ULSAB

Ultra Light Steel Auto Body

Phase 2 Findings

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PHASE 2

PORSCHE

Porsche Engineering Services, Inc.

Preface

In 1994, the steel industry, through the Ultra Light Steel Auto Body Consortium (ULSAB), commissioned Porsche Engineering Services, Inc. (PES) to conduct a concept phase (Phase 1) of the ULSAB project to determine if a substantially lighter steel body structure could be designed.

In September 1995, worldwide auto industry attention was focused on the study when the results of Phase 1 were announced. The results also affected the growth of the ULSAB Consortium to 35 member steel companies, representing 18 nations worldwide.

Encouraged by the results of Phase 1, the ULSAB Consortium once again commissioned PES to continue with Phase 2, the validation of the Phase 1 concepts, culminating in the build of the demonstration hardware. Phase 2 proved that the weight reduction, predicted in Phase 1, could be achieved. The use of high strength steels, tailor welded blanks, hydroforming and laser welding in assembly were particular challenges to overcome in Phase 2. ULSAB Consortium members committed themselves to supplying all steel materials, as well as the tailor welded blanks and raw materials for hydroforming, for all parts to be manufactured.

The focus of Phase 2 was the same as in Phase 1, i.e., weight reduction without compromising safety or structural performance. Without altering the aggressive targets for mass and structural performance, the safety requirements were increased in Phase 2 in response to growing industry and government concern for increased auto safety. It was imperative to keep up with safety requirement changes that occurred during the course of the program, which ran from spring 1994 to spring 1998. As a result, it was necessary to analyze the ULSAB structure for offset crash behavior. With this new challenge, and valuable input gathered in discussions with OEMs during the presentation of Phase 1 findings, PES and the ULSAB Consortium commenced Phase 2.

Phase 2 ended in Spring 1998 with the debut of the ULSAB demonstration hardware and will prove the Phase 1 concept to be not only feasible, but that performance targets will be exceeded by 60% for torsional rigidity, 48% for bending rigidity and 50% for the normal mode frequency. Relative to the benchmark average, mass reduction remained at 25%, while crash analysis showed excellent results for the selected crash analysis events, including the offset crash.

As a result of Phase 2, the use of high strength steels in the ULSAB demonstration hardware structure has now increased to 90% relative to its mass. The trend toward using high strength steel and new technologies to reduce body structure mass while improving safety, can be seen already in recently launched cars. The new Porsche Boxster, for example, uses 30% high strength steel, as well as tailored blanking, hydroforming and laser welding in assembly.

Cost analysis in Phase 1 was conducted by IBIS Associates under contract to the ULSAB Consortium. In Phase 2, a more detailed cost analysis study was conducted, under the supervision of PES with the support of ULSAB consortium member companies. With the detailed information provided with the concept validation in Phase 2, a new cost model was created and the cost to produce the ULSAB structure was analyzed. The results show that it is possible to reduce the mass of body structures without cost penalty.

1. Executive Summary

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Ultra Light Steel Auto Body (ULSAB) Phase 2

Introduction

On behalf of an international Consortium of 35 of the world's leading sheet-steel producers from 18 countries, Porsche Engineering Services, Inc. (PES) in Troy, Michigan, was responsible for the program management, design, engineering, and the building of the demonstration hardware (DH). In addition, PES conducted the economic analysis study for the Ultra Light Steel Auto Body (ULSAB) program.

Program Goal

The goal of the ULSAB program was to develop a light-weight body structure design that is predominantly steel. This goal included:

- Providing a significant mass reduction based on a future reference vehicle
- Meeting functional and structural performance targets
- Providing concepts that will be applicable for future car programs

Program Structure

In order to achieve the above-mentioned goals the program was structured in three phases:

- Phase 1 Concept Development (paper study)
- Phase 2 Concept Validation (build of demonstration hardware)
- Phase 3 Vehicle Feasibility (total vehicle prototype assembly and evaluation)

Phase 1 – Concept

In September 1995, the results of Phase 1 were published. In this phase, the ULSAB program concentrated on developing design concepts for light-weight body structures and validating crashworthiness. Based on benchmarking data, the performance of a future reference vehicle was predicted and the structural performance targets for the ULSAB structure, excluding doors, rear deck lid, hood and front fenders were established. Because the ULSAB program focuses on mass reduction, a much more aggressive target was set for mass than for the other structural performance targets. These targets were:

Performance	ULSAB Targets*	Future Reference Vehicle Prediction
Mass	$\leq$200 kg	250 kg
Static torsional rigidity	$\geq$13000 Nm/deg	13000 Nm/deg
Static bending rigidity	$\geq$12200 N/mm	12200 N/mm
First body structure mode	$\geq$40 Hz	40 Hz

* All targets were set for body structure with glass, except the target for mass

For the concept validation, the following crash analysis was performed in Phase 1:

- NCAP, 100% frontal crash at 35 mph
- Rear moving barrier crash at 35 mph (FMVSS 301)
- EEVC, side impact crash at 50 km/h (with rigid barrier)
- Roof crush (FMVSS 216)

The analytical results of Phase 1 were:

Performance	Phase 1 Results*
Mass	205 kg
Static torsional rigidity	19056 Nm/deg
Static bending rigidity	12529 N/mm
First body structure mode	51 Hz

*Structural performance results were calculated with glass; the mass excludes glass

With the exception of mass, the results exceeded the targets. Mass was calculated at 205 kg and slightly above the aggressive target of 200 kg.

An independent cost study indicated that, based on a North American manufacturing scenerio, the Phase 1 concept could cost less to produce than comparable current vehicle structures. This result, based on the relatively low level of detail of the ULSAB Phase 1 concept, indicated that a light weight structure could make substantial use of high strength steel, tailor welded blanks, laser welding in assembly, and hydroforming, and end up in the cost range of structures of similar size using a more conventional approach at a higher mass.

Phase 2 - Validation

The Phase 1 design concept and its structural and crash performance results having had a relatively low mass, provided an excellent foundation for Phase 2 of the ULSAB program. Based on the success of this Phase 1 paper study, and the positive recognition by OEMs around the world, the ULSAB Consortium commissioned PES to undertake Phase 2 starting in November 1995.

The overall goal of Phase 2 was the validation of Phase 1 results, culminating in the build of the ULSAB demonstration hardware structure. The tasks and responsibilities of Phase 2 for PES, besides the program management, were to manage the necessary detail design, engineering, crash analysis, material selection, design optimization for manufacturing, supplier selection for parts and to assemble, test and deliver the demonstration hardware to the ULSAB Consortium. In addition, PES was responsible for a detailed cost analysis based on the Phase 2 detailed design.

Crash Analysis

During the course of the ULSAB program after the start in Spring 1994, the public demanded increased vehicle safety, and governments reacted with new requirements for crashworthiness. Therefore, the decision was made prior to the beginning of Phase 2, to analyze and to design the ULSAB structure for offset crash. This would enhance the credibility of the results. The AMS (Auto Motor Sport) 50% offset frontal crash at 55 km/h was considered the most severe test at that time and would represent the structural requirements an offset crash demands. This test was then added to the Phase 1 previously selected crash analysis events. For side impact crash analysis, a deformable barrier was used instead of the rigid barrier as used in Phase 1.

The following crash analysis was performed in Phase 2:

- AMS, 50% frontal offset crash at 55 km/h
- NCAP, 100% frontal crash at 35 mph (FMVSS 208)
- Side impact crash at 50 km/h (96/27 EG, with deformable barrier)
- Rear moving barrier crash at 35 mph (FMVSS 301)
- Roof crush (FMVSS 216)

All crash calculations indicate excellent crash behavior of the ULSAB structure, even at speeds that exceed federal requirements. The front and rear impacts were run at 5 mph above the required limit, meaning 36% more energy had to be absorbed in the frontal impact. The offset crash also confirmed the overall integrity of the structure. The roof crush analysis validated that the federal standard requirement was met, partialy due to the hydroformed side roof rail concept design.

Package

At the start of Phase 2, as a result of various discussions with OEMs during the presentation of Phase 1 results, the ULSAB package was re-examined. In order to make the results of Phase 2 more credible, the decision was made not to consider secondary mass savings. This resulted in significant changes in several areas of the body structure.

The relatively small engine specified in Phase 1 was replaced by an average size 3-liter V6, necessitating a complete redesign of the front-end structure, including a revised front suspension layout and subframe design. The rear suspension also was revised and the rear rails redesigned accordingly. Essentially, the whole structure was redesigned, from front to rear bumper, but it still maintained the structure features as developed in Phase I, such as the side roof rail and the smooth load flow concept of front and rear rails into the rocker.

Styling

Using the revised package and the adjusted body structure design, styling the ULSAB was the next challenge. Styling became necessary to create the surfaces for the body side outer panel with its integrated exposed rear quarter panel, the windshield, the backlight and the roof panel. The styling concept for the greenhouse had to consider, in order to integrate, the side roof rail, as well as the overlapping upper door frame concept. This door concept was chosen mainly for cosmetic reasons; to cover the visible weld seams, in the upper door opening area of the body side outer panel which were caused by the tailor welded blank design of the body side outer panel. For the overall styling approach, the decision was made to create a neutral, not too futuristic or radical, more conservative styling.

Styling was the first major milestone in Phase 2 and was performed entirely by computer-aided styling (CAS).

Design and Engineering

After the exterior styling was created, the package was then optimized and the design modified accordingly. The implication of any design change was assessed by modifying the Phase 1 static analysis model. Design changes resulting as an outcome of the analysis were then incorporated into the styling and the package. With the performance targets met, styling and the Phase 2 package were frozen, and with a more detailed Phase 2 design, a new shell model for the structural performance analysis was created. Static analysis was then used to optimize the

Phase 2 design until the requirements were met and new crash analysis models were built. In the process of design optimization, which included material grade and thickness selection, both static analysis and crash analysis were performed with constantly updated models until the targets were met.

Throughout this process, simultaneous engineering provided input from the tool and part suppliers, as well as from steel manufacturers, to ensure the manufacturing feasibility of the designed parts. As a result of the simultaneous engineering process, only minor design and tool changes were needed after the drawings were released. When the first part set was completed, a workhorse (test unit) was built. The validation of the test unit lead to further part optimization and, finally, to the build of demonstration structures.

Suppliers

At the start of the detail design process in Phase 2, suppliers for stamped and hydroformed parts were selected in order to be included in the simultaneous engineering process. Among the selection criteria were quality, experience, skills and location. Supplier flexibility and their willingness to explore new manufacturing methods, utilizing material grades rarely used in these applications and to "push the envelope" in the application of tailor welded blanks or in hydroforming technologies, were as important in the selection process as their cost competitiveness.

Steel Materials

- **Steel Grades**

  Perhaps the most important factor in meeting the targets for mass and crash performance is high strength steel. More than 90% of the ULSAB structure utilizes high strength and ultra high strength steel. High strength steels are applied where the design is driven by crash and strength requirements. Ultra high strength steels with yield strength of more than 550 MPa are used for parts to provide additional strength for front and side impact. High strength and ultra high strength steel material specifications range from 210 to 800 MPa yield strength with a thickness range from

0.65 to 2 mm. With the restriction of lower elongation, different forming characteristics and greater spring back of high strength steels, material supplier support combined with forming simulations were important factors in meeting the challenges for the development of manufacturable part designs.

- **Steel Sandwich Material**

  The use of steel sandwich material has contributed to considerable mass savings. The sandwich material is made with a thermoplastic (polypropylene) core, with a thickness of 0.65 mm and is layered between two thin steel skins, each with a thickness of 0.14 mm and yield strength of 240 MPa for the spare tire tub and 140 MPa for the dash panel insert. The steel sandwich shares many of the same processing possibilities of sheet steel, such as deep drawing, shear cutting, drilling, bonding, and riveting. However, it cannot be welded. Parts manufactured from steel sandwich material can be up to 50% lighter than those made of sheet steel with similar dimensional and functional characteristics. The spare tire tub made of steel sandwich material is a pre-painted module that is pre-assembled with the spare tire and repair tools. The module is dropped into place and bonded to the structure during the final assembly of the vehicle.

  Another application of sandwich material is the dash panel insert, which is bolted and bonded into the body structure, during final vehicle assembly.

Tailor Welded Blanks

Tailor welded blanks enable the engineers to accurately locate the steel within the part precisely where its attributes are most needed, while at the same time allowing for the elimination of mass that does not contribute to performance. Other benefits of tailor welded blanks include the use of fewer parts, dies and joining operations, as well as improved dimensional accuracy through the reduction of assembly steps. Nearly half (45%) of the ULSAB demonstration hardware mass consists of parts manufactured using laser welded tailored blanks.

The best example of tailor welded blank usage is the body side outer panel. It employs a fully laser welded tailored blank with different thicknesses and grades of high strength steel. Careful placement of the seams in the tailor welded blank is critical in order to minimize mass and facilitate forming. This consideration was especially important in the body side outer panel because of its complexity and size, its use of high strength steels and the integration of the rear quarter panel with its Class A surface requirement. Mass reduction and the elimination of reinforcements were key goals in the development of this one-piece design. The consolidation of parts reduced mass and assembly steps.

Hydroforming

- **Tubular Hydroforming**

  The use of hydroforming should be considered as one of the most significant manufacturing processes applied in the ULSAB program for part manufacturing. The hydroformed side roof rail represents a significant structural member in the ULSAB structure. The side roof rail distributes loads appearing in the structure during vehicle operation, and in the event of an impact, distributes loads from the top of the A-pillar along the roof into B and C-pillar and then into the rear of the structure. The hydroformed side roof rail reduces the total number of parts and optimizes available package space. The raw material used to manufacture the side roof rail is a laser welded, high-strength steel tube 1 mm thick with an outside diameter of 96 mm and a yield strength of 280 MPa. The design was optimized and analyzed for feasibility using forming simulation.

- **Hydromechanical Sheet Forming**

  The use of hydromechanical sheet forming was chosen for the roof panel for mass reduction reasons. This process provided the opportunity to manufacture the roof panel at a thinner material thickness and still achieve a work-hardening effect in the center area, where the degree of stretch is normally minimal and an increased material thickness is needed to meet dent resistance requirements. With hydro-mechanical sheet forming, this work-hardening effect is achieved by using fluid pressure to pre-stretch the blanks in the opposite direction towards the punch. This plastic elongation causes a work-hardening effect in the center area of the blank. In the second step, the punch forms the panel towards controlled fluid pressure and because there is no metal-to-metal contact on the outer part surface, excellent part quality is achieved. The ULSAB roof panel is manufactured in 0.7 mm high strength steel with a yield strength of 210 MPa.

Tooling

All tools for stamped parts are “soft” tools made of materials such as kirksite and built to production intent standards. Tools used for hydroforming are “hard” tools made of steel. In both cases, part manufacturing tolerances and quality standards were the same as those used in high-volume production.

DH Assembly

- **Joining Technologies**

  For the final assembly of the ULSAB structure, four types of joining technologies were applied. Spot welding is used for joining the majority of parts. Laser welding became necessary to join the hydroformed side roof rail to its mating parts. In addition, the rails in the front end structure are laser welded for improved structural performance. Laser welding in body structure assembly is already being used in mass production by many OEMs. The active gas metal arc welding (MAG) process, with its disadvantages, such as slow welding speed and relatively large heat impact zones, was kept to a minimum and used only in locations with no weld access for spot or laser welding. Bonding is used to join the sandwich parts that cannot be spot or laser welded into the structure. For the joining of the DH, about one-third fewer spot welds and significantly more laser welding is employed than for conventional body structures.

- **Assembly Sequence**

  For the DH build, the assembly sequence uses two stage body side framing. The assembly sequence includes underbody assembly, body side assemblies, roof and rear panel assemblies. All DHs were built in a single build sequence.

- **Assembly Fixtures**

  To assemble the DH, a modular fixture system was used. The fixtures were developed in a CAD system and the positions of locator holes were then incorporated into the parts design.

DH Testing

Testing was performed on the ULSAB test unit structure to validate its structural performance and mass. Included were tests for static torsion rigidity, static bending rigidity, modal analysis and mass in various configurations, including some bolt-on parts. Testing was performed at Porsche's Research & Development Center in Weissach, Germany. Physical testing for crash was not part of the ULSAB program in Phase 2 and may be performed in a possible Phase 3, after the necessary components are built and/or assembled into the ULSAB structure.

Economic Analysis

With the detailed information created in Phase 2 of the ULSAB program, the costs of parts and assembly of the body structure were analyzed. Under the management of a PES' team, and with support from the ULSAB Consortium members, an economic analysis group, comprising of analysts from the Massachusetts Institute of Technology (MIT), IBIS Associates and Classic Design, a detailed cost model was constructed that includes all aspects of fabrication and assembly. This cost model will enable the automotive OEMs to calculate ULSAB cost based on their own manufacturing criteria. Considering that the focus of Phase 2 was on mass reduction and not on cost savings, the result of this cost analysis is quite remarkable. It confirms that significant mass reduction of the body structure, in comparision to the benchmark vehicle average mass, was achieved with the use of steel with no cost penalty.

Summary/Conclusion

Throughout Phase 2, timely execution of the program was critical. All parts designed and released to our suppliers and all tooling and assembly of the first test unit have been on schedule. With the data acquired from the validation of the first test unit and subsequent testing, parts were refined and design optimization was performed. Refined parts were then used to build the demonstration hardware.

Based on the testing of the demonstration hardware, the ULSAB structure shows

Performance*	Target	Results
Mass	≤ 200 kg	203 kg
Static torsional rigidity	≥ 13000 Nm/deg	20800 Nm/deg
Static bending rigidity	≥ 12200 N/mm	18100 N/mm
First body structure mode	≥ 40 Hz	60 Hz

*Structural performances are test results with glass. ULSAB structure mass without glass

the following structural performances:

Achieving these results in a timely manner could only be achieved by utilizing the team approach that involved all parties in the early stages of the ULSAB program. A close working relationship with the ULSAB Consortium members and the commitment of our suppliers and their enthusiasm for the program helped to meet the challenge of manufacturing parts made of steel materials and combinations that have not been commonly applied previously. This “pioneering spirit” was carried on by all members of the PES team, including designers and engineers. The ULSAB program has explored the potential for mass reduction in the body structure using steel as the chosen material. State-of-the-art manufacturing and joining technologies, such as laser welding in assembly and hydroforming as well as commercially available materials, contributed to the success of the ULSAB program. It proves that steel offers the potential for light weight vehicle design which contributes to the preservation of resources and the reduction of emissions.

Based on this experience, the steel industry should further intensify its dialogue and cooperation with OEMs to achieve their common goal of mass reduction of tomorrow’s vehicles, to protect the environment and to secure mobility of future generations.