5. Design and Engineering

5. Design and Engineering

5.1. Phase 2 Design and Engineering Approach

After the package was revised and the styling frozen, the challenge in Phase 2 was to maintain the structural performances, especially the mass, as analyzed in the Phase 1 concept. Further research into steel sandwich material led to additional changes in the Phase 2 design. Because of restrictions in size and application of the material, new design solutions had to be created to compensate for the advantages in mass reductions using sandwich material as it was applied in Phase 1. The hydroformed parts were analyzed for manufacturing feasibility using the detailed design data created in Phase 2. The restrictions of the hydroforming process, in combination with the refinement of the design, led to different concepts, design adjustments, and new solutions to achieve the target for mass. Furthermore, the 50% off-set crash, an additional crash analysis introduced in Phase 2, significantly influenced the design of parts, the application of steel grades, the material thicknesses and in particular, the changes to tailor welded blanks.

Every change in the design process also had to be analyzed for its suitability for assembly and parts manufacturing. The design approach was driven by mass reduction and created innovative results without allowing initial component cost consideration to limit options. The design also focused on a production volume of more than 100,000 units per year.

As well as concentrating on reaching the targets for performance and mass, importance was also placed on the reduction of assembly steps, the integration of reinforcements, the use of tailor welded blanks, and the avoidance of metal arc welding, wherever possible. Using the same design approach in both Phases 1 and 2, it was possible to maintain low mass and high structural performances. The Phase 1 design concept and approach, the flexibility of the concept and the potential that it could be adjusted to various design tasks, were challenged in Phase 2 and ultimately justified.

5.2. Design and Engineering Process

The design and engineering process used in Phase 2 is shown in the flow chart (Fig. 5.2-1). All through this process, a simultaneous engineering approach was taken to find the best solutions to overcome the design and engineering challenges emerging in Phase 2.

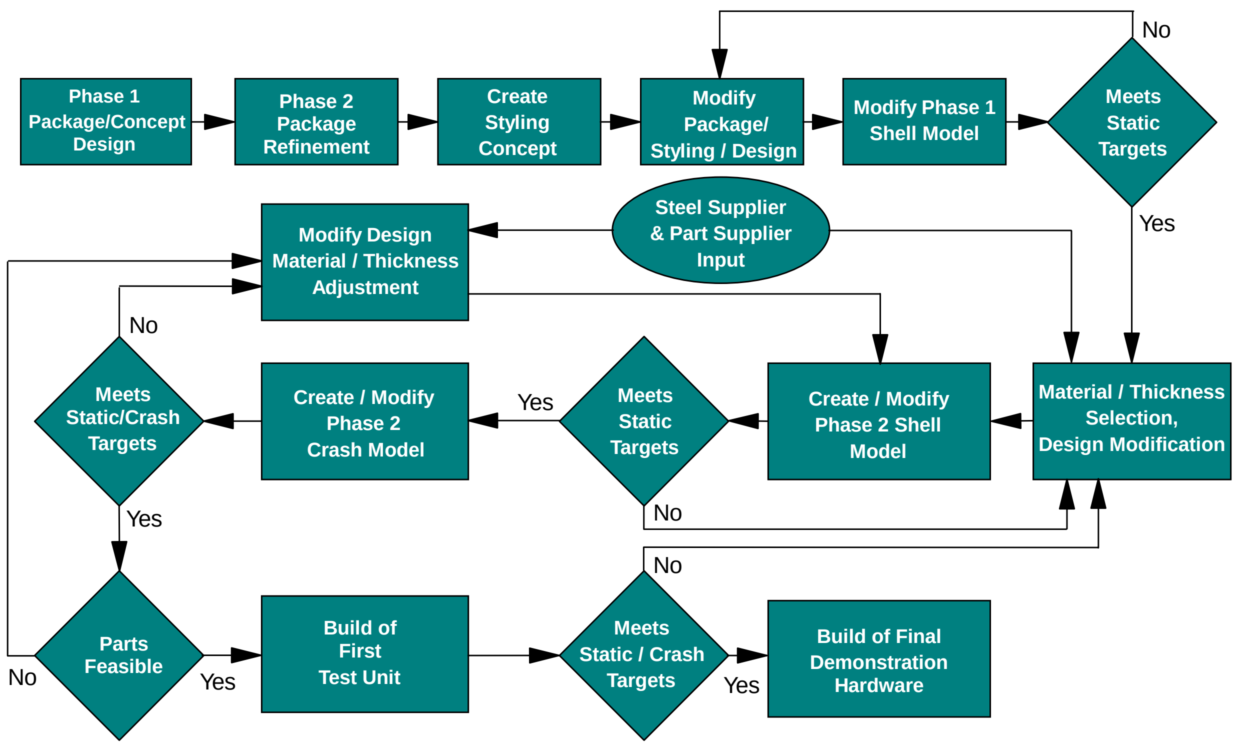


Figure 5.2-1 *Design and Engineering Process*

Using the Phase 1 package and concept design as the starting point, Phase 2 then refines the package. This refined Phase 2 package was the basis for the first styling layout, and in an interactive process, both were adjusted until the engineering requirements were met. The styling was frozen and the Phase 1 shell model was adjusted and analyzed using material thickness optimization to achieve the mass target while maintaining the structural performance goals. Together with the selected suppliers and the Material Group of the ULSAB Consortium, the part design was discussed and the material thicknesses were selected. With this information, the design was revised and the Phase 2 shell model created, analyzed and modified until all targets were met. New Phase 2 crash analysis models were built and after the first analysis, design modifications, material grade and thickness selection, further crash analyses were performed, until the results were satisfactory. With the revised design and material selection, the shell model was updated and the static analysis performed. The crash and static analysis models were constantly updated as a result of information from tool, part and steel suppliers. This was repeated until all results were satisfactory. The design was then modified and the part drawings released to the suppliers. With the first part set delivered, a test unit was built and the tests following provided the results for static performance and most importantly for mass. The design was enhanced and material substituted as needed. The process of shell and crash model modifications and analysis was performed again to validate the design. After the final design was released to the suppliers, parts were manufactured and the demonstration hardware built.

Part of this process included regular design review meetings (not shown in the flow chart) of the design and engineering team as well as design review meetings with the demonstration hardware build team, engineers and analysts at Porsche R & D Center in Germany. In these internal PES meetings, technical problems were discussed and design directions decided in order to prepare for the demonstration hardware build and meet established deadlines.

5.3. ULSAB Phase 2 Design Description

Figure 5.3-1 ULSAB Demonstration Hardware

The ULSAB structure went through many adjustments and modifications in its transition from the Phase 1 concept to its final design stage at the end of Phase 2. This was due to added crash performance requirements, package issues, manufacturing processes and material application limitations. The exploded view (see Fig. 5.3-2) shows the demonstration hardware in the final Phase 2 design stage with the exception of minor brackets and reinforcements. Bolt-on parts and components, used in the analysis for crash performance, such as front and rear bumpers, engine, suspension, subframe, shock tower braces, tunnel bridge and fenders, are not considered part of the body structure and therefore are not shown in the exploded view. However, the structure is equipped with important brackets and reinforcements. Because tailor welded blanks can eliminate reinforcements, fewer were required. Included in the demonstration hardware, as shown on the exploded view, are the bolt-on front-end module and the dash-panel insert, including the brake booster reinforcement.

5.3.1. Parts List – Demonstration Hardware

The parts list (Fig. 5.3.1-1) corresponds directly with the exploded view of the demonstration hardware (Fig. 5.3.1-2) and shows the part name and number, the material grade, and thickness and the mass of the manufactured part. Parts listed that have two or more material thicknesses and grades indicate that this part is made from a tailor welded blank. The mass of the parts listed, is taken from actual manufactured parts, but does not represent an average of all parts manufactured. Therefore, the mass of the demonstration hardware can vary slightly in comparison to the listed mass of the total number of parts.

Demonstration Hardware Parts List

Part No		Part Name		Material Grade (MPa)	Material Thickness (mm)	Actual Part Mass (kg)
001		Assy Reinf Radiator Support Upper	(Bolted on)	350	1.00	1.613
002		Reinf Front Rail Extension RH		350	1.00	0.485
003		Reinf Front Rail Extension LH		350	1.00	0.489
008	A	Assy Rail Front Outer RH		350	1.50	3.013
	B	*(Tailor Welded Blank)*		350	1.60	
	C			350	2.00	
009	A	Assy Rail Front Outer LH		350	1.50	3.037
	B	*(Tailor Welded Blank)*		350	1.60	
	C			350	2.00	
010	A	Assy Rail Front Inner RH		350	1.50	5.470
	B	*(Tailor Welded Blank)*		350	1.60	
	C			350	1.80	
011	A	Assy Rail Front Inner LH		350	1.50	5.500
	B	*(Tailor Welded Blank)*		350	1.60	
	C			350	1.80	
012		Rail Front Extension RH		350	1.40	2.096
013		Rail Front Extension LH		350	1.40	2.061
014		Bracket Roof Rail Mount Lower RH		350	1.20	0.153
015		Bracket Roof Rail Mount Lower LH		350	1.20	0.150
021		Panel Dash		210	0.70	5.830
022		Panel Dash Insert	(Bolted on)	Sandwich	0.95	0.875
026		Member Dash Front		600	1.20	2.290
028		Panel Cowl Lower		210	0.70	1.272
032		Panel Cowl Upper		210	0.70	1.374
034		Assy Member Front Floor Support (2-Req'd)		800	0.70	1.290
038		Assy Reinf Floor Front Seat Rear Outer (2-Req'd)		280	0.80	0.120
040		Pan Front Floor		210	0.70	14.650

Figure 5.3.1-1

Demonstration Hardware Parts List (Cont'd)

Part No		Part Name	Material Grade (MPa)	Material Thickness (mm)	Actual Part Mass (kg)
042	A	Panel Rocker Inner RH	350	1.30	6.490
	B	*(Tailor Welded Blank)*	350	1.70	
043	A	Panel Rocker Inner LH	350	1.30	6.625
	B	*(Tailor Welded Blank)*	350	1.70	
045		Member Rear Suspension	280	0.70	1.344
046	A	Assy Rail Rear Inner RH	350	1.00	5.250
	B	*(Tailor Welded Blank)*	350	1.30	
	C		350	1.60	
047	A	Assy Rail Rear Inner LH	350	1.00	5.240
	B	*(Tailor Welded Blank)*	350	1.30	
	C		350	1.60	
048	A	Assy Rail Rear Outer RH	350	1.00	2.527
	B	*(Tailor Welded Blank)*	350	1.30	
	C		350	1.60	
049	A	Assy Rail Rear Outer LH	350	1.00	2.565
	B	*(Tailor Welded Blank)*	350	1.30	
	C		350	1.60	
050		Panel Spare Tire Tub (Bonded on)	Sandwich	0.96	2.107
055		Member Panel Back	210	0.65	1.305
057		Panel Back	140	0.65	2.502
060	A	Panel Body Side Outer RH	210	0.70	15.780
	B	*(Tailor Welded Blank)*	280	0.90	
	C		280	1.30	
	D		350	1.50	
	E		350	1.70	
061	A	Panel Body Side Outer LH	210	0.70	15.650
	B	*(Tailor Welded Blank)*	280	0.90	
	C		280	1.30	
	D		350	1.50	
	E		350	1.70	
062		Panel A-Pillar Inner Lower RH	350	1.00	1.365
063		Panel A-Pillar Inner Lower LH	350	1.00	1.375
064		Panel B-Pillar Inner RH	350	1.50	3.586
065		Panel B-Pillar Inner LH	350	1.50	3.586
066		Reinf B-Pillar Lower (2-Req'd)	350	0.90	0.830
068		Panel Wheelhouse Inner RH	210	0.65	1.931
069		Panel Wheelhouse Inner LH	210	0.65	1.923
070	A	Panel Wheelhouse Outer RH	140	0.65	2.116
	B	*(Tailor Welded Blank)*	210	0.80	
071	A	Panel Wheelhouse Outer LH	140	0.65	2.194
	B	*(Tailor Welded Blank)*	210	0.80	

Figure 5.3.1-1

Demonstration Hardware Parts List (Cont'd)

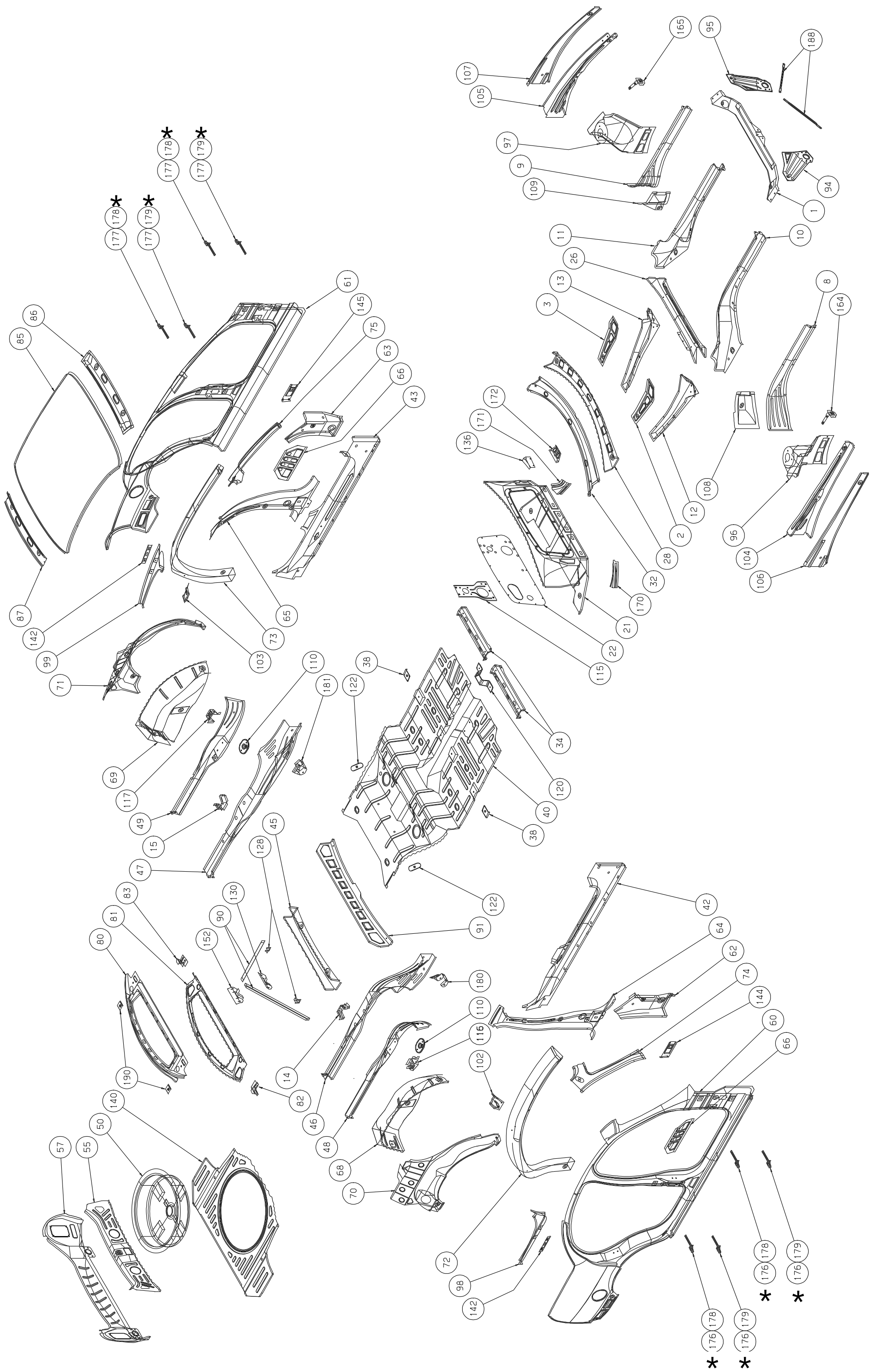
Part No		Part Name		Material Grade (MPa)	Material Thickness (mm)	Actual Part Mass (kg)
072		Rail Side Roof RH		280	1.00	4.700
073		Rail Side Roof LH		280	1.00	4.860
074		Panel A-Pillar Inner Upper RH		350	1.50	1.425
075		Panel A-Pillar Inner Upper LH		350	1.50	1.416
080		Panel Package Tray Upper		210	0.65	1.876
081		Panel Package Tray Low er		210	0.65	1.497
082		Support Package Tray RH		280	0.80	0.084
083		Support Package Tray LH		280	0.80	0.076
085		Panel Roof		210	0.70	8.680
086		Panel Front Header		280	0.70	0.813
087		Panel Rear Header		140	0.70	0.773
090		Member Pass Through (2-Req'd)		140	0.65	0.662
091		Member Kick Up		800	0.70	1.397
094		Reinf Radiator Rail Closeout RH	(Bolted on)	350	1.00	0.567
095		Reinf Radiator Rail Closeout LH	(Bolted on)	350	1.00	0.575
096	A	Panel Skirt RH		140	2.00	3.457
	B	*(Tailor Welded Blank)*		140	1.60	
097	A	Panel Skirt LH		140	2.00	3.468
	B	*(Tailor Welded Blank)*		140	1.60	
098		Panel Gutter Decklid RH		140	0.65	0.434
099		Panel Gutter Decklid LH		140	0.65	0.437
102		Support Panel Rear Header RH		140	0.70	0.098
103		Support Panel Rear Header LH		140	0.70	0.098
104		Rail Fender Support Inner RH		420	1.20	2.712
105		Rail Fender Support Inner LH		420	1.20	2.699
106		Rail Fender Support Outer RH		350	0.90	1.297
107		Rail Fender Support Outer LH		350	0.90	1.297
108		Reinf Front Rail RH		350	1.00	0.838
109		Reinf Front Rail LH		350	1.00	0.830
110		Plate Rear Spring Upper (2-Req'd)		350	2.00	0.526
115		Reinf Panel Dash Brake Booster	(Bolted on)	350	1.00	0.464
116		Assy Bracket Rear Shock Absorber Mount RH		350	2.00	0.335
117		Assy Bracket Rear Shock Absorber Mount LH		350	2.00	0.339
120		Reinf Floor Front Seat Rear Center		350	1.20	0.250
122		Assy Reinf Rear Seat Inner Belt Mount (2-Req'd)		350	2.00	0.244
128		Bracket Member Pass Through Low er (2-Req'd)		350	1.00	0.056
130		Bracket Member Pass Through Upper Front		350	1.00	0.129
136		Reinf Panel Dash Upper		350	1.00	0.100
140		Pan Rear Floor		210	0.70	4.240
142		Assy Reinf Hinge Decklid (2-Req'd)		350	1.50	0.224
144		Reinf A-Pillar RH		350	1.50	0.229

Figure 5.3.1-1

Demonstration Hardware Parts List (Cont'd)

Part No	Part Name	Material Grade (MPa)	Material Thickness (mm)	Actual Part Mass (kg)
145	Reinf A-Pillar LH	350	1.50	0.230
152	Bracket Member Pass Through Upper Rear	350	1.00	0.145
164	Assy Closeout Fender Support Rail RH	350	1.00	0.115
165	Assy Closeout Fender Support Rail LH	350	1.00	0.115
170	Reinf Rail Dash RH	350	1.30	0.309
171	Reinf Rail Dash LH	350	1.30	0.312
172	Assy Reinf Cowl Lower	350	1.00	0.127
455	Assy Hinge Door Upper RH (2-Req'd)	280	-	0.515
456	Assy Hinge Door Lower RH (2-Req'd)	280	-	0.549
457	Assy Hinge Door Upper LH (2-Req'd)	280	-	0.515
458	Assy Hinge Door Lower LH (2-Req'd)	280	-	0.549
180	Bracket Trailing Arm Mount RH	350	2.00	0.333
181	Bracket Trailing Arm Mount LH	350	2.00	0.341
188	Brace Radiator (2-Req'd) (Bolted on)	350	0.80	0.250
190	Assy Reinf Seat Belt Retractor Rear (2-Req'd)	350	1.20	0.104
			Total Mass of Parts	**196.770**

Figure 5.3.1-1



* See Assemblies 455 - 458

Figure 5.3.1-2 ULSAB Phase 2 Exploded View

5.3.2. ULSAB Structure Mass

For the Phase 1 concept, it was assumed that future average body structures would contain approximately 12 kg of brackets and reinforcements. This number can vary, up or down, depending on the type of vehicle, i.e., front or rear wheel drive, and the package of components. Since the goal of the ULSAB program is to provide solutions for a generic concept, it was assumed in Phase 1 that the 12 kg for brackets and reinforcements have to be considered in the calculation for mass to give the Phase 1 results more credibility. In Phase 1, the ULSAB structure was calculated with a mass of 193 kg. With the 12 kg for brackets and reinforcements, the total mass equals 205 kg. In Phase 2, some of the brackets and reinforcements are already welded into the structure. These are reflected accordingly in the mass of the demonstration hardware and also included in the parts list. With the refinement of the Phase 2 package, minor brackets and reinforcements were designed (but not manufactured) and their mass was calculated to get a more accurate determination than the general assumption used in Phase 1. These brackets and reinforcements represent a more generic, than detailed, selection. The selection was based on package information, chosen components and engineering judgment. It can be assumed that in a possible Phase 3, the number of brackets and reinforcements, and their actual mass when manufactured, can be insignificantly higher or lower. This depends on the final component selection; their position in the structure and efforts made to minimize their mass. Also included in the mass calculation are 100 weld studs. This also represents a generic number for this type of structure and is based on engineering judgment. The calculated mass of the ULSAB structure (Fig. 5.3.2-1) is the measured mass of the demonstration hardware parts and the calculated mass of brackets and reinforcements shown in Fig. 5.3.2-2 and Fig. 5.3.2-3. The ULSAB structure mass in Phase 2 is 203 kg, with the variation assumed to be +/- 1%. This low variation is due to each part being manufactured from one coil of steel. The differences in sheet thicknesses between coils do not apply for the demonstration hardware, but would have to be considered in mass production.

ULSAB Structure Mass	=	Mass of Demonstration Hardware (Parts)	+	Calculated Mass of Brackets and Reinforcements
203.2 kg	=	196.8 kg	+	6.4 kg

Figure 5.3.2-1 Definition of ULSAB Structure Mass

Designed Brackets not Manufactured but Considered Part of the ULSAB Structure

Part No	Name	Qty	Calc Mass [Kg]
331	Bracket Exhaust Mount	2	0.060
332/333	Bracket Engine Mount RH/LH	2	0.528
334/335	Bracket Fender Mount Rear RH/LH	2	0.228
336	Bracket Battery Tray	1	0.412
337	Bracket Spare Tire Mount	1	0.089
338/339	Bracket Fuel Tank Mount Rear RH/LH	2	0.242
340	Bracket Front Tie Down Hook	2	0.236
341	Bracket Rear Tie Down Hook	2	0.236
342/343	Bracket Front Jack Support RH/LH	2	0.656
344/345	Bracket Rear Jack Support RH/LH	2	0.548
346	Bracket Plenum Support Center	1	0.445
N/A	Weld Studs ~ 100	-	0.300
	TOTAL	19	3.980

Figure 5.3.2-2

Designed Reinforcements not Manufactured but Considered Part of the ULSAB Structure

Part No	Name	Qty	Calc Mass [Kg]
310	Reinf Hood Hinge Mount	2	0.086
311	Reinf Instrument Panel Beam Mount	2	0.134
312/313	Reinf Sub-Frame Front Mount	2	0.050
314/315	Reinf Sub-Frame Center Mount	2	0.116
316/317	Reinf Sub-Frame Rear Mount	2	0.418
318	Reinf Steering Rack Assembly Mount RH	1	0.032
319	Reinf Steering Rack Assembly Mount LH	1	0.041
320	Reinf Gear Shift Mount	1	0.271
321	Reinf Front Door Lock Striker	2	0.106
322	Reinf Front Door Check Arm	2	0.030
323	Reinf Rear Door Lock Striker	2	0.146
324	Reinf Rear Door Check Arm	2	0.028
325	Reinf Front D-Ring Adjustment	2	0.298
326	Reinf Rear Seat Cushion Mount	2	0.140
327	Reinf Rear Seat Latch	2	0.068
328	Reinf Rear Seat Back Mount Outer	2	0.278
329	Reinf Rear Seat Back Mount Center	1	0.035
330	Reinf Deck Lid Latch	1	0.136
	TOTAL	31	2.413

Figure 5.3.2-3

5.3.3. ULSAB Demonstration Hardware Mass

The mass of the demonstration hardware is 196.770 kg. This reflects the total amount of the mass of one complete part set, including brackets, reinforcements and bolt-on parts, as measured.

In Phase 1, nearly all brackets and reinforcements were included in the theoretical number of 12 kg and only a few were included in the Phase 1 concept design of the body structure. With the level of detail design in Phase 2 and the refined package, it was now possible to design and finally manufacture most of these brackets and reinforcements and weld or bolt them to the demonstration hardware. It was not the task in Phase 2 of the ULSAB program to design and to manufacture all brackets and reinforcements and therefore, the approach to concentrate only on the important ones was taken.

The mass of these manufactured brackets, reinforcements and bolt-on parts is included in the demonstration hardware mass and listed in the parts list (Fig. 5.3.1-1). The parts are shown on the exploded view (Fig. 5.3.1-2).

For easier identification, the extracted list from the parts list (Fig. 5.3.3-2, -3 to Fig. 5.3.3-4) identifies these parts including their mass.

The mass of the demonstration hardware as shown in Fig 5.3.3-1, consists of the mass of the pure body structure and the mass of brackets, reinforcements, bolt-on parts manufactured and welded or assembled to the body structure.

DH Mass	=	Body Structure Mass	+	Mass of Brackets, Reinforcements, Bolt-on Parts, Welded and Assembled to the Body Structure
196.8 kg	=	186.6 kg	+	10.2 kg

Figure 5.3.3-1 Demonstration Hardware Mass Definition

Reinforcements Manufactured and Welded to Structure

Part No	Name	Qty	Mass [Kg]
038	Assy Reinf Floor Front Seat Rear Outer	2	0.120
110	Plate Rear Spring Upper	2	0.526
120	Reinf Floor Front Seat Rear Center	1	0.250
122	Reinf Rear Seat Inner Belt Mount	2	0.244
136	Reinf Panel Dash Upper	1	0.100
142	Assy Reinf Hinge Decklid	2	0.224
144	Reinf A-Pillar RH	1	0.229
145	Reinf A-Pillar LH	1	0.230
164	Assy Closeout Fender Support Rail RH	1	0.115
165	Assy Closeout Fender Support Rail LH	1	0.115
176	Hinge Base RH	4	0.650
177	Hinge Base LH	4	0.650
178	Hinge Stem 119	4	0.379
179	Hinge Stem 141	4	0.449
172	Assy Reinf Cowl Lower	1	0.127
190	Assy Reinf Seat Belt Retractor Rear	2	0.104
		33 parts	4.512

Figure 5.3.3-2

Brackets Manufactured and Welded to Structure

Part No	Name	Qty	Mass [Kg]
116	Assy Bracket Rear Shock Absorber Mount RH	1	0.335
117	Assy Bracket Rear Shock Absorber Mount LH	1	0.339
180	Bracket Trailing Arm Mount RH	1	0.333
181	Bracket Trailing Arm Mount LH	1	0.341
		4 parts	1.348

Figure 5.3.3-3

Bolt-On Parts Manufactured and Attached to Structure

Part No	Name	Qty	Mass [Kg]
001	Assembly Reinf Radiator Support Upper	1	1.613
022	Panel Dash Insert	1	0.875
094	Reinf Radiator Rail Closeout RH	1	0.567
095	Reinf Radiator Rail Closeout LH	1	0.575
115	Reinf Panel Dash Brake Booster	1	0.464
188	Brace Radiator	2	0.250
		7 parts	4.344

Figure 5.3.3-4

5.3.4. Mass of Brackets and Reinforcements – Phase 2

The total mass of all brackets and reinforcements, (meaning the calculated mass of designed, not manufactured parts) and bolted-on parts welded or assembled to the demonstration hardware, amounts to 16.6 kg, and is included in the ULSAB structure mass of 203.2 kg.

Total Mass of Brackets, Reinforcements & Bolt-on Parts - 16.6 kg

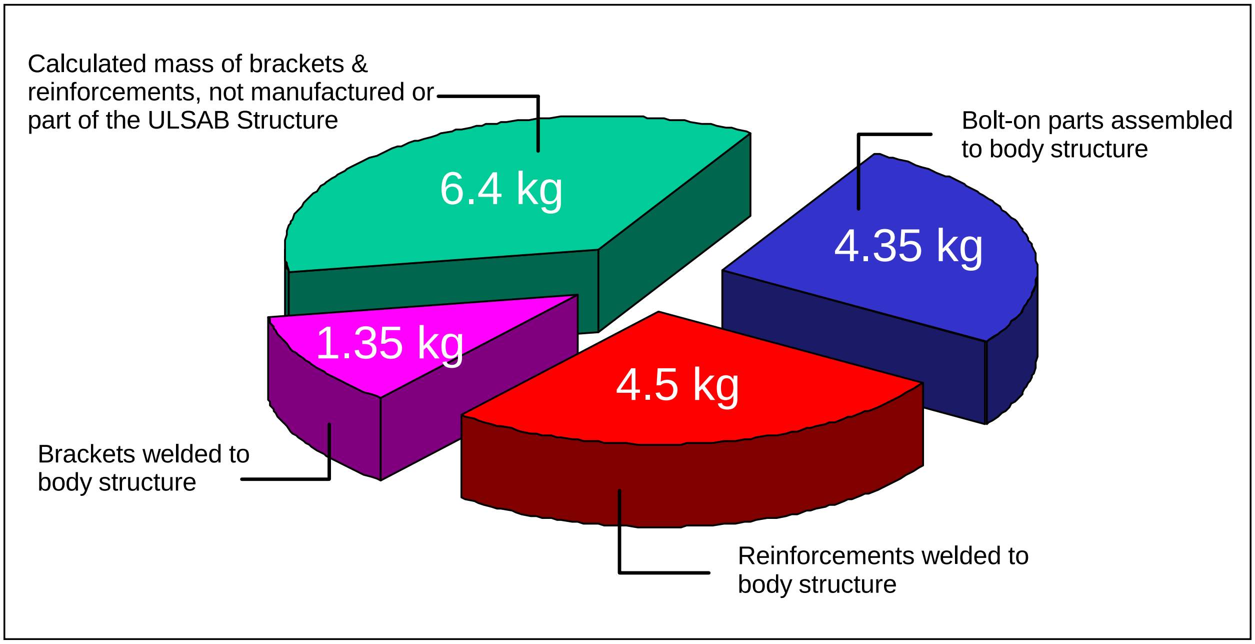


Figure 5.3.4-1 Mass Breakdown of Brackets, Reinforcements and Bolt-on Parts

5.3.5. ULSAB Structure Mass Comparison Phase 1 – Phase 2

The comparison of the results of the ULSAB structure mass is shown in Fig. 5.3.5-1. In Phase 2 the measured body structure mass has decreased with the refinement of the design, compared with the body structure mass as calculated in Phase 1.

The total calculated mass of 205 kg, as in the Phase 1 ULSAB structure, is compared to the Phase 2 ULSAB structure mass of 203.2 kg, which includes the actual mass of the demonstration hardware plus the calculated mass of brackets and reinforcements.

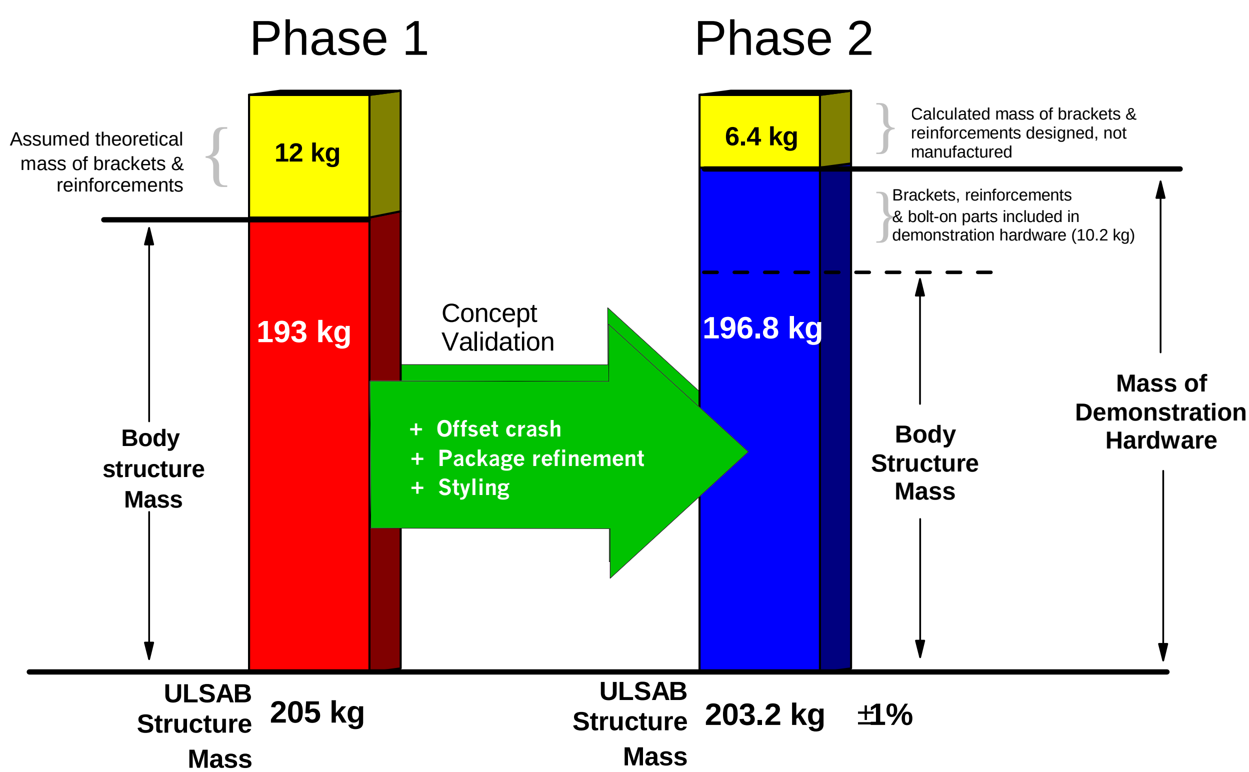


Figure 5.3.5-1 ULSAB Structure Mass Phase 1 - Phase 2

5.3.6. DH Part Manufacturing Processes

The ULSAB structure as developed during Phase 1 and refined in Phase 2 is in general, a unibody design, with the exception of the hydroformed side roof rails. Stamping was the main manufacturing process considered for the parts design.

Relative to the body structure mass of 196.8 kg, 89.2% is the mass of all stamped parts.

The stampings can be divided into two groups; conventional stampings and stamped parts made from tailor welded blanks. 42.8% of the body structure mass is represented by conventionally stamped parts and 44.9% is the mass of parts made from tailor welded blanks. This relatively high percentage of tailor welded blank stampings, relative to the body structure mass, is one good indication of how the mass reduction was achieved. Especially if the use of high strength steels, in connection with the tailor welded blanks, is put into consideration.

The hydroforming process is applied in the form of two processes:

- The tubular hydroforming process for the side roof rail manufacturing
- The hydromechanical sheet forming process, for the roof panel manufacturing.

The spare tire tub and the dash panel insert are designed to be manufactured from steel sandwich material, also using the stamping process.

The mass of the stamped parts made from steel sandwich material is 1.5% relative to the overall mass. 1.5% are miscellaneous parts, stock materials, such as tubes, or the forged hinge base of the weld through hinges.

The pie chart in Fig. 5.3.6-1 shows the mass distribution of the manufacturing processes relative to the DH mass.

The process used to manufacture the parts is shown in Fig. 5.3.6-2.

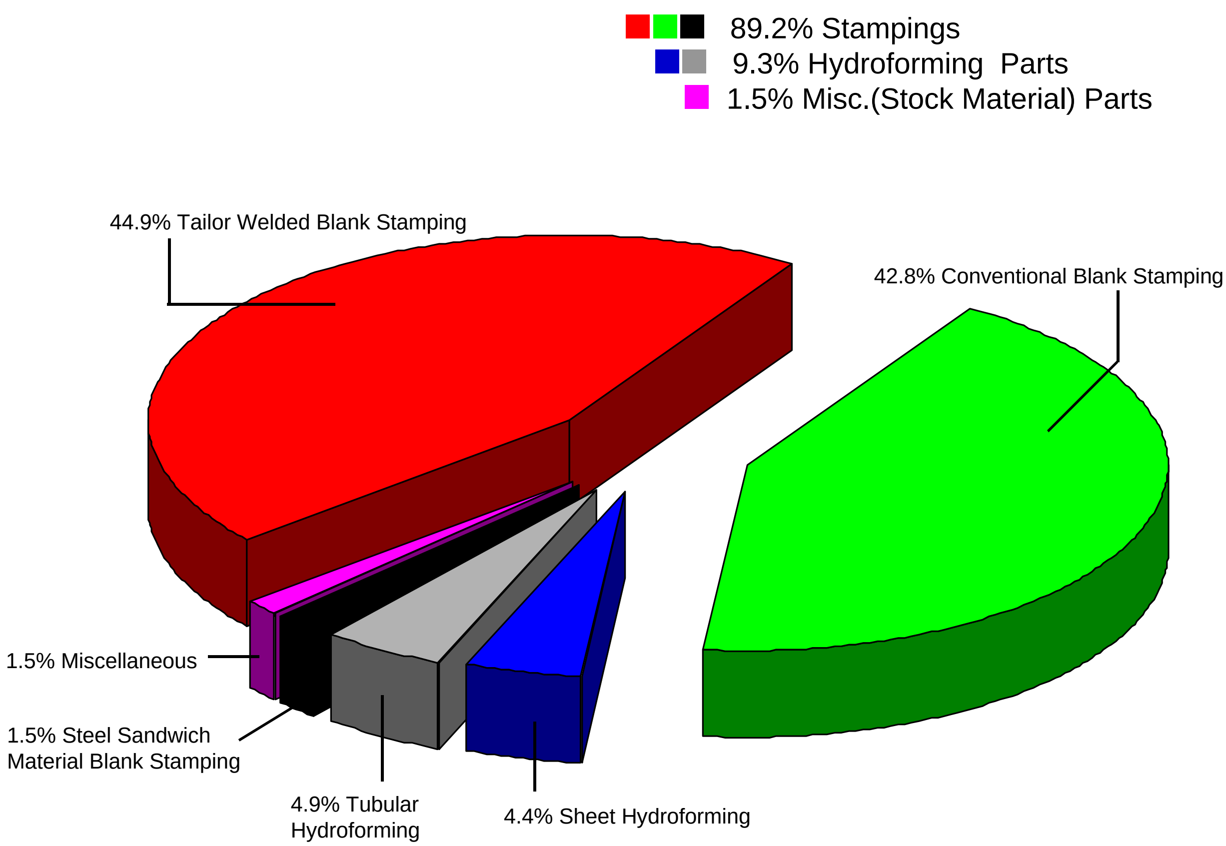
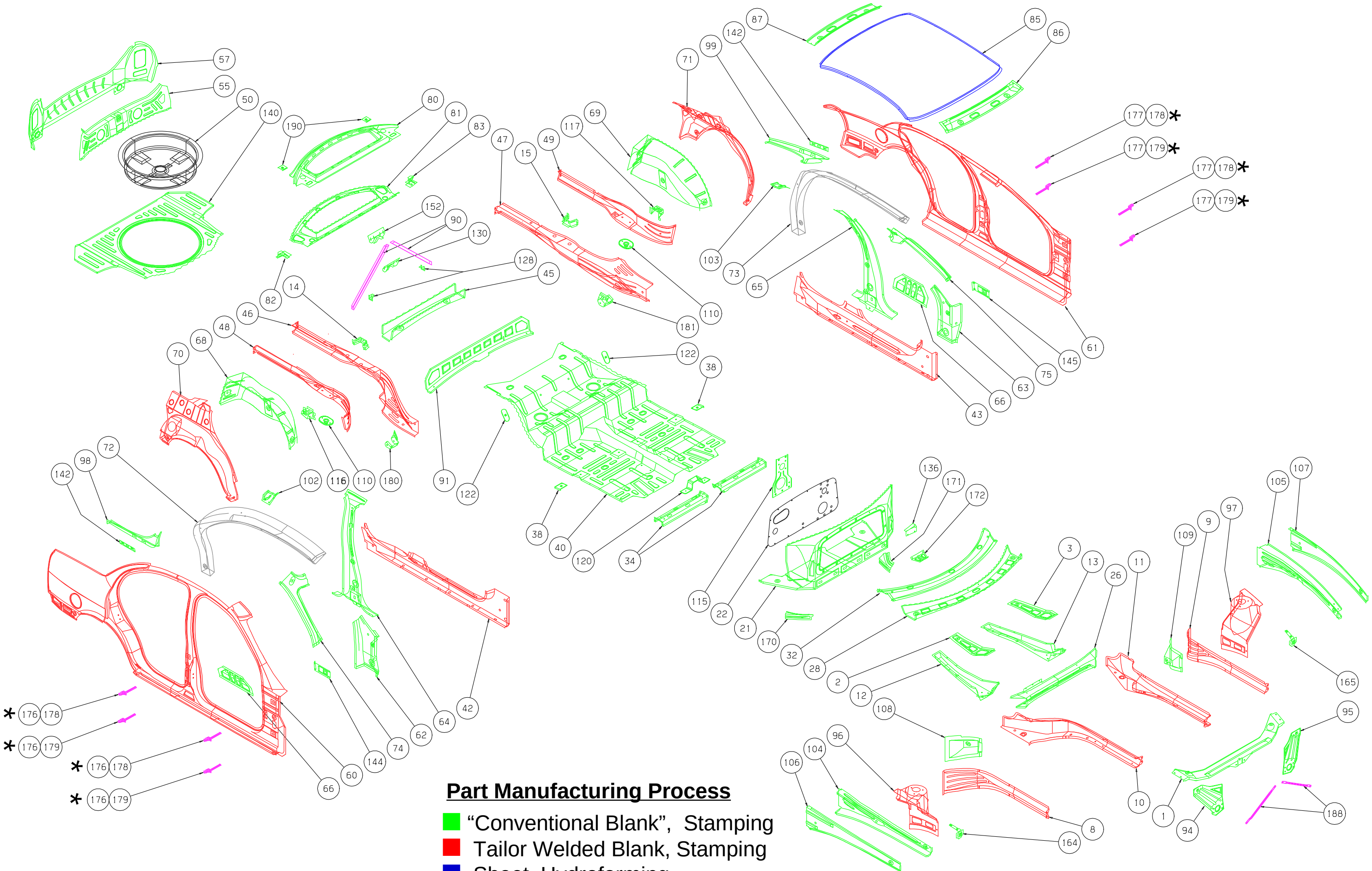


Figure 5.3.6-1 Manufacturing Process Relative to DH Mass



Part Manufacturing Process

- "Conventional Blank", Stamping
- Tailor Welded Blank, Stamping
- Sheet, Hydroforming
- Tubular Hydroforming
- Sandwich Material Blank, Stamping
- Misc.(Stock Materials)

** See Assemblies 455 - 458*

Figure. 5.3.6-2 ULSAB Manufacturing Processes of Demonstration Hardware Parts

5.3.7. Material Grades

The selection of the steel grades is a result of the need for good crash performance and mass reduction.

In Phase 2, the utilization of high strength steel is 91%, relative to the DH mass (Fig. 5.3.7-1) of Phase 1.

The parts design had to consider the lower elongation, and together with the tool manufacturer, the parts design was optimized to accommodate the different forming characteristics and greater spring back of high and ultra high strength steels. This was most important for the design of the tailor welded blank stamped parts which where different grades and thicknesses of high strength steels and combined into one part.

High strength and ultra high strength steel material was used on parts contributing to the crash management of the structure, i.e. front rails, rear rails, rocker, etc. (Fig. 5.3.7-2). With this approach, and in combination with tailor welded blanks, it was possible to avoid the need for reinforcements and thus reduced the total number of parts.

For mass reduction, steel sandwich material was applied in the spare tire tub and the dash panel insert. Steel sandwich material contributes to 1.5% of the DH mass.

Due to the overall design, material specifications of steel sandwich material and restrictions in its applications, such as low heat resistance and available size, this material's use was limited during Phase 2.

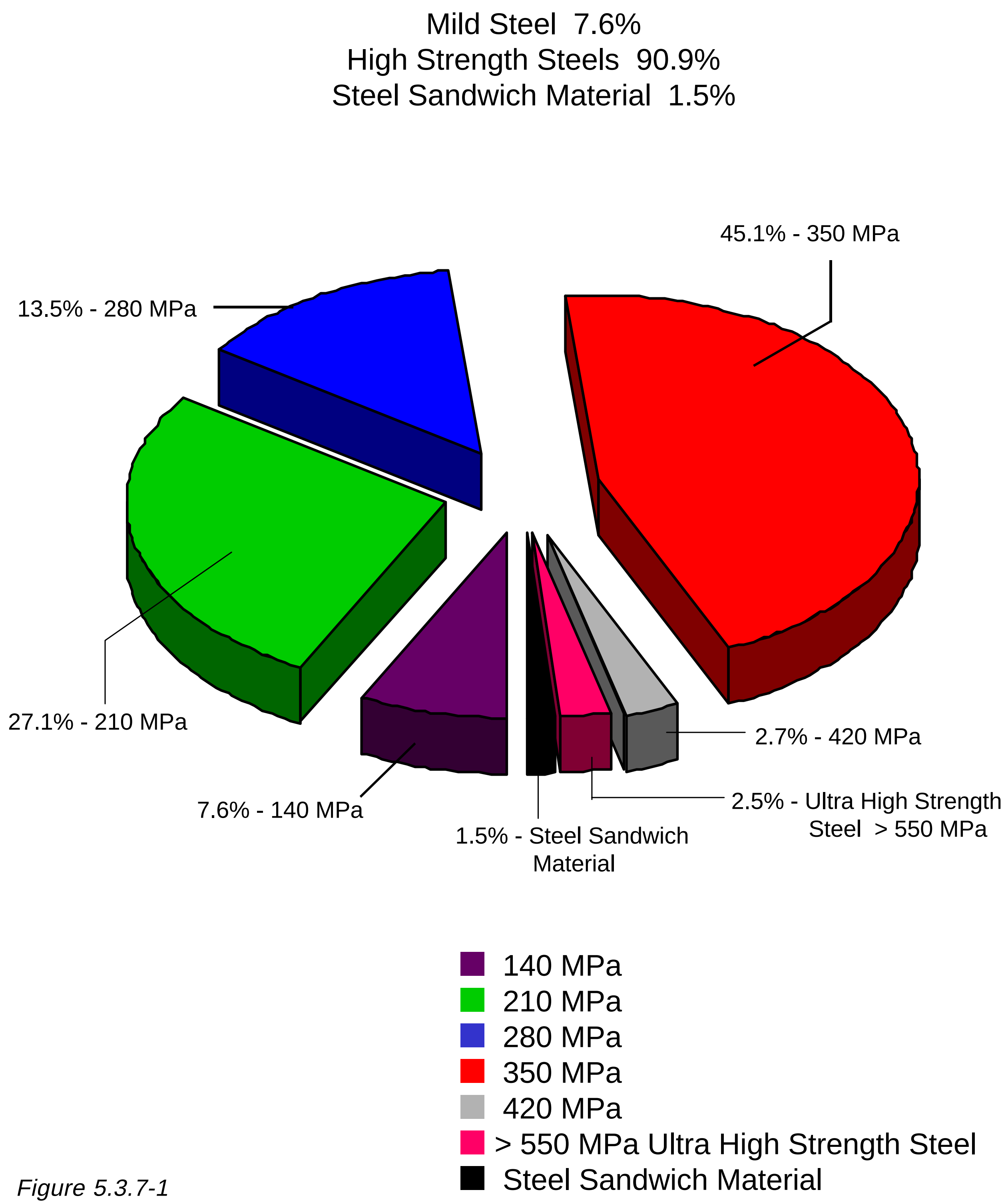
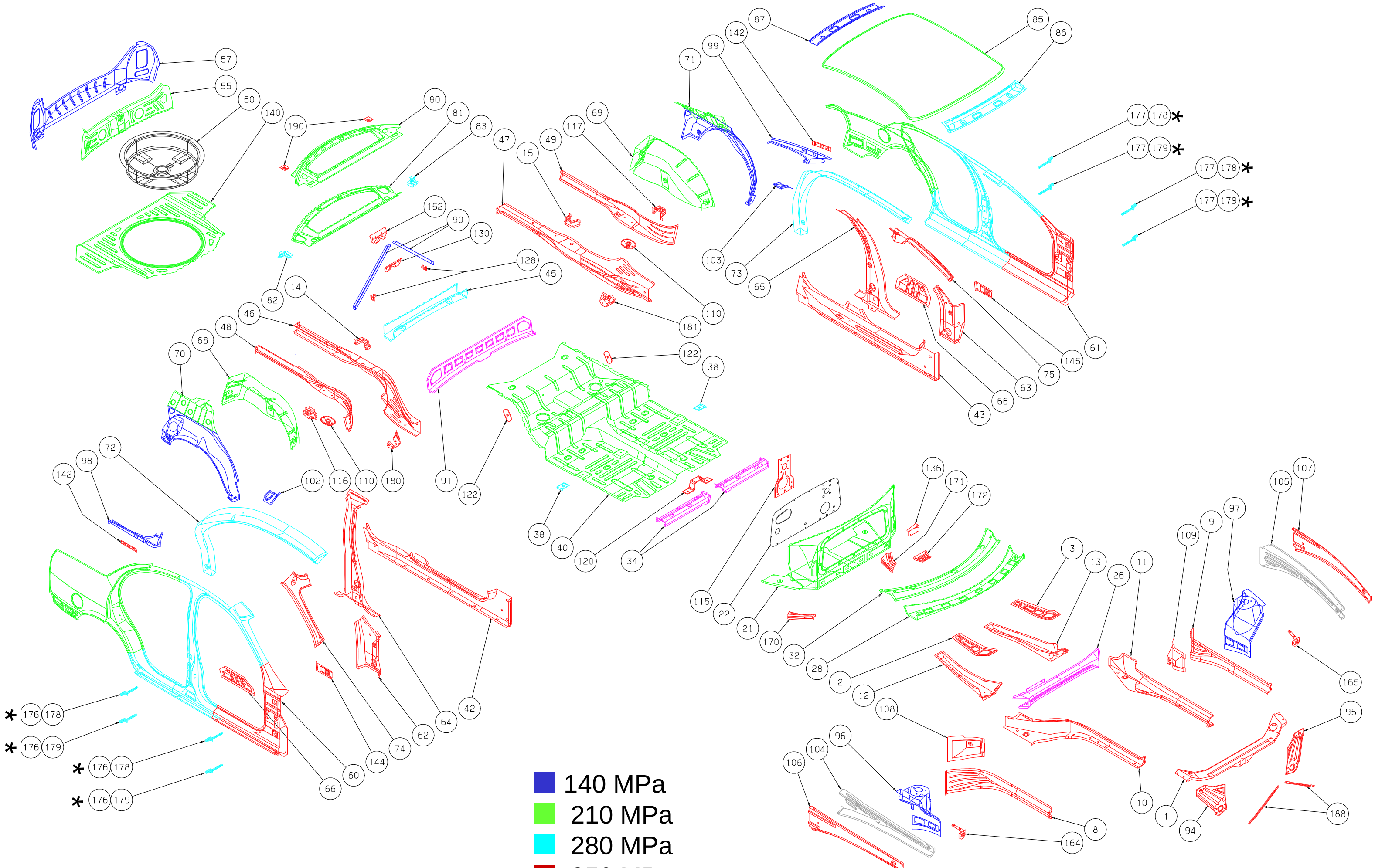

Mild Steel 7.6%
High Strength Steels 90.9%
Steel Sandwich Material 1.5%
45.1% - 350 MPa
13.5% - 280 MPa
27.1% - 210 MPa
2.7% - 420 MPa
7.6% - 140 MPa
2.5% - Ultra High Strength Steel > 550 MPa
1.5% - Steel Sandwich Material
140 MPa
210 MPa
280 MPa
350 MPa
420 MPa
> 550 MPa Ultra High Strength Steel
Steel Sandwich Material

Figure 5.3.7-1



■	140 MPa
■	210 MPa
■	280 MPa
■	350 MPa
■	420 MPa
■	>550 MPa
■	Steel Sandwich Material

** See Assemblies 455 - 458*

Figure. 5.3.7.-2 Material Grades of DH Parts

5.3.8. Material Thickness

The distribution of the used material sheet thicknesses relative to the DH mass is shown in Fig. 5.3.8-1. The majority of the mass (25%) is made from 0.7 mm sheet steel. Parts with a large surface area such as the panel floor, the panel dash and the panel roof are manufactured of high strength steel of this thickness, and are parts with secondary influence in crash performance.

All 1.3 mm thickness material is high strength steel with the yield strength ranging from 280 MPa (46%) to 350 MPa (54%). The parts made of 1.3 mm material used in “conventional” stampings and tailor welded blank stampings have primary influence on crash performance.

Since the demonstration hardware mass consists of 91% high strength steel, nearly all parts are made from high strength steel sheets in a thickness ranging from 0.65mm to 2.0mm.

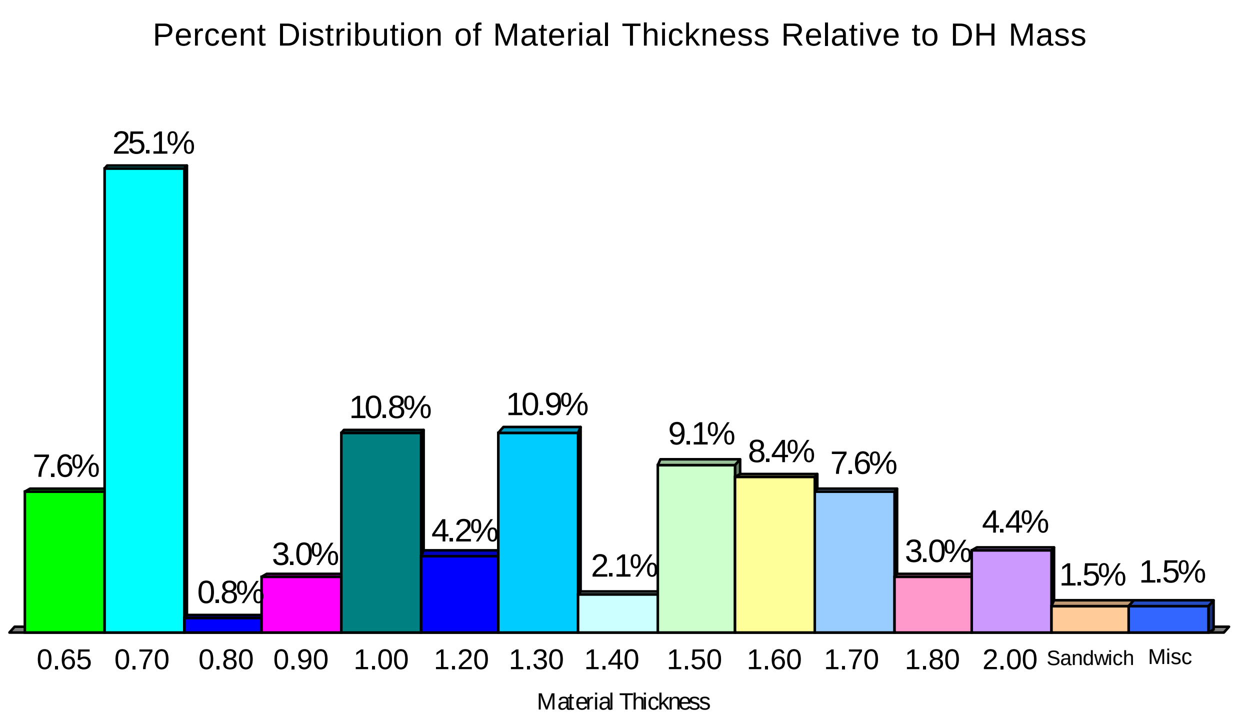


Figure. 5.3.8-1

5.4. Detail Design

PES executed an entirely paperless design using Computer Aided Design (CAD) and CATIA software for the detail design. With the involvement of part suppliers in the United States and Europe, the Porsche R & D Center, in Germany, and the necessary data exchange for the tool development and the design of the assembly fixtures, this approach proved to be very efficient.

5.4.1. Weld Flange Standards

For the detail parts design it was important to define standards for the design of the weld flanges. The decision was made not to reduce the weld flange width for mass reduction, which allowed the use of standard weld equipment for the demonstration hardware assembly.

5.4.1.1. Weld Flanges for Spot or Laser Welding

For the design of parts to be spot welded, the flange length was designed to the Porsche standards shown in Fig. 5.4.1.1-1.

For the laser welding in assembly, the same standards were applied.

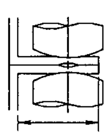
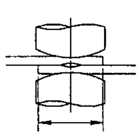
ULSAB Spotweld Standards											
Material Thickness (thickest panel only)	**0.65**	**0.75**	**0.8**	**0.9**	**1.0**	**1.25**	**1.5**	**1.75**	**2.0**	**2.5**	**3.0**
Electrode Tip Diameter	13.0	13.0	13.0	13.0	13.0	13.0	13.0	16.0	16.0	16.0	16.0
Edge of Weld Flange to Spotweld Center	4.4	4.6	4.7	5.0	5.2	5.8	6.2	6.5	7.0	7.6	8.2
Weld Flange Width 	14.0	14.0	14.5	15.0	15.5	16.0	17.0	18.0	18.5	19.0	19.5
Weld Flange Width 	10.0	10.5	10.5	11.0	11.5	12.5	13.5	14.5	15.0	16.5	17.5

Figure 5.4.1.1-1 ULSAB Spot Weld Standards

5.4.1.2. Scalloped Spot Weld Flanges

Scalloped flanges were used for mass reduction.

Figure 5.4.1.2-1 Part no. 81 Panel Package Tray Lower with Scalloped Flanges

The design is similar to the scalloped flanges used in production of the Porsche 911 and Boxster. The second reason for scalloping weld flanges was to create two sheet spot welding where three sheet spot welding would have been applied, otherwise. Scalloped flanges were applied to parts not critical for sealing and not sensitive to crash or durability. The mass reduction achieved with scalloped flanges on the selected parts, based on the calculated part mass equals 0.43 kg. (Fig. 5.4.1.2-4)

The flange geometry is shown in Fig. 5.4.1.2-2. The layout for a two sheet weld flange and a three sheet weld flange with scalloped flanges is shown in Fig. 5.4.1.2-3.

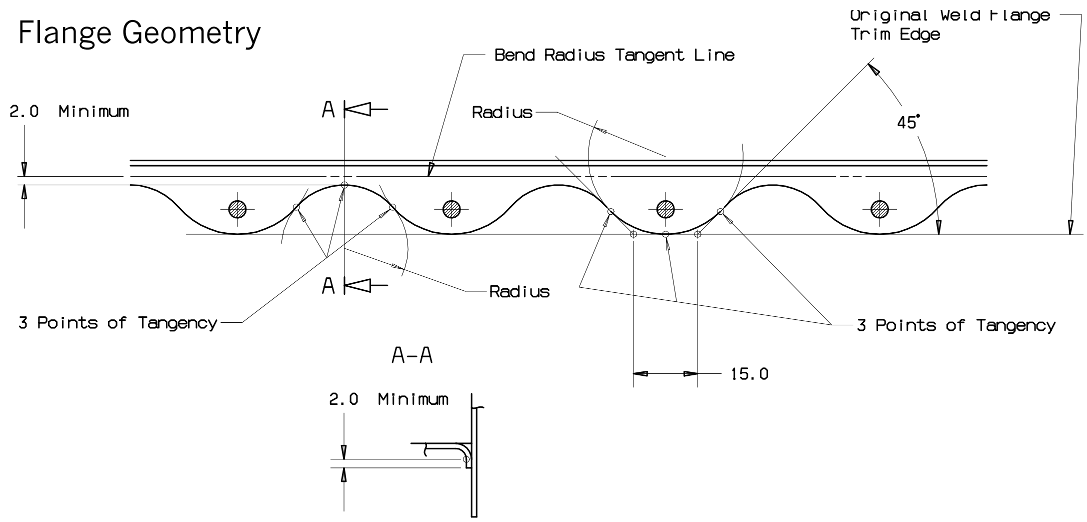


Figure 5.4.1.2-2 Flange Geometry

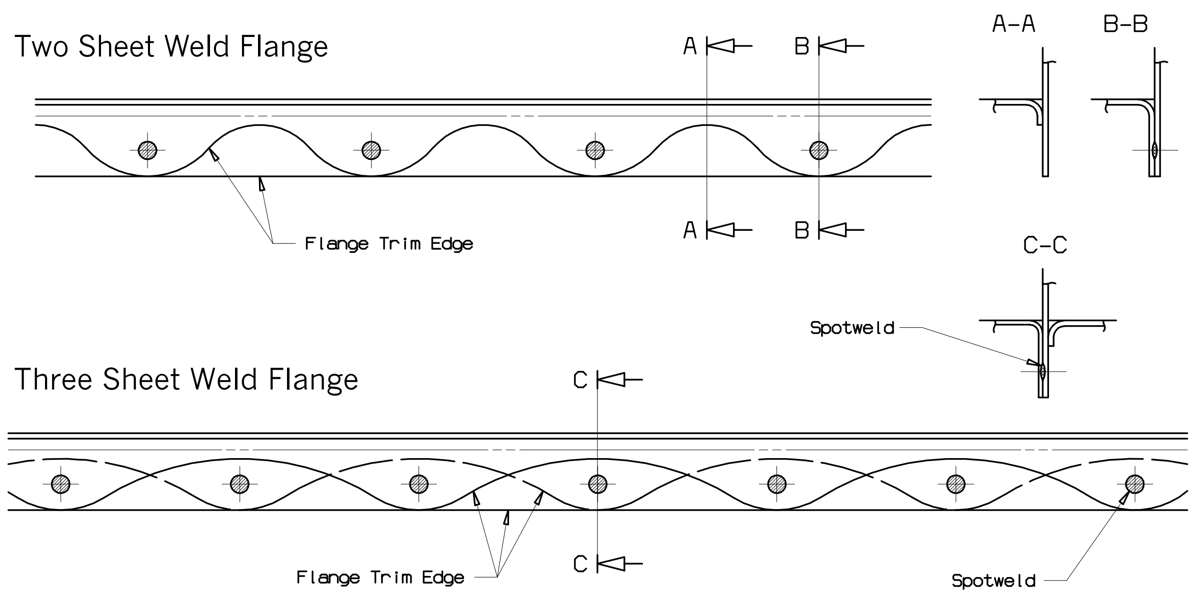


Figure 5.4.1.2-3 Layout of 2 and 3 Sheet Weld Flanges

Part Number	Part Name	Calculated Part Mass [kg]	Calculated Part Mass with Scalloped Flange [kg]	Mass Reduction [kg]
21	Panel Dash	6.180	6.140	0.040
28	Panel Cowl Lower	1.400	1.326	0.074
40	Pan Front Floor	15.934	15.892	0.042
45	Member Rear Suspension	1.486	1.440	0.046
55	Member Panel Back	1.450	1.424	0.026
68	Panel Wheelhouse Inner RH	2.141	2.110	0.031
69	Panel Wheelhouse Inner LH	2.141	2.110	0.031
81	Panel Package Tray Lower	1.700	1.594	0.106
140	Pan Rear Floor	4.330	4.298	0.032
				0.428

Figure. 5.4.1.2-4 Mass Reduction with Scalloped Flanges

5.4.1.3. Locator, Tooling and Electrophoresis Holes

Included in the detail part design are all locator holes for the assembly. All locator holes needed for parts manufacturing and the holes necessary for the electrophoresis of the body structure. After the location of the holes for electrophoreses were first determined, they were then incorporated into the crash models and the crash analysis was performed to verify that their position did not have any negative influence on the crash performance. After this verification, the holes were incorporated into the parts design.

5.4.2. Design Refinement

Phase 1 reflected a concept design. In Phase 2, the task was to make the design feasible for manufacturing of the parts to maintain low mass and structural performances and also, to achieve the crashworthiness of the structure. In the refinement of the design, changes to the design concept were done for the following reasons:

- Mass reduction
- Manufacturing and tooling
- Assembly
- Material specifications
- Crash performance
- Package
- Styling

The overview of design changes as shown in Fig. 5.4.2-1, names the parts or areas of the structure, the design change and the reason for the different solution or change from Phase 1 to Phase 2.

Overview of Major Design Changes in Phase 2

Part No.	Part / Location Area	Description of Change	Reason for Change
1	Fender Support Rail	Hydroforming part was replaced with 2 part stamping	Assembly, part manufacturing
2	Pan Front & Pan Rear Floor	3 part front floor with sandwich material tunnel deleted	Heat resistance of sandwich material not sufficient for bake hardening process
3	Rear Rails	Spring & shock absorber relocated with new rear suspension	Mass reduction, package
4	Front Rails	Space between rails increased	Package of bigger engine
5	Panel Skirt	Rear part of the front wheelhouse deleted Redesigned, tailor welded blank Reinforcement shock tower deleted, integrated in new panel skirt	Mass reduction Package of new front suspension in conjunction with #4 Mass reduction
6	Panel Spare Tire	Tub designed as separate module from steel sandwich material and to be bonded to the rear floor after final assembly	Heat resistance of sandwich material, not sufficient for bake hardening process
7	Package Tray	Redesigned from 3 part to 2 part design roll formed member package tray front deleted	Assembly
8	Member Dash Front, Member Front Floor Support, Member Kick-up	Material changed from high strength to ultra high strength steel >550 MPa yield strength	Front Crash, side impact crash
9	Panel Body Side Outer	Blank configuration in tailor welded blank with all blanks in high strength steels	Crash analysis, mass reduction
10	B-Pillar Joint	Rocker inner extended upwards into B-Pillar. B-Pillar lower reinforcement modified	Side impact, crash assembly
11	A-Pillar - Cowl - Fender Support Rail-Hinge Pillar Joint	Joint modified	Assembly, revised fender support rail
12	Panel Back	3 Piece design integrated into one part	Mass reduction, assembly
13	Side Roof Rail	Design refinements	Manufacturing process - hydroforming
14	Bolt on Front End	Welded	Change in front end module concept

Figure 5.4.2-1