X. Future Generation Passenger Compartment (ASP240[i])

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Contract No.: DE-FC05-02OR22910

Project Background

- Various studies conducted by the automotive OEMs (original equipment manufacturers), American Iron & Steel Institute (AISI), International Iron & Steel Institute (IISI) and the Auto/Steel Partnership (A/SP) have clearly demonstrated that AHSS (advanced high strength steel) can be effectively utilized in automotive lightweighting, or mass-avoidance strategies, to provide the required performance at a lower overall cost. New methodologies and designs must be developed to achieve equal or improved functionally and performance when compared to traditional design, while simultaneously ensuring cost-effective manufacturability of the appropriate automotive systems.
- Choices pertaining to design, manufacturing and materials are closely related. However, a through understanding and documentation of such choices and consequences does not exist today. Addressing this issue, along with bridging other technological “gaps”, is a prerequisite for enabling the use of steel in lightweighting automotive structures. Recent technologies anticipate multifunctional and multidisciplinary systems that can use the current and future AHSS in combination with an innovative optimized design.
- The USAMP and A/SP strategy for the FGPC project is to propose a new safety cage and underbody that can provide the OEMs with an example of AHSS usage in combination with a highly optimized design.

Phase 1- Objective

- The objective of the Future Generation Passenger Compartment (FGPC) project is to incorporate current propulsion systems and fuel cell-technologies into concept architectures. This project will reduce passenger compartment mass by 25% or greater with cost parity relative to FreedomCAR baseline while meeting the structural crash performance objectives for the IIHS side impact test and anticipated future crash requirements for the FMVSS pole side impact test and FMVSS 2.5x vehicle weight roof strength test. Further, it will maintain performance in static and dynamic stiffness, durability and front and rear crash requirements and also comprehend packaging requirements for fuel-cell powertrains. The study will address a 5-passenger 4-door sedan donor vehicle design and finally identify opportunities for steel properties that exceed the capability of existing automotive steel grades to improve light weighting potential.

Phase 1-Approach: Concept Development

The project will take a clean-sheet approach to developing mass-efficient structural load paths and select the most appropriate use of existing and future high strength-steels which include Dual Phase, Transformation Induced Plasticity (TRIP), Complex Phase (CP), Hot-Stamped Boron, Martensite, and New Application of Nano Obstacles (NANO) and definitions of future grades using targeted material properties.

The study will benchmark, develop and document integrated solutions that will balance the interaction of materials, manufacturing, performance and cost. In addition, it will focus on solutions that will address high-volume manufacturing and assembly applied to fuel-cell technology vehicles. The project supports the goals of FreedomCAR as follows:

- High-strength steels are a mass-efficient solution in crash-dominated vehicle structures (e.g., body, closures, chassis, etc.) at a significant cost advantage versus other materials.
- A passenger compartment is thus an enabler to facilitate the application of other lightweight alloys to achieve half the vehicle mass while maintaining affordability.
- Steel has the proven and existing infrastructure for high-volume production and 100% recycling.
- This and other projects also allow the industry to migrate to lightweight structures that will accommodate fuel-cell powertrains.

Phase 1-Accomplishments

- Passenger compartment mass was reduced by 31.4% relative to typical 2005 baseline vehicle at cost parity.
- Crash performance of donor vehicle was improved to achieve an IIHS side impact good rating, and meet FMVSS pole test and FMVSS roof strength requirements. IIHS side impact and pole test criteria were met, while roof strength performance was 3.3x vehicle weight exceeding the 2.5x requirement.
- Maintained performance in static and dynamic stiffness, durability and front and rear crash criteria.
- Packaging comprehended fuel-cell powertrain requirements. Identified that worst case loading scenarios for IIHS side impact was ICE (internal combustion engine) variant and not the fuel cell variant.
- Identified that steel grades with a tensile strength of 1600 MPa capable of meeting application manufacturing requirements (formability) could improve mass saving by 6 to 8 percent.
- Identified a load path at side-impact bumper height that carries crash loading across B-pillars is a significant load path to enable mass reduction.
- Solutions developed were verified to be robust to IIHS side impact bumper height variations and to vehicle weight increases.

Future Direction

- Validation of the Phase 1 results into a donated production vehicle design.
- Roll-out learnings into advanced vehicle development.
- Incorporate results into future production vehicles.

Introduction

The Future Generation Passenger Compartment (FGPC) project was divided into eleven (11) tasks.

1.0 Benchmarking
2.0 Calibration Baseline
2.5 Mass Redistribution
3.0 Optimization
4.0 Concept Design
5.0 Concept Design Analysis Check
5.5 Concept Design Check Supplement
6.0 Final Optimization
7.0 Final Optimization Design Check
7.5 Barrier Height & Curb Weight Sensitivity
8.0 Final Concept Design

1.0 Project Strategy

Develop a robust design that considered two different perspectives, near-term or 5-years and long-term or 15 years. Near-term is defined as the knowledge gained from FGPC Phase 1 used in combination with knowledge that could be applied to a present vehicle with minor modifications**.** Issues relating to manufacturing, joining and material selection are considered within reach. FGPC-Validation (Phase 2) will apply the knowledge gained in Phase 1 to a donor vehicle.

Near-term selection was driven by grade/gauge availability and by manufacturing capability. Although these considerations did include an appropriate amount of stretch, it is difficult to apply the specifics of these enabling technology requirements on a design concept.

The long-term perspective considers issues such as manufacturing components from materials that are not presently available or in gauges that current design practice would not view as practical. Hence, the steel industry will require further research to meet these challenges.

The long-term outlook also revised the underbody design to package both traditional diesel and fuel-cell powertrains. The diesel option was a conventional front-wheel-drive configuration. The second option considered packaging a fuel-cell and its fuel tanks. Design guidelines were developed for the major components of a fuel-cell vehicle, including hydrogen-storage tanks, batteries, fuel cell-stack, and electric drive, to meet established crashworthiness performance criteria.

Using the ULSAB-AVC BIW (body-in-white) as a base model, the FGPC objective was to model the BIW to accommodate both diesel and fuel-cell powertrains and to reduce the BIW mass while still meeting the requirements of the new IIHS side impact and roof crush regulations.

Strategy

1. Efficient use of geometry to define the load path that meets crashworthiness and stiffness requirements, while absorbing energy through total system topology optimization.
2. Investigate the usage of AHSS materials and manufacturing techniques, such as tailor-welded blanks, to reduce vehicle mass and increase its performance.
3. Reduce the vehicle mass by using topology and shape optimization.

1.0 Relative Material Costs:

In order to discourage the use of high-strength steel parts where it is not required, a cost penalty function was setup to estimate the relative cost of different associated with each grade selection. The cost factors defined in Table 1 were used to calculate the relative cost of each design. The cost of each part was calculated by multiplying the mass of the part with the normalized cost factor for the material considered.

Table 1. Relative material costs.

Material Name	Relative Cost
IF 140/270	1.0
DQSK 210/340	1.104
BH 250/550	1.13
DP 300/500	1.169
HSLA 350/600	1.1948
DP 350/600	1.39
DP 500/800	1.506
Boron 1550	1.805
DP 700/1000	1.584
Mart 1300	1.688

2.0 Structure & Material Independency

The strategy implemented by this project concentrated primarily upon multi-disciplinary load path optimization, which addressed all crashworthiness, stiffness and NVH loadcases under consideration. Once the most efficient load paths were defined, the second optimization was then allowed to review the gauge and material gauge of each individual component. Thus, when considering another material such as composite, aluminum or multi-material vehicle, the knowledge and technology developed by the load-path optimization in this project is still valid. However, the project has demonstrated, that the geometry, gauge, and the impact of manufacturing, joining, and assembly must be considered for each material proposed.

3.0 FGPC & Fuel Cell Opportunities

As part of the long-term perspective, the vehicle underbody was redesigned to be capable of accommodating both diesel and fuel cell powertrains. Task 2 evaluated the IIHS side-impact performance of both. Although both did not satisfy IIHS impact target, the fuel cell did provide improved performance over diesel. This was because fuel-cell components provided structural load paths during the crash that improved its performance. Consequently, the remainder of the design optimization focused on the diesel powertrain as the worst-case scenario, with the confidence that the final optimized design could be easily adapted to provide equivalent performance for the fuel cell.

4.0 Conclusions

The optimization methods applied to this study achieved an 11% mass reduction of the modified parts of the BIW (body-in-white) and door impact beams (see Table 2) and 30% mass savings over a conventional, in-class vehicle's BIW and IP (instrument panel) beam (Table 3). Table 4 is a comparison of an industry-standard vehicle's safety cage to FGPC which shows a 31% mass reduction.

Table 2. Final mass summary for FGPC project-modified parts only.

Modified Parts	Baseline FGPC kg	Final FGPC kg	Mass Savings kg	Change %
BIW	130.6	121.0	9.6	7
Doors	12.6	6.4	6.2	49
Total	**143.2**	**127.4**	**15.8**	**11**

Table 3. Final mass summary for FGPC project-comparison to industry standard.

Structure	Industry Standard kg.	Final FGPC kg.	Mass Savings kg	Change %
BIW+IP Beam	**310.0**	**217.6**	**92.4**	**30**

Table 4. Final mass summary for FGPC project- safety cage comparison to industry standard.

Structure	Industry Standard kg	Final-FGPC kg	Mass Savings kg	Change %
Safety Cage	**246.8**	**169.3**	**77.5**	**31**

List of Presentations and Publications:

None at this time.

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[i] Denotes project 240 of the Auto/Steel Partnership (A/SP), the automotive-focus arm of the American Iron and Steel Institute. See www.a-sp.org. The A/SP co-funds projects with DOE through a Cooperative Agreement between DOE and the United Sates Automotive Materials Partnership (USAMP), one of the formal consortia of the United States Council for Automotive Research (USCAR), set up by the "Big Three" traditionally USA-based automakers to conduct joint pre-competitive research and development. See www.uscar.org.