



A DESIGN AND VALIDATION STUDY IN LIGHTWEIGHT, SAFE AND AFFORDABLE STEEL CLOSURES



ULSAC Door with Sheet Hydroformed Outer Panel Reduces Weight, Not Performance

During the design and development of ULSAC frameless door, the ULSAC Consortium evaluated further mass reduction using sheet hydroforming for the outer panel. This research was conducted as a means to compile practical documentation that may prove its feasibility.

Door structures are successfully manufactured with 0.6 mm Dual Phase 600 steel outer panels, achieving additional weight savings.



ULSAC Frameless Door: Up to 46% Lighter Than Any On The Road Today!

ULSAC Door with Sheet Hydroformed Outer Panel
Normalized mass: 12.38 kg/m² Total mass: 9.77 kg



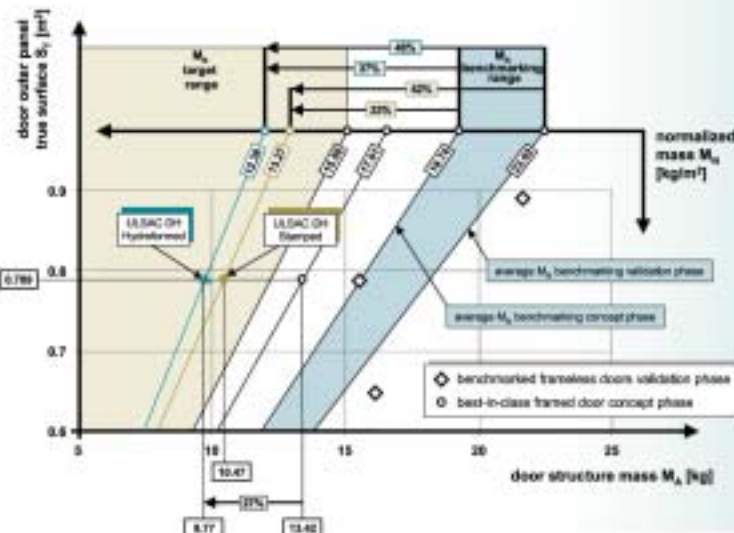
RESULTS:

- ▶ 46% lighter than benchmarked doors
- ▶ 27% lighter than the best-in-class framed door
- ▶ Affordable high volume manufacture
- ▶ State-of-the-art structured performance
- ▶ Reduced mass with no compromise to safety

FEATURES:

- ▶ Unique tubular frame structure
- ▶ 0.6 mm Dual Phase 600 steel outer panel
- ▶ Employs advanced steels, tailor welded blanks, tube and sheet hydroforming

ULSAC Results Compared to Benchmark

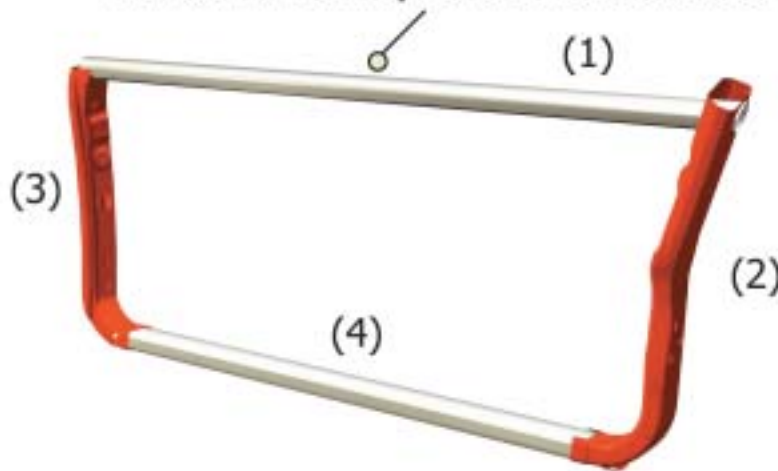


TAKE A LOOK AT THE ULSAC FRAMELESS DOOR DESIGN

The ULSAC consortium contracted Porsche Engineering Services, Inc. (PES) of Troy, Mich., to provide engineering management for the project and to define the project goals. PES used a holistic approach to design, in which the structure is viewed as an integrated whole and evaluated how changes in one area affect other areas, and where further optimization opportunities exist. This approach resulted in the creation of an efficient, optimized door structure. Consequently, the ULSAC frameless door is notable for its efficient material usage and the design and functionality of its parts.

The design eliminates the need for a full door inner panel. This is partly a result of the four tubes that make up the basic door structure, which are high-strength workhorses for achieving required crash safety and structural performance at a significantly reduced weight.

Laser and MIG welding joins these four parts to create a structurally sound door inner structure.



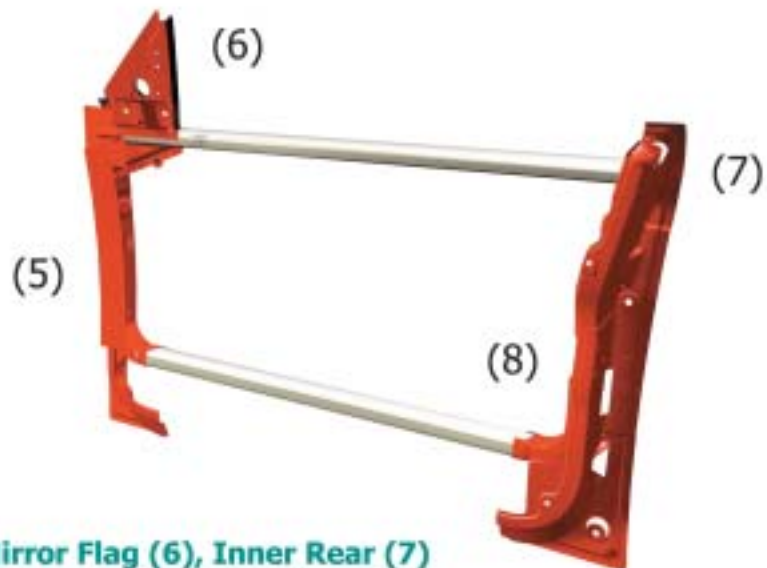
Outer Belt Reinforcement (1) and the Lower Tube (4)

- In a frontal collision, these two parts, made of dual phase ultra high-strength steel, supply excellent load-carrying capabilities between the A- and B- pillars.
- In a side crash, they provide the strength and absorption capabilities to efficiently manage impact energy forces.

Latch (2) and Hinge (3) Tubes

These parts are hydroformed tubes, a process chosen for its advantages of high strength and excellent part formation for complex shapes at minimum weight. Here are some highlights:

- Tube hydroforming allows designers to create complex tube shapes, with optimal mechanical characteristics, adjusting for packaging. In assembly it enables making the connection to the door beam and the outer belt reinforcement.
- Hydroforming reduces the number of parts through part consolidation.



Inner Front (5), Mirror Flag (6), Inner Rear (7) and Latch Reinforcement (8)

- Four additional stamped parts and the stamped outer panel of Bake Hardenable 260, 0.7mm steel complete the door.

ADVANCED STEEL TECHNOLOGIES COMBINE TO CREATE EFFICIENT ULSAC DOOR STRUCTURE

The frameless door demonstration build uses mild, high-strength and ultra high-strength steels taken from normal steel mill production. To demonstrate optimal mass, safety and performance results at affordable costs, the ULSAC door uses some steel materials that are not commonly applied to closure panels.

ULSAC illustrates lightweighting of automotive closures with steel, combined with processes including conventional stamping, tailor welded blanks, hydroforming, laser welding and adhesive bonding. These materials and advanced processes enabled design engineers to consolidate functions in fewer parts, resulting in mass savings while maintaining performance, safety, and affordability.

Part	Material Yield Strength (MPa)	Specified Material Thickness (mm)	Actual Weight (kg)
(1) Outer Belt Reinforcement	800	1.00	0.835
(2) Latch Hydroformed Tube	280	0.90*	0.676
(3) Hinge Hydroformed Tube	280	1.10*	0.755
(4) Lower Tube	800	1.50	1.438

* average uniform thickness after forming

Part	Material Yield Strength (MPa)	Specified Material Thickness (mm)	Actual Weight (kg)
(5) Inner Front (Tailor welded blank)	140	1.00/1.20	1.238
(6) Mirror Flag	140	1.00	0.388
(7) Inner Rear	140	0.60	0.518
(8) Latch Reinforcement	140	1.20	0.057

Bake Hardenable Steels = Formability + High Strength Dent Resistance @ Reduced Mass

Dent resistance of outer vehicle body panels is critical to automakers since it impacts everything from material handling and warranty costs to quality and customer satisfaction. The successful introduction of high-strength steels for outer body panels, such as the ULSAC door, hood and decklid designs, demonstrates the potential for reducing mass, while maintaining or even improving dent resistance.

○ ULSAC Outer Door Panel: ○ Material: BH 260 ○ Material Thickness: 0.7mm ○ Weight: 4.874 kg ○ Part Manufacturing Process: Stamping

The material specified for the door outer panel is considered to be the best material for this door design. With a different door design, even greater mass efficiency may be achieved with higher-strength steel, such as Dual-Phase 600, which displays excellent dent resistant qualities.

Ultra High-Strength Dual-Phase Steels Supply the Right Attributes

Dual-Phase steel grades are medium alloy steels that provide superior formability for part manufacture. Yet this steel work hardens during forming to produce high strength in the finished part. Then, under the stress of crash forces, steel absorbs energy by deforming and elongating, as well as becoming stronger under the strain-hardening effect of crash forces.

ULSAC Belt Reinforcement Exhibits New Dual Phase Technology

Though both part (1) and (4) use Dual-Phase 800 steel, the steel used in the outer belt reinforcement (1) is produced using a different galvanizing process than that used in the lower tube. This required a different chemistry to achieve the same characteristics. The dual phase steel used in the lower tube (4) is a proven commercial grade. The material used in the outer belt reinforcement is new and represents future steel materials that are lightweight, high strength and highly formable. Each was selected for ULSAC for its unique combination of properties and its purpose within the structural system.

EFFICIENT MANUFACTURING AND ASSEMBLY OF THE ULSAC DOOR

The ULSAC Consortium member companies provided all material-specific data required to design, develop and construct the ULSAC frameless door demonstration hardware and provided all materials used in manufacture. These included sheet steel and tailor welded blanks, as well as straight tubes for manufacturing of the hydroformed parts. In addition, member companies supported the program with data and expertise related to material selection and tailor welded blank development, as well as forming simulation on selected parts.

Steel Tailor Welded Blanks: The Right Material for the Right Job

Tailor welded blanks consist of two or more pieces of sheet steel with different material thicknesses, grades and/or coatings, joined by laser or mash seam welding.

Tailor welded blanks enable the design engineer to accurately situate the steel within the part precisely where its attributes are most needed. This leads to mass reduction because it allows for removal of mass that does not contribute to performance—using the right material for the right job.

Steel's attributes strongly support the use of this technology, making it the only material currently delivering the benefits of tailor welded blanks in high volume manufacture.

Tailor welded blanks achieve:

- ▶ Increased vehicle safety through improved structural performance
- ▶ Reduced weight
- ▶ Reduced part count
- ▶ Reduced costs
- ▶ Optimal use of steel material in parts

Stamping: Steel's Foremost Automotive Process

Stamping is the most common manufacturing process for making structural parts in the automotive industry.

The inner rear is a stamped part, but at very thin gauge (0.6 mm) providing structural strength at reduced mass.

An extension on the door inner front plus a stamped panel mirror flag outer form a two-piece mirror flag. This design allows for the outer belt reinforcement to be sandwiched between the two parts, creating a strong structural node.

The ULSAC door includes stamped parts as follows:

- ▶ Panel Front Door Outer
- ▶ Inner Front (5)
- ▶ Mirror Flag (6)
- ▶ Inner Rear (7)
- ▶ Latch Reinforcement (8)

Tube Hydroforming Process: Making the Best Use of High-Strength Steel

Tube hydroforming, generally used when a complex shape is needed, is gaining increasing acceptance in the automotive industry for making a wide variety of components. Current applications include suspension frames, body structure, powertrain components and exhaust tubes.

In ULSAC, hydroforming is used to produce the latch and hinge tubes, adding stability to the door structure and allowing for integration of additional functions, such as the hinge attachment, latch attachment, and bushings.

When used with high-strength steels, hydroforming produces structurally superior parts with thinner sections at reduced mass.

Hydroforming provides several advantages versus stamped and welded structures, including:

- ▶ Reduced mass
- ▶ Reduced tooling costs
- ▶ Part integration and reduced part costs
- ▶ Integration of piercing and/or punching operations
- ▶ Elimination of pinch weld flanges
- ▶ Improvements to dimensional repeatability

Forming Analysis

Forming analysis was performed on both stamped and tubular hydroform parts. A thorough forming analysis is critical preparation for tube hydroformed part manufacture, especially for complex parts. Forming simulations do the following:

- ▶ Determine critical process parameters, including the level of internal pressure, the pressure force built during forming and, in the pre-forming phase, the optimal movement of the tools.
- ▶ Allow investigation of material behavior during forming.
- ▶ Determine work-hardening effect, the thinning/thickening of the material, and the distance between the outer surface of the part and the inner surface of the tool.

During this analysis, the process parameters and part geometry are adjusted to reach optimal part formation. Once the forming simulation achieves satisfactory part formation, part manufacturing begins.

Putting it all Together in Assembly



ULSAC DOOR MEETS ALL PERFORMANCE REQUIREMENTS

Dual Phase 600 Steels for Outer Body Panels Thin Gauge, Above-Average Dent Resistance

Vehicle outer body panel dent resistance is critical to our automaker customers since it impacts everything from material handling and warranty costs to quality and customer satisfaction. The successful introduction of advanced high-strength steels for outer body panels, such as ULSAC's door featuring a sheet hydroformed outer, demonstrates ongoing potential for reducing mass, while maintaining dent resistance and improving oil canning.

ULSAC's Door Outer Panel:

Material: Dp 600
Material Thickness: 0.6 mm
Weight: 3.813 kg
Part Mfg. Process: Sheet Hydroforming

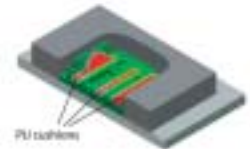
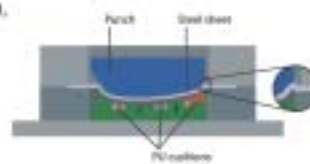
Advanced High-Strength Steels: How They Work

Dual Phase steel is a member of the multi-phase family of advanced high-strength steels. Multi-phase steels change during work hardening, which occurs when stress is applied like during part forming. Before work hardening the steel is "soft" and therefore highly formable. Work hardening causes the steel to gain strength, which, in some multi-phase steels, can nearly double its ordinal strength.

Consequently, these steels yield excellent part formation at a thin gauge. This reduces part mass, while providing results like the above-average dent resistance and oil canning performance in the ULSAC door.

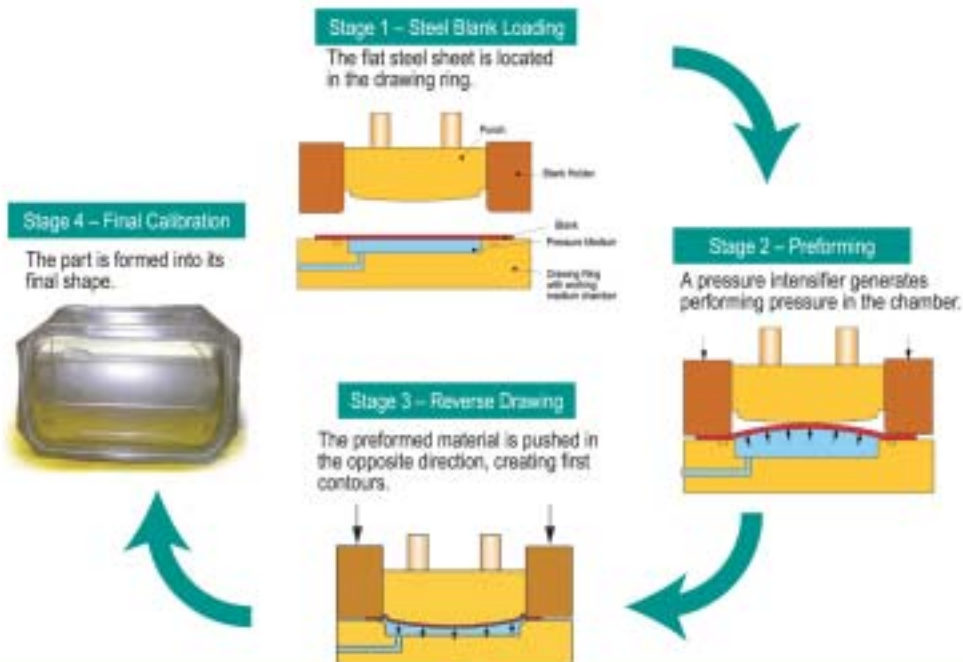
Developing the AHM Process for ULSAC Outer Panels

The combination of high-strength steel materials and small radii, as specified in the parts design, required a high working medium pressure to form the part to its final shape. DP 600 steels at 0.6 mm thicknesses with a minimum radius of 3 mm would require a press force of more than 10,000 tons, indicating a press size that would not be economical.



The Sheet Hydroforming Process

ULSAC used the active hydromechanical metal forming (AHM) process. The Process is a multi-stage forming technology with a liquid working medium. The die consists of three main components: a drawing ring, which is designed as a working median chamber, the blankholder (binder) and the drawing punch. Here's how it works:



ULSAC Results: Lightweight, Safe, Affordable Structural Performance

ULSAC Door Outer: Superior Dent Resistance at Thin Gauge

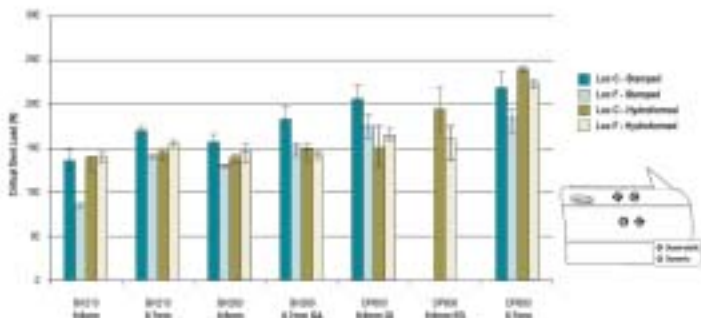
Both ULSAC doors exhibit state-of-the-art lateral stiffness compared to the benchmarked frameless doors, at significantly reduced mass. Test results further confirmed the door design is not sensitive to structural performance in the tested range when changing the material thickness (0.7 mm BH260 to 0.6 mm DP600).

All of the hydroformed outer panels were thinner than their stamped counterparts, yet displayed essentially the same dent resistance because of the increased work hardening that occurred during hydroforming.

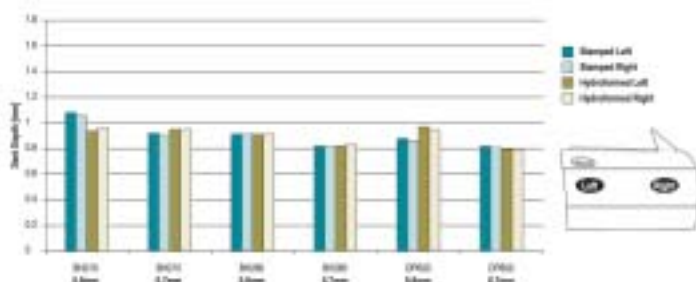
Dent test used were:

- ▶ Quasi-static incremental
- ▶ Dynamic incremental
- ▶ Dynamic high speed

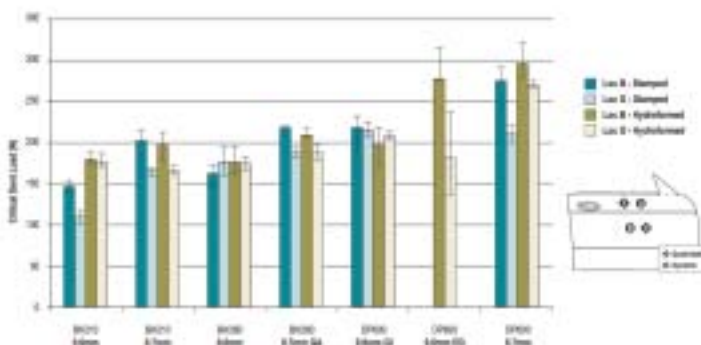
Quasi-Static Incremental - Critical Dent Load for 0.1 mm Dent



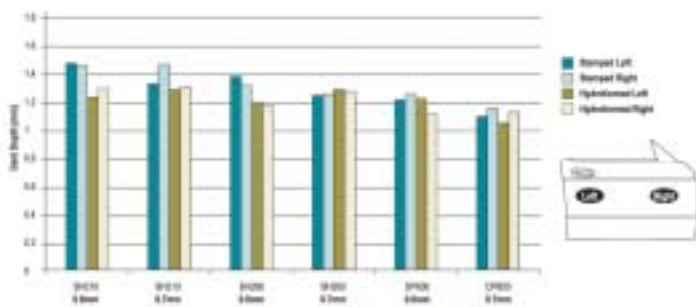
Lab 1a - Dynamic High Speed - Dent Depth (6mm, 0.88 g bullet)



Dynamic Incremental - Critical Dent Load for 0.1 mm Dent



Lab 1b - Dynamic High Speed - Dent Depth (18mm, 23.8 g bullet)



Oil Canning Performance

ULSAC doors also were evaluated for oil canning. For doors with stamped outer panels, those with 0.7 mm BH 260 steel outer panels exhibited the best performance, with slight oil canning in the mid region that would meet current expectations.

Oil canning performance in sheet hydroformed outer panels was significantly improved over the behavior of doors with stamped outers. Ultimately, 0.6 mm DP 600 steel sheet hydroformed outer were chosen to manufacture the demonstration hardware shown here because of its above-average oil canning performance and excellent dent resistance.

ULSAC Results: Lightweight, Safe, Affordable Structural Performance

Upper and Lower Lateral Stiffness

Both ULSAC doors exhibit state-of-the-art lateral stiffness compared to the benchmarked frameless doors, at significantly reduced mass. Test results further confirmed the door design is not sensitive to structural performance in the tested range when changing the material thickness (0.7 mm BH260 to 0.6 mm DP600).

	Door A	Door B	Door C	ULSAC DH Stamped Outer Panel	ULSAC DH Sheet Hydroformed Outer Panel
Upper Torsion Nm/deg	352	197	188	245	242
Lower Torsion Nm/deg	467	309	188	250	203

Door Sag

Compared to benchmarked frameless doors, ULSAC doors perform similarly to those in current production at slightly reduced mass. The test confirmed that the effect of material thickness change is negligible to the door sag performance.

	Door A	Door B	Door C	ULSAC DH Stamped Outer Panel	ULSAC DH Sheet Hydroformed Outer Panel
N/mm	109	199	497	157	181

Lightweight, Safe Performance at Affordable Costs

ULSAC's detailed cost model estimates manufacturing costs and compares it to a state-of-the-art generic door.

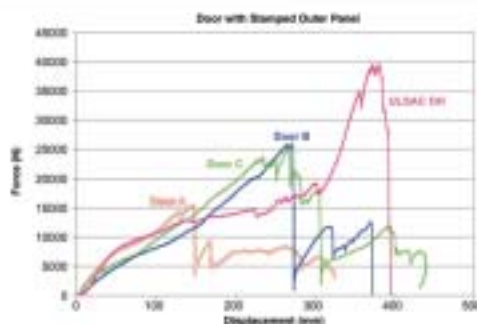
The results of the economic analysis prove that a steel door structure with significant weight saving can be built at affordable costs. With further development to reduce cycle times, sheet hydroformed outer panels could be used to achieve additional weight reduction over the already significant achievements of the ULSAC door with stamped outer panels.

	Stamped Outer ULSAC LH&RH Door	Sheet Hydroformed Outer ULSAC LH&RH Door	"State-of-the-Art" Generic Door LH&RH Door
Parts Fabrication	\$79	\$66	\$91
Material	\$28	\$28	\$48
Stamping	\$15	\$6	\$16
Tailored Blank Stamping	\$12	\$12	\$20
Tubular Hydroforming	\$15	\$15	\$0
Purchased Parts	\$0	\$0	\$7
Assembly	\$54	\$54	\$47
Total Cost of Doors (2)	\$133	\$140	\$138

Quasi-Static Intrusion Testing

To test the door structure for side intrusion protection, a quasi-static side intrusion test, similar to U.S. FMVSS 214, in which a door is tested in a full vehicle, was performed on doors with stamped outer panels.

The benchmarked frameless door were also tested to analyze how ULSAC performs compared to doors that had been previously tested in a full vehicle. It is assumed that by achieving similar results as the benchmarks, ULSAC would also meet FMVSS 214 requirements. Test results show that the ULSAC door actually performs better than the comparison door.



ULTRALIGHT STEEL AUTO CLOSURES (ULSAC)

A Success Story in Producing Lightweight, Safe and Affordable STEEL Closures

Program Objective

Demonstrate the effective use of steel in producing lightweight, structurally sound steel automobile closure panels that are manufacturable in large volumes and affordable.

Program Background

ULSAC is a companion to the UltraLight Steel Auto Body (ULSAB) study released in 1998 and the recently completed (May, 2000) UltraLight Steel Auto Suspensions (ULSAS) study. The ULSAC program was commissioned by an international consortium of sheet steel producers to assist their automotive customers with viable lightweighting steel solutions. The Consortium contracted Porsche Engineering Services, Inc. to provide design and engineering management for both the Concept and Validation Phases of the program.

Concept Phase

The Concept Phase was a study of automotive closures, which included: doors, hoods, decklids and hatchbacks. This Phase encompassed benchmarking, target setting and conceptual design, and included FEA calculation and cost analysis. The result of this phase was the selection of a frameless door as the design example for validation.

Validation Phase

The Validation Phase includes additional benchmarking, additional design, and the building of demonstration hardware to validate the design concepts. This includes managing detailed design engineering, CAE analysis, design optimization for manufacturing and assembly, supplier selection for parts manufacturing and assembly, cost estimation and cost model development and testing.

ULSAC Frameless Door - Up to 46% Lighter



The ULSAC study also demonstrated similar weight savings in:

- ▶ Hoods- 32% lighter than the benchmarked average
- ▶ Decklids- 29% lighter than the benchmarked average
- ▶ Hatchbacks- up to 32% lighter than the benchmarked average

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