Y. Lightweight Rear Chassis Structure (ASP601[i])

Project Manager: Jim Cran
Auto/Steel Partnership
2000 Town Center, Suite 320
Southfield, MI 48075-1123
(905) 385-8276; fax: (905) 383-3200; e-mail: jim.cran@sympatico.ca

Co-Chair: Ken Oikarinen
DaimlerChrysler Corporation
1030 Doris Road
CIMS 489-00-00
Auburn Hills, MI, 48326
(248) 754-9763; fax: (248) 754-9750; e-mail:kco3@daimlerchrysler.com

Co-Chair: Michael Gulas
Dofasco Inc.
P.O. Box 2460
1330 Burlington St .E.
Hamilton, ON, Canada, L8N 3J5
(905) 548-4719; fax: (905) 548-4250; e-mail:michael_gulas@dofasco.ca

Technology Area Development Manager: Joseph A. Carpenter
(202) 586-1022; fax: (202) 586-1600; e-mail: joseph.carpenter@ee.doe.gov

Expert Technical Monitor: Technical Manager: Philip S. Sklad
(865) 574-5069; fax: (865) 576-4963; e-mail: skladps@ornl.gov

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Contractor: U.S. Automotive Materials
Contract No.: DE-FC05-02OR22910

Objective

- Obtain a minimum mass reduction of 25% for a baseline passenger car rear chassis structure with no more than a 9% cost premium.
- Develop and document integrated solutions that balance the interaction of materials, manufacturing and cost. The solutions will focus on high volume manufacturing (200,000 plus vehicles per year).
- Develop a matrix of cause and effect for all variable parameters (+/- x kg in mass and +/- y dollars in cost for a given performance).
- Demonstrate the successful use of AHSS in a passenger car rear chassis structure.
- Address corrosion and durability issues associated with reduced thickness AHSS.

Approach

- Phase 1: Material optimization. Through material substitution and minimal size and shape changes, the goal is to reduce mass by 10%. Prototypes will be fabricated and tested. Completion is scheduled for January of 2007.
- Phase 2: Design optimization. Through a clean sheet redesign and the use of lessons learned in Phase 1, the goal is to obtain a minimum mass reduction of 25% with no more than a 9% cost premium. Prototypes will be fabricated and tested. Completion is scheduled for September of 2007.

- Phase 3: Communications. The goal is to transfer the technology developed in the project to OEM and Tier 1 chassis structure designers. Completion is scheduled for March of 2008.

Accomplishments

- Completed a Benchmark Study for passenger car and light truck chassis structures.
- Selected DaimlerChrysler's LX rear cradle as the donor chassis.
- Identified four technology gaps that prevent the use of AHSS in chassis structures.
- Designed the Phase 1 (Material Optimization) prototypes.
- Obtained uncoated DP590 and TRIP780 for the Phase 1 prototypes.
- Fabricated successfully five Phase 1 prototypes.
- Developed three unique concepts for the Phase 2 (Design Optimization) prototypes.
- Selected a hybrid concept for the Phase 2 prototypes.
- Prepared a preliminary design for the hybrid Phase 2 prototypes.
- Implemented a formal approach to technology gap analysis.

Future Direction

- Conduct physical testing on the Phase 1 prototypes.
- Complete the technology gap analysis and summarize the lessons leaned.
- Undertake a cost study for the Phase 2 Preliminary Design.
- Finalize the Phase 2 Preliminary Design.
- Fabricate and test Phase 2 prototypes.
- Prepare Final Report for the project.
- Transfer the technology through road shows to A/SP member companies and key Tier 1 suppliers.

Project Progress
October 1/06 – September 30/06

1.0 Timeline

The original project timeline is shown in Table 1. The plan was to incorporate the lessons learned from Phase 1 into Phase 2. However, in September of 2006 it became clear it was impossible for this to happen. The Phase 1 prototypes had yet to be built let alone tested. Further, the Phase 2 design was nearing completion with little input from Phase 1. Thus, the Team decided to revise the timeline to that shown in Table 1. In essence, the timing for Phase 2 was pushed out to allow lessons learned from Phase 1 to be incorporated into the Phase 2 clean sheet design.

2.0 Phase 0: Baseline Structure (6/05 -7/05)

The rear chassis selected for this project is based on DaimlerChrysler's LX rear chassis (Figure 1).

DaimlerChrysler provided the CAD and FE models, specifications and design targets. In addition, DaimlerChrysler will conduct durability, NVH, impact and corrosion testing on the Phase 1 and 2 prototypes.

Table 1. Project Timeline.

	Original Timing	Revised Timing
Phase I		
a) Design	Jun/05-Jan/06	Jun/05-Aug/06
b) Gap Analysis	Jun/05-Jan/06	Jun/05-Jan/07
c) Prototype Build	Feb/06-Apr/06	Feb/06-Oct/06
d) Performance Testing	May/06-Jun/06	Oct/06-Dec/06
Phase II		
a) Design	Nov/05-Jul/06	Nov/05-Mar/07
b) Prototype Build	Aug/06-Sep/06	Apr/07-Jun/07
c) Performance Testing	Oct/06-Dec/06	July/07-Sep/07
Phase III		
a) Communications	Jan/07-Mar/07	Feb/07-Mar/08

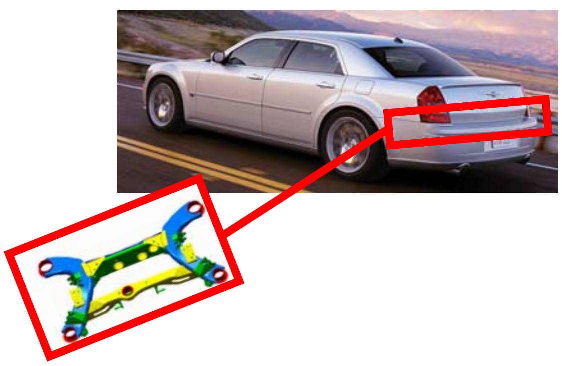

Figure 1. DaimlerChrysler LX rear chassis structure.

The actual rear chassis structure chosen as the baseline is a derivative of the LX rear chassis structure. Altair Engineering, as an in-kind contribution, prepared CAD and FE models for the baseline. The baseline structure is shown in Figure 2.

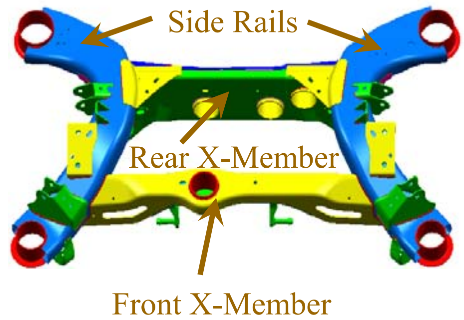

Figure 2a. Baseline structure.

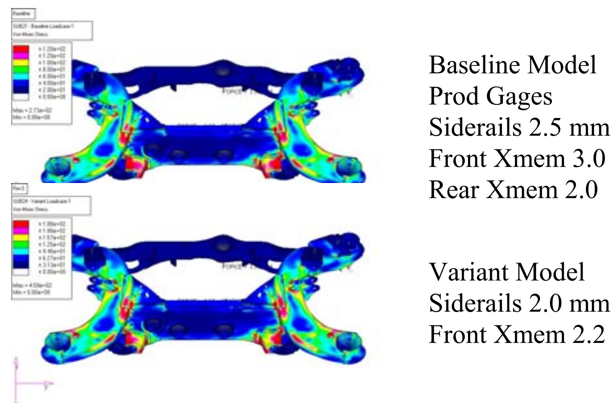

Figure 2b. Altair Phase 1 redesign.

3.0 Phase 1: Material Optimization

3.1 Phase 1a): Design Analysis (8/05 – 8/06)

Altair Engineering was retained by A/SP to reduce the baseline mass by 10% through material substitution and minimal size and shape changes. Altair, through trial and error, arrived at redesign steel grades and thicknesses as shown in Figure 3.

LX Rear Cradle	Base-line	Re-design
Side Rails	3.13mm 240 MPa	2.0mm DP590
Rear X-member	2.0mm 208 MPa	1.7mm DP590
Front X-member	3.7mm 362 MPa	2.2mm DP780
Weight (Est.)	29.14 kg	21.5 kg

Figure 3. Altair Phase 1a) Stresses for suspension load case number one.

Stresses, modes and stiffnesses were checked for four load cases: three suspensions and one torsion. For example, the stress check results for suspension load case number one are shown in Figure 3. As shown in Figure 2, the redesign mass was 21.5 kg, a mass reduction of 7.6 kg or 26%. This portion of the Phase 1a) work was conducted between 8/05 and 10/05. Altair's CAD and FE models were delivered to DaimlerChrysler.

Between October of 2005 and December of 2005, Altair conducted an "A" versus "B" fatigue comparison for the siderail. Although the stress in the siderail increased from 34 to 74 MPa, the fatigue life of the base steel increased by 20% because of the switch from low-carbon to DP590 steel. The fatigue strength of the MIG welds in the rear chassis structure is not sensitive to steel grade.

In December of 2005, Altair submitted the following conclusions for Phase 1a):

- Gage can be significantly decreased in most structural members using AHSS, and still meet stress targets.
- Stress at the weld joints increased significantly. The welded area should be redesigned to reduce stress in the weld.
- Fatigue life of the material does not increase proportional to the yield strength of the material, so fatigue of the structure should be analyzed.
- Normal modes of the structure reduce by approximately 10%.
- Dynamic stiffness of the structure decreases by approximately 10%.
- Miscellaneous brackets could be a significant source of weight reduction.

In March of 2006, The Team decided to make two design changes to Altair's Phase 1a) redesign. First, the front crossmember was changed from a two-piece closed section to a single-piece open section. Second the number of attachment points on the rear cross member was changed from three to two. DaimlerChrysler agreed to incorporate these changes into Altair's Phase 1a) CAD and FE models as an in-kind contribution to the project. DaimlerChrysler provided preliminary CAD data in June to the prototype supplier (Experi-Metal) and final CAD data in July. The CAD models did not include welds. However, DaimlerChrysler provided weld sizes and lengths to Experi-Metal in August of 2006. DaimlerChrysler is adding the welds to the CAD model of the Phase 1 prototypes.

3.2 Phase 1b): Manufacturing Analysis (10/05 – 2/06)

The A/SP Rear Chassis Team, in consultation with A/SP forming experts, concluded there should be no difficulty in forming the DP590 rear crossmember and the DP780 front crossmember. However, the Team had strong reservations about the ability to hydroform the siderails from 2.0 mm DP590. Cosma and ThyssenKrupp Budd both agreed to undertake a forming analysis on the siderail as an in-kind contribution to the project. The Cosma and ThyssenKrupp hydroforming processes differ. Thus, the Team asked each company to undertake a forming analysis. Cosma's analysis concluded that during pre-bending, all of the DP590's ductility would be used up at the critical locations. Therefore, during hydroforming, splits would occur at these locations. ThyssenKrupp Budd arrived at a similar conclusion. In view of this finding, the Team decided to manufacture each siderail as a seamless clamshell.

As another in-kind contribution, Cosma delivered a presentation to the Team titled Hydroforming 101. An example slide is shown in Figure 4.

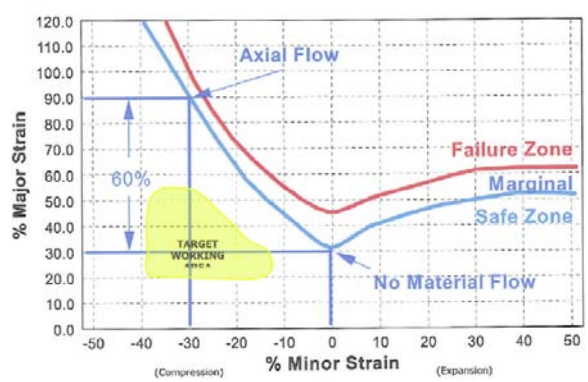

Figure 4. Advantages of material flow when hydroforming.

3.3 Phase 1c): Prototype Material and Build (12/05 – 10/06)

Starting in December of 2005, considerable effort was expended in locating material for the Phase 1 prototypes. Advanced High Strength Steels (AHSS) are in various stages of introduction to the marketplace. Many AHSS grades, especially uncoated and in the thicknesses associated with chassis structures, are not produced in North America. Thus, in addition to all North American steel mills in A/SP, leading steel mills in both Europe and Japan were contacted regarding availability. Another complicating factor was the need to have the prototype steel delivered by March 31, 2006 to satisfy our original prototype construction schedule. Arrangements were finalized in early March with Nippon Steel and Mittal Steel and the prototype material was received on schedule. Nippon and Mittal supplied the steel as in-kind. A comparison between the redesign material requirements and the actual steel obtained is shown in Table 2.

Table 2. Phase 1 Prototype Material

PHASE 1 REDESIGN	**PHASE 1 ACTUAL**
NIPPON STEEL (Japan)	
Front Xmember CR	
2.2mm DP780	**2.3mm TRIP780**
MITTAL STEEL (USA)	
Rear Xmember CR	
1.7mm DP 590	**1.8mm DP590**
Siderails CR	
2.0mm DP590	**1.99mm DP590**

The Team believes successful parts for the clamshell siderails can be fabricated from either DP780 or TRIP 780. Thus, because DP780 was unavailable, the Team selected TRIP 780, which was available. The thicknesses, again for the reason of availability, vary insignificantly from the redesign thicknesses.

The DP590 and TRIP780 prototype materials were subjected to physical and chemical tests. The tests confirmed that the AHSS prototype materials met the requirements of SAE J2745 (February, 2006 draft).

Cosma fabricates the current LX rear chassis. Thus, in March of 2006, A/SP purchased from Cosma 10 sets of the carry-over parts required for the Phase 1 prototypes.

In January of 2006, an RFQ to build the Phase 1 prototypes was sent to five companies. Three companies submitted quotes. The Team placed two of them on a short list (Experi-Metal and Urgent Design and Manufacturing). These two companies were asked to a meeting to review their quotes. As a result of the discussions, the two firms were asked to re-quote. In February, the Team selected Experi-Metal to fabricate ten Phase 1 prototypes at a cost of $135,150. Experi-Metal was given the redesign CAD and FE data, which Altair prepared between August and October of 2005.

As explained in Section 3.1, design changes meant that Experi-Metal did not receive preliminary CAD data until June and final CAD data until July. Thus, it became impossible to meet the original delivery date for the prototypes. On receipt of the preliminary CAD data in June, Experi-Metal commenced casting of the Kirksite zinc alloy dies for the AHSS stampings. In July, on receipt of the final CAD data, the dies were CNC cut. In August, on receipt of welding instructions, Experi-Metal built the first prototype. The mass (20.86kg) was below target. However, there were significant measurement deviations. In September, Experi-Metal built two more prototypes (Figure 5).

Figure 5. Phase 1 Prototype.

The dimensionality and weld quality in Build Number 3 was satisfactory and the Team authorized Experi-Metal to build five additional prototypes (in conformance with Build Number 3) for testing. The test prototypes are scheduled for delivery in October of 2006.

The Team plans to build the remaining two prototypes after the five prototypes have been tested. If required, one or two more prototypes will be built for additional testing. If not required for additional testing, one new prototype might be built with all 350 MPa HSLA steel to determine if the dimensionality issues are caused by the AHSS stampings. Also, if the large weld gaps in the five test prototypes cause issues during testing, one new prototype with all gaps <1.5mm might be constructed.
The prototype build phase of the project should be completed by January of 2007.

3.4 Phase 1d): Prototype Testing (10/06 – 12/06)

DaimlerChrysler has re-scheduled Phase 1 prototype testing to meet the revised timeline. Testing will take place between October and December of 2006.

3.5 Phase 1e): Technology Gap Analysis (06/05 – 01/07)

In September of 2005, the Team agreed to analyze five technology gaps, which were hindering mass reduction through the use of AHSS:

- Commercial availability of uncoated AHSS for chassis structures in the gage range of 1.6 to 2.8mm
- Forming of AHSS (hydroforming, stamping, extrusions)
- Welding of AHSS
- Strength and fatigue of AHSS joints
- Corrosion protection for steel <2.0mm thick

The original timeline called for the technology gap analysis to be completed by January of 2006. In hindsight, this date was unrealistic. Proper gap analysis depended on the lessons learned during fabrication and testing of the Phase 1 prototypes. In September of 2006, as part of setting a revised Timeline (see Section 1.0), the Team implemented a major effort to summarize the lessons learned from Phase 1 by January of 2007. A summary of the work already completed or now underway follows:

<u>Availability of AHSS.</u> The Team is seeking a table showing the global availability of AHSS by grade, coating, and thickness. It has asked the American Iron and Steel Institute to present this request to the International Iron and Steel Institute.

<u>Forming of AHSS.</u> The Team pursued AHSS hydroforming as discussed in Section 3.2. Circle grid analysis was undertaken on DP 590 and TRIP780 parts in the Phase 1 prototypes. Tensile tests will be performed on the formed DP590 and TRIP780 parts in the Phase 1 prototypes. The A/SP Stamping Team has reviewed the formability for the stampings in the Preliminary Phase 2 Design. It is conducting a forming analysis on the four parts that it believes are the most difficult to form. The Stamping Team (see 2.T) is considering the Lightweight Chassis Structure Team's request to prepare Guidelines for AHSS Stampings (This Team has prepared Guidelines for HSS Stampings).

<u>Welding of AHSS.</u> The tubular siderails of the Phase 1 prototypes are made by butt welding an upper DP590 stamping to a lower DP590 stamping. Tensile tests were performed on the butt welds. Each weld in a Phase 1 prototype was sectioned. Micrographs of the sectioned welds have been examined (see Figure 6) and micro-hardness traverses are being prepared. A/SP's Joining Team (see 2.P) has provided its findings on arc welding processes for AHSS. The Team is dialoguing with

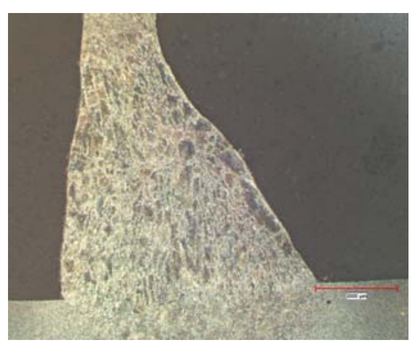

Figure 6. Micrograph of Phase 1 prototype weld.

A/SP's Joining Team and ORNL (see 5.C) on the properties and modeling of the HAZ in AHSS welds.

Strength and Fatigue of Joints. The Team is concerned that the mechanical properties in the HAZ of AHSS welds might be less than those of the parent steel. Hence, it is working with A/SP's Joining Team (see 2.P) and ORNL (see 5.C) to better understand this issue. Fatigue is also a concern. Presentations to the Team from A/SP's Fatigue Team have indicated that the fatigue strength of parent AHSS material is proportional to its tensile strength. However, the fatigue strength of welds in AHSS is the same as the fatigue strength in low-carbon materials. A/SP's joining Team has research underway to better understand the fatigue strength of arc welded AHSS.

Corrosion. Chassis Structures typically count on the thickness of the steel itself to provide long term corrosion resistance. Thus, there is likely some thickness below which adequate corrosion protection is not provided. As a rule of thumb, this thickness is 2.0mm. The Team has assembled a group of chassis corrosion experts (mainly from the OEMs) to investigate appropriate corrosion protection methods for thin AHSS members.

4.0 Phase 2: Design Optimization

4.1 Phase 2a): Benchmarking Study (11/05 – 3/06)

A/SP, in collaboration with the American Iron and Steel Institute (AISI), retained Dr. Alan Hine to conduct a benchmarking study. Dr. Hine assembled chassis structure data for 53 vehicles sold in North America from 2004 to 2006. The vehicles include small cars, mid-size standard cars, mid-size luxury cars, full-size luxury cars, SUVs and sports-specialty vehicles. For each of these vehicle categories, Dr. Hine identified (in his opinion) the best-in-class chassis structures. He presented the reasons and innovations, which led him to select the best-in-class chassis structures. The RFQ issued for Phase 2c) specified that the successful supplier would be required to analyze the Hine benchmarking data, summarize the lessons learned and apply them during the Phase 2 redesign.

4.2 Phase 2b): Topology Optimization (11/05 – 5/06)

A/SP retained Altair Engineering to mesh the solid volume of the baseline rear chassis structure and to conduct a series of topology runs to understand the topology that will best meet the system requirements.

For the final iteration of the topology optimization, Altair created a 3D mesh, which was used as the starting point for Phase 2c).

4.3 Phase 2c): Design/Process (12/05 – 3/07)

Through a clean sheet redesign and the use of lessons learned in Phase 1, the goal is to obtain a minimum mass reduction of 25% with no more than a 9% cost premium.

In December 2005, an RFQ to conduct Phases 2c) and 3 was sent to 19 companies. Seventeen companies submitted quotes. The Team reviewed the quotes and placed five companies on a short list (eta, Quantech, Martinrea, Cosma and Menard). These five companies were asked to a meeting to review their quotes. Individually, each company was asked to outline its technical approach, the amount of in-kind it would contribute to the project and its best price. As a result of the discussions, Martinrea International was selected in February, 2006 to conduct Phases 2a) and 3 at a cost of $350,575. In early March, Martinrea submitted a detailed timeline for the work with the following milestones and completion dates:

- Milestone 1: Review 3 Design Footprints & Formulate Basic Design Structure (6/14/06)
- Milestone 2: Present 3 Design Alternatives for Review (7/19/06)
- Milestone 3: Kick-off Design for Prototype Parts (8/31/06)
- Milestone 4: MIT Cost Model (9/29/06)
- Milestone 5: Model Clean-up and Drawings (10/31/06)
- Milestone 6: Phase 2 Report Outs (12/22/06)
- Milestone 7: Phase 3 Report Outs (3/30/07)

Milestone 1: Three Design Footprints. On June 14, 2006, Martinrea presented six optional footprints with basic design structures. Martinrea also provided a ranking of the options as well as the pros and cons for each option. The Team selected three footprints for Milestone 2.

Milestone 2: Three Design Alternatives. On July 19, 2006, Martinrea presented three alternative designs (hybrid, stamped clamshell and tubular) as shown in Figure 7.

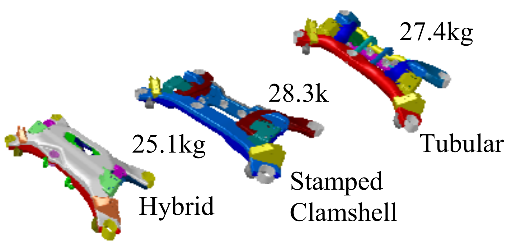

Figure 7. Three design alternatives.

A comparison between stress analysis results and stiffness results showed that the stiffness targets are harder to meet than the stress targets. The mass of all three alternatives exceed the target mass (21.9kg). However, mass may be reduced in Milestone 3 because many of the stiffnesses exceed the stiffness targets.

DaimlerChrysler conducted an initial cost review. All three alternatives are within the 9% cost premium target. On August 9, 2006, the Team selected the hybrid design for Milestone 3. It has the least mass and the most opportunity for stiffness optimization.

Milestone 3: Kick-off Design. On September 28, 2006, Martinrea presented the preliminary Phase 2 design as shown in Figures 8 to 11. The mass is 22.3kg versus the target mass of 21.9kg. There are 33 parts made from DP780, 350MPa HSLA and 245MPa low-carbon steel grades. Eleven parts are less than 2.0mm thick. As in the baseline chassis structure, the stress in some areas exceeds the yield strength. The key stiffness targets are met.

Although cost analysis is to be completed in Milestone 4, it appears that the cost will be less than the targeted 9% maximum premium.

Milestones 4 to 7. As indicated in Section 1.0, the Team revised the project timeline in September of 2006. Martinrea agreed to discontinue work on the project until the technology gap review is completed in January of 2007. At that time, Martinrea will resume the design activities per an agreed upon updated timeline and cost variance.

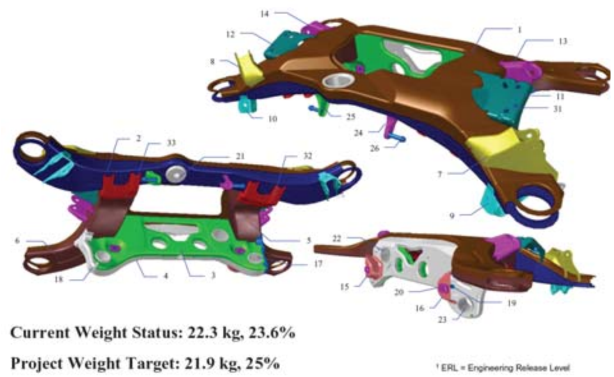

Figure 8. Preliminary Phase 2 design.

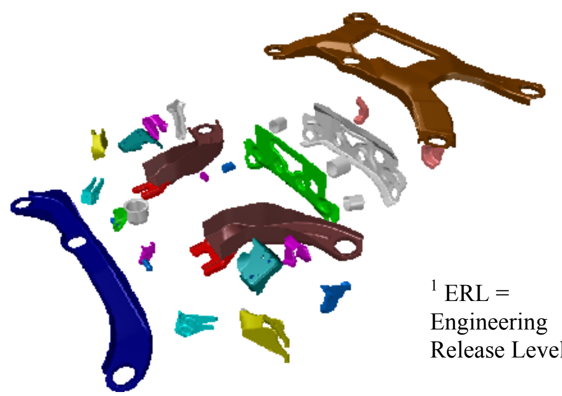

Figure 9. Preliminary Phase 2 design – exploded view.

4.4 Phase 2d): Phase 2 Prototype Build (4/07 – 6/07)

The fabrication of Phase 2 prototypes is scheduled for April to June of 2007. An RFQ for the prototype build will be issued early in April of 2007.

4.5 Phase 2e): Performance Testing (7/07 – 9/07)

DaimlerChrysler has scheduled Phase 2 prototype testing for July to September of 2007.

Item	Part Description	Qty	Material	Thickness (mm)
1	Upper Shell	1	DP780	1.7
2	Front Lateral Member - Lower Shell	1	DP780	2.2
3	Rear Lateral - Front Shell	1	DP780	1.6
4	Rear lateral - Rear Shell	1	DP780	1.7
5	Rear Longitudinal Lower - Left	1	DP780	1.7
6	Rear Longitudinal Lower - Right	1	DP780	1.7
7	Tension Link - Left	1	50 ksi	2.5
8	Tension Link - Right	1	50 ksi	2.5
9	Compression Link Bracket - Left	1	50 ksi	2.7
10	Compression Link Bracket - Right	1	50 ksi	2.7
11	Sta-Bar Bracket - Left	1	50 ksi	1.7
12	Sta-Bar Bracket - Right	1	50 ksi	1.7
13	Camber Link Bracket - Left	1	50 ksi	2.5
14	Camber Link Bracket - Right	1	50 ksi	2.5
15	Toe Link Bracket - Left	1	50 ksi	2.5
16	Toe Link Bracket - Right	1	50 ksi	2.5
17	Rear Closure Plate - Left	1	50 ksi	1.6
18	Rear Closure Plate - Right	1	50 ksi	1.6
19	Toe Link Sleeve	2	50 ksi	4.0
20	Toe Link Alignment Bracket	4	50 ksi	2.5

Figure 10. Preliminary Phase 2 design – bill of materials.

5.0 Phase 3: Communications (2/07 - 3/08)

A Communications Direction Sheet is being prepared by the Team. Communications of the Phase 1 results will begin in February 2006. The main communications for the Phase 2 results will be in the first quarter of 2008.

[i] Denotes project 601 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.