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**Executive Summary**

The objective of this project was to develop a lightweight steel proof-of-concept twist beam design that achieves a 15 to 25% mass reduction with equivalent structural and elasto-kinematic performance relative to the baseline design at a ≤ 10% cost premium. A current production original equipment manufacturer (OEM) twist beam assembly was used to establish the baseline for package, performance, mass and cost.

Computer-aided engineering (CAE) structural optimization methods were used to determine the initial designs. Two designs were selected for further development and one design was subsequently selected as the best-performing and lightest alternative that met all typical performance criteria.

An iterative optimization strategy was used to minimize the mass of each design, while meeting the specified strength, durability and elasto-kinematic requirements. The manufacturing cost was estimated for the preferred design relative to the baseline design for three production volumes.

The results of the study indicate that the preferred **U-Beam Design** based on 22MnB5 tubular construction with DP780 and SPFH540 sheet achieves a 30.0% mass reduction relative to the baseline assembly, at a 12 to 15% premium in manufacturing cost. The **S-Beam Design** based on 22MnB5 sheet, DP780 tube and HSLA550 materials was predicted to have a 14.9% mass reduction relative to the baseline assembly.

All designs were deemed manufacturable based on expert manufacturing assessment and relevant production application examples.
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Purpose

The objective of this project was to develop a lightweight steel proof-of-concept twist beam design that achieves a 15 to 25% mass reduction with equivalent structural and elasto-kinematic performance relative to the baseline design at a ≤ 10% cost premium. A current production OEM twist beam assembly was used to establish the baseline for package, performance, mass and cost.

Conclusions

The results of the study support the following conclusions:

- The **U-Beam design** is predicted to be 30.0% lighter than the OEM baseline design at a 12 to 15% cost premium at production volumes of 30,000 to 250,000 vehicles per year, respectively. The design is deemed production feasible based on expert manufacturing assessments.
- The **S-Beam design** is predicted to have the best strength performance at a 14.9% mass reduction relative to the OEM baseline design. The design is deemed production feasible based on expert manufacturing assessments.

Recommendations

The twist beam designs are driven by durability and strength requirements at the component level and elasto-kinematic requirements at the vehicle level.
Durability (Max Twist load case) and strength (Max Vertical load case) are the primary design drivers for both designs.

CAE fatigue and strength modeling guidelines for the weld Heat Affected Zone (HAZ) have been developed based on Steel Market Development Institute (SMDI) recommendations. Currently, OEM best practices specify reduced material properties for all MIG welds and adjacent material in the weld HAZ to account for the effect of welding. Typically, the same reduced material properties are specified, regardless of the grade of steel. Some studies have shown that reduction in fatigue performance of advanced high-strength steel (AHSS) can be minimized by optimizing joint geometries [1]. Further study and development of robust high-volume welding practices and other advances in the area of sheet steel joining, especially with AHSS and ultra high-strength steel (UHSS) are recommended. Welding practices that result in improved HAZ properties could enable additional mass reduction by improving durability performance and thus more fully exploiting the benefits of high-strength materials in chassis components.

Additionally, with the aggressive gage reductions enabled by the use of AHSS and UHSS, typical corrosion protection strategies may not be sufficient for these materials in chassis applications. Additional studies of the corrosion performance of these materials in welded assemblies, including pre- and post-assembly coatings, are recommended with the goal of developing definitive corrosion treatment strategies for chassis applications.
Baseline Design

The baseline design, as chosen by the SMDI team, is depicted in Figure 2. The main structure is comprised of a tubular transverse beam and tubular trailing arms extending from the bushings to the damper mounts. Upper and lower reinforcements are added at the joints between the transverse and longitudinal members. The transverse beam features an inverted “V” in cross section, rotated from vertical orientation. Each damper mount is in single-shear via a threaded sleeve welded to the longitudinal tube.

The spindle mounts are cantilevered above the trailing arm tubes and include reinforcement plates, machined for rear wheel static alignment.

Figure 2: OEM baseline design
**Design Targets**

The overall project design targets are illustrated in the schematic shown in Figure 3.

The objective was to develop a minimum mass design within the packaging constraints that met the structural and elasto-kinematic performance targets. Corrosion requirements are addressed by appropriate selection of material coatings, which typically do not add significant mass, but can increase cost. Mass and cost are the primary outputs of the study.
The specific structural performance requirements are summarized in the schematic shown in Figure 4. The fundamental design requirements are strength, durability and elasto-kinematic performance (as demonstrated by subsystem-level Kinematic and Compliance or K&C, performance).

The strength requirements include (5) quasi-static extreme load cases in which the twist beam may not exhibit more than the allowable permanent set. The durability requirements include a total of (16) load cases that must be satisfied.

Only the load cases that drive the designs will be discussed in this report. These include the top (3) extreme load cases and the top (3) durability load cases.
A high-level breakdown of the OEM baseline twist beam assembly mass is shown in Figure 5. The complete assembly mass of 24.9 kg, including bushings, is used as the overall basis for comparison of the designs with respect to mass. A detailed component mass breakdown for the twist beam assembly is provided in Table 1.
Figure 5: Baseline twist beam assembly mass summary

Table 1: Detail OEM baseline twist beam assembly mass summary

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass per Asy</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seat-Spring</td>
<td>2.16</td>
<td>8.7%</td>
</tr>
<tr>
<td>Pipe-T/Arm Bush</td>
<td>0.70</td>
<td>2.8%</td>
</tr>
<tr>
<td>Brkt-Spindle, Rr Axle</td>
<td>2.15</td>
<td>8.6%</td>
</tr>
<tr>
<td>Brkt-Damper, Rr Axle</td>
<td>0.41</td>
<td>1.7%</td>
</tr>
<tr>
<td>Plate-Spindle, Rr Axle</td>
<td>0.98</td>
<td>3.9%</td>
</tr>
<tr>
<td>Trailing Arm - Rr Axle</td>
<td>7.39</td>
<td>29.7%</td>
</tr>
<tr>
<td>Beam-Rear Axle</td>
<td>7.26</td>
<td>29.2%</td>
</tr>
<tr>
<td>Brkt-Parking Brake Rr</td>
<td>0.16</td>
<td>0.7%</td>
</tr>
<tr>
<td>Welding-Rr Axle</td>
<td>0.33</td>
<td>1.3%</td>
</tr>
<tr>
<td>Reinf-Beam Upr</td>
<td>0.48</td>
<td>1.9%</td>
</tr>
<tr>
<td>Reinf-Beam Lwr</td>
<td>0.44</td>
<td>1.8%</td>
</tr>
<tr>
<td>Patch-T/Arm</td>
<td>0.07</td>
<td>0.3%</td>
</tr>
<tr>
<td>Pipe-Insulator</td>
<td>0.16</td>
<td>0.7%</td>
</tr>
<tr>
<td>Twist Beam Asy less bushings</td>
<td>22.71</td>
<td>91.2%</td>
</tr>
<tr>
<td>Bushings</td>
<td>2.19</td>
<td>8.8%</td>
</tr>
<tr>
<td>Complete Twist Beam Asy</td>
<td>24.90</td>
<td>100.0%</td>
</tr>
</tbody>
</table>
**Package**

The overall design environment and resulting available package space is illustrated in Figure 6. The twist beam package space is defined by the fuel tank, the spare tire well, the rear floor pan, the tire envelope, the required clearances to these components and the required twist beam suspension travel.

![Figure 6: Package volume and design environment](image)

**Corrosion**

The project target for corrosion performance was based on typical OEM corrosion requirements. These requirements vary, but were assumed to require a minimum 10-year life in a highly-corrosive environment.

**Cost**

Recognizing the aggressive weight reduction targets enabled by the use of AHSS and UHSS, the project cost target was a ≤ 10% increase relative to the OEM baseline design. To assess cost, the manufacturing cost was estimated for the selected U-Beam proposal and compared to the baseline design cost.

The project costing assumptions were:

- Manufacturing cost for the twist beam assembly including the structure and bushings;
• Production volumes of 30,000, 100,000 and 250,000 vehicles per year; and
• Program life of six years.
Development Process

An iterative optimization strategy was used to minimize the mass of each design, while meeting the specified structural requirements. A schematic of the overall development strategy is shown in Figure 7. The key elements of the strategy are discussed in the following sections.

**1. Concept Development**

Initial design concepts were developed based on size and shape optimization of the available design space shown in Figure 6. Stiffness and strength-based topology optimization methods were used to identify promising concepts using the optistruct solver [2]. Without manufacturing constraints, the optimization output was a truss structure with a distinct “U” shape in plain view. This result was interpreted into a concept “U-Beam” design as shown in Figure 8, named for its plan-view shape.

Various draw constraints were also used to identify potential design concepts. The extruded constraint that resulted in a second initial concept is shown in Figure 9. This concept was termed the “S-Beam” since the cross-section developed into an “S” shape as additional optimization was performed.
2. Design Development

A total of two (2) candidate design concepts were identified in the concept development stage for further development. As indicated in Figure 10, these were the U-Beam and
the S-Beam concepts. Various optimization strategies were utilized to meet each load requirement, while minimizing the overall mass. Shape optimization was used to develop the component geometry. Numerous additional design iterations were conducted to fine tune the material selection, thickness and local geometry to meet strength, durability and elasto-kinematic requirements. The elasto-kinematic requirements were cascaded into component twist beam stiffness requirements allowing for rapid early assessments in Abaqus before creation of flex bodies and full K&C assessments via Adams.

The U-Beam design was later selected as the preferred alternative due to its superior structural, mass and elasto-kinematic performance. The S-Beam design details are also provided in this paper.

![Figure 10: Candidate design concepts](image)

### 3. Manufacturing and Corrosion

The manufacturing feasibility of each design was assessed at various stages of the development process. Additional design development was conducted to meet manufacturing feasibility requirements. Corrosion requirements including selection of coatings were considered as part of the manufacturing feasibility assessments.

### 4. Cost Assessment

The final step of the development process was to estimate the manufacturing cost for the selected U-Beam design and the OEM baseline design. Production costing methodologies were applied to estimate the manufacturing costs for the U-Beam design, and the costs were compared to the OEM baseline cost.
Design – Package Effects

Two design changes with system-level effects were made to the candidate twist beams relative to the OEM baseline design:

First, the hub mounting strategy will require attachment of the hub from the outboard rather than inboard direction (similar to the Honda Fit or Ford Fiesta designs as shown in Figure 11).

![Figure 11: Twist beam example with outboard-driven hub fasteners](image)

Second, the rear damper lower attachment was moved 40 mm outboard on both designs to facilitate a much improved load path to the beam structure. The move maintained the tire clearance envelope and resulted in a damper motion ratio change from 1.12 to 1.11. This is illustrated in Figure 12.
Figure 12: Damper attachment for OEM baseline and U-Beam designs
Design Proposals

The final U-Beam and S-Beam design proposals are shown in Figure 13 and Figure 14, respectively.

U-Beam Design

The U-Beam design utilizes UHSS and AHSS to enable aggressive gage and mass reductions.

The U-Beam design features hot-formed tubular transverse and swept longitudinal members, all from 22MnB5 material with a constant 2.5 mm thickness. The transverse member has a closed inverted “U” cross section to provide the desired shear center location for roll steer performance. The roll steer can be tuned if required with this design by adding a rear-view sweep to the beam. The final design presented in this report has been tuned to achieve the OEM baseline roll steer with an unswept design for simplicity.

The transverse member also features a fixed material gage but with a 20% increase in OD near vehicle centerline. This adds stiffness via section enlargement with minimum added mass. This increase in section is achieved either through the ACCRA® hot-forming process or by a purchased variable-diameter tube.

The normally circular cross section of the longitudinal members is formed to a rectangular cross section at the hub mounts, facilitating integration of the hub attachment features without additional parts.

A unique feature of this design is the addition of structural “bulkheads” to locally stabilize the beam assembly in the critical transition area from the lateral beam to the longitudinal arms.

Trailing arms containing the bushings are simple inverted “U” profile stampings from DP780 material.

All components are MIG-welded to form the assembly.
The S-Beam design features a hot-stamped main beam and an associated hot-stamped lower reinforcement, all from 22MnB5 material. The stamped beam design provides the “S” cross section derived from optimization. The overall shape of the beam is also a “U” in the plan view, reflecting the optimization results consistently observed during development.

The S-Beam also includes bulkheads to stabilize the lateral-to-longitudinal beam transition area.

Trailing arms containing the bushings are closed-section tubular components from DP780 material, also designed to be compatible with the ACCRA® hot-forming process.

All components are MIG-welded to form the assembly.
Figure 14: S-Beam design concept
Performance

Finite element (FE) analysis methods were used to predict the structural performance of each design. The FE model for the two new design concepts is shown in Figure 15. As mentioned previously, an iterative optimization strategy was used to minimize the mass of each design while meeting the specified structural requirements. Optistruct [2], Abaqus / Standard [3] and nCode DesignLife [4] software products were used to optimize and assess the structural performance of designs. The final design material selections and structural performance are discussed in the following sections.

Figure 15: Twist Beam Finite Element Models

Materials

For the U-Beam and S-Beam designs, the material grade selection was primarily influenced by the durability and extreme load cases. Additional material selection criteria included formability, weldability, availability and cost. A table summarizing the Auto/Steel Partnership team recommended sheet materials is provided in Table 2.

Engineering stress-strain curves for the sheet and forged materials utilized in this study are compared in Figure 16. The yield and ultimate tensile strengths are indicated for each material. Fatigue properties were obtained from [5].
Table 2: Steel sheet material properties

<table>
<thead>
<tr>
<th>Item #</th>
<th>Steel Grade</th>
<th>Thickness (mm)</th>
<th>Width (mm)</th>
<th>Modulus of Elasticity (GPa)</th>
<th>YS (MPa)</th>
<th>UTS (MPa)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Min</td>
<td>Max</td>
<td>Min</td>
<td>Max</td>
<td>Typical</td>
</tr>
<tr>
<td>1</td>
<td>Mild 100/300</td>
<td>0.5</td>
<td>2.3</td>
<td>A50</td>
<td>A50</td>
<td>140</td>
</tr>
<tr>
<td>2</td>
<td>High 100/300</td>
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<td>A50</td>
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<td>200</td>
</tr>
<tr>
<td>3</td>
<td>IF 300/400</td>
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<td>2.9</td>
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<td>4</td>
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<td>6</td>
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<tr>
<td>7</td>
<td>HSLA 350/450</td>
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<td>200</td>
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<td>A50</td>
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<td>9</td>
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<td>A50</td>
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<td>150</td>
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<td>10</td>
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<td>A50</td>
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<td>11</td>
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<td>A50</td>
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<td>12</td>
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<td>A50</td>
<td>A50</td>
<td>150</td>
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<td>13</td>
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<td>2.9</td>
<td>A50</td>
<td>A50</td>
<td>150</td>
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<td>A50</td>
<td>A50</td>
<td>150</td>
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<td>15</td>
<td>DP 700/1000</td>
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<td>A50</td>
<td>150</td>
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<td>16</td>
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<tr>
<td>18</td>
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<td>A50</td>
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<tr>
<td>19</td>
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<td>2.9</td>
<td>A50</td>
<td>A50</td>
<td>150</td>
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<td>20</td>
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<td>A50</td>
<td>150</td>
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<td>21</td>
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<td>A50</td>
<td>A50</td>
<td>150</td>
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<tr>
<td>22</td>
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<td>2.9</td>
<td>A50</td>
<td>A50</td>
<td>150</td>
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<tr>
<td>23</td>
<td>DP 1100/1000</td>
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<td>2.9</td>
<td>A50</td>
<td>A50</td>
<td>150</td>
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<tr>
<td>24</td>
<td>DP 1150/1000</td>
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<td>2.9</td>
<td>A50</td>
<td>A50</td>
<td>150</td>
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<td>A50</td>
<td>150</td>
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<tr>
<td>26</td>
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<td>A50</td>
<td>A50</td>
<td>150</td>
</tr>
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<td>27</td>
<td>DP 1300/1000</td>
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<td>2.9</td>
<td>A50</td>
<td>A50</td>
<td>150</td>
</tr>
<tr>
<td>28</td>
<td>DP 1350/1000</td>
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<td>2.9</td>
<td>A50</td>
<td>A50</td>
<td>150</td>
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<td>29</td>
<td>DP 1400/1000</td>
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<td>A50</td>
<td>A50</td>
<td>150</td>
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<td>30</td>
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<td>A50</td>
<td>A50</td>
<td>150</td>
</tr>
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<td>31</td>
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<td>A50</td>
<td>A50</td>
<td>150</td>
</tr>
<tr>
<td>32</td>
<td>DP 1550/1000</td>
<td>0.6</td>
<td>2.9</td>
<td>A50</td>
<td>A50</td>
<td>150</td>
</tr>
</tbody>
</table>

Figure 16: Engineering stress-strain curve comparison
**Material Modeling Considerations**

Material processing considerations were taken into account in the finite element modeling. Specifically, the effects of welding-induced material property reduction in the Heat Affected Zone (HAZ) were included in the durability and strength load cases per the SMDI team’s recommendations as follows:

- For the durability load cases, material fatigue property reductions of 20% in the weld HAZ were applied for all high-strength, advanced high-strength and ultra-high strength steel grades [6]. To achieve the reduced properties, the K’ parameter of the cyclic stress-strain amplitude curve was scaled by 0.8. The strain life curve was not modified. This is shown in Figure 17.

- For strength load cases, material strength reductions of 20% in the HAZ zone were applied for UHSS grades with ultimate strengths greater than 800MPa. [6]. Shell welds were assigned properties corresponding to the lower-strength material of the two joining components. The shell weld thickness was determined by a weighted average between the two component thicknesses.

An example of the durability modeling of the HAZ can be seen in Figure 18. An example of the strength modeling of the HAZ is illustrated in Figure 19.

![Figure 17: Material fatigue property reductions – HAZ](image)
Material Selection

The materials were selected for each design based on meeting all of the strength and durability requirements, formability considerations and SMDI’s recommendations. The
resulting material selections and gage are illustrated in Figure 20 and Figure 21. The materials for the OEM baseline design are specified in Figure 22. The OEM baseline material grades are labeled generically to maintain OEM material specification confidentiality.

Based on existing corrosion guidelines, a nickel-plating coating process is recommended for the U-Beam in consideration of its components at <2.0mm gage (see Figure 20). An appropriate E-coat finish is also recommended for both the U-Beam and the S-Beam (see Figure 21) designs.

![Figure 20: U-Beam design material selection and gage](image-url)
Figure 21: S-Beam design material selection and gage

Figure 22: OEM baseline design material selection and gage
Durability

The predicted durability life performance is compared in Figure 23 for all designs. The minimum life values are shown for the worst case (3) load cases. For each design, the worst case loading results from the Max Twist event. The associated life contour plots are shown in Figure 24 for the OEM baseline design, Figure 25 for the U-Beam design, and Figure 26 for the S-Beam design. In all cases, the limiting location of each design is the transition area near the lateral-to-longitudinal transition of the main beam structure. In all cases the area of low life occurs in the parent material rather than in a weld.

Note that in Figure 24, the OEM baseline predicted design life is 0.18, significantly less than the 1.0 life minimum target. When this result was first observed, investigations into potential causes began. Multimatic performed coupon testing from production OEM baseline twist beam parts to measure as-formed material properties and compare them to the published values for the transverse beam material. While these material properties roughly doubled the predicted life, the results were still well below the 1.0 life target. After further consultation with the OEM, it was determined that internal OEM predictions closely bounded the 0.18 life result, and consequently, the OEM agreed to use 0.18 lives as the target for the max twist load case.
Figure 24: Predicted OEM baseline design durability life

Figure 25: Predicted U-Beam design durability life
**Extreme Loads**

The predicted permanent set performance is compared in Figure 27 for all designs. The permanent set values are shown for the worst case (3) load cases. In each case, the worst case loading is from the maximum vertical event condition. The U-Beam and S-Beam both meet the 1.0 mm maximum set requirement as measured at the wheel center, with the S-Beam exhibiting the best overall strength performance.

The associated plastic strain contours for the maximum vertical event are shown in Figure 28 for the OEM baseline design, Figure 29 for the U-Beam design and Figure 30 for the S-Beam design. The plastic strain contours are contoured to 1.00% for visualization.
Figure 27: Predicted extreme load permanent set comparison

Figure 28: Predicted OEM baseline extreme load plastic strain
Figure 29: Predicted U-Beam design extreme load plastic strain

Figure 30: Predicted S-Beam design extreme load plastic strain
Performance Summary

The relative structural performance of each design is summarized in Table 3, where the relative performance is defined as the actual performance normalized by the indicated target value. To meet the required level of durability performance, the relative value must be $\geq 1.0$, while the relative value for permanent set due to extreme loads must be $\leq 1.0$. The primary and secondary design drivers for each design are identified in the table. All of the designs are primarily fatigue limited by the max twist load case. A secondary design driver for the OEM baseline and U-Beam designs is the max vertical event strength load case. Finally, both the U-Beam and the S-Beam designs are further limited by the max cornering event durability case.

Table 3: Performance summary

<table>
<thead>
<tr>
<th>Design</th>
<th>OEM Baseline Design</th>
<th>U-Beam</th>
<th>S-Beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial</td>
<td>Tr3</td>
<td>Tr539</td>
<td>Tr784</td>
</tr>
</tbody>
</table>

**Extreme Load/Permanent Set (nonlinear material & geometry)**

<table>
<thead>
<tr>
<th>Load Case Name</th>
<th>Max target (mm)</th>
<th>Set / target</th>
<th>Set / target</th>
<th>Set / target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Vertical Event</td>
<td>1.0</td>
<td>1.00</td>
<td>0.52</td>
<td>0.01</td>
</tr>
<tr>
<td>Max Forward event</td>
<td>1.0</td>
<td>0.22</td>
<td>0.14</td>
<td>0.00</td>
</tr>
<tr>
<td>Max Aft Event</td>
<td>1.0</td>
<td>0.08</td>
<td>0.53</td>
<td>0.00</td>
</tr>
</tbody>
</table>

**Durability Analysis**

<table>
<thead>
<tr>
<th>Load event</th>
<th>Target (1 life)</th>
<th>Life / Target</th>
<th>Life / Target</th>
<th>Life / Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHS/RHS Bump Event</td>
<td>1.0</td>
<td>1.0</td>
<td>1.5</td>
<td>17.3</td>
</tr>
<tr>
<td>Max Twist Event</td>
<td>0.18*</td>
<td>1.0</td>
<td>4.3</td>
<td>3.7</td>
</tr>
<tr>
<td>Max Cornering Event</td>
<td>1.0</td>
<td>1.0</td>
<td>5.8</td>
<td></td>
</tr>
</tbody>
</table>

* 0.18 life target established based on OEM prediction and concurrence for this load case.
Mass

The final twist beam assembly mass results, including bushings, are compared in Figure 31. The results indicate that the mass of the U-Beam design is 30.0% less than the OEM baseline assembly mass, while the S-Beam design is 14.5% lighter than the OEM baseline.

The final twist beam welded structure mass results are compared in Figure 32. The results indicate that the mass of the U-Beam structure is 32.8% less than the OEM baseline mass, while the S-Beam structure is 15.9% lighter than the OEM baseline.

The detail component masses are summarized in Table 4.

Figure 31: Twist beam assembly mass comparison
Figure 32: Twist beam structure mass comparison

Table 4: Detail mass summary

<table>
<thead>
<tr>
<th>Material Type</th>
<th>OEM Baseline Design</th>
<th>U-Beam</th>
<th>S-Beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR690 tube, SPFH590 tube,</td>
<td>8.19</td>
<td>9.67</td>
<td>7.57</td>
</tr>
<tr>
<td>SPFH640</td>
<td></td>
<td>1.17</td>
<td>6.92</td>
</tr>
<tr>
<td>22MnB5 tube, DP780,</td>
<td>8.16</td>
<td>1.55</td>
<td>1.84</td>
</tr>
<tr>
<td>SPFH640</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22MnB5, DP780 tube, HSLA550</td>
<td>0.00</td>
<td>0.25</td>
<td>0.19</td>
</tr>
<tr>
<td>Damper Mounts and Reinfor.</td>
<td>0.41</td>
<td>0.68</td>
<td>0.79</td>
</tr>
<tr>
<td>Hub Mounting Structure</td>
<td>3.13</td>
<td>1.03</td>
<td>0.88</td>
</tr>
<tr>
<td>Brackets – Park Brakes</td>
<td>0.16</td>
<td>0.16</td>
<td>0.16</td>
</tr>
<tr>
<td>Weld</td>
<td>0.20</td>
<td>0.76</td>
<td>1.07</td>
</tr>
<tr>
<td>Twist Beam Structure</td>
<td>22.71</td>
<td>18.25</td>
<td>19.01</td>
</tr>
<tr>
<td>Bushings</td>
<td>7.19</td>
<td>2.19</td>
<td>2.19</td>
</tr>
<tr>
<td>Complete Twist Beam Asy</td>
<td>24.90</td>
<td>20.44</td>
<td>21.20</td>
</tr>
</tbody>
</table>
**Elasto-Kinematic Performance**

A key aspect of the development project was to closely match the OEM baseline elasto-kinematic behavior. Unlike many other suspension components, twist beam axles are designed to exhibit significantly compliant behavior. This behavior is typically measured by industry-standard kinematics and Compliance (K&C) testing.

An Adams [7] model of the OEM baseline twist beam was created so that the K&C response of the proposed designs could be compared to the baseline design. First, flex bodies for the baseline twist beam were generated based on mesh created for structural analysis. Next, the Adams model was refined with the following information provided by the OEM:

- Spring rate / Spring preload at Design position;
- Jounce / rebound bumper stiffness;
- Bushing stiffnesses;
- Tire stiffness; and
- Tire unloaded radius.

Once the initial Adams model was complete, the response of Adams K&C simulations were correlated with physical K&C test results. To further improve the correlation, bushings from a current production OEM baseline twist beam were obtained, the stiffnesses were measured as-installed in the beam, and the measured stiffnesses were incorporated into the Adams model.

A subset of the K&C plots for the selected U-Beam design and OEM baseline twist beam are presented here as Figure 33-Figure 38. The U-Beam closely matched the OEM baseline K&C characteristics, thereby providing confidence that the on-road vehicle ride and handling behavior of the two beam designs would be very similar.

A full set of K&C plots is included in this report as Appendix 1: Kinematics and Compliance Plots.
Figure 33: K&C results: bounce – bump steer

Figure 34: K&C results: bounce – bump camber
Figure 35: K&C results: roll – roll steer

Figure 36: K&C results: longitudinal braking – toe stiffness
Figure 37: K&C results: lat parallel – toe stiffness

Figure 38: K&C results: align opposed – toe stiffness
Manufacturing

Each design was assessed to ensure manufacturing feasibility. Assessment included a combination of expert engineering and manufacturing experience, including input from partner companies on hot forming processes. Additional design development was conducted in some cases to improve manufacturing feasibility.

U-Beam Design

The main manufacturing considerations for the U-Beam design were the feasibility of forming the 22MnB5 transverse tubular member and the swept longitudinal members that join the transverse member and provide the spindle mounting structure.

The 20% increased length of line near the centerline of the transverse tube is achieved either through the Multimatic / Linde+Wiemann ACCRA® hot-forming process or by a purchased variable-diameter tube. Both options were assessed by internal and external manufacturing experts to confirm feasibility.

The “U” cross-section of the transverse beam is also achieved via the ACCRA® hot-forming process. The swept longitudinal members include a 90° bend which was judged feasible by manufacturing experts. The bulkheads are sub-assembled to the transverse member during the beam assembly. A formed shoulder on the bulkheads is recommended to provide location and self-centering on the transverse tube.

The remaining stampings are judged feasible based on the observation that the individual twist beam components are simple stamped and / or blanked components for which the trim lines can readily be developed and without major draw or other geometric limitations.

The overall beam assembly was evaluated for weld access and judged feasible. Weld length for this design is 5980mm.

S-Beam Design

The main manufacturing considerations for the S-Beam design were the feasibility of the 22MnB5 main beam stamping and feasibility of MIG welding the assembly in production.

To evaluate the stamping feasibility of the main beam, a hot-stamping supplier partner was consulted to evaluate the design. Expert review revealed no concerns. In addition, a one-step forming simulation was conducted to assess formability. Based on the results of the forming simulation shown in Figure 39, the main stamping is judged feasible.
The remaining stampings are judged feasible based on the observation that the individual twist beam components are simple stamped and/or blanked components for which the trim lines can readily be developed and without major draw or other geometric limitations.

The overall beam assembly was evaluated for weld access and judged feasible. Weld length for this design is 8510mm.

Figure 39: Stamping formability for 22MnB5 main beam structure
Corrosion

To meet OEM corrosion requirements, corrosion protection is generally applied to components based on material gage. The sheet steel material gage limit is OEM specific, and is assumed to be 2.0 mm for the purpose of this study.

Typical requirements on a component basis are as follows:

- Gage > 2.0 mm: E-coat finish required.
- Gage < 2.0 mm: Hot dipped galvanized coating + E-coat finish required.

The specific type of galvanized coating is also OEM specific. Examples of coating specifications include Hot Dip G60 / G60 (GI) or Hot Dip Galvanneal A-40 (GA).

For a complex welded assembly such as a twist beam, if components are included below 2.0mm gage, the manufacturing recommendation from this study is a zinc-nickel plating process after assembly followed by E-coat. This is a current production process and eliminates manufacturing concerns by ensuring common welding processes for all components.

The project also included consulting with the Auto/Steel Partnership Lightweight Chassis Corrosion Project Team on corrosion countermeasures for the beam designs. This team plans to conduct a build and test program to gather data on the corrosion performance of AHSS and UHSS with various treatments. Possible approaches include:

- Powder coating weld areas;
- Mild alloying of materials via added copper or chrome; and
- Post-formed coatings, especially for hot stamped boron steels.
Cost Estimates

Production costs were estimated for the OEM baseline and selected U-Beam designs based on the SMDI-provided project assumptions. All costs are reported relative to the functionally equivalent OEM baseline design for comparison purposes. Costing was completed using Multimatic’s proprietary production cost estimation methodology.

Assumptions

The following assumptions were used to estimate the cost of the twist beam structure for the OEM baseline and the U-beam designs.

Material Costs

Sheet steel material costs were based on published data for the period of June 2013 to July 2013, with the exception of DP780 and Mn22B5 costs, which are based on data from material suppliers. The costs are summarized in Table 5.

<table>
<thead>
<tr>
<th>Material Type</th>
<th>CDN/lb</th>
<th>US/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>HSLA 550 CR, 1.5mm</td>
<td>$0.4969</td>
<td>$1.0952</td>
</tr>
<tr>
<td>HSLA 550 HR, 2.6mm</td>
<td>$0.5050</td>
<td>$1.1130</td>
</tr>
<tr>
<td>HSLA 300 HR, 2mm</td>
<td>$0.4642</td>
<td>$1.0231</td>
</tr>
<tr>
<td>SPH590 HR, 1.5mm</td>
<td>$0.5244</td>
<td>$1.1558</td>
</tr>
<tr>
<td>HSLA 550 HR, 3mm</td>
<td>$0.4948</td>
<td>$1.0905</td>
</tr>
<tr>
<td>DP780, 1.8mm</td>
<td>$0.6284</td>
<td>$1.3850</td>
</tr>
<tr>
<td>Mn22B5, 2.5mm</td>
<td>$0.6553</td>
<td>$1.4443</td>
</tr>
</tbody>
</table>

Design

- OEM baseline design:
  Content included the welded assembly and the bushings (Figure 1). E-Coat finish included.
- U-Beam design:
  Content included the welded assembly and the bushings. Nickel plate and E-Coat finish included.

* CRU Index for steel costs, June 12, 2013 - July 10, 2013, except for DP780 and Mn22B5
Program
- Production volumes of 30,000, 100,000 and 250,000 vehicles per year were evaluated.
- Program life: six years

Variable Costs
The following were considered in estimating the variable costs:
- Material blank size;
- Material type and coating;
- Plating and / or E-coating;
- Purchased components (bushings, etc.);
- Machining labor and burden;
- Variable overhead;
- Capital equipment; and
- Selling, General & Administrative Expense (SG&A).

Fixed Costs
The following were considered in estimating the fixed costs:
- Tooling (machining, stamping, welding, etc.); and
- Fixed overhead.

Component Costs
The total component costs were calculated from the sum of the variable and fixed costs, with the fixed costs calculated on an amortized basis. For comparison, only the total costs for each design are reported as costs relative to the baseline design cost.

Cost Comparison
Component costs were estimated as a function of production volume based on the above-mentioned assumptions. The relative cost results are summarized in a bar chart in Figure 40, where the cost basis for the comparison is the cost of the baseline at the indicated volume. The relative cost results are again plotted in the graph of Figure 41. However, in this case, the cost basis is the cost of the baseline design at the highest production volume (250,000 vehicles / year). The relative percent cost difference between the U-Beam design and the baseline is also indicated in Figure 41.

The cost results indicate that the U-Beam design has a 12% higher cost compared to the OEM baseline at the lowest production volume and a 15% higher cost at the higher production volumes. Further, the results in Figure 41 indicate the relative change in the baseline cost as a function of the production volume.
Figure 40: Relative cost comparison
Cost relative to OEM Baseline at 250,000 volume

Figure 41: Relative cost comparison plot
References


Appendix 1: Kinematics and Compliance Plots

K&C Correlation

K&C Results: Bounce - Wheel Force

REAR LEFT

Bounce - Wheel Force

REAR RIGHT

wheel force Z [N]

wheel to body Z displacement [mm]

→ bump

bump →

ADAMS :: OEM Baseline

ADAMS :: Trial 539 U Beam
K&C Correlation

K&C Results: Bounce - Tire Force

[Graph showing comparison of bounce-tire force between REAR LEFT and REAR RIGHT with two graphs side by side, one for each side, showing wheel force Z [N] on the x-axis and tire compression [mm] on the y-axis for ADAMS:: OEM Baseline and ADAMS:: Trial 539 U Beam.]
K&C Correlation

K&C Results: Bounce - Ride Force

![Diagram showing Bounce - Ride Force for REAR LEFT and REAR RIGHT with ADAMS:: OEM Baseline and ADAMS:: Trial 539 U Beam]
K&C Correlation

K&C Results: Bounce – Bump Steer
K&C Correlation

K&C Results: Bounce – Bump Camber

![Graph showing Bounce Bump Camber comparison between ADAMS: OEM Baseline and ADAMS: Trial 539 U Beam for Rear Left and Rear Right wheels.](image-url)
K&C Correlation
K&C Results: Bounce – Bump Caster

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K&C Correlation

K&C Results: Bounce – Lateral WC Displacement

[Graph showing comparison of bounce lateral WC displacement between OEM Baseline and Trial 539 U Beam for REAR LEFT and REAR RIGHT.]
K&C Correlation

K&C Results: Bounce – Longitudinal WC Displacement

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K&C Correlation
K&C Results: Roll - Wheel Load
K&C Correlation
K&C Results: Roll – Roll Steer
K&C Correlation
K&C Results: Roll – Roll Camber
K&C Correlation

K&C Results: Long Braking – WC Stiffness
K&C Correlation

K&C Results: Long Braking – Toe Stiffness

[Graph showing comparison of ADAMS OEM Baseline versus ADAMS Trial 539 U Beam for Long Braking - Toe Stiffness for Rear Left and Rear Right sides.]
Lightweight Twist Beam Development – Final Report

K&C Correlation

K&C Results: Lat Parallel – WC Stiffness
K&C Correlation

K&C Results: Lat Parallel – Toe Stiffness
K&C Correlation

K&C Results: Lat Parallel – Camber Stiffness

REAR LEFT

Lat Parallel - Camber Stiffness

REAR RIGHT

ADAMS :. OEM Baseline  ADAMS :. Trial 539 U Beam

ADAMS :. OEM Baseline  ADAMS :. Trial 539 U Beam
K&C Correlation

K&C Results: Lat Opposed - WC Stiffness

![Graph showing Lat Opposed - WC Stiffness](image-url)
K&C Correlation

K&C Results: Lat Opposed – Toe Stiffness
K&C Correlation

K&C Results: Lat Opposed – Camber Stiffness

![Graph showing comparison of lateral wheel force vs wheel camber for REAR LEFT and REAR RIGHT beams. The graph compares ADAMS simulation with OEM Baseline and Trial 539 U Beam.]
K&C Correlation
K&C Results: Align Parallel – Toe Stiffness

Lightweight Twist Beam Development – Final Report
K&C Correlation

K&C Results: Align Opposed – Toe Stiffness

![Graph showing K&C Correlation for Align Opposed - Toe Stiffness](image)