U. Lightweight Front End Structures

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Objective

- The objective of the Auto/Steel Partnership (A/SP) Lightweight Front End Structure (LWFES) project is to benchmark, develop and document solutions that balance the interaction of material, manufacturing and performance in the lightweighting of steel automotive structures. The initial phase of this study focused on automotive front-end system solutions that address high-volume manufacturing and assembly. Furthermore, example solutions were manufactured and physical testing was performed to evaluate the advanced high-strength steel (AHSS) designs.
- The AHSS solutions will provide choices and consequences that address real-world challenges faced in the vehicle development process. A comprehensive knowledge-base design tool was developed to capitalize on a set of robust AHSS automotive design guidelines relating choices to consequences.

Approach

- An existing Front Rail System from a donor vehicle was retrofitted with AHSS Dual Phase (DP) 800 steel to save 22% of the mass. In addition, a front bumper made from DP 980 steel replaced the existing bumper design.
- The AHSS rail system and bumper were manufactured and tested to compare performance with the conventional design it replaced.

- Analytical and physical testing was carried out on both the original and the redesigned rail system.
- Comparisons will now be drawn and recommended practices documented.

Accomplishments: Additional Phase 2 Deliverables

- Selected a stamped rail concept.
- Obtained final optimized stamped rail and bumper designs.
- Completed formability simulation of the stamped design.
- Generated Computer Aided Design (CAD) data for manufacturing of the new stamped rail and bumper designs.
- Developed prototype tools for manufacturing rail and bumper stampings.
- Manufactured prototype dies for the rails, rail extensions and bumper.
- Developed new welding schedules for AHSS joining.
- Developed static and dynamic stiffness Design of Experiment (DoE) Finite Element (FE) Models.
- Developed static stiffness DoE response surface.
- Developed dynamic stiffness DoE response surface.
- Stamped and assembled rails, rail components and bumpers.
- Prepared the donor vehicle to accommodate the new rails and bumper.
- Installed the new AHSS rails and bumper into the vehicle.
- Conducted a successful (certified) Insurance Institute for Highway Safety (IIHS) 35-mile-per-hour crash test of the retrofitted vehicle and recorded the results.
- Correlated the vehicle crash test data with the analytical results.
- Updated Proteus, a knowledge-base tool, with the findings of this project.
- Published a final report detailing all of the findings of this project, including lessons learned.
- Tech transfer of project results (Deep Dive Presentation) conducted at DaimlerChrysler.
- Project results "display" was completed and used in road show presentations.

Future Direction

- The original Phase 1 and Phase 2 have been completed**.**

Manufacturing Feasibility

The primary intent of the Lightweight Front End Structures (LWFES) project was to demonstrate the mass savings potential of advanced high-strength steels (AHSSs) combined with efficient design in an existing production vehicle package space while addressing manufacturing feasibility. To ensure manufacturing feasibility, several A/SP enabler teams were utilized to review the design recognizing that the members of these teams represent the manufacturing interests of their companies and ensured that the project developed a solution that addressed manufacturing feasibility. The enabler teams were consulted to assist in developing designs, and designs were modified to accommodate enabler teams' design review comments.

The LWFES team would like to recognize the efforts of the A/SP High-Strength Steel Stamping team (see report 2.R), Hydroformed Materials and Lubricants team (see report 2.O), Strain-Rate Characterization team (see report 2.S) and the High-Strength Steel Joining Technologies team (see report 2.N) for their overview and support of the project.

The project team went to every effort, within the confines of the program, to demonstrate manufacturing feasibility. The project does not address manufacturing capability required to understand the influence of the many variables of a high-volume manufacturing environment. The extent to which manufacturing feasibility is addressed is documented in the following sections.

The manufacturing feasibility report is composed of the input from many of the participants of the program. Detailed chapters are provided for each of the key manufacturing areas. The following is a summary of the manufacturing feasibility section of the report.

Materials

The redesigned rail bumper system relies on DP 780 and DP 980 steels, grades that are commercially available from North American sheet steel producers. The existing rail design utilizes steel in strength ranges from BH 210 to HSLA 340 compared to the new optimized design, which utilizes DP 780 and DP 980. The mass-saving potential of different steel grades in a crash event can best be compared by the relative area under the true-stress true-strain curve between 0 and 10%, as shown in Figure 1.

It is the high ductility of these grades that enable the stamping of the components and application to the rail/bumper system. In comparison, a HSLA 800 grade has a total elongation of 3% to 4% compared to 16% to 19% for DP780. Prior to applying the AHSS grades to automotive applications, such limitation in ductility has prevented the stamping of steels at these strength levels into rail and bumper components.

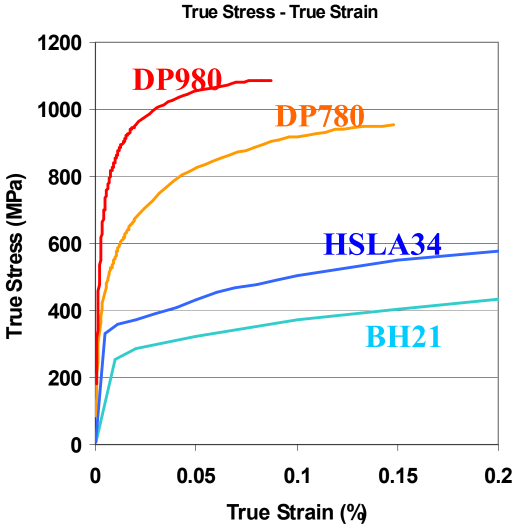


Figure 1. True Stress-True Strain Curves

Laser-Welded Blanks

Six of the 12 stampings comprising the redesigned rail bumper system are produced using laser-welded blanks (LWBs) (Figure 2) of DP 780 and are a key design feature required for structural efficiency and affordability.

Figure 2. Rail inner and rail outer laser-welded blanks

The LWBs are primarily responsible for the part consolidation achieved in the redesign, reducing the part count from 27 in the original design to 13 on the redesigned system. The blanks were manufactured under production conditions, with no special edge preparations in the blanking operations and the equipment run at production speed.

Laser-weld seam quality was evaluated for geometrical imperfections and tested with an Olsen tester. The testing indicated the blanks met all quality requirements. The weld seam produced by the laser-welding process was usually convex, displayed a narrow weld seam and a very small heat-affected zone (HAZ). Examples of microstructures for DP 780 Hot Dip Galvanized (HDG) steel after laser welding are shown in Figure 3. Micro-hardness values indicate that the welds are typical of a good quality laser-welding process and demonstrate high feasibility for industrial applications of DP 780 LWBs.

The most severe testing placed on the laser-welded blanks was during the actual stamping operations and in the crash event where the laser welds performed as expected and without incident.

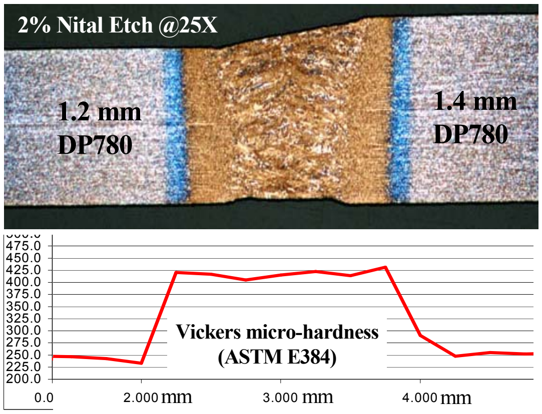


Figure 3. Laser weld's HAZ and micro-hardness.

Stamping

Steel stamping dies were built to produce the prototype components, with the exception of the rail extension, which used a soft tool for the draw operation. The process is designed to produce components representative of a production operation. The process is also intended to investigate and address manufacturing feasibility within the confines of the project. The detailed report describes each component as in the following example of the rail extension, which was the most difficult stamping.

A prototyping process was developed to produce the part, in this case, a five-stage operation.

Finite element analysis (FEA) simulation was used to address the feasibility of forming the component. In this case, failure was predicted but it was felt a solution could be developed during die development.

Blank optimization was utilized to allow the steel to draw into the die and address potential splitting and wrinkling concerns.

A single-piece draw die was used to form the part. As predicted by the forming simulation, the parts did demonstrate forming problems. Several design changes were required to address splitting issues, including opening the sidewalls and changing the binder pad surface to improve material flow.

A re-strike tool was required to finish-form the sidewall and correct the sidewall springback.

Finally, a checking fixture was used to confirm conformance to design and understand and address springback issues. A graphic representation of the above is shown in Figure 4.

It was anticipated that trimming was to be accomplished by laser or saw operations in prototyping. However, the parts configuration accommodates a typical trim-die operation.

A recommended production process is accomplished for each component. This is a conservative approach and the intent would be to look for design concessions and process improvements to reduce the number of operations.

Tooling reports

Tooling reports were performed on each of the stampings to understand final part severity and the need for additional work on each part. The tooling report for the rail extensions is shown in Figure 5. The analysis shows that several locations on the parts are not safe and additional die modifications or part concessions are required for a production-ready stamping.

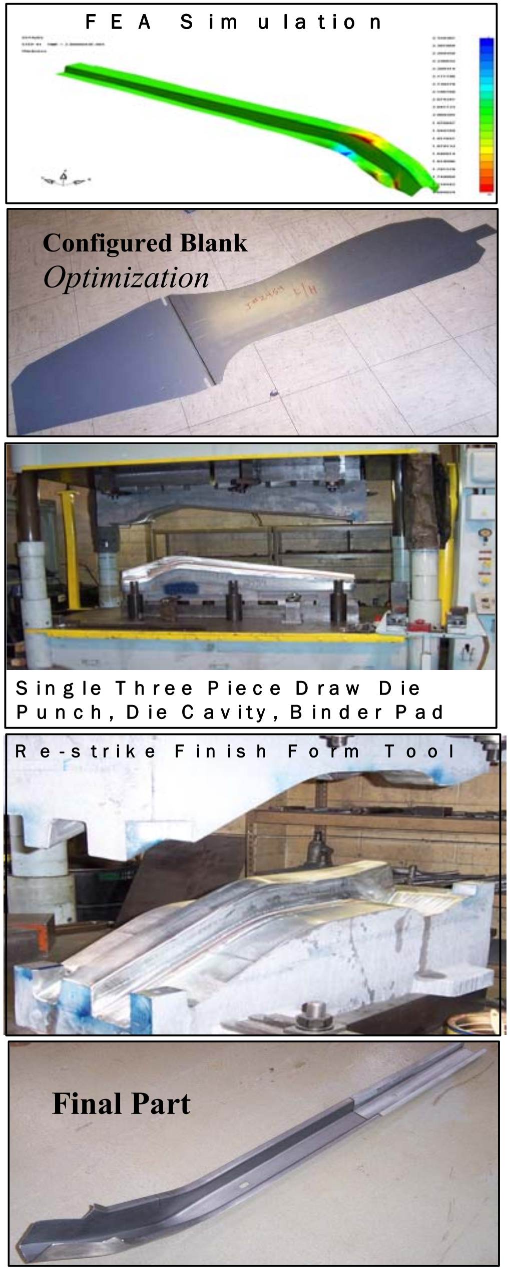
The forming strain evaluations shown in Figure 6 indicate that, in addition to the rail extension, the rail extension reinforcement and the bumper stampings do not meet a safe criterion. The dies have been assigned to the A/SP High-Strength Steel Stamping team for additional development and the improved understanding required for production of these steel grades.

Spot Welding

The A/SP High-Strength Steel Joining team developed weld schedules for the stack-ups required by the design as shown in Figure 7. All resistance welds were produced using standard, portable gun-tyle welders typical of a body shop that uses manual welding.

Where single-side access was the only access to weld joints, material was drilled out on the top sheet to provide effective MIG puddle welds. This technique was used where the donor body was attached to the rail assembly. This was a restriction of the prototype vehicle build and not indicative of

Prototyping Process	
Part Name	**Processes**
Rail Extension	Rough Oversize Profile Flat Blank
	Single 3 Piece Draw Die
	Restrike Operation using Second Form Die
	Laser Trim Finish
	Pierce Construction Holes



Recommended Production Process	
Part Name	**Processes**
Rail Extension	Oversized Flat Developed Blank
	First Draw Form
	Second Form
	Pierce and Trim Outside Profile
	Final Form Operation

Figure 4. Stamping process flow diagram

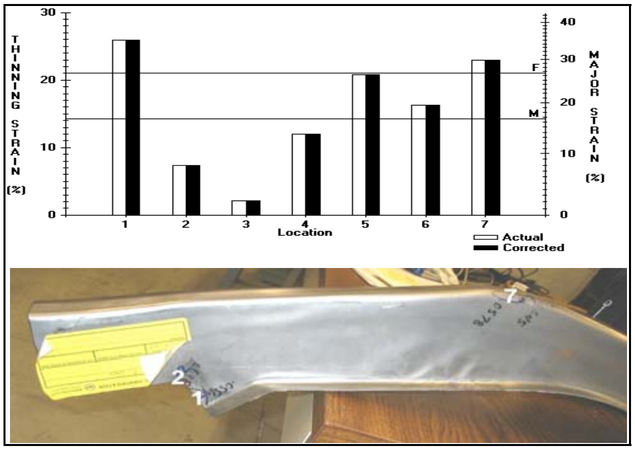


Figure 5. Rail extension tooling report

Table 1 - Stamping Material Properties and Component Forming Evaluations

Part	Grade & Gauge & Coating	YS (MPa)	TS (MPa)	%El	n-value (terminal)	Part Forming Status	
						Status	Safety Margin
Rail Inner (3 pc. LWB)	DP780 1.0mm GA	489	875	16.6	0.116	Safe	18.50%
	DP780 1.2mm GA	508	896	16.4	0.113	Safe	10.80%
	DP780 1.4mm GA	429	837	19.2	0.118	Safe	12.90%
Rail Outer (3 pc. LWB)	DP780 1.0mm GA	489	875	16.6	0.116	Safe	18.50%
	DP780 1.2mm GA	508	896	16.4	0.113	Safe	13.30%
	DP780 1.4mm GA	429	837	19.2	0.118	Safe	13.50%
Rail Inner Reinf.	DP780 2.0mm GA	495	892	13.6	0.111	Safe	16.70%
Rail Extension (2 pc. LWB)	DP780 1.2mm GA	508	896	16.4	0.113	Safe	11.90%
	DP780 2.0mm CR	517	806	23.0	0.111	Critical	-8.30%
Rail Ext. Reinf.	DP780 1.4mm GA	429	837	19.2	0.118	Marginal	6.10%
Bumper Inner	DP980 1.0mm CR	814	983	14.0	0.084	Marginal	1.20%
Bumper Outer	DP980 1.0mm CR	814	983	14.0	0.084	Critical	-3.80%

Figure 6. Tooling Report Summary Table

what would be accomplished in a production assembly.

A post-crash inspection of the welds was undertaken to assess performance of the welds in the crash event. Observation of all visually-accessible rail welds indicated that no welds separated without pulling buttons from adjacent material. The welds performed as expected in the crash event.

The study suggests that conventional equipment and processing would be able to deliver acceptable welds for these material combinations.

Assembly

The assembly was a “one-off” build and is the least representative aspect of a production process, and little was gained toward the demonstration of manufacturing feasibility. An assembly fixture, shown in Figure 8, was used for the assembly of the rail and then for attachment to and alignment on the donor vehicle.

Weld Schedules Specified For Materials In LWFES Rail Assembly.

Stack up ID	Material Location	AISI	Metal grade, gage	Weld cycles	I min-Imax (kA)	Nom Current kA (1)
114	TOP	-	DP980-1.03 mm			
	BOTTOM	-	DP890 1.03 mm	22	8.8-11.6	10.5
115	TOP	-	GA DP800 1.0 mm	22	8.8-12.4	11(2)
	BOTTOM	-	GA DP800 1.0 mm			
116	TOP		GA DP800 1.20 mm	22	9.0-10.8	10
	BOTTOM	208	GA DP800 1.20 mm			
117	TOP	209	GA DP800 1.40 mm	22	9.0-10.4	10.5(2)
	BOTTOM	209	GA DP800 1.40 mm			
118	TOP	210	HDG DP800 2.0 mm	22	10.0-11.5	10.8
	BOTTOM	209	GA DP800 1.40 mm			
119	TOP	208	GA DP800 1.20 mm	22	10.0-12.0	11.0(2)
	BOTTOM	210	HDG DP800 2.00 mm			
120	TOP	209	GA DP800 1.40 mm	22	10.0-11.5	10.8
	BOTTOM	210	HDG DP800 2.00 mm			
121	TOP	209	GA DP800 1.40 mm	22	9.8-11.0	10.8(2)
	MID	210	HDG DP800 2.00 mm			
	BOTTOM	209	GA DP800 1.40 mm			

Nominal force 1500 lbs, nominal hold 30 cycles, tips 45-degree truncated with 7.0 mm face.
GA = Galvanneal
HDG = hop dip galvanized

NOTES:
(1) Nominal current produced better than 97% good welds without weld tip stabilization.
(2) Required tip stabilization to obtain buttons on tip (point) evaluation test.

Figure 7. Weld schedules for specified materials

Figure 8. Modified rail assembly on check fixture

It was noted that the parts fit together without the need for excessive clamping, indicating that the parts were near desired shape.

The project does not comprehend all of the manufacturing variables prevalent in a high-volume manufacturing environment. However, this project does address several aspects of meeting those goals and can be used in the accumulation of knowledge needed to develop robust manufacturing practices suitable for AHSS.

Testing

The AHSS rail and bumper designs were validated by conducting a New Car Assessment Program (NCAP) 35-miles-per-hour rigid-barrier impact test at the Transportation Research Center in East Liberty, Ohio. The bumper and the front section of the rails crushed completely and there was no significant deformation of the A-Pillar, B-Pillar, roof rails and rail extension rear. The B-pillar acceleration peak of the new AHSS design was lower than that of the baseline design; however, the time-to-stop of the new AHSS design was longer than that of the baseline design.

There are two observations to be noted relating to the condition of the test vehicle:

- it had been driven prior to this test, and
- the engine and engine mounts from a previously crashed vehicle were used.

Overall, the new AHSS design had an NCAP performance similar to that of the baseline design.

Photos 1 through 7 provide visual and graphic representation of pre- and post-test conditions.

Photo 1. NCAP Test – Left-Hand (LH) Side Views

Photo 2. NCAP Test - Front Views

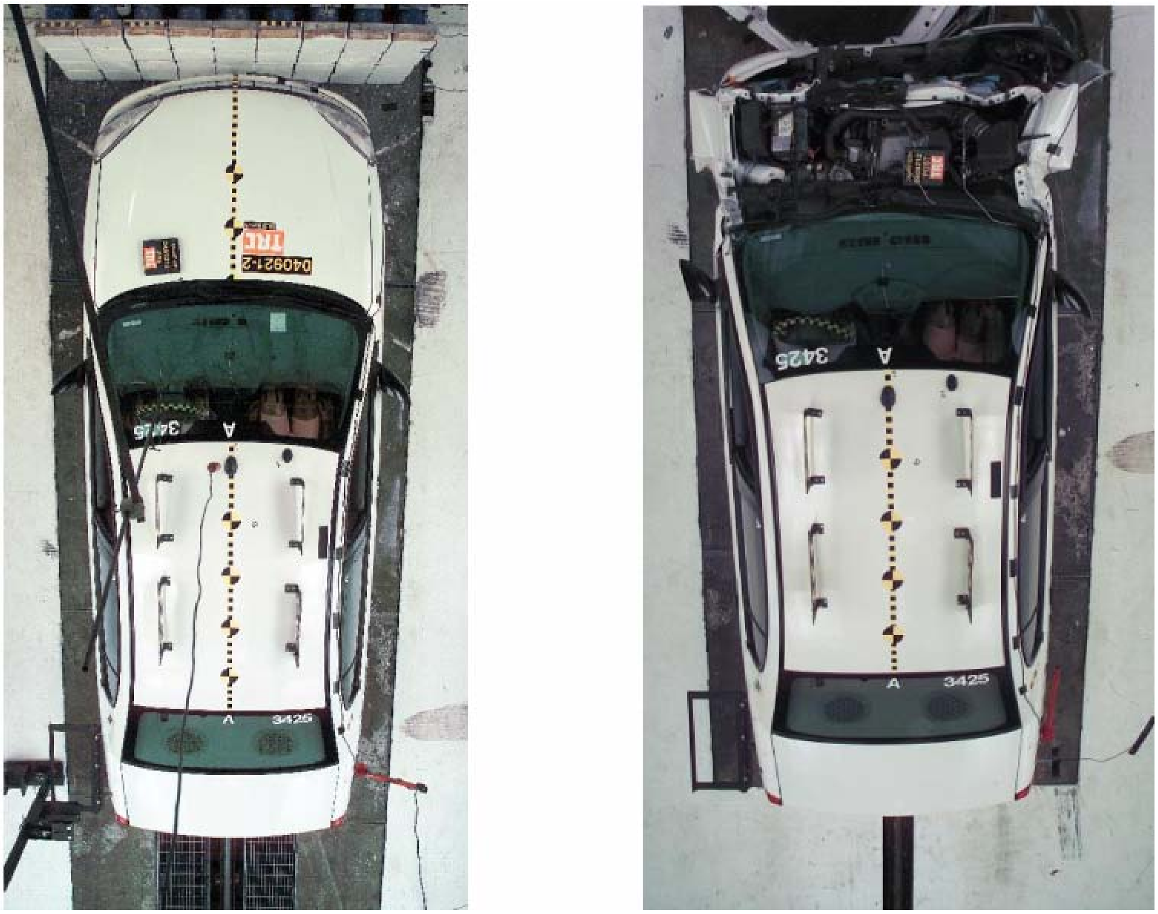


Photo 3. NCAP Test - Top Views

Photo 4. NCAP Test - Underbody Views

Photo 5. NCAP Test – Front End/Bumper View


RH LH

Photo 6. NCAP Test - Bumper Close-up Views

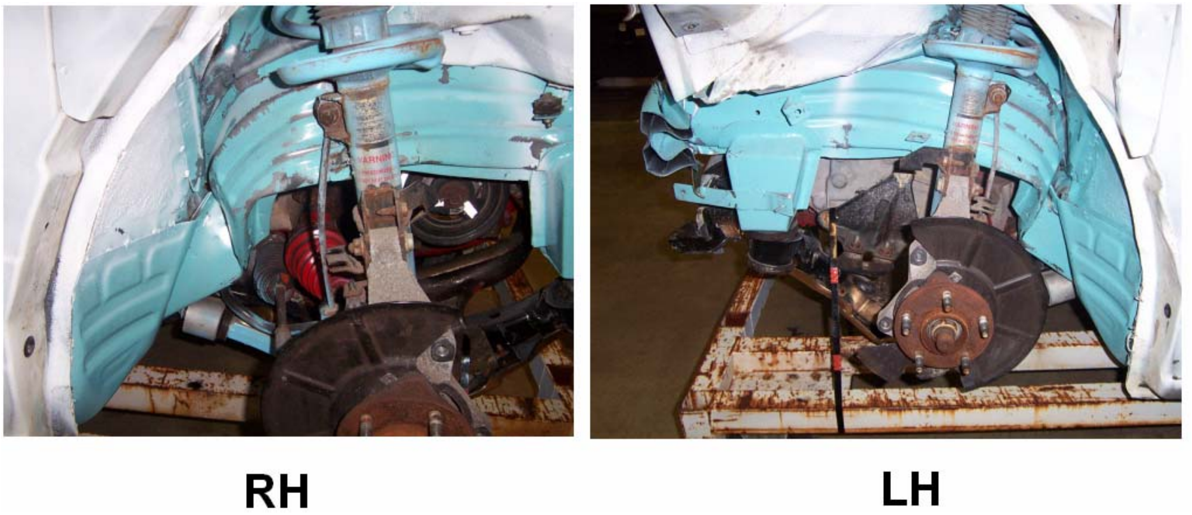

RH LH

Photo 7. NCAP Test - Front Rail Views

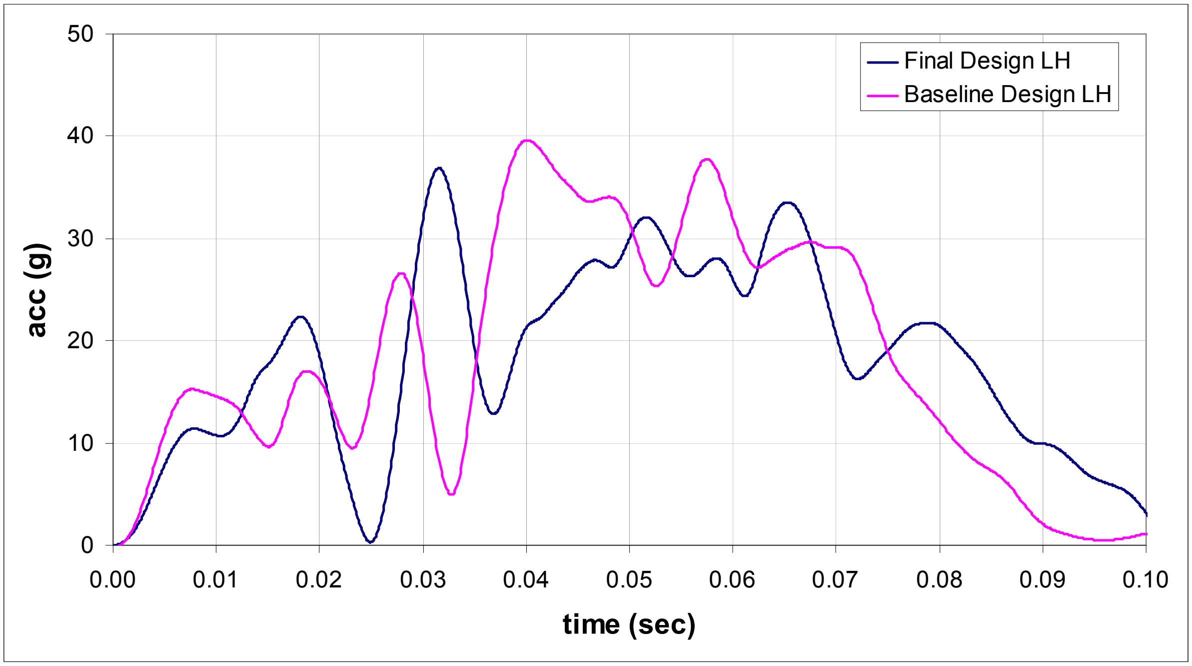


Figure 9. NCAP Test – Left-Hand B-Pillar Acceleration Pulse Comparison

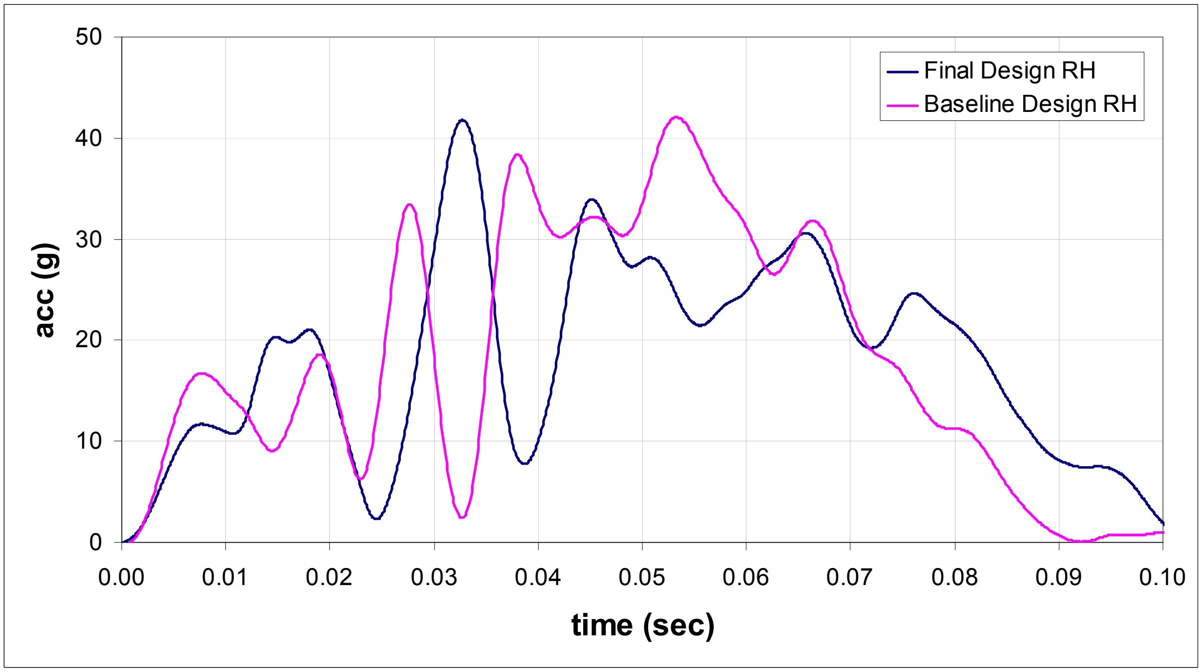


Figure 10. NCAP Test – Right Hand B-Pillar Acceleration Pulse Comparison

Post-Crash Report of Weld Performance

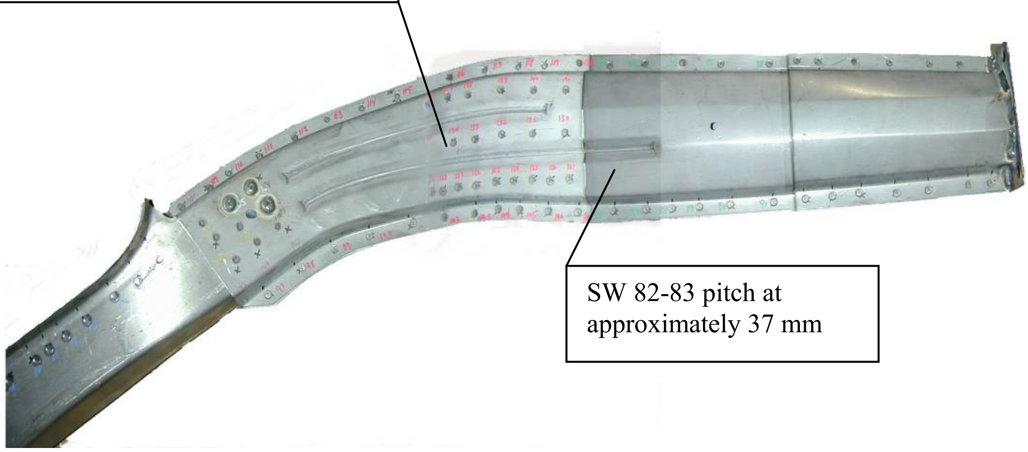
The crash test was performed with all front structure components in place, including engine, suspension and heating and air-conditioning equipment. The original-design structural components are painted white. All structural adhesive and sealers were applied per the production requirements of the original design. The AHSS components that were redesigned to replace the original steel rails are painted blue. The apron assembly, or shock tower, was not part of the redesigned LWFES rail project.

The body structure was mounted on a 45-degree viewing rack to allow easy access to areas of interest. Due to the mounting, the most easily photographed rail components were on the right-hand (RH) side of the body.

Where single-side access was the only access to weld joints, material was drilled out on the top sheet to provide effective metal inert gas (MIG) puddle welds. This technique was used where the donor body was attached to the rail assembly. One joint on the rail assembly restricted access of the weld gun and plug welds were used in place of resistance spot-welds (RSW) for some welds in this joint. The bumper reinforcement attachment bracket was also arc-welded to the end of the rail assembly. All resistance welds were produced using standard portable gun-style welders typical of a body shop that employs manual welding. All arc-welding was performed using standard body-shop MIG welding equipment and E70 filler wire. Observation of the post-rash weld conditions suggests that conventional equipment and processing should be able to deliver acceptable welds for these material combinations.

Observation of all visually-accessible rail welds did not indicate that any welds separated without pulling buttons from adjacent material. Photos 8 through 17 show principal views of the rails and associated assemblies. The performance of the welded rail assembly is largely unremarkable as welds performed as intended.

Weld pitch was approximately 37 mm for the heavier stock. The closest pitch for RSW was approximately 25 mm.



Normal pitch at approximately 25 mm

SW 82-83 pitch at approximately 37 mm

Photo 8. A portion of the right-hand rail assembly showing spot pattern layout prior to crash testing. This view does not include the rail length extending under the floor pan of the body.

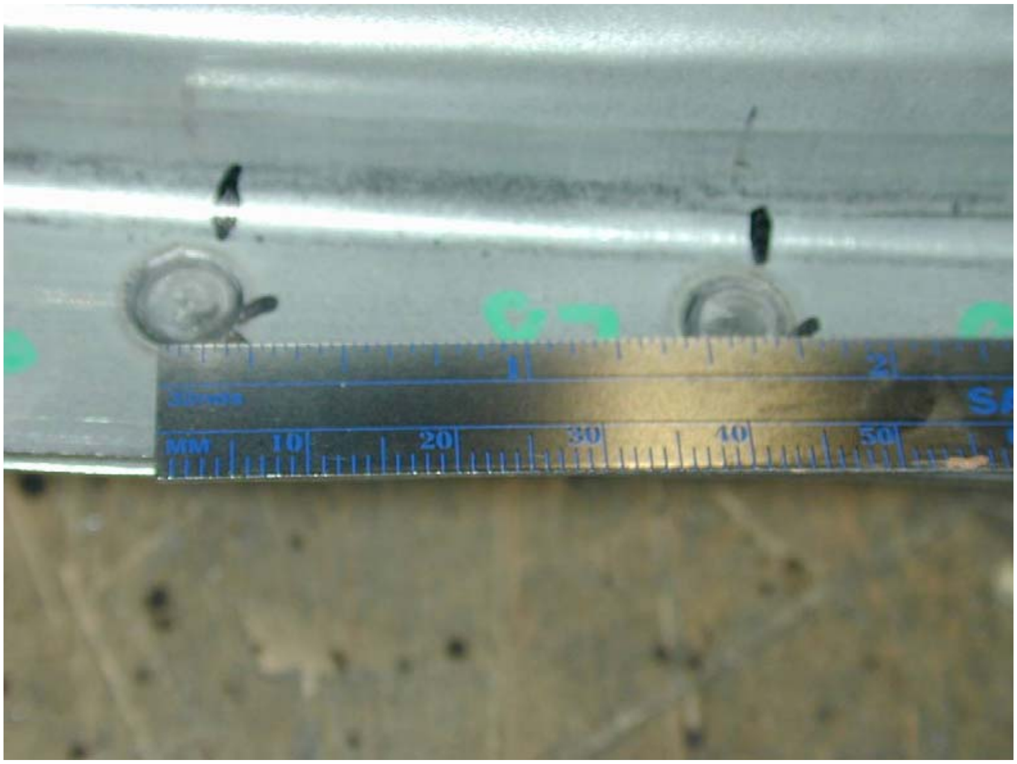


Photo 9. Pitch for spot welds from bumper attachment to end of tailor-welded blank.

Photo 10. Standard MIG puddle welds were used where RSW guns would not fit into the box section.

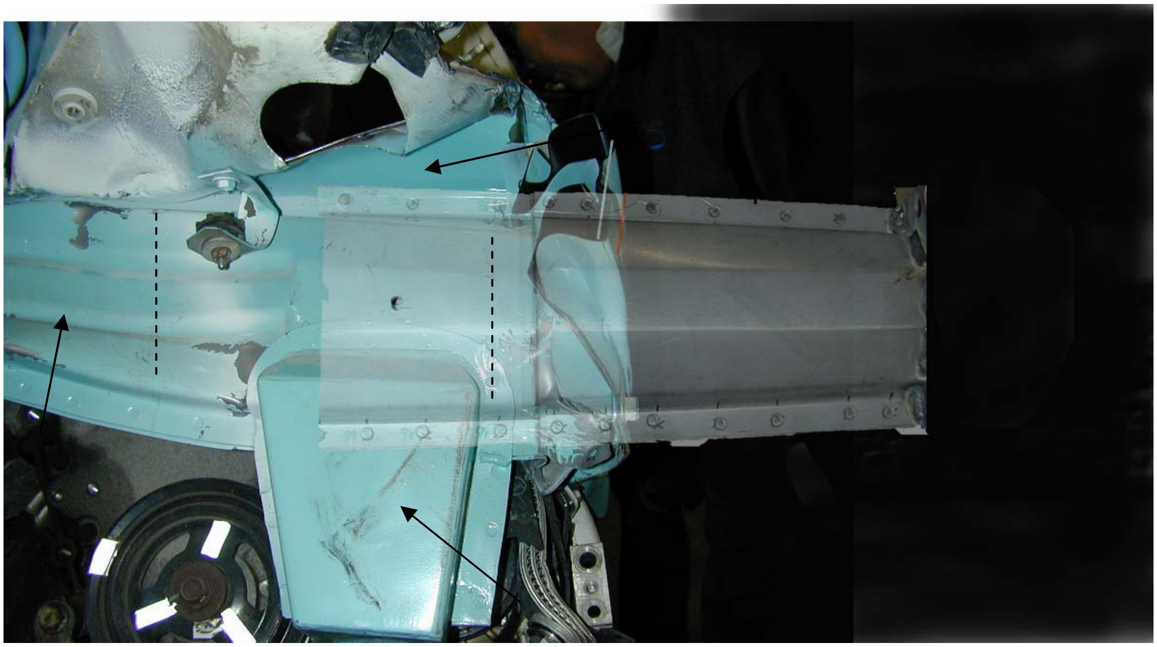


Photo 11. View showing right-hand rail assembly with phantom view of original rail superimposed. Dashed lines are approximate location of the laser-welded blank joints.

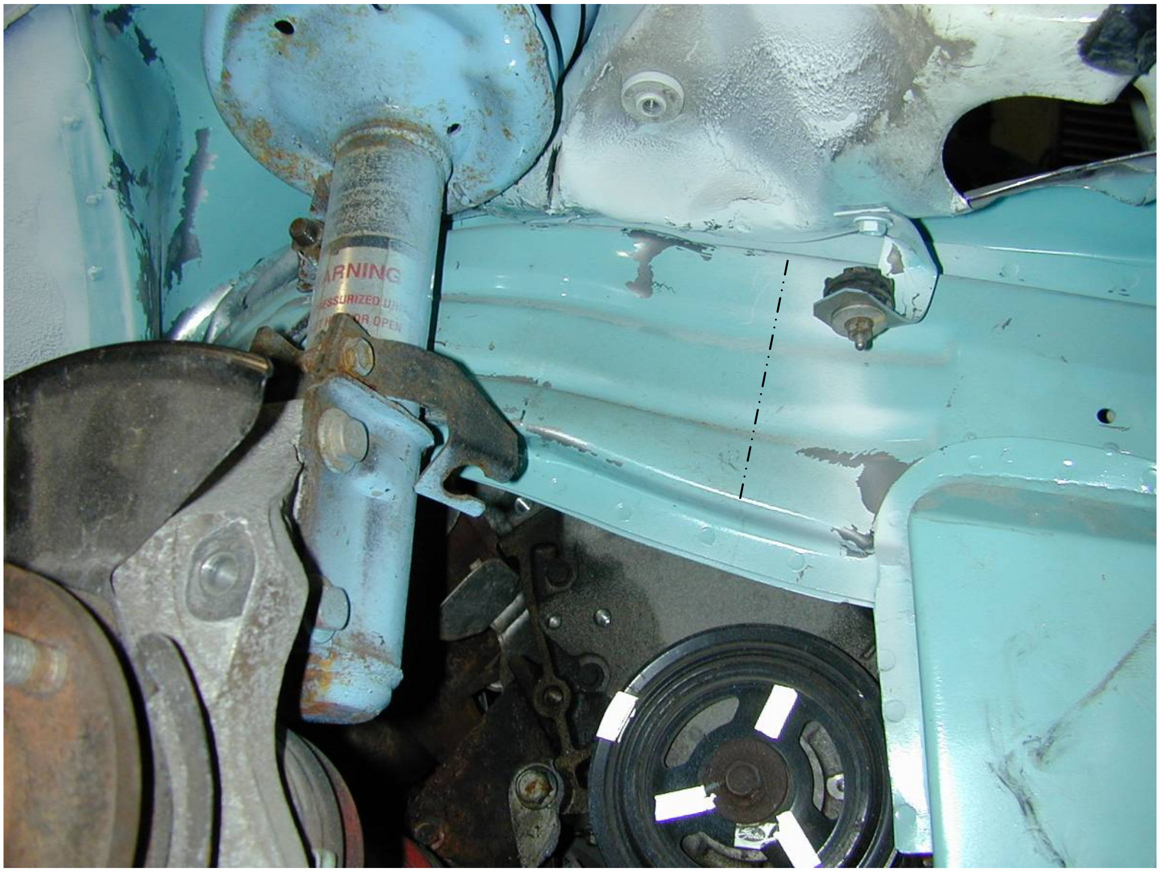


Photo 12. Right-hand rail aft of laser-welded blank joints.

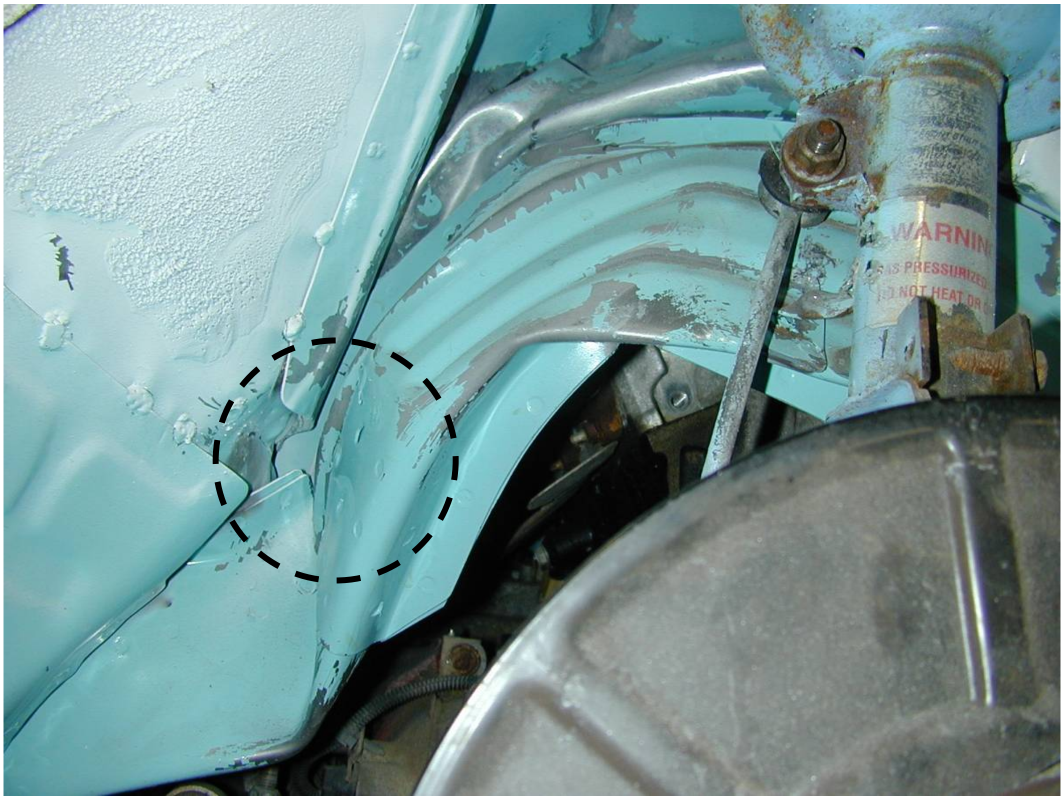


Photo 13. Slip joint with resistance spot and MIG puddle welds highlighted.

Photo 14. Left-hand rail-to-bumper reinforcement collapse. Weld buttons were pulled from the AHSS materials when separation was observed.

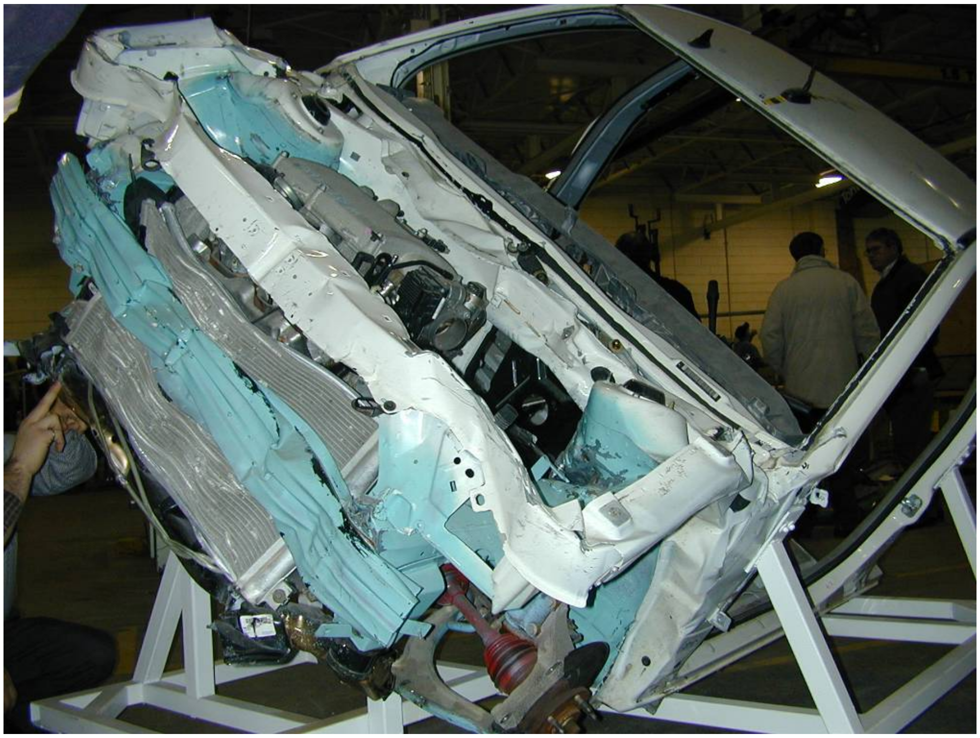


Photo 15. Front view showing bumper reinforcement and rail collapse. All welds were acceptable.

Photo 16. Left-hand side view of test vehicle.

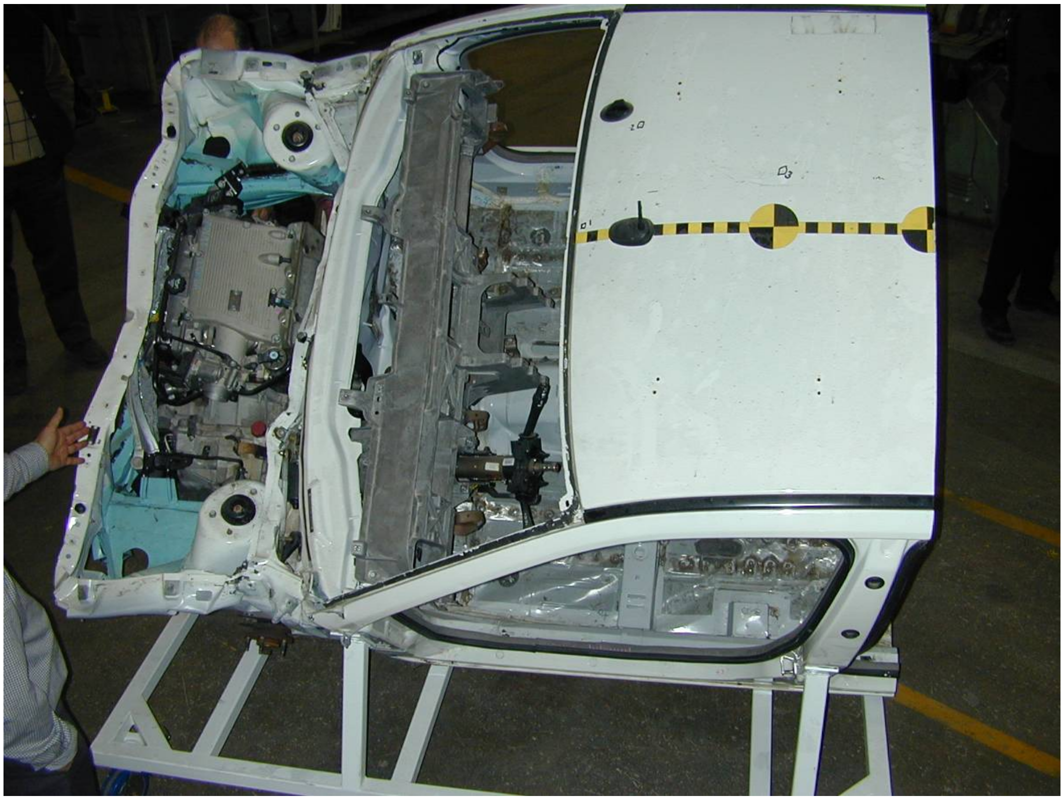


Photo 17. Body top view. Note powertrain components contacting radiator support and dash panel.

Conclusion

The front rails and bumper were designed and fabricated using AHSS DP 800 and DP 980. The AHSS design achieved a mass reduction of 8.77 kg (22.36%) compared to the baseline design. The performance of the AHSS design was similar to that of the baseline design. Conducting an NCAP 35-mph rigid-barrier impact test on the donor vehicle fitted with the AHSS rails and bumper, validated the AHSS design.

It can be concluded that the use of AHSS in conjunction with effective part design can result in significant mass reductions without compromising crash performance. Priority should be given to design stability and load path as opposed to maximizing sections. Parts can be manufactured using DP 800 and DP 980 steels, provided proper attention is given to manufacturing constraints early in the design process.

Technology Transfer

Final results from Phase 1 and Phase 2 were rolled out at “Great Designs in Steel” seminar held in March 2005, including the completion of the display and backdrop with the crash vehicle front end and project results.

Subsequently, a deep-dive presentation was given to DaimlerChrysler (DCX) engineers by the project team and a workshop conducted. A front end for a future DCX vehicle was selected to allow a comparison by the A/SP project team representatives against the project results.

Future deep-dive type presentations are scheduled with General Motors and Ford Motor Company as a means to allow their product engineers to compare future vehicles with these results in a similar manner.

The engineering final report with project results is being finalized and will be made available on the Auto/Steel Partnership website, as well as media and public opportunities.