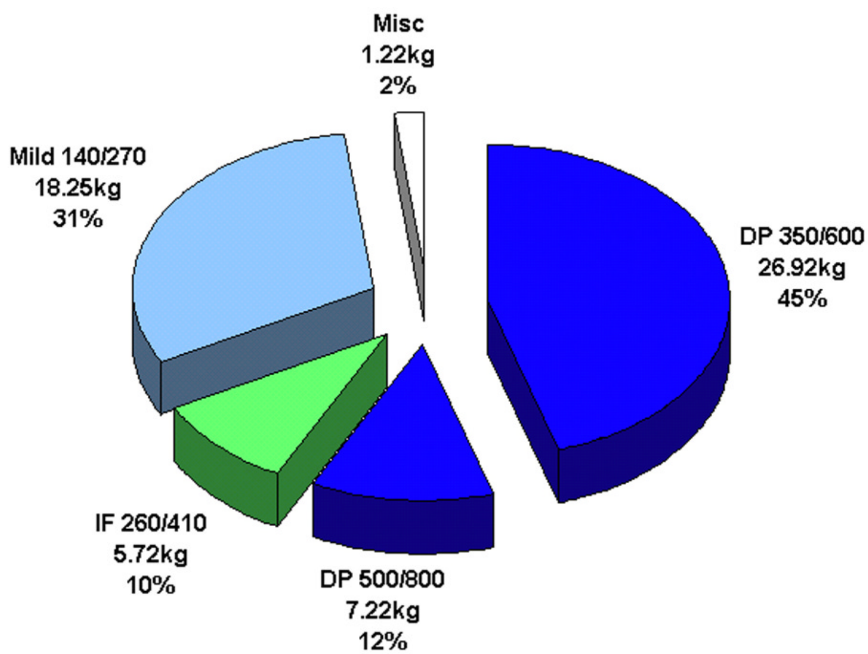


Figure 95: **PNGV-Class Closures Steel Grade Distribution**



DP	350/600
DP	500/800
IF	260/410
Mild	140/270
Misc	

Material Type	Mass [kg]
DP	34.14
IF	5.72
Mild	18.25
Misc	1.22
Total	59.33

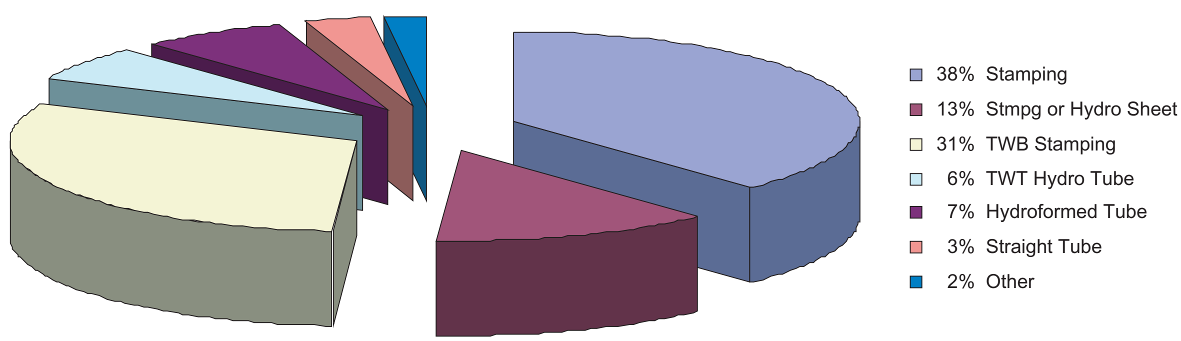
3.8 Manufacturing Processes

The pie charts in Figure 96 summarize the breakdown of the manufacturing processes used in the ULSAB-AVC body structure and closures. Noteworthy is the use of hydroformed parts and nearly 40 percent use of tailored blanks and tailored tubes in the structures of each vehicle class. Stamping continues to be the backbone of steel forming processes, proving that this process continues to be an industry staple, even as the use of more complex steels grows.

It should be noted that at this concept design stage there are, of course, manufacturing feasibility issues that would still be addressed as a program moves on from concept to production. Manufacturing process development work would be done for ULSAB-AVC in a similar manner to that which was done for ULSAB when that previous program went from a concept phase to a validation phase. For example, forming feasibility (i.e., incremental forming simulations, spring back, dimensional tolerances,) of advanced high-strength steels for difficult to form parts would be addressed in a detailed design phase. Fine tuning part design, tool design, and process parameters, such as die surface treatments and lubrications, would be considered. Additionally, welding/joining techniques, particularly for spot welding, also have to be further refined for combinations of different advanced high-strength steel grades and thicknesses, as well as joint durability characteristics.

This development process would involve continuing simultaneous engineering between steel company and automotive company representatives.

Figure 96: **ULSAB-AVC Manufacturing Processes**



3.8.1 Tailored Blanks

The ULSAB-AVC design incorporates extensive use of tailored blanks, using previous experience gained from the ULSAB Program. For example, the PNGV-Class body side outer design principle uses a similar blank layout as that used in ULSAB, but it specifies AHSS for some areas.

As mentioned previously, all tailored blank parts were subjected to forming simulation, which indicated that all parts are feasible to form. A full catalog of body structure and closures parts blank layouts can be reviewed in the ULSAB-AVC Engineering Report Section 9.0.

Unique to ULSAB-AVC, tailored blanks were chosen for specific chassis components, like the upper and lower wishbone. Details on these suspension parts can be found in Section 2.4 of this Overview Report.

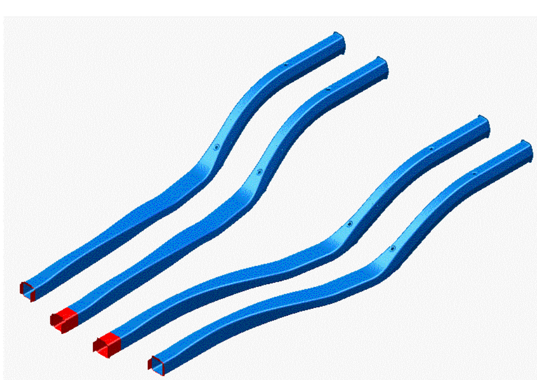
3.8.2 Hydroforming

The ULSAB side roof rail and the ULSAC hinge and latch tubes provided valuable experience toward the development of hydroformed tubes for automotive applications. These applications have shown high structural efficiency, and the merits of hydroformed tubes have gained wide acceptance in the industry as enablers for optimized load flow.

An example of tube hydroforming in ULSAB-AVC is its front rails (see Figure 97). The structural efficiency of these AHSS hydroformed components (DP 500/800) was further enhanced by using tailor welded tubes (TWT), bringing together the same grade and diameter tubes at different thicknesses (1.3 mm and 1.5 mm) to optimize the efficiency and mass of these parts. Though there is not much industry experience with this type of design, future research and development programs most likely will bring about its general acceptance, as with the side roof rail application.

Hydroforming, with both single thickness and tailor welded tubes, was also used for the subframe, trailing arm and rear axle twist beam. An overview of these components can be found in Section 2.4 of this report.

Figure 97: **Front Rail Members RH/LH, C-Class and PNGV-Class**



The Active Hydromechanical (AHM) sheet forming process, as described in the January 2001 ULSAC Engineering Report, was used for the closure outer panels and the body structure outer panels, except the rear quarter panel, to obtain stretch in the center area. This emerging process shows potential for material thickness reduction to attain dent resistance and resistance to oil canning. However, the maturity of this process for use in high volume production by the year 2004 is unknown. In addition, conventional stamping using AHSS also was considered as described in the next section.

3.8.3 Stamping

Stamping is the most common manufacturing process for making structural parts in the automotive industry. ULSAB-AVC exemplifies this commonality with about 70 percent of the body structure and closure parts using this process. These parts range from complicated tailored blanks, like the vehicles' body side outer to stampings of single materials, like the cross members or cowl.

For closure and body structure outer panels other than the rear quarter panel, Consortium member companies performed forming simulations to confirm that the outer panels could be successfully stamped using AHSS grades. The data from the forming simulations, along with alternative cost model calculations for the stamped parts, are available in a separate report, Outer Panels Stamping vs. Sheet Hydroforming, available through the ULSAB-AVC Consortium.

3.9 Joining Technologies

ULSAB-AVC uses arc, spot and conventional laser welding technologies. Laser assembly welding provides proven structural performance and the ability to join components where only one side is accessible, such as joining stamping to tubes. This technology becomes essential when incorporating hydroformed parts or other closed sections.

Though conventional laser welding was used for ULSAB-AVC, there is potential for using the Remote Laser Welding process, which has already been introduced by various OEMs. Remote laser welding carries the advantage of eliminating some robot movement and devices.

When laser welding was needed for some applications, the use of the required laser weld station was maximized and applied to eliminate other spot welds. A catalog of assembly process sheets located in the ULSAB-AVC Engineering Report Appendix details the number and type of welds for each body structure subassembly.

Following is a summary of ULSAB-AVC vehicles' joining technologies:

Table 14: **Joining Technologies**

	C-Class	PNGV-Class
Laser welds	114 m	100 m
Spot welds	723	814
Adhesive bonding	1.6 m	1.6 m
MIG welding	<1 m	<1 m

4.1 ULSAB-AVC CAE Analysis Results

Computer Aided Engineering (CAE) techniques were used in the ULSAB-AVC Program as a tool to evaluate and optimize the structural concepts for crash worthiness and mass reduction.

4.1.1 Structural Performance

The ULSAB-AVC C-Class and PNGV-Class body structures were analyzed for static torsional rigidity, static bending rigidity and normal modes.

Stiffness model sizes are summarized in Table 15

Table 15: **ULSAB-AVC Stiffness Model Sizes**

	C-Class	PNGV-Class
Number of Nodes	61000	66100
Number of Elements	59000	64000

Torsional stiffness graphs are shown in Figures 98 and 99.

Figure 98: **C-Class Static Torsion Angle of Twist**

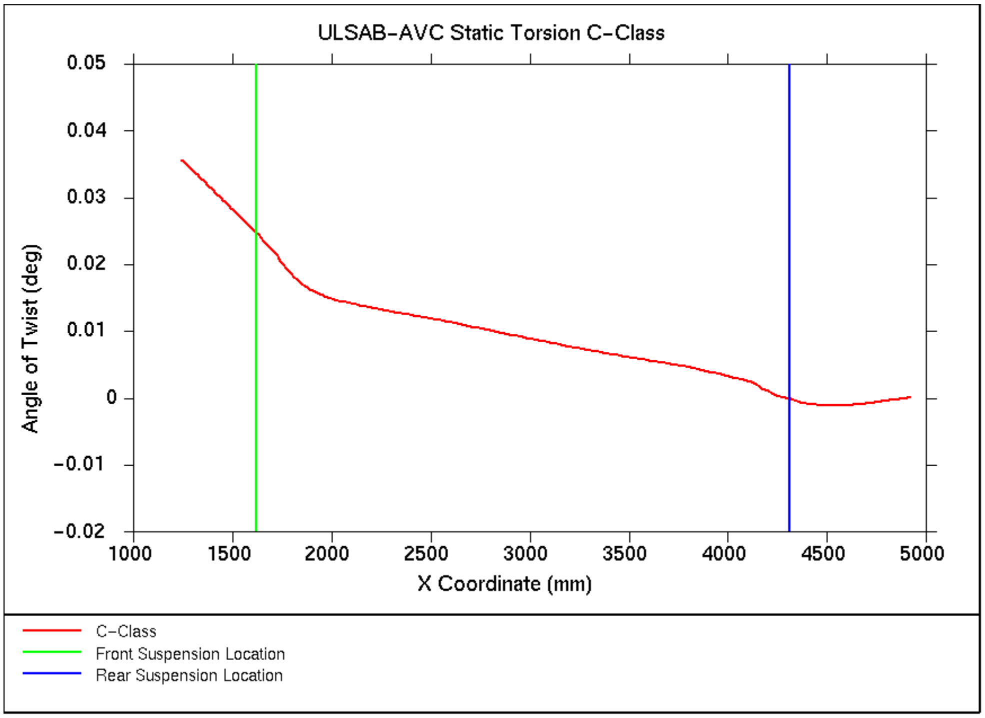
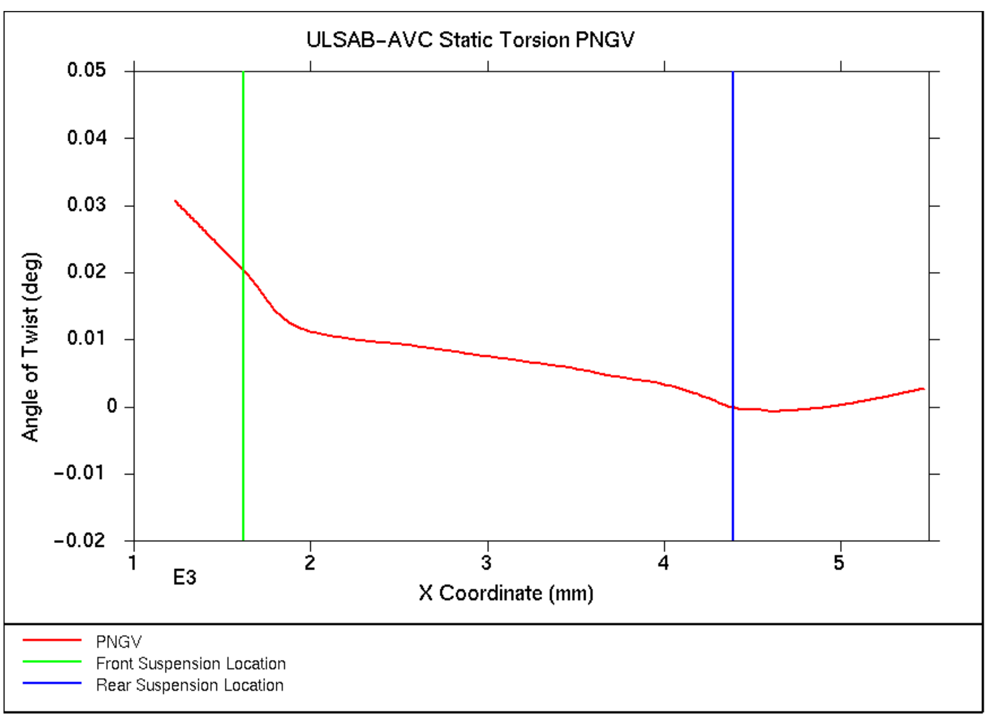


Figure 99: **PNGV-Class Static Torsion Angle of Twist**



Bending stiffness graphs are shown in Figures 100 and 101.

Figure 100: **C-Class Vertical Displacement Graph**

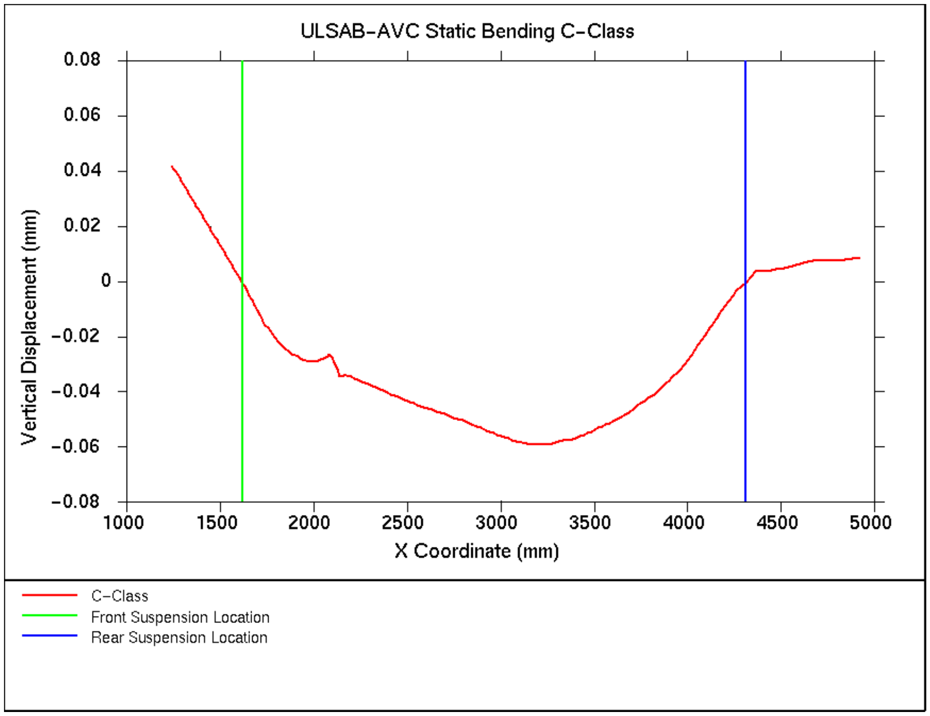
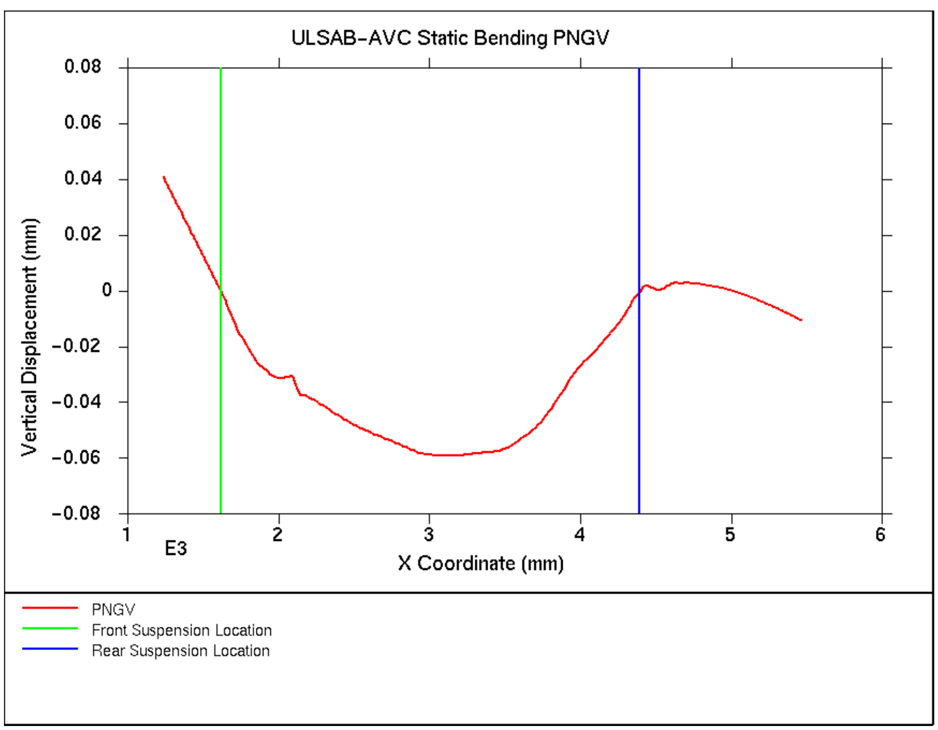


Figure 101: **PNGV-Class Vertical Displacement Graph**



Bending rigidity, torsion rigidity and normal modes analysis results are shown in Table 16.

Table 16: **Structural Performance Results**

	C-Class		PNGV-Class	
	Target	Results	Target	Results
Static Bending Rigidity (N/mm)	11,000	17,050	12,000	17,150
Static Torsion Rigidity (Nm/deg)	12,000	14,350	13,000	17,400
First Bending Mode (Hz)	48	58	48	66
First Torsion Mode (Hz)	35	49	40	44
Front End Lateral (Hz)	> 55	> 70	> 55	>70

Note: All data without bumper.

A stress analysis to simulate typical peak road load inputs to the structure was undertaken to provide information on the potential high-risk areas of the body structure, which could be susceptible to durability concerns. A "3G" bump load was applied to the suspension locations, and the resulting stresses are presented in Figures 102 and 103. These stress distributions could be used in a subsequent project to identify areas of the structure that should be assessed for their durability.

Figure 102: **C-Class 3g Bump Load Stress Contours**

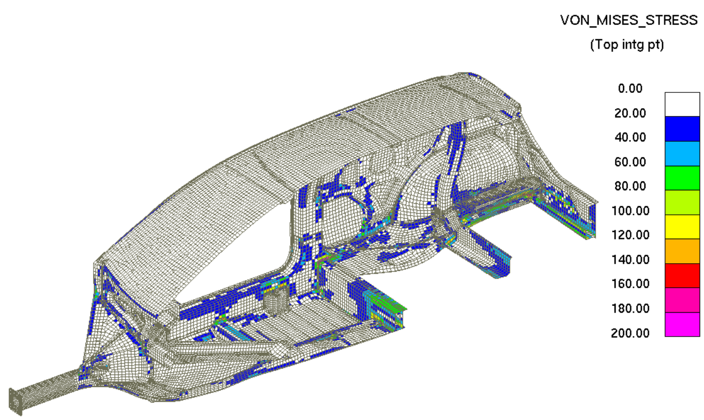
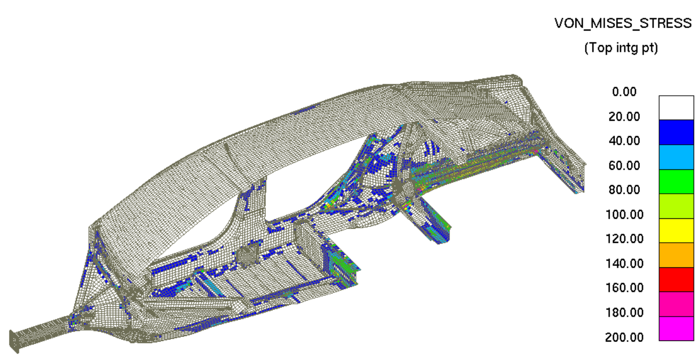


Figure 103: **PNGV-Class 3g Bump Load Stress Contours**



4.1.2 Crash Analysis and Star Rating Assessment

One common crash model was generated for each of the C-Class and PNGV-Class vehicles to conduct the following load cases:

- US-NCAP: 100% frontal crash at 35 mph (56 km/h) into rigid barrier
- Euro-NCAP frontal offset crash: 40% overlap offset frontal crash at 64 km/h (40 mph) into deformable barrier
- US-SINCAP: U.S. side impact barrier impact at 38.5 mph (62 km/h)
- Side Pole Impact: side impact into rigid pole at 20 mph (32 km/h)
- Rear Impact: moving barrier crash at 35 mph (56 km/h)
- Roof Crush/Rollover
- Low speed impact: 100% front crash at 15 km/h (9 mph) into rigid barrier

A full description of each crash event and ULSAB-AVC target can be reviewed in Section 1.1.

All crash-relevant car components were modeled, such as wheels, tires, engine, transmission, chassis system with subframe, steering column, fuel tank, bumper system including crashbox, radiator with fan, front and rear doors without glass, and fixed glass.

Crash model sizes are summarized in Table 17.

Table 17: **Crash model sizes**

	C-Class	PNGV-Class
Number of Nodes	182500	201500
Number of Elements	178000	196000

The ULSAB-AVC member companies provided the dynamic mechanical steel properties for use in computer crash simulations. Dynamic properties enhance the CAE crashworthiness prediction capabilities.

Following is the crash mass used in the analysis:

Table 18: **Crash Mass**

	C-Class		PNGV-Class	
	Gasoline (kg)	Diesel (kg)	Gasoline (kg)	Diesel (kg)
Curb Mass	980	1023	1059	1102
Luggage	113	113	113	113
Occupants (2)	149	149	149	149
Optional Equipment	49	49	49	49
Total Crash Mass	1291	1334	1370	1413

For each of the crash events a vehicle variant was selected to show the most severe case or the range of results possible. In the US-NCAP, for example, the acceleration (i.e. negative acceleration) level is an important parameter, and therefore, the C-Class gasoline (lightest variant) was chosen to show the most severe results.

It is not possible to directly predict a star rating since no occupants or restraint systems have been included in ULSAB-AVC simulations. However, ULSAB-AVC vehicles' potential to achieve a given Star Rating has been assessed by comparing the predicted ULSAB-AVC structural performance with that of current high star-rated vehicles.

The assessed Star Rating potential assumes that further development of the detailed vehicle design will include development of an occupant restraint system, which would fully utilize the potential predicted in the CAE analysis.

All crash targets were successfully met. In the roof crush/rollover event, which was conducted at a target load of 2.5 times the vehicle curb mass, the roof structures meet the peak load requirements and the deformation mode is steady and predictable. The rear impact analysis predicted good fuel system structural integrity and no fuel leakage expected. Furthermore, the low impact event results show that permanent deformation is contained within the bumper system.

This summary report only covers key information on those crash analysis results directly related to the Star Rating assessment. For a complete review of all crash analysis results for all the events, please see the ULSAB-AVC Engineering Report Section 10.0.

4.1.2.1 US-NCAP Front Crash

The ULSAB-AVC design focus was on progressive crush as follows:

- main front longitudinal members
- distribution of the load into the tunnel, sill and A-pillar
- A-pillar stability and stability of the door ring
- footwell intrusion
- passenger compartment residual space

The objective was to make use of the available crush space in an efficient manner and minimize deformation of the occupant compartment.

The US-NCAP Frontal Crash events are shown in Figures 104 and 105.

Figure 104: **C-Class US-NCAP Deformed Shape**

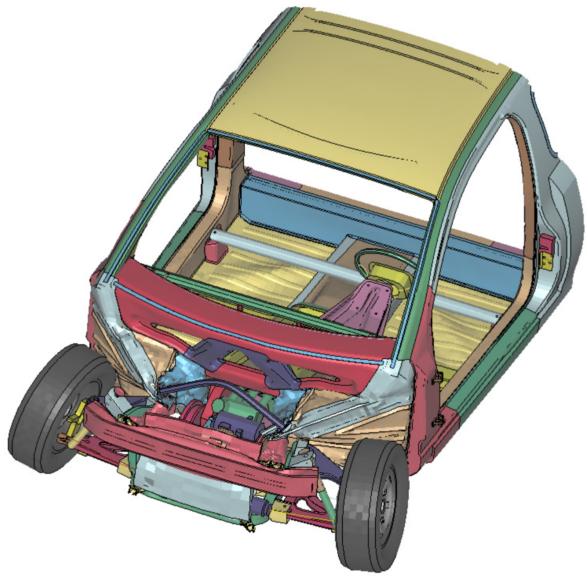
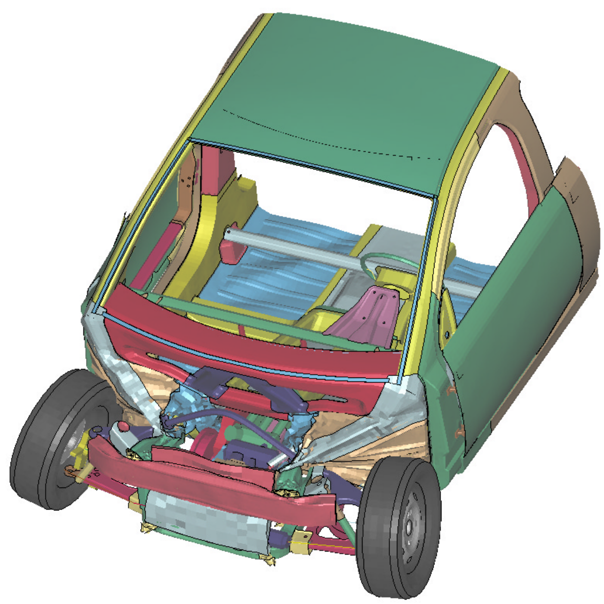


Figure 105: **PNGV-Class US-NCAP Deformed Shape**



Figures 106 and 107 show the B-Pillar longitudinal acceleration pulse curve from the US NCAP.

Figure 106: **C-Class Average B-Pillar Acceleration**

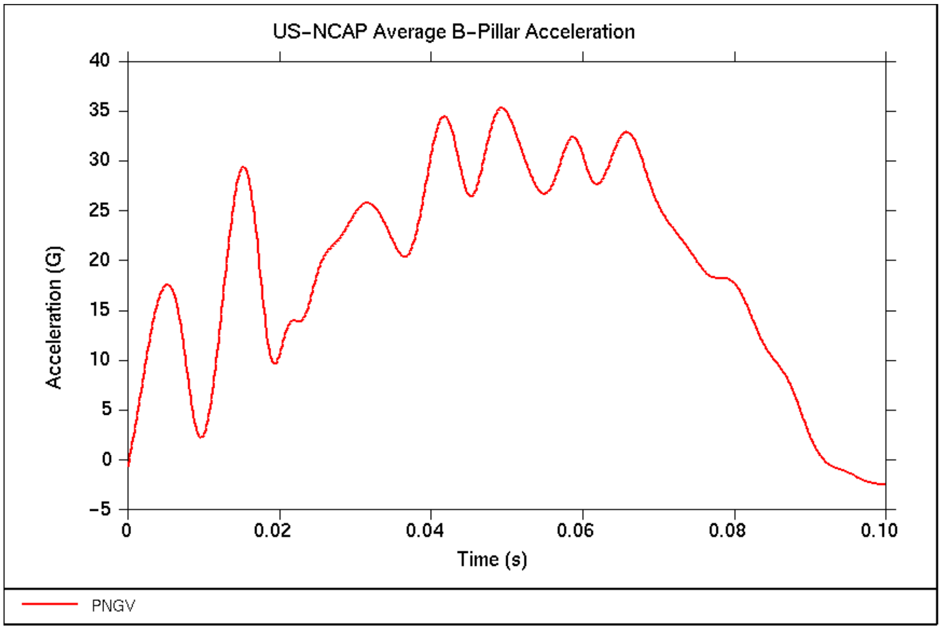


Figure 107: **PNGV-Class Average B-Pillar Acceleration**

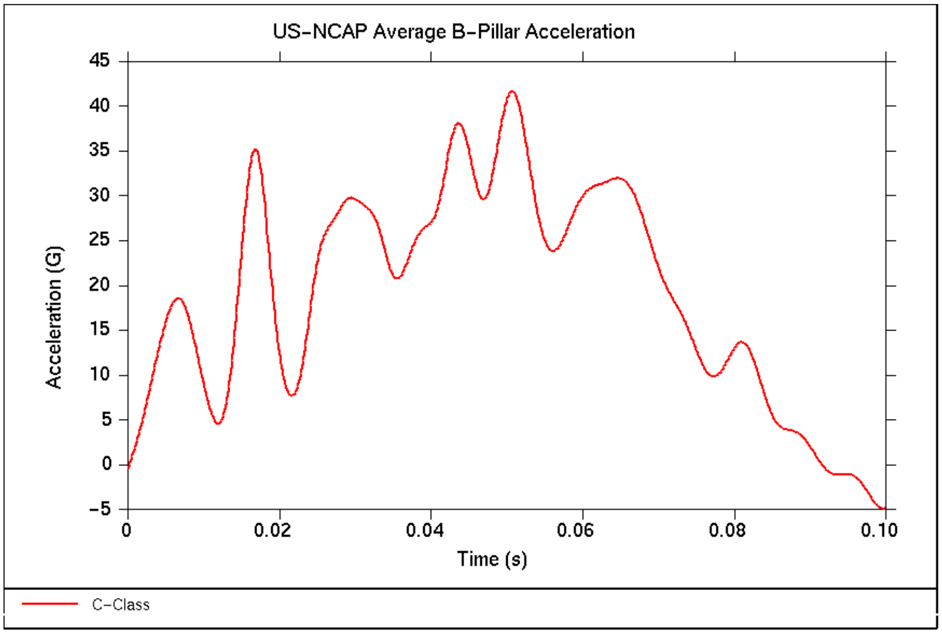


Table 19 gives the sequence of events during the crash pulse.

Table 19: **US-NCAP Crash Events**

Time (msec)		US-NCAP Timing of Major Events
C-Class	PNGV-Class	
6	6	Bumper crush box starts to crush
16	16	Initial crush of longitudinal rails
18	18	Radiator/cooling pack contacts barrier
22	22	Tires contact barrier
32	32	Engine contacts barrier
34	34	Rear subframe mount detaches from body
40	40	Rear of tires contact body
44	44	Engine bay brace buckles, longitudinal crush ends
66	70	Maximum dynamic deformation reached

Overall the analysis illustrates good progressive crush of the main longitudinal members. The engine and subframe detach from the body structure at the rear mounts to allow full use of the available crush space and to minimize footwell intrusion. The low levels of footwell intrusion and steering column movement predicted are good results from an occupant injury perspective.

Table 20 summarizes the targets and results of each of the vehicles for this crash event. Dynamic crush results were just below target. However, the structure is efficient, achieves a high level of crashworthiness at this design phase and is comparable in dynamic crush with benchmarked vehicles.

Table 20: **US-NCAP Results Summary**

US-NCAP	Target	C-Class	PNGV-Class
Dynamic Crush (mm)	650	610	645
Time to Zero Velocity (msec)	n/a	66	70
Steering Col Rear Movement (mm)	< 80	10	10

US-NCAP Star Rating Assessment

Detailed US-NCAP crash event comparison displacement, velocity and acceleration curves can be found in the ULSAB-AVC Engineering Report Section 10.0. In order to present the results in a simplified, summary form, a number of parameters have been selected to categorize the structural performance of the test vehicles. These parameters are:

- Dynamic crush
- Time to zero velocity (i.e., time of maximum dynamic crush)
- Average B-pillar acceleration in the time window 40-70 milliseconds
- Peak B-pillar acceleration in the time window 40-70 milliseconds

For comparison with the ULSAB-AVC concept vehicles, a number of current vehicles were selected from the related weight/size classes that achieved 4-star and 5-star ratings. In the figures below, Vehicles A, B and C are 4-star rated and Vehicles D, E, F and G are 5-star rated.

The results of the parameter comparison are shown in Figures 108 to 111.

Figure 108: **Dynamic Crush Parameter Comparison**

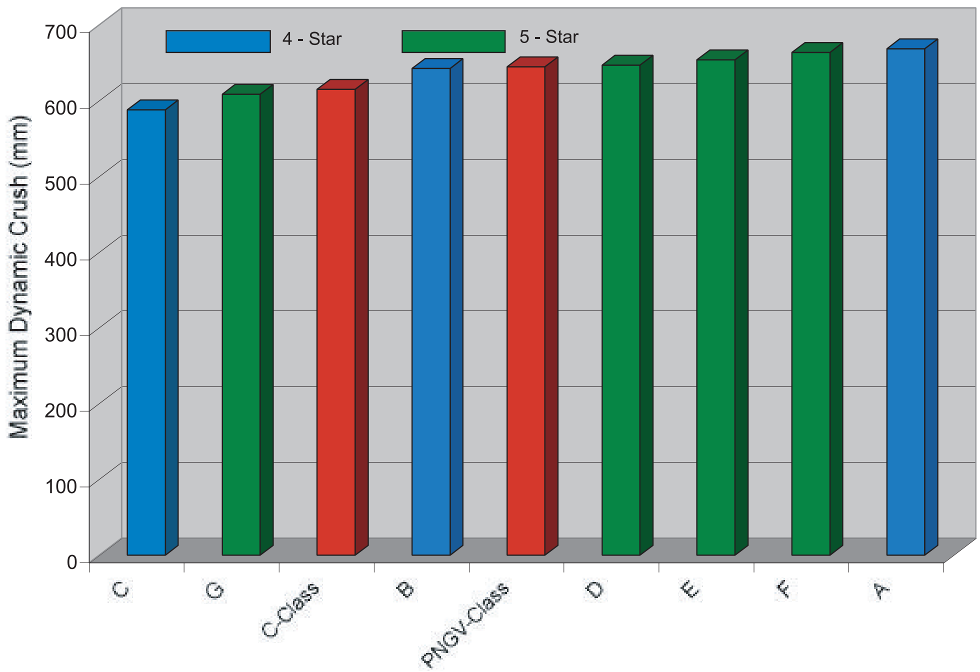


Figure 109: **Time to Zero Velocity Parameter Comparison**

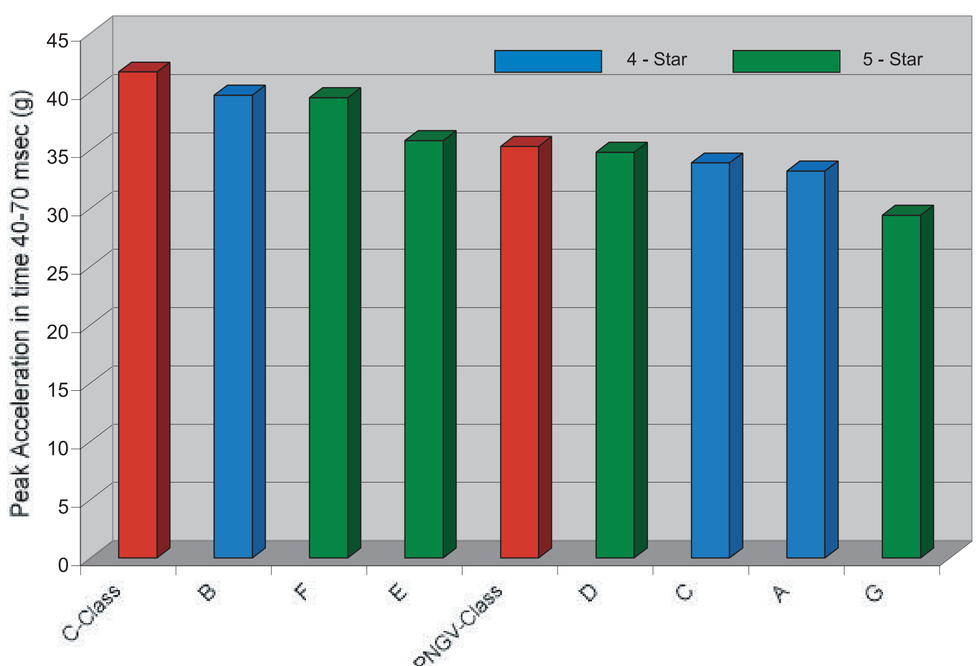


Figure 110: **Average B-Pillar Acceleration (40-70 msec.) Parameter Comparison**

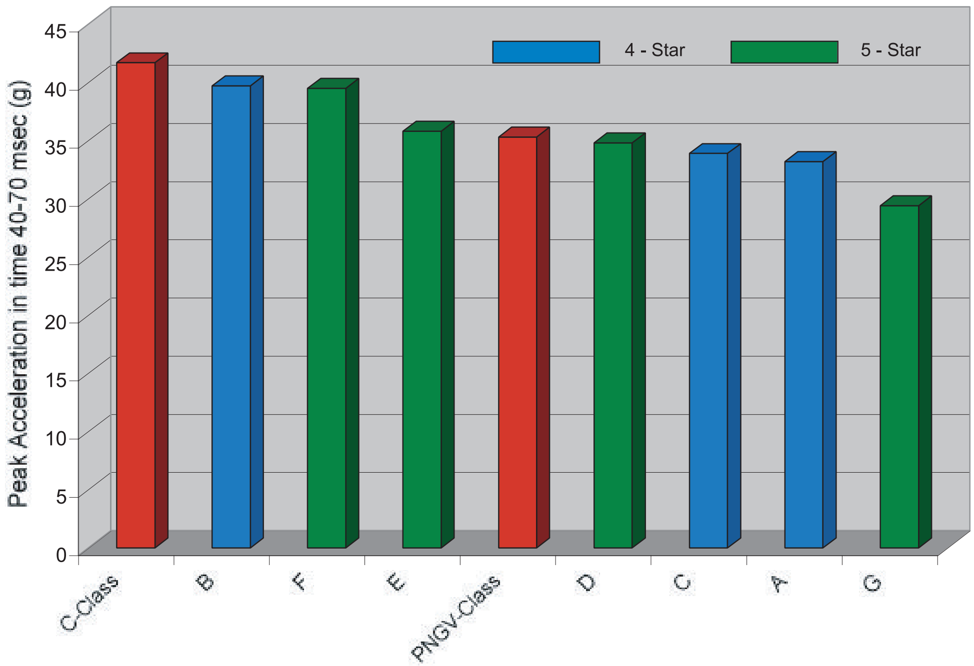
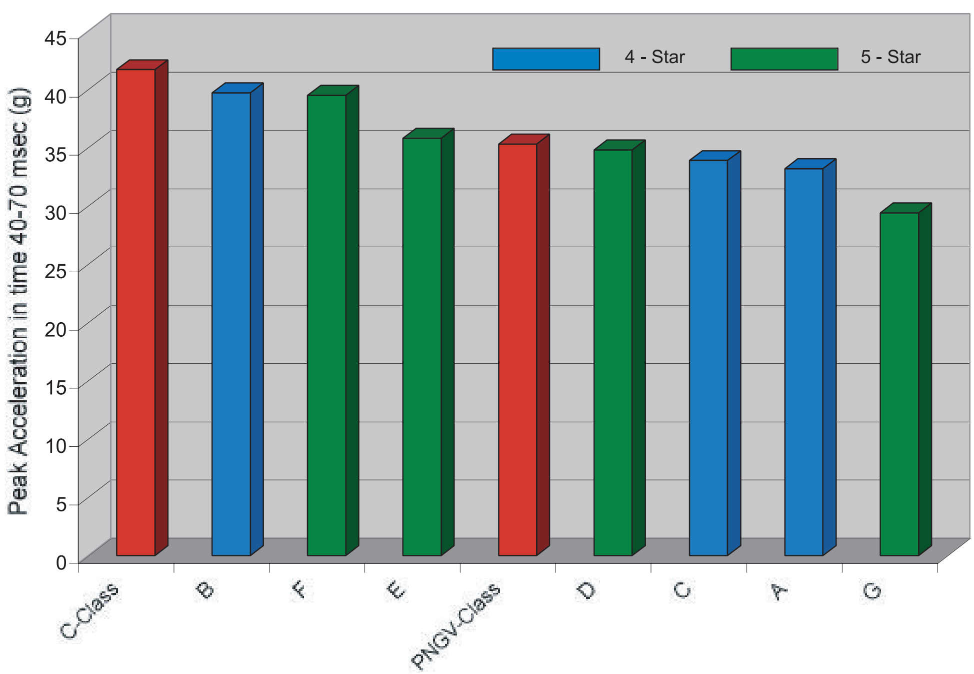


Figure 111: **Peak B-Pillar Acceleration (40-70 msec.) Parameter Comparison**



The structural performance of the PNGV-Class vehicle is assessed to be a good basis for five-star performance in the US-NCAP test. The C-Class is assessed to provide a basis for either a 4- or 5-star performance for this event.

4.1.2.2 US-SINCAP Analysis

Vehicle performance for this test is based on the occupant injury measurements recorded during the event. Because the analysis scope did not include side impact dummies, injury assessment could not be made. Occupant injury performance is greatly affected by seats, interior trim, restrain system design and side airbags, as well as by the structural behavior.

The SINCAP events are shown in Figures 112 and 113.

Figure 112: **C-Class US-SINCAP Deformed Shape**

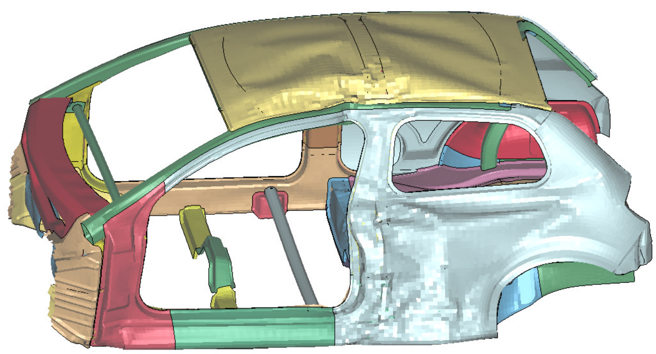
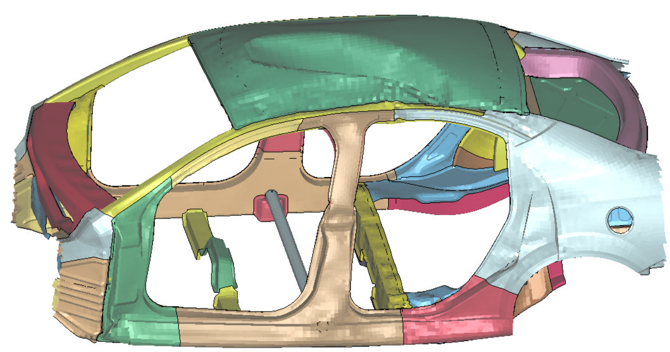


Figure 113: **PNGV-Class US-SINCAP Deformed Shape**



The intrusion velocity of the B-pillar in the region of the thorax is an important parameter for occupant injury. Figures 114 and 115 show the intrusion velocities of each vehicle. The results presented are the average intrusion velocities of two points on the B-pillar located at mid-height, and this enables comparison with real test data to assess Star Ratings.

Figure 114: **C-Class US-SINCAP B-Pillar Intrusion Velocity (at waist)**

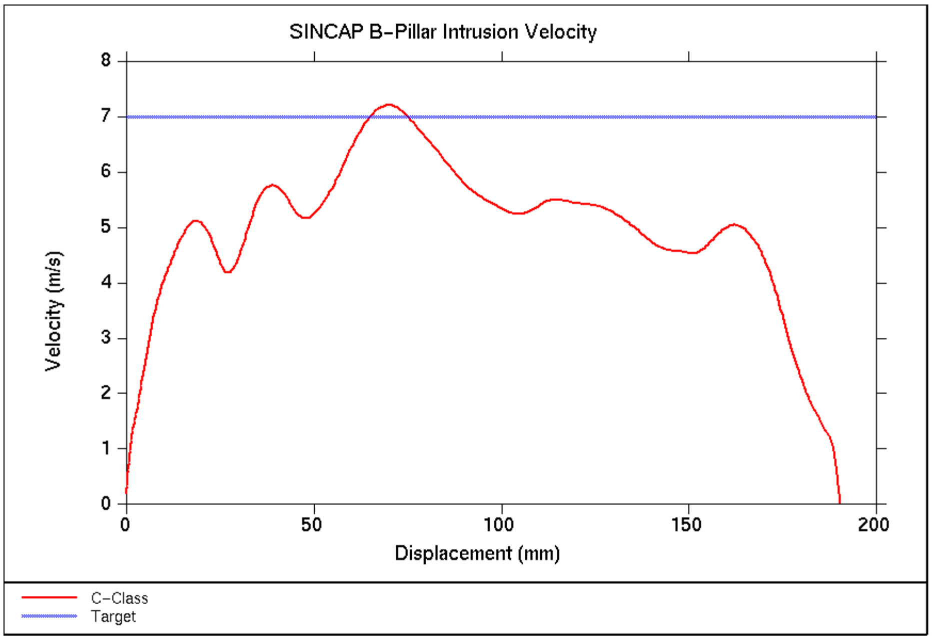


Figure 115: **PNGV-Class US-SINCAP B-Pillar Intrusion Velocity (at waist)**

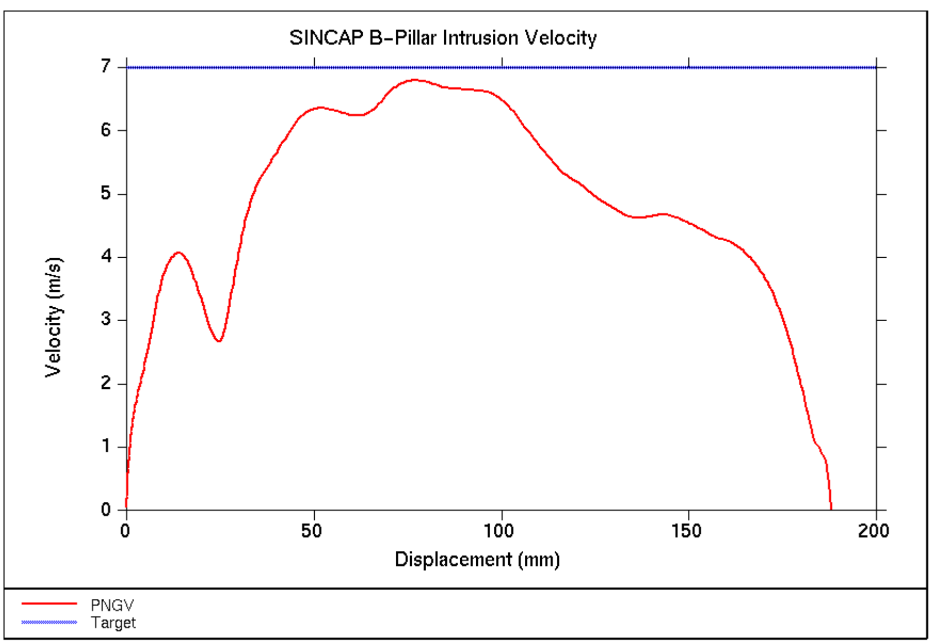


Table 21 summarizes results for this event.

Table 21: **US-SINCAP Results**

SINCAP	Target	C-Class	PNGV-Class
B-Pillar Intrusion Velocity (m/sec)	7	7.2	6.8
Maximum Intrusion at Waist (mm)	n/a	190	185

The C-Class vehicle does not meet the intrusion velocity target for the US-SINCAP, but the results that were achieved are adequate to demonstrate a good level of structural performance at this concept design stage. The following Star Rating Assessment presents a comparison of these results with high star-rated production vehicles and demonstrates that the ULSAB-AVC concept has achieved a high level of crashworthiness.

US-SINCAP Star Rating Assessment

Two current vehicles were selected for comparison from the Compact and Mid-Size weight classes, both of which achieved a 5-star performance and are identified as Vehicle H and J. Comparisons of the B-pillar intrusion velocity graphs are shown in Figures 116 and 117.

Figure 116: **C-Class Comparison of B-Pillar Intrusion Velocity w/5-Star Vehicles**

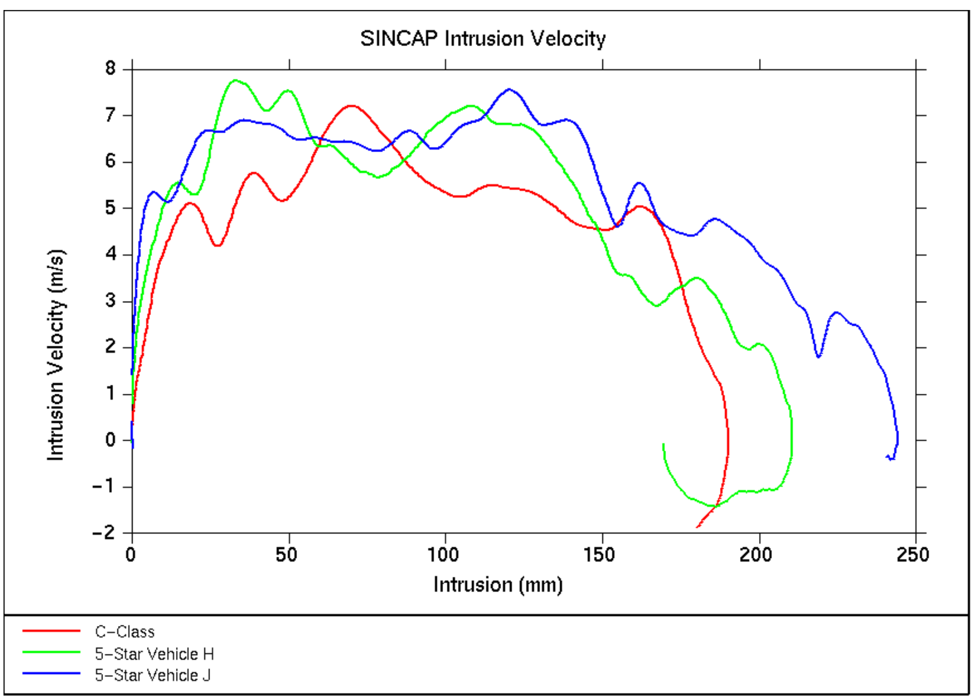
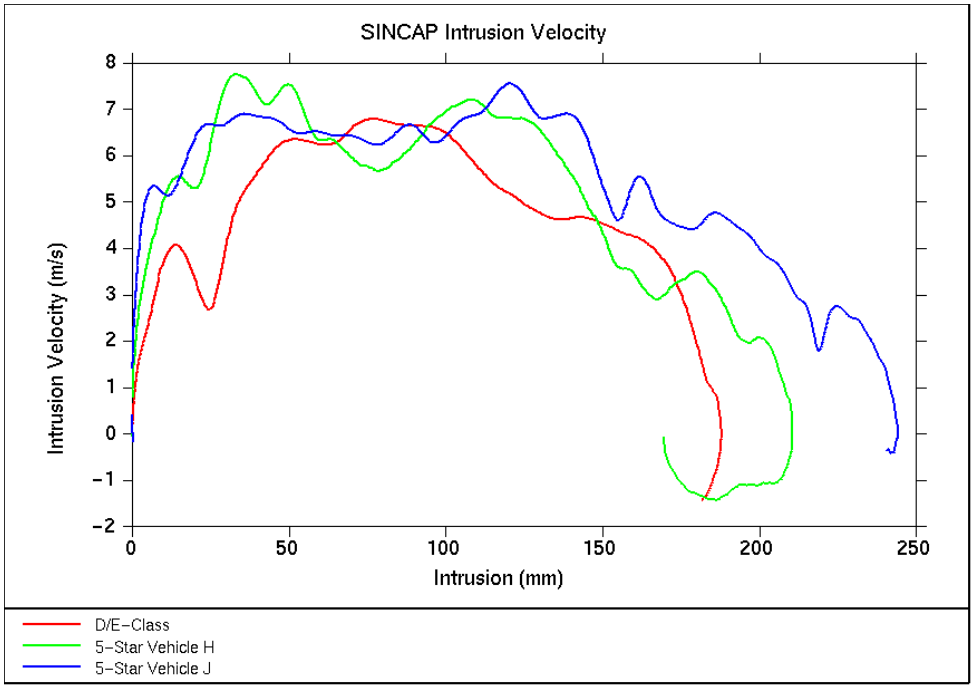


Figure 117: **PNGV-Class Comparison of B-Pillar Intrusion Velocity w/5-Star Vehicles**



Both ULSAB-AVC vehicle structures demonstrate intrusion velocity characteristics similar to the two comparison vehicles. The ULSAB-AVC designs' peak and maximum intrusion velocities are less than the comparison vehicles. Based on this analysis, it is assessed that both ULSAB-AVC vehicles would be a good basis for five-star performance in the US-SINCAP test.

4.1.2.3 Euro-NCAP 40% Offset Frontal Crash

Euro-NCAP crash events are shown in Figures 118 and 119. The deformable barrier specified in this analysis conforms to ECE R-94 "Frontal Collision Protection."

Figure 118: **C-Class EuroNCAP Deformed Shape**

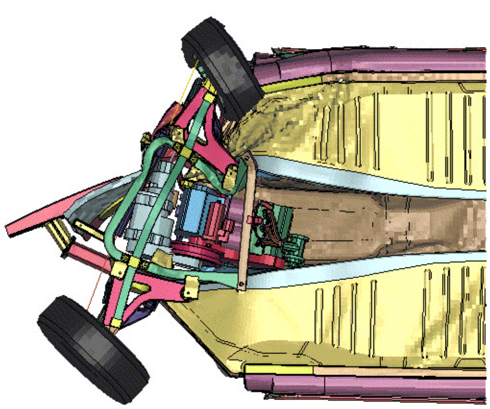


Figure 119: **PNGV-Class EuroNCAP Deformed Shape**

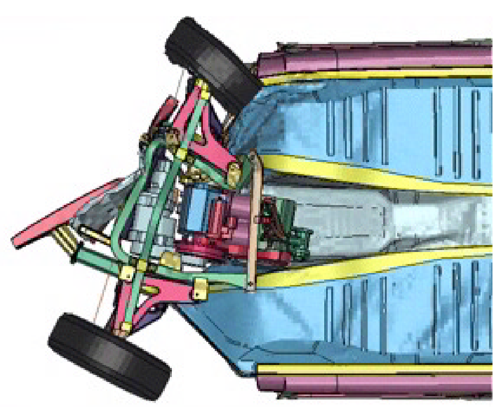


Table 22 summarizes the targets and results of each of the vehicles for this crash event.

Table 22: **Euro-NCAP Results Summary**

Euro-NCAP	Target	C-Class	PNGV-Class
Res. Footwell Intrusion (mm) max.	< 150	115	130
Steering Col Rear Movement (mm)	< 80	25	20
A-pillar Displacement (mm)	< 50	10	10

The structures demonstrated good performance with a stable occupant compartment and minimal levels of footwell intrusion. Good results were also achieved for steering column movement and A-pillar stability, which are desirable attributes for occupant protection.

4.1.2.4 Side Pole Impact

The impact speed chosen for the ULSAB-AVC program is 10 percent higher than the speed specified in FMVSS 201 and Euro-NCAP to account for anticipated future requirements. Minimizing occupant injury in this test is dependent on the integrity of the body structure as well as the secondary restraint systems such as side head airbags. The focus for ULSAB-AVC was on good structural performance measured by the intrusion velocity of the pole at the time when impact with the driver's head would occur, and overall deformation of the structure.

Side Pole Impact deformed shape test results are shown in Figures 120 and 121.

The fixed seat concept using the seat crossmember, with extension and support components, contributed to good performance in this event.

Figure 120: **C-Class Side Pole Impact Deformed Shape**

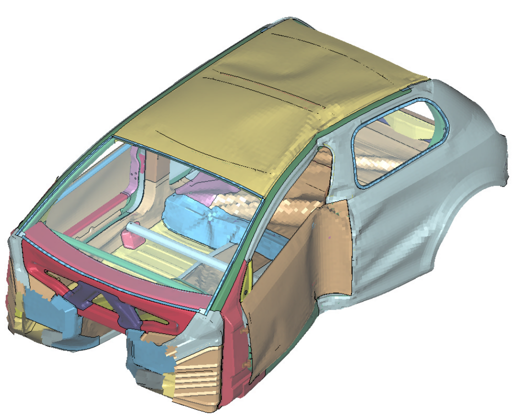


Figure 121: **PNGV-Class Side Pole Impact Deformed Shape**

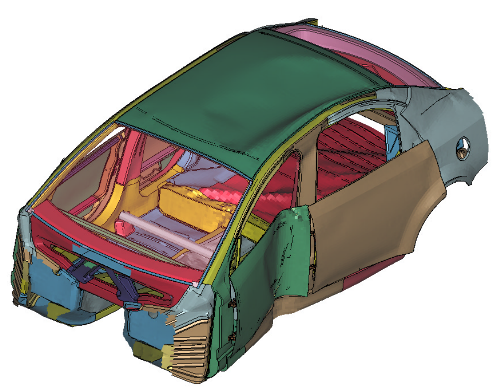


Table 23 summarizes event results and Figures 122 and 123 show the pole intrusion velocities for both vehicles.

Figure 122: **C-Class Side Pole Energy Distribution**

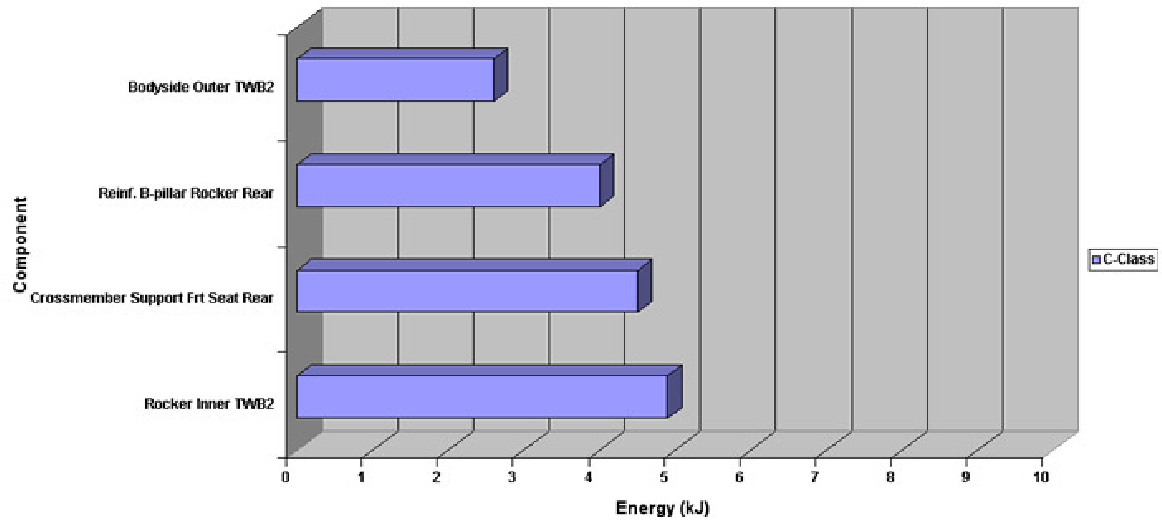


Figure 123: **PNGV-Class Side Pole Energy Distribution**

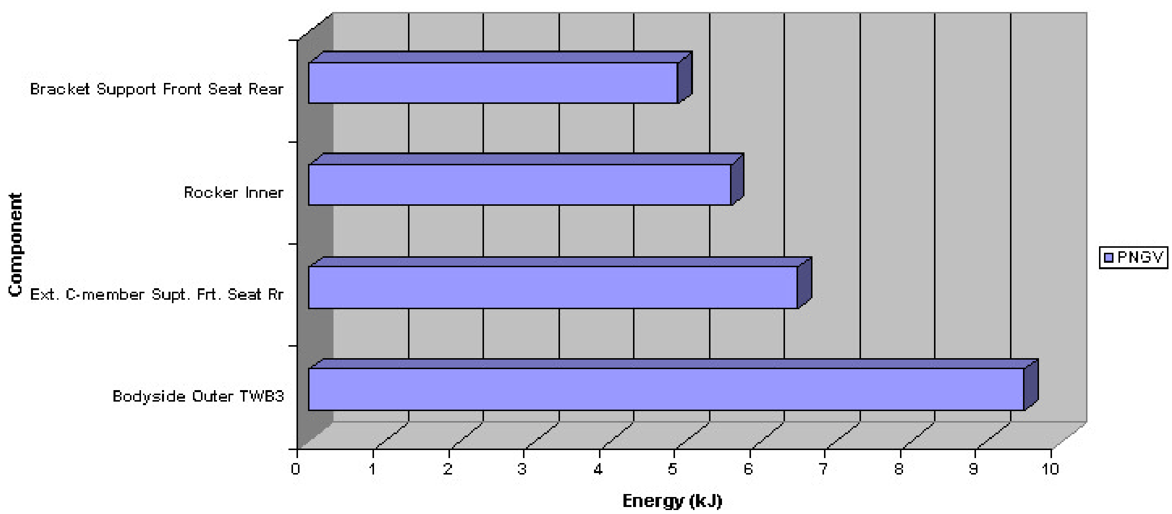


Table 23: **Side Pole Impact Intrusion Velocity Summary**

Side Pole	Target	C-Class	PNGV-Class
Pole Intrusion Velocity (m/sec)	< 8	7.8	5.3
Max. Intrusion at Waist (mm)	< 500	345	300

Euro-NCAP, Side Impact and Side Pole Star Rating Assessment

Euro-NCAP test reports and detailed results are not as freely available to the public as the US-NCAP test reports, therefore no detailed comparison of ULSAB-AVC vehicles to current production vehicles can be completed. However a general structural performance assessment can be made:

- Both vehicle structures have a stable occupant compartment with predicted residual footwell intrusion levels below 150 mm. Euro-NCAP tests measure footwell intrusion parameters, which is important to minimizing lower leg injury.

- A-pillar displacement and steering column movement are also low, which demonstrates a stable basis for the deployment of a steering wheel airbag.

- The ULSAB-AVC program used the US-SINCAP rather than the European Side Impact test as the more severe structural requirement. Good performance in the US-SINCAP does not necessarily guarantee good performance in the European test since test configurations and crash dummies differ in each. However, the B-pillar remains stable without collapse of the section at the waist, which is desirable structural behavior necessary to aid in achieving low occupant injury levels according to the European side impact test.

- Both vehicles demonstrate good performance in the Side Pole Impact event, which for ULSAB-AVC was conducted at a speed 10 percent higher than specified for the Euro-NCAP test. ULSAB-AVC vehicles' strong side structure would allow the impact to be sensed and a side head airbag to be deployed in sufficient time to enable the loads on the occupant to be minimized.

Considering this assessment, the structures are considered to provide a good basis for achieving a five-star performance in the Euro-NCAP events.

4.1.3 Insurance Institute for Highway Safety (IIHS) Assessment

The Insurance Institute for Highway Safety (IIHS) is an independent, non-profit, research and communications organization in the United States. The IIHS undertakes crashworthiness evaluations of new passenger vehicles and has adopted the 40 mph, 40% offset front impact test with the deformable barrier as a basis for these evaluations. While there are some differences in testing procedures and the number of occupants between the IIHS and Euro-NCAP evaluation, as used in this program, it is general practice to use the same CAE model to do both assessments.

IIHS makes an overall evaluation and publishes the results (Good, Acceptable, Marginal, Poor). The vehicle concept designs were evaluated for the structure/safety cage part of the assessment only.

Figures 124 and 125 show that both ULSAB-AVC vehicles lie within the "Good" range for structural performance, which indicates that the structural concepts are a good basis for further development to achieve the same overall evaluation in a detailed design phase. This result is further confirmation of the high level of crashworthiness achieved for these mass-efficient steel body structure concepts.

Figure 124: **C-Class IIHS Structure Evaluation**

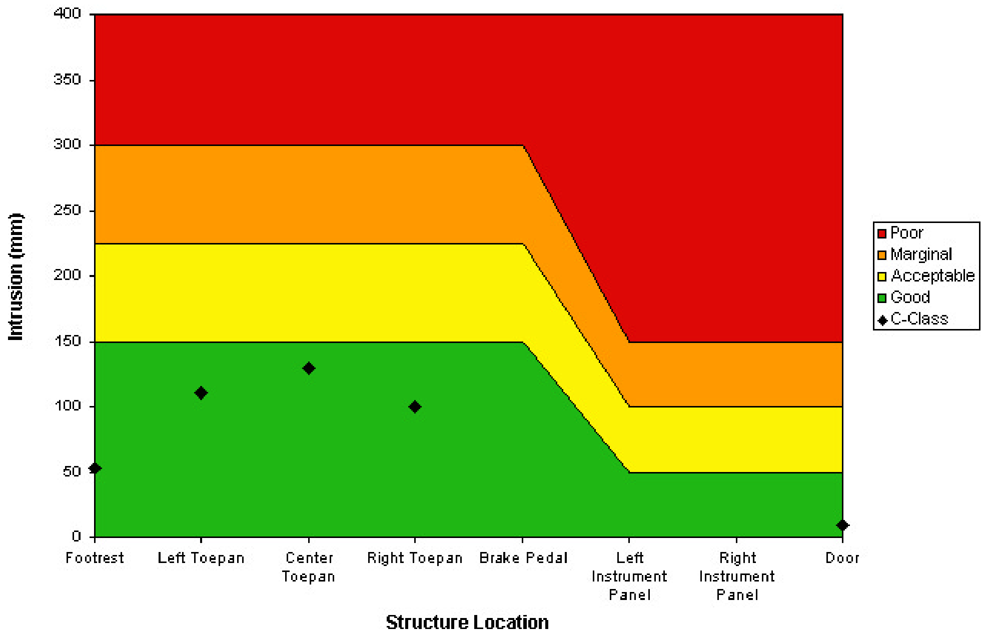
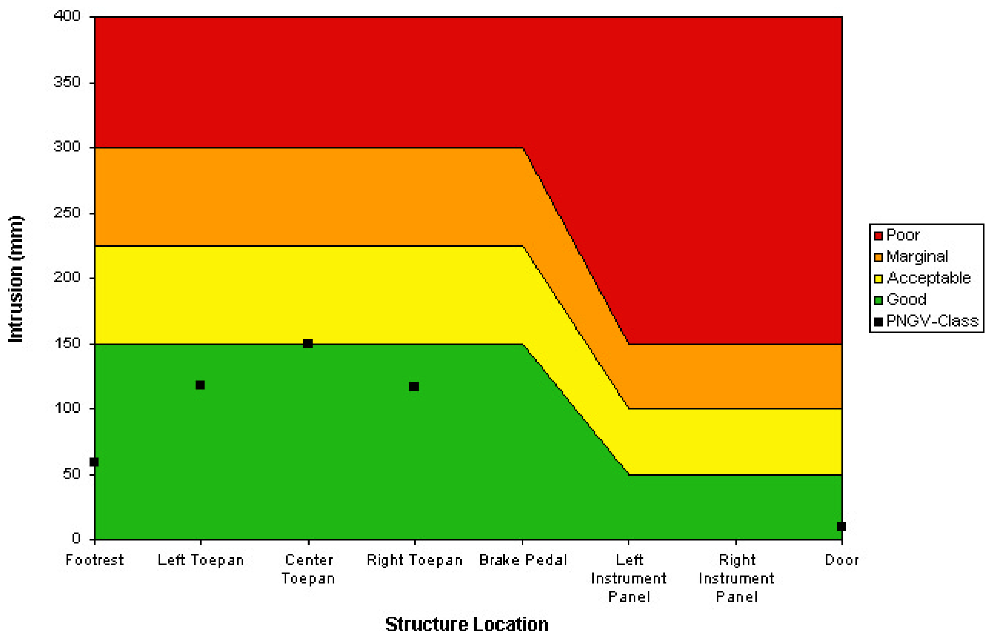


Figure 125: **PNGV-Class IIHS Structure Evaluation**



4.2 Aerodynamic Drag Assessment

A vehicle's aerodynamic drag has a significant influence on its CO_2 emissions (fuel consumption). Since CO_2 emissions (<140 g/km) was a primary target of this program, careful consideration was given to targeting and designing for good vehicle aerodynamic qualities.

For the calculation of the aerodynamic drag, the aerodynamic drag coefficient (c_w) is a necessary input parameter (Aerodynamic drag = (air density/2) x Frontal Area x Aerodynamic Drag Coefficient x Velocity^2).

Optimization of the aerodynamic drag, which is normally done with wind tunnel testing in a full vehicle development program, was not within the scope of the ULSAB-AVC concept phase. It is expected that in a further design phase, additional analysis and the necessary wind tunnel testing would be performed to achieve fully-optimized vehicle designs.

4.2.1 Aerodynamic Drag Benchmarking

In the ULSAB-AVC Program, benchmarking data of aerodynamic drag coefficients [c_w] were gathered to establish the range of c_w for current C-Class and PNGV/PNGV-size vehicles.

Benchmarking C-Class Vehicles

Benchmarking data of aerodynamic drag coefficients for current C-Class vehicles were gathered through publicly available information (e.g. internet, OEM publications). The data gathered are displayed in Figure 126. The benchmark data for the different versions of the Ford Focus are included to illustrate a typical current range of drag coefficients derived from a common platform and frontal design. Benchmarking data were gathered for PNGV prototype vehicles, which are optimized for low aerodynamic drag through intensive wind tunnel testing. A prototype vehicle is shown in red.

Benchmarking PNGV-Class Vehicles

PNGV/PNGV-size vehicle benchmark data also were gathered through publicly available information. The benchmark data for all PNGV/PNGV-size vehicles are displayed in Figure 127. PNGV prototype vehicles are shown in red.

Figure 126: **C-Class Benchmarks for Aerodynamic Drag Coefficients**

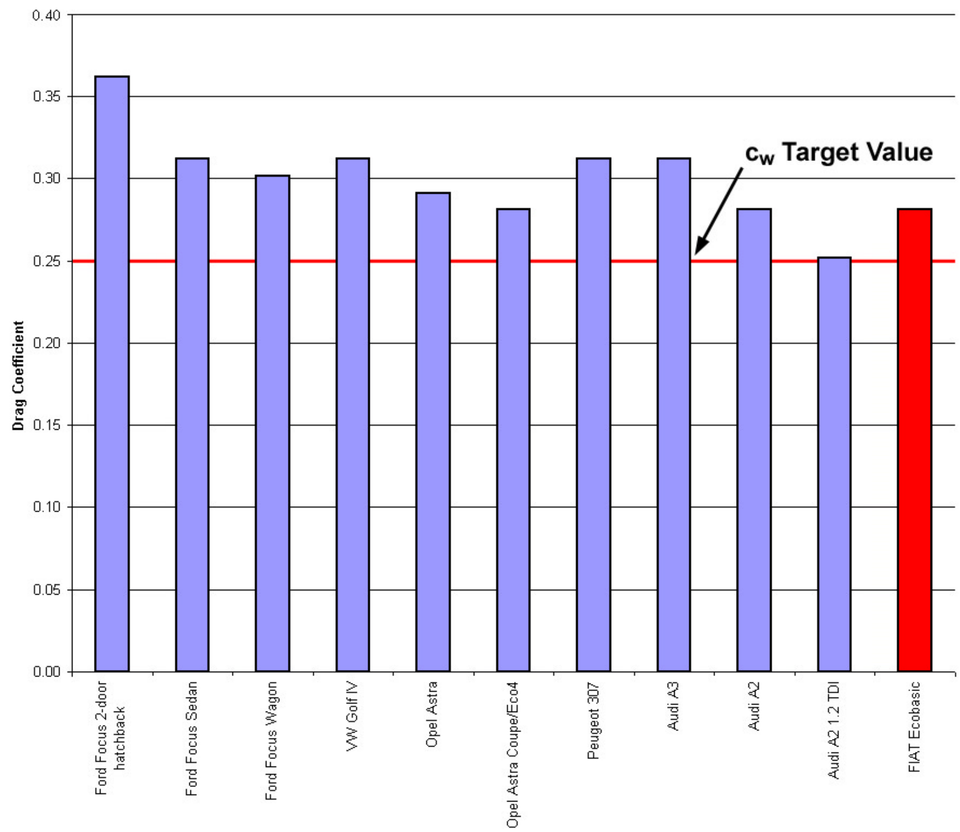
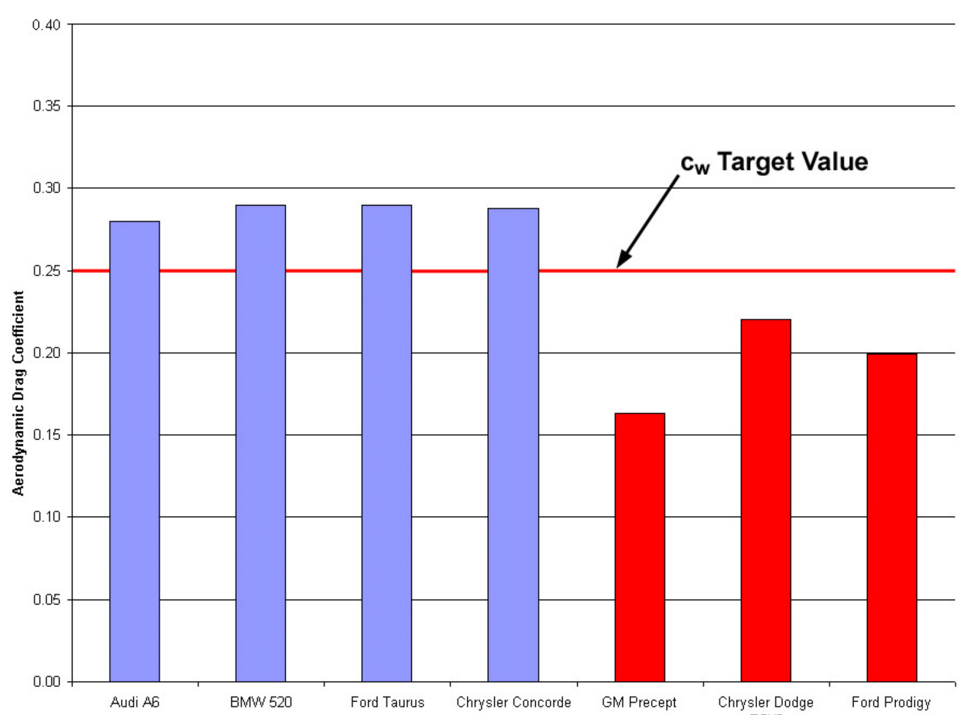


Figure 127: **PNGV-Class Benchmarks for Aerodynamic Drag Coefficients**



4.2.2 ULSAB-AVC CFD Analysis

Computer Fluid Dynamic (CFD) analysis, performed with the Powerflow® software program, was used as a visualization of the computed flow field data in a virtual wind tunnel. This allowed evaluation of the aerodynamic concept from the very beginning of vehicle concepts, where no hardware models were available. An initial analysis investigated the aerodynamic drag quality of both the C-Class and PNGV-Class vehicles. Early design measures were taken to achieve low c_w coefficients, including:

- Covered underbody
- Guided cooling airflow through the vehicle
- Reduced front surface area, i.e., the elimination of rearview mirrors

4.2.3 Aerodynamic Drag Analysis Results

Initial streamline flow patterns for the CFD analyses were obtained with turning wheels on a moving plane (road). The analyses included the radiator air stream through the tunnel.

The results from this initial study of the C-Class aerodynamic performance confirm that, with some additional modifications and subsequent analyses and wind tunnel testing, there is high potential to achieve the target of 0.25. Further, the analyses revealed that the PNGV-Class demonstrates a credible aerodynamic quality. It confirmed that, with further optimization, this design has the potential to achieve the c_w target of 0.25.

4.2.4 Measures for Further Optimization

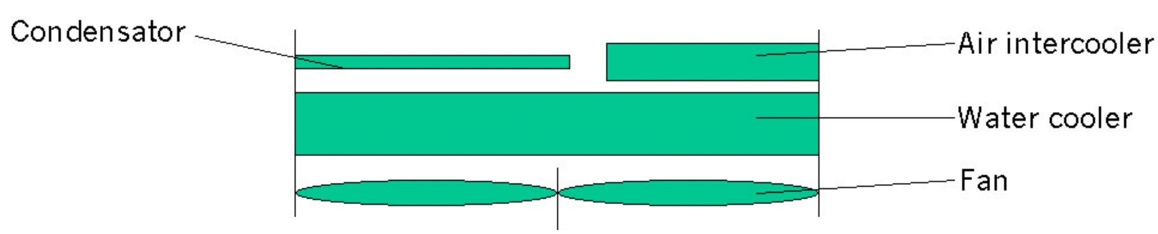
The initial analysis results precipitated some conclusions for future aerodynamic optimization, which could be evaluated in a continuing development phase through additional CFD analysis and wind tunnel testing. These conclusions follow:

C-Class Vehicle:

For the C-Class vehicle:
- Tail area reduction
- Optimize position, size and angle of rear spoiler
- Optimize C-pillar radii in rear window area
- Optimize radii to create a tearing edge in rear light area

For both vehicles:
- Develop and optimize the rear floor behind the rear suspension to create a diffuser
- Develop and optimize a cover for the rear suspension pick-up points to the body structure
- Optimize body shape behind the rear wheels to add cover to rear wheels
- Develop and optimize tearing edge at the transition of the rear floor pan to rear fascia
- Develop and optimize aerodynamic devices front and rear of the wheels
- Optimize airflow through radiator module with opening to wheelhouse rearrangement of the radiator as shown in Figure 128

Figure 128: **Radiator Rearrangement**



4.3 CO_2 Emissions and Vehicle Performance

The ULSAB-AVC program adopted low CO_2 emissions as a primary target for vehicle performance. The European EUCAR proposed future requirement was used as a basis for target setting, which specifies a CO_2 emissions fleet average of <140 g/km. This fleet average was adopted as a single vehicle target for ULSAB-AVC.

The CO_2 emissions target influenced vehicle design in many ways. One of the most important influences is that the engine concept and front-end architecture are purpose-built to get an optimized balance of fuel efficiency and safety, with the added benefit of supporting a modular design for assembly approach and servicing. The use of rear-view cameras, and a closed underbody design also contribute to improved aerodynamics, which influences CO_2 emissions. Further, state-of-the-art drive train technology has been used to contribute to fuel and CO_2 emissions efficiencies.

4.3.1 Approach

Two procedures were applied to calculate CO_2 emissions:

- New European Driving Cycle (NEDC) 2000 requirement with the test mass defined as: Test Mass = Vehicle Curb Weight + 100 kg

- U.S. Combined Driving Cycle (FTP 75, Highway--a combination of city and highway driving) with the vehicle test mass defined as: Vehicle Mass = Curb Weight + 300 lbs.

4.3.2 Vehicle Acceleration Calculation

To determine vehicle acceleration, the vehicle mass is calculated according to DIN 70020 (3) where driving performances are defined with the following vehicle mass: vehicle mass = vehicle curb weight + (payload / 2). This procedure was used for the vehicle performance calculation of both vehicle variants, as well as to determine the gear ratios needed to achieve the 14 sec. acceleration target (0-100 km/h).

4.3.3 Calculation Parameters

The engine characteristics, e.g., power and torque, idle speed and fuel consumption, were used for the calculation. An aerodynamic drag coefficient of 0.25 was used based on the results of the aerodynamic analysis, summarized in Section 4.2, which concluded that this coefficient can be achieved.

The calculations for the gasoline engine variant were based on fuel density of 0.756 kg/L (at 15° Celsius), which was specified according to the following:

- UTG 96 (US), premium unleaded fuel octane rating (anti-knock index) of 93 [(R+M)/2] method
- EU 3RF (Europe), super unleaded fuel with ROZ minimum 95

The diesel engine variant used a fuel density of 0.84 kg/L (at 15° Celsius)

Table 24: **General Parameters**

General Parameters	C-Class		PNGV-Class	
	Gasoline	Diesel	Gasoline	Diesel
Curb weight (according to DIN Leer) [kg]	933	966	998	1031
Maximum payload [kg]	450	450	500	500
Calculated Test Mass - NEDC 2000 [kg]	1035	1065	1100	1130
Calculated Test Mass - U.S. Combined [kg]	994	1024	1059	1089
Calculated Test Mass - 0-62 mph/100 km/h [kg]	1160	1190	1250	1280
Vehicle Frontal Surface Area [m^2]	2.03	2.03	2.03	2.03
Dynamic Roll Radius (tire) [m]	0.275	0.275	0.275	0.275
Aerodynamic Drag Coefficient [c_w]	0.25	0.25	0.25	0.25
Rolling Resistance Coefficient	0.12	0.12	0.12	0.12
Transmission Efficiency Coefficient	0.95	0.95	0.95	0.95

4.3.4 Results Summary

The ULSAB-AVC manual transmission with an automatic gearshift actuator can be operated in either a manual or automatic shift mode. Results for the NEDC are shown in automatic shift mode, as this achieves the optimal efficiency for CO_2 emissions. The U.S. Combined CO_2 emissions figure is an average of both shift modes, as specified by the U.S. requirements. A range of values for city and highway results are also indicated in table 25.

At this early concept design development stage, ULSAB-AVC vehicle concepts exceed the target for CO_2 emissions, resulting in dramatically decreased fuel consumption compared to current vehicles, further supporting the keystone beliefs of this program that, with steel, fuel efficiency does not have to be obtained at the expense of safety and affordability.

Achievement of the EU4 Exhaust Emissions targets by 2005 is dependent on future technology developments. The results achieved by the ULSAB-AVC program provide an excellent basis to support these developments.

Table 25: **CO_2 emissions/Fuel Consumption Summary**

	C-Class		PNGV-Class	
	Gasoline	Diesel	Gasoline	Diesel
European Driving Cycle				
CO_2 emissions* (NEDC 2000) [g/km]	106	86	108	89
L/100 km*	4.4	3.2	4.5	3.4
U.S. Driving Cycle				
CO_2 emissions (Combined)** [g/km]	105	86	108	92
Combined** [mpg]	53	73	52	68
City [mpg]	49	66	48	62
Highway [mpg]	61	84	60	78

** Automatic Shift Mode*
*** Average automatic & manual shift modes*

Table 26: **Performances Summary**

	C-Class		PNGV-Class	
	Gasoline	Diesel	Gasoline	Diesel
Acceleration (0-100 km/h:0-62 mph)	13.5	13.4	13.9	13.9
Interm. Accel. (80-120 km/h:50-75 mph)	17.9	16.8	18.0	17.4
Top Speed Continuous (km/h)	194	184	193	184

4.4 Mass Results

A summary of results for the mass of all ULSAB-AVC main components is shown in Table 27. For reference, vehicle dimensions are shown in Table 27.

Table 27: **Main Component Summary**

	C-Class				PNGV-Class			
	Targets		Results		Targets		Results	
	Gasoline (kg)	Diesel (kg)	Gasoline (kg)	Diesel (kg)	Gasoline (kg)	Diesel (kg)	Gasoline (kg)	Diesel (kg)
Body Structure	208.0		201.8	201.8	228.0		218.1	218.1
Closure Struc, Assbly & Fndrs	71.5		55.2	55.2	104.0		81.7	81.7
Glazing	32.1		23.9	23.9	32.8		26.5	26.5
Chassis	198.5		182.1	182.1	198.5		182.1	182.1
Engine	143.5	183.5	122.1	150.9	144.5	184.5	123.7	152.5
Gear Box	50.0		43.1	44.1	50.0		43.1	44.1
Interior	173.0		152.5	152.5	192.0		160.4	160.4
Exterior	4.5		4.2	4.2	6.5		4.5	4.5
Electrics	41.7		36.7	36.7	41.5		35.5	35.5
Automotive Fluid	41.0	44.0	39.9	42.9	41.0	44.0	39.9	42.9
Other Concept Related	NA	NA	40.6	41.1	N/A	NA	42.2	42.7
Paint	16.0		16.0	16.0	20.0		20.0	20.0
Brackets/Undercover/ Aerodynamic Devices			15.0	15.0	0		20.0	20.0
Total Curb Weight	979.8	1023.0	933.1	966.4	1058.8	1101.8	997.7	1031.0

4.5 Manufacturing Cost Assessment

The ULSAB-AVC Program included an assessment to estimate the manufacturing costs of both vehicle concepts. To complete this task, PES organized an interactive process between product designers, manufacturing engineers, materials experts and cost analysts. The ULSAB (1998) and ULSAC (2000) cost models were the basis for creating an expanded ULSAB-AVC cost model. The ULSAB-AVC Program required an evaluation of the complete vehicle manufacturing costs, which included several different fabrication technologies.

To be consistent with the methodology used in previous programs, the assumption was made that one Euro is equal to one US Dollar (1=US$1).

4.5.1 Cost Assessment Process

Several cost assessment methods were used to establish the manufacturing costs:

- Technical Cost Modeling was applied to body structure, closures, and interior sheet metal parts. Major part fabrication process data, such as blank size, cycle time, utilized press line and tooling investment, were developed based on part drawings. Upon validation, this data were integrated into the cost model for calculation of part costs.
- Supplier Cost Assessments were obtained by providing leading suppliers with component function and performance descriptions.
- Cost assessment team expert judgment was continually employed, along with internal and external information to assess the components and subsystems costs.

Because there is no set definition of manufacturing costs, it is necessary to define the cost elements included and excluded in the model. These inclusions/exclusions can be reviewed in detail in the ULSAB-AVC Engineering Report Section 17.0.
In summary, inclusions are parts fabrication and assembly of body structure and closures (Body-In-White), purchased components, assembly plant paint shop, and assembly trim line. The model excludes manufacturing logistics costs and all overhead costs not directly related to manufacturing.

Also a virtual plant scenario, including two manufacturing facilities, with defined annual production volumes was the basis of assumptions for the whole assessment. Both plants have a body shop, paint shop and final trim line.

4.5.2 Cost Model Description

A detailed cost model was developed which provides a platform for understanding the costs of all aspects of manufacturing an entire vehicle. As with ULSAB and ULSAC, the cost model is an invaluable tool for reviewing different cost scenarios and their impact on the vehicle, with both a macro and micro view. The model tracks the costs of all parts in the vehicle, the production of subassemblies and the final assembly process. Emphasis is placed on understanding the costs of metal fabrication and assembly processes, which are modeled in considerable detail.

The remaining parts costs are estimated via supplier quotes, industry information and other cost estimates. Automotive assembly plant activities' such as painting and final assembly/trim line are modeled using industry data concerning these processes. To account for varying opinions as to the make up of manufacturing costs, the cost model was developed so that individual users can input their own assumptions into the various elements of the model.

For ease of use, the model was constructed in spreadsheet workbook format. The workbook provides the basis for estimating the cost of a single vehicle, and does not provide a comparison with other vehicles, although this can be accomplished by making multiple copies of the model. The model workbook consists of 14 worksheets that can be classified into three types: inputs, calculations and outputs. Each of these can be further divided into four topics: body structure, closures, "non body" (all parts that are neither body structure nor closures structure) and paint & trim lines. There are also worksheets with general inputs that are applicable to the entire model, and a summary of results.

4.5.3 ULSAB-AVC Manufacturing and Assembly Cost Results

The cost assessment results of the ULSAB-AVC overall manufacturing costs are detailed in Table 28. These results show that the ULSAB-AVC family of vehicles can be built at affordable costs.

Table 28: **ULSAB-AVC Manufacturing Cost Assessment**

	C-Class		PNGV-Class	
	Gasoline	Diesel	Gasoline	Diesel
Parts Fabrication Cost	$7,906	$8,606	$8,163	$8,863
Assembly Cost	$1,284	$1,284	$1,375	$1,375
ULSAB-AVC Manufacturing Cost	$9,190	$9,890	$9,538	$10,238

Sensitivity analyses were performed to demonstrate the effects of changing key process variables and assumptions on the ULSAB-AVC vehicle cost results. Details on these analyses can be found in the ULSAB-AVC Engineering Report Section 17.6.

Results show only small differences between the C-Class and PNGV-Class designs, which are a result of the common platform strategy.

Table 29 shows the breakdown of the major systems parts fabrication costs and identifies the subsystems included. Tables through the end of this section summarize key portions of the manufacturing cost assessment results.

Table 29: **Parts Fabrication Costs**

System	Subsystem	C-Class		PNGV-Class	
		Gasoline	Diesel	Gasoline	Diesel
Powertrain	Engine, inc. electrics Cooling system Fuel system Exhaust system Manual transmission, (auto shifted) Drive Shafts				
	Total Powertrain	$2,350	$3,100	$2,350	$3,100
Chassis	Front suspension,inc.subframe Rear suspension Pedal system Wheels and tires Braking system Steering system Accessories				
	Total Chassis	$1,845	$1,845	$1,845	$1,845
Body	Body structure ** Closure structures ** Fenders, appliqués ** Closure assembly parts Front,rear end/underbody/aerodynamic devices Glazing/sealing Interior equipment Seats, inc. side airbag, seatbelts Climate system				
	Total Body	$2,711	$2,711	$2,968	$2,968
Electrics	General electric Lighting Electrical wiring Radio system Wiper system Washing system Battery				
	Total Electrics	$1,350	$1,350	$1,350	$1,350
Potential Cost Reduction w/SE Process*		($350)	($400)	($350)	($400)
Overall Parts Fabrication		$7,906	$8,606	$8,163	$8,863

** Assumption 10% of total supplier cost assessments*

*** Body-in-white costs are calculated in the cost model, other component costs are supplier assessments.*

Table 30: **Overall Vehicle Assembly Costs**

	C-Class	PNGV-Class
Investment costs	$218	$254
Direct and indirect labor	108	136
Others	30	36
Body Shop Assembly	$356	$426
Material	$135	$135
Investment costs	245	245
Direct and indirect labor	116	116
Others	84	84
Paint Shop	$580	$580
Investment costs	$75	$75
Direct and indirect labor	265	287
Others	8	8
Final Trim Line	$348	$370
Overall Assembly Costs	$1,284	$1,376

Table 31: **Body-in-White Manufacturing Costs**

	C-Class	PNGV-Class
Body Structure parts	$637	$681
Closure Structures parts	164	233
Fenders parts	16	16
Appliqués parts	8	12
Body-in-White Parts Fabrication Costs	$825	$942
Body Structure assembly	$278	$291
Closures Structures assembly	78	135
Body-in-White Assembly Costs	$356	$426
Body-in-White Manufacturing Costs	$1,181	$1,368

Table 32: **Body Structure Costs**

	C-Class	PNGV-Class
Stamped parts	$258	$263
Tailored blank parts	208	248
Sheet hydroformed parts	22	22
Tube hydroformed parts	103	103
Purchased parts	46	45
Parts Fabrication Costs	$637	$681
Assembly Costs	$279	$291
Total Body Structure Costs	$916	$972

Table 33: **Steel Components Cost Breakdown**

	Part/Component Cost	
	C-Class	PNGV-Class
Body structure (assembled)	$916	$972
Closure structures		
• Door front structures (assembled)	137	137
• Door rear structures (assembled)		128
• Hood structure (assembled)	51	51
• Decklid structure (assembled)		52
• Hatchback structure (assembled)	54	
Fenders	16	16
Appliqués	8	12
Bumper Front and Rear	22	22
Instrument Panel Beam (assembled)	15	15
Front seat structure (RH&LH)	40	40
Lightweight steel wheels (4)*	65	65
Fuel tank with filler (assembled) **	81	81
Exhaust system (w/o catalyst) ** (G) (D)	100 96	102 98
Front suspension w/o subframe, leaf spring, brakes and steering system**	200	200
Front suspension subframe and bushings**	100	100
Rear suspension **	175	175

* *Costs assessed by consortium member company*
** *Costs assessed by systems suppliers*

The results of this assessment show that lightweight advanced vehicle concepts, which have the potential to achieve four or five star crash ratings, and are fuel efficient, can be built affordably with steel.

4.6 Affordability

Many decisions were made during the development process to ensure that ULSAB-AVC would be affordable, both to the manufacturer and the consumer. Modular assembly, fewer body-in-white parts through part integration, and use of proven powertrain technology all contributed to keep manufacturing costs down. Key to affordability is the steel-intensive design—steel continues to be the most cost-effective structural material for automobile manufacturing.

To establish a method for judging ULSAB-AVC's affordability, PES conducted a study on selling prices of C-Class and PNGV/PNGV-type vehicles (reported in August 2000). This study included extensive benchmarking of selling price, vehicle features and CO_2 emissions/fuel economy with which to compare the ULSAB-AVC findings.

There are some important factors to keep in mind when interpreting the conclusions of this selling price comparison. Safety features, such as antilock brake systems and side impact bags, were not available on most of the PNGV-type vehicles in this benchmark study. Additionally, since ULSAB-AVC aims at 2004 safety and other performance targets, few of the vehicles in either class compare directly to ULSAB-AVC's crash performance or Star Ratings potential, the technology available in the vehicle (e.g., rear-view cameras) or the engine and powertrain concept (VR3 auto-shift). Consequently, ULSAB-AVC designs offer vehicle makers improved technology and safety performance at production cost levels that would allow for incorporating their features at competitive consumer prices.

4.6.1 Approach

C-Class vehicles (e.g., VW Golf) currently sold in the German market were investigated. The study focused on this one market to avoid conflicting information due to OEM selling price adjustments for specific markets. Only vehicles with dimensions and engine power similar to the ULSAB-AVC C-Class specifications were selected and included in the study.

For the PNGV-Class the PNGV homepage (http://www.ta.doc.gov/pngv/cover/pngvcover.htm) specifies three baseline vehicles: Ford Taurus, Chrysler Concorde and Chevrolet (General Motors) Lumina. Besides these, a list of potential PNGV-type vehicles was established. Investigations on this vehicle type were based on vehicles sold only in the American market using the State of Michigan as the point of purchase. Only those cars with dimensions and features similar to the ULSAB-AVC PNGV-Class were considered.

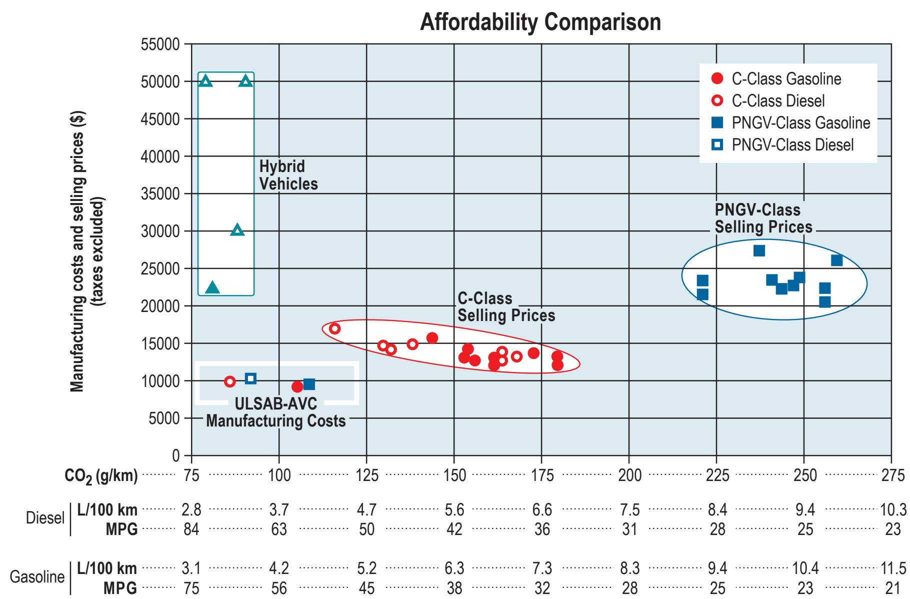
Information was gathered from manufacturer data available through the Internet, company literature and generally available sources. The selling price calculation was established on the base price with standard equipment. For the ULSAB-AVC vehicles, the following features are specified as standard:

When specified features were missing from benchmark vehicles, the most appropriate and least expensive upgrade packages were added. An additional 20 kg was added to the curb weight to account for the mass of such additional equipment. Also, only standard trim colors were selected for comparison.

4.6.2 Affordability Assessment

Figure 129 illustrates the results of the benchmarking study for both vehicle classes. Since lower emissions/improved fuel economy was a major target of this program, the results are delivered in terms of the selling price versus the CO_2 emissions. It is important to keep in mind that benchmark vehicles have not been adjusted for inflation. Recently, a follow-up benchmark initiative was conducted to gather 2001 C-Class selling price comparison data. This new data can be found in Appendix 4, Affordability References.

Figure 129: **Affordability Comparison Chart**



ULSAB-AVC vehicles are represented on these plots by the manufacturing cost only. Since each automobile manufacturer applies its own unique cost factors to set vehicle prices, the consortium chose to display the information as such that automotive companies can add their own cost factors to draw conclusions as to the selling price of the ULSAB-AVC vehicles. Appendix 4 also provides some reference information concerning studies of the logistics, overhead and profit margin figures that may be factored in addition to manufacturing costs to roughly estimate typical selling prices.

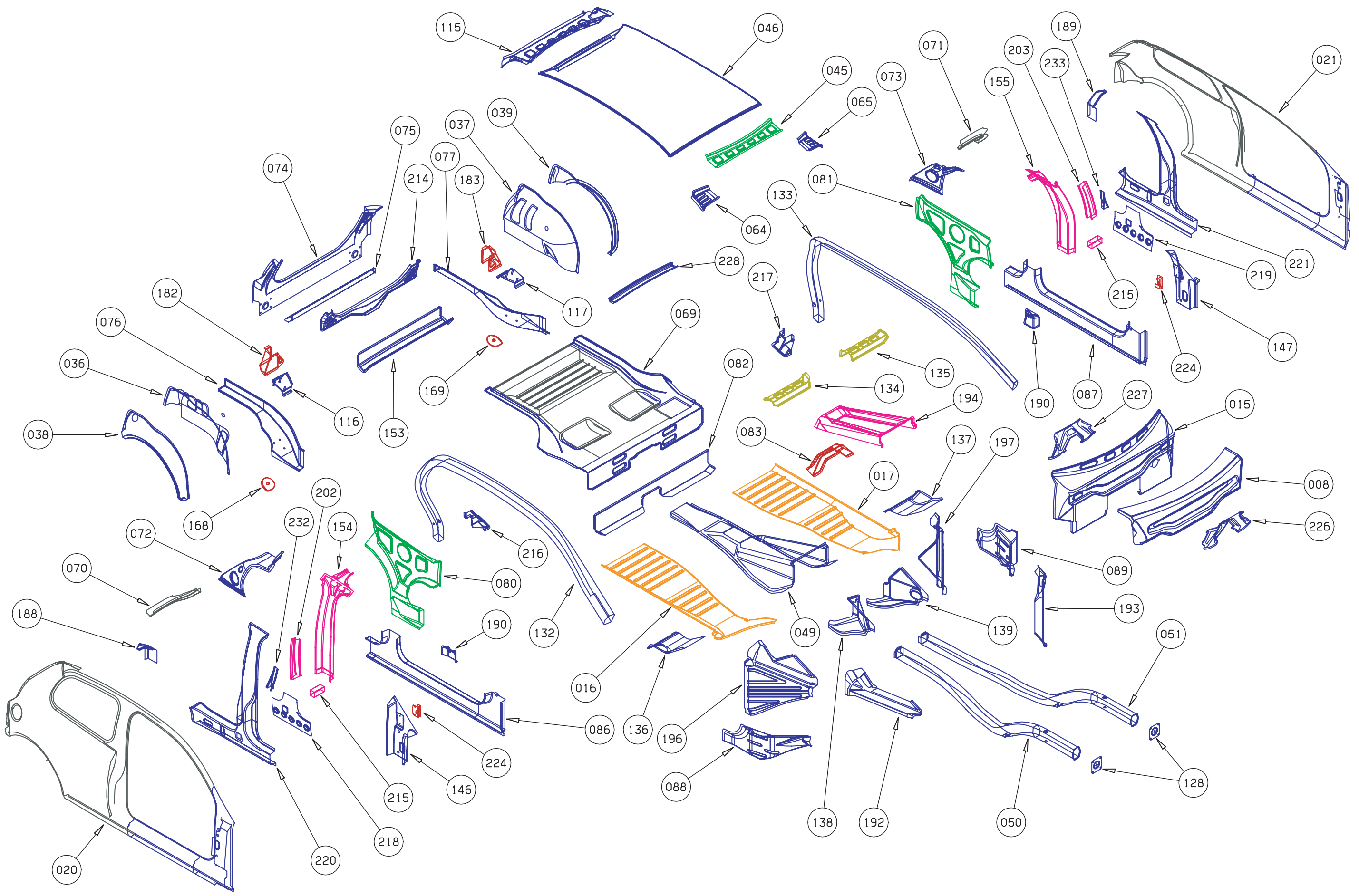
The data clearly indicates that ULSAB-AVC concept vehicles selling price would be far below the selling price of current hybrid-engine concept vehicles, while offering substantial reduction in CO_2 emissions over conventional vehicles.

This demonstrates that steel can remain the structural material of choice for new generations of affordable, fuel efficient vehicles that meet stringent safety standards. ULSAB-AVC offers viable near- and long-term solutions for affordable, safe, environmentally responsible automobiles.

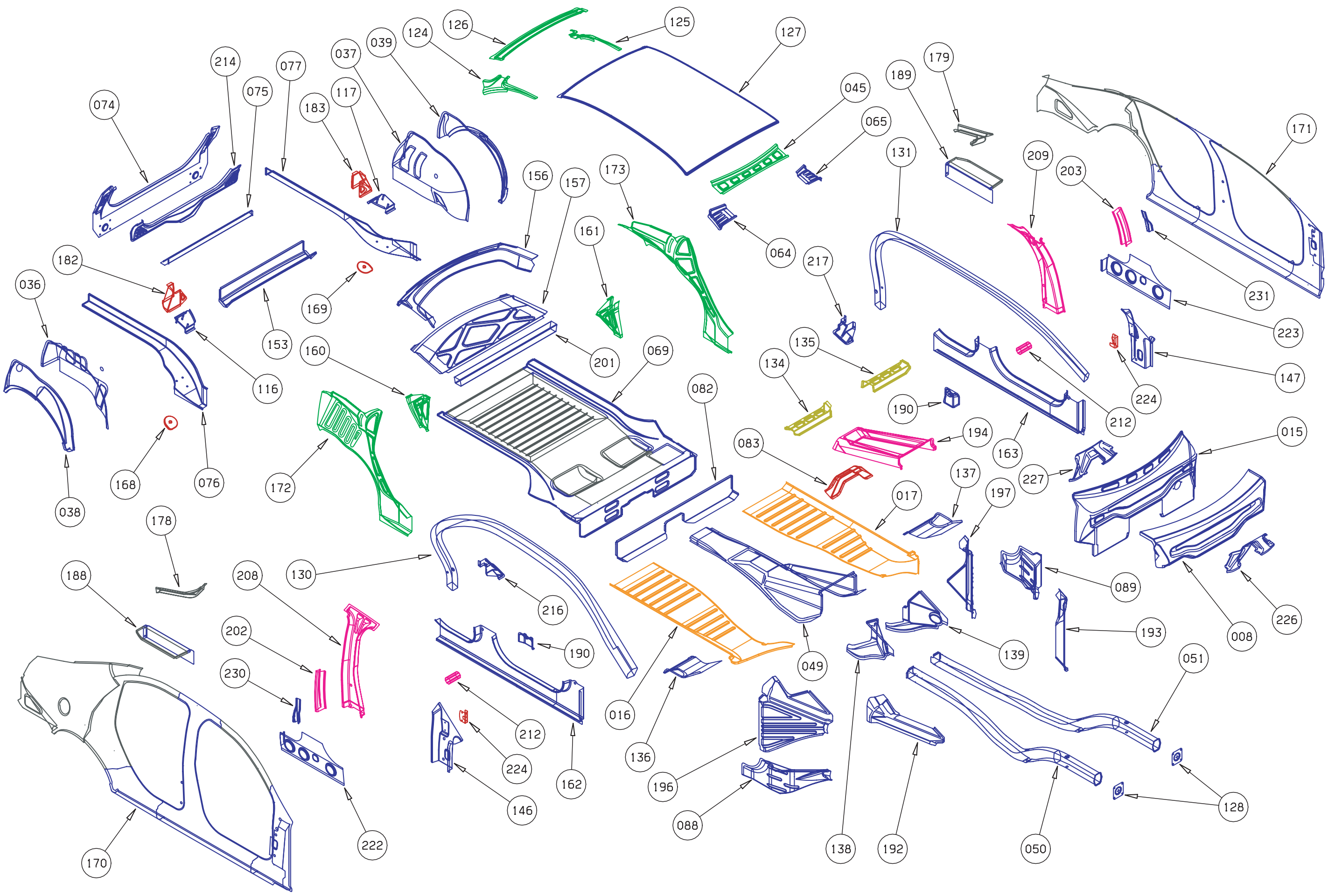
Appendix

ULSAB-AVC
Advanced Vehicle Concepts

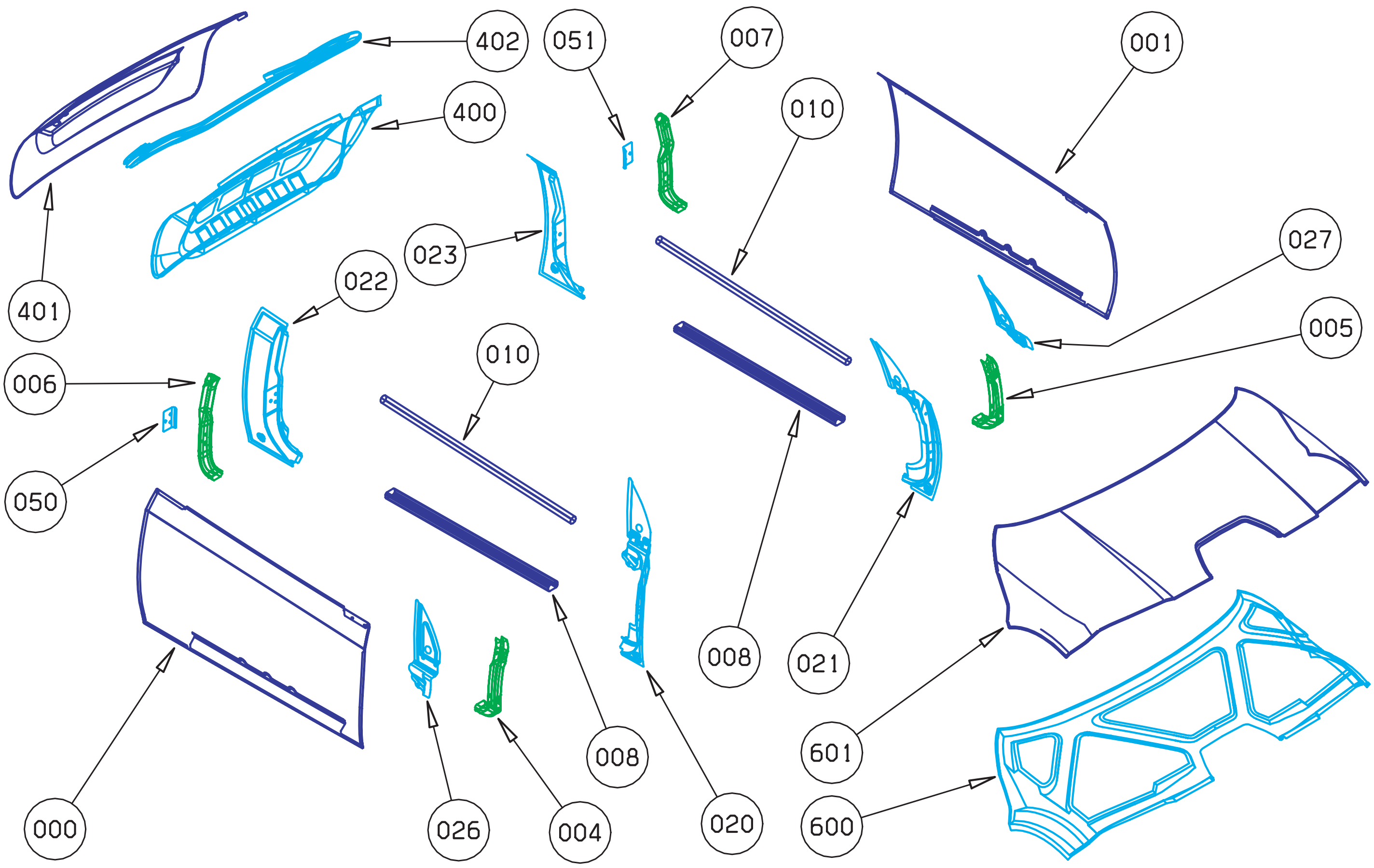
C-Class Body Structure Exploded View



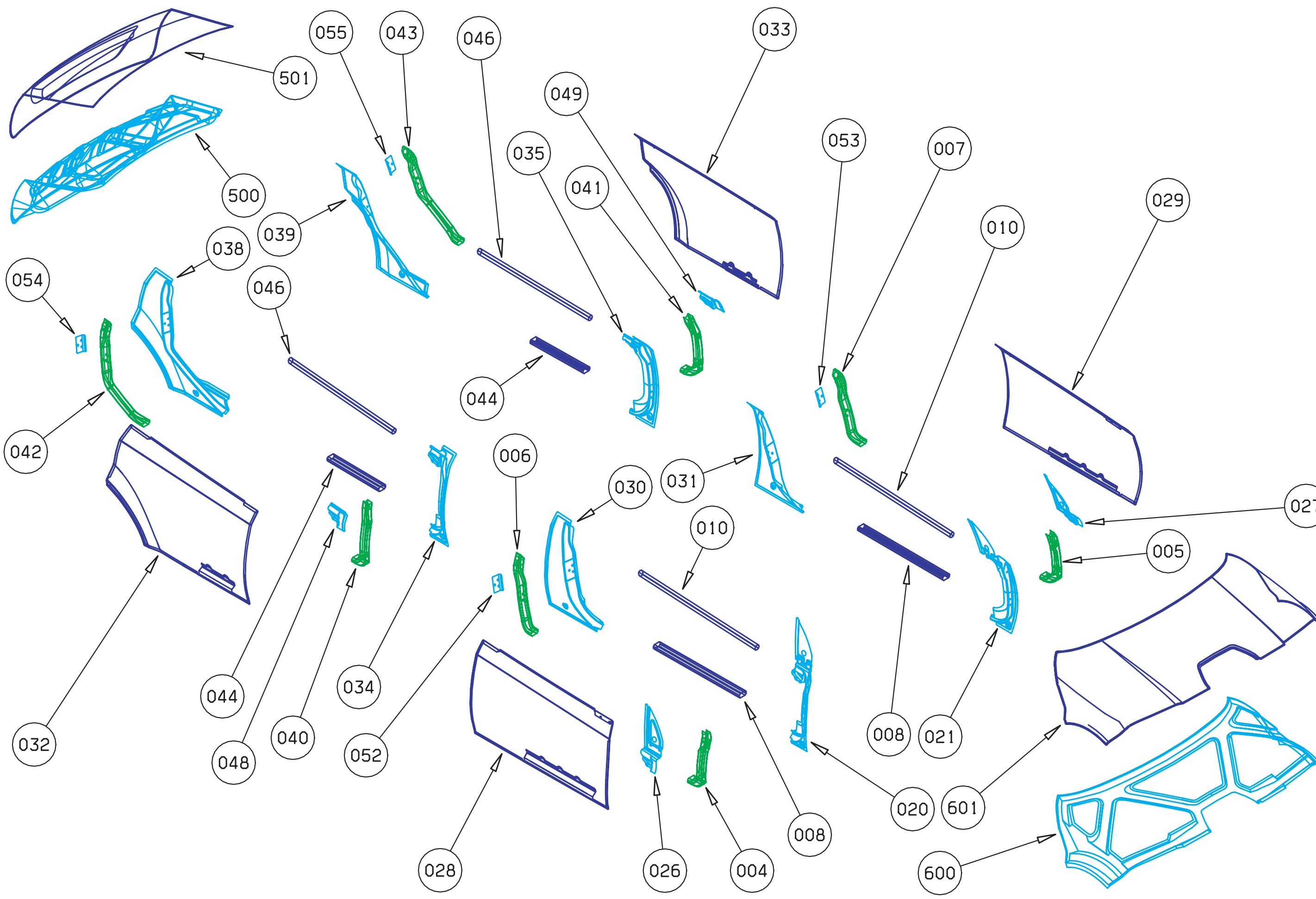
PNGV-Class Body Structure Exploded View



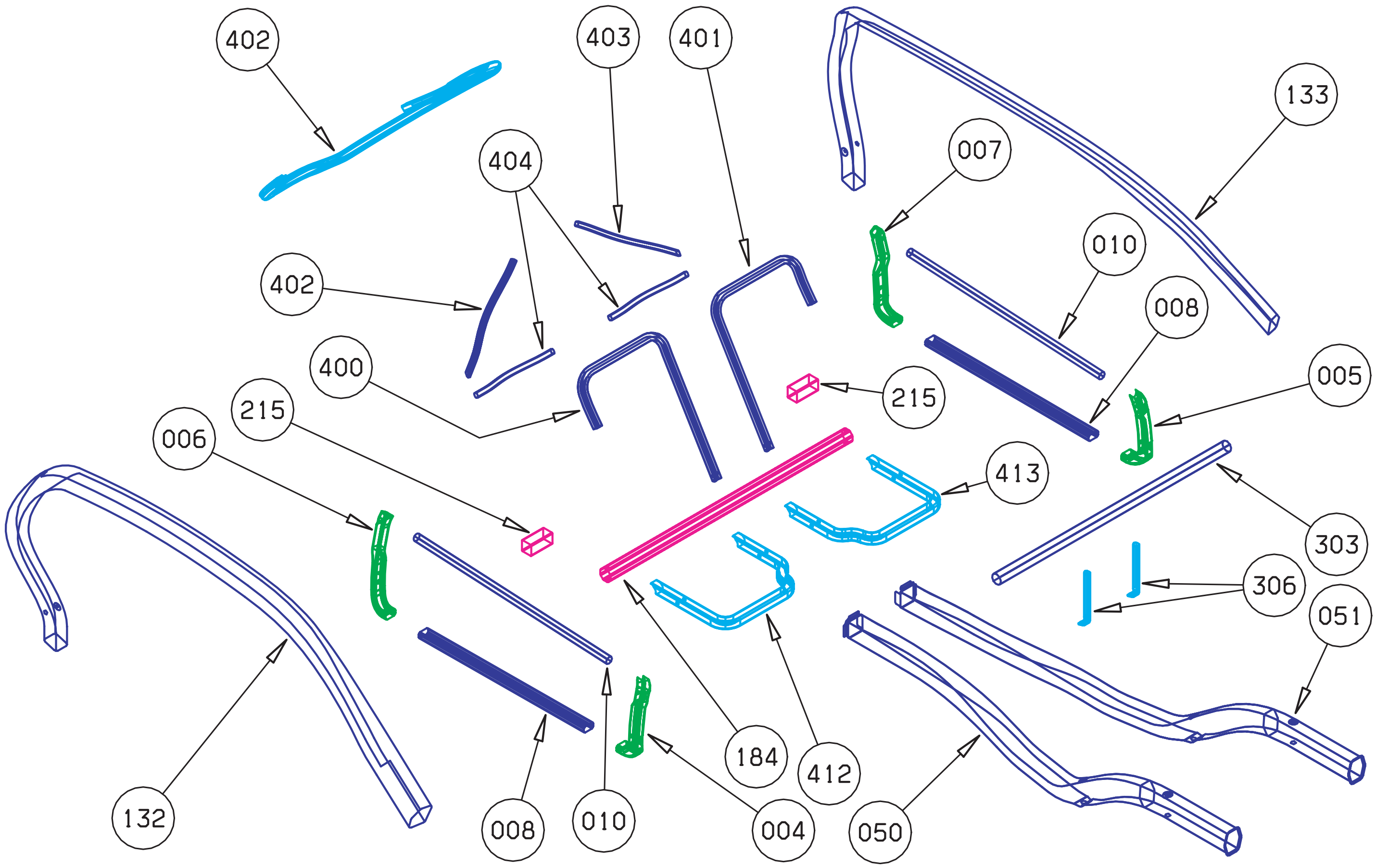
C-Class Closures Exploded View



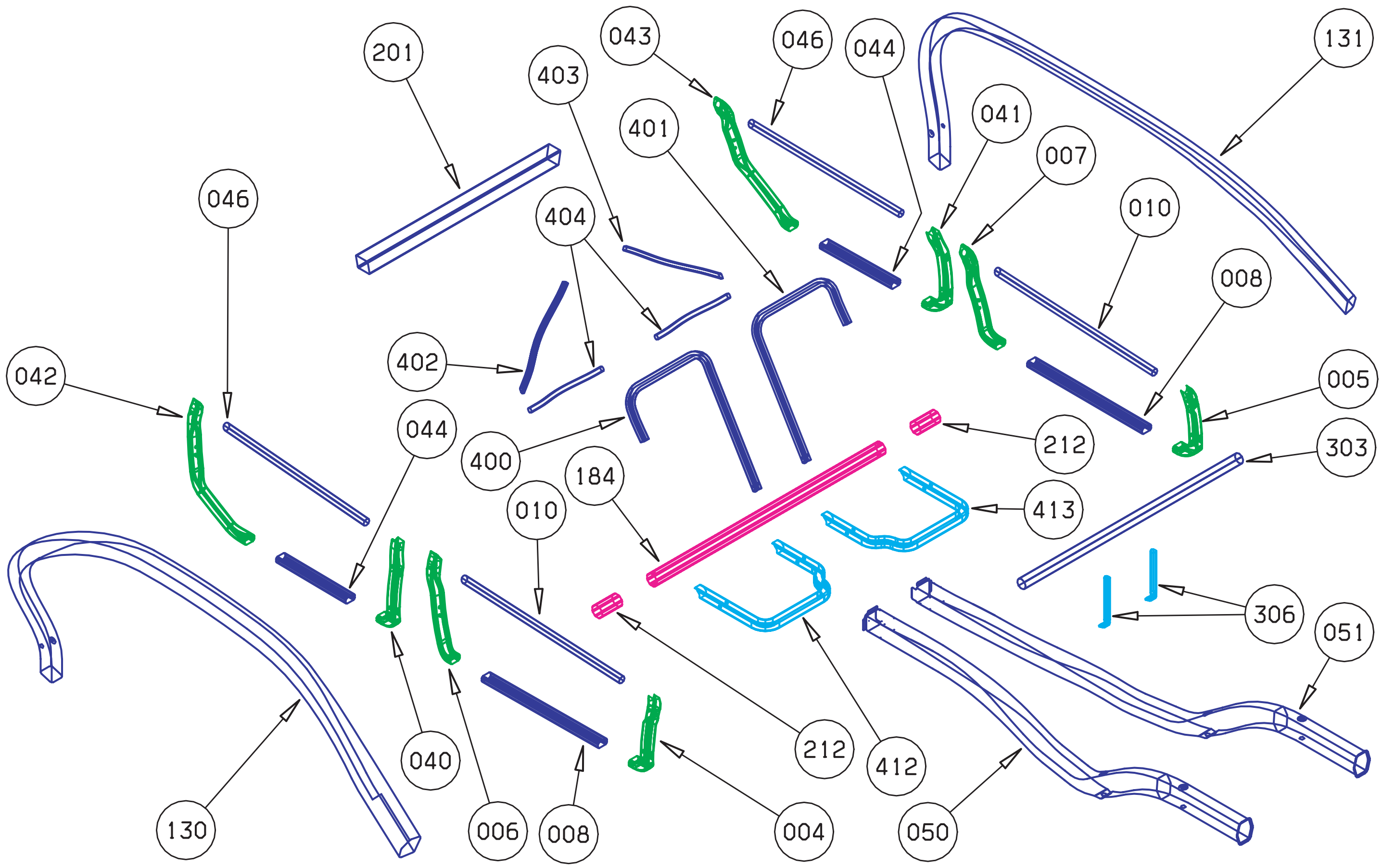
PNGV-Class Closures Exploded View



C-Class Tubes Exploded View (chassis parts not shown)



PNGV-Class Tubes Exploded View (chassis parts not shown)



Number			Name	Blnk No.	Gage (mm)	Material Type	Grade (MPa) Yield Strength	Tensile Strength	Manuf. Process	Designed Mass (kg) C-Class	PNGV-Class
			Body Structure - Common C-Class & PNGV-Class								
AVC	1	1008	Cowl Front		0.80	DP	500	800	S	4.416	4.416
AVC	1	1015	Dash		0.65	DP	280	600	S	4.381	4.381
AVC	1	1045	Header Front		0.70	IF	300	420	S	0.686	0.686
AVC	1	1064	Support Header Front RH		0.70	DP	280	600	S	0.231	0.231
AVC	1	1065	Support Header Front LH		0.70	DP	280	600	S	0.231	0.231
AVC	1	1075	Crossmember Back Panel		0.65	DP	280	600	S	0.832	0.832
AVC	1	1082	Crossmember Kick-Up		0.70	DP	700	1000	S	2.002	2.002
AVC	1	1083	Crossmember Tunnel		0.70	HSLA	350	450	S	0.602	0.602
AVC	1	1088	Bulkhead Crash Box Dash RH		1.20	DP	700	1000	S	2.376	2.376
AVC	1	1089	Bulkhead Crash Box Dash LH		1.20	DP	700	1000	S	2.376	2.376
AVC	1	1116	Assy Reinf Rail Rear Suspension Attach RH		1.30	DP	500	800	S	0.455	0.455
AVC	1	1117	Assy Reinf Rail Rear Suspension Attach LH		1.30	DP	500	800	S	0.455	0.455
AVC	1	1128	Plate Crash Box Rail Front Attach (x2)		3.00	DP	700	1000	S	0.600	0.600
AVC	1	1134	Crossmember Support Front Seat Front RH		0.70	CP	700	800	S	0.567	0.567
AVC	1	1135	Crossmember Support Front Seat Front LH		0.70	CP	700	800	S	0.567	0.567
AVC	1	1136	Closeout Lower Crash Box Dash RH		0.90	DP	500	800	S	1.161	1.161
AVC	1	1137	Closeout Lower Crash Box Dash LH		0.90	DP	500	800	S	1.161	1.161
AVC	1	1138	Closeout Inner Crash Box Dash RH		0.80	DP	400	700	S	1.072	1.072
AVC	1	1139	Closeout Inner Crash Box Dash LH		0.80	DP	400	700	S	1.040	1.040
AVC	1	1146	A-Post Inner RH		0.90	DP	700	1000	S	1.152	1.152
AVC	1	1147	A-Post Inner LH		0.90	DP	700	1000	S	1.152	1.152
AVC	1	1153	Crossmember Rear Suspension		1.00	DP	700	1000	S	2.640	2.640
AVC	1	1168	Reinf Rail Rear Spring Attach RH		1.20	HSLA	350	450	S	0.144	0.144
AVC	1	1169	Reinf Rail Rear Spring Attach LH		1.20	HSLA	350	450	S	0.144	0.144
AVC	1	1182	Reinf Rail Rear Suspension C-Member RH		1.50	HSLA	350	450	S	0.765	0.765
AVC	1	1183	Reinf Rail Rear Suspension C-Member LH		1.50	HSLA	350	450	S	0.765	0.765
AVC	1	1190	Bracket Support Front Seat Rear (x2)		1.20	DP	500	800	S	0.576	0.576
AVC	1	1192	Reinf Crash Box Dash RH		1.00	DP	400	700	S	1.170	1.170
AVC	1	1193	Reinf Crash Box Dash LH		1.00	DP	400	700	S	1.170	1.170
AVC	1	1194	Reinf Tunnel		0.70	Mart	950	1200	S	2.394	2.394
AVC	1	1196	Closeout Outer Crash Box Dash RH		0.80	DP	400	700	S	2.344	2.344
AVC	1	1197	Closeout Outer Crash Box Dash LH		0.80	DP	400	700	S	2.344	2.344
AVC	1	1202	Reinf Waist B-Pillar Inner RH		1.50	Mart	1250	1520	S	0.885	0.885
AVC	1	1203	Reinf Waist B-Pillar Inner LH		1.50	Mart	1250	1520	S	0.885	0.885
AVC	1	1216	Bracket Member Body Side Inner Att Rear RH		1.20	DP	500	800	S	0.396	0.396
AVC	1	1217	Bracket Member Body Side Inner Att Rear LH		1.20	DP	500	800	S	0.396	0.396
AVC	1	1224	Bracket Crossmember Inst Panel Attach RH		1.20	HSLA	350	450	S	0.132	0.132
AVC	1	1225	Bracket Crossmember Inst Panel Attach LH		1.20	HSLA	350	450	S	0.132	0.132
AVC	1	1226	A-Brace Cowl Front		1.00	DP	500	800	S	0.980	0.980
AVC	1	1227	A-Brace Cowl Rear		1.00	DP	500	800	S	0.820	0.820
			SUB-TOTAL - Body Structure - Common Parts C-Class & PNGV-Class							46.597	46.597

Code	Steel Types
Mild	Mild Steel
BH	Bake Hardenable
IF	Interstitial-Free
HSLA	High Strength, Low Alloy
DP	Dual Phase
CP	Complex Phase
Mart	Martensitic
TRIP	Transformation-Induced Plasticity

* denotes **Tube**

Code	Manufacturing Process
S	Stamped
S/TWB	Stamped / Tailor Welded Blanks
HFT	Hydroformed Tube
HFT/TWT	Hydroformed Tube / Tailor Welded Tubes
S or HFS	Stamped or Hydroformed Sheet
ST	Straight or Shapted Tube
Misc	Miscellaneous

Number			Name	Blnk No.	Gage (mm)	Material Type	Grade (MPa) Yield Strength	Grade (MPa) Tensile Strength	Manuf. Process	Designed Mass (kg) C-Class	Designed Mass (kg) PNGV-Class
			Body Structure - C-Class Only								
AVC	2	1016	Floor Front RH		0.65	TRIP	450	800	S	4.219	
AVC	2	1017	Floor Front LH		0.65	TRIP	450	800	S	4.219	
AVC	2	1020	Body Side Outer RH	1	1.50	DP	700	1000	S/TWB	3.645	
	2	1020	Body Side Outer RH	2	0.70	BH	260	370	S/TWB	8.358	
	2	1020	Body Side Outer RH	3	1.80	DP	700	1000	S/TWB	3.618	
AVC	2	1021	Body Side Outer LH	1	1.50	DP	700	1000	S/TWB	3.645	
	2	1021	Body Side Outer LH	2	0.70	BH	260	370	S/TWB	8.414	
	2	1021	Body Side Outer LH	3	1.80	DP	700	1000	S/TWB	3.618	
AVC	2	1036	Wheelhouse Inner RH	1	0.60	DP	500	800	S/TWB	1.320	
	2	1036	Wheelhouse Inner RH	2	1.40	DP	700	1000	S/TWB	0.966	
	2	1036	Wheelhouse Inner RH	3	1.10	DP	700	1000	S/TWB	0.616	
AVC	2	1037	Wheelhouse Inner LH	1	0.60	DP	500	800	S/TWB	1.320	
	2	1037	Wheelhouse Inner LH	2	1.40	DP	700	1000	S/TWB	0.966	
	2	1037	Wheelhouse Inner LH	3	1.10	DP	700	1000	S/TWB	0.616	
AVC	2	1038	Wheelhouse Outer RH		0.60	DP	280	600	S	1.074	
AVC	2	1039	Wheelhouse Outer LH		0.60	DP	280	600	S	1.092	
AVC	2	1046	Roof		0.65	DP	300	500	S or HFS	9.464	
AVC	2	1049	Tunnel		0.65	DP	300	500	S	5.122	
AVC	2	1050	Member Rail Front RH	1	1.50	DP *	500	800	HFT/TWT	1.845	
	2	1050	Member Rail Front RH	2	1.30	DP *	500	800		6.331	
AVC	2	1051	Member Rail Front LH	1	1.50	DP *	500	800	HFT/TWT	1.845	
	2	1051	Member Rail Front LH	2	1.30	DP *	500	800		6.331	
AVC	2	1069	Floor Rear	1	0.60	BH	210	340	S/TWB	5.838	
	2	1069	Floor Rear	2	1.10	DP	350	600	S/TWB	2.519	
	2	1069	Floor Rear	3	1.10	DP	350	600	S/TWB	2.255	
	2	1069	Floor Rear	4	0.70	DP	700	1000	S/TWB	1.988	
AVC	2	1070	Gutter C-Pillar RH		0.65	BH	210	340	S	0.403	
AVC	2	1071	Gutter C-Pillar LH		0.65	BH	210	340	S	0.403	
AVC	2	1072	C-Pillar Inner RH		0.65	DP	500	800	S	0.774	
AVC	2	1073	C-Pillar Inner LH		0.65	DP	500	800	S	0.774	
AVC	2	1074	Back Panel		0.60	DP	300	500	S	2.532	
AVC	2	1076	Rail Rear RH	1	1.80	DP	700	1000	S/TWB	3.168	
	2	1076	Rail Rear RH	2	1.10	DP	500	800	S/TWB	0.737	
AVC	2	1077	Rail Rear LH	1	1.80	DP	700	1000	S/TWB	3.168	
	2	1077	Rail Rear LH	2	1.10	DP	500	800	S/TWB	0.737	
AVC	2	1080	Body Side Inner Rear RH		0.70	IF	300	420	S	2.541	
AVC	2	1081	Body Side Inner Rear LH		0.70	IF	300	420	S	2.541	
AVC	2	1086	Rocker Inner RH	1	1.50	DP	700	1000	S/TWB	1.815	
	2	1086	Rocker Inner RH	2	0.70	DP	700	1000	S/TWB	2.345	
AVC	2	1087	Rocker Inner LH	1	1.50	DP	700	1000	S/TWB	1.815	
	2	1087	Rocker Inner LH	2	0.70	DP	700	1000	S/TWB	2.345	
AVC	2	1115	Header Rear		0.65	DP	350	600	S	1.807	
AVC	2	1132	Member Body Side Inner RH		1.00	DP *	500	800	HFT	7.120	
AVC	2	1133	Member Body Side Inner LH		1.00	DP *	500	800	HFT	7.120	
AVC	2	1154	B-Pillar Inner RH		0.70	Mart	950	1200	S	1.610	
AVC	2	1155	B-Pillar Inner LH		0.70	Mart	950	1200	S	1.610	
AVC	2	1188	Rail Rear Outer Floor Extension RH		1.10	DP	500	800	S	0.319	
AVC	2	1189	Rail Rear Outer Floor Extension LH		1.10	DP	500	800	S	0.319	
AVC	2	1214	Support Back Panel		0.60	DP	300	500	S	1.020	
AVC	2	1215	Extension C-Member Kick-Up (x2)		1.20	Mart *	950	1200	ST	0.480	
AVC	2	1218	Reinf B-Pillar Lower RH		0.70	DP	700	1000	S	0.595	
AVC	2	1219	Reinf B-Pillar Lower LH		0.70	DP	700	1000	S	0.595	
AVC	2	1220	Reinf B-Pillar Rocker Rear RH	1	1.20	DP	700	1000	S/TWB	3.216	
	2	1220	Reinf B-Pillar Rocker Rear RH	2	1.40	DP	700	1000	S/TWB	2.184	
AVC	2	1221	Reinf B-Pillar Rocker Rear LH	1	1.20	DP	700	1000	S/TWB	3.216	
	2	1221	Reinf B-Pillar Rocker Rear LH	2	1.40	DP	700	1000	S/TWB	2.184	
AVC	2	1228	Crossmember Roof		0.70	DP	700	1000	S	0.490	
AVC	2	1232	Reinf Waist B-Pillar Outer RH		0.80	DP	700	1000	S	0.104	
AVC	2	1233	Reinf Waist B-Pillar Outer LH		0.80	DP	700	1000	S	0.104	
			SUB-TOTAL - Body Structure - C-Class Only							151.433	

* denotes **Tube**

Number			Name	Blnk No.	Gage (mm)	Material Type	Grade (MPa)		Manuf. Process	Designed Mass (kg)	
							Yield Strength	Tensile Strength		C-Class	PNGV-Class
			Body Structure - PNGV-Class Only								
AVC	3	1016	Floor Front RH		0.65	TRIP	450	800	S		4.459
AVC	3	1017	Floor Front LH		0.65	TRIP	450	800	S		4.459
AVC	3	1036	Wheelhouse Inner RH	1	0.60	DP	500	800	S/TWB		1.356
	3	1036	Wheelhouse Inner RH	2	1.40	DP	700	1000	S/TWB		0.966
	3	1036	Wheelhouse Inner RH	3	1.10	DP	700	1000	S/TWB		0.660
AVC	3	1037	Wheelhouse Inner LH	1	0.60	DP	500	800	S/TWB		1.356
	3	1037	Wheelhouse Inner LH	2	1.40	DP	700	1000	S/TWB		0.966
	3	1037	Wheelhouse Inner LH	3	1.10	DP	700	1000	S/TWB		0.660
AVC	3	1038	Wheelhouse Outer RH		0.60	DP	280	600	S		1.134
AVC	3	1039	Wheelhouse Outer LH		0.60	DP	280	600	S		1.146
AVC	3	1049	Tunnel		0.65	DP	300	500	S		5.252
AVC	3	1050	Member Rail Front RH	1	1.50	DP *	500	800	HFT/TWT		1.845
	3	1050	Member Rail Front RH	2	1.30	DP *	500	800	HFT/TWT		6.604
AVC	3	1051	Member Rail Front LH	1	1.50	DP *	500	800	HFT/TWT		1.845
	3	1051	Member Rail Front LH	2	1.30	DP *	500	800	HFT/TWT		6.604
AVC	3	1069	Floor Rear	1	0.60	BH	210	340	S/TWB		7.932
	3	1069	Floor Rear	2	1.10	DP	350	600	S/TWB		3.135
	3	1069	Floor Rear	3	1.10	DP	350	600	S/TWB		2.882
	3	1069	Floor Rear	4	0.70	DP	700	1000	S/TWB		2.002
AVC	3	1074	Back Panel		0.60	DP	300	500	S		2.172
AVC	3	1076	Rail Rear RH	1	1.80	DP	700	1000	S/TWB		3.168
	3	1076	Rail Rear RH	2	1.10	DP	500	800	S/TWB		1.408
AVC	3	1077	Rail Rear LH	1	1.80	DP	700	1000	S/TWB		3.168
	3	1077	Rail Rear LH	2	1.10	DP	500	800	S/TWB		1.408
AVC	3	1124	Support Header Rear RH		0.70	IF	300	420	S		0.336
AVC	3	1125	Support Header Rear LH		0.70	IF	300	420	S		0.336
AVC	3	1126	Header Rear		0.70	IF	300	420	S		0.938
AVC	3	1127	Roof		0.65	DP	300	500	S or HFS		8.905
AVC	3	1130	Member Body Side Inner RH		1.00	DP *	500	800	HFT		7.070
AVC	3	1131	Member Body Side Inner LH		1.00	DP *	500	800	HFT		7.070
AVC	3	1156	Package Tray Upper		0.60	DP	280	600	S		2.316
AVC	3	1157	Package Tray Lower		0.60	DP	280	600	S		2.208
AVC	3	1160	Support Package Tray Lower RH		1.20	IF	300	420	S		0.852
AVC	3	1161	Support Package Tray Lower LH		1.20	IF	300	420	S		0.852
AVC	3	1162	Rocker Inner RH	1	1.50	DP	700	1000	S/TWB		1.815
	3	1162	Rocker Inner RH	2	0.70	DP	700	1000	S/TWB		2.527
AVC	3	1163	Rocker Inner LH	1	1.50	DP	700	1000	S/TWB		1.815
	3	1163	Rocker Inner LH	2	0.70	DP	700	1000	S/TWB		2.527
AVC	3	1170	Body Side Outer RH	1	1.50	DP	700	1000	S/TWB		3.645
	3	1170	Body Side Outer RH	2	0.70	BH	260	370	S/TWB		0.280
	3	1170	Body Side Outer RH	3	1.80	DP	700	1000	S/TWB		9.108
	3	1170	Body Side Outer RH	4	1.20	DP	700	1000	S/TWB		2.148
	3	1170	Body Side Outer RH	5	0.70	BH	260	370	S/TWB		5.649
AVC	3	1171	Body Side Outer LH	1	1.50	DP	700	1000	S/TWB		3.645
	3	1171	Body Side Outer LH	2	0.70	BH	260	370	S/TWB		0.280
	3	1171	Body Side Outer LH	3	1.80	DP	700	1000	S/TWB		9.108
	3	1171	Body Side Outer LH	4	1.20	DP	700	1000	S/TWB		2.148
	3	1171	Body Side Outer LH	5	0.70	BH	260	370	S/TWB		5.712
AVC	3	1172	Body Side Inner Rear RH		0.70	IF	300	420	S		2.555
AVC	3	1173	Body Side Inner Rear LH		0.70	IF	300	420	S		2.555
AVC	3	1178	Gutter Deck Lid RH		0.70	BH	260	370	S		0.385
AVC	3	1179	Gutter Deck Lid LH		0.70	BH	260	370	S		0.385
AVC	3	1188	Rail Rear Outer Floor Extension RH	1	1.10	DP	500	800	S/TWB		0.913
	3	1188	Rail Rear Outer Floor Extension RH	2	0.60	BH	210	340	S/TWB		0.378
AVC	3	1189	Rail Rear Outer Floor Extension LH	1	1.10	DP	500	800	S/TWB		0.913
	3	1189	Rail Rear Outer Floor Extension LH	2	0.60	BH	210	340	S/TWB		0.378
AVC	3	1201	Crossmember Package Tray		1.00	DP *	280	600	ST		2.540
AVC	3	1208	B-Pillar Inner RH		0.70	Mart	950	1200	S		1.491
AVC	3	1209	B-Pillar Inner LH		0.70	Mart	950	1200	S		1.491
AVC	3	1212	Extension C-Member Supt Front Seat Rr (x2)		1.20	Mart *	950	1200	ST		0.456
AVC	3	1214	Support Back Panel		0.60	DP	300	500	S		1.068
AVC	3	1222	Reinf B-Pillar Lower RH		1.00	DP	700	1000	S		1.430
AVC	3	1223	Reinf B-Pillar Lower LH		1.00	DP	700	1000	S		1.430
AVC	3	1230	Reinf Waist B-Pillar Outer RH		0.80	DP	700	1000	S		0.120
AVC	3	1231	Reinf Waist B-Pillar Outer LH		0.80	DP	700	1000	S		0.120
			SUB-TOTAL - Body Structure - PNGV-Class Only								166.485

* denotes **Tube**

ULSAB-AVC Master Parts List

Number			Name	Blnk No.	Gage (mm)	Material Type	Grade (MPa)		Manuf. Process	Designed Mass (kg)	
							Yield Strength	Tensile Strength		C-Class	PNGV-Class
Body Structure Total:											
			SUB-TOTAL - Common Parts C-Class & PNGV-Class							46.597	46.597
			SUB-TOTAL - C-Class Only							151.433	
			SUB-TOTAL - PNGV-Class Only								166.485
AVC	-	1900	Brackets, Reinforcements and Hinges NOT Designed						Misc	3.746	5.042
TOTAL										201.776	218.124

Code	Steel Types
Mild	Mild Steel
BH	Bake Hardenable
IF	Interstitial-Free
HSLA	High Strength, Low Alloy
DP	Dual Phase
CP	Complex Phase
Mart	Martensitic
TRIP	Transformation-Induced Plasticity

Code	Manufacturing Process
S	Stamped
S/TWB	Stamped / Tailor Welded Blanks
HFT	Hydroformed Tube
HFT/TWT	Hydroformed Tube / Tailor Welded Tubes
S or HFS	Stamped or Hydroformed Sheet
ST	Straight or Shapted Tube
Misc	Miscellaneous

(Closures, Interior, and Bumper Parts - see following pages)

ULSAB-AVC Master Parts List

Number			Name	Blnk No.	Gage (mm)	Material Type	Grade (MPa)		Manuf. Process	Designed Mass (kg)	
							Yield Strength	Tensile Strength		C-Class	PNGV-Class

Closures - C-Class - Front Doors

AVC	1	2004	Hinge Tube - Front Door RH		1.20	IF *	260	410	HFT	0.648	
AVC	1	2005	Hinge Tube - Front Door LH		1.20	IF *	260	410	HFT	0.648	
AVC	1	2020	Inner Front - Front Door RH	1	1.00	Mild	140	270	S/TWB	0.500	
	1	2020	Inner Front - Front Door RH	2	1.20	Mild	140	270	S/TWB	0.384	
AVC	1	2021	Inner Front - Front Door LH	1	1.00	Mild	140	270	S/TWB	0.500	
	1	2021	Inner Front - Front Door LH	2	1.20	Mild	140	270	S/TWB	0.384	
AVC	1	2026	Mirror Flag Outer - Front Door RH		1.00	Mild	140	270	S	0.330	
AVC	1	2027	Mirror Flag Outer - Front Door LH		1.00	Mild	140	270	S	0.330	
AVC	1	2045	Assy W-Reg Attach Upper - FD (0.007kg x4)		0.90	Mild	140	270	S	0.028	
AVC	1	2047	Hinge Bushing - Front Door (0.041kg x6)		NA	NA	NA	NA	NA	0.246	
AVC	1	2056	Latch Bushing - Front Door (0.014kg x6)		NA	NA	NA	NA	NA	0.084	
AVC	1	2057	U-Clip M6 x 1.00 - Front Door (0.011kg x4)		NA	NA	NA	NA	NA	0.044	
AVC	1	2058	Hex Flange Head M6 x 15 - FD (0.040kg x4)		NA	NA	NA	NA	NA	0.160	
AVC	1	2059	Weld Stud M6 x 16 - Front Door (0.005kg x8)		NA	NA	NA	NA	NA	0.040	
AVC	1	2060	Adhesive Bond Lwr Tube - FD (0.070kg x2)		NA	NA	NA	NA	NA	0.140	
AVC	2	2000	Outer - Front Door RH		0.60	DP	350	600	S orHFS	4.542	
AVC	2	2001	Outer - Front Door LH		0.60	DP	350	600	S or HFS	4.542	
AVC	2	2006	Latch Tube - Front Door RH		1.00	IF *	260	410	HFT	0.610	
AVC	2	2007	Latch Tube - Front Door LH		1.00	IF *	260	410	HFT	0.610	
AVC	2	2008	Lower Tube - Front Door (x2)		1.50	DP *	500	800	ST	3.450	
AVC	2	2010	Outer Belt Reinforcement - Front Door (x2)		1.00	DP *	500	800	ST	1.860	
AVC	2	2022	Inner Rear - Front Door RH		0.60	Mild	140	270	S	0.696	
AVC	2	2023	Inner Rear - Front Door LH		0.60	Mild	140	270	S	0.696	
AVC	2	2050	Reinforcement Latch - Front Door RH		1.20	Mild	140	270	S	0.060	
AVC	2	2051	Reinforcement Latch - Front Door LH		1.20	Mild	140	270	S	0.060	
TOTAL										**21.592**	

Closures - PNGV-Class - Front Doors

AVC	1	2004	Hinge Tube - Front Door RH		1.20	IF *	260	410	HFT		0.648
AVC	1	2005	Hinge Tube - Front Door LH		1.20	IF *	260	410	HFT		0.648
AVC	1	2020	Inner Front - Front Door RH	1	1.00	Mild	140	270	S/TWB		0.500
	1	2020	Inner Front - Front Door RH	2	1.20	Mild	140	270	S/TWB		0.384
AVC	1	2021	Inner Front - Front Door LH	1	1.00	Mild	140	270	S/TWB		0.500
	1	2021	Inner Front - Front Door LH	2	1.20	Mild	140	270	S/TWB		0.384
AVC	1	2045	Assy W-Reg Attach Upper - FD (0.007kg x4)		0.90	Mild	140	270	S		0.028
AVC	1	2047	Hinge Bushing - Front Door (0.041kg x6)		NA	NA	NA	NA	NA		0.246
AVC	1	2056	Latch Bushing - Front Door (0.014kg x6)		NA	NA	NA	NA	NA		0.084
AVC	1	2057	U-Clip M6 x 1.00 - Front Door (0.011kg x4)		NA	NA	NA	NA	NA		0.044
AVC	1	2058	Hex Flange Head M6 x 15 - FD (0.040kg x4)		NA	NA	NA	NA	NA		0.160
AVC	1	2059	Weld Stud M6 x 16 - Front Door (0.005kg x8)		NA	NA	NA	NA	NA		0.040
AVC	1	2060	Adhesive Bond Lwr Tube - FD (0.070kg x2)		NA	NA	NA	NA	NA		0.140
AVC	1	2026	Mirror Flag Outer - Front Door RH		1.00	Mild	140	270	S		0.330
AVC	1	2027	Mirror Flag Outer - Front Door LH		1.00	Mild	140	270	S		0.330
AVC	3	2006	Latch Tube - Front Door RH		1.00	IF *	260	410	HFT		0.620
AVC	3	2007	Latch Tube - Front Door LH		1.00	IF *	260	410	HFT		0.620
AVC	3	2008	Lower Tube - Front Door (x2)		1.50	DP *	500	800	ST		2.580
AVC	3	2010	Outer Belt Reinforcement - Front Door (x2)		1.00	DP *	500	800	ST		1.600
AVC	3	2028	Outer - Front Door RH		0.60	DP	350	600	S or HFS		3.792
AVC	3	2029	Outer - Front Door LH		0.60	DP	350	600	S or HFS		3.792
AVC	3	2030	Inner Rear - Front Door RH		0.60	Mild	140	270	S		0.798
AVC	3	2031	Inner Rear - Front Door LH		0.60	Mild	140	270	S		0.798
AVC	3	2052	Reinforcement Latch - Front Door RH		1.20	Mild	140	270	S		0.060
AVC	3	2053	Reinforcement Latch - Front Door LH		1.20	Mild	140	270	S		0.060
TOTAL											**19.186**

* denotes **Tube**

ULSAB-AVC Master Parts List

Closures - PNGV-Class - Rear Doors

Number			Name	Blnk No.	Gage (mm)	Material Type	Grade (MPa) Yield Strength	Grade (MPa) Tensile Strength	Manuf. Process	Designed Mass (kg) C-Class	Designed Mass (kg) PNGV-Class
AVC	1	2045	Assy W-Reg Attach Upper - FD (0.007kg x4)		0.90	Mild	140	270	S		0.028
AVC	1	2047	Hinge Bushing - Front Door (0.041kg x6)		NA	NA	NA	NA	NA		0.246
AVC	1	2056	Latch Bushing - Front Door (0.014kg x6)		NA	NA	NA	NA	NA		0.084
AVC	1	2059	Weld Stud M6 x 16 - Front Door (0.005kg x8)		NA	NA	NA	NA	NA		0.040
AVC	1	2060	Adhesive Bond Lwr Tube - FD (0.070kg x2)		NA	NA	NA	NA	NA		0.140
AVC	3	2032	Outer - Rear Door RH		0.60	DP	350	600	S or HFS		3.792
AVC	3	2033	Outer - Rear Door LH		0.60	DP	350	600	S or HFS		3.792
AVC	3	2034	Inner Front - Rear Door RH	1	1.00	Mild	140	270	S/TWB		0.430
	3	2034	Inner Front - Rear Door RH	2	1.20	Mild	140	270	S/TWB		0.408
AVC	3	2035	Inner Front - Rear Door LH	1	1.00	Mild	140	270	S/TWB		0.430
	3	2035	Inner Front - Rear Door LH	2	1.20	Mild	140	270	S/TWB		0.408
AVC	3	2038	Inner Rear - Rear Door RH		0.60	Mild	140	270	S		1.062
AVC	3	2039	Inner Rear - Rear Door LH		0.60	Mild	140	270	S		1.062
AVC	3	2040	Hinge Tube - Rear Door RH		1.20	IF *	260	410	HFT		0.744
AVC	3	2041	Hinge Tube - Rear Door LH		1.20	IF *	260	410	HFT		0.744
AVC	3	2042	Latch Tube - Rear Door RH		1.00	IF *	260	410	HFT		0.850
AVC	3	2043	Latch Tube - Rear Door LH		1.00	IF *	260	410	HFT		0.850
AVC	3	2044	Lower Tube - Rear Door (x2)		1.50	DP *	500	800	ST		1.560
AVC	3	2046	Outer Belt Reinforcement - Rear Door (x2)		1.00	DP *	500	800	ST		1.480
AVC	3	2048	Reinf Belt Hinge Tube - Rear Door RH		1.10	Mild	140	270	S		0.143
AVC	3	2049	Reinf Belt Hinge Tube - Rear Door LH		1.10	Mild	140	270	S		0.143
AVC	3	2054	Reinforcement Latch - Rear Door RH		1.20	Mild	140	270	S		0.060
AVC	3	2055	Reinforcement Latch - Rear Door LH		1.20	Mild	140	270	S		0.060
TOTAL											**18.556**

Closures - C-Class / PNGV-Class - Hood

Number			Name	Blnk No.	Gage (mm)	Material Type	Grade (MPa) Yield Strength	Grade (MPa) Tensile Strength	Manuf. Process	Designed Mass (kg) C-Class	Designed Mass (kg) PNGV-Class
AVC	1	2600	Inner - Hood		0.60	Mild	140	270	S	3.408	3.408
AVC	1	2601	Outer - Hood		0.60	DP	350	600	S or HFS	5.676	5.676
AVC	1	x	Striker Assembly - Hood		2.50	Mild	140	270	S	0.070	0.070
AVC	1	x	Reinforcement Striker - Hood		1.50	Mild	140	270	S	0.070	0.070
AVC	1	x	Reinforcement Hinge - Hood (x2)		1.50	Mild	140	270	S	0.310	0.310
TOTAL										**9.534**	**9.534**

Closures - C-Class - Liftgate

Number			Name	Blnk No.	Gage (mm)	Material Type	Grade (MPa) Yield Strength	Grade (MPa) Tensile Strength	Manuf. Process	Designed Mass (kg) C-Class	Designed Mass (kg) PNGV-Class
AVC	2	2400	Inner - Liftgate		0.60	Mild	140	270	S	2.796	
AVC	2	2401	Outer - Liftgate		0.60	DP	350	600	S or HFS	3.408	
AVC	2	2402	Member Aperture - Liftgate		0.70	Mild *	140	270	HFT	2.240	
AVC	2	x	Reinforcement Latch - Liftgate		1.50	Mild	140	270	S	0.120	
TOTAL										**8.564**	

Closures - PNGV-Class - Deck Lid

Number			Name	Blnk No.	Gage (mm)	Material Type	Grade (MPa) Yield Strength	Grade (MPa) Tensile Strength	Manuf. Process	Designed Mass (kg) C-Class	Designed Mass (kg) PNGV-Class
AVC	3	2500	Inner - Deck Lid		0.60	Mild	140	270	S		3.768
AVC	3	2501	Outer - Deck Lid		0.60	DP	350	600	S or HFS		6.072
AVC	3	x	Striker Assembly - Decklid		1.50	Mild	140	270	S		0.070
AVC	3	x	Reinforcement Striker - Decklid		1.50	Mild	140	270	S		0.040
AVC	3	x	Reinforcement Hinge - Decklid (x2)		1.20	Mild	140	270	S		0.320
TOTAL											**10.270**

Closures - C-Class / PNGV-Class - Ancillary Closures

Number			Name	Blnk No.	Gage (mm)	Material Type	Grade (MPa) Yield Strength	Grade (MPa) Tensile Strength	Manuf. Process	Designed Mass (kg) C-Class	Designed Mass (kg) PNGV-Class
AVC	1	2300	Engine Service Lid		0.60	Mild	140	270	S	0.348	0.348
AVC	1	2602	Fender RH		0.60	DP	350	600	S or HFS	1.608	1.608
AVC	1	2603	Fender LH		0.60	DP	350	600	S or HFS	1.608	1.608
AVC	2	2301	Fuel Filler Lid		0.60	Mild	140	270	S	0.090	
AVC	2	2700	Applique - Roof Side Rail RH		0.50	Mild	140	270	S	1.290	
AVC	2	2701	Applique - Roof Side Rail LH		0.50	Mild	140	270	S	1.290	
AVC	3	2302	Fuel Filler Lid		0.60	Mild	140	270	S		0.090
AVC	3	2702	Applique - Roof Side Rail RH		0.50	Mild	140	270	S		1.430
AVC	3	2703	Applique - Roof Side Rail LH		0.50	Mild	140	270	S		1.430
TOTAL										**6.234**	**6.514**

* denotes **Tube**

ULSAB-AVC Advanced Vehicle Concepts

ULSAB-AVC Master Parts List

Number			Name	Blnk No.	Gage (mm)	Material Type	Grade (MPa) Yield Strength	Grade (MPa) Tensile Strength	Manuf. Process	Designed Mass (kg) C-Class	Designed Mass (kg) PNGV-Class

Front Seats

Number			Name	Blnk No.	Gage (mm)	Material Type	Yield Strength	Tensile Strength	Manuf. Process	C-Class	PNGV-Class
AVC	1	1184	Crossmember Support Front Seat Rear		1.20	Mart*	950	1200	ST	2.568	2.568
AVC	1	1400	Frame Member Back Support Front Seat RH		1.00	DP*	350	600	ST	1.120	1.120
AVC	1	1401	Frame Member Back Support Front Seat LH		1.00	DP*	350	600	ST	1.120	1.120
AVC	1	1402	Diagonal Member Back Supt Front Seat RH		1.00	DP*	350	600	ST	0.300	0.300
AVC	1	1403	Diagonal Member Back Supt Front Seat LH		1.00	DP*	350	600	ST	0.300	0.300
AVC	1	1404	Crossmember Back Support Front Seat (x2)		1.00	DP*	350	600	ST	0.500	0.500
AVC	1	1405	Bracket Head Support Attach Front Seat (x2)		1.00	HSLA	350	450	S	0.400	0.400
AVC	1	1406	Bracket Retractor Attachment Front Seat RH		1.50	TRIP	450	800	S	0.510	0.510
AVC	1	1407	Bracket Retractor Attachment Front Seat LH		1.50	TRIP	450	800	S	0.510	0.510
AVC	1	1408	Reinf Retractor Attachment Front Seat RH		1.50	TRIP	450	800	S	0.135	0.135
AVC	1	1409	Reinf Retractor Attachment Front Seat LH		1.50	TRIP	450	800	S	0.135	0.135
AVC	1	1410	Retainer Spring Back Support Front Seat RH		1.00	DP	500	800	S	0.710	0.710
AVC	1	1411	Retainer Spring Back Support Front Seat LH		1.00	DP	500	800	S	0.710	0.710
AVC	1	1412	Frame Member Seat Support Front Seat RH		0.70	Mild *	140	270	ST	0.931	0.931
AVC	1	1413	Frame Member Seat Support Front Seat LH		0.70	Mild *	140	270	ST	0.931	0.931
AVC	1	1414	Bracket Back Supt Attach Outer Frt Seat (x2)		2.00	HSLA	350	450	S	0.760	0.760
AVC	1	1415	Bracket Back Supt Attach Inner Frt Seat (x2)		2.00	HSLA	350	450	S	0.480	0.480
AVC	1	1416	Bracket Seat Attach Outer Front Seat RH		2.00	HSLA	350	450	S	0.260	0.260
AVC	1	1417	Bracket Seat Attach Outer Front Seat LH		2.00	HSLA	350	450	S	0.260	0.260
AVC	1	1418	Bracket Seat Attach Inner Front Seat RH		2.00	HSLA	350	450	S	0.100	0.100
AVC	1	1419	Bracket Seat Attach Inner Front Seat LH		2.00	HSLA	350	450	S	0.100	0.100
AVC	1	1420	Frame Cushiion Support Front Seat (x2)		1.00	Mild	140	270	S	1.320	1.320
AVC	1	1421	Reinf Cushion Support Front Seat (x2)		1.00	Mild	140	270	S	1.300	1.300
AVC	1	1422	Assy Tilt Mech Cushion Supt Front Seat RH		Assy	Assy	Assy	Assy		1.952	1.952
AVC	1	1423	Assy Tilt Mech Cushion Supt Front Seat LH		Assy	Assy	Assy	Assy		1.952	1.952
TOTAL										**19.364**	**19.364**

Rear Seats

Number			Name	Blnk No.	Gage (mm)	Material Type	Yield Strength	Tensile Strength	Manuf. Process	C-Class	PNGV-Class
AVC	1	1424	Assy Seat Support 60% Rear Seat		4.00	Mild	140	270	ROD	0.745	0.745
AVC	1	1425	Assy Seat Support 40% Rear Seat		4.00	Mild	140	270	ROD	0.531	0.531
AVC	1	1426	Bracket Seat Support Attach Rear Seat (x4)		1.50	Mild	140	270	S	0.045	0.045
AVC	1	1427	Bracket Back Supt Inner Floor Attach Rr Seat		2.00	HSLA	350	450	S	0.300	0.300
AVC	1	1428	Brkt Back Supt Outer Floor Atach Rr Seat RH		2.00	HSLA	350	450	S	0.280	0.280
AVC	1	1429	Brkt Back Supt Outer Floor Atach Rr Seat LH		2.00	HSLA	350	450	S	0.280	0.280
AVC	1	1430	Back Support 60% Rear Seat		0.80	DP	350	600	S	3.136	3.136
AVC	1	1431	Back Support 40% Rear Seat		0.80	DP	350	600	S	1.984	1.984
AVC	1	1432	Reinf Back Support Outer Rear Seat RH		1.00	HSLA	350	450	S	0.380	0.380
AVC	1	1433	Reinf Back Support Outer Rear Seat LH		1.00	HSLA	350	450	S	0.380	0.380
AVC	1	1434	Reinf Back Support Inner Rear Seat RH		1.00	HSLA	350	450	S	0.380	0.380
AVC	1	1435	Reinf Back Support Inner Rear Seat LH		1.00	HSLA	350	450	S	0.380	0.380
AVC	1	1436	Bracket Head Support Attach 60% Rear Seat		1.00	HSLA	350	450	S	0.950	0.950
AVC	1	1437	Bracket Head Support Attach 40% Rear Seat		1.00	HSLA	350	450	S	0.380	0.380
TOTAL										**10.151**	**10.151**

Instrument Panel Structure

Number			Name	Blnk No.	Gage (mm)	Material Type	Yield Strength	Tensile Strength	Manuf. Process	C-Class	PNGV-Class
AVC	1	1302	Bracket Steering Column Attachment		2.50	Mild	140	270	S	1.775	1.775
AVC	1	1303	Crossmember Instrument Panel		2.00	DP *	350	600	ST	3.260	3.260
AVC	1	1304	Bracket C-Member Inst Panel Support RH		2.00	Mild	140	270	S	0.220	0.220
AVC	1	1305	Bracket C-Member Inst Panel Support LH		2.00	Mild	140	270	S	0.220	0.220
AVC	1	1306	Brace C-Member Inst Panel Support (x2)		2.00	Mild *	140	270	ST	0.720	0.720
AVC	1	1307	Plate C-Member Inst Panel Attachment (x2)		2.00	Mild	140	270	S	0.120	0.120
TOTAL										**6.315**	**6.315**

Bumper Beam Structure

Number			Name	Blnk No.	Gage (mm)	Material Type	Yield Strength	Tensile Strength	Manuf. Process	C-Class	PNGV-Class
AVC	1	1009	Assy Crash Box Bumper Front (x2)		1.10	DP	400	700	S	1.408	1.408
AVC	1	1012	Bumper Beam Front Inner		1.00	Mart	1250	1520	RF	1.940	1.940
AVC	1	1013	Bumper Beam Front Outer		1.00	Mart	1250	1520	S	2.640	2.640
AVC	1	1206	Assy Crash Box Bumper Rear (x2)		1.00	HSLA	350	450	S	0.920	0.920
AVC	2	1047	Bumper Beam Rear Inner		0.80	Mart	1250	1520	RF	1.312	
AVC	2	1048	Bumper Beam Rear Outer		0.80	Mart	1250	1520	S	2.064	
AVC	3	1047	Bumper Beam Rear Inner		0.80	Mart	1250	1520	RF		1.536
AVC	3	1048	Bumper Beam Rear Outer		0.80	Mart	1250	1520	S		2.336
TOTAL										**10.284**	**10.780**

* denotes **Tube**

ULSAB-AVC Master Parts List

Number	Name	Blnk No.	Gage (mm)	Material Type	Grade (MPa) Yield Strength	Grade (MPa) Tensile Strength	Manuf. Process	Designed Mass (kg) C-Class	Designed Mass (kg) PNGV-Class

Suspension

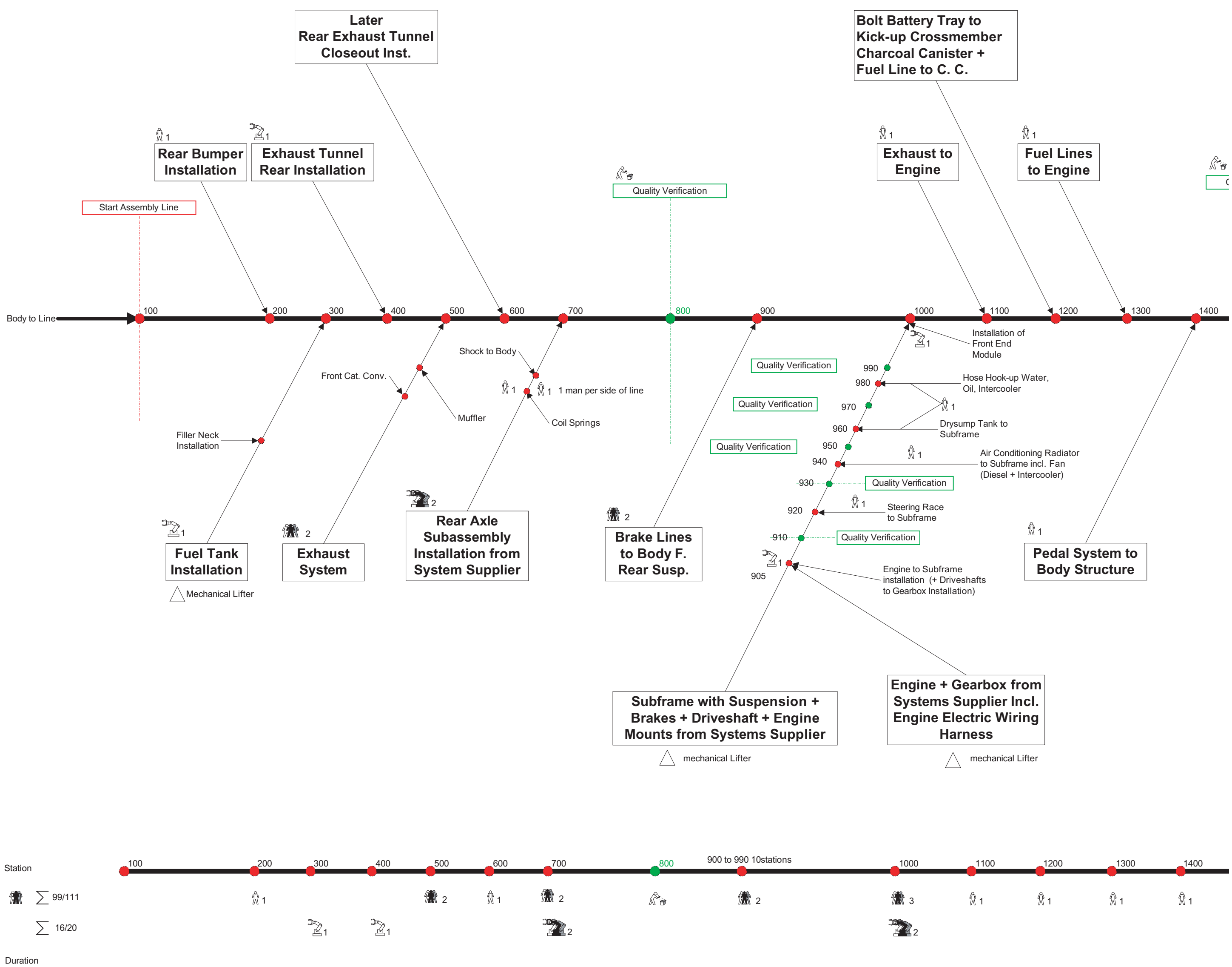
Number	Name	Blnk No.	Gage (mm)	Material Type	Yield Strength	Tensile Strength
AVC 1 3121	Assembly Module Front Axle					
AVC 1 3135	Subframe					
AVC 1 3135	U Pipe		2.0	DP *	350	600
AVC 1 3135	Cross member rear		2.0	DP	350	600
AVC 1 3135	Retaining plate (2 parts)		2.0	DP	350	600
AVC 1 3135	Brackets control arms (2 parts)		2.0	DP	350	600
AVC 1 3135	Brackets radiator (2 parts)		1.0	DP	350	600
AVC 1 3135	Inner frame (2 parts)		2.0	DP	350	600
AVC 1 3135	Outer frame (2 parts)		2.0	DP	350	600
AVC 1 3143	Leaf spring with support rubber					
AVC 1 3123	Shock Absorber Front (2 parts)					
AVC 1 3125	Steering gear					
AVC 1 3171	Assembly-lower wishbone (2 parts)					
AVC 1 3173	Lower wishbone	1	2.0	SF	570	640
AVC 1 3173	Lower wishbone	2	1.6	SF	570	640
AVC 1 3181	Spring console		2.0	DP	350	600
AVC 1 3183	Assembly-upper wishbone (2 parts)					
AVC 1 3185	Upper wishbone	1	2.0	SF	570	600
AVC 1 3185	Upper wishbone	2	1.6	SF	570	600
AVC 1 3161	Steering knuckle complete (2 parts)					
AVC 1 3163	Inner shell		3.0	DP	350	600
AVC 1 3165	Outer shell		3.0	DP	350	600
AVC 1 3193	Brakes					
AVC 1 3131	Drive shafts					
AVC 1 3127	Steering column assembly					
AVC 1 3129	Steering wheel assembly					
AVC 1 3221	Rear Axle Module					
AVC 1 3231	Twistbeam Axle welding assembly					
AVC 1 3237	Trailing arm (2 parts)	1	3.0	DP	350	600
AVC 1 3237	Trailing arm (2 parts)	2	2.2	DP	350	600
AVC 1 3233	Twist-beam profile		2.5	MnB	1200	1600
AVC 1 3235	Spring plate (2 parts)		2.5	DP	350	600
AVC 1 3239	Wheel carrier (2 parts)		5.0	DP	350	600
AVC 1 3227	Spring (2 parts)					
AVC 1 3223	Shock Absorber Rear (2 parts)					

Wheels

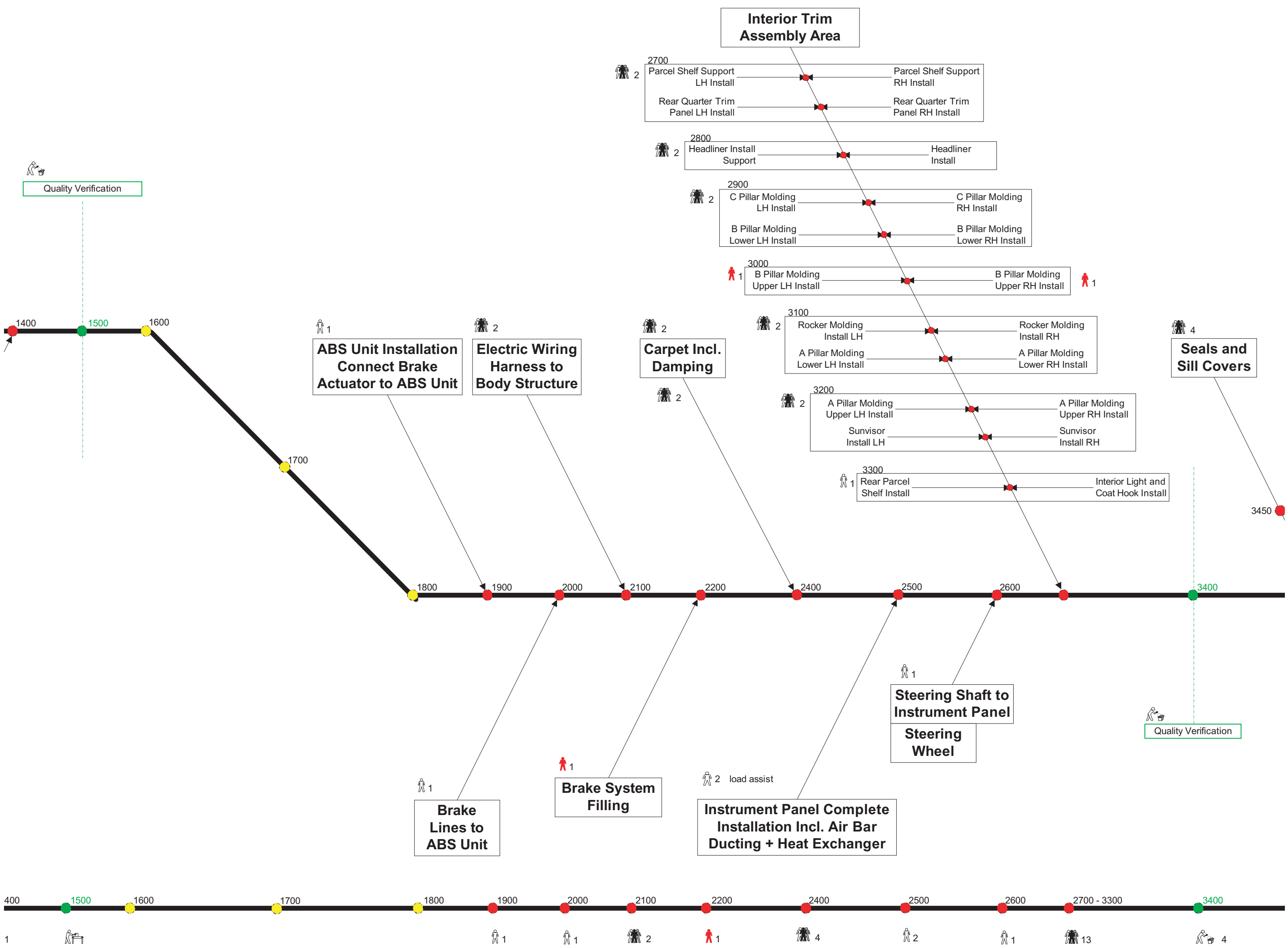
Number	Name	Blnk No.	Gage (mm)	Material Type	Yield Strength	Tensile Strength
AVC 1 3281	Wheels (4)					
AVC 1 3283	Rim - outer	1	1.2	DP	350	600
AVC 1 3283	Rim - center	2	1.8	HSLA	490	600
AVC 1 3283	Rim - inner	3	1.2	DP	350	600
AVC 1 3283	Disc		2.1	DP	500	800
AVC 1 3285	Tire					
AVC 1 3281	Bolts (4 per wheel)					

* denotes **Tube**

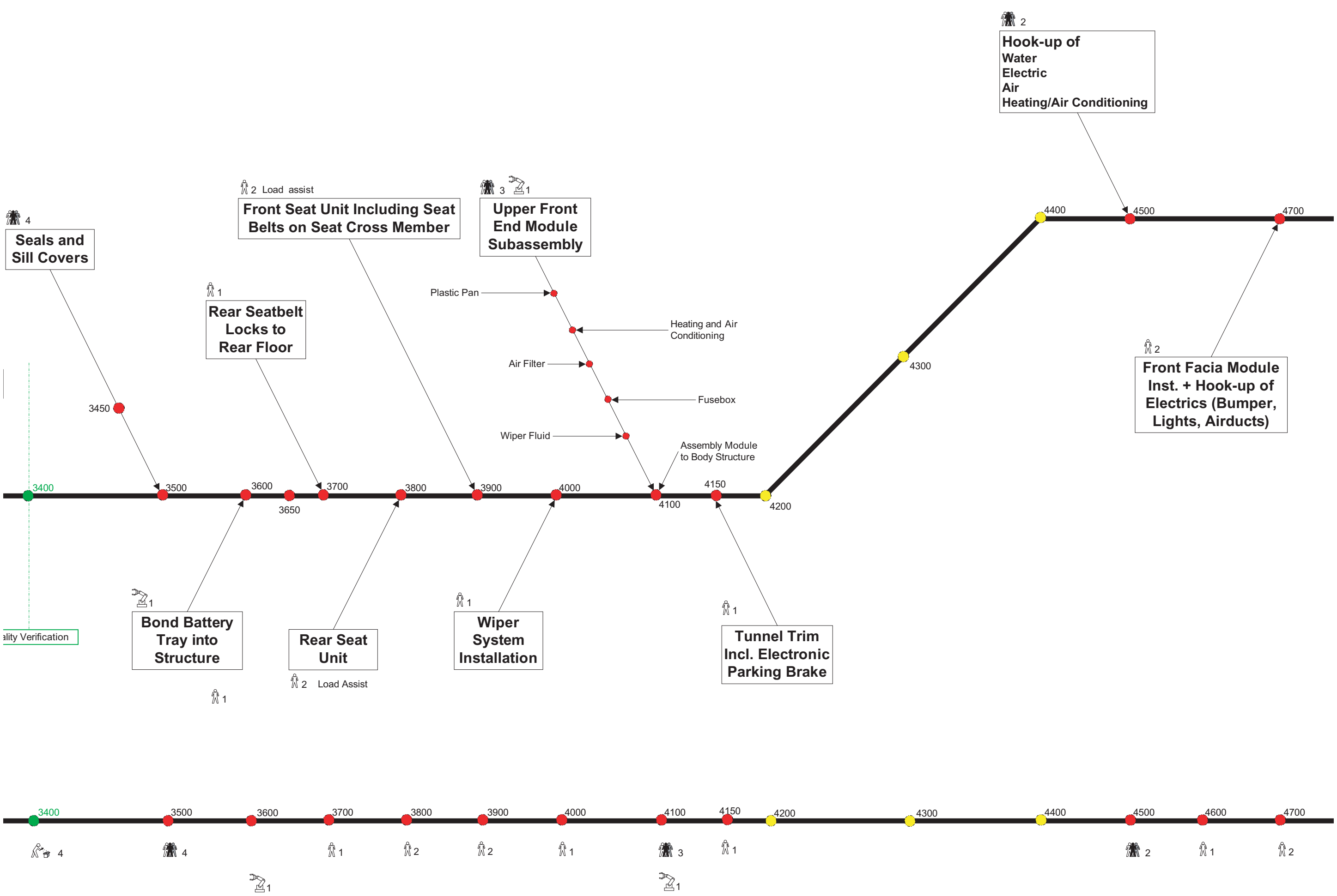
ULSAB-AVC Appendix 2: Final Trim Line



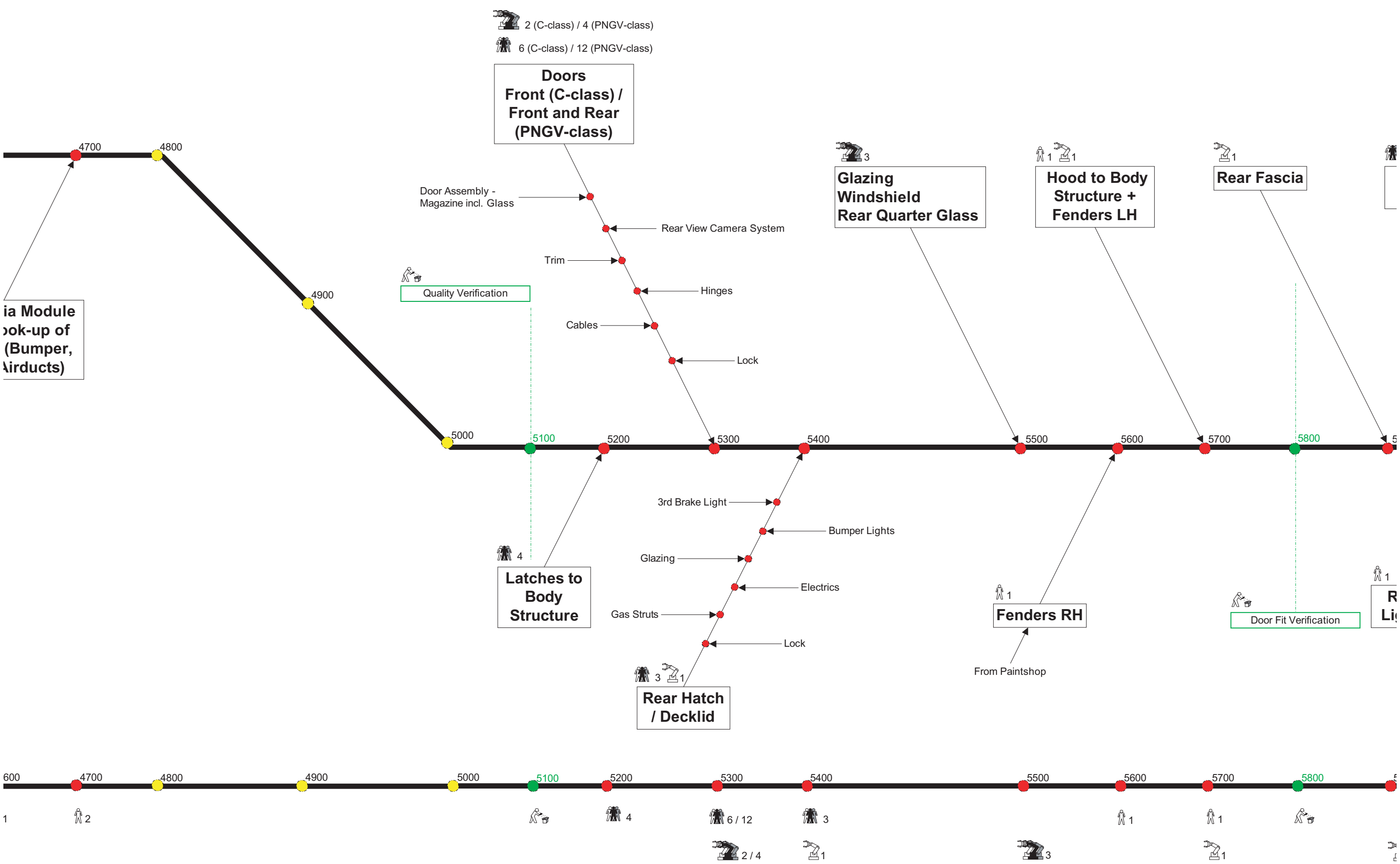
ULSAB-AVC Appendix 2: Final Trim Line



ULSAB-AVC Appendix 2: Final Trim Line

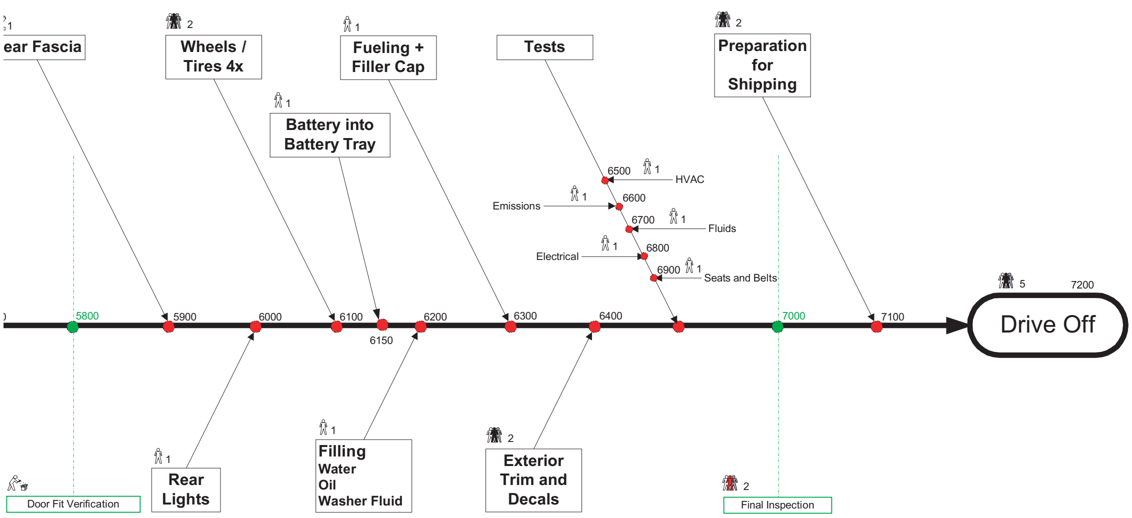


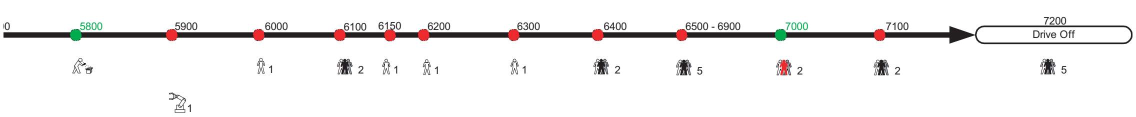
ULSAB-AVC Appendix 2: Final Trim Line



ULSAB-AVC Appendix 2: Final Trim Line

Version 08/21/01





Appendix 3: AHSS Definitions

The fundamental metallurgy of conventional low- and high-strength steels is generally well understood by manufacturers and users of steel products. Since the metallurgy and processing of AHSS grades is, however, somewhat novel compared to conventional steels, they will be described briefly to provide a baseline understanding of how their unique mechanical properties evolve from their unique processing and structure.

Dual Phase (DP) Steels

The microstructure of dual phase (DP) steels is composed of soft ferrite and, depending on strength, between 20 and 70% volume fraction of hard phases, normally martensite*. Figure 1 displays the microstructure of a DP ferrite + martensite steel with 350 MPa yield strength and 600 MPa. The soft ferrite phase is generally continuous, giving these steels excellent ductility. When these steels deform, however, strain is concentrated in the lower strength ferrite phase, creating the unique high work hardening rate exhibited by these steels.

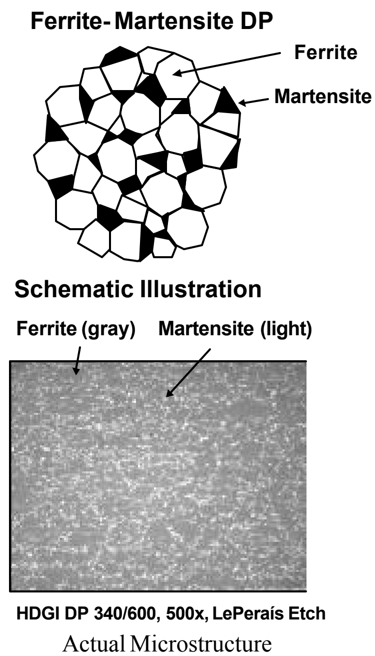


Figure 1. Microstructure of dual phase steel.

The work hardening rate along with excellent elongation combine to give DP steels much higher ultimate tensile strength than conventional steels of similar yield strength. Figure 2 illustrates this, where the quasi-static stress-strain behavior of high strength, low alloy (HSLA) steel is compared with that of a DP steel of similar yield strength. The DP steel exhibits higher initial work hardening rate, uniform and total elongation, ultimate tensile strength, and lower YS/TS ratio than the similar yield strength HSLA. DP and other AHSS also have another important benefit compared with conventional steels. The bake hardening effect, which is the increase in yield strength resulting from prestraining (representing the work hardening due to stamping or other manufacturing process) and elevated temperature aging (representing the curing temperature of paint bake ovens) continues to increase with increasing strain. Conventional bake hardening effects, of BH steels for example, remain somewhat constant after prestrains of about 2%. The extent of the bake hardening effect in AHSS depends on the specific chemistry and thermal histories of the steels. DP steels are designed to provide ultimate tensile strengths of up to 1000 MPa.

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*In some instances, especially for hot rolled steels requiring enhanced capability to resist stretching on a blanked edge (as typically measured by hole expansion capacity), the microstructure can also contain significant quantities of bainite.

In DP steels, carbon enables the formation of martensite at practical cooling rates. That is, it increases the hardenability of the steel. Manganese, chromium, molybdenum, vanadium and nickel added individually or in combination also increase hardenability. Carbon also strengthens the martensite as a ferrite solute strengthener, as do silicon and phosphorus. Silicon also strengthens the martensite since it helps to partition carbon to the austenite to increase its hardenability and the strength of the resultant martensite phase. These additions are carefully balanced, not only to produce unique mechanical properties, but also to minimize any difficulties with resistance spot welding, which is, in general good. However, when welding the highest strength grade (DP 700/1000) to itself, the spot weldability may require welding practice adjustments.

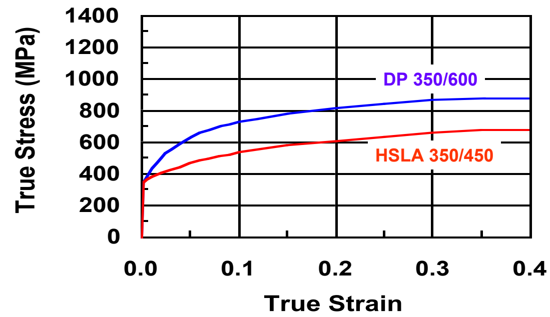

Figure 2 Comparison of quasi-static stress-strain behavior of HSLA 350/450 and DP 350/600 steels.

Transformation Induced Plasticity (TRIP) Steels

The microstructure of TRIP steels consists of a continuous ferrite matrix containing a dispersion of hard second phases--martensite and/or bainite. These steels also contain retained austenite in volume fractions greater than 5%. A typical TRIP steel microstructure is shown in Figure 3.

During deformation, the dispersion of hard second phases in soft ferrite creates a high work hardening rate, as observed in the DP steels. However, in TRIP steels, the retained austenite also progressively transforms to martensite with increasing strain, thereby increasing the work hardening rate at higher strain levels. This is schematically illustrated in Figure 4, where the stress-strain behavior of HSLA, DP and TRIP steels of approximately similar yield strengths are compared. The TRIP steel has a lower initial work hardening rate than the DP steel, but the hardening rate persists at higher strains where that of the DP begins to diminish.

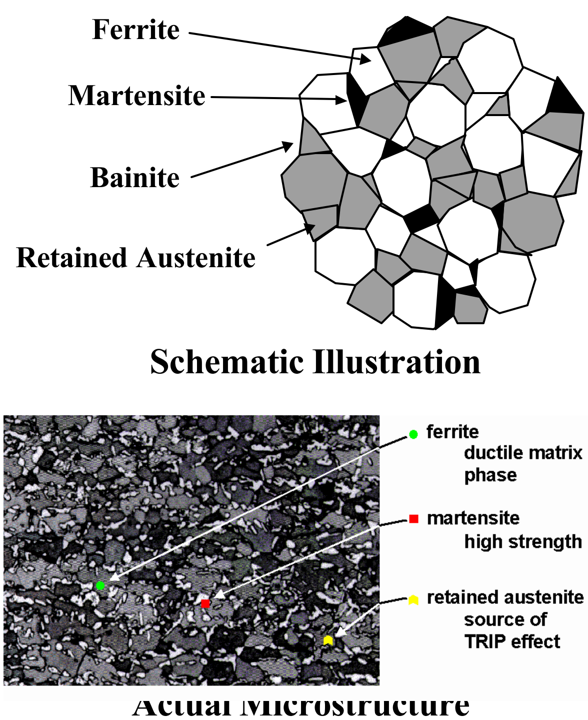

Figure 3. Microstructure of TRIP steel

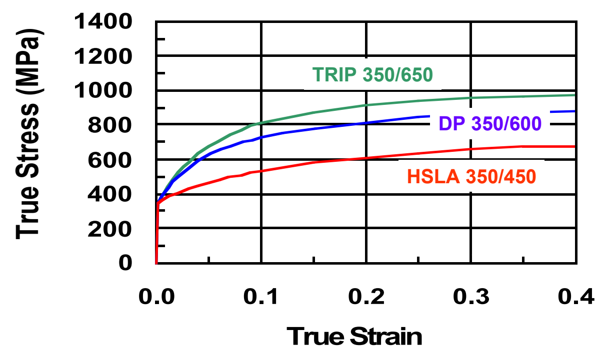

Figure 4. Comparison of the stress-strain behaviors of HSLA 350/450, DP 350/600, and TRIP 350/650 steels.

The work hardening rates of DP and TRIP steels are substantially higher than for conventional HSS, providing DP and TRIP with significant formability advantages. This is particularly useful when designers take advantage of the high work hardening rate (and increased Bake Hardening effect) and design to as-formed mechanical properties. High work hardening rate persists to higher strains in TRIP steels, providing a slight advantage over DP in the most severe stretch forming applications.

TRIP steels use higher quantities of carbon and silicon and/or aluminum than DP steels to lower the martensite finish temperature to below ambient temperatures to form the retained austenite phase. The strain level at which retained austenite begins to transform to martensite can be designed by adjusting carbon content. At lower carbon levels, the retained austenite begins to transform almost immediately upon deformation, increasing work hardening rate and formability during the stamping process. At higher carbon contents, the retained austenite is more stable and begins to transform only at strain levels beyond those produced during stamping and forming. At these carbon levels the retained austenite persists into the final part. It transforms to martensite during subsequent deformation, such as a crash event, and provides greater crash energy absorption. TRIP steels can therefore be engineered or tailored to provide excellent formability for manufacturing complex AHSS parts or to exhibit high work hardening during crash deformation to provide excellent crash energy absorption. The additional alloying requirements of TRIP steels degrade their resistance spot welding behavior. This can be addressed somewhat by modification of the welding cycles used (for example, pulsating welding or dilution welding).

Complex Phase (CP) Steels

Complex phase steels typify the transition to steel with very high ultimate tensile strengths. CP steels consist of a very fine microstructure of ferrite and a higher volume fraction of hard phases, that are further strengthened by fine precipitates. They use many of the same alloy elements found in DP and TRIP steels, but additionally have small quantities of niobium, titanium and/or vanadium to form fine strengthening precipitates. Complex phase steels provide ultimate tensile strengths of 800 MPa and greater. Under the conditions of strain and strain rates typically encountered in a crash, this AHSS absorbs greater energy. Complex phase steels are characterized by high deformability, high energy absorption, and high residual deformation capacity. Typical candidate applications for CP steels are those that require high energy absorption capacity in the elastic and low-plastic range, such as bumper and B-Pillar reinforcements.

Martensitic (Mart) Steels

In martensitic 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 annealing line. (This structure can also be developed with post-forming heat treatment) Martensitic steel microstructure largely contains lath martensite as shown in Figure 5.

Tempered Martensite (M190), 500x

Figure 5. Microstructure of martensitic steels.

Martensitic steels provide the highest strengths, up to 1500 MPa ultimate tensile strengths. Martensitic steels are often subjected to post-quench tempering to improve ductility, and can provide remarkable formability even at extremely high strengths.

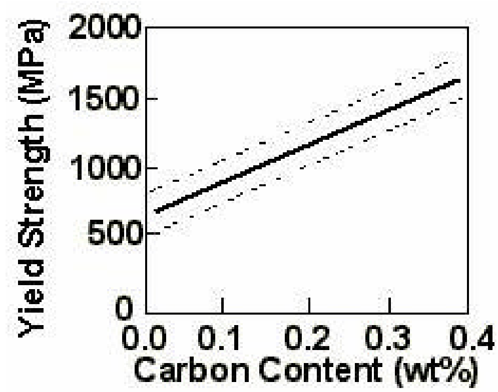

Figure 6. Relation between carbon content and yield strength in untempered martensite

Carbon is added to martensitic steels to increase hardenability and also to strengthening the martensite. The data of Figure 6 illustrate the relationship between carbon content and 0.2% offset yield strength in untempered martensite. Manganese, silicon, chromium, molybdenum, boron, vanadium, and nickel are also used in various combinations to increase hardenability.

Advanced High-Strength Steel Processing

All AHSS are produced by controlling the cooling rate from the austenite or austenite plus ferrite phase, either on the runout table of the hot mill (for hot rolled products) or in the cooling section of the continuous annealing furnace (continuously annealed or hot dip coated products). AHSS cooling patterns and resultant microstructures are schematically illustrated on the continuous cooling-transformation diagram. See in Figure 7. Martensitic steels are produced from the austenite phase by rapid quenching to

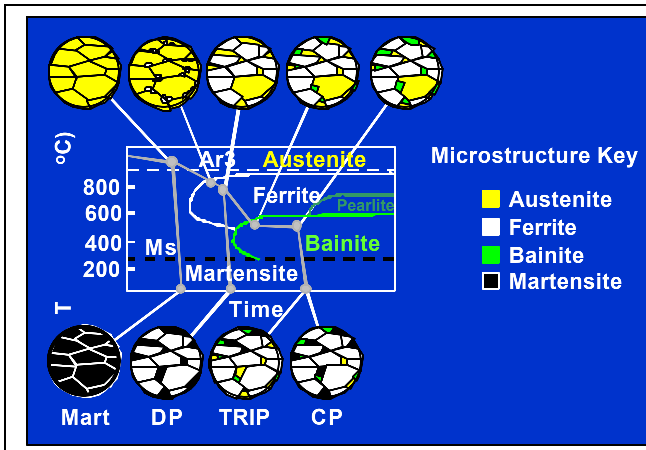

Figure 7. Cooling patterns and micro structural evolution in the production of AHSS.

transform most of the austenite to martensite. Dual phase ferrite + martensite steels are produced by controlled cooling from the austenite phase (in hot rolled products) or from the two-phase ferrite + austenite phase (for continuously annealed and hot dip coated products) to transform some austenite to ferrite before rapid cooling to transform the remaining austenite to martensite. TRIP steels typically require the use of an isothermal hold at an intermediate temperature, which produces some bainite. The higher silicon and carbon content of TRIP steels also results in significant volume fractions of retained austenite in the final microstructure. Complex phase steels also follow a similar cooling pattern, but here, the chemistry is adjusted to produce less retained austenite and form fine precipitates to strengthen the martensite and bainite phases.

Appendix 4: Affordability References

Updated Selling Price Data

An investigation on selected C-Class models evaluated the selling price change from the original August 2000 selling price study report to August 2001 selling prices. Results are summarized below:

Table34: C-Class 2001 Selling Price Data (all data in Euros)

Selected Models	Original (Aug 2000)	Updated (Aug 2001)	Difference	Comments
Opel Astra	14601	14612	+11	Same features
VW Golf	14885	15758	+873	ESP system incl'd in both
Ford Focus	14254	15843	+1589	Aug 2001 without alarm system
Peugeot 306/307	12804	14783	+1979	Current 307 is successor of 306

Overhead Costs References

Automotive manufacturers have different definitions of what is included in their manufacturing and overhead costs. Additionally, automotive manufacturers use different approaches to calculate the selling price of their vehicles depending on vehicle class, vehicle positioning in the market (high end/low end), market location (country/continent), or if the vehicle has to intrude a market (introduction of a new model line). This makes it difficult to generalize overhead costs.

For overhead cost groups, the following literature references offer some information concerning automotive overhead cost estimates:

- North American Dealers Association (NADA) Annual Statistics, NADA Data 2000
- Vyas, Santani and Cuenca, Argonne National Laboratories, Comparison of Indirect Cost Multipliers for Vehicle Manufacturing, April 2000
- Sliwa, Chen and Mahajan, Ernst & Young, Improving Customer Value Delivery

Every cost model user should use his or her own data for the logistics and overhead costs.