Introduction

The UltraLight Steel Auto Closure (ULSAC) program is a study undertaken by the global steel industry to demonstrate the effective use of steel in producing lightweight, structurally sound steel automotive closure panels that are manufacturable and affordable. ULSAC began as a concept development program, which produced concept designs for doors, hoods, decklids and hatches that are up to 32 percent lighter than benchmarked averages and ten percent lighter than best-in-class, while meeting stringent structural performance targets. They can be fabricated in high volume using manufacturing processes and materials that are current and affordable.

These impressive results were obtained largely through materials such as high and ultra high strength steels and steel sandwich, combined with technologies such as tailor welded blanks and hydroforming.

Like the UltraLight Steel Auto Body (ULSAB) study, the ULSAC study was commissioned by an international consortium of sheet steel producers to assist their automotive customers with viable lightweighting solutions. The ULSAC consortium contracted Porsche Engineering Services, Inc. (PES) in Troy, Mich., to provide engineering management for the program.

The ULSAC program has proceeded to the validation of a frameless door concept design, results of which will be available in May 2000. Current status of the validation, including important achievements in stampings, can be found on page 4.

Concept Program

Approach

The ULSAC Concept Program encompassed benchmarking, target setting and conceptual design, which includes FEA calculation and cost analysis. Benchmarking was performed to define current state-of-the-art design concepts; target setting provided specific mass and performance objectives; and conceptual design was undertaken to develop ideas that would meet these targets and to produce data to support the concepts.

ULSAC’s design team started with a “clean sheet of paper” and used an iterative holistic approach to design. The holistic approach emphasizes total structure analysis by enabling engineers to reduce weight in certain areas while strengthening strategic locations. The net effect is the creation of a more efficient closure with no compromise to performance.
The Porsche design team first conducted a screening process to evaluate materials, processes and joining techniques that provided the most promising concept design solutions.

Another initial consideration concerned dent resistance and oil canning. Porsche dealt with these two issues by following conventional design techniques such as:

- High strength steel used for outer panels
- Forming techniques that maximize work hardening
- Feature lines added to outer panels
- Inner panels designed to support outer panels

**Benchmarking**

The following 1997 vehicle models were benchmarked:

- Audi A6
- BMW 528I
- Cadillac Sedan Deville
- Chevrolet Malibu
- Dodge Stratus
- Ford Contour
- Mercedes E320
- Mitsubishi Eclipse
- Nissan Sentra
- Ford Probe
- Ford Taurus
- Honda Accord
- Porsche Boxster
- Renault Laguna
- Saturn LS
- Toyota Camry
- VW Golf
- VW Passat

The benchmark vehicles were chosen to provide evaluations of specific closures. For the door these included roof integrated, frame integrated and frameless. Hood design concepts included conventional and grill integrated. The decklid design was the conventional with a tail, and the hatch design was the lift gate type.

The benchmark study established mass (without glass), dimension and structural performance standards for doors, hoods, decklids and hatchbacks. PES normalized this data, converting all closures to Kg./m², to make accurate comparisons among the closures and then evaluated designs and components of the benchmarked closures. In addition, PES assessed costs associated with manufacturing each of the closures.

PES also calculated mass breakdown to discover opportunities for greatest mass reduction. Calculations for mass breakdown revealed that structure represented approximately 50 percent of the mass of the doors. For hoods and decklids, that number increased to approximately 90 percent. The structure in hatches accounts for about 45 percent of the mass. After gathering this benchmarking data and processing it appropriately, mass and performance targets were established for the closure designs.

**Target Setting**

PES developed targets for dimensions, structural performances and mass for doors, hoods, decklids and hatches. Dimensional targets for doors, hoods and decklids were based on ULSAB styling surface dimensions because those dimensions were very close to ULSAC benchmarked averages, and they provided the outer surface data needed to conduct this closure study. For hatch dimensional targets, PES used the measurements from a lift gate-type hatch, which was the lightest and smallest one benchmarked. Structural performance targets were set at the midpoint in the range from a survey of OEM requirements. Mass targets, however, were set for 10 percent better than best-in-class of the benchmarked closures.
Concept Program Results

The ULSAC Concept Program achieved innovative closure designs that met or exceeded structural targets, while significantly reducing weight at little or no cost increase. A final engineering report of the results of the concept phase, including designs for all closures, FEA analysis and results, cost information and structural performance are available on CD-ROM from the ULSAC Program Management Office.

Mass and cost comparison results for each design are given in the tables below.

Mass Comparison

<table>
<thead>
<tr>
<th></th>
<th>Benchmark (kg/m²)</th>
<th>Target (kg/m²)</th>
<th>ULSAC (kg/m²)</th>
<th>(kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Average</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Door - Roof Integrated</td>
<td>17.0 - 23.4</td>
<td>19.7</td>
<td>15.5</td>
<td>13.2</td>
</tr>
<tr>
<td>Door - Frame Integrated</td>
<td></td>
<td></td>
<td>15.5</td>
<td>13.2</td>
</tr>
<tr>
<td>Door - Frameless</td>
<td></td>
<td></td>
<td>14.3</td>
<td>11.5</td>
</tr>
<tr>
<td>Hood - Conventional*</td>
<td>8.8 – 14.2</td>
<td>11.5</td>
<td>7.9</td>
<td>13.3</td>
</tr>
<tr>
<td>Hood - Grill Integrated*</td>
<td></td>
<td>8.0</td>
<td>7.9</td>
<td>13.7</td>
</tr>
<tr>
<td>Hood - Conventional**</td>
<td></td>
<td>8.5</td>
<td>8.4</td>
<td>14.7</td>
</tr>
<tr>
<td>Hood - Grill Integrated**</td>
<td></td>
<td>8.4</td>
<td>8.6</td>
<td>10.6</td>
</tr>
<tr>
<td>Decklid - Conventional*</td>
<td>8.9 – 16.1</td>
<td>11.2</td>
<td>8.0</td>
<td>9.8</td>
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<tr>
<td>Decklid - Conventional**</td>
<td></td>
<td>8.0</td>
<td>8.6</td>
<td>10.6</td>
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<tr>
<td>Hatch - Tube Hydroformed</td>
<td>12.5 – 15.2</td>
<td>13.9</td>
<td>10.3</td>
<td>6.7</td>
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<td>Hatch - Tailored Blank Inner</td>
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<td></td>
<td>10.6</td>
<td>6.9</td>
</tr>
<tr>
<td>Hatch - Hydroformed Ring</td>
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<td></td>
<td>10.9</td>
<td>7.1</td>
</tr>
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<td>Hatch - Sheet Hydroformed</td>
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<td></td>
<td>9.5</td>
<td>6.2</td>
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</tbody>
</table>

* with sandwich material inner panel
** with sheet steel inner panel

Cost Comparison in US $

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>ULSAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Door - Roof Integrated</td>
<td>67</td>
<td>67</td>
</tr>
<tr>
<td>Door - Frame Integrated</td>
<td>40 Frame Integrated</td>
<td>65</td>
</tr>
<tr>
<td>Door - Frameless</td>
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<td>46</td>
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<td>Hood - Conventional*</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>Hood - Grill Integrated*</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>Hood - Conventional**</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Hood - Grill Integrated**</td>
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<tr>
<td>Decklid - Conventional*</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>Hatch - Tube Hydroformed***</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>Hatch - Tailored Blank***</td>
<td>29</td>
<td>29</td>
</tr>
</tbody>
</table>

* with sandwich material inner panel
** with sheet steel inner panel
*** The hydroformed ring and sheet hydroformed designs were preliminary concepts, therefore no cost estimates were completed for these designs. However, preliminary investigation indicates that they can be manufactured at no cost penalty.
Validation Program

Scope of Validation of Frameless Door Design

ULSAC has proceeded to the validation phase of the program, using a frameless door concept design. By validation of the frameless door, ULSAC also validates the other closure concepts which use similar design concepts, materials, and manufacturing technology. The ULSAC Validation Program includes further optimization of the frameless door design plus building and testing of demonstration hardware to illustrate affordable manufacturing feasibility. The program encompasses the following:

- Detail design optimization and CAE analysis of structural performances
- Forming simulation of stamping and hydroformed parts
- Build of door structure assemblies, for testing and demonstration hardware
- Comparative testing for dent-resistance and oil-canning (dimple testing)
- Testing for structural performance
- Validation of forming simulation with strain analysis
- Documentation of manufacturing parameters such as press environment, lubrication, tonnage, etc.
- Documentation of material properties
- Documentation of dimensional control data
- Economic analysis to evaluate cost effectiveness

The frameless door validation illustrates lightweighting of automotive closures with steel combined with processes including conventional stamping, hydroforming and laser welding. Forming tools are soft tools except hydroforming tools, which are made of steel. All forming operations are done in tools (hem flange excluded). Laser cutting is used for trim operations.

Current Status

In the validation program, the frameless door concept design has been optimized and fabrication of all parts, except sheet hydroformed door outer panels, has been completed. Door assemblies, using high strength steel stamped outer panels, have been completed. Forming simulation and fabrication trials for sheet hydroformed door outer panels have been underway and are on-going.

Stamping Achievements

High strength steel blanks have been successfully stamped into quality panel door outers using two different thicknesses (0.60mm and 0.70mm) and bake hardenable (210, 260 MPa) dual phase (500, 600 MPa), rephosphorized (260 MPa), and isotropic (260 MPa) steels. This is an important achievement in steel stampings consisting of these grades and thicknesses.

Although all six of the aforementioned grades were successful in press formation, three were finally selected for comparative dent testing in the validation: Bake hardenable 210 and 260 MPa and Dual phase 600 MPa. These three grades were selected because they represent a good range of steel grades for comparison purposes and they are at the leading edge of steel material use in closure panels.
Tubes and Tube Hydroforming Achievements

The lower tube is made of a straight, rectangular ultra high strength dual phase steel tube of 1.5 mm wall thickness and 650 MPa yield strength/840 MPa tensile strength, successfully achieving a small dimension, tight radius section that provides the door beam structure.

The outer belt reinforcement, the upper tube is made of a straight, round ultra high strength dual phase steel tube of 1.0 mm wall thickness and 650 MPa yield strength/840 MPa tensile strength to provide a strong, lightweight reinforcement structure.

Dual phase steel is used in these two parts because it provides the high yield strength, excellent formability and ultra high tensile strength needed to manage energy forces in a side impact crash.

High strength steel tubes have been successfully formed into hydroformed door frame components. Hinge tubes were formed using round tubes of 1.2 mm wall thickness, and latch tubes were formed using round tubes of 1.0 mm wall thickness, both of 280 MPa yield strength.

Furthermore, during the door manufacturing process, these hydroformed tubes of complicated shapes proved to have excellent part fit in the door assembly. Also, the tubes formed precisely as indicated in the forming simulations.

Sheet Hydroforming

Extensive efforts have been undertaken during the ULSAC Validation to produce door outer panels with the active hydro-mechanical sheet metal forming process of Schuler/SMG. The try-outs conducted so far with existing component/tooling geometry have demonstrated manufacturing problems, which will require re-configuring both the tooling and the press.

Actions underway to complete sheet hydroformed door outers include the following:

- Additional Finite Element Simulations will be carried out to support tooling modifications.
- Modifications will be made to the tooling system and the forming press.

Performance

Based on FEA calculations, the ULSAC frameless door design meets or exceeds the targets set for structural performance. In the on-going validation work, door assemblies are being physically tested to confirm the FEA calculations. In addition, dent testing will be conducted and documented to compare the effect of different steel grades and different forming processes. First tests will be performed on doors with stamped outer panels only.

Mass Status

FEA calculations and initial actual measurements show that the frameless door design achieves the aggressive design objectives that were set for this program. As the demonstration hardware door assemblies are produced, complete documentation of mass savings achieved will be prepared. All calculation and measurement data will be presented in the final report.
May 2000 Release of Results

An Engineering Report covering the validation of the frameless door with stamped outer panels will be released in May 2000, and will include the following detail:

- Program highlights
- Design and engineering summary
- Documentation of forming simulation
- CAE results
- Physical Testing results
- Documentation of material properties
- Documentation of press environment, lubrication, tonnage, etc.
- Documentation of strain analysis
- Documentation of dimensional control
- Parts List, Parts Drawings and Typical sections
- Assembly drawings and assembly description
- Virtual assembly demonstration in form of animated assembly process
- Economic analysis including a detailed cost model

A set of communication deliverables, including a summary of all concept designs, assembled frameless doors (demonstration hardware), sets of individual parts, an overview report, presentations, images, and a press release will also be issued in May 2000. An ULSAC Internet site, www.ulsac.org, will also display the ULSAC concept designs and the results of ULSAC Validation.

Future Release of Results

Additional information concerning on-going work with the same frameless door design, utilizing sheet hydroforming for the door outer panel, will be released later. This on-going work focuses on attaining the maximum possible benefit of steel’s excellent strain hardening characteristics. Results of this work will be presented in early 2001.