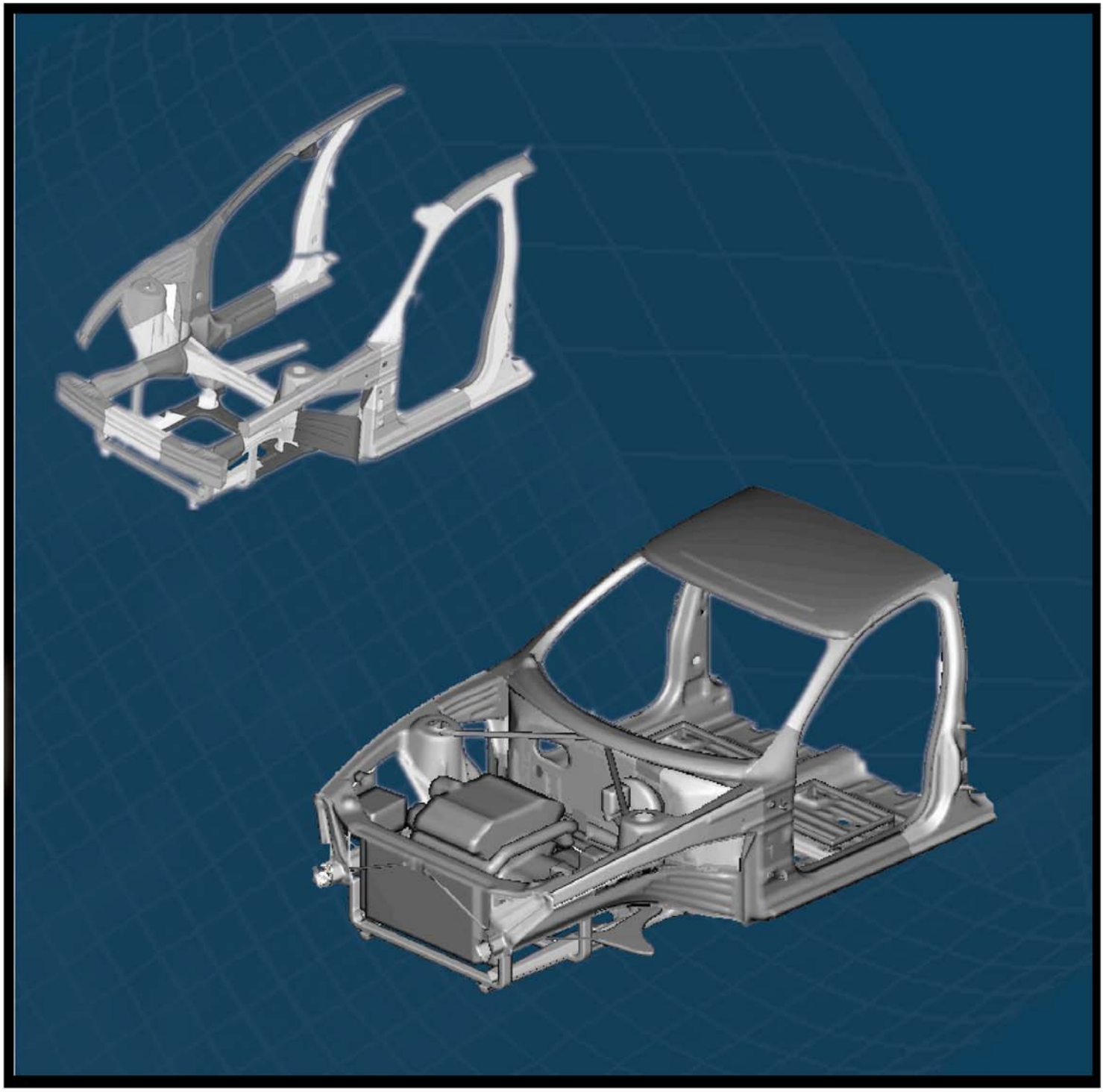


Lightweight Front End Structure

Phase I & II - Final Report

A parametric study of automotive front end structure design sensitivities

A/S P Auto/Steel Partnership

Introduction

The Lightweight Front End Structure project was a purely analytical, parametric study of automotive front end design sensitivities, sponsored and overseen by the Auto/Steel Partnership (A/SP). The objective of the A/SP is to improve technology, quality and reliability in the manufacture and application of automotive sheet steel, by leveraging the resources of automotive, steel and other related organizations. Find out more about the A/SP at the site address shown below.

The project, utilizing math data from the original Ultra Light Steel Auto Body (ULSAB) initiative, was organized into a series of independent, and selectively discrete activities, which together formed the basis of an integrated strategy for further development of a lightweight front end structure utilizing advanced high strength steels (AHSS). The various methodologies employed, included: Design of Experiments (DoE), Response Surface Modeling (RSM) and Computer Aided Optimization (CAO).

About the Final Report

The Final Report provides detailed information about the various elements of the Lightweight Front End Structure project. This report was compiled upon completion of the project, unlike the milestone reports that it is based on, and is provided in such a context. The milestone reports (Appendix A) may be referenced for more in-depth information on each particular chapter.

This report assumes you have a rudimentary understanding of automotive structure, the application of finite element methodologies, optimization techniques and automotive engineering nomenclature. References are provided if you wish to learn more.

The A/SP Lightweight Front End Structure team included representatives from Daimler Chrysler, Ford and General Motors in addition to steel company members and representatives from Quantech Global Services, the engineering analysis resource used exclusively in the execution of this project.

Auto/Steel Partnership web-site: http://www.a-sp.org

Ultra Light Steel Auto Body web-site: http://www.ulsab.org

Quantech Global Services web-site: http://www.quantechglobal.com

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Objectives

The objectives of the Lightweight Front End Structure project were to develop a methodology, a knowledge database and an associated user interface that would provide access to mass and cost information, for variations of a given front end package. Two front end packages were considered in this study - the **initial front end package** and the **upgraded front end package**. The structure had to meet stringent stiffness, modal and crash performance criteria, and had to be manufacturing feasible. Access to the database should allow early trade-off decisions to be made that comprehend effects of more front end content and less space, on mass, cost and performance. This project focused on the utilization of advanced high strength steels (AHSS) to mitigate cost and mass.

Results Summary

Optimization of the baseline **initial front end package** resulted in a **double five-star NHTSA** rating and an **overall good IIHS** rating. This was achieved with a **mass savings of 12kg** and a **cost reduction of $69,** compared to the baseline initial package. Furthermore, the baseline initial front end package did not meet all the target requirements. The optimized initial package also has a bumper design that is very efficient in high-speed impacts.

Optimization of the baseline **upgraded front end package** resulted in a **double five-star NHTSA rating** and an **overall good-acceptable IIHS** rating. This was achieved with an addition of 16kg of mass and a cost increase of $15, compared to the baseline upgraded package. The increase in mass is required as the baseline upgraded package did not meet the target requirements.

The upgraded front end package was obtained from the initial front end package by replacing the 3.1 litre V6 engine/powertrain package by a larger 3.6 litre V6 engine/powertrain package. Furthermore, the 196/60 R15 wheel/tire was replaced by a larger 205/60 R16 wheel/tire. The upgraded front end package has a 50 mm shorter front-end and represents a 180kg

Project Management Tool (SPInE)

A web based project management tool (SPInE) was developed to capture project activity and facilitate project communication. It featured all milestone reports, presentations, meeting minutes, discussions, etcetera, from the project. It enabled the technical team to report their progress, and the A/SP members to monitor the progress and provide timely and constructive feedback. This web-site can be viewed at http://www.aspquantum.com

heavier vehicle. In addition, the upper and lower rails were modified in order to accommodate the bigger engine and wheel. This resulted in a rail architecture that had a significant departure from the straight rails of the initial front package. The upgraded front end package also has a bumper design that is very efficient in high-speed impacts.

Approach

As a result of funding and timing constraints, the study was divided into two phases. The first phase focused on the determination of the allowable design space, and benchmarking and target setting for structure performance. Also included in this phase were, initial bumper characteristics development and web site development (see SPInE, below).

The second phase determined, for each parametric variation, the cost , mass and performance effects , in order to arrive at an optimized design that would meet the targets established in the first phase . The findings were compiled into a comprehensive database and an intuitive web tool (Proteus) was developed providing access to the data in the database. The schematic in Figure 1.1 illustrates the overall project approach and the following sections provide more detail.

***NCAP**: In 1978 the New Car Assessment Program (NCAP) in the United States was initiated by the National Highway Transportation and Safety Administration, with the primary purpose of providing consumers with a measure of the relative safety potential of vehicles in frontal crashes. (http://www.nhtsa.dot.gov/ncap/Info.html)*

***IIHS**: In the Insurance Institute for Highway Safety's 40mph offset test, 40 percent of the total width of each vehicle strikes a barrier on the driver side. (http://www.iihs.org/vehicle_ratings/ce/offset.htm)*

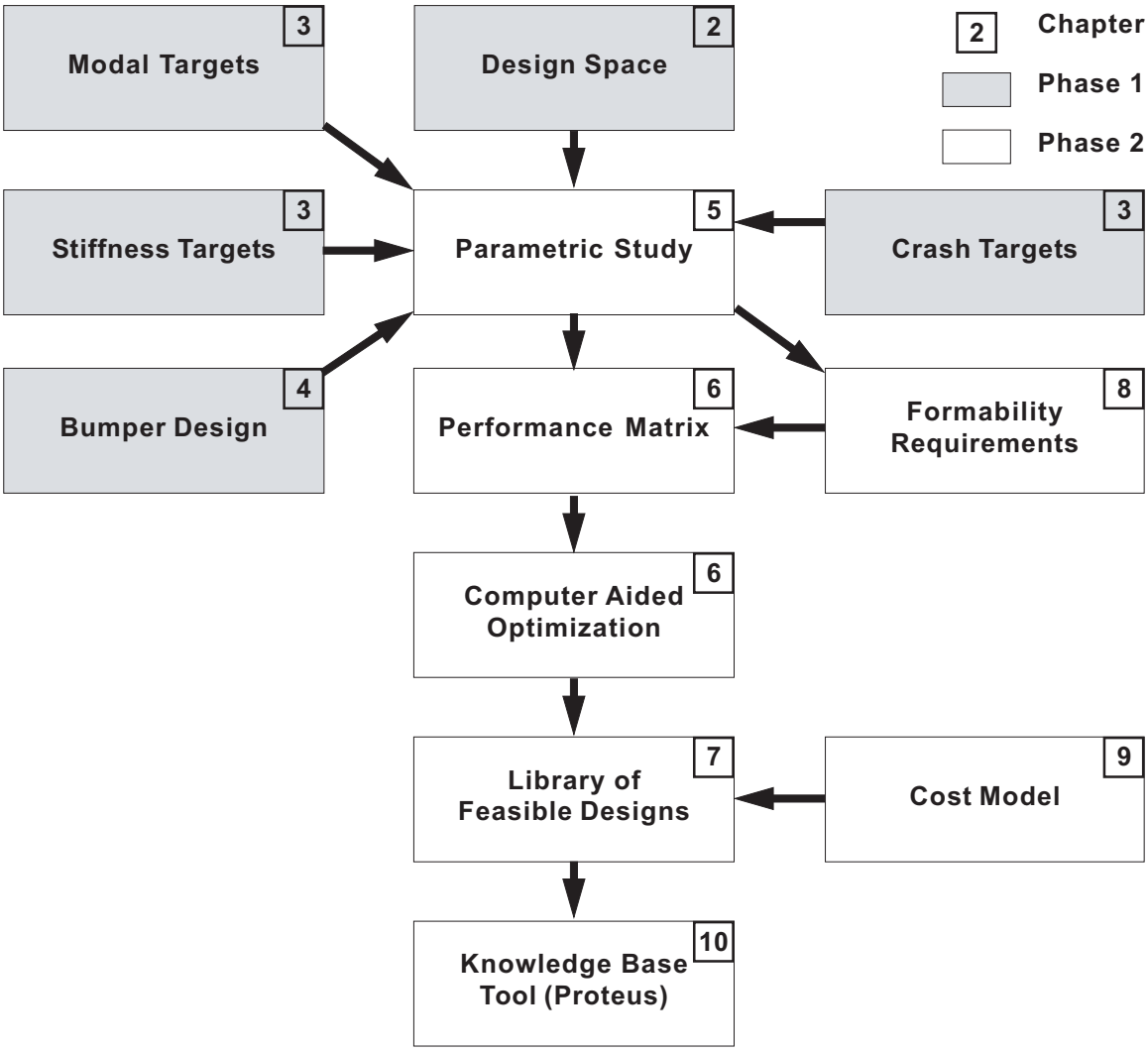


Figure 1.1: Schematic Illustrating Overall Project Approach

Design Space [2]

To study the effects on mass, cost and manufacturability for a given structural performance, it was first necessary to define the appropriate parameters and their realistic bounds. These were initially the result of expert opinion and were later fine tuned through pilot DoE studies that yielded design sensitivities that quantified the variation of vehicle response with respect to the design parameters. The design space initially included grade and gauge for the baseline studies and was later expanded to include topological parameters for an “upgraded powertrain” package.

Structural Performance Targets [3]

The Phase I study also arrived at structural performance targets that would enable certain weight class vehicles to achieve five star ratings in NCAP 35mph full frontal crash, and 'Overall Good' performance in IIHS 40mph, 40 percent offset crash (commonly referred to as ODB - offset deformable barrier). This was achieved by studying all available test data (including NHTSA and IIHS, see below) for 3000-4000lb weight class vehicles. The peak accelerations at various locations in the vehicle, and the corresponding timings, were defined as performance targets for the lightweight front end design. The structural targets for intrusions were derived from the minimum intrusions in the IIHS 40-40 ODB tests of five star rated (NCAP) vehicles. Stiffness and modal targets were set at the same levels as for the original ULSAB structure.

In addition to crashworthiness targets, static and dynamic stiffness targets were also determined. The static bending and torsion values being sought were to be at least as good as the original ULSAB. This was also true for torsion and bending modal frequencies.

Bumper Design [4]

There has been considerable investigation in the past into vehicle bumper performance in low speed collisions. However very little information was available in the literature about the vehicle bumper performance in high-speed collisions. The goal of this part of the investigation was to develop a series of bumper designs for better bumper system energy absorption in high-speed collisions. This would reduce the energy absorption requirement on the rest of the front structure and hopefully reduce the overall mass and cost. A parametric study of the bumper beam under low and high-speed impacts was undertaken. Initial bumper designs were developed that had virtually no damage in low speed impacts, acceptable bumper damageability in moderate speed impacts and maximized energy absorption in high speed impacts.

Parametric Study / Design of Experiments [5]

The design of experiments (DoE) techniques enabled the study of the effect of the parametric variables on system response using the least number of experiments (in this case an experiment was synonymous with an analysis using NASTRAN or LS-DYNA3D). The DoE method for the parametric study was required for the following reasons:

- traditional one-parameter-at-a-time study does not consider interaction of parameters (the effect of one parameter on others cannot be determined)

- full factorial study requires a very large number of analysis runs (the number of runs required is L^N, where L is the number of parameter levels and N is the number of parameters -- a study involving 40 parameters and 2 levels of each parameter requires 2^{40} analysis runs!).

On the other hand, employing DoE methodology has the following advantages:

- interaction between parameters are considered

- a minimum number of analysis runs are required (typically only 64 analyses runs are required for 31 parameters with 2 levels of each parameter).

Performance Matrix Computer Aided Optimization [6]

The objective was to minimize the mass of the vehicle subject to performance (stiffness, modal and crash) constraints. A performance matrix of design sensitivities and regression equations was built using the results of the DoE based parametric studies. The regression equations represented the objective function and the constraint functions.

The resulting regression equations (also referred to as response surfaces) were used in the Computer Aided Optimization (CAO) of the initial and the upgraded front end packages.

The problem was then solved using a computer aided optimizer. Sequential Quadratic Programming with a Quasi-Newton Line search algorithm was used for the optimization. Various solutions were obtained from the response surfaces derived from the DoE studies by minimizing the mass subject to performance constraints . This yielded a Library of Designs with mass reduction and better-than-baseline performance.

Library of Designs [7]

The library of designs were designs with better -than-baseline performance and lower mass, discovered by exploring the design space using the response surfaces generated from the DoE studies. This set of designs were obtained by using combinations of objective function, constraints and design space. The designs were either one of the actual DoE runs or were derived using Computer Aided Optimization (CAO).

Formability Requirements [8]

Formability studies were an integral part of this project. An important consideration in the analytical investigation was to evaluate the feasibility of realizing the proposed Advanced High Strength Steel designs in manufacturing practice. In order to accomplish this goal analytical formability studies were undertaken to explore the possibility of using high strength/ultra high strength steels towards existing or modified critical components in the front end structure. As more high strength steels are proposed for future automobile structure, it is very beneficial to have an early examination of the impacts they will bring on parts manufacturing.

Critical components targeted for high strength steel usage were analyzed using simulation software. Potential problems related to formability were identified and addressed. Furthermore, minimum gauges required to form specific parts using suggested materials were predicted from one-step simulations.

Cost Model [9]

The Cost model was used to ascertain the cost ramifications for different design solutions. A significant component of this investigation was to develop a refined cost model which incorporated real-life overall cost implications of the following:

- Blank Size
- Stamping Costs
- Welding Costs
- Assembly Costs
- Material Tables
- Interface with Knowledge Based Tool

Provisions were made to characterize the blank size as a function of the part dimensions and the stamping cost was modified to incorporate the material reject rates and the welding cost was modified to incorporate the Weld Line Length for tailor-blanked parts. Assembly costs were reevaluated as laser welds were replaced by spot welds. Material costs were modified for hydroformed parts and tailor-welded parts.

Knowledge Base [10]

A Knowledge Based Engineering tool was developed in order to comprehensively archive and provide easy access to the “lessons learned” from the suite of investigations undertaken. This tool, named *Proteus*, provides access to all the data that was generated from the analyses and experiments during this project, in an easy and intuitive fashion. Proteus will help in determining the effects of various parameters and constraints on significant responses and provide cost and mass for a

given vehicle performance. Proteus is extensible; it has the ability to accumulate information from new investigations.

Proteus features a comprehensive knowledge base that addresses the following:

- Design Parameters
- Thickness and material for:
  - Bumper
  - Lower and Upper Rails
  - Hinge Pillar/Dash
  - Cross Member
  - Body Side Panel
- Length and shape for rails
- Length and cross section for shotgun
- Mass
- B-pillar acceleration
- Footwell Intrusions
- Torsional stiffness
- Bending stiffness
- Cost
- Objective function
- Constraints

Proteus will enable practicing engineers to obtain a design in the design space that optimizes the objective function, while satisfying all the constraints.

Weld Study

An additional study was conducted to analyze the effect of spot weld stiffness on the NCAP and IIHS crash responses of the ULSAB vehicle. The study was in three phases. Phase I involved selection of a suitable weld material model for the weld study of the ULSAB vehicle. Phase II involved selection of a suitable DoE model for the weld study of the ULSAB vehicle, in order to assess the effect of the weld parameters on crash response. The study of the ULSAB vehicle using the material model and DoE model obtained in the previous phases was undertaken in Phase III.

The reports for this study can be found in Appendix A.

Design Space

The objectives of the Lightweight Front End Structure project were, as previously stated:

"To develop a methodology, a knowledge database and an associated user interface that would provide access to mass and cost information, for variations of a given front end package. The structure had to meet stringent stiffness, modal and crash performance criteria, and had to be manufacturing feasible".

The first task the team had to face was to determine what given "front end package" to use as a baseline for the study. The team included members from DaimlerChrysler, Ford and GM and their A/SP steel partners. Under the circumstances, it was decided that the ULSAB† Steel Consortium's structure would serve the purpose very well.

Using the ULSAB models as a starting point, a suitable set of analytical models were prepared. Design parameters comprising allowable variables and their corresponding upper and lower boundaries were selected initially by expert opinion (Ref. 4). The bounds were based on durability and formability considerations as well as on the accuracy of the DOE models. The bounded variables defined the study's "design space" which was initially constrained to grade (strength) and gauge of selected parts for the baseline studies. The design space was later expanded to include topological parameters for a modified front end package (Ref. 8).

†*The UltraLight Steel AutoBody (ULSAB) project was an intensive, multi-phase study to demonstrate steel's capability to reduce substantially the weight of a vehicle's body structure and, at the same time, ensure safety with improved comfort and driving performance, all at affordable cost. ULSAB was undertaken by a consortium of 35 leading steel producers from 18 countries around the world.*

UltraLight Steel Auto Body web-site: http://www.ulsab.org

Finite Element Model Preparation

Although the study focused on the front end of the structure, full body models were used based on original finite element (FE) models that represented the unique structure known as the UltraLight Steel Auto Body (ULSAB). The ULSAB approach utilized high percentages of high strength and ultra-high strength steels, laser tailor-welded blank parts and assembly laser welding. The team decided that tailor blanks and newer advanced high strength steels (AHSS) were to be included in the front end structure project, but that assembly laser welding would not, due to current North America infrastructure limitations.

The ULSAB static, modal and crash models had not previously been used for DoE based studies and required enhancements to make them appropriate baselines for parametric study and optimization.

Static and Dynamic Stiffness Model (NASTRAN)

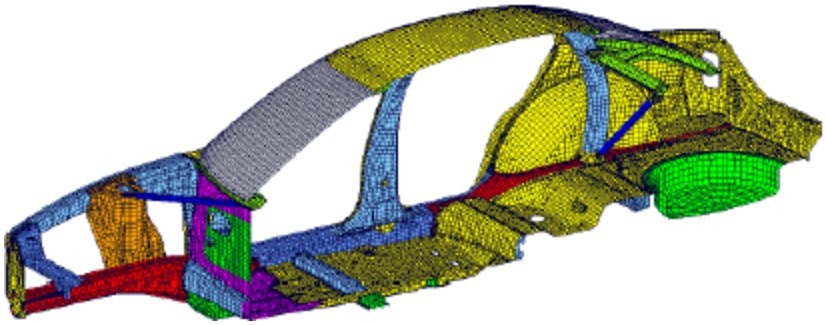


Figure 2.1: Original ULSAB Nastran Finite Element Model

The original ULSAB NASTRAN model (Ref. 2), shown, was utilized for the static bending and torsional stiffness analysis of the initial front end package . This same model was also used for baseline body structure dynamic stiffness (bending and torsional modes). Due to the symmetry in the structure, only a half model with the required boundary conditions at the symmetry plane was used for the static and dynamic stiffness simulations. The model consisted of triangular and quadrilateral elements. For expediency, laser welded parts were left as-is in the FE-Model, with the nodes of the flanges equivalenced. For spot welded areas the middle flange nodes were connected with rigid elements. The weld pitch was about 50 mm. The static stiffness was computed using the North American method of absolute deflections. *However later on, all laser welds were converted to spotwelds, and the stiffness was computed using the European method of relative deflections*. The knowledge base tool, *Proteus* (Ref.10), has the database corresponding to the spotwelded model. However, the milestone report for the static and dynamic study (Ref. 5) was not updated, and has the results corresponding to the laserwelded model.

For the upgraded front end package, a spotwelded model was employed for the static bending and torsional stiffness analysis . The static stiffness was computed using the European method of relative deflections.

The CAE configuration for the static and dynamic simulations consisted of the following parts:

- Welded Body Structure
- Bonded Windshield and Back Light
- Bonded and bolted Panel Dash Insert
- Bonded Panel Spare Tire Tub
- Bolted Reinforcement Panel Dash Brake Booster
- Bolted Braces Radiator
- Bolted Reinforcement Radiator Rail Closeout RH/LH
- Bolted Reinforcement Radiator Support Upper
- Bolted Tunnel Bridge Lower/Upper
- Bolted Brace Cowl to Shock Tower Assembly

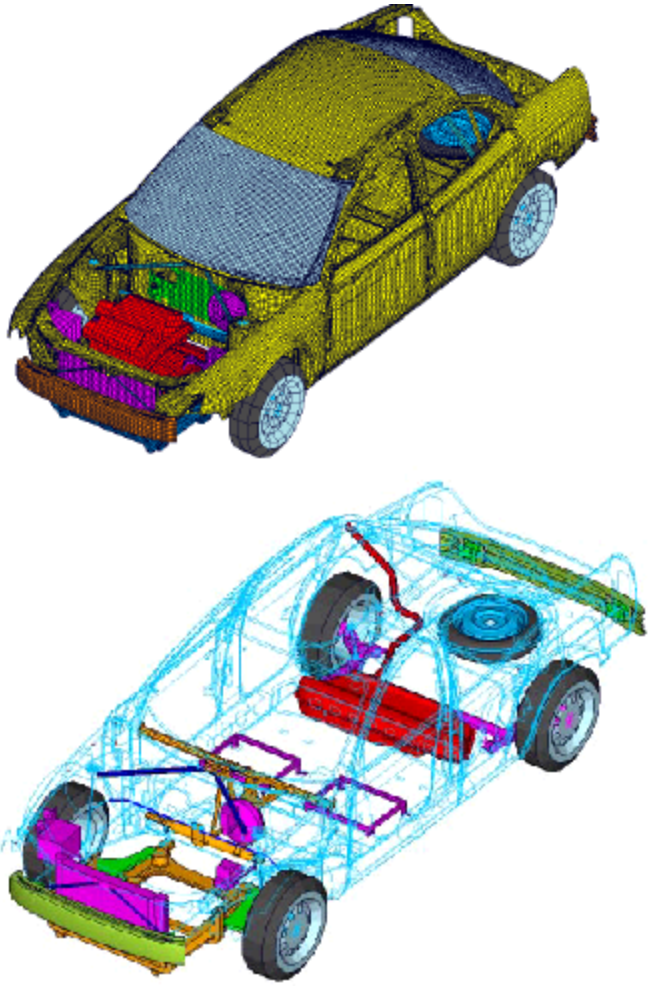


Figure 2.2: Original ULSAB LS-Dyna Finite Element Model

Crash Model (LS-DYNA3D)

For the crash scenarios of this project, one common crash model (with different barrier representations) was utilized for NHTSA's NCAP and IIHS's 40/40 ODB load cases (Ref. 1). The crash models for the initial front end package and the upgraded front end package were separate.

The illustration below shows the high level of detail for the FE crash model. The model included:

- Wheels with tire model
- Engine and transmission
- Steering system
- Chassis system with subframe
- Fuel tank
- Bumper system including crashbox
- Radiator with fan
- Battery
- Spare tire
- Brake booster, ABS box and cylinder
- Doors, front and rear without glass

Model Changes

This section summarizes the changes made to the original ULSAB crash model in order to make it more suitable for use as the basis for DoE based parametric study and optimization (Ref. 2).

- The original bumper system was replaced by a new bumper design (the first of a series of designs aimed at improving bumper system contributions to frontal impact energy management - see Bumper Design [4]). This was done because the original ULSAB was not designed to meet the IIHS 40/40 ODB impact (a requirement that was under development during ULSAB's original project). The new bumper design was developed to help absorb more energy.

- The front rail, rocker and the rear rail (originally modelled to represent continuous laser welded assemblies) were offset and spot welds were created at a spacing of 50 mm.

The UltraLight Steel AutoBody (ULSAB) project was documented in an in-depth Electronic Report, available on CD from your ULSAB Consortium steel representative or from the American Iron and Steel Institute (AISI).

The report contains detailed design, materials and manufacturing data including safety analysis, performance testing and an economic study.

- Duplicate elements were offset and spot weld connections created, as necessary.
- New material properties provided by the A/SP were implemented.
- The engine material model was changed from piecewise linear plastic to rigid. The engine brackets were made rigid as well.
- The suspension model was modified so as to capture the tire rotation more accurately.
- The automatic single surface contact in the model was simulated with a soft constraint formulation with the edge-to-edge penetration check turned on.

In addition to the above modifications, changes necessary to supplement the conversion of sequential file format to the keyword format in HyperMesh were also made. Examples include redefinition of the control volumes, contact, load curves and output blocks. The model was organized into LH and RH components, which were named and numbered logically.

Load Cases

Torsional Stiffness

A load of 1000N was applied at the shock tower front while the body structure was constrained at the rear center spring attachment in the lateral and vertical directions. Stiffness calculations were conducted, as follows:

North American Method of Absolute Deflections

$$K_t = T/q$$
$$T = 2FY_f$$
$$q = \text{atan}(dz/Y_e)$$

Where,

K_t = torsional stiffness
T = applied torque
F = applied force (at front shock mount)
Y_f = Y coordinate (lateral direction) of the point of application of F (centerline is Y=0)
q = angular deflection of point of measurement
dz = Z deflection of point of measurement
Y_e = Y coordinate of point of measurement

For torsional stiffness, the point of measurement of deflection dz is the load application point at the front shock mount.

European Method of Relative Deflections

$K_b = P/Äz_c$

$\Delta z_c = \Delta z - \Delta z_g$

$\Delta z_g = \Delta z_{trans} - \Delta z_{rot}$

$z_g = z_{trans} + \Delta z_{rot}$

$z_{trans} = Äz_F$

$\Delta z_{rot} = (x - x_F)$ è $= (x - x_F)^* (\Delta z_R - \Delta z_F)/ (x_{R_} x_F)$

Where,

P = Total Force (Full Model)

Δz_F = Z displacement at front rail with an X coordinate equal to that of the front strut tower center .

Δz_R = Z displacement at rear rail with an X coordinate equal to that of the rear spring seat center.

x = X coordinate of the point on the node set in the longitudinal direction where Z displacement is maximum.

x_F = X coordinate of F

x_R = X coordinate of R

Additional load cases for low and mid-speed bumper assessment are detailed in the section - Bumper Design [4].

Bending Stiffness

A load of 2000 N was applied at the front and rear seat mounts in the half model. The rear shock mount was constrained in the longitudinal and vertical directions and the front shock mount was constrained in the vertical direction.

North American Method of Absolute Deflections

$$K_b = F/dz$$

Where,

K_b = bending stiffness
F = total applied force (at front and rear seat mounts)
dz = Z deflection of point of measurement

For bending stiffness, the deflection dz is the average of the Z deflections at the load application points.

European Method of Relative Deflections

$$K_t = (T/\theta_D)$$

$$\theta_D = \theta_F - \theta_R$$

$$\theta = \text{atan}(\Delta z/y)$$

Where,

T = Total Torque (Full Model)

θ_F = Twist angle at the front rail at an X coordinate equal to that of the front strut tower center

θ_R = Twist angle at the rear rail at an X coordinate equal to that of the rear spring center

Δz = Z displacement at a point (F or R)

y = Y coordinate of the point (F or R)

Normal Modes

Free-free bending and torsional modes were evaluated. Appropriate boundary conditions were given for bending and torsion.

NHTSA New Car Assessment Program (NCAP) 35mph Rigid Barrier Impact

In 1978, the New Car Assessment Program (NCAP) in the United States was initiated by the National Highway Transportation and Safety Administration, with the primary purpose of providing consumers with a measure of the relative safety potential of vehicles in frontal crashes.

For more information visit:
http://www.nhtsa.dot.gov/ncap/Info.html

The NCAP full frontal 35mph test was selected as the criterion for deriving structural targets based on occupant accelerations because this test achieves high pulse severity.

IIHS 40 Percent Offset 40mph Deformable Barrier Impact

In the Insurance Institute for Highway Safety's 40mph offset test, 40 percent of the total width of each vehicle strikes a deformable barrier on the driver side. The finite element model for the deformable barrier was obtained from Oasys Ltd.

For more information visit:
http://www.iihs.org/vehicle_ratings/ce/offset.htm

The IIHS 40 percent offset test was selected as the criterion for deriving structural intrusion targets, because this test is very severe with respect to structural stiffness, occupant compartment integrity and occupant lower extremity injuries.

Other frontal crash requirements, for example FMVSS 208, which include occupant environment and restraint systems, were considered beyond the scope of this front-end development project.

Parametric Variables

For the stiffness based studies, only part gauge (thickness) was considered as a variable. For these studies material strength (yield or tensile) does not effect the results and the modulus is considered the same for all parts.

For the initial studies representing crash events, the variables included part material selection (steel grade) and part thickness (gauge).

Additional variables in the upgraded package were topological and included structural member curvatures, lengths, heights, etcetera.

Initial Front End Package

This project included investigation into two different front end packages. The initial package was the as received ULSAB, including a 3.1L V6 engine with 15” tires/wheels (see ULSAB Electronic Report).

Front End Components Selected For Initial Package Stiffness Studies

The following major structural components of the front end were selected for the parametric initial stiffness studies:

- Front Rail Inner (tailor welded blank - front, mid, rear)
- Front Rail Outer (tailor welded blank - front, mid, rear)
- Upper Rail Inner (Shotgun)
- Upper Rail Outer (Shotgun)
- #1 Crossmember
- Dash Panel
- Side Roof Rail
- A-Pillar Asm (Hinge Pillar, Rocker Inner, Bodyside outer - TWB (2))
- B-Pillar Asm (B-Pillar Inner, Bodyside outer)

Variables Selected for Initial Package Front End Stiffness Studies

The variables selected for the Phase 1 (initial package) parametric stiffness studies, are shown in Table 2.1, below (Ref. 5).

The levels 1, 2, and 3 in the columns of the table represent the baseline, lower and upper bounds of each parameter. The A-Pillar and B-Pillar assemblies were grouped, as shown, to reduce the overall number of parameters studied.

This resulted in thirteen parameters that were assigned to different columns of the L27 array (see Chapter 5, Parametric Study / Design of Experiments).

Parameters	Thickness Levels		
	Level 1 (Baseline)	Level 2	Level 3
Rail Front Inner	1.5	1.0	2.0
Rail Mid Inner	1.6	1.0	2.0
Rail Rear Inner	1.8	1.0	2.0
Rail Front Outer	1.5	1.0	2.0
Rail Mid Outer	1.6	1.0	2.0
Rail Rear Outer	2.0	1.0	1.5
Shot Gun Inner	1.2	0.7	2.0
Shot Gun Outer	0.9	0.7	2.0
1st Cross Member	1.2	0.7	2.0
Dash Panel	0.7	0.6	1.2
Rail Side Roof	1.0	0.8	1.2
Hinge Pillar	1.0	1.5	2.0
Rocker Inner	1.7	1.0	2.0
Body Side Outer A-Pillar (1)	1.5	1.0	2.0
Body Side Outer A-Pillar (2)	1.7	1.0	2.0
A-Pillar Upper	1.5	1.0	2.0
B-Pillar Inner	1.5	1.0	2.0
Body Side Outer B-Pillar	1.3	1.0	2.0

Table 2.1: Phase 1 Parametric Variables - Stiffness

Front End Components Selected For Initial Package NCAP Studies

For expediency, the initial package crashworthiness full DoE studies focused on NCAP performance (although some IIHS performance analyses were performed to ensure that NCAP optimized front end design would be IIHS performance capable).

The following major structural components of the front end were selected for the parametric initial NCAP studies (Ref. 6):

- Bumper
- Front Rail Inner (tailor welded blank - front, mid, rear)
- Front Rail Outer (tailor welded blank - front, mid, rear)
- Front Rail Extension
- Front Rail Extension Reinforcement
- Upper Rail Inner
- Upper Rail Outer
- #1 Crossmember
- Skirt (tailor welded blank - upper, lower)
- Cradle
- Cradle Extension
- Cradle Crossmember Front
- Cradle Crossmember Rear

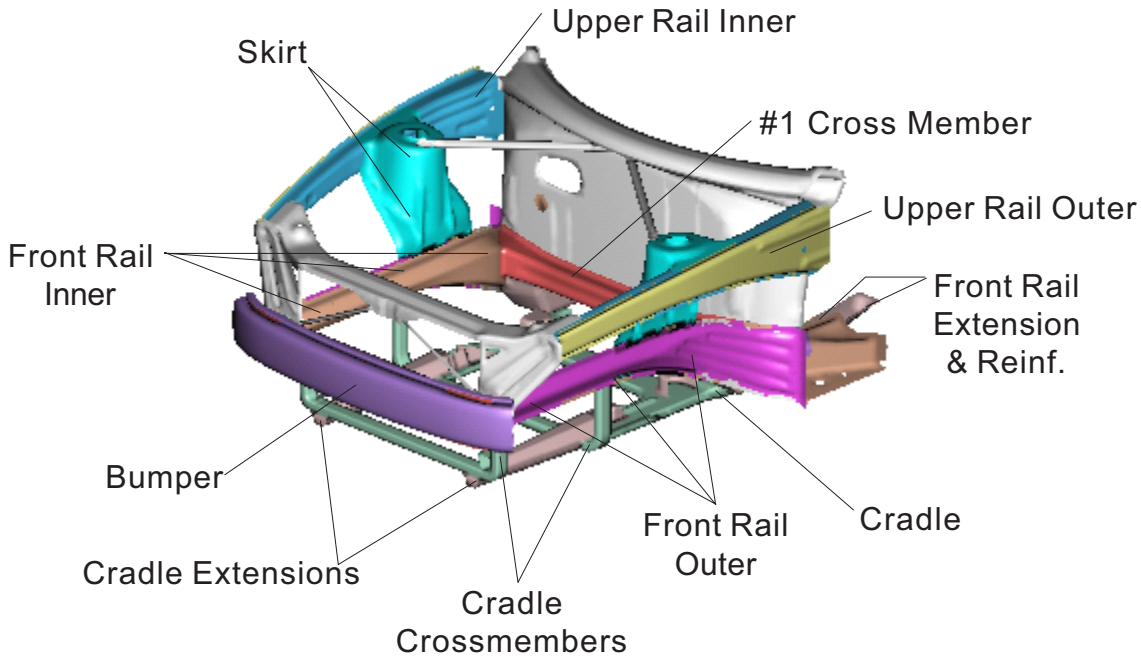


Figure 2.3: Selected Front End Components for Parametric Study - NCAP

Parameters	Thickness (mm)		Material Yield/Ultimate (MPa)	
	Level 1	Level 2	Level 1 *	Level 2
Bumper C-Section	1.3	2.0	HSLA 350/450	DP 500/800
Rail Front Inner	1.0	1.5	HSLA 350/450	DP 500/800
Rail Front Outer	1.0	1.5	HSLA 350/450	DP 500/800
Rail Mid Inner	1.0	1.6	HSLA 350/450	DP 500/800
Rail Mid Outer	1.0	1.6	HSLA 350/450	DP 500/800
Rail Rear Inner	1.2	1.8	HSLA 350/450	DP 500/800
Rail Rear Outer	1.3	2.0	HSLA 350/450	DP 500/800
Shot Gun Inner	0.8	1.2	HSLA 425/770	DP 500/800
Shot Gun Outer	0.7	0.9	HSLA 350/450	DP 500/800
Cradle Cross Mbr 1	1.0	1.3	HSLA 350/450	DP 500/800
Cradle Cross Mbr 2	1.0	1.6	HSLA 350/450	DP 500/800
Cradle	1.3	2.0	HSLA 350/450	DP 500/800
Cradle Extension	1.0	1.5	DP 280/600	DP 500/800
1st Cross Member	0.8	1.2	HSLA 425/770	DP 700/1000*

* Indicates baseline values

Table 2.2: Phase 1 Parametric Variables - NCAP

Table 2.2 gives a list of the variables considered for the NCAP parametric study, along with the levels for each gauge and grade.

The lower gauge levels on the parameters were determined from formability and durability considerations. The higher grade levels were also determined from formability considerations (see Chapter 8, Formability Requirements). The higher gauge and lower grade levels were the same as the baseline values.

It was determined from pilot studies on the front rails that interaction effects were considerable in NCAP, unlike the static stiffness case. Thus, the 3-level L27 array that was adequate for the parametric stiffness studies, would not suffice for the NCAP study. There were then two choices – either to increase the size of the DoE array or to reduce the number of levels. The former would increase the number of DYNA runs tremendously and was therefore infeasible, given the resources and the time available. It was therefore decided to conduct a 2-level study requiring 64 runs, which would include interaction effects and generate an accurate response surface that could be extrapolated beyond the second level. The levels 1 and 2 in the columns of the table represent the lower and upper bounds of each parameter. The cradle cross members were grouped, as shown, to reduce the overall number of parameters studied.

Upgraded Front End Package

The upgraded package was the as received ULSAB, modified so as to accommodate an upgraded powertrain, larger tire flop and higher mass, in order to represent a vehicle in a higher gross vehicle weight (GVW) class. Various topological changes were made to the front-end structure of the original ULSAB model, in order to accommodate the higher-end engine package and tires (Ref. 7). The upgraded ULSAB model also incorporated a new more efficient bumper design (see Chapter 4, Bumper Design).

Summary of Topological Changes

The modifications made to the original ULSAB model for accommodating the high-end engine package are documented in the following sections. The primary changes consist of the basic topological modifications made to certain front-end parts, such as rails and shotgun, in order to accommodate the large powertrain and tire size. Secondary changes are the modifications made to the parts affected by the primary changes. Bumper design changes were carried out in conjunction with the primary changes. Rails stiffeners and modifications were designed in order to improve the crashworthiness performance. The front section of the rails were modified and stiffeners were redesigned so as to reduce buckling and induce greater axial crush. Rail extension and rail extension reinforcement were designed for improving the load path to the rear rail section. The total mass of the vehicle lumped mass was increased by 360lb, and was distributed on the powertrain, suspension and rear seat locations.

Figure 2.4 below depicts the various topological changes in the ULSAB front-end structure, as well as the large tire flop and lumped mass distribution in the upgraded ULSAB. The original ULSAB 3.1 liter, V6 engine was upgraded by increasing its mass by 220 lb and its volume envelope suitably, in order to be representative of a larger 3.8 liter V6 package. In accordance with the original ULSAB, a clearance of 9.5 mm was maintained between the powertrain and all sheet metal. Divots were introduced in the front section of the right rail, in order to achieve this clearance. The larger tire flop necessitated cross section reduction and change in plan curvature in both the rails. The length of the front rail section was reduced by 100 mm, as the original ULSAB has a front-end that is longer than is typical for a vehicle in that class. Feasibility of accommodating different tire flops in the ULSAB architecture was studied. The 195/60 R15 tire used in the original ULSAB model was replaced by 205/60 R16 tire.

Primary Changes

- Topological changes
  - LH rail
  - RH rail
  - Bumper design
  - Rail extension joint
  - Shot gun and fender
- Length of front rail section reduced by 100 mm
- ULSAB tire size changed from 195/60 R15 to 205/60 R16
- Vehicle lumped mass increased by 360 lb

Secondary Changes

Due to topological modifications in the LH rail, secondary changes were made to the following:

- Suspension tower (Skirt)
- Cradle – 2nd U bar
- Engine bracket and engine mount bracket
- Reinforcement added in the middle of the LH rail, due to rail bump, and at rear of the rail, due to tire flop (rail plan curvature change)

Due to topological modifications in the RH rail, secondary changes were made to the following:

- Suspension tower (Skirt)
- Battery size and position changed due to changes in the front rail design
- Reinforcement added at the front of the RH rail, due engine divot, and at the rear of the rail, due to tire flop (rail plan curvature change)

The bumper height and width were suitably increased in order to achieve a better crush pattern (see Chapter 4, Bumper Design).

Front End Components Selected For Upgraded Package Studies

The following parametric studies were performed for the upgraded package:

- Static stiffness
- Dynamic stiffness
- NCAP
- IIHS

Details of the parameters selected for the upgraded package studies can be obtained from *Parametric Study/Design of Experiments [5].*

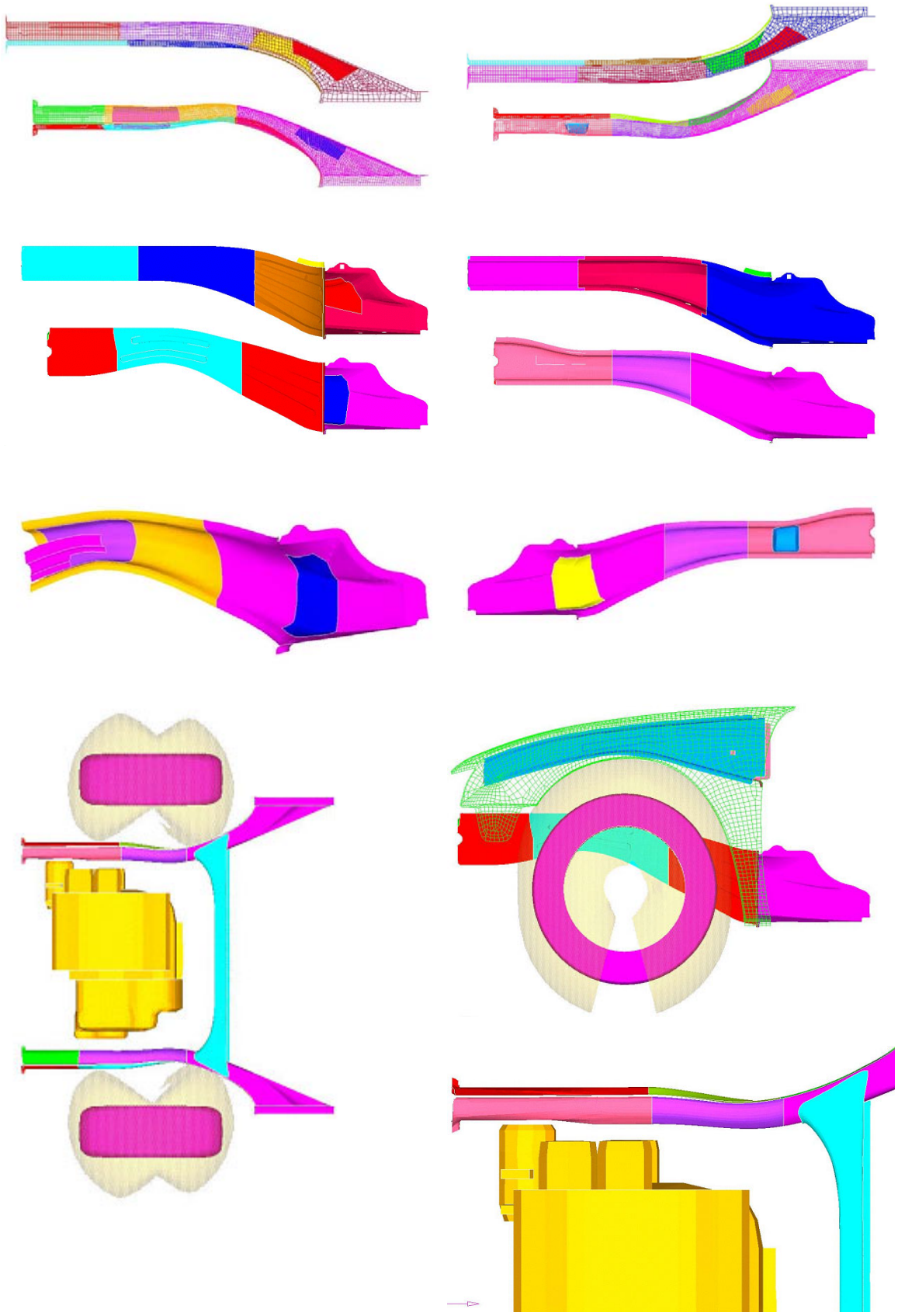


Figure 2.4: Topological Changes to ULSAB

References

1) *Phase I Structural Performance Targets Report*.

2) *Baseline Model for CAO Report, Milestone 3*.

3) *First Bumper Design Report, Milestone 5*.

4) *Parametric Design Combinations Report, Milestone 7.*

5) *ULSAB Static and Dynamic Stiffness Study, Milestone 8*.

6) *NCAP 35mph Study, Milestone 11*.

7) *ULSAB Model with Upgraded Powertrain Report, Milestone 14*.

8) *Upgraded Powertrain DOE Study, Milestone 15*.

9) *Fourth Bumper Design Report, Milestone 26*.

10) *Proteus Knowledge Base, Milestone 32*.

Structural Performance Targets

This chapter discusses the frontal crash requirements and ratings that were studied in order to establish structural performance targets for the optimization of the front-end structure. These performance targets would create a favorable environmnet for achieving high frontal crash ratings.

The NCAP structural performance of vehicles in the 3000-4000lb weight class, were studied by collecting crash test data from the National Highway Traffic Safety Administration (NHTSA) Research and Development test data base. Structural intrusions data for the Insurance Institute of High Safety (IIHS) 40mph, 40 percent offset crash into a deformable barrier, were gathered for the same class of vehicles, from the IIHS test database.

The test data was reviewed with the aim of defining a set of very stringent structural targets that would enable the front end structure to satisfy both the NCAP and the 40/40 offset test requirements simultaneously (Ref. 1).

The NCAP full frontal 35mph test was selected as the criterion for deriving structural targets based on occupant accelerations because this test achieves high pulse severity. The IIHS 40 percent offset test was selected as the criterion for deriving structural intrusion targets, because this test is very severe with respect to structural stiffness, occupant compartment integrity and occupant lower extremity injuries. Other frontal crash requirements, for example the FMVSS 208, which include occupant environment and restraint systems, were considered beyond the scope of this front end development project.

NHTSA: The NHTSA Vehicle Crash Test Database contains engineering data measured during various types of research, the New Car Assessment Program (NCAP), and compliance crash tests. Information in this database refers to the performance and response of vehicles and other

Selection of Benchmark Vehicles

'C' class vehicles were selected as benchmark targets. The weight of this class vehicle being between 3000 and 4000lb. The targets were derived by taking the "best response" of NCAP double five star vehicles that also achieved 'best pick' performance in the IIHS offset test (Ref. 1).

For the NHTSA NCAP star ratings, all vehicles in the above weight class that achieved double 5 - star, 4 - star driver or 3- star driver ratings, were selected. Only models from 1998 and later were considered for this study.

The selection criteria yielded the following vehicles for the Phase I structural performance study:

2000 Models of Ford Taurus, Volks Wagen Passat, Buick Lesabre, Chrysler LHS, Subaru Legacy, Nissan Maxima/Infinity130, 1999 models of Mitsubishi Gallant and 1998 models of Toyota Camry, Honda Accord, Toyota Avalon, Volvo S70.

Procedure

The following procedure was employed in order to arrive at structural performance targets that would ensure double five star ratings potential in NHTSA 35mph frontal crash without actually including occupant models in the crash simulation (Ref. 1):

· Review of all available crash test data pertaining to structural performance and occupant response from the NHTSA website for the selected vehicles.

· Filter accelerometer test data using filters (Head – SAE1000, chest – SAE180 and others SAE60) [4].

· Tabulate peak accelerations and their timings at engine, brake caliper, dash panel and seat-rear/floor panel.

· Determining lower bound values from double five star vehicle responses.

· Selecting lower bound values corresponding to double five star vehicles, which are also 'best pick' in IIHS 40mph 40 percent offset tests, as the logical intermittent targets which can assure a desirable vehicle pulse at rocker inside B-pillar (hereafter referred as B-pillar).

SAE: Founded in 1905, The Society of Automotive Engineers is a network of over 83,000 engineers, writing automotive engineering standards that are used in designing, building, maintaining, and operating self-propelled vehicles.

Table 3.1 lists the structural performance ratings in the IIHS offset tests as well as their corresponding driver-side NCAP star ratings. Table 3.2 compares the occupant (driver) responses in NCAP tests. Table 3.3 lists the intrusions in IIHS 40-40 offset tests.

Vehicle Name/ Model	Vehicle Weight	NHTSA Frontal Crash Rating	IIHS Frontal Offset Crash Test Performance							Other Evalutions	
			Overall	Structure/ Safety Cage	Injury Measures				Restraints/ Dummy Kinematics	Head Restraint Design	Bumper
					Head/ Neck	Chest	Leg/Foot	left, right			
FORD TAURUS/ MERCURY SABLE **2000 models**	3333	★★★★★	G Best Pick	G	G	G	G	G	A	A M depends on seat	A
BUICK LESABRE **2000 models**	3558	★★★★★	G Best Pick	G	G	G	G		A	G	M
SUBARU LEGACY **2000 models**	3298	★★★★	G Best Pick	G	G	G	G	A	G	M	A
MITSUBISHI GALANT **1999-2000 models**	3069	★★★★	A	A	G	G	G	A	A	M	A
HONDA ACCORD **1998-2000 models**	3047	★★★★	A	A	G	G	G	P		P	G
NISSAN MAXIMA/ INFINITI I30 **2000 models**	3220	★★★★	A	A	G	G	P	P	G	G A depends on seat	M
Legend :			Good G		Acceptable A				Marginal M	Poor P	

The table includes only those vehicles for which both NCAP and IIHS test data were available.

Table 3.1: Combined NCAP and Offset Ratings

NCAP Rating	Vehicle	HIC	Chest G	Seat Ave. Acc in 40-80 ms (g)	Seat Disp at 40 ms (mm)
5-star	Buick Lesabre	467	43	24.08	10.30
	Ford Taurus	345	41	25.78	9.80
	Volkswagen Passat	377	44	23.05	11.80
	Volvo S70	259	46	24.98	10.50
4-star	Nissan Maxima	437	50	28.35	8.30
	Toyota Avalon	504	50	25.60	11.10
	Subaru Legacy	559	45	24.63	12.50
	Mitsubishi Galant	439	50	30.48	5.50
	Toyota Camry	525	46	26.88	13.70
	Honda Accord	631	49	27.83	10.50
3-star	Chrysler LHS	708	61	26.60	10.00
	Nissan Altima	908	50	26.25	8.70

Table 3.2: NHTSA 35mph Frontal Crash Tests

Vehicle	Weight (lb)	Footwell Intrusions (cm)			A-Pillar Rearward Movement (cm)
		Left	Center	Right	
FORD TAURUS 2000	3333	12	14	13	3
BUICK LESABRE2000	3558	18	18	15	5
NISSAN MAXIMA 2000	3220	26	25	21	9
SUBARU LEGACY 2000	3298	10	18	10	1
MITSUBISHI GALANT 1999	3069	22	25	21	5
HONDA ACCORD1998	3047	18	21	17	3

Table 3.3: Intrusions in IIHS 40-40 Offset Tests

Structural Performance of 5, 4 and 3-Star Vehicles in NCAP Test

The peak acceleration responses at various locations in the front-end revealed a great deal of information regarding the vehicle architecture, structural stiffness and energy management. The acceleration responses should be studied in conjunction with the physical dimensions of the vehicle.

All of the five star vehicles except the VW Passat had peak engine accelerations less than 122g and attained peak before 35ms (Figures 3.2 and 3.3). The VW Passat exhibited very high engine acceleration, as it had the lowest overhang in front of the engine and a stiff bumper. The Mitsuhishi Gallant received 4 - star driver side and 5-star on the passenger side, even though it had a peak engine acceleration of only 110g. This could be due to the fact that the time of occurrence of peak (42ms) was too late to be managed by the restrain system. Hence, it was concluded that both peak acceleration and its time of occurrence were very critical.

The engine accelerations reflected the architecture and stiffness of the front-end structure. The engines in vehicles with shorter overhang or with stiffer bumper system very rapidly decelerated and attained zero velocity compared to engines in vehicles with longer overhang and relatively softer bumper systems. Except for VW Passat, the vehicles that attained higher engine peak deceleration (higher than 122g) have lower star rating. It was also observed that all 5-star and close to 5-star vehicles (except VW Passat) attained peak deceleration around 35ms. Thus, it is possible that there may not be any correlation between the engine deceleration and 5-star ratings. But, in a conventional design it may have helped to monitor the engine response and try to duplicate the 5-star vehicle's engine response and control the front of engine structure stiffness and rate of energy absorption.

The band of variations narrows at the seat /floor location (Figures 3.2 and 3.4). The 5-star vehicles formed the lower bounds for the peak accelerations. Since the actual physical locations in these vehicles were different, it was possible that peak acceleration plots would spread out further and create a narrow band for 5-star vehicles. Most of the 5-star vehicles had lower and earlier peaks. It must be noted that most of the 4-star rated vehicles listed here have 5-star ratings for passenger side occupant. This clearly indicates that these vehicles received lower driver side ratings due to driver side compartment variables and restraint system.

A study was carried out to check whether there was any influence on the duration of the pulse on the star rating. The pulse duration was measured as the width of the acceleration curve at average peak value. It was observed that there was no significant difference between the pulse duration between the vehicles.

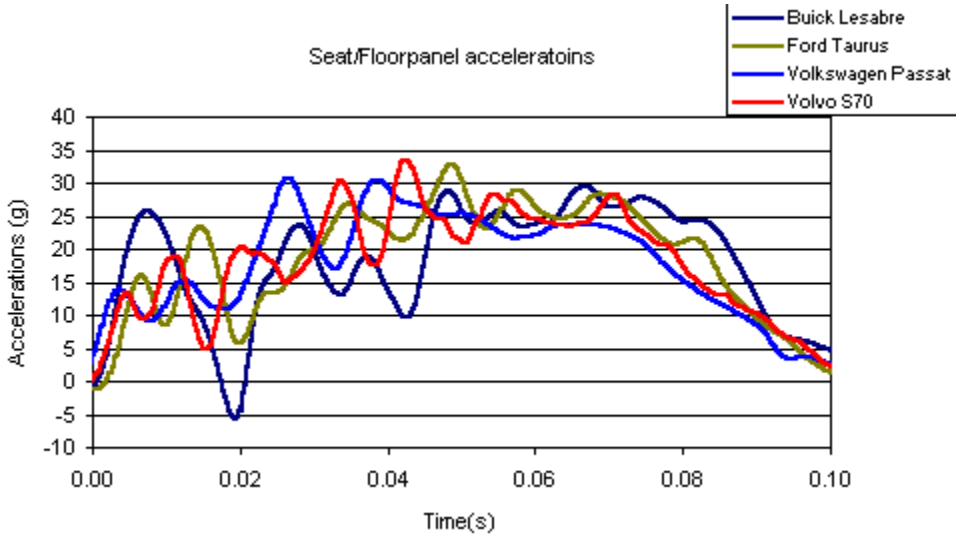


Figure 3.1: Left Front Seat Rear / Floor Panel Center (B-Pillar)

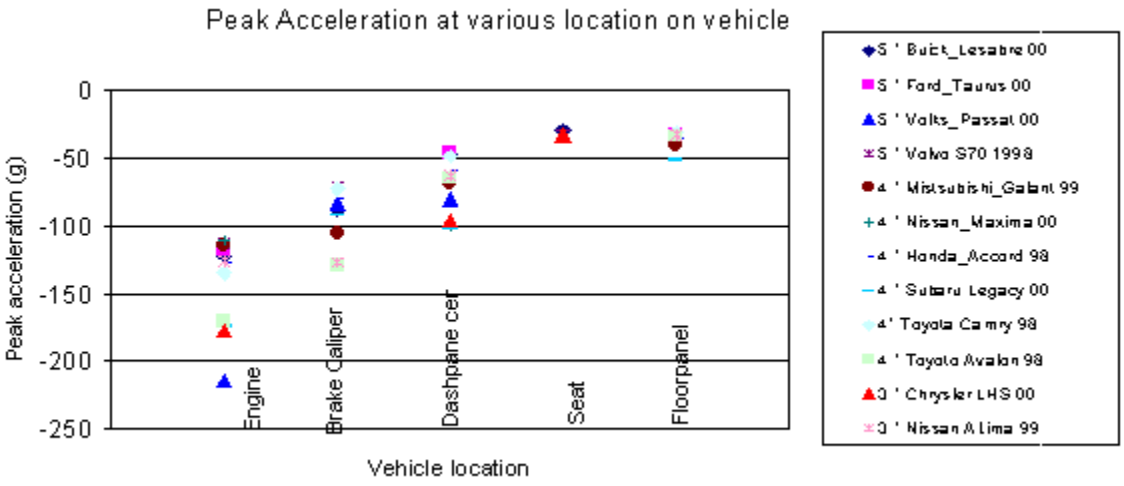


Figure 3.2: Peak Accelerations at Various Locations in the Front End

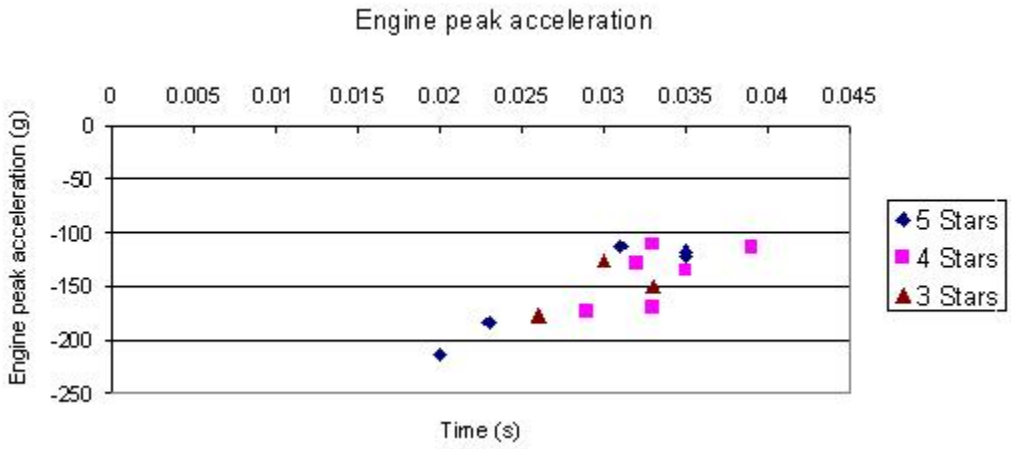


Figure 3.3: Engine Peak Accelerations and Corresponding Time

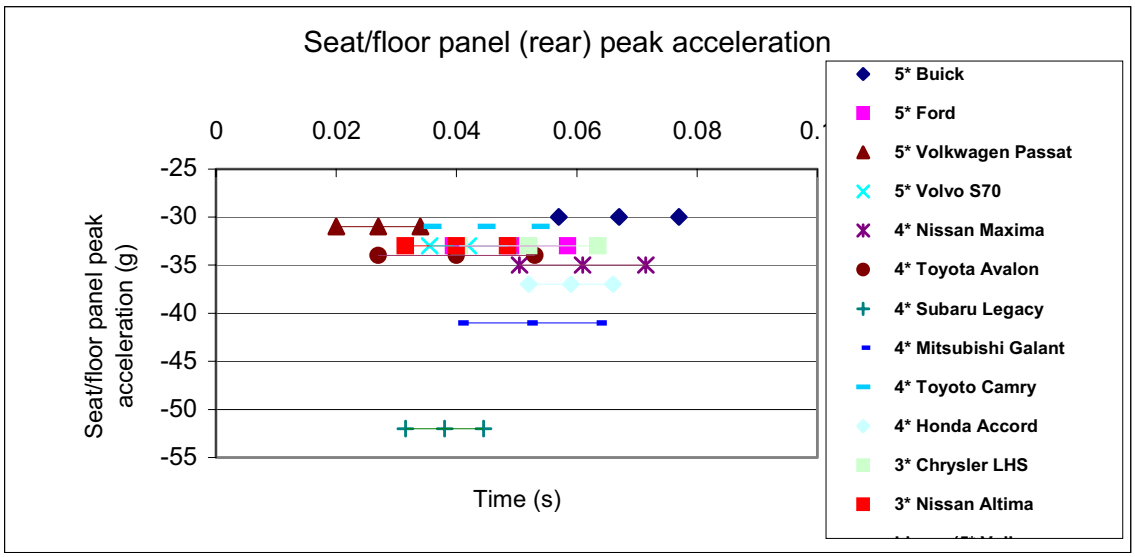


Figure 3.4: Seat / Floor Panel Accelerations and Corresponding Time of Peak

Occupant Environment Deformations and Occupant Injuries

The occupant compartment deformations, HIC and chest accelerations are summarized in Figures 3.5 and 3.6. In Figure 3.5, the HIC values are plotted against average ‘g’ value at seat rear/floor panel. The seat/floor average value was calculated from the area under the curve in a 40ms duration between 40ms and 80ms, when the seat/floor/accelerations were at their maximum. The 40ms corresponded to the engine coming close to zero velocity and 80ms corresponded to vehicle reaching close to zero velocity. Average seat/floor acceleration of 26g seemed to be the limiting value in order to achieve a 5-star rating. A similar conclusion can be drawn from the chest accelerations plot in Figure 3.6. It must be noted, that some of the 4-star vehicles have 5-star passenger ratings and are therefore very close to the 5-star vehicles in performance.

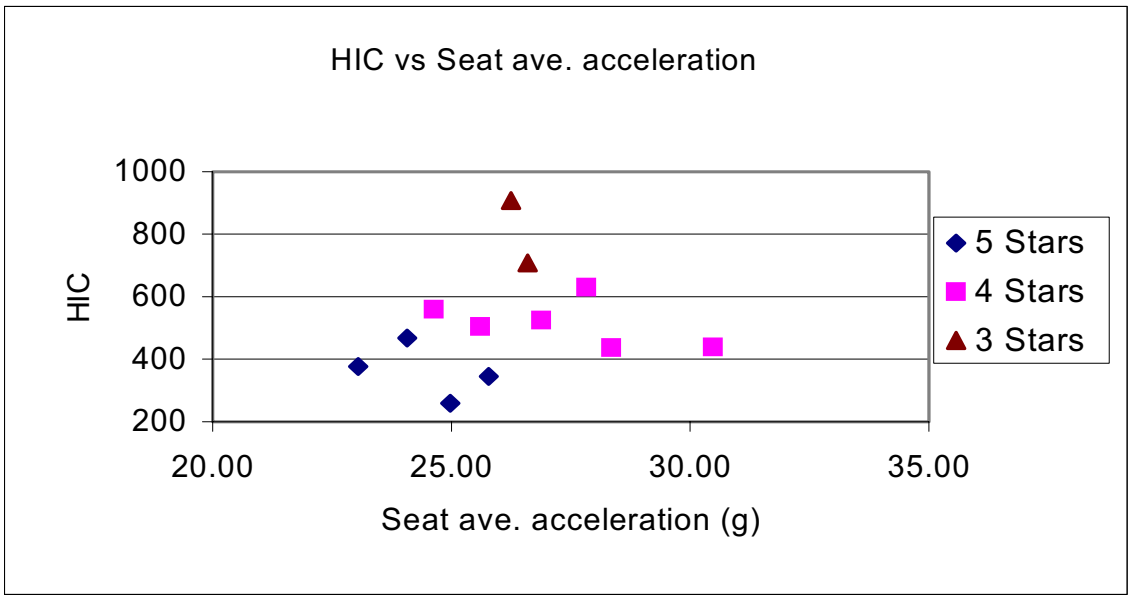


Figure 3.5: HIC vs. Seat Average Accelerations

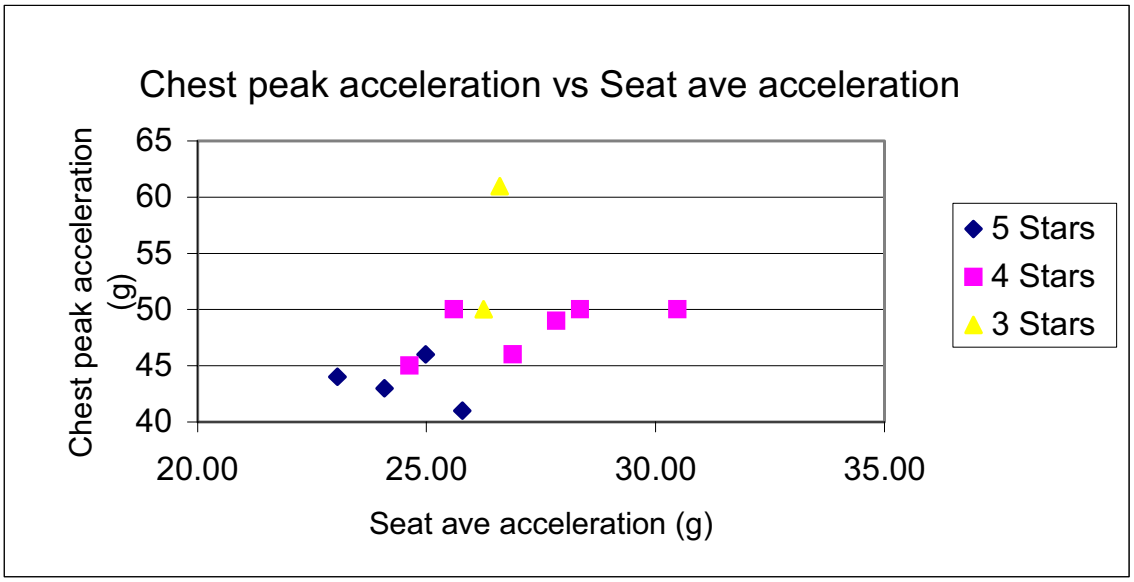


Figure 3.6: Chest Acceleration vs. Seat Average Accelerations

Correlation Studies

The coefficients of correlation gave a good indication of relationships of occupant parameters (HIC and chest acceleration) with vehicle accelerations (engine, brake caliper, dash, seat peak and seat average acceleration) as shown in Figures 3.7 and 3.8. All occupant parameters showed positive correlation with all vehicle accelerations (except for chest acceleration with seat peak acceleration, which yielded a small negative correlation). Occupant parameters showed the highest correlation with brake caliper acceleration. However, the brake caliper data was suspect and available for fewer vehicles. The correlation was much higher with seat average acceleration as compared to seat peak acceleration.

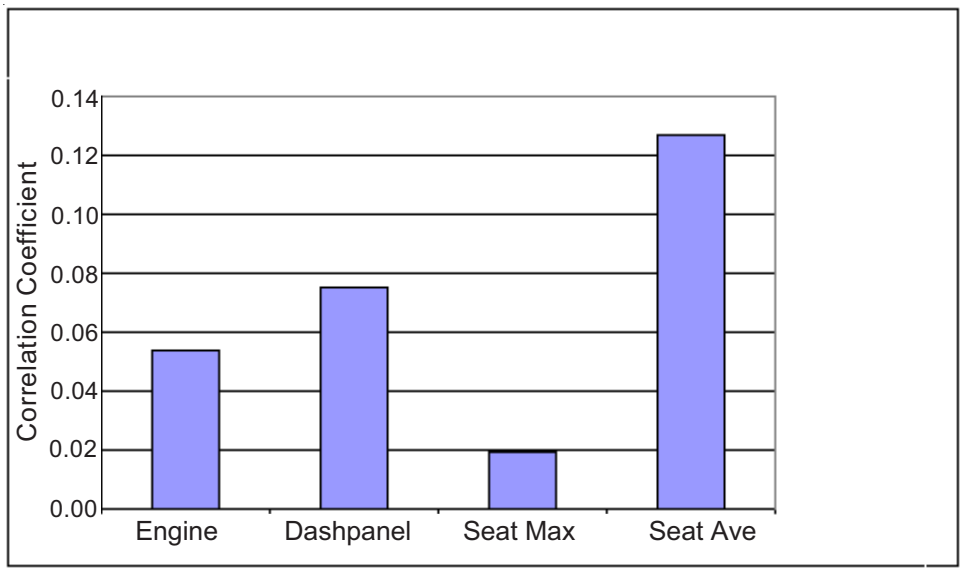


Figure 3.7: Correlation of HIC with Vehicle Accelerations

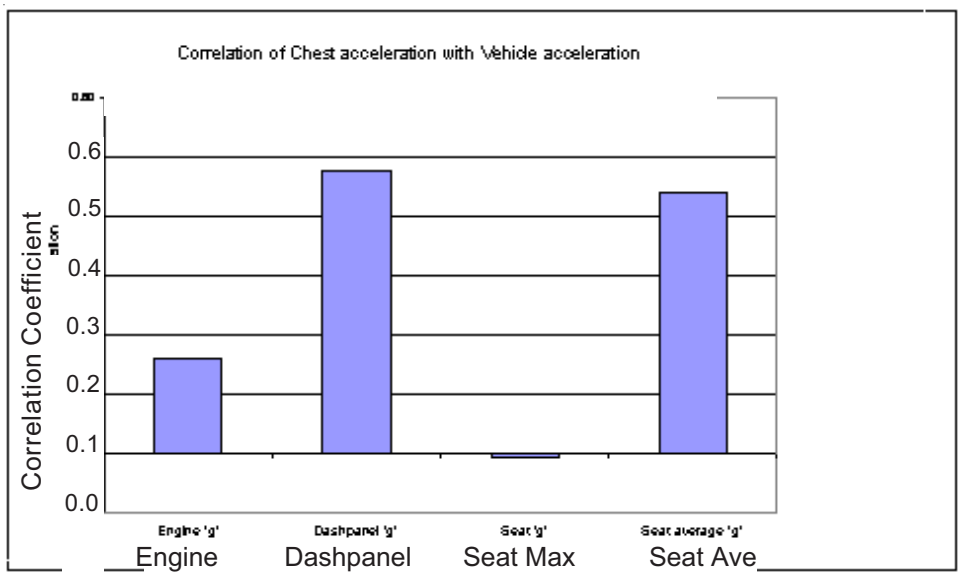


Figure 3.8: Correlation of Chest Acceleration with Vehicle Accelerations

Structural Targets

The review of the NCAP and IIHS offset crash data has lead to a set of structural performance targets that will provide a favorable environment for achieving a 'double 5-star' rating in NCAP and an 'overall good' rating in IIHS tests (Ref. 1).

It can be inferred from the test data that the strongest correlation of the occupant response was with the average seat acceleration (Figures 3.5-3.8). Consequently, the acceleration pulse at the B-Pillar was used to characterize the occupant response in 35mph full frontal NCAP test by OEMs, since the occupant experiences this acceleration (deceleration). In all the test data collected from NHTSA , the location of the accelerometer was either at the rear of the front seat near the rocker or at the center of the floor right behind the front seats. The responses at these locations are essentially the same as that at the B-Pillar on rocker.

Based on the OEM expert's input, a **target NCAP B-Pillar pulse** that ramps up to 26g within 8ms and stays below 26g, is presented in Figure 3.9. This target pulse, which was front-loaded in terms of achieving higher acceleration in the first 8ms, would ensure lower peak between 40ms and 80ms, which would reduce the occupant injury. The actual curve would have a number of peaks and valleys at various intervals depending on the front-end structural architecture, stiffness and energy absorption mechanism. The bumper deformation and initial rail crush would define the early phase of the B-Pillar pulse. The following phase is influenced by the rail and cradle design and energy absorption mechanism within the allowable crush space. The response in the final phase is influenced largely by the tire impact and A/B pillar stiffness.

It may be noted that even though the objective of the targets was to ensure 5-star and good rating for the baseline model, a more stringent upper limit on B–pillar pulse would lead to innovative structural concepts, material challenges and new manufacturing techniques.

The **maximum intrusion targets** for the **IIHS test** are shown in Figure 3.10. The target values for the left, center and right footwell are 12cm, 13cm, and 14cm respectively. In addition, there is a target of 5 cm for AB closure. The intrusion targets are simply the minimum intrusions observed in the IIHS test data. Other intrusion targets were not considered as the FE model did not have the desired details, such as brake pedal and steering column.

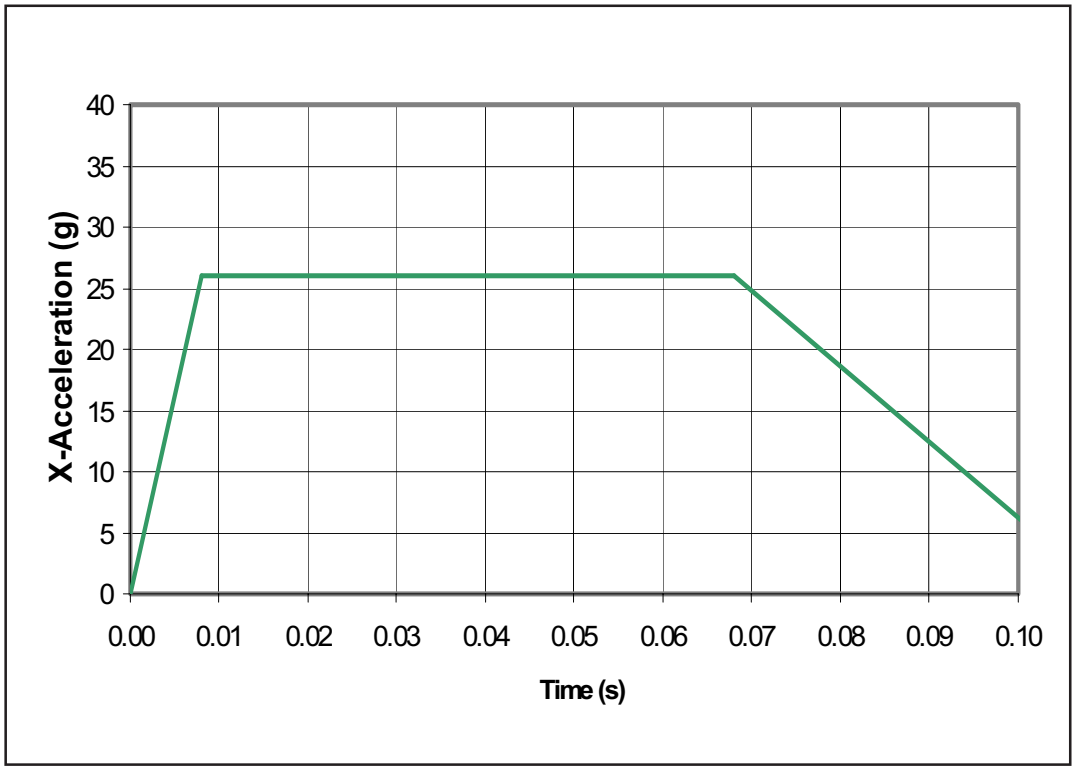


Figure 3.9: Target B-Pillar Pulse

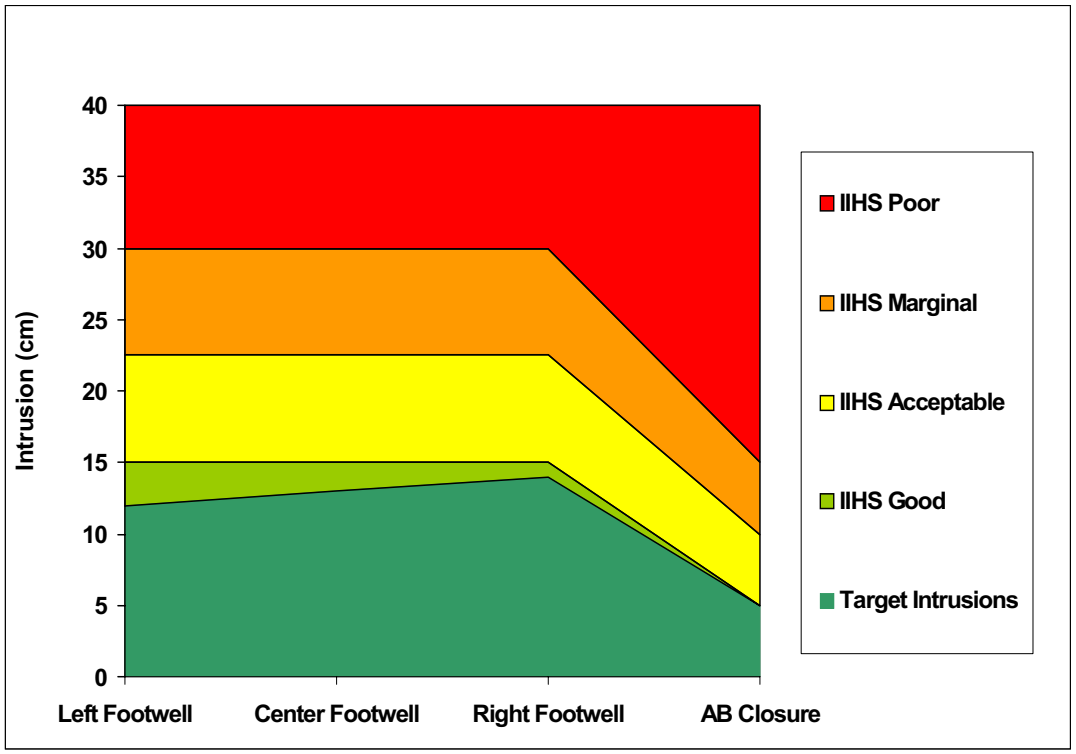


Figure 3.10: Target Maximum Intrusions for IIHS 'Good' Rating

Conclusions

This chapter established structural targets that would provide a favorable environment for achieving a 'double five-star' rating in NHTSA 35mph full frontal crash and an 'overall good' rating in IIHS 40mph 40 percent offset crash tests. A series of intermittent targets and the B-Pillar acceleration were derived from the test data of NCAP five star vehicles that were also 'best picks' in IIHS. The results of the study were used as targets and bounds for the parametric study and optimization of the front-end structure.

References

1) *Phase I Structural Performance Targets Report*.

2) Ingrid Planath-Skogamo and Richard Nilsson, *"Frontal Crash Tests – A Comparison of Methods*", SAE paper 942228.

3) Abbreviated Injury Scale 1985 revision, AAAM, Jeffrey Pike, SAE Seminar, *"Injuries, Anatomy, Biomechanics & Federal Regulations".*

4) Report No. NCAP-TRC-98-005, *"Flat Frontal Impact Barrier Test"*, 1998 Volvo S-70, TRC test no. 980219.

5) SAE standard J211

6) Ching-Yau Chan, *"Fundamentals of Crash Sensing Automotive Air Bag System"* .

Bumper Design

The goal of this part of the investigation was to develop a series of bumper designs for better bumper system energy absorption in high-speed collisions. This would reduce the energy absorption requirement on the rest of the front structure and hopefully reduce the overall mass and cost. Using a design criteria and approach, a parametric study of the bumper beam under low and high-speed impacts was undertaken. Four initial bumper designs were developed that had virtually no damage in low speed impacts, acceptable bumper damageability in moderate speed impacts and maximized energy absorption in high speed impacts.

Design Criteria

The preferred characteristics of the bumper system can be summarized as (Ref. 1):

- No bumper damage (no yield at 5mph).
- Does not intrude beyond the rail during 10mph crash with minimum damage to the rail and along with EA, absorbs all the energy.
- Does not induce lateral loads that will initiate lateral buckling of the rails.
- Collapses normally during Danner, NCAP and IIHS crash without inducing buckling of the rail.
- Absorbs 1% of total energy every millisecond.
- Absorbs 15% of total energy in NCAP crash including engine hit.
- Efficient use of crush space between bumper, EA and rails.
- Meets the air bag sensor requirements in low, medium and high-speed impacts.
- Reduced weight, compared to the existing baseline bumper system.
- Maintains current baseline static and dynamic stiffness.

Design Approach

The following load cases were considered in the analysis:

· 5mph (Flat Frontal) - In this load case the vehicle was impacted against a rigid wall at 5mph. The criteria was to have no yield in the bumper system in this load case. The criterion was to have minimum yield (< 2 %) in the bumper system for this load case.

· 35mph (NCAP) - In this load case the vehicle was impacted against a rigid wall at 35mph. The objective was to maximize the energy absorption in the bumper system.

· 10mph (Danner) - In this load case the vehicle was impacted against a rigid barrier as per Danner criteria, with a 40 % offset. The objective was to have no damage to the radiator and other costly equipments in the front and minimum/no damage to the rail.

- 40/40mph (IIHS) - In this load case the vehicle was impacted against a deformable barrier as per IIHS criteria, with a 40% offset. The objective in this load case was to ensure that the bumper system did not break and that it should be capable of transferring the load to the right rail, there by minimizing the damage.

Performance Summary

The Bumper 3 design (Ref. 4) has the best performance characteristics out of all the bumper systems. It achieves a very high initial peak of 23g and results in an NCAP B-pillar acceleration pulse that is very close to the target pulse established for the lightweighting project. The Bumper 4 design (Ref. 5) is a variation of the Bumper 3 design, adapted to the upgraded powertrain package. Although the baseline upgraded powertrain model with Bumper 4 has an initial peak lower than the one for Bumper 3, the final optimized design of the upgraded powertrain model possesses an initial peak that higher than one for the Bumper 3 design.

The Bumper 2 design (Ref. 3) performs better than Bumper 1 design (Ref. 2). However, it requires a careful tuning of the thickness of the energy absorber components. The Original ULSAB Bumper design fails to meet the Danner criterion.

The bumper design characteristics are summarized in Tables 4.1 and 4.2. A brief description of the bumper designs is included in the following sections, and details may be obtained from Ref. 1-6.

bumper rail joint.

Case	Bumper Beam (Kg)	EA (Kg)	Total (Kg)	% Energy Absorbed NCAP*	NCAP B-Pillar Pulse (g)	
					Initial	Peak
ULSAB	13.6	0.8	14.4	11.8	14.0 (16.0)*	30.3
First Bumper	11.1	2.9	14.0	15.8	11.4 (10.0)*	29.9
Second Bumper	6.5	1.9	8.4	14.7	15.3 (14.2)*	28.3
Third Bumper DP 500/800 Rails	7.6	-	7.6	13.8	23.3 (23.5)*	28.5
Fourth Bumper DP 500/800 Rails Upgraded Powertrain	8.4	-	8.4	14.4	17.4 (17.5)*	29.9

- With respect to total vehicle energy

* -RH value

Table 4.1: Comparison of Bumper Systems

Location	Target Intrusions (cm)	ULSAB Bumper (cm)	First Bumper Design (cm)	Second Bumper Design (cm)	Third Bumper Design (cm)	Fourth Bumper Design* (cm)
Footwell - Left	12	14.9	15.6	17.2	13.7	24.9
Footwell - Center	14	11.9	12.3	12.2	10.8	20.4
Footwell - Right	13	9.3	9.3	9.3	7.8	15.8

* with upgraded powertrain

Table 4.2: Comparison of IIHS Intrusions

Cost Summary

Bumper 3 and **Bumper 4** designs are the **simplest** of all the designs, requiring minimum assembly. Consequently, their **unit price** is the **lowest** of all the bumper systems (Ref. 6). They do have the highest tooling cost due to the presence of the energy absorbing tear drop features. These designs are also the **most efficient** in enhancing the performance of the front-end structure in high-speed crashes.

Bumper 1 design is the **most complex** of all the designs, requiring significant assembly. There is also a high cost associated with the aluminum-honeycomb energy absorber. Consequently, its **unit price** is the **highest** of all the bumper systems. Furthermore, this design is not as efficient as Bumper 3 in high-speed crashes.

Bumper 2 and the **Original ULSAB Bumper** designs have a **unit price** that is **slightly higher** than that of **Bumper 3**, and have a lower tooling cost. However, these designs are not as efficient as Bumper 3 in high-speed crashes. In addition, the Original ULSAB Bumper fails to meet the Danner test.

The bumper costs are summarized in Table 4.3. The assumptions used to derive the bumper costs are listed below.

Bumper	Tooling Cost	Unit Cost
Original ULSAB	$780,000	$80
First Bumper	$950,000	$145
Second Bumper	$780,000	$85
Third Bumper	$1,150,000	$78
Fourth Bumper	$1,150,000	$78

Table 4.3: Comparison of Bumper Costs

Original ULSAB Bumper Design

The original ULSAB bumper design consists of a bumper beam with end plates for the attachment of an energy absorber. The energy absorber is simply an extension of the front lower rails. This bumper was not designed for high-speed impact and does not pass the Danner test. The original ULSAB bumper serves as a baseline for comparison with the bumper designs developed during the course of the front-end project.

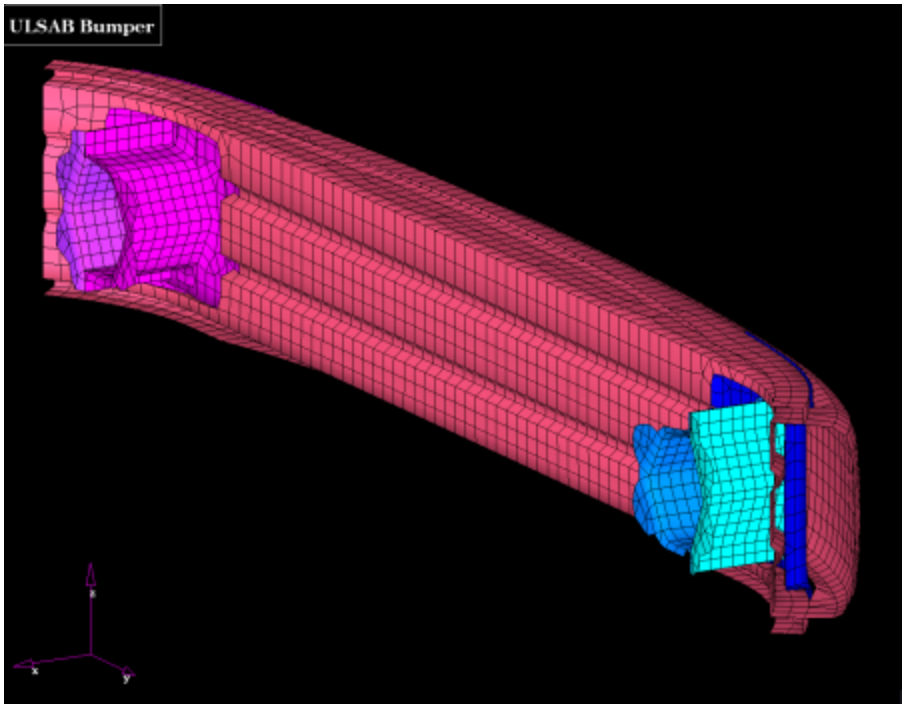


Figure 4.1: Original ULSAB Bumper

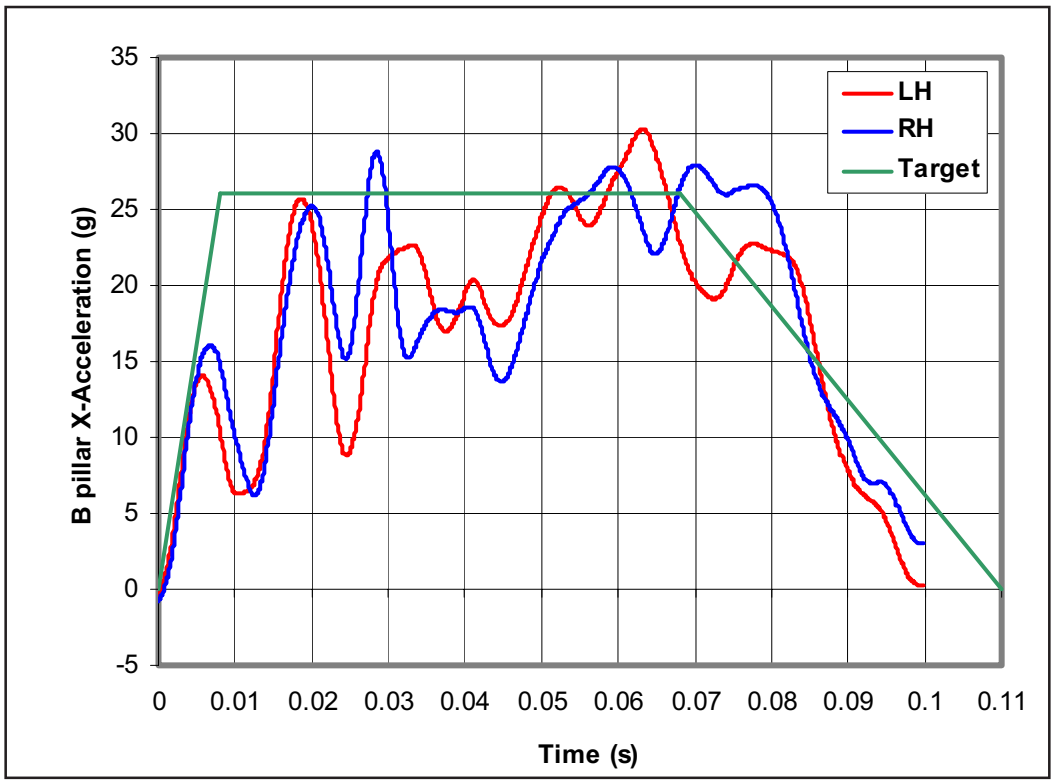


Figure 4.2: B-Pillar Pulse - Original ULSAB Bumper

S. N.	Component	Thickness (mm)	Material
1.	Bumper Beam	2.5	HSLA 350/450
2.	Bumper End Plates	2.0	HSLA 350/450
3.	EA - Outboard	1.8	HSLA 350/450
4.	EA - Inboard	1.8	HSLA 280/600
5.	Foam	130	Expanded Polypropylene Bead Foam

Table 4.4: Grade/Gauge - Original ULSAB Bumper

First Bumper Design

The first bumper system included an energy absorber and a bumper reinforcement beam (Ref. 2). The first bumper design **met the design criteria** arrived at in the *first* study, and also satisfied some additional requirements. Thus, it was a **feasible** bumper system that could be used for future parametric study and optimization of the baseline front-end structure.

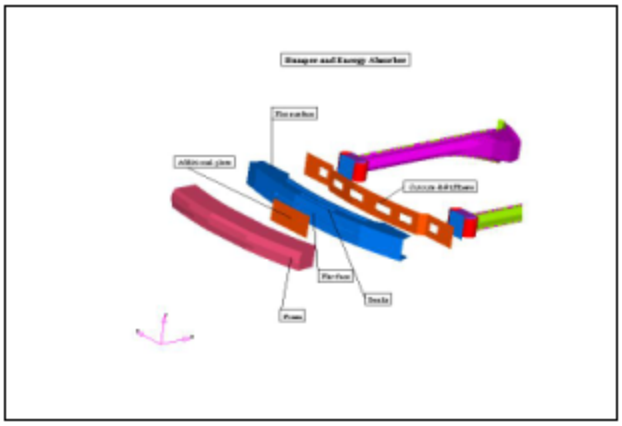


Figure 4.3: First Bumper Design - Exploded View

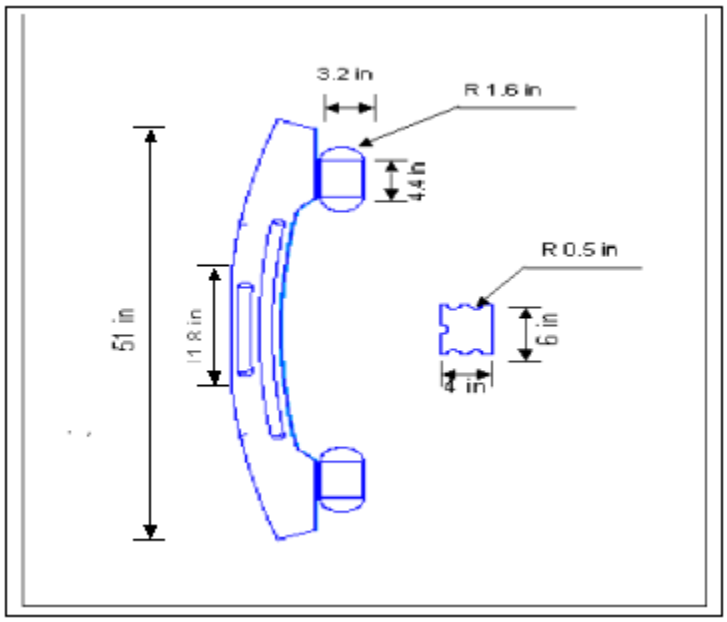


Figure 4.4: First Bumper Design Dimensions

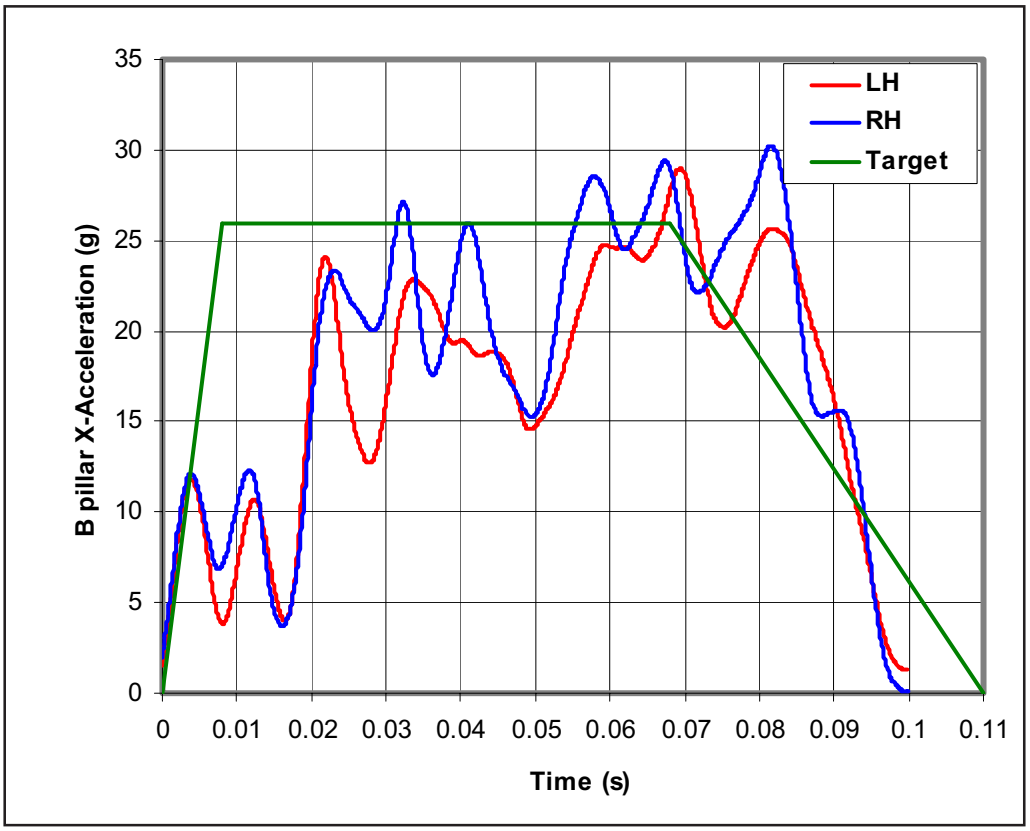


Figure 4.5: B-Pillar Pulse - First Bumper Design

Design Features

The proposed bumper system (Fig. 3) consisted of a high strength steel channel section and an ultra high strength steel back plate. An ultra high strength steel plate was welded at the front center of the beam for better load distribution in pole impact. The front of the bumper had a 3.7pcf expanded polypropylene bead foam. The energy absorber (EA) consisted of an aluminum honeycomb core absorber enclosed in a high strength steel elliptical shell. The elliptical steel cage maintained the load axial to the rail even at 0-30 angle corner impacts. The major dimensions of the bumper system are illustrated in figure 4.4. The bumper beam weighed 11.1kg and the EA weighed 2.9kg.

Beam Section

Based on the *Phase 1* studies (35mph impact energy absorption), a box section was chosen as the preferred shape of the bumper. The interface of the reinforcing beam with the EA was designed to become normal to the EA to ensure that the loading to the EA and rail were axial. The box section of high strength steel (53ksi) showed large intrusions in the Danner load case (Table 4.6) whereas the section with ultra high strength steel required rails with very large load carrying capacity in order to be efficient in energy absorption. This led to the use of two materials for the bumper; the front channel of 53ksi material and back plate of ultra high strength material (186ksi). The UHSS back plate, which was nearly flat, supported the channel section so that the channel crushed efficiently in high speed impact. The near flat back plate will not have any formability problems associated with UHSS.

	Description	Thickness (mm)	Material
1.	Bumper Front C Section	2.0	53 ksi
2.	Bumper C- Back	2.0	186 ksi (M-190)
3.	Bumper Front Addl. Plate	2.0	186 ksi (M-190)
4.	EA - Shell	2.5	186 ksi (M-190)
5.	EA - Honey Case	0.8	Mild Steel
6.	Foam	130	Expanded Polypropylene Bead Foam
7.	Honeycomb - EA	80.0	Aluminum

Table 4.5: Grade/Gauge - First Bumper Design

Beads were introduced in the front, top and bottom faces of the bumper to avoid initial local buckling of the bumper faces.

The beam, which had a large sweep, was made flat at the front in order to distribute the load and avoid local buckling in low velocity impacts.

An additional plate in the front of the bumper substantially reduced the deformation in the case of pole impact.

Later, cutouts were introduced in the back plate of the bumper to optimize the weight and enhance the accessibility inside the bumper. ·

Energy Absorber

The energy absorber was designed to maximize energy absorption and minimize lateral load transfer to the rails. To arrive at the above objective several shapes were considered for the design of the energy absorber. Most of the energy absorbers currently in use required perfect axial loading to be effective and fail under any lateral loads. The high strength steel elliptical shell of the EA ensured the load transfer was normal to the honeycomb. The honeycomb, which was modeled as a solid block, would not undergo any lateral buckling.

Bumper Material	Bumper Intrusion* (mm)
Mild Steel	209.0
53 ksi	182.0
Mild Steel & 186 ksi (back)	172.0
53 ksi &186 ksi (back)	139.0

Table 4.6: Danner Intrusions - First Bumper Design

Bumper System Attachment

The assembly of the bumper system developed required three sub-assembly processes

1. Two piece reinforcing beam that had to be welded along the top and bottom flanges.

2. The honeycomb core covering case was welded to the elliptical shell on three surfaces and then the core was inserted with adhesive on the front and rear surfaces. The core was closed with a cover plate and completely sealed.

3. The energy absorber was then attached to the bumper beam through pre-sunk fasteners.

4. The bumper sub-system was then attached to the rails through four bolts pre-sunk in the rail flanges.

5. The high strength pre sunk nuts and studs into the pre-finished sheet metal provided the required joint efficiency at the bumper rail joint.

The bolted bumper system can be easily replaced following Danner type of damage.

SR. No.	Material	Young's Modulus (N/mm^2)	Poisson's Ratio	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)
1.	53 ksi	210000	0.3	367.8	536.0
2.	M-190	210000	0.3	1286.0	1622.0
3.	Mild	210000	0.3	210.0	527.0
4.	Foam	10.5	0.1	0.70	-
5.	Honeycomb (fully compressed)	70000.0	0.3	210.0	-

Table 4.7: Material Properties - First Bumper Design

Second Bumper Design

The second bumper system also included a bumper reinforcement beam and an energy absorber (Ref. 3). This alternate bumper system was lighter in weight, shorter in overhang and more homogeneous compared to the first bumper design. The energy absorber design was based on the principle of energy absorption by extrusion (roll-up), and not by axial folding. This type of energy absorber could be tuned to suite the rail strength. The thickness of the foam in the front was also reduced considerably compared to the first bumper design, in order to reduce the overhang.

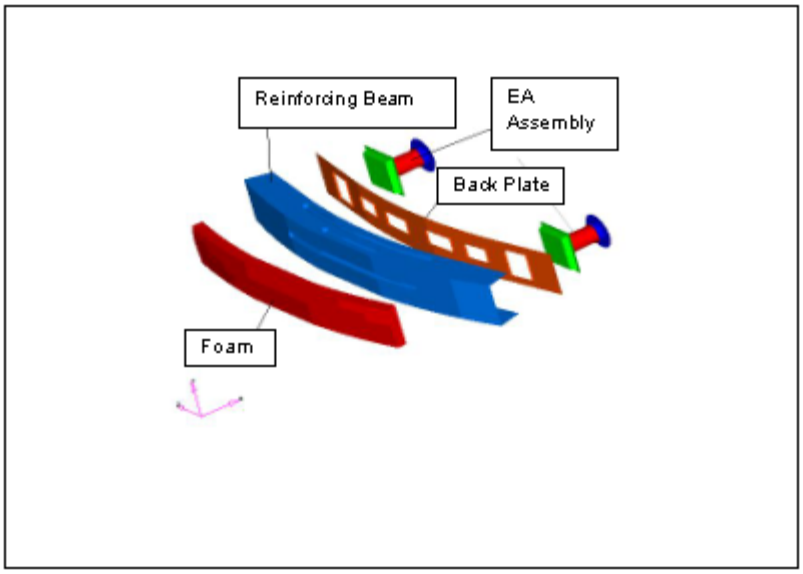


Figure 4.6: Second Bumper Design - Exploded View

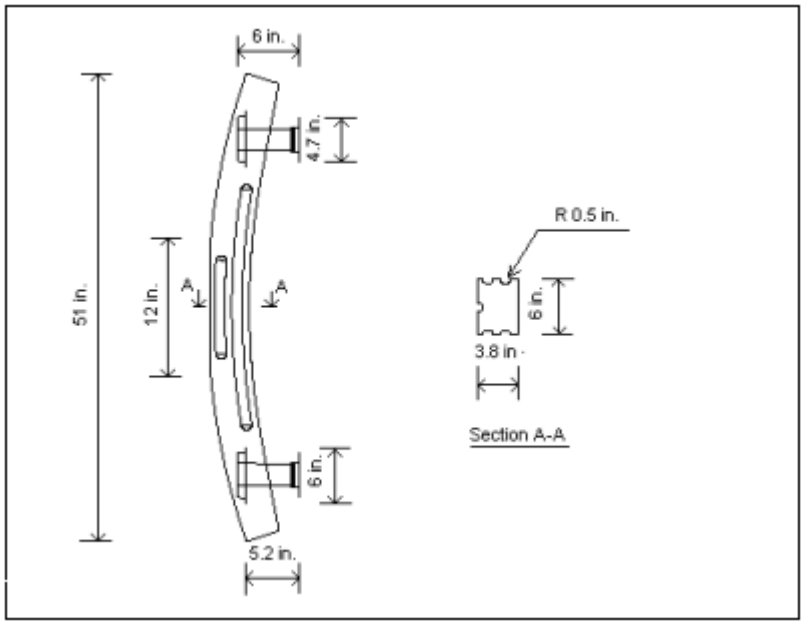


Figure 4.7: Second Bumper Design Dimensions

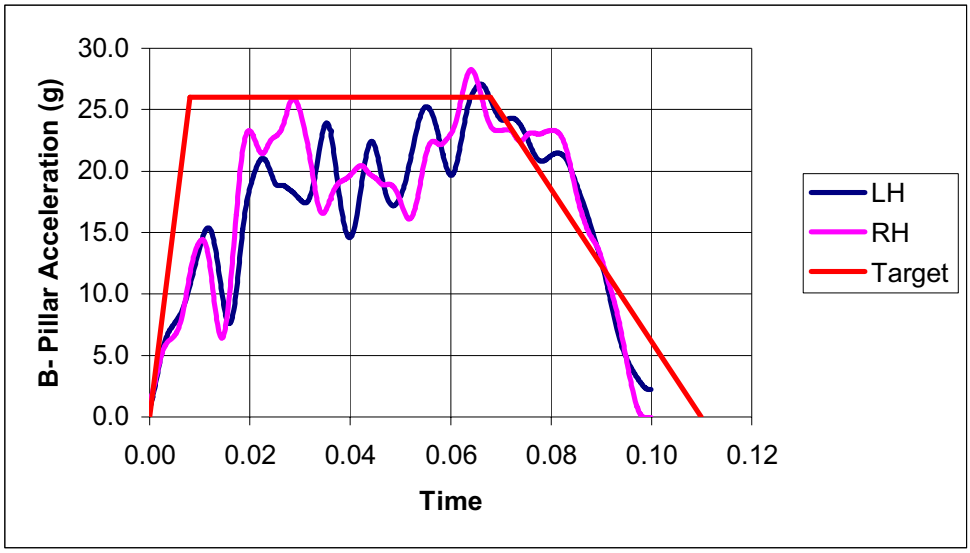


Figure 4.8: B-Pillar Pulse - Second Bumper Design

Design Features

The proposed bumper system (Fig. 6) consisted of an ultra high strength steel channel section and a back plate. The front of the bumper has 3.7pcf expanded polypropylene bead foam. The energy absorber (EA) consisted of high strength material roll-up tube with a ring, which connected to the rail. The ring transferred the load uniformly to the tube from the rail. The tube was connected to the rail-reinforcing beam through an ultra high strength plate in the middle of the reinforcing beam. Major bumper dimensions were given in Fig. 7. The bumper beam weighed 6.5kg and the EA weighed 1.9kg. The overhang in this design was 143mm less compared to the first bumper design.

Beam Section

Based on the feed back of the first bumper system design, ultra high strength material, namely the DF-140T was selected as the bumper beam material. The beam was composed of a single sweep for easy manufacturability.

Component	Material	Gauge (mm)
C - Section	DF - 140 T	1.3
Back Plate	DF - 140 T	1.3
EA Front Plate	DF - 140 T	2.0
EA Tapered Tube	53 Ksi	1.5
EA Ring	53 Ksi	1.5

Table 4.8: Grade/Gauge - Second Bumper Design

S.N.	Material	Young's Modulus (N/mm^2)	Poisson's Ratio	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)
1.	53 ksi	210000	0.3	350.0	672.3
2.	DF - 140 T	210000	0.3	995.0	1470.0
4.	Foam	10.5	0.1	0.70	-

*Post bake properties

Table 4.9: Material Properties - Second Bumper Design

Beads were introduced on the front, top and bottom faces of the bumper to avoid initial local buckling of the bumper faces. The beam, which had a large sweep, was made flat at the front in order to distribute the load and avoid local buckling in low velocity impacts.

Cutouts were introduced in the back plate of the bumper to optimize the weight and enhance the accessibility inside the bumper. Two additional large cutouts were also introduced to accommodate the energy absorber.

The details of the reinforcing beam are included in Table 4.8.

Energy Absorber

The energy absorber was designed to maximize energy absorption and minimize lateral load transfer to the rails. The energy absorber consisted of three components; front plate, a tapered tube (roll–up tube) and a ring. The interface of the energy absorber with the reinforcing beam was designed in such a way that the loading to the EA was mainly axial. The shape and thickness of the tube was arrived at after a series of simulations to ensure that the tube absorbed energy by roll-up, and not by axial collapse. The section of the tube with the smaller diameter rolled up into the one with the larger cross section without tearing. A relatively larger force was required to initiate the roll-up, after which the force dropped down to a constant level. Using this principle, relatively large deformations could be attained, resulting in a higher absorption of energy. The ring at the end of the tube was added to ensure uniform loading to the tube from the rail. The details of the EA are given in Table 4.8.

Bumper System Attachment

The assembly of the bumper system developed required two sub-assembly processes

1. The two-piece reinforcing beam had to be welded along the top and bottom flanges.
2. The tapered EA tube had to be welded with the ring and front plate.
3. This assembly was then welded to the reinforcing beam.
4. The bumper sub-system was then attached to the rails through four bolts pre-sunk in the rail flanges.
5. The high strength pre-sunk nuts and studs into the pre-finished sheet metal provided the required joint efficiency at the bumper rail joint.

The bolted bumper system could be easily replaced following Danner-type of damage.

Third Bumper Design

The third bumper design was unique compared to the previous designs, in that it did not have a separate energy absorber (Ref. 4). This alternate bumper system was lighter in weight, shorter in overhang, easier to manufacture and more homogeneous compared to the previous bumper designs. This report also discusses the need for upgrading the existing rails so as to meet the target requirements. The design configuration arrived at met almost all the targets set in Phase 1.

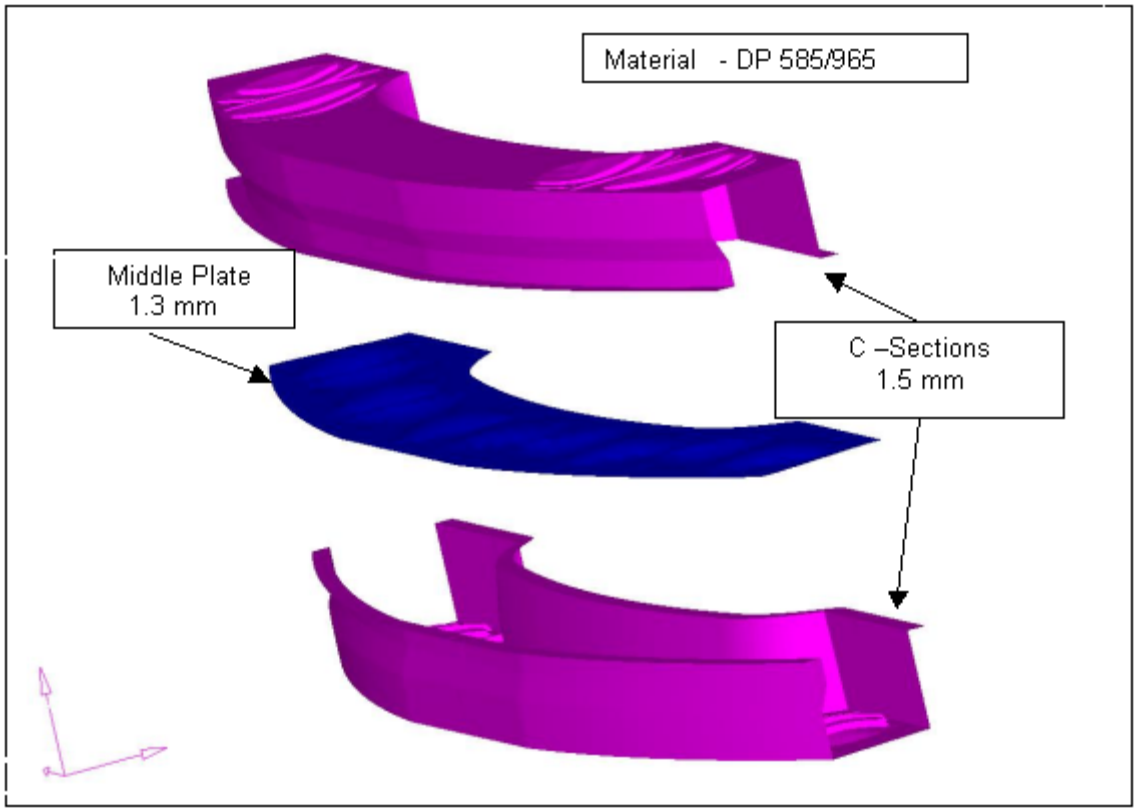


Figure 4.9: Third Bumper Design - Exploded View

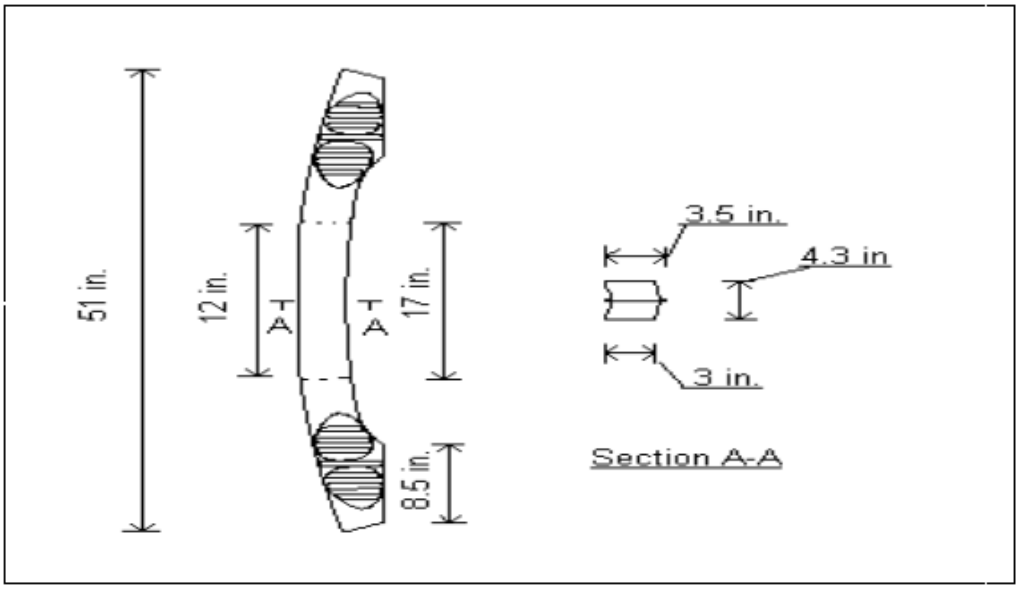


Figure 4.10: Third Bumper Design Dimensions

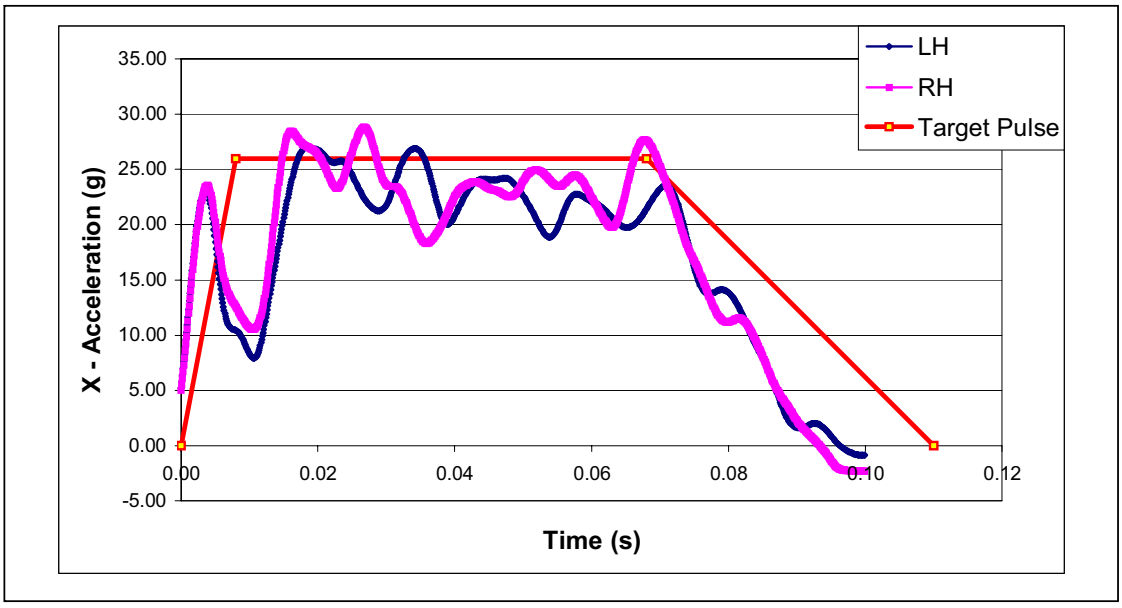


Figure 4.11: B-Pillar Pulse - Third Bumper Design

Design Features

The proposed bumper system (Fig. 9) consisted of three parts: upper and lower channel sections, and a middle plate. The channel sections were corrugated near the interface with the rails, in order to act as an energy absorber. The middle plate was also corrugated to increase the bending stiffness. Various topological changes, with and without tailor blanking, were studied before arriving at this final design.

This type of bumper systems (with no separate energy absorbers) had to be specially designed to absorb energy, especially in Danner, without intruding into the engine compartment. The studies showed that the existing rails needed to be strengthened in order to support this design of bumper systems and avoid damage to the rail and prevent intrusion into the engine compartment.

Another design criterion that was considered was to increase the initial B-Pillar pulse to the target value. The initial peak in the B-Pillar pulse was very much dependent on the bumper system design. Although the target initial B-Pillar pulse was to achieve 26g in 8ms, the initial B- Pillar pulse did not exceed 15.3g in all the previous designs. Hence the bumper system design was modified along with the rails in order to achieve the desired initial B-Pillar pulse. A detailed study of rails and bumper system showed that there was a need to upgrade the rail strength from the existing 350MPa to a 500MPa material, so as to achieve the target initial B-Pillar pulse. The IIHS simulation showed that the intrusions in this load case were found to be almost within the target limits. Only the left footwell intrusion was over the target by 1.7cm.

Component	Material	Gauge (mm)
C - Section	DP 585/965	1.5
Middle Plate	DP 585/965	1.3
Rails	DP 500/700	Same as in Original ULSAB

Tab;e 4.10: Grade/Gauge - Third Bumper Design and Rails

	Part	Material	Young's Modulus (N/mm^2)	Poisson's Ratio	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)
1.	Front Rails	DP 500/800	210000	0.3	500.0	800.0
2.	Bumper Beam	DP 585 / 965 Post Bake	210000	0.3	995.0*	1470.0
3.	Bumper Foam	Foam	10.6	0.1	0.84	-

Tab;e 4.11: Material Properties - Third Bumper Design and Rails

Major bumper dimensions are given in Fig. 2. The bumper beam weighed 7.6kg, which was almost half of the original baseline bumper system. The overhang (distance from the front of the rail to the front of bumper) in this design was 131mm compared to 180mm in the baseline model.

Design Approach

A summary of how the final design was arrived at is given in the following section.

Beam Section

The beam section properties including geometry and gauge were arrived at after a series of parametric studies involving all load cases. Initially tailor welded C-sections were considered in the design. Based on the feedback from the OEMs, the use of tailor blanking was discontinued. The present design did not have any tail-blanked components, there by reducing cost. The corrugations in the middle plate were needed to increase the bending stiffness. Laser welding was assumed in the design.

The details of the reinforcing beam are given in Table 4.10.

Rails

Parametric study of the rails showed that the rail strength needed to be increased. The study was focused on changing the material rather than gauge or geometry so as to keep the existing baseline architecture undisturbed. Results showed that front rails with a material of yield strength of 500 MPa (Table 4.11) used in conjunction with the proposed bumper system design meets all the requirements.

Bumper System Attachment

A rigid plate connected the reinforcing beam to the rails through a four-bolt connection. In the baseline architecture, the radiator clout, which extends to the front of the rails, had been modified to provide the required rigidity to the connection.

The assembly of the bumper system developed was a two-step process,

1. The two C–sections and the middle plate are laser welded.

2. The bumper sub-system is then attached to the rails through four bolts pre-sunk in the rail flanges.

3. The high strength pre-sunk nuts and studs into the pre-finished sheet metal will provide the required joint efficiency at the bumper rail joint.

The bolted bumper system can be easily replaced following Danner-type of damage.

Fourth Bumper Design

The fourth bumper design was used for the upgraded engine package (Ref. 5). This design is basically a modification of the third bumper design, in order to adapt it to the upgraded engine package. The bumper beam weighs 8.4kg, which is 5.2kg less than the Original ULSAB Bumper system. The overhang in this design is 164mm compared to 180mm in ULSAB. The Bumper 4 design is essentially the same as the Bumper 3 design. Hence,

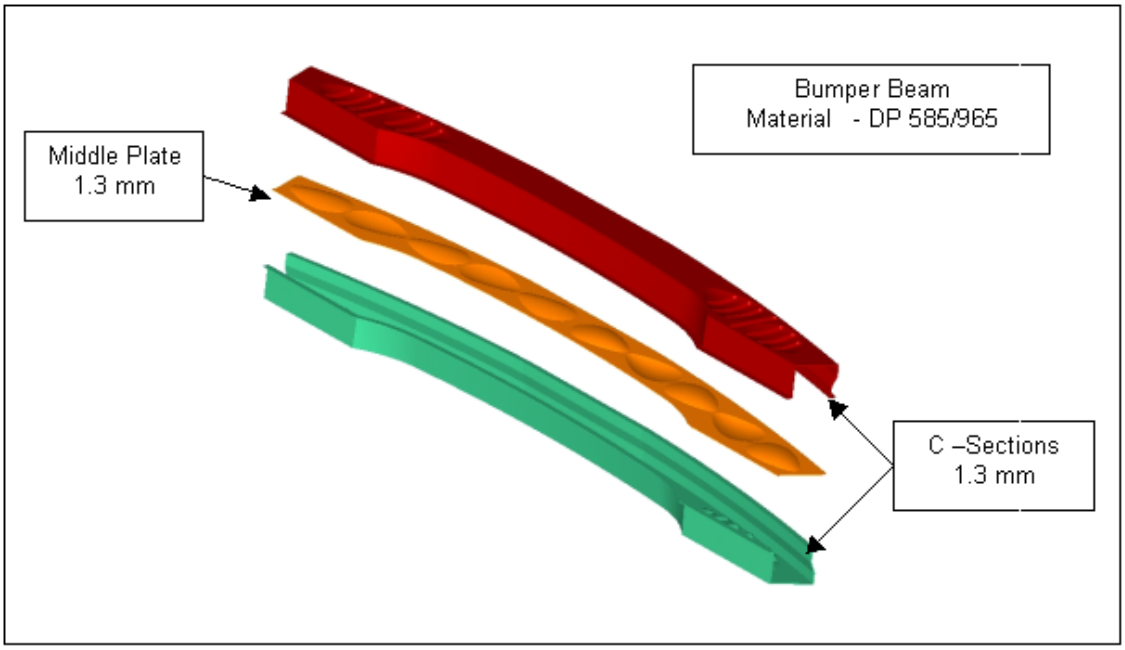


Figure 4.12: Fourth Bumper Design - Exploded View

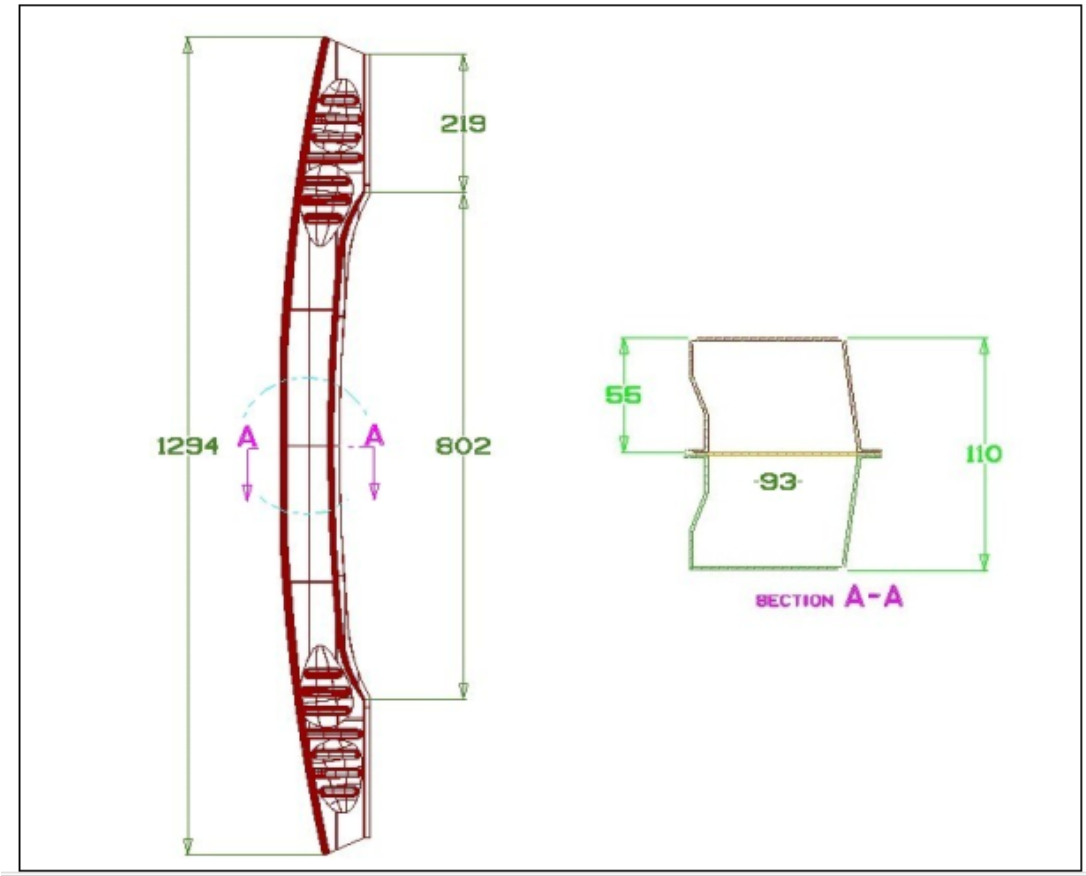


Figure 4.13: Fourth Bumper Design Dimensions (Millimeters)

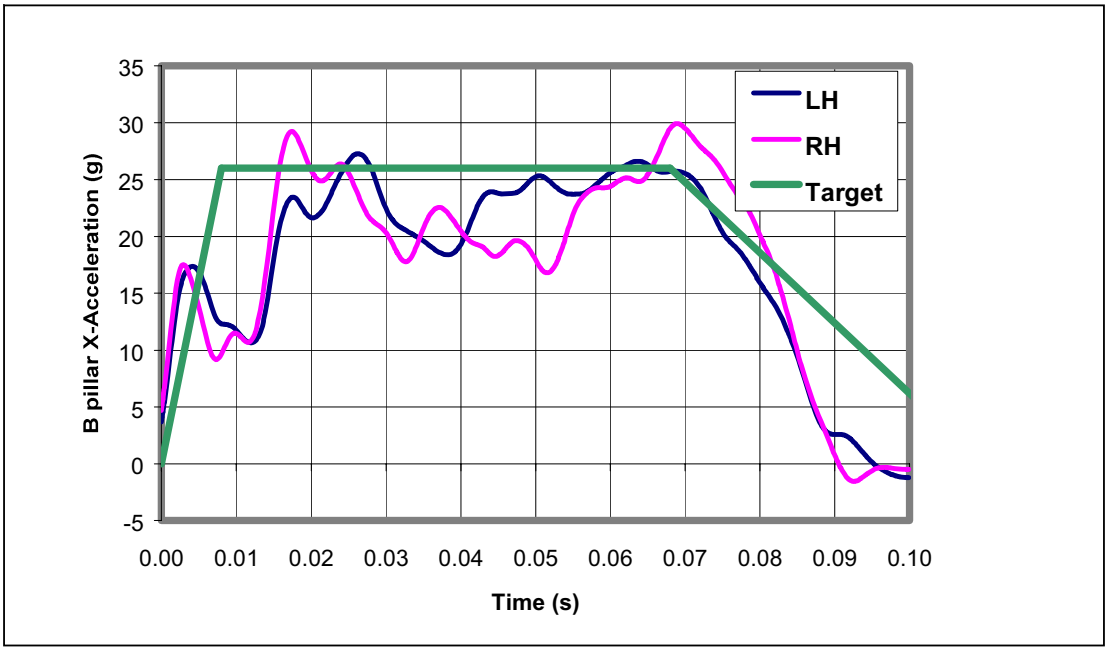


Figure 4.14: NCAP B-Pillar Pulse - Fourth Bumper Design

the cost and manufacturing issues of Bumper 4 are the same as that of Bumper 3 design.

Design Features

The proposed bumper system (Fig. 12) consisted of three parts: upper and lower channel sections, and a middle plate similar to Bumper 3 design (Ref. 4). The channel sections were corrugated near the interface with the rails, in order to act as an energy absorber. The middle plate was also corrugated to increase the bending stiffness. This type of bumper system (with no separate energy absorbers) had to be specially designed to absorb energy, especially in Danner, without intruding into the engine compartment.

Initial studies with the topological changes in the rail with the upgraded powertrain showed the need for increased cross sectional area in the front portion of the rails. This was primarily needed on the left rail due to the bump in the x-z plane due to the transaxle. However in order to maintain similar interface with the bumper, the right rail front was also modified. A series of designs were tried with different types of stiffeners/gauge/ topological changes to ensure axial collapse of the rails.

The major changes in the fourth bumper design compared to the third bumper design were:

- Height increase (109 mm to 140 mm)
- Width increase (89 mm to 109 mm)
- Introduction of new beads in the middle
- Reduction in bumper beam C-section gauge (1.5 mm to 1.3 mm)

The major bumper dimensions are given in Fig. 13. The bumper beam weighed 8.4kg, which was 5.2kg less than the original baseline bumper system. The overhang (distance from the front of the rail to the front of bumper, not considering the foam) in this design was 164mm compared to 180mm in the Baseline model.

There was an increase in mass by 0.8kg, as compared to the third bumper design. This was due to the increase in the height and width of the bumper beam, which offsets the reduction in gauge. The increase in height and width increased the percentage of energy absorption by the bumper system from 13.8% to 14.4%. The increase in height was also necessary in order to provide suitable attachment for the modified front rails, as the front and middle sections of the front rails had to be moved upwards due to the bump

in the x-z plane (caused by the transaxle). The performance in NCAP increased significantly as a result of the changes in the bumper beam dimensions.

The bumper beam material was the same as that for the third bumper design - DP 585/965 Post Bake. This material was found to be quite effective in increasing the energy absorption by the bumper system, due to the large area under its stress-strain curve.

Design Approach

Beam Section

The beam section properties including geometry and gauge were arrived at after a series of parametric studies involving all load cases. The present design did not have any tail-blanked components, there by reducing cost. Laser welding was assumed in the design.

The details of the bumper beam are given in Tables 4.12-4.14.

Rails

Component	Material	Gauge (mm)
C - Section	DP 585/965 Post Bake	1.3
Middle Plate	DP 585/965 Post Bake	1.3

Table 4.12: Grade/Gauge - Fourth Bumper Design

Component	Material	Gauge (mm)
Front, Mid Rear Sections	AVC DP 500/800	1.5, 1.8, 2.0

Table 4.13: Grade/Gauge - Rails

	Part	Material	Young's Modulus (N/mm^2)	Poisson's Ratio	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)
1.	Front Rails	DP 500/800	210000	0.3	500.0	800.0
2.	Bumper Beam	DP 585 / 965 Post Bake	210000	0.3	995.0*	1470.0
3.	Bumper Foam	Foam	10.6	0.1	0.84	-

*Post bake properties

Table 4.14: Material Properties

As mentioned earlier, the cross section of the rails in the front was increased in order to support a larger bumper. The rail material was DP 500/800.

Bumper System Attachment

A rigid plate connected the bumper beam to the rails through a four-bolt connection. In the baseline architecture, the reinforcement radiator closeout, which extended to the front of the rails, had been modified to provide the required rigidity to the connection.

The assembly of the bumper system developed was a two-step process,

1. The two C–sections and the middle plate are laser welded.

2. The bumper sub-system is then attached to the rails through four bolts pre-assembled in the rail flanges.

3. The high strength pre-assembled nuts and studs into the pre-finished sheet metal will provide the required joint efficiency at the

The bolted bumper system can be easily replaced following Danner-type of damage.

Conclusion

The first and second bumper designs satisfied all the required load cases in performance. They met the design criteria and also satisfied some additional requirements. However, the third bumper design surpassed the other two bumper designs in performance and is cheaper to manufacture. It is therefore the preferred bumper design to be used on the ULSAB. The fourth bumper design is basically the third bumper design adapted to the upgraded front end package.

First Bumper Design

The combined use of HSS and UHSS steel was found to be very efficient in energy absorption and in minimizing the intrusions for the Danner load case. The bumper beam, which had a sweep of 43, was flattened in the front to prevent local initial buckling. The beads on the top and bottom faces provided the adequate stiffness to these surfaces and helped in the gradual crushing of the bumper. This increased the energy absorption by the bumper. The bumper beam had an extended interface at the EA mounting locations to ensure axial loading of the rails. Cutouts in the back plate were introduced in order to reduce mass and provide accessibility.

The new concept energy absorber, which consisted of an aluminum honeycomb core enclosed in a high strength steel shell, ensured that the load transfer was axial to the rails, even in case of an angular impact.

A static and dynamic stiffness of the baseline model with the first bumper system were higher than with the existing bumper system. Thus, the new design was stiffer than the existing bumper system. In addition, the new bumper system had a lower weight than the existing bumper system.

Second Bumper Design

The use of UHSS steel was found to be very efficient in minimizing the mass, intrusions in the Danner load case and maximizing the energy absorption. The bumper beam, which had a single sweep, was flattened in the front to prevent local initial buckling. The beads on the front, top and bottom faces provided adequate stiffness to these surfaces and helped in the gradual crushing of the bumper. Cutouts in the back plate were introduced in order to reduce mass and provide accessibility.

The new energy absorber design, which consists of a tapered tube,

efficiently absorbed energy especially in the Danner load case. The EA connection to the reinforcing beam being perpendicular to the rail ensured the load transfer was axial to the rails and hence reduced the chance of rail bending. The ring helped transfer the load from the rail uniformly to the tube.

Although the initial peak in the B- pillar pulse in NCAP simulation had gone up compared to the first bumper design, there was still scope for design changes to the bumper systems to take this peak even higher. By achieving a high initial peak, the global peak will be reduced. However this can only be achieved by employing rails of higher load carrying capacity than the existing rails. Hence modifications to the current design are possible only after the rail design is finalized. The current global peak value of 28g is above the target value by 2g. The intrusions in the 40/40 IIHS load case were higher than the targets. The intrusions also were reduced with a stiffer design of rails.

Third Bumper Design

This alternate bumper system was lighter in weight, shorter in overhang, easy to manufacture and more homogeneous compared to the previous bumper designs. Without a separate energy absorber, this system was very easy to assemble and integrate with the rails. Another advantage of this bumper system was that it could be easily tuned for various rail strengths.

The existing structure integrated with the third bumper system together with the modified rails meets almost all the requirements arrived at in Phase 1. The initial peak of 24g at 5ms in NCAP simulation is more aggressive than the target value of 26g at 8ms. Furthermore, the maximum B–Pillar pulse is very close to the target value of 26g. The intrusions in IIHS simulation are also very close to the target intrusions.

Hence the present configuration meets all the design requirements, along with a reduction in structural weight (approximately 7kg). Since the geometry of the rail remains unchanged, there will not be any manufacturing issues.

Fourth Bumper Design

The bumper system was essentially below yield in the 5mph flat frontal impact. It absorbed almost 15% of the total kinetic energy of the vehicle. There was no damage to the rails beyond 135 mm, or to any other front-end component. This was much less than the maximum allowable damaged length of 300 mm. The bumper system did not break and was successful in transferring the impact load to the right rail.

The fourth bumper system was lightweight and had a short overhang. It had simple and homogenous design that should present no manufacturing difficulties. Without a separate energy absorber, this system was very easy to assemble and integrate with the rails. Another advantage of this bumper system was that it could be tuned for various rail strengths.

Recommendations

The third bumper design is the preferred bumper design to be used on the ULSAB. The fourth bumper design is basically the third bumper design adapted to the upgraded front end package. The bumper system gauges are related to the rails and other critical front-end components. Hence, the optimized vehicle design will have gauges that are different from the gauges listed in this chapter.

References

1) *Phase I Bumper Design Report*.

2) *First Bumper Design Report, Milestone 5.*

3) *Second Bumper Design Report, Milestone 9.*

4) *Third Bumper Design Report, Milestone 18*.

5) *Fourth Bumper Design Report, Milestone 26*.

6) *Cost and Manufacturability of Bumper Systems, Milestone 25*.

Parametric Study / Design of Experiments

Objective

The design of experiments (D.O.E.) techniques enabled the study of the effect of the parametric variables on system response using the least number of experiments (in this case an experiment was synonymous with an analysis using NASTRAN or LS-DYNA3D). The D.O.E. method for the parametric study was required for the following reasons:

Traditional one-parameter-at-a-time study did not consider interaction of parameters (the effect of one parameter on others).

Full factorial study required a very large number of analysis runs (the number of runs required was L^N, where L was the number of parameter levels and N was the number of parameters - a study involving 40 parameters and 2 levels of each parameter required 2^{40} analysis runs!).

On the other hand, D.O.E. methodology had the following advantages:

Interaction between parameters were considered

A minimum number of analysis runs were required (typically only 64 analyses runs were required for 31 parameters with 2 levels of each parameter).

Static and Dynamic Stiffness Parametric Study

The Static and Dynamic Stiffness Parametric Study determined the Performance Matrix of Design Sensitivities that would quantify the variation of vehicle bending and torsion stiffness with respect to Design Parameters. It was also useful in generating a response surface (regression equation) which could then be used as one of the constraint functions for the Computer Aided Optimization (C.A.O.) of the vehicle.

NCAP Parametric Study

The NCAP Parametric Study determined the Performance Matrix of Design Sensitivities that would quantify the variation of the vehicle response in NCAP with respect to Design Parameters. It was also useful in generating response surfaces (regression equations) which could then be used as constraint functions for the Computer Aided Optimization (C.A.O.) of the vehicle.

IIHS D.O.E. Study

The objective of the IIHS parametric study was to determine the Performance Matrix of Design Sensitivities that would quantify the variation of the IIHS response of the Upgraded Powertrain model with respect to Design Parameters.

Initial Front End Package

Summary of Changes

This section summarizes the changes made to the original ULSAB model in order to convert it to the current baseline model that served as the basis for parametric study and optimization.

The original bumper system was replaced by the first bumper design (Ref. 3).

The front rail, rocker and the rear rail were offset and spot welds were created at a spacing of 50 mm. The NCAP DoE study was performed on the spotwelded model. The static stiffness study was initially performed on the original laserwelded model, but was later repeated for the spotwelded model. The knowledge base tool, *Proteus*, has the database corresponding to the spotwelded model. However, this report as well as the milestone report for the static and dynamic stiffness study (Ref. 5) have the results corresponding to the laserwelded model. The dynamic stiffness study was performed on the original laserwelded model. The dynamic study was not repeated for the spotwelded model as there is very less sensitivity of modes to gauge.

The new data for material properties from A/SP was used.

The engine material model was changed from piecewise linear plastic to rigid. The engine brackets were made rigid as well.

The automatic single surface contact in the model was simulated with a soft constraint formulation with the edge-to-edge penetration check turned on.

In addition to the above modifications, changes necessary to supplement the conversion of sequential file format to the keyword format in Hypermesh were also made. Examples included redefinition of the control volumes, contact, load curves and output blocks. The model was organized into LH and RH components, which were named and numbered logically.

Results Summary

The results for the crash response of the initial front end package with the first bumper design (Ref. 3) and the model with the baseline bumper were compared, wherever applicable. The targets for the static and dynamic stiffness were based on the response of the original BIW model with the original bumper. In addition, the first bumper design met all the low velocity impact criteria and also satisfied the 15+1kph Danner/Thatcham no damage criteria.

Static Torsional Stiffness Parametric Study

The components of the front-end structure that were likely to affect the response of the baseline model, were considered in the study. Figure 5.1 shows the FE model of the body-in-white (BIW). Figure 5.2 shows the front-end components that had been considered in this study.

The thickness of each component had been taken as parameters (design variables).

The original laserwelded BIW model with first bumper design had been used for the study. The stiffness calculations were performed with the standard North American method using absolute deflections, as the stiffness calculation methodology was not finalized prior to the commencement of this study. *However later on, all laser welds were converted to spotwelds, and the stiffness study was computed using the European method of relative deflections*. The knowledge base tool, *Proteus*, has the database corresponding to the spotwelded model. However, this report as well as the milestone report for the static and dynamic stiffness study (Ref. 5) have the results corresponding to the laserwelded model.

The parametric study was conducted based on the Design of Experiments method (D.O.E.). Orthogonal Arrays and Linear Graphs have been for this purpose. Analysis of Means (AMEAN - Ref. 12) was used for the interpretation of the results. An experiment in this case referred to a static analysis using MSC/NASTRAN.

The responses were validated by comparing the D.O.E. predictions with actual NASTRAN runs. The validation runs were chosen in such a way that they span the entire design space.

Sensitivities were determined from the Analysis of Mean.

Response surfaces were built in order to optimize the mass, subject to stiffness constraint. Sequential Quadratic Programming with Quasi Newtonian Line Search was utilized for the optimization purpose.

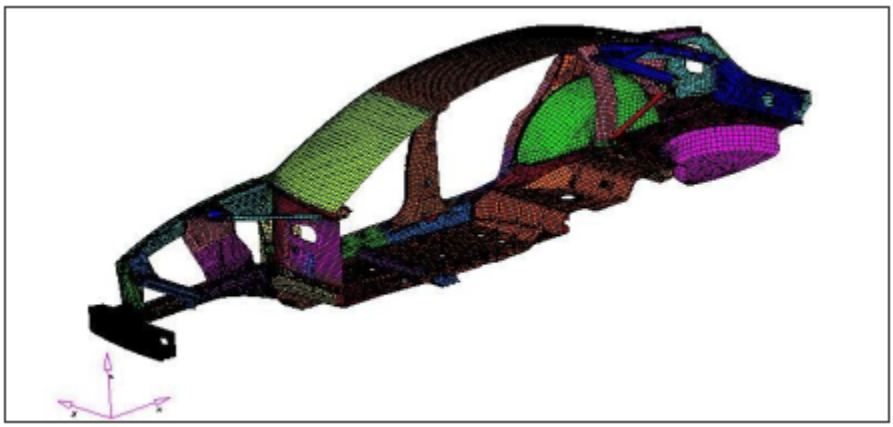


Figure 5.1: Original Baseline BIW F.E. Model with First Bumper Design

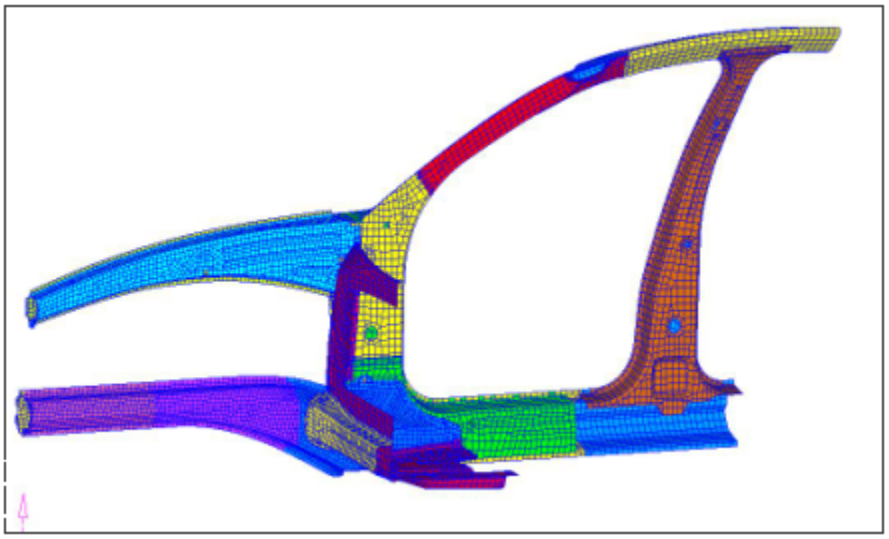


Figure 5.2: Compoonents included in the D.O.E. Study

Design Parameter and Bounds

Table 5.1 gives a list of parameters considered for the static and dynamic stiffness study. The minimum, baseline and maximum values for each parameter are also given in the table. The minimum and maximum bounds on the parameters were determined from practical considerations.

D.O.E.

The Design of Experiments Method was used for the stiffness parametric study. Orthogonal Arrays were used for this purpose. In this study, L27 orthogonal array was used. L27 array was a 3-level array that could accommodate 13 parameters with 27 runs without interactions. With interactions, it could accommodate 7 parameters and 6 two-factor interactions. In practice it was difficult to say whether the interactions played significant roles or not, as it was dependent on the system one was studying, as well as on the response that was to be measured. One way of assessing the presence of interactions was through interaction plots. Another way of checking interactions was to conduct the D.O.E study and then give some validation run for the optimum design. If the results of the optimum design matched well with the actual run, then it could be concluded that the search direction for the optimum was correct and the D.O.E prediction was close to reality. If the results did not match, then one included interactions by selecting a bigger array or use the same array with reduced number of parameters, after screening some of the parameters based on the main effects.

In this study there were 18 thickness parameters. The parameters and their D.O.E levels are shown in the Table 5.2. Some of the parameters were grouped together. The numbers 1, 2, and 3 in the columns of the array represent the levels of each parameter. The results were analyzed using the Analysis of Means method.

Parameters	Thickness (mm)		
	Minimum	Mid*	Maximum
Rail Front Inner	1.0	1.5	2.0
Rail Mid Inner	1.0	1.6	2.0
Rail Rear Inner	1.0	1.8	2.0
Rail Front Outer	1.0	1.5	2.0
Rail Mid Outer	1.0	1.6	2.0
Rail Rear Outer	1.0	1.5	2.0*
Shot Gun Inner	0.7	1.2	2.0
Shot Gun Outer	0.7	0.9	2.0
1st Cross Member	0.7	1.2	2.0
Dash Panel	0.6	0.7	1.2
Rail Side Roof	0.8	1.0	1.2
Hinge Pillar and Assembly			
Hinge Pillar	1.0	1.5	2.0
Rocker Inner	1.0	1.7	2.0
Body Side Outer A Pillar	1.0	1.5	2.0
Body Side Outer A Pillar	1.0	1.7	2.0
A Pillar Upper	1.0	1.5	2.0
B Pillar and Assembly			
B Pillar Inner	1.0	1.5	2.0
Body Side Outer B Pillar	1.0	1.3	2.0

* Baseline values

Table 5.1: Parameters and their Bounds - Static/Dynamic Stiffness Study

Parameters	D.O.E. Array Column Number	Thickness (mm)		
		Level 1 *	Level 2	Level 3
Rail Front Inner	1	1.5	1.0	2.0
Rail Mid Inner	2	1.6	1.0	2.0
Rail Rear Inner	5	1.8	1.0	2.0
Rail Front Outer	9	1.5	1.0	2.0
Rail Mid Outer	10	1.6	1.0	2.0
Rail Rear Outer	12	1.5	1.0	2.0*
Shot Gun Inner	3	1.2	0.7	2.0
Shot Gun Outer	13	0.9	0.7	2.0
1st Cross Member	4	1.2	0.7	2.0
Dash Panel	6	0.7	0.6	1.2
Rail Side Roof	11	1.0	0.8	1.2
Hinge Pillar and Assembly	7			
Hinge Pillar	7	1.5	1.0	2.0
Rocker Inner	7	1.7	1.0	2.0
Body Side Outer A Pillar	7	1.5	1.0	2.0
Body Side Outer A Pillar	7	1.7	1.0	2.0
A Pillar Upper	7	1.5	1.0	2.0
B Pillar and Assembly	8			
B Pillar Inner	8	1.5	1.0	2.0
Body Side Outer B Pillar	8	1.3	1.0	2.0

* Baseline values

Table 5.2: Levels of Parameters - Static/Dynamic Stiffness Study

Results and Discussion

The experiments were conducted as per the L27 array. Each experiment was a static NASTRAN run. Table 5.3 shows the comparison of the results by D.O.E prediction and by actual NASTRAN runs.

For validation, three runs with all the parameters thickness at level 1 (baseline), at level 2 (minimum gauge) and at level 3 (maximum gauge) were conducted. It can be seen from the table that the D.O.E predictions compared favorably with the actual FEA values. Table 5.4 shows the relative sensitivity of each parameter. The parameters were ranked in the descending order of sensitivity. The parameters at the top contributed the most to the stiffness.

The D.O.E predictions were intuitive as well. The BIW was constrained at the rear shock mounting point and loaded at the front shock mounting point. Thus, the transverse parts like the dash panel and first cross member, and the cab parts like the hinge pillar assembly and B-pillar assembly, affected the bending stiffness significantly. Consequently, hinge pillar assembly, shotgun, B-pillar assembly and dash panel were all expected to have a greater effect on the torsional stiffness, as compared to the rails and the shotgun. Indeed, the sensitivities derived from D.O.E were higher for the first set of parts.

The DOE results were analyzed graphically. The main effect plots for the hinge pillar assembly, shotgun, B-pillar assembly and dash panel showed a high slope, which implied a high sensitivity. The main effect plots for the rails and the shotgun showed a lower slope, indicating a lower sensitivity.

Hence, the DOE predictions were accurate and can be employed for building a response surface for the torsional stiffness to be used for optimization.

Thickness	Torsional Stiffness (N-m/deg)		% Error
	As Predicted By D.O.E.	Actual NASTRAN	
Base Line	12335.04	12335.04	0.00
Lower Bounds	11330.90	11225.00	+ 0.68
Upper Bounds	13394.40	13337.80	+ 0.42

Table 5.3: Comparison of D.O.E. and Actual NASTRAN Runs - Torsional Stiffness

Components	Sensitivities	Normalized
		w.r.t Baseline
Hinge Pillar Assembly	12658.8	1.026247179
Shot Gun Inner	12540.4	1.016648507
B Pillar Assembly	12525.6	1.015448673
Dash Panel	12444.2	1.008849586
Shot Gun Outer	12431.4	1.007811892
Rail Rear Outer	12393.6	1.004747451
1st Cross Member	12393.2	1.004715023
Rail Rear Inner	12390.6	1.004504242
Rail Mid Inner	12379.4	1.003596259
Roof Rail	12367.2	1.002607207
Rail Mid Outer	12362.8	1.002250499
Rail Frt Outer	12356.9	1.001772187
Rail Frt inner	12354.4	1.001568513

Table 5.4: Components in the Decreasing Order of Torsional Stiffness Sensitivities

Static Bending Stiffness Parametric Study

The procedure for this study was the same as that discussed for the torsional stiffness study.

Design Parameters and Bounds

The same parameters shown in Table 5.1 were used in this study.

D.O.E.

L27 Orthogonal Array was used for the study. The D.O.E Levels are the same as shown in Table 5.2. Other details were similar to those discussed previously.

Results and Discussion

The experiments were conducted as per the L27 array. Each experiment was a static NASTRAN run. The bending stiffness value is listed against each run. The method of calculation for the bending stiffness is discussed in the appendix. Table 5.5 shows the comparison of the results by D.O.E prediction and by actual NASTRAN runs.

For validation, three runs with all the parameters thickness at level 1 (baseline), at level 2 (minimum gauge) and at level 3 (maximum gauge) were conducted. It can be seen in the table that the D.O.E predictions and the actual runs yielded similar results. Table 5.6 shows the relative sensitivity of each parameter. The parameters were ranked in the descending order of sensitivity. The parameters at the top contributed the most to the stiffness.

The D.O.E predictions were intuitive as well. The BIW was constrained at the front and rear shock mounting points and loaded at the seat mounting points. Thus, the parts in between the supports affected the bending stiffness significantly, as compared to the parts in the overhang. Consequently, the dash panel, hinge pillar assembly, B-pillar assembly and first cross member were all expected to have a greater effect on the bending stiffness, as compared to the rails and the shotgun. Indeed, the sensitivities derived from D.O.E were higher for the first set of parts.

The D.O.E results were also analyzed graphically. The main effect plots for the dash panel, hinge pillar assembly, B-pillar assembly and first cross member showed a high slope, which implied a high sensitivity. The main effect plots for the rails and the shotgun showed a lower slope, indicating a lower sensitivity.

The D.O.E. predictions were further verified by increasing the dash panel gauge (high sensitivity) and front rail section gauge (low sensitivity) separately by unit amounts. A higher change in bending stiffness was observed for the dash panel, implying that the dash panel had a greater effect on the bending stiffness as compared to the front rail section.

Hence, the D.O.E predictions are accurate and can be employed for building a response surface for the bending stiffness to be used for optimization.

Thickness	Bending Stiffness (N/mm)		% Error
	As Predicted By D.O.E.	Actual NASTRAN	
Base Line	2259.88	2259.88	0.00
Lower Bounds	2125.82	2116.4	+ 0.44
Upper Bounds	2391.45	2395.2	- 0.16

Table 5.5: Comparison of D.O.E. and Actual NASTRAN Runs - Bending Stiffness

Components	Sensitivities	Normalized
		w.r.t Baseline
Dash Panel	2309.55	1.021975878
Hinge Pillar Assembly	2283.73	1.010550528
B-Pillar Assembly	2273.94	1.006218453
I st Cross Member	2271.86	1.005298053
Rail Rear Inner	2270.1	1.004519253
Shot Gun Inner	2269.28	1.004156403
Roof Rail	2263.56	1.001625303
Shot Gun Outer	2262.41	1.001116428
Rail Rear Outer	2262.35	1.001089878
Rail Mid Inner	2261.16	1.000563303
Rail Frt Outer	2260.46	1.000253553
Rail Mid Outer	2260.37	1.000213728
Rail Frt Inner	2260.26	1.000165053

Table 5.6: Components in the Decreasing Order of Bending Stiffness Sensitivities

Torsion Modal Parametric Study

The original laserwelded BIW model with first bumper design had been used for the torsion modal study.

Design Parameters and Bounds

Table 5.1 gives the design parameters and their bounds.

D.O.E.

L27 Orthogonal Array has been used for D.O.E. The D.O.E levels for the used in this study are shown the Table 5.2.

Results and Discussion

Table 5.7 gives the comparison between the D.O.E prediction and the actual NASTRAN Runs. Table 5.8 ranks the parameters in order of decreasing sensitivity.

The first global torsion was quite insensitive to changes in gauge. The difference in frequency with gauges at the upper and lower bounds was less than 2 Hz. All main effect plots showed almost a flat line, indicating the insensitivity of torsional modes to gauge. Nevertheless, the D.O.E. predictions were highly accurate, with less than 1% error.

This behavior was quite intuitive as both mass and stiffness had a first order dependence on gauge, for sheet metal parts. Since torsional frequency was directly proportional to stiffness and inversely proportional to mass, there was no net effect of gauge on frequency.

For all practical purposes, torsional modes were considered to be insensitive to changes in gauge. Hence, the torsional modal constraint was ignored in the mass optimization of the baseline model, providing there were no topological changes.

Thickness	First Modal Frequency (Torsion), Hz		% Error
	As Predicted By D.O.E.	Actual NASTRAN	
Base Line	65.230	65.230	0.00
Lower Bounds	64.671	64.970	-0.46
Upper Bounds	65.710	67.510	-2.66

Table 5.7: Comparison of D.O.E. and Actual NASTRAN Runs - First Torsion Frequency

Components	Sensitivities
Rail Front Inner	65.9989
Shot Gun Inner	65.8822
Rail Side Roof	65.8656
Rail Mid Inner	65.7567
Hinge Pillar Assy	65.65
Rail Rear Inner	65.62
Rail Front Outer	65.5989
Shot Gun Outer	65.5978
Ist Cross Member	65.5689
Dash Panel	65.5044
Rail Mid Outer	65.5
B-Pillar Assy	65.3833
Rail Rear Outer	65.3744

Table 5.8: Components in the Decreasing Order of First Torsion Frequency Sensitivities

Bending Modal Parametric Study

The procedure for this study was the same as that discussed for the torsion modal study.

Design Parameters

The Design Space was same as before.

D.O.E.

L27 Orthogonal Array has been used for D.O.E.

Results

Table 5.9 gives the comparison between the D.O.E prediction and the actual NASTRAN Runs. Table 5.10 ranks the parameters in order of decreasing sensitivity.

The first global bending was quite insensitive to changes in gauge. The difference in frequency with gauges at the upper and lower bounds was less than 2 Hz. All main effect plots showed almost a flat line, indicating the insensitivity of bending modes to gauge. Nevertheless, the D.O.E. predictions were highly accurate, with less than 1% error.

This behavior was quite intuitive as both mass and stiffness had a first order dependence on gauge, for sheet metal parts. Since bending frequency was directly proportional to stiffness and inversely proportional to mass, there was no net effect of gauge on frequency.

Thus, for all practical purposes, bending modes were considered to be insensitive to changes in gauge. The bending modal constraint was ignored in the mass optimization of the baseline model, provided there were no topological changes.

Thickness	First Modal Frequency (Bending), Hz		% Error
	As Predicted By D.O.E.	Actual NASTRAN	
Base Line	61.225	61.225	0.00
Lower Bounds	59.601	59.850	- 0.42
Upper Bounds	61.349	61.250	+ 0.16

Table 5.9: Comparison of D.O.E. and Actual NASTRAN Runs - First Bending Frequency

Components	Sensitivities
B-Pillar Assy	62.0167
Hinge Pillar Assy	61.5311
Shot Gun Outer	61.15
Rail Rear Outer	61.1411
Rail Mid Outer	61.0133
Rail Side Roof	61.0078
Rail Front Outer	60.9833
Rail Mid Inner	60.9394
Ist Cross Member	60.9216
Rail Front Inner	60.8761
Rail Rear Inner	60.8739
Dash Panel	60.8244
Shot Gun Inner	60.7494

Table 5.10: Components in the Decreasing Order of First Bending Frequency Sensitivities

Computer Aided Optimization (C.A.O)

An attempt was made to assess how optimized the ULSAB was, subject to stiffness constraints. The optimization problem is stated below:

Problem Statement

Objective: Minimize Mass

Constraints: Torsional Stiffness >= Baseline Stiffness (12335.0 N-m/deg)

Bending Stiffness >= Baseline Stiffness (2259.887 N/mm)

Design Variables: Design variables were the component gauges. The design variables, their lower and upper limits are given in Table 5.1.

The allowable stiffness constrains were scaled suitably in order to account for the D.O.E experimental error.

Torsional and bending mode responses were not included in the C.A.O. study as they had a very low sensitivity to gauge.

Procedure

Regression Equations were built using the results of the D.O.E based Parametric Study using Regression Analysis.

These Equations represented the objective function and the constraint functions.

The resulting regression equations (also referred to as response surface) were used in the C.A.O.

The problem then was solved using a computer-aided optimizer. Sequential Quadratic Programming with Quasi-Newton Line search algorithm had been used for the optimization.

Results and Discussion

The optimum solution obtained from C.A.O is shown in Tables 5.11 and 5.12. Table 5.13 summarizes the sensitivities of all the responses. The C.A.O. solution indicated that the BIW was quite optimized from stiffness considerations alone. Upon examining Table 5.13, we can see that this was quite intuitive as well. Parts like hinge pillar assembly and B-pillar assembly had high stiffness as well as mass sensitivities. On the other hand, parts like rails and shotguns that had lower stiffness as well as mass sensitivities. The only way a significant mass reduction was possible was if there were parts with high stiffness sensitivity, but a low mass sensitivity, or if these parts had a low gauge. However, since this was not the case, only a minor mass reduction was achieved. Most of the high stiffness sensitivity parts, like the hinge pillar assembly, retained their baseline gauges or had heir gauges increased slightly. Most of the low stiffness parts, like the rails, had their gauges reduced. Table 5.12 shows that the gauge assignment after optimization .

Table 5.14 shows an example that illustrates the optimization of gauges very clearly. The front inner rail section had a higher mass sensitivity, but a lower stiffness sensitivity, as compared to the front outer rail section. Both parts had a baseline gauge of 1.5 mm. Consequently, after optimization, the front outer rail section should have had a higher gauge than front inner rail section. This was indeed the case.

The gauges obtained after optimization were rounded-off, due to the availability of only standard gauges. This led to a slight increase in mass.

An obvious conclusion from the stiffness optimization study was that since there was not much scope to reduce mass even by considering stiffness alone, it would not be possible to optimize the baseline model with respect to crash and stiffness, unless the stiffness criteria were relaxed, or if topological changes and extra parts were included in the optimization study.

	Base Line	After Optimization (From C.A.O)	After Optimization and Rounding-Off (From NASTRAN Run)	Remarks (w.r.t. baseline)
Mass (Kg)	39.0	37.58	38.0	2.5 % reduction
Torsional Stiffness (N-m/deg)	12335	12415	12280	0.4 % constraint violation
Bending Stiffness (N/mm)	2260	2270	2260	0.0 % constraint violation

Table 5.11: Predicted Optimum Results

Parameters	Thickness Levels		
	Baseline	Optimized	Rounded Off
Rail Front Inner	1.5	1.0	1.0
Rail Mid Inner	1.6	1.5038	1.5
Rail Rear Inner	1.8	1.4224	1.4
Rail Front Outer	1.5	1.1878	1.2
Rail Mid Outer	1.6	1.4201	1.4
Rail Rear Outer	2.0	1.5	1.5
Shot Gun Inner	1.2	1.4718	1.5
Shot Gun Outer	0.9	0.7	0.7
1st Cross Member	1.2	0.9975	1.0
Dash Panel	0.7	0.7546	0.8
Rail Side Roof	1.0	0.8801	0.9
Hinge Pillar and Assembly			
Hinge Pillar	1.0	1.0	1.0
Rocker Inner	1.7	2.0	2.0
Body Side Outer A Pillar	1.5	2.0	2.0
Body Side Outer A Pillar	1.7	2.0	2.0
A Pillar Upper	1.5	2.0	2.0
B Pillar and Assembly			
B Pillar Inner	1.5	2.0	1.0
Body Side Outer B Pillar	1.3	1.0	1.0

Table 5.12: Optimum Solution

Mass	Torsional Stiffness	Bending Stiffness
Hinge Pillar Assy	Hinge Pillar Assembly	Dash Panel
B-Pillar Assy	Shot Gun Inner	Hinge Pillar Assembly
Dash panel	B-Pillar Assembly	B-Pillar Assembly
Shot Gun Inner	Dash Panel	I st Cross Member
Rail Rear Inner	Shot Gun Outer	Rail Rear Inner
Roof Rail	Rail Rear Outer	Shot Gun Inner
Shot Gun Outer	I st Cross Member	Roof Rail
Rail Mid Inner	Rail Rear Inner	Shot Gun Outer
I st Cross Member	Rail Mid Inner	Rail Rear Outer
Rail Rear Outer	Roof Rail	Rail Mid Inner
Rail Frt Inner	Rail Mid Outer	Rail Frt Outer
Rail Mid Outer	Rail Frt Outer	Rail Mid Outer
Rail Frt Outer	Rail Frt Inner	Rail Frt Inner

Table 5.13: Comparison of Sensitivities

Component	Mass Sensitivity	Stiffness Sensitivity	Optimized Thickness (mm)
Rail Front Inner	Higher	Lower	1.0 (1.5*)
Rail Front Outer	Lower	Higher	1.2 (1.5*)

* Baseline values

Table 5.14: Intuitive Example

Conclusions and Recommendations

The following conclusions were made regarding the baseline vehicle.

BIW mass was quite optimized with respect to stiffness.

In order to optimize the system subject to crash constraints, we have to consider one or more of the following approaches:

1. Consider topological changes

2. Include more components for mass reduction, for example floor and roof.

3. Relax stiffness criteria

Including extra parts for mass optimization was not possible in this front-end study as these parts affected responses in other load cases, such as side impact and rollover. Making topological changes to the front-end parts was certainly possible and will be included in future work.

It may have been possible to relax the stiffness criteria, if the crash constraints were satisfied. Table 5.15 shows that a 31% mass reduction of the front-end parts is possible with a 9% and 6% reduction in the torsional and bending stiffness requirements. This implied a 6% reduction in the total BIW mass.

Response	Baseline	After Relaxing	% Reduction
Mass (Kg)	39.0	27.0	30.76
Torsional Stiffness Nm / deg	12335	11225	8.99
Bending Stiffness N / mm	2260	2116	6.37

Table 5.15: Effect of Relaxing Stiffness Criteria

NCAP Parametric Study

The components of the front-end structure that were likely to affect the response of the baseline model in NCAP load case (Ref.1), were considered in this study.

The thickness and material of each component had been taken as parameters (design variables).

The baseline model (Ref. 2) with the first bumper design (Ref. 3) had been used for the NCAP study. This model was essentially the same as that documented in Ref. 2, except for some minor changes (Ref. 6).

The parametric study was conducted based on the Design of Experiments method (D.O.E.). Orthogonal Arrays and Linear Graphs were for this purpose (Ref. 12). Analysis of Means (AMEAN - Ref. 12) was used for the analyses of the results. An experiment in this case referred to an NCAP analysis using LS-DYNA3D.

The responses were validated by comparing the D.O.E. predictions with actual LS-DYNA3D runs. The validation runs were chosen in such a way that they span the entire design space.

Response surfaces were generated for crush and B-pillar acceleration using regression analyses (Ref. 13).

The entire B-pillar pulse was predicted by generating response surfaces for maximum and minimum acceleration in 10ms time windows.

Response surfaces were then utilized to optimize the mass, subject to stiffness constraint. Sequential Quadratic Programming with Quasi Newtonian Line Search (Ref. 13) was utilized for the optimization purpose.

Design Parameters and Bounds

The NCAP study included the grades and gauges of 13 front-end components. Table 5.16 gives a list of the components considered for the NCAP study, along with the levels for each gauge and grade (Ref. 6). These components accounted for 80% of the energy absorption in the NCAP load case. The lower gauge levels on the parameters were determined from formability and durability considerations. The higher grade levels were also determined from formability considerations. The higher gauge and lower grade levels were the same as the baseline values.

D.O.E

The Design of Experiments Method was used for the stiffness parametric study. Orthogonal Arrays were used for this purpose (Ref. 10-12). In this study, the L64 orthogonal array was employed. L64 array is a 2-level array that can accommodate 26 parameters with 37 interactions, using 64 runs. It was determined from pilot studies on the front rails that interaction effects were considerable in NCAP, unlike the static stiffness case. Thus, the 3-level L27 array that was adequate for the parametric study of the static stiffness, would not suffice for the NCAP study. There were then two choices – either to increase the size of the D.O.E. array or to reduce the number of levels. The former would increase the number of DYNA runs tremendously and was therefore infeasible, given the resources and the time available. It was therefore decided to conduct a 2-level study requiring 64 runs, which included interaction effects and generated an accurate response surface that could be extrapolated beyond the second level.

It is worth mentioning that parameters were judiciously assigned to the main columns so as to include the most significant interactions. All two-way interactions of the highest energy absorbing components were included. Thus, all 28 interactions between grade and gauge of the bumper beam, front rail inner, front rail outer and cradle extension were taken into account. The individual interactions between grade and gauge of the other 9 components accounted for the remaining 18 interactions. The results were analyzed using the techniques of regression analysis (Ref. 13).

Results and Discussion

The experiments were conducted according to the L64 array. Each experiment was an LS-DYNA3D run. The maximum crush and peak accelerations are plotted in Figures 5.3 and 5.4 respectively. The minimum and maximum crush were 767mm and 926mm respectively. The minimum and maximum accelerations were 26.4g and 44.7g respectively. All 64 cases ran to normal completion. The crush and accelerations derived from the response surface yielded values outside these bounds. However, the minimum and maximum values from the 64 runs indicated the range of variation expected in the design space. This was because the L64 was a balanced array in which all factors were varied simultaneously across all levels.

	Component	Thickness (mm)		Material Yield / Ultimate (MPa)	
		Level 1	Level 2 *	Level 1 *	Level 2
1	Bumper C-Section	1.3	2.0	HSLA 350/450	DP 500/800
2	Rail Front Inner	1.0	1.5	HSLA 350/450	DP 500/800
3	Rail Front Outer	1.0	1.5	HSLA 350/450	DP 500/800
4	Rail Mid Inner	1.0	1.6	HSLA 350/450	DP 500/800
5	Rail Mid Outer	1.0	1.6	HSLA 350/450	DP 500/800
6	Rail Rear Inner	1.2	1.8	HSLA 350/450	DP 500/800
7	Rail Rear Outer	1.3	2.0	HSLA 350/450	DP 500/800
8	Shot Gun Inner	0.8	1.2	HSLA 425/770	DP 500/800
9	Shot Gun Outer	0.7	0.9	HSLA 350/450	DP 500/800
10	Cradle Cross Mbr 1st Ubar1	1.0	1.3	HSLA 350/450	DP 500/800
	Cradle Cross Mbr 2nd Ubar2	1.0	1.6	HSLA 350/450	DP 500/800
11	Cradle	1.3	2.0	HSLA 350/450	DP 500/800
12	Cradle Extension	1.0	1.5	DP 280/600	DP 500/800
13	Ist Cross Member	0.8	1.2	HSLA 425/770	DP 700/1000 *

1,2 - Combined Parameters ***Indicates baseline values**

Table 5.16: NCAP D.O.E. Parameters

The results from the 64 runs were analyzed using main effects, interaction plots and ANOVA (Analysis of Variance - Ref. 12). Regression analysis was used to generate response surfaces for maximum crush and maximum B-pillar acceleration. It was determined that a response surface for the absolute acceleration peak could not be generated accurately. Consequently, the entire pulse was broken up into segments of 10ms each. The response surfaces were then generated for the maximum and minimum accelerations in each 10ms window. In this fashion, the entire B-pillar pulse was constructed. The choice of 10ms for sampling was based on the observation that in most of the 64 runs, there was one local maximum and minimum every 10ms, related to a specific crash event. Choosing a window smaller than 10ms would increase the probability of an event shifting to the neighboring window. Increasing the window size would result in missing some local maxima and minima. Thus, a 10ms window was found to be an appropriate for sampling the acceleration pulse.

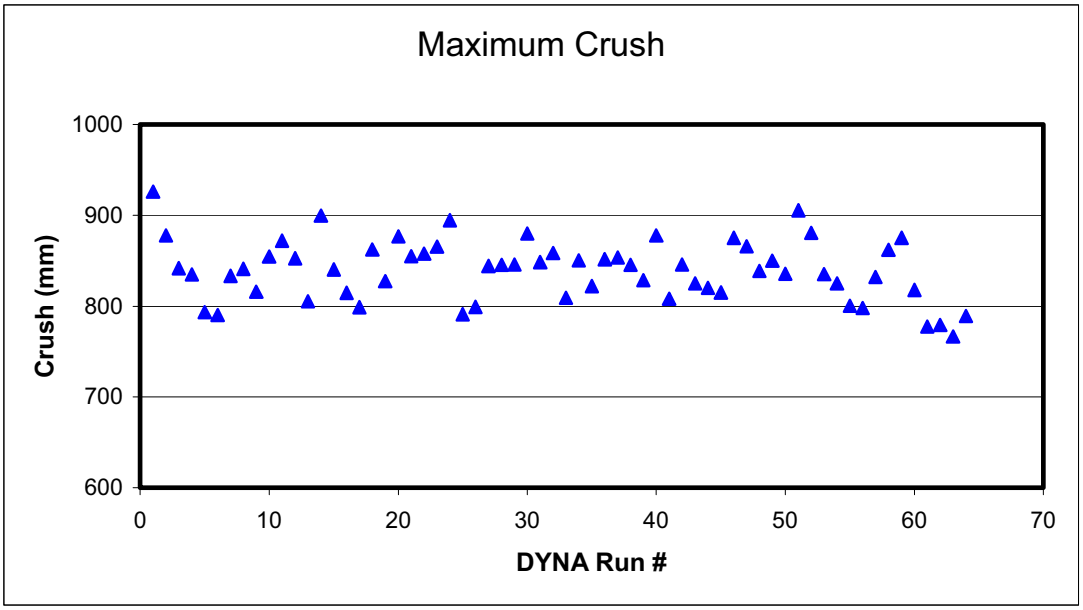


Figure 5.3: NCAP D.O.E. Parameters

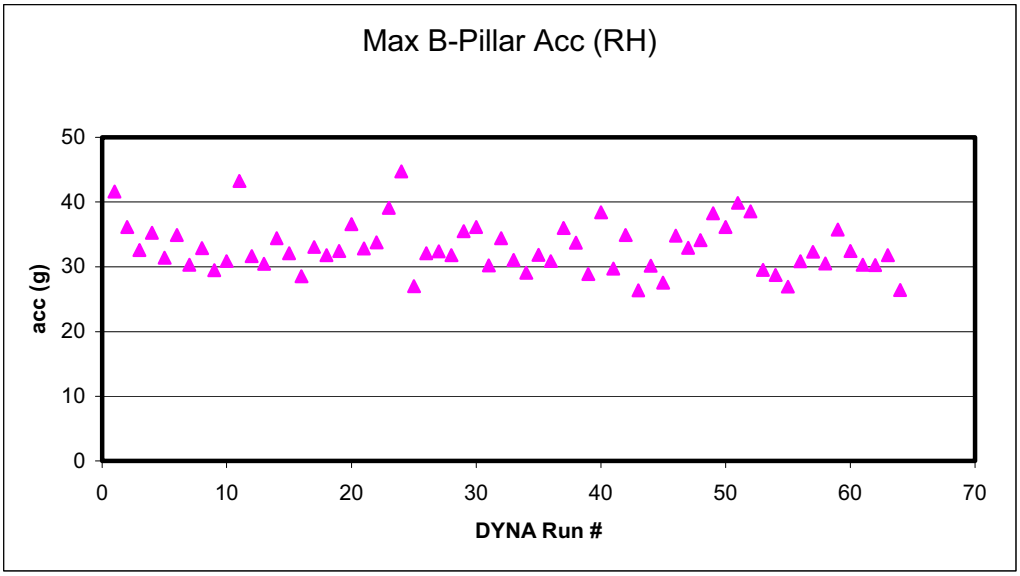


Figure 5.4: L64 - Max RH B-Pillar Acceleration Scatter Plot

For validation, several runs spanning the entire design space were given. The maximum crush and the entire B-pillar pulse were used for comparison. Figure 5.5 shows the correlation between the crush values predicted by D.O.E. and the actual values from LS-DYNA3D runs. The D.O.E predictions were within 10% of the actual LS-DYNA3D values, for the D.O.E space. Furthermore, the similar shape of the curves indicated that the sensitivities were also predicted correctly. In general, the D.O.E. predictions were on the higher side, thereby predicting a slightly softer system.

Figures 5.8 and 5.9 show the optimum and baseline comparison between the B-pillar pulse predicted by D.O.E. and the actual pulse from LS-DYNA3D runs. The initial peak in the first 10ms was the most accurately predicted peak. The peaks close to the time of rebound were the most inaccurately predicted peaks.

A measure of the accuracy of prediction was obtained by comparing crush and maximum acceleration between 50-70ms for predicted and actual values for 21 combinations that span the entire design space. These errors are plotted on a normalized design space in Figures 5.6 and 5.7. The blue rectangle represents the D.O.E. boundary on which the predictions will be the most accurate, as the L64 runs were conducted in this region. The region inside the blue rectangle represents the interpolated design space. The region outside the blue rectangle and bounded by the magenta rectangle represents the extrapolated design space. The predictions were expected to be less accurate in the interpolated and extrapolated regions. The maximum errors in crush and acceleration predictions were 17.5% and 23.2% respectively. The maximum errors occurred in the extrapolated region of the design space. The maximum error in the D.O.E. space was

less than 10% for crush and less than 15% for acceleration. Extrapolating beyond the D.O.E. space resulted in inaccurate predictions for crush and acceleration. The response surfaces can be used for computer-aided optimization of the baseline model, in order to obtain designs with mass savings and better performance.

Computer Aided Optimization (C.A.O)

An attempt was made to test the NCAP response surfaces by searching for designs with lower mass and better-than-baseline NCAP performance. The optimization problem is stated below:

Problem Statement

Objective: Minimize Mass

Constraints: Crush <= Baseline Crush (793 mm)

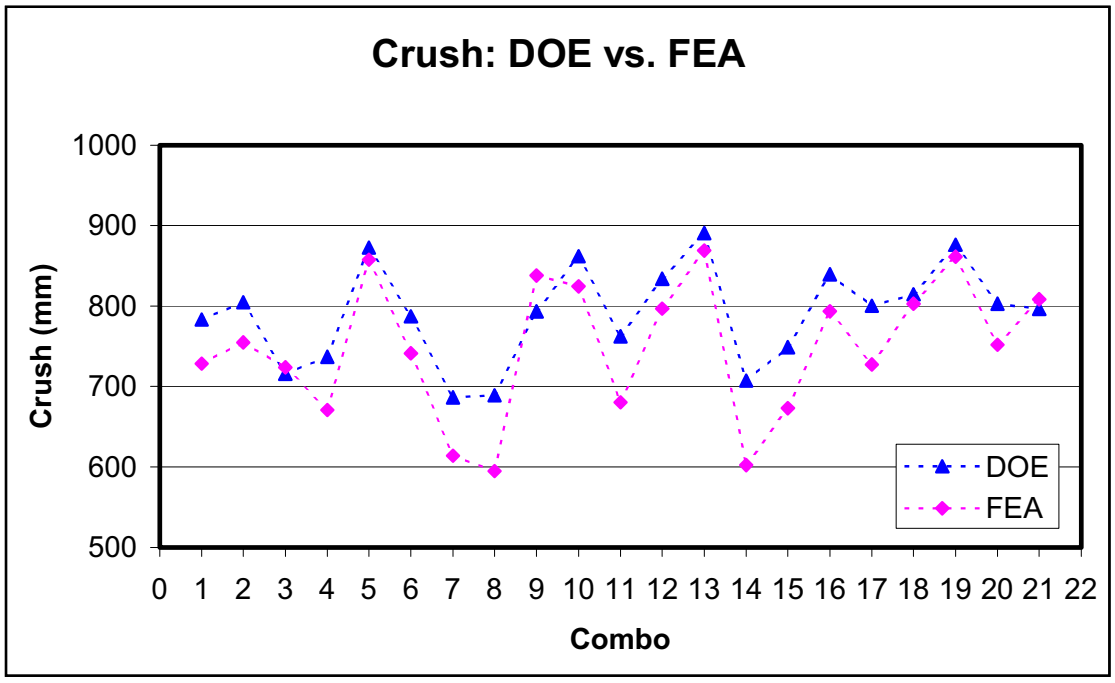


Figure 5.5: Crush Response Surface Verification - D.O.E. vs. FEA

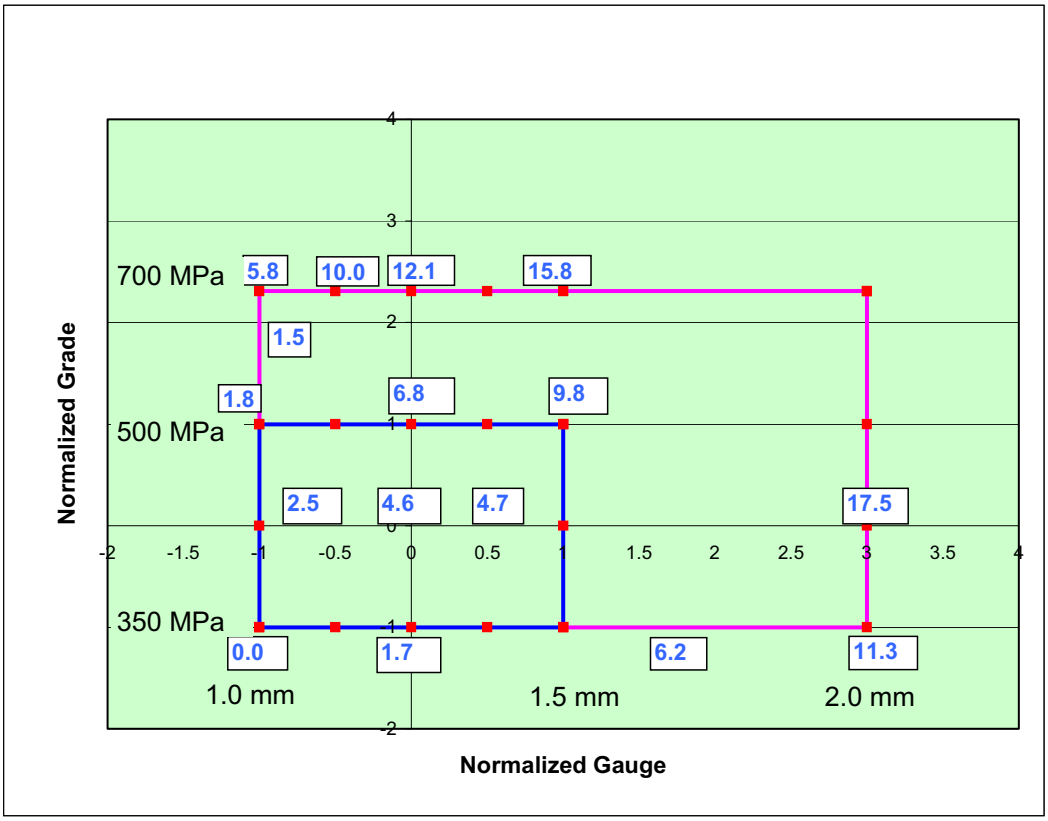


Figure 5.6: Design Space - Crush % Error

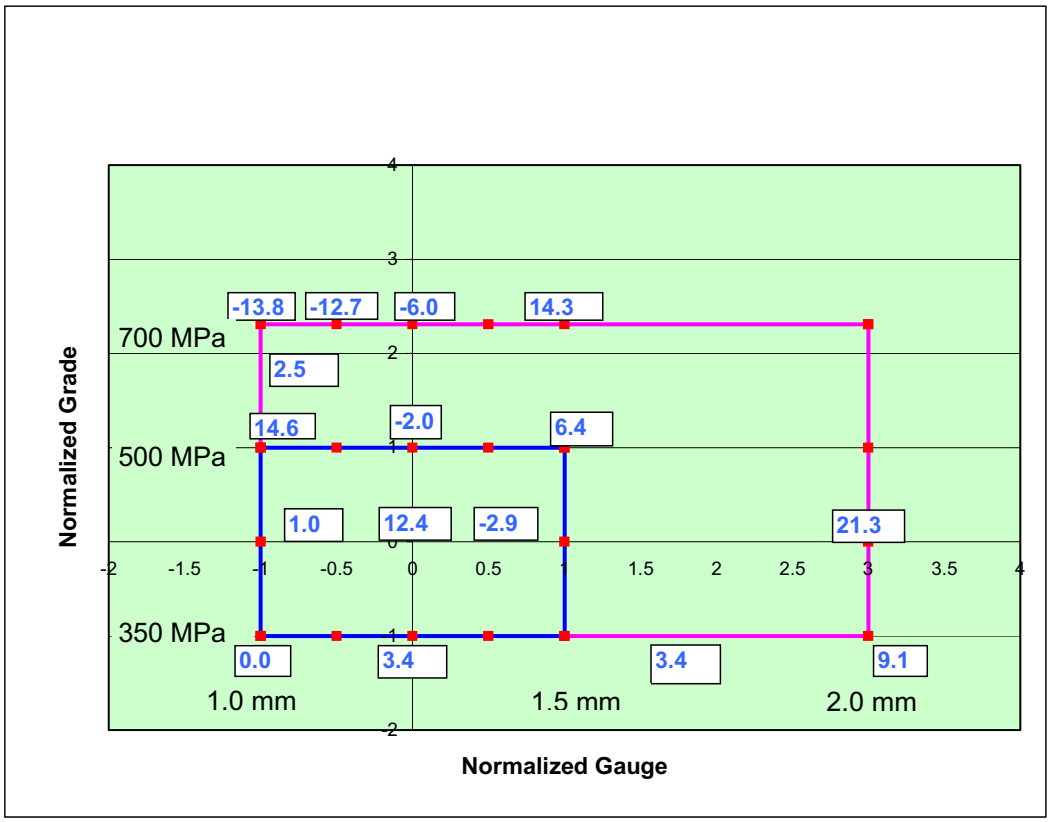


Figure 5.7: Design Space - 50-70 ms Acceleration % Error

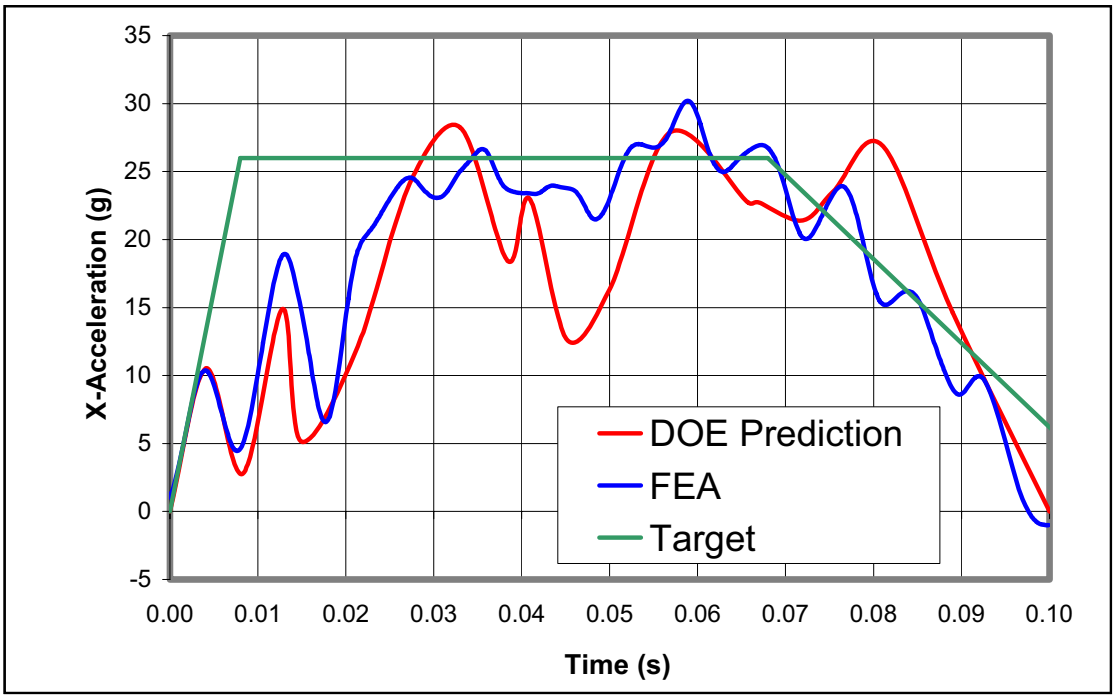


Figure 5.8: Optimum 1

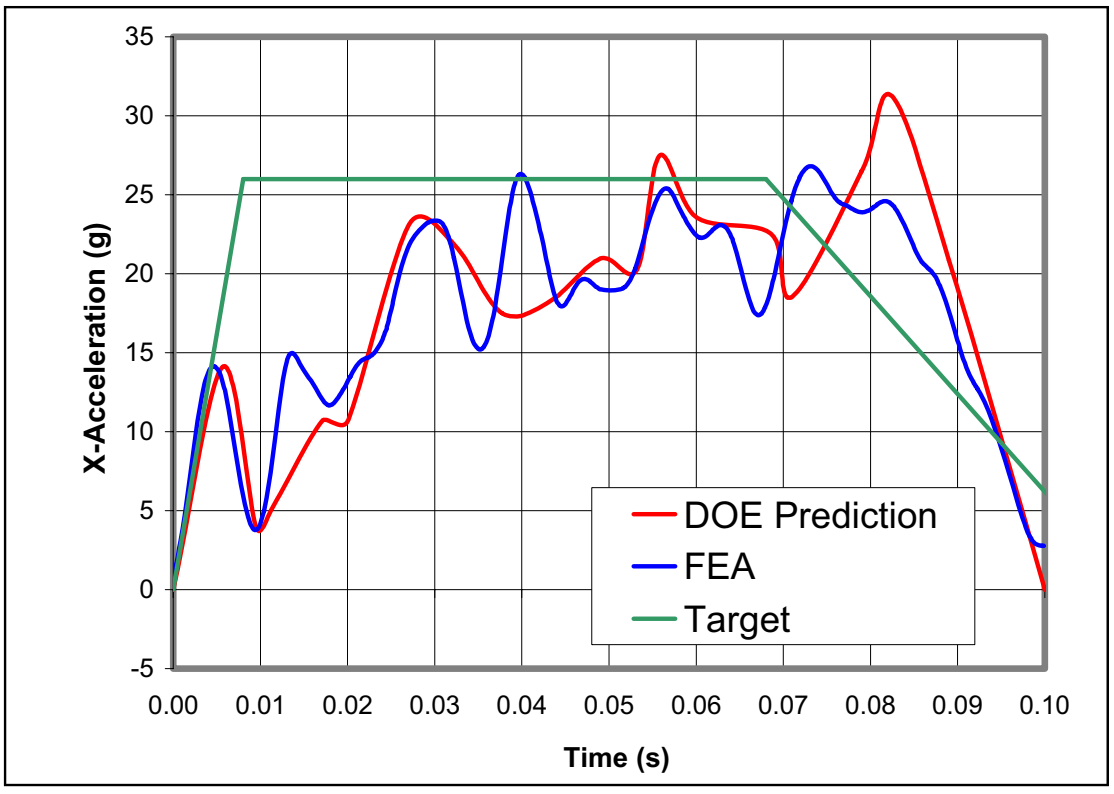


Figure 5.9: Baseline

Acceleration <= Target Acceleration (26g)

Design Variables:

Design variables are the component gauges and grades. The design variables, their lower and upper limits are given in Table 5.16.

- The constraints were varied, in order to obtain different optimum solutions.
- Low crush is an indicator of good performance in IIHS.
- Potential solutions from the optimization were then tested for IIHS performance.

Procedure

Regression Equations were built using the results of the D.O.E based Parametric Study discussed previously using regression analysis (Ref. 13).

These equations represented the objective function and the constraint functions.

The resulting regression equations (also referred to as response surface) were used in the C.A.O. of the baseline front-end structure.

The problem then was solved using a computer-aided optimizer. Sequential Quadratic Programming with Quasi-Newton Line search algorithm had been used for the optimization (Ref. 13).

Results and Discussion

An optimum solution was obtained by minimizing the mass subject to peak acceleration constraint only. This yielded a design with 8.37kg mass reduction and better-than-baseline NCAP and IIHS performance. A comparison of the optimum solution with the baseline is shown in Tables 5.17 and 5.18.

It is clear from Table 5.17, that the levels of gauges and grades were not all

	Component	Thickness (mm)		Material Yield / Ultimate (MPa)	
		Baseline	Optimum 1	Baseline	Optimum 1
1.	Bumper C-Section	2.0	1.3	HSLA 350/450	DP 500/800
2.	Rail Front Inner	1.5	1.5	HSLA 350/450	DP 500/800
3.	Rail Front Outer	1.5	1.5	HSLA 350/450	HSLA 350/450
4.	Rail Mid Inner	1.6	1.6	HSLA 350/450	DP 500/800
5.	Rail Mid Outer	1.6	1.6	HSLA 350/450	HSLA 350/450
6.	Rail Rear Inner	1.8	1.8	HSLA 350/450	DP 500/800
7.	Rail Rear Outer	2.0	1.3	HSLA 350/450	HSLA 350/450
8.	Shot Gun Inner	1.2	1.2	HSLA 425/770	HSLA 425/770
9.	Shot Gun Outer	0.9	0.9	HSLA 350/450	DP 500/800
10.	Cradle Cross Mbr 1st Ubar 1	1.3	1.3	HSLA 350/450	DP 500/800
	Cradle Cross Mbr 2nd Ubar 2	1.6	1.6	HSLA 350/450	DP 500/800
11.	Cradle	2.0	1.3	HSLA 350/450	DP 500/800
12.	Cradle Extension	1.5	1.0	DP 280/600	DP 500/800
13.	lst Cross Member	1.2	1.2	DP 700/1000	DP 700/1000

Table 5.17: Performance Comparison - Baseline vs. Optimum 1

	Mass Savings	NCAP Peak Acc (g)		IIHS Intrusions (cm)		
Baseline	-	26.0	26.8	17.9	14.7	11.2
Optimum 1	8.27	27.6	30.2	14.7	11.6	8.3

Table 5.18: Design Comparison - Baseline vs.Optimum 1

intuitive. All inner rail grades had been set to the higher grade material, DP 500. However, all outer rail grades had been retained at the baseline levels.

This was just one good solution obtained by searching the design space utilizing the response surface generated from the D.O.E results. There was a potential for several more good solutions, perhaps with better performance and/or mass reduction. A library of designs were created,

consisting of all solutions derived from the response surface driven C.A.O (Chapter 7). These designs satisfy objectives of reduced mass and/or improved performance.

Conclusions and Recommendations

The NCAP gauge and grade parametric study was performed for the original baseline model, based on the methodology of Design of Experiments. Response surfaces for maximum crush and the entire B-pillar acceleration have been generated. These response surfaces have been validated for combinations involving the D.O.E. levels (less than 10% error for crush and less than 15% error for accelerations). The response surface was also fairly accurate for interpolated and extrapolated levels of gauges and grades (less than 18% error for crush and less than 22% error for accelerations). A design with 8.37kg mass reduction and better-than-baseline performance had also been obtained from the response surface.

A library of designs has been created from the response surface derived from the NCAP D.O.E. study. It consists of improved front-end designs

derived from the response surface driven C.A.O. of the baseline front-end structure. In order to predict more accurately beyond the levels of the present 2-level D.O.E. study, a 3-level D.O.E. study, such as L243, may be undertaken. However, this study is beyond the scope of the current project.

Upgraded Front End Package

Summary of Changes

The modifications made to the original model for accommodating the high-end engine package are documented in the following sections. The primary changes consisted of the basic topological modifications made to certain front-end parts, such as rails and shotgun, in order to accommodate the large powertrain and tire size. Secondary changes were the modifications made to the parts affected by the primary changes. Details of the Fourth Bumper Design were included in the Fourth Bumper Design report (Ref. 9). The bumper design was carried out in conjunction with the primary changes. Rails stiffeners and modifications were designed in order to improve the crashworthiness performance. The primary changes in the front-end structure resulted in a worsening of the crash response. The bump in the left rail and divots in the right rail (due to the larger upgraded powertrain) resulted in an increased buckling of the rails. The front section of the rails was suitably modified and stiffeners were redesigned so as to reduce buckling and induce greater axial crush. Rail extension and rail extension reinforcement were designed for improving the load path to the rear rail section. The total mass of the vehicle lumped mass was increased by 360lb, and was distributed on the powertrain, suspension and rear seat locations.

The original 3 liter, V6 engine was upgraded by increasing its mass by 220lb and its volume envelope suitably, in order to be representative of a larger 3.8 liter V6 package. In accordance with the original model, a clearance of 9.5 mm was maintained between the powertrain and all sheet metal. Divots were introduced in the front section of the right rail, in order to achieve this clearance. The larger tire flop necessitated cross section reduction and change in plan curvature in both the rails. The length of the

front rail section was reduced by 100 mm, as the original model had a front-end that was longer than what was typical for a vehicle in that class. Feasibility of accommodating different tire flops in the model architecture was studied. The 195/60 R15 tire used in the original model was replaced by 205/60 R16 tire.

Primary Changes

- LH rail
- RH rail
- Bumper design
- Rail extension joint
- Shot gun and fender
- Length of front rail section reduced by 100mm
- Tire size changed from 195/60 R15 to 205/60 R16
- Vehicle lumped mass increased by 360lb

Secondary Changes

Due to topological modifications in LH rail, secondary changes were made to the following:

- Suspension tower (Skirt)
- Cradle – 2nd U bar
- Engine bracket and engine mount bracket
- Reinforcement added in the middle of the LH rail, due to rail bump, and at rear of the rail, due to tire flop (rail plan curvature change).

Due to topological modifications in RH rail, secondary changes were made to the following:

- Suspension tower (Skirt)
- Battery size and position changed due to changes in the front rail design

- Reinforcement added at the front of the RH rail, due to engine divot, and at the rear of the rail, due to tire flop (rail plan curvature change).

The bumper design was a modification of the Third Bumper Design. The bumper height and width were suitably increased in order to achieve a better crush pattern.

		Upgraded Powertrain		
Location	TargetsPeak Values(g)	Peak value (g)	Time at peak (ms)	Remarks
B-Pillar - LH	26	27	26	
B-Pillar - RH	26	30	69	
Engine Top	Not more than 122g after 35 ms	283	24	Intermittent target enabler
Dashpanel	40 g at 45 ms	61	55	Intermittent target enabler

Table 5.19: NCAP - Accelerations

Parameter	Location	Targets (cm)	Upgraded Powertrain(cm)
Intrusion	Footwell - Left	12	24.9
	Footwell - Center	14	20.4
	Footwell - Right	13	15.8
	A-B closure	-	1.4

Table 5.20: IIHS - Intrusions

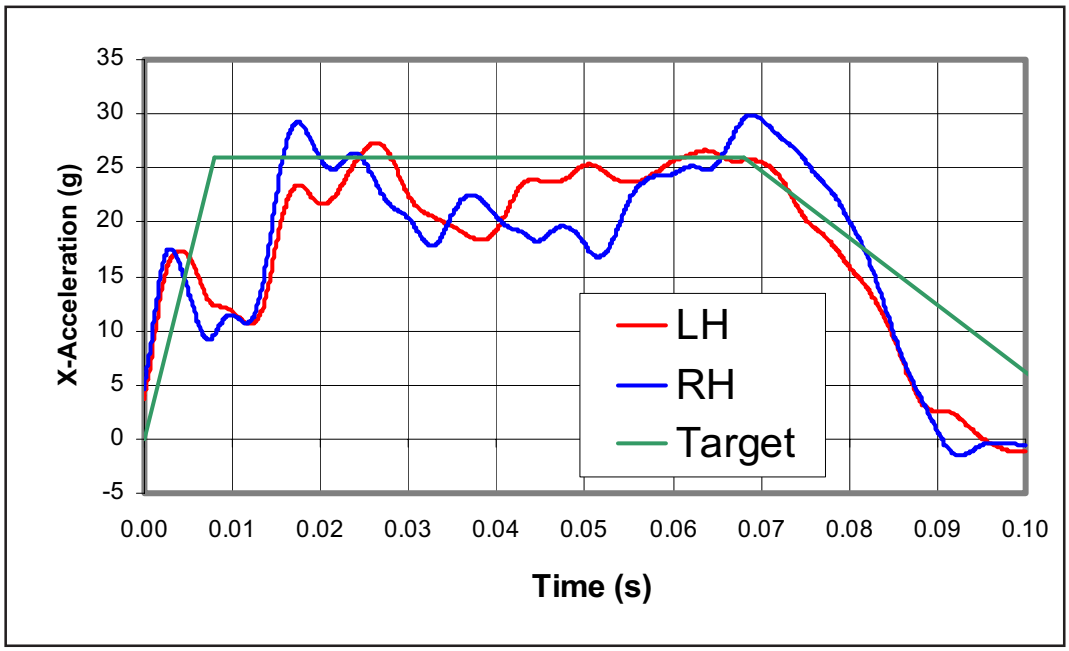


Figure 5.10: NCAP - B-Pillar Pulse

Results Summary

Tables 5.19 and 5.20 compare the crash response of the upgraded baseline model with the targets established in Phase I (Ref. 1). The IIHS intrusions are considerably higher than the established targets. The peak B-pillar acceleration in NCAP is higher than the target value of 26g and occurs after 50ms, which is not desirable. The initial peak is also considerably lower than the desired target of 26g.

Upgraded Front End Package Static and Dynamic Stiffness Studies

The components of the front-end structure that were likely to affect the static and dynamic stiffness of the Upgraded Powertrain model , were considered in this study .

The Upgraded Powertrain model (Ref. 7) with the fourth bumper design (Ref. 9) was used for the static and dynamic stiffness study.

The parametric study was conducted based on the Design of Experiments method (D.O.E.). An experiment in this case referred to an analysis using NASTRAN.

Response surfaces were generated for the static and dynamic stiffness using regression analysis (Ref. 13).

The responses were validated by comparing the D.O.E. predictions with results from actual NASTRAN runs. The validation runs were chosen in such a way that they span the entire design space.

Design Parameters and Bounds

The static and dynamic stiffness study includes 24 front-end parameters - 3 topological and 21 gauges. The static and dynamic stiffness study was conducted on the right half model of the BIW, in order to be consistent with the stiffness study of the Baseline ULSAB model. Since the elevation (XZ) curvature occurs only the left side, this parameter is not relevant in the stiffness study. Table 5.21 summarizes the gauge of each component as well as the topological parameters, and their levels. The lower-gauge levels on the parameters were determined from formability and durability considerations.

D.O.E Model

S.N.	Component Name	L81 Col	PID	Level 1	Level 2*	Level 3
1a	Bumper Middle Section	26	400021	1.3	1.6	2.0*
1b	Bumper End Section	26	400023	1.3	1.6	2.0*
1c	Bumper Middle Plate	26	400022	1.3	1.6	2.0*
2	Rail Front Inner	36	65021	1.0	1.5	2.0
3	Rail Front Outer	38	65011	1.0	1.5	2.0
4	Rail Mid Inner	10	65022	1.0	1.6	2.0
5	Rail Mid Outer	18	65012	1.0	1.6	2.0
6	Rail Rear Inner	13	65023	1.0	1.8	2.0
7	Rail Rear Outer	20	65013	1.0	1.5	2.0*
8	Shot Gun Inner	12	65049	0.7	1.2	2.0
9	Shot Gun Outer	15	65051	0.7	0.9	2.0
10a	Rail Extension	32	65035	1.0	1.4	2.0
10b	Rail Extension Reinf	32	65033	0.8	1.0	1.2
11	Ist Cross Member	9	60031	0.7	1.2	2.0
12a	Skirt 1	17	65039	1.0	1.6	2.0
12b	Skirt 2	17	65040	1.0	1.5	2.0*
13	A-Pillar Upper	23	65225	1.0	1.5	2.0
14a	A-Pillar Body Side Outer	21	65277	1.0	1.5	2.0
14b	A-Pillar Body Side Outer	21	65278	1.0	1.7	2.0
15	A-Pillar Hinge Pillar	1	65226	1.0*	1.5	2.0
16	B-Pillar Inner	2	65261	1.0	1.5	2.0
17	B-Pillar Body Side Outer	16	65273	1.0	1.3	2.0
18	Rocker Inner	5	65221	1.0	1.7	2.0
19a	B-Pillar Body Side Outer	33	65274	0.9*	1.5	2.0
19b	Rocker Inner	33	65222	1.0	1.3	2.0
20	Roof Rail	37	65241	0.8	1.0	1.2
21	Dash Panel	14	60071	0.6	0.7	1.2
22	XY Curve	29	-	High	Low	-
23	Shot Gun Width	34	-	Baseline	Baseline+10mm	-
24	Rail Length	28	-	Baseline	Baseline+50mm	-

* Baseline values

Table 5.21: Staic and Dynamic Stiffness D.O.E. Parameters

The topological parameters have two levels, where as the gauge parameters have three levels. Consequently, the D.O.E model is a mixed level model. A modified L81 array was used for this purpose. All interactions were taken between gauge factors. Thus, three columns out of 81 were eliminated. These redundant columns arise due to the fact that the three topological factors have only 2 levels. The resulting array is balanced in all main effects, except those for the three topological factors. All interactions are balanced as well, since they are between the gauge factors. The results of the IIHS study are analyzed using the techniques of regression analysis (Ref. 13).

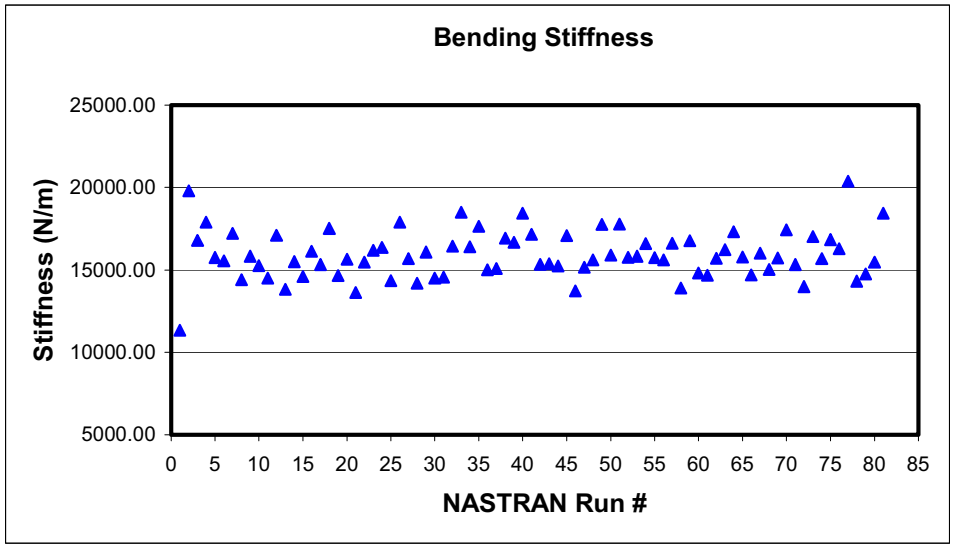


Figure 5.11: Bending Stiffness

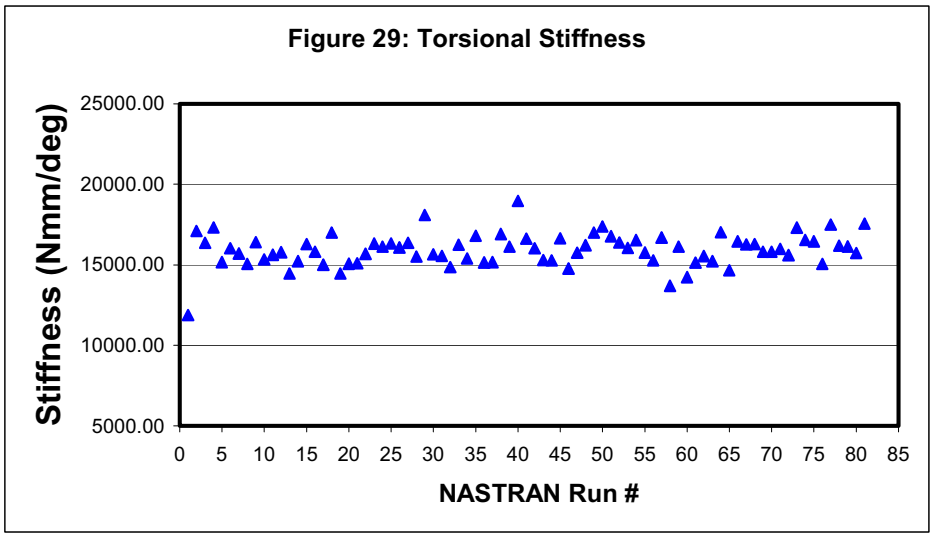


Figure 5.12: Torsional Stiffness

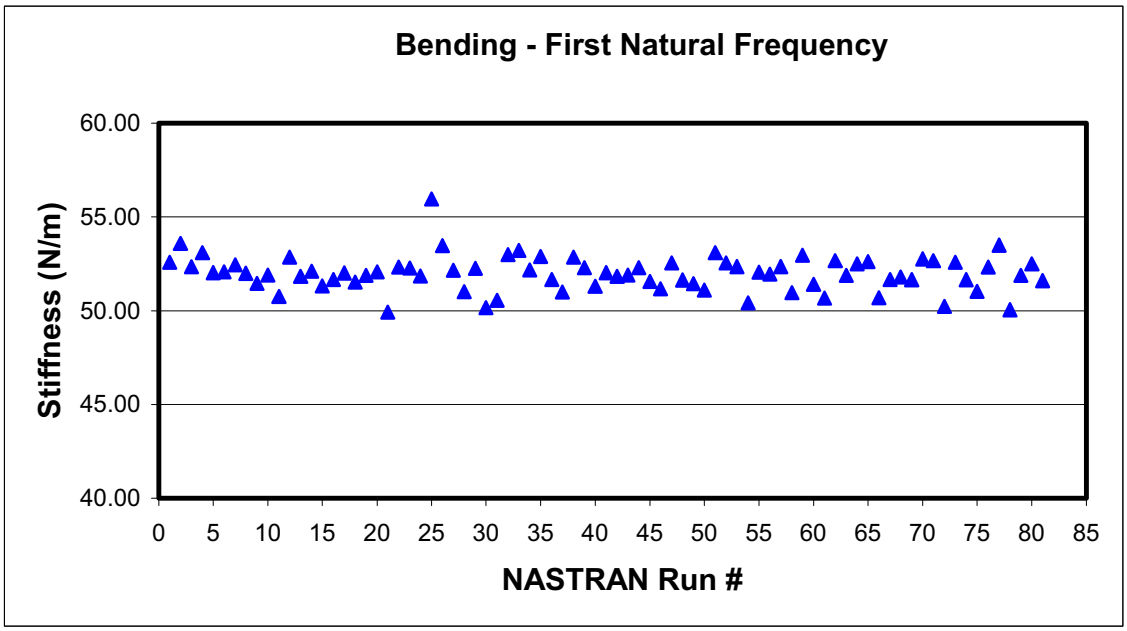


Figure 5.13: Bending - First Natural Frequency

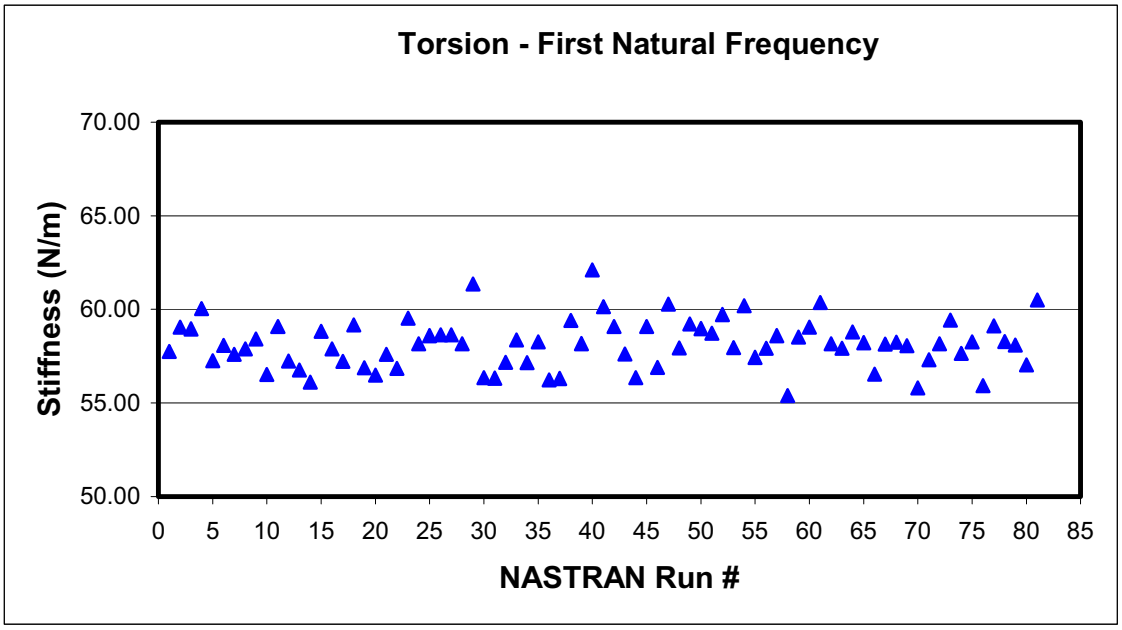


Figure 5.14: Torsion - First Natural Frequency

Results and Discussion

The static and dynamic stiffness are plotted in Figures 5.11-5.14. The minimum and maximum bending stiffness were 11341 N/mm and 20375 N/mm respectively. The minimum and maximum torsional stiffness were 11891 Nm/deg and 18970 Nm/deg respectively. The minimum and maximum bending frequencies were 49.9 Hz and 56.0 Hz respectively. The minimum and maximum torsional frequencies were 55.4 Hz and 62.1 Hz respectively. The values derived from the response surface yielded values outside these bounds. However, the minimum and maximum values from the D.O.E runs did indicate the range of variation expected in the design space. The variation for the modal response was much less than that for the static stiffness response. This was consistent with the D.O.E study of the initial front end package. The gauge had the same first order effect on mass and stiffness. Since modal frequencies were a function of the ratio of mass to stiffness, there was little net effect of stiffness. The topological factors also did not cause much variation in the modal response.

	All Level 2			All Level 3		
Response	DOE	Actual	% Error	DOE	Actual	% Error
Bending Stiffness (N/mm)	16115	16258	-0.9	20095	21717	-7.5
Torsional Stiffness (Nm/deg)	16181	16118	0.4	19283	19629	-1.8
Bending Frequency (Hz)	51.5	52.2	-1.2	53.2	53.8	-1.0
Torsional Frequency (Hz)	58.1	58.8	-1.3	60.9	60.9	0.007

Table 5.22: Static and Dynamic Stiffness % Error

Table 5.22 shows the correlation between the values predicted by D.O.E, and the actual values from LS-DYNA3D runs. The predictions were within 2% of the actual NASTRAN values, except for bending stiffness response, for which the maximum error is 7.5%.

The response surfaces for static stiffness and modal frequencies were employed for supplying constraint functions for the optimization of the Upgraded Powertrain model, in order to generate the Library of Designs. They can also be used to assess the effect of design parameters on static and dynamic stiffness.

Upgraded Front End Package NCAP Study

The components of the front-end structure that were likely to affect the response of the Upgraded Powertrain model in the NCAP load case (Ref.1) were considered in this study.

The Upgraded Powertrain model (Ref. 7) with the fourth bumper design (Ref. 9) was used for the NCAP study.

The parametric study was conducted based on the Design of Experiments method (D.O.E.). Orthogonal Arrays and Linear Graphs have been for this purpose (Ref. 10-12). An experiment in this case referred to an NCAP analysis using LS-DYNA3D.

Response surfaces were generated for crush and B-pillar acceleration using regression analysis (Ref. 13).

The responses were validated by comparing the D.O.E. predictions with results from actual LS-DYNA3D runs. The validation runs were chosen in such a way that they span the entire design space.

The entire B-pillar pulse was predicted by generating response surfaces for maximum and minimum acceleration in 10ms time windows.

Design Parameters and Bounds

The NCAP study included the 31 front-end parameters - 4 topological, 14 gauges and 13 grades. Table 5.23 summarizes the gauge and grade levels of each component. Table 5.24 shows the four topological parameters and their levels. The lower-gauge levels on the parameters were determined from formability and durability considerations. The higher-grade levels were also determined from formability considerations.

S.N.	Component	Thickness (mm)		Material Yield / Ultimate (MPa)	
		Level 1*	Level 2**	Level 1	Level 2
1a	Bumper Middle Section	1.2	1.6	Post Bake DP 585/965	DP 700/1000
1b	Bumper End Sections	1.2	1.6	Post Bake DP 585/965	DP 700/1000
1c	Bumper Middle Plate	1.2	1.6	Post Bake DP 585/965	DP 700/1000
2	Rail Front Inner	1.4	1.9	HSLA 350/450	DP 500/800
3	Rail Front Outer	1.4	1.9	HSLA 350/450	DP 500/800
4	Rail Mid Inner	1.5	2.0	HSLA 350/450	DP 500/800
5	Rail Mid Outer	1.5	2.0	HSLA 350/450	DP 500/800
6	Rail Rear Inner	1.6	2.2	HSLA 350/450	DP 500/800
7	Rail Rear Outer	1.8	2.4	HSLA 350/450	DP 500/800
8	Shot Gun Inner	1.1	1.5	HSLA 425/770	DP 500/800
9	Shot Gun Outer	0.8	1.1	HSLA 350/450	DP 500/800
10a	Rail Extension	1.3	1.8	HSLA 350/450	DP 500/800
10b	Rail Extension Reinf.	1.3	1.8	HSLA 350/450	DP 500/800
11	Cradle Extension	1.4	1.9	DP 280/600	DP 500/800
12	lst Cross Member	1.1	1.5	HSLA 425/770	DP 700/1000
13a	Skirt 1	1.5	2.0	AKDQ 160/525	DP 280/600
13b	Skirt 2	1.8	2.4	AKDQ 160/525	DP 280/600
14a	Cradle CM Ubar 1	1.2	1.6	DP 500/800	DP 500/800
14b	Cradle CM Ubar 2	1.5	2.0	DP 500/800	DP 500/800
14c	Cradle	1.8	2.4	DP 500/800	DP 500/800

* Level 1 = 10% less than Initial Front End Package baseline

** Level 2 = 20% more than Initial Front End Package baseline

Table 5.23: NCAP D.O.E. Parameters

S.N.	Topological Parameter	Upgraded Powertrain Baseline	Level 1	Level 2
1	Elevation (XZ) Curvature of LH Rail	Higher Bump Height = 2h	Higher Bump Height = 2h	Lower Bump Height = h
2	Plan (XY) Curvature of both LH and RH Rails	Higher Curvature Height = 2h	Higher Curvature Height = 2h	Lower Curvature Height = h
3	Rail Length	l =100 mm less than Baseline ULSAB	l	l + 50 mm
4	Shotgun Width	Width = w	w	w +10 mm

Note: Changes to other components like shotgun, cradle extension ext were done in conjunction with the above topological changes.

Table 5.24: Topological Parameters and Levels

D.O.E Model

The Design of Experiments Method was used for the NCAP parametric study. L64 orthogonal array was used for this study (Ref. 10-11). L64 array is a 2-level array that can accommodate 31 parameters with 32 interactions, using 64 runs. Interactions between various components of the previously conducted NCAP D.O.E study of the initial front end package (Ref. 6) were studied and the information gained from it was used to select the most significant interactions. The results were analyzed using the techniques of regression analysis (Ref. 13).

Results and Discussion

The experiments were conducted according to the L64 array. Each experiment constitutes an LS-DYNA3D run. The maximum crush, peak LH accelerations and peak RH acceleration were plotted in Figures 5.15, 5.16 and 5.17 respectively. The minimum and maximum crush were 592.82mm and 749.31mm respectively. The minimum and maximum LH accelerations were 19.52g and 35.62g respectively. The minimum and maximum RH accelerations were 26.62g and 47.3g respectively All 64 cases ran to normal completion. The crush and accelerations derived from the response surface yielded values outside these bounds. However, the minimum and maximum values from the 64 runs indicated the range of variation expected in the design space. This was because the L64 was a balanced array in which all factors are varied simultaneously across all levels.

The results from the 64 runs were analyzed using main effects, interaction plots and ANOVA. Regression analysis was used to generate response surfaces for maximum crush and B-pillar acceleration. It was determined from the NCAP D.O.E study of the Baseline model, that a response surface for the absolute acceleration peak could not be generated accurately.

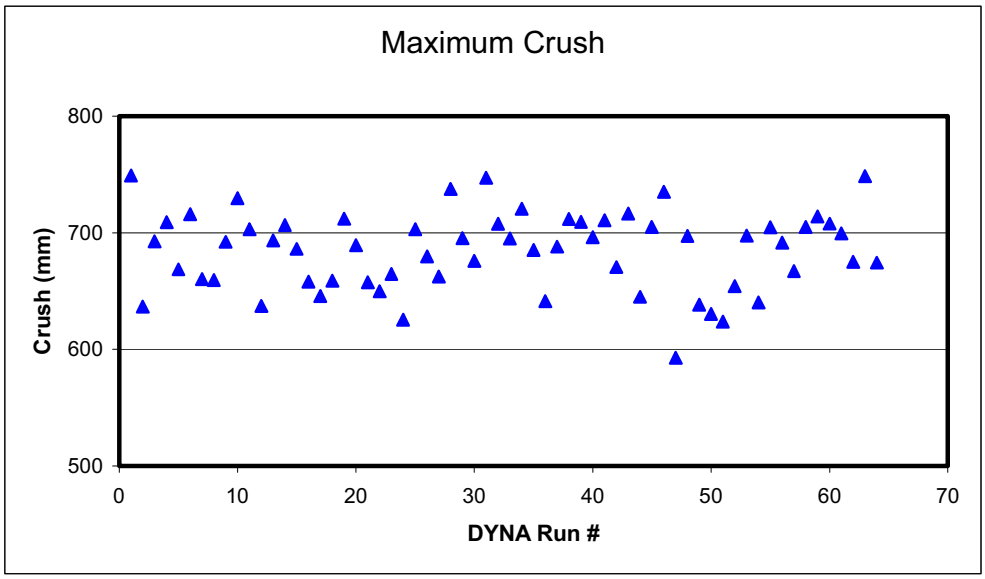


Figure 5.15: Crush Scatter Plot

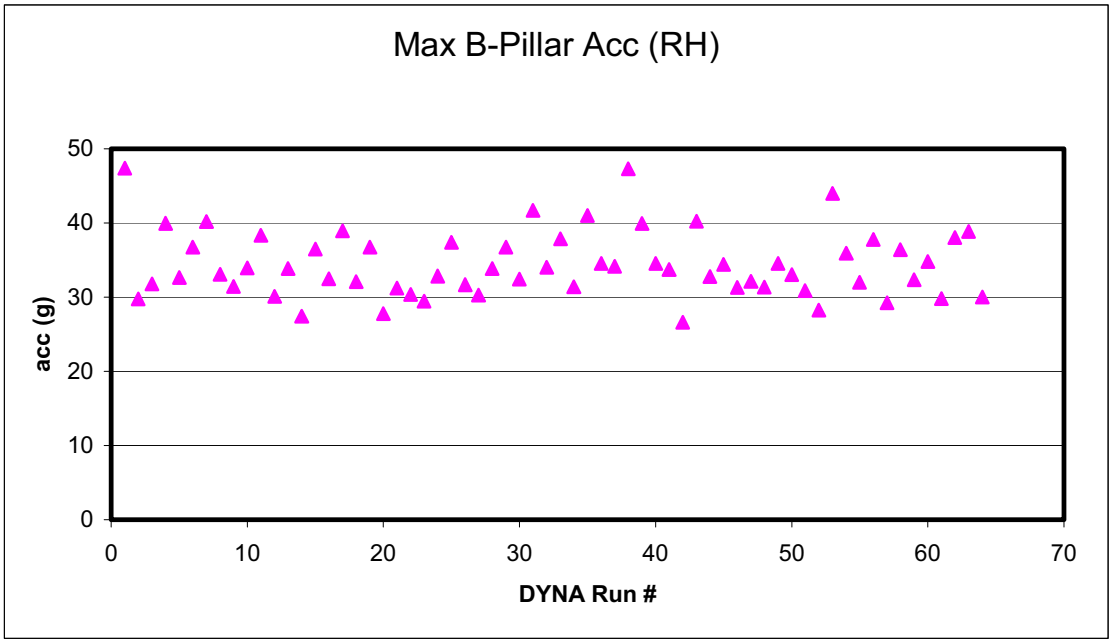


Figure 5.16: Max RH B-Pillar Accelerations Scatter Plot

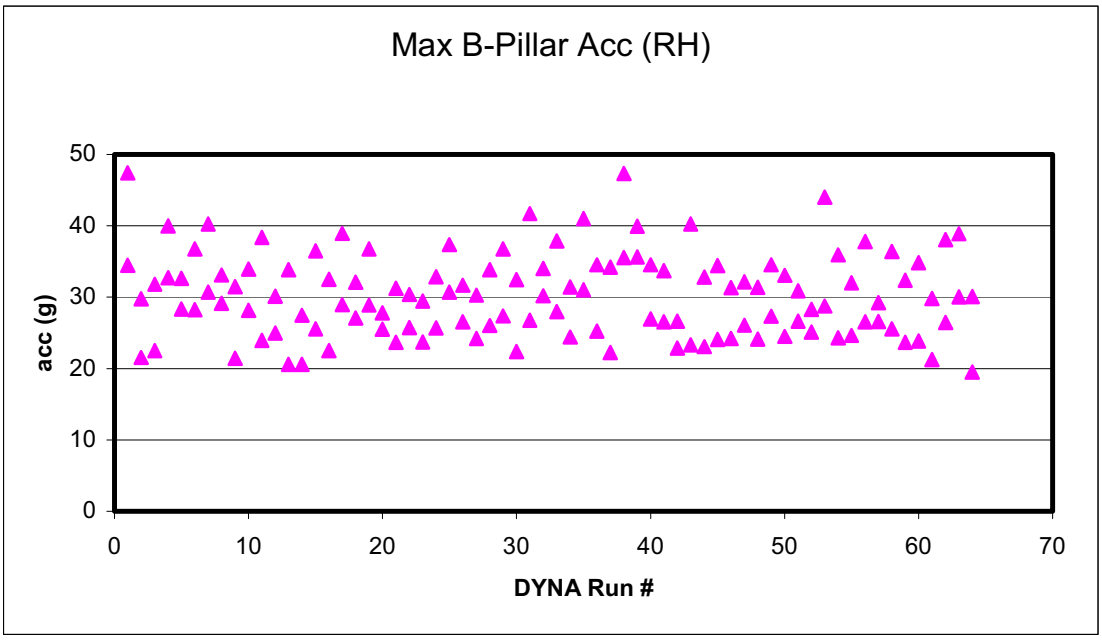


Figure 5.17: Max LH B-Pillar Accelerations Scatter Plot

Consequently, the entire pulse was broken up into segments of 10ms. the response surfaces were then generated for the maximum and minimum accelerations in each 10ms window. In this fashion, the entire B-pillar pulse was constructed. The choice of 10 ms for sampling was based on the observation that in most of the 64 runs, there was one local maximum and minimum every 10ms, related to a specific crash event. Choosing a window smaller than 10ms would increase the probability of an event shifting to the neighboring window. Increasing the window size would result in missing some local maxima and minima. Thus, a 10ms window was found to be appropriate for sampling the acceleration pulse.

For validation, several runs spanning the entire design space were given. The maximum crush and the entire B-pillar pulse were used for comparison. Figure 5.18 shows the correlation between the crush values predicted by D.O.E. and the actual values from LS-DYNA3D runs. The D.O.E predictions were within 10% of the actual LS-DYNA3D values, for the D.O.E space. Furthermore, the similar shape of the curves indicated that the sensitivities are also predicted correctly. In general, the D.O.E. predictions are on the higher side, thereby predicting a slightly softer system.

Figures 5.22 and 5.23 compare the B-pillar pulse predicted by D.O.E. and the actual pulse from LS-DYNA3D runs. The initial peak in the first 10ms was the most accurately predicted peak. The peaks close to the time of rebound were the most inaccurately predicted peaks. In general, the predictions at lower levels of grade and gauge were more accurate than at higher levels.

A measure of the accuracy of prediction was obtained by comparing crush and maximum acceleration between 50-70ms for predicted and actual values for 23 combinations that span the entire design space. These errors were plotted on a normalized design space in Figures 24-25. The blue rectangle represents the D.O.E. boundary on which the predictions will be the most accurate, as the L64 runs were conducted in this region. The region inside the blue rectangle represents the interpolated design space. The region outside the blue rectangle represents the extrapolated design space. The predictions are expected to be less accurate in the interpolated and extrapolated regions. The average error in the D.O.E. space was less than 4% for crush and less than 14% for acceleration. Extrapolating beyond the D.O.E. space resulted in inaccurate predictions for crush and acceleration.

An assessment of the relative importance of factors and interactions can be made by examining the Sum of the Squares (Ref. 10-12). Figures 5.19-5.21 plot the normalized Sum of Squares for crush, initial peak and the 50-70ms acceleration pulse. The accurate prediction for the initial peak was

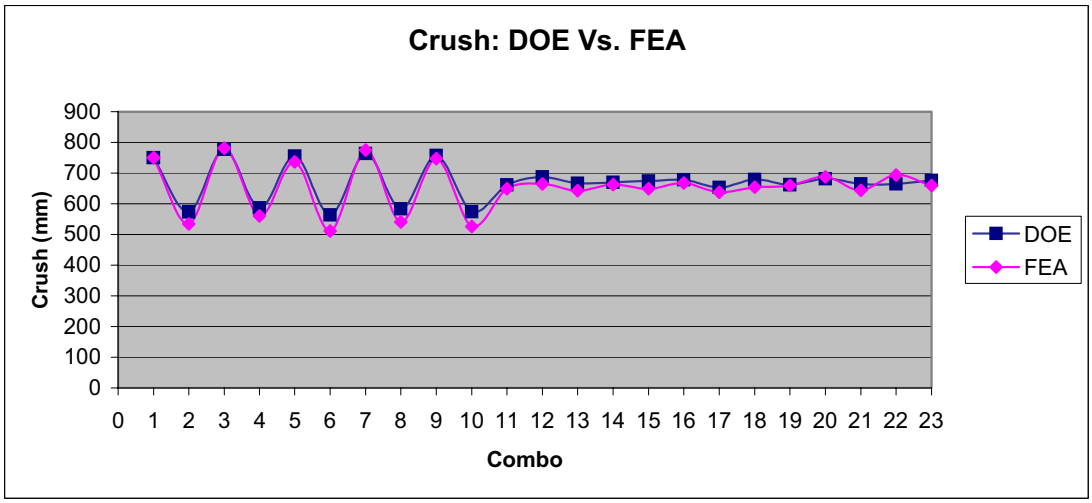


Figure 5.18: Crush Response Surface Verification

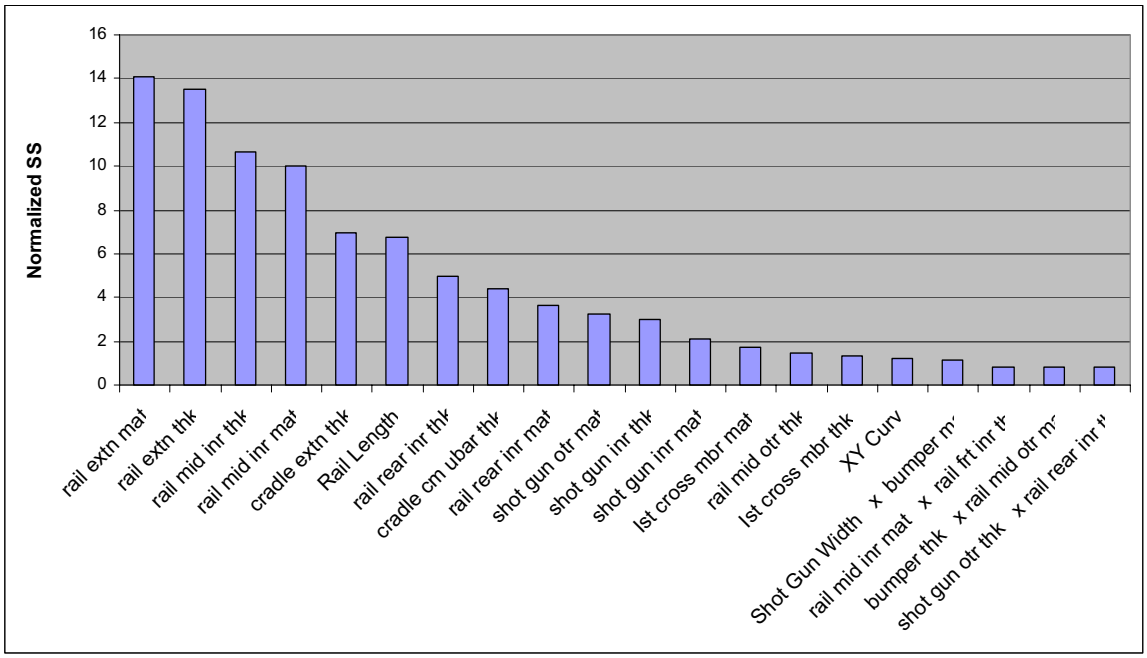


Figure 5.19: Crush Response - Top 20 Factors/Interactions

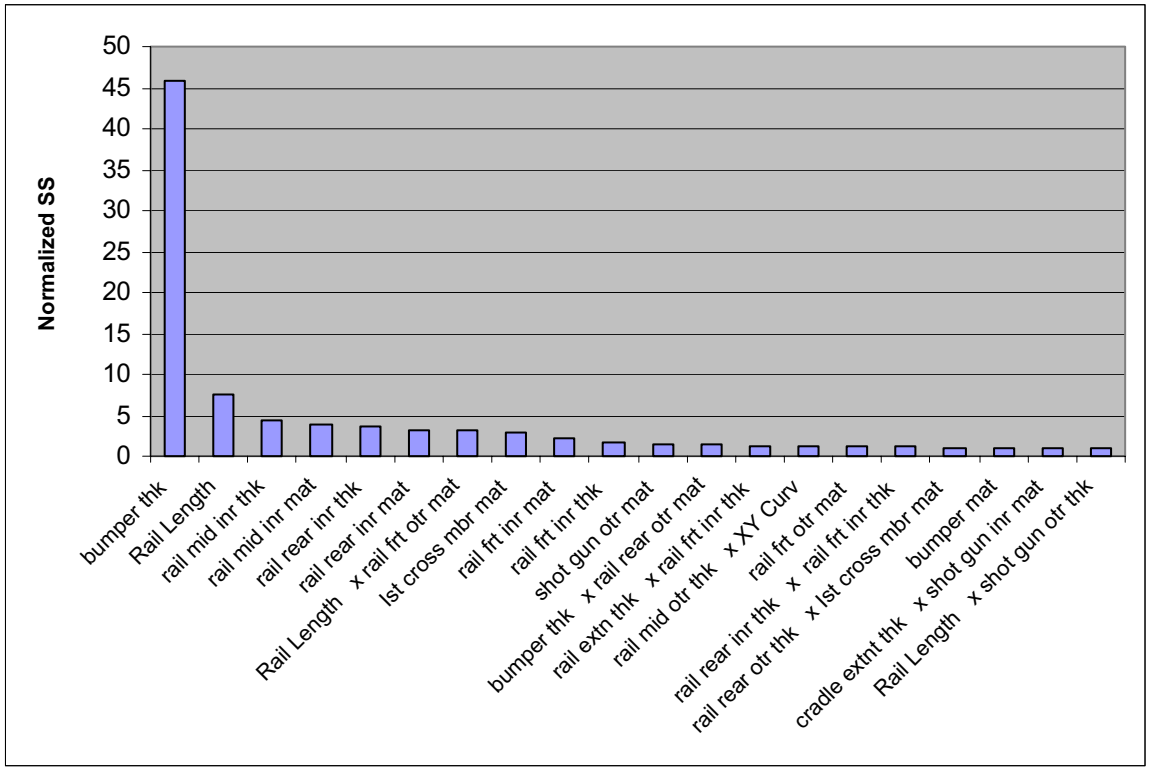


Figure 5.20: Initial Peak - Top 20 Factors/Interactions

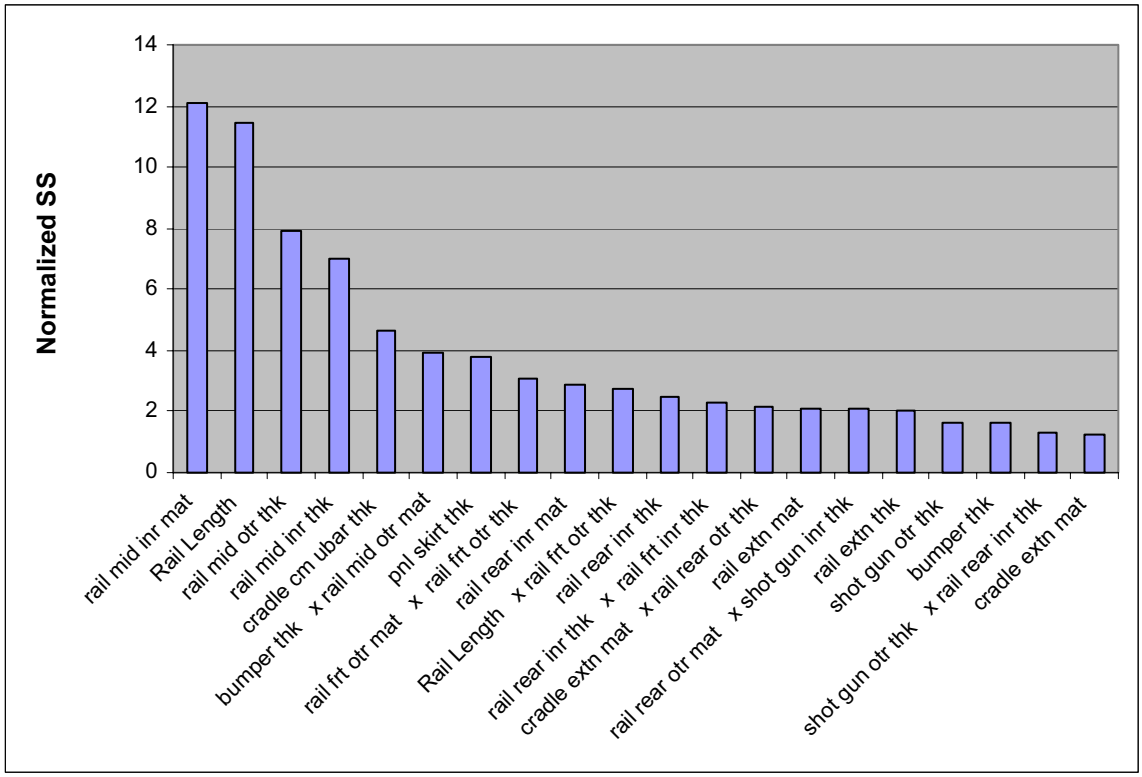


Figure 5.21: 40-70 ms Peak - Top 20 Factors/Interactions

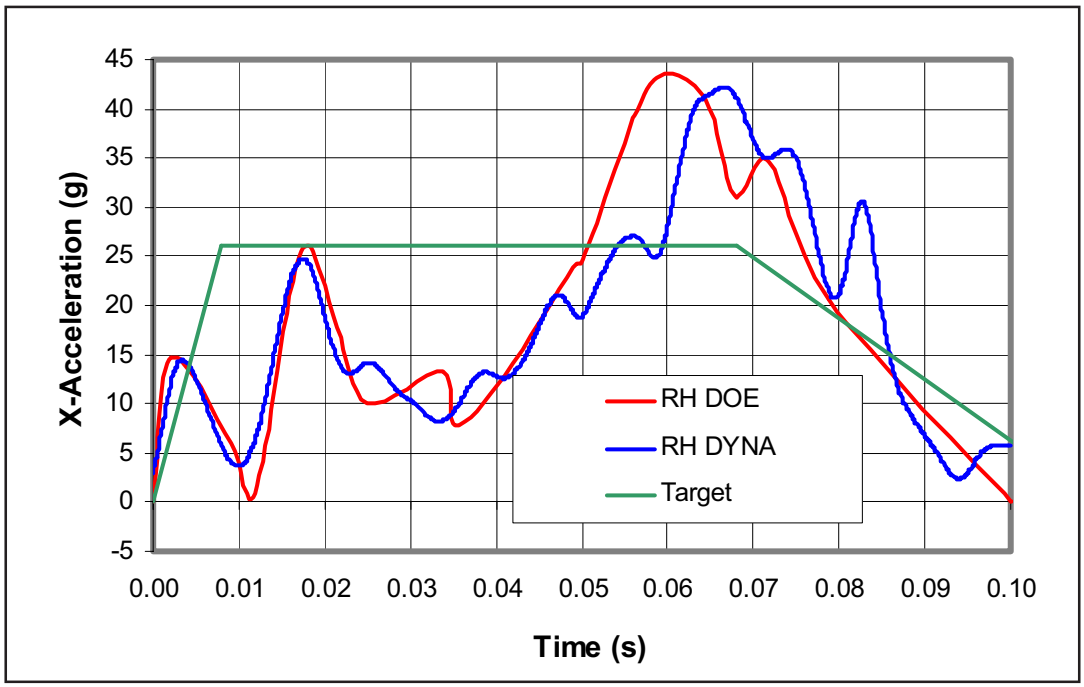


Figure 5.22: Topological Set 2 - All Grade/Gauge at Lower Levels

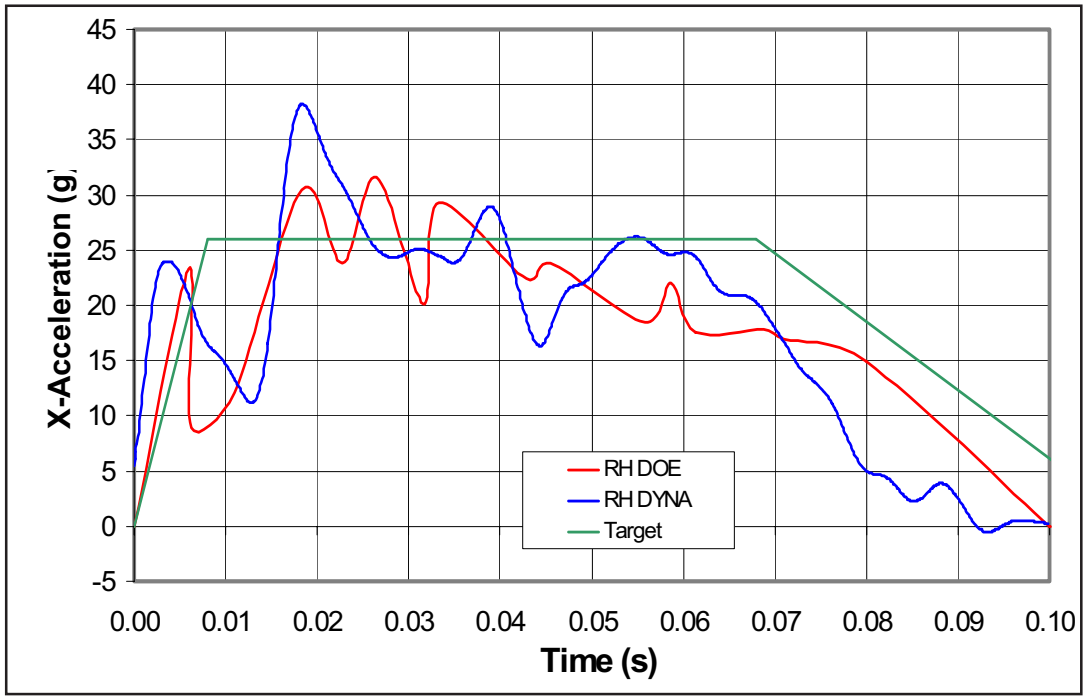


Figure 5.23: Topological Set 2 - All Grade/Gauge at Higher Levels

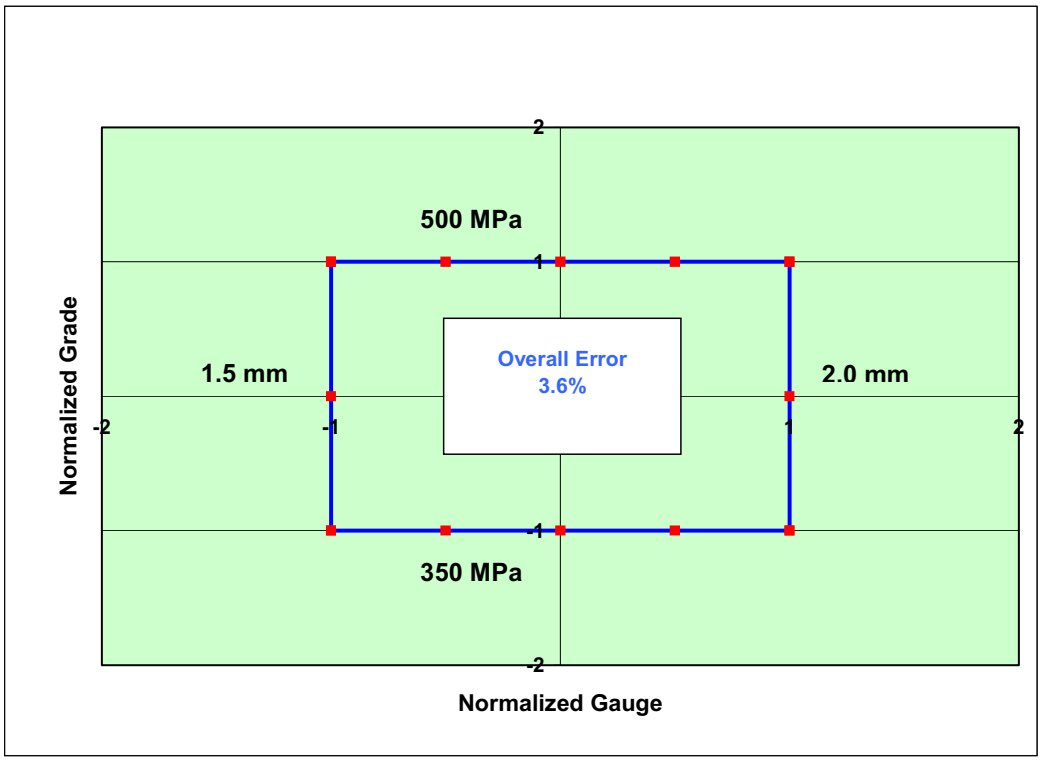


Figure 5.24: Design Space - Crush % Error

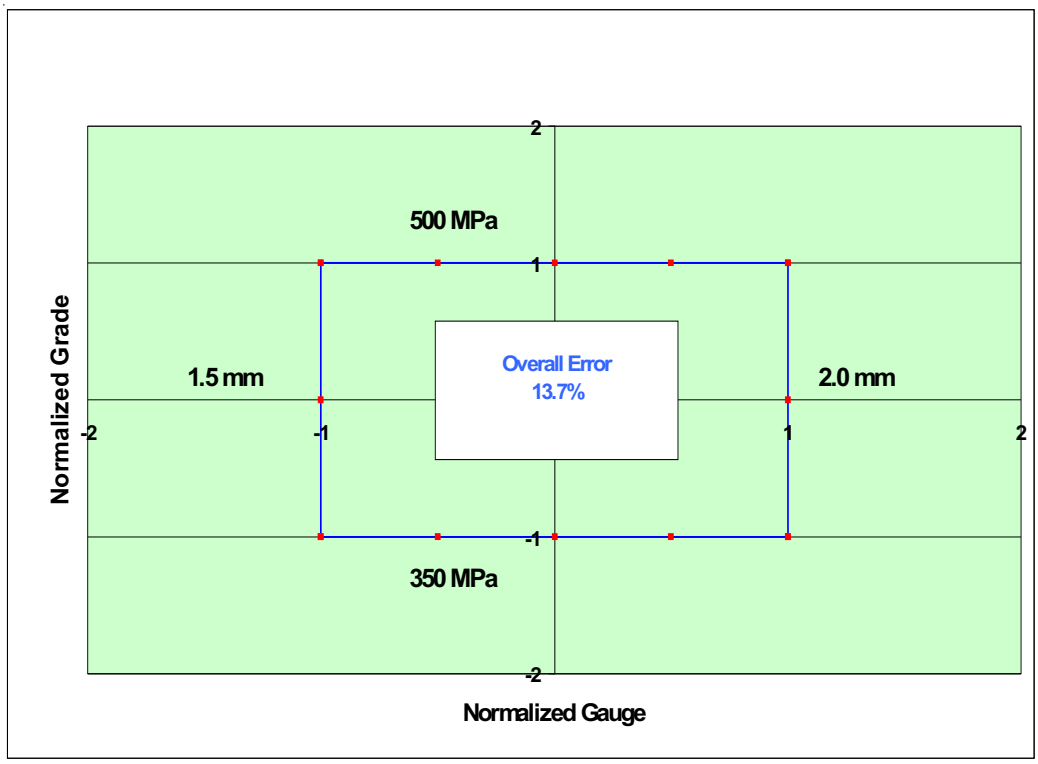


Figure 5.25: Design Space - Max RH Acc % Error

explained by the fact that the bumper thickness accounts for 45% of the Sum of Squares. Hence, the initial peak was basically determined by the bumper thickness, and no interactions are significant. The prediction for crush was also quite accurate as main effects were more dominant than interactions. The accuracy for 50-70ms acceleration pulse was less accurate as interactions were quite significant.

The NCAP response surfaces will be employed for supplying constraint functions for the optimization of the Upgraded Powertrain model, in order to generate the Library of Designs. They can also be used to assess the effect of design parameters on NCAP response.

Upgraded Front End Package IIHS Study

The components of the front-end structure that were likely to affect the response of the Upgraded Powertrain model in the IIHS load case (Ref.1), were considered in this study (Table 5.25).

The Upgraded Powertrain model (Ref. 7) with the fourth bumper design (Ref. 9) was used for the IIHS study.

The parametric study was conducted based on the Design of Experiments method (D.O.E.). An experiment in this case refers to an IIHS analysis using LS-DYNA3D.

Response surfaces were generated for the footwell intrusions using regression analysis (Ref. 13).

The responses were validated by comparing the D.O.E. predictions with results from actual LS-DYNA3D runs. The validation runs were chosen in such a way that they span the entire design space.

Design Parameters and Bounds

The IIHS study included the 46 front-end parameters - 4 topological, 21 gauges and 21 grades. Compared to the NCAP study, additional A-pillar and B-pillar components were included in the IIHS study. These components had a significant effect on the IIHS intrusions. Table 5.25 summarizes the gauge and grade levels of each component. Table 5.26 shows the four topological parameters and their levels. The lower-gauge levels on the parameters were determined from formability and durability considerations. The higher-grade levels were also determined from

S.N.	Component	Thickness (mm)		Material Yield / Ultimate (MPa)	
		Level 1*	Level 2**	Level 1	Level 2
1a	Bumper Middle Section	1.2	1.6	Post Bake DP 585/965	DP 700/1000
1b	Bumper End Sections	1.2	1.6	Post Bake DP 585/965	DP 700/1000
1c	Bumper Middle Plate	1.2	1.6	Post Bake DP 585/965	DP 700/1000
2	Rail Front Inner	1.4	1.9	HSLA 350/450	DP 500/800
3	Rail Front Outer	1.4	1.9	HSLA 350/450	DP 500/800
4	Rail Mid Inner	1.5	2.0	HSLA 350/450	DP 500/800
5	Rail Mid Outer	1.5	2.0	HSLA 350/450	DP 500/800
6	Rail Rear Inner	1.6	2.2	HSLA 350/450	DP 500/800
7	Rail Rear Outer	1.8	2.4	HSLA 350/450	DP 500/800
8	Shot Gun Inner	1.1	1.5	HSLA 425/770	DP 500/800
9	Shot Gun Outer	0.8	1.1	HSLA 350/450	DP 500/800
10a	Rail Extension	1.3	1.8	HSLA 350/450	DP 500/800
10b	Rail Extension Reinf.	1.3	1.8	HSLA 350/450	DP 500/800
11	Cradle Extension	1.4	1.9	DP 280/600	DP 500/800
12	Ist Cross Member	1.1	1.5	HSLA 425/770	DP 700/1000
13a	Skirt 1	1.5	2.0	AKDQ 160/525	DP 280/600
13b	Skirt 2	1.8	2.4	AKDQ 160/525	DP 280/600
14a	Cradle CM Ubar 1	1.2	1.6	HSLA 350/450	DP 500/800
14b	Cradle CM Ubar 2	1.5	2.0	HSLA 350/450	DP 500/800
14c	Cradle	1.8	2.4	HSLA 350/450	DP 500/800
	Hinge Pillar and Assembly				
15	Rocker Inner	1.5	2.0	HSLA 350 / 450	DP 500/800
16	Hinge Pillar	0.9	1.2	HSLA 350 / 450	DP 500/800
17	A-Pillar Upper	1.3	1.8	HSLA 350 / 450	DP 500/800
18a	Body Side Otr A-Pillar m	1.3	1.8	HSLA 350 / 450	DP 500/800
18b	Body Side Otr A-Pillar	1.5	2.0	HSLA 350 / 450	DP 500/800
	B Pillar / Roof Rail Asm				
19	B-Pillar Inner	1.3	1.8	HSLA 350 / 450	DP 500/800
20	Body Side Otr B-Pillar	1.2	1.6	DP 280 / 600	DP 500/800
21	Roof Side Rail	0.9	1.2	DP 280 / 600	DP 500/800

* Level 1 = 10% less than Initial Front End Package baseline

** Level 2 = 20% more than Initial Front End Package baseline

Table 5.25: IIHS D.O.E. Parameters

S. N.	Topological Parameter	Upgraded PowertrainBaseline	Level 1	Level 2
1	Elevation (XZ) Curvature of LH Rail	Higher Bump Height = 2h	Higher BumpHeight = 2h	Lower BumpHeight = h
2	Plan (XY) Curvature of both LH and RH Rails	Higher Curvature Height = 2h	Higher CurvatureHeight = 2h	Lower CurvatureHeight = h
3	Rail Length	l =100 mm less than Baseline Model	l	l + 50 mm
4	Shotgun Width	Width = w	w	w +10 mm

Table 5.26: Topological Parameters and their Levels

formability considerations.

D.O.E Model

Due to the large number of variables in the IIHS study, a different approach was used for the design of experiments. An unbalanced, nearly orthogonal array was used to determine the main effects. The accuracy of the response surface based only on the main effects was tested. Additional DYNA runs were then given in order to determine interaction terms. In this way, the response surface was progressively made more accurate by adding more interaction terms. The results of the IIHS study were analyzed using the techniques of regression analysis (Ref. 13).

Results and Discussion

The footwell intrusions are plotted in Figures 5.26-5.28. The minimum and maximum left footwell intrusions were 9.3 cm and 28.1 cm respectively. The minimum and maximum center footwell intrusions were 8.9 cm and 26.5 cm respectively. The minimum and maximum right footwell intrusions were 6.5 cm and 18.9 cm respectively. All DYNA runs ran to normal completion. The intrusions derived from the response surface yielded values outside these bounds. However, the minimum and maximum values from the 64 runs did indicate the range of variation expected in the design space.

Figures 5.29-5.31 shows the correlation between the intrusions predicted by regression analysis and the actual values from LS-DYNA3D runs. The similar shape of the curves indicated that the sensitivities were predicted correctly. In general, the predictions were more accurate for lower grade and gauge combinations.

The regression errors were plotted on a normalized design space in Figure

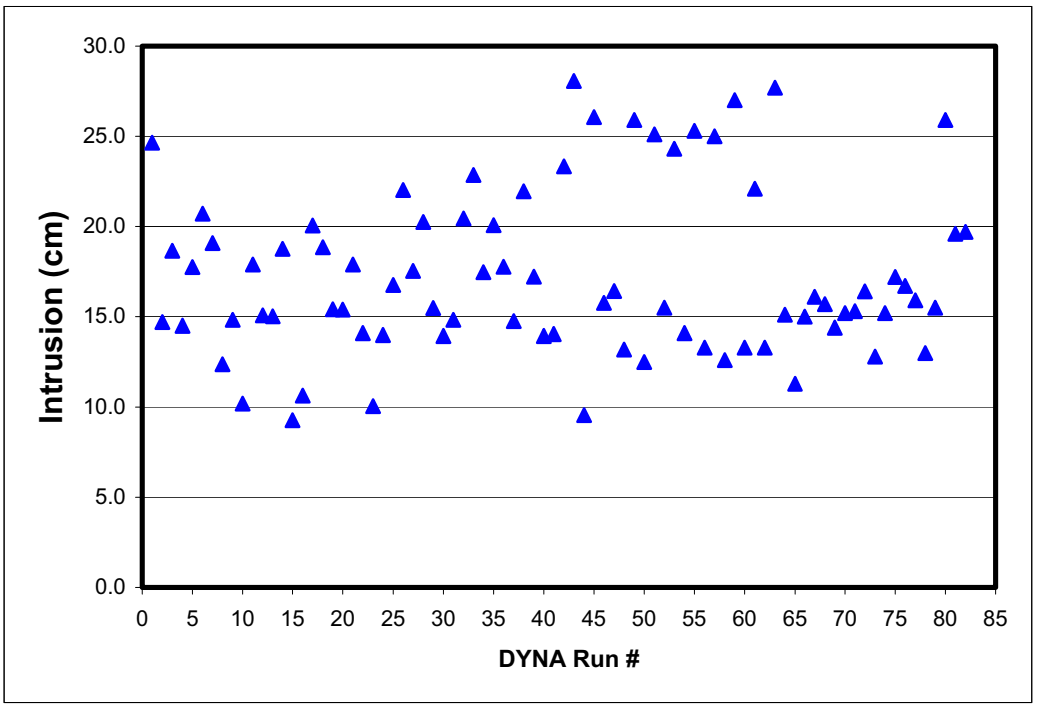


Figure 5.26: Left Footwell Intrusion

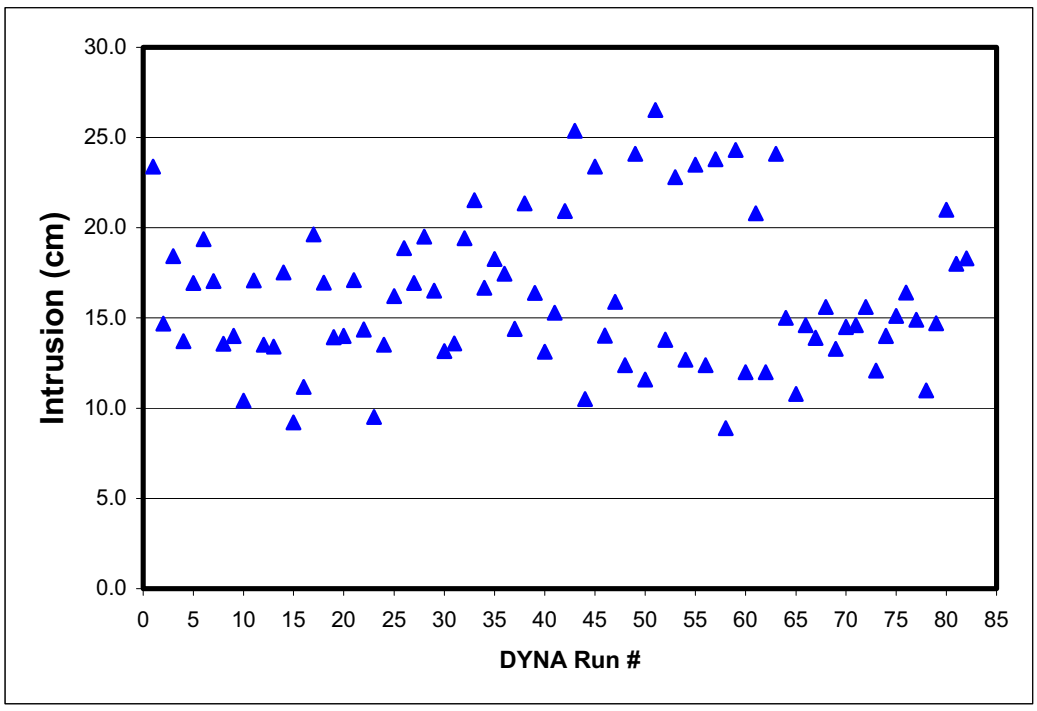


Figure 5.27: Center Footwell Intrusion

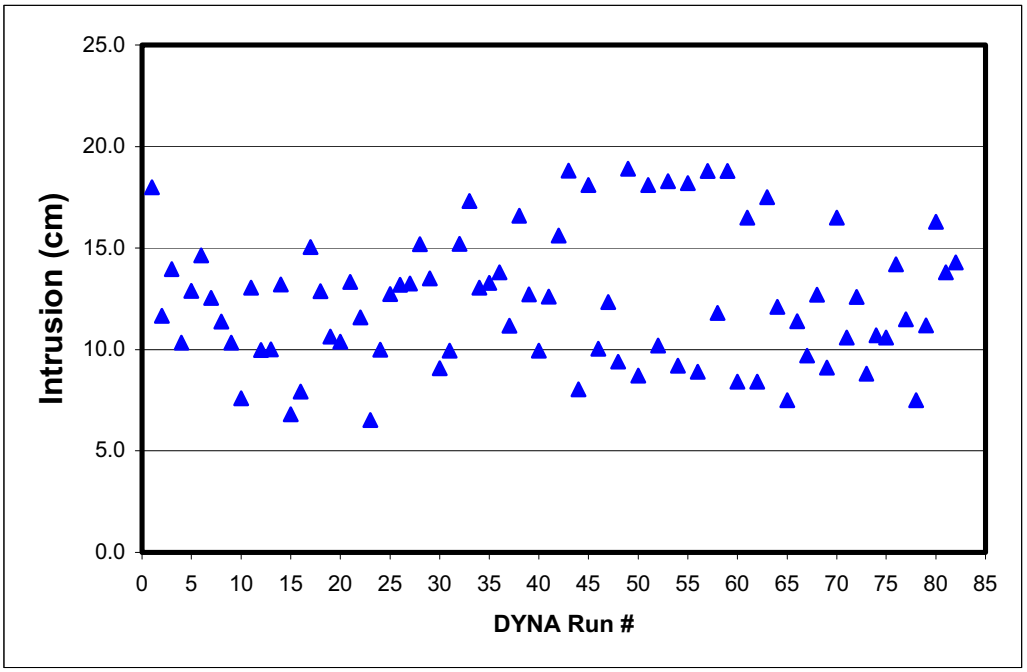


Figure 5.28: Right Footwell Intrusion

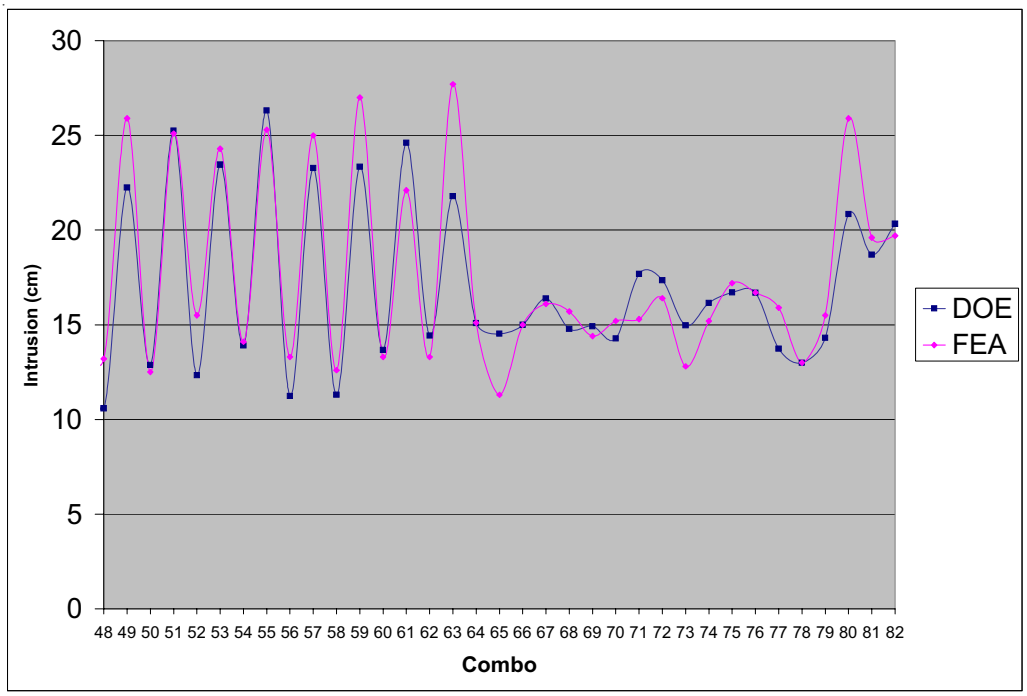


Figure 5.29: Left Footwell Intrusion D.O.E. vs. FEA

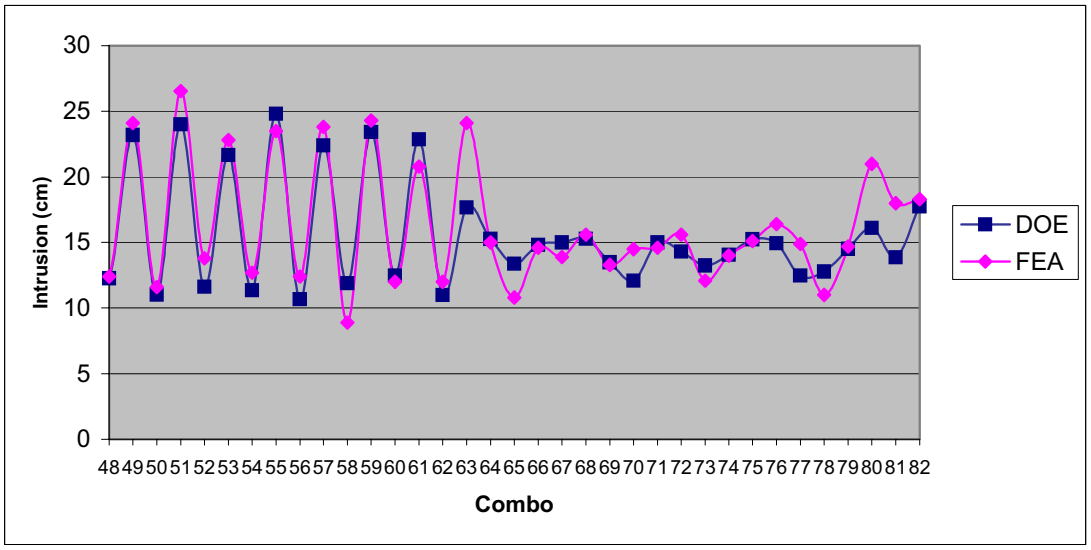


Figure 5.30: Center Footwell Intrusion D.O.E. vs. FEA

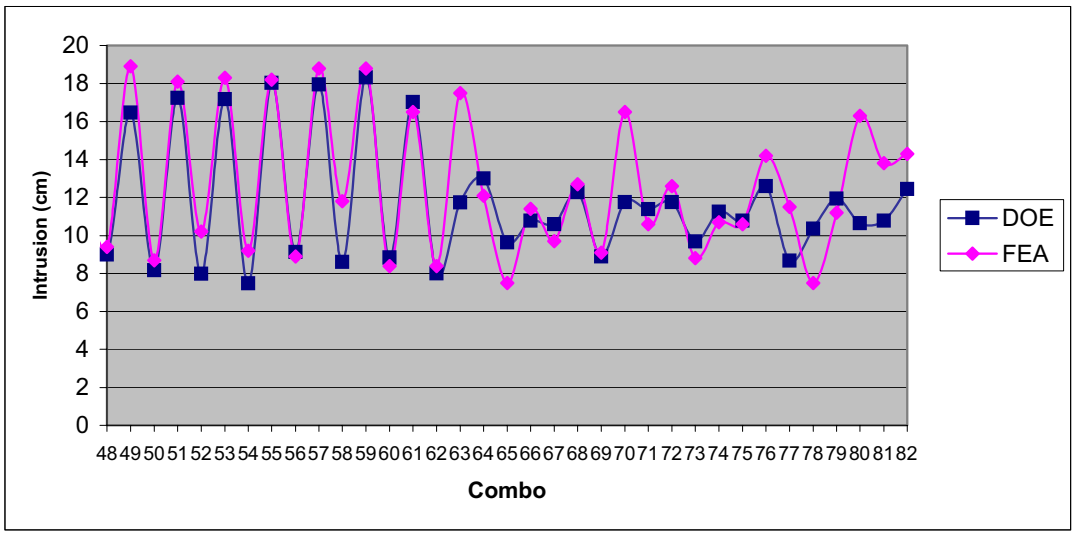


Figure 5.31: Right Footwell Intrusion D.O.E. vs. FEA

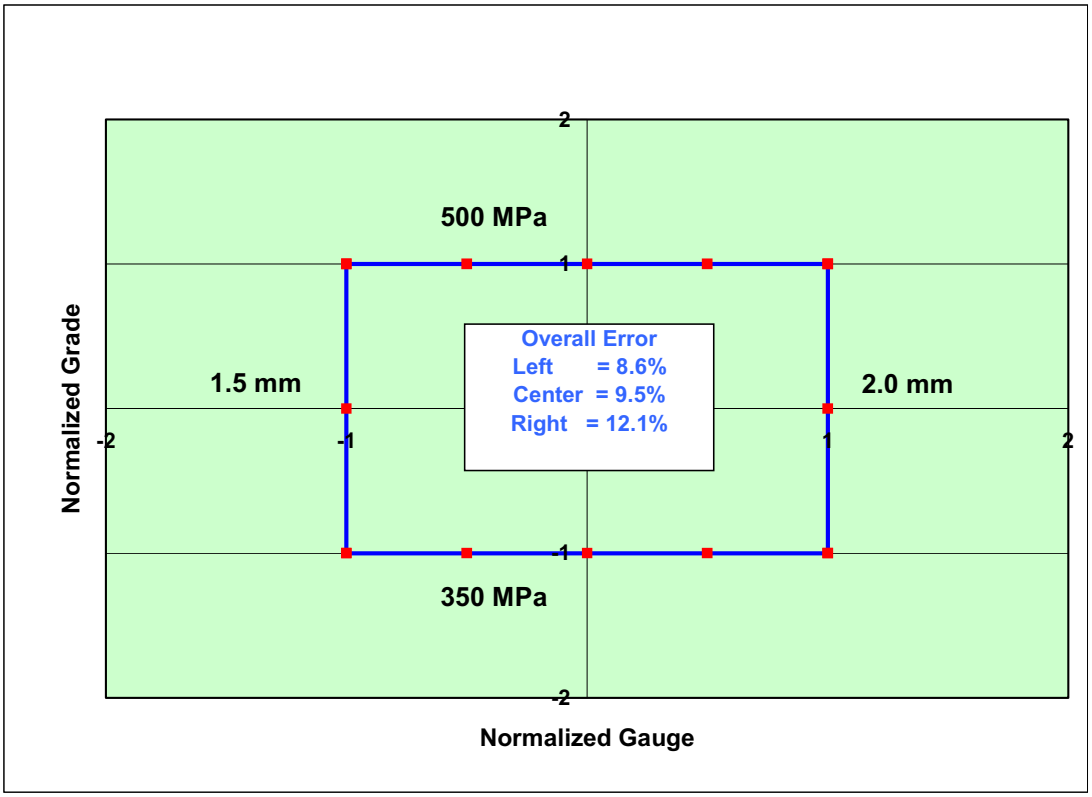


Figure 5.32: Design Space - Footwell Intrusion % Error

5.32. The blue rectangle represents the D.O.E. boundary on which the predictions will be the most accurate. The region inside the blue rectangle represents the interpolated design space. The region outside the blue rectangle represents the extrapolated design space. The predictions are expected to be less accurate in the interpolated and extrapolated regions. The average regression error for the footwell intrusions in the design space was less than 12%. Extrapolating beyond the D.O.E. space resulted in inaccurate predictions for the footwell intrusions.

The IIHS response surfaces will be employed for supplying constraint functions for the optimization of the Upgraded Powertrain model, in order to generate the Library of Designs. They can also be used to assess the effect

of design parameters on IIHS response.

Conclusions

Parametric studies of the Upgraded Front End Package have been undertaken, based on the methodology of Design of Experiments (D.O.E). The parametric studies have been performed for NCAP, IIHS, static and dynamic stiffness. Regression analysis has been employed for the generation of response surfaces from the D.O.E. results. The response surfaces obtained from these studies will be employed for the Computer Aided Optimization (C.A.O.) of the upgraded powertrain model, in order to generate the Library of Designs. The response surfaces may also be used to conduct parametric analysis of the front-end structure and to evaluate the structural performance of specific designs.

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Performance Matrix Computer Aided Optimization

Objectives

This chapter discusses the performance matrix obtained from the regression analyses of the results of the D.O.E. based parametric studies of the Initial and Upgraded front end packages. The performance matrix is utilized by the knowledge base tool, *Proteus*, as well as for computer-aided optimization.

Performance Matrix

The performance matrix includes the following responses:

Initial Front End Package:

NCAP

Static Stiffness

Dynamic Stiffness

Upgraded Front End Package:

NCAP

IIHS

Static Stiffness

Dynamic Stiffness

Initial Front End Package - NCAP

The performance matrix for the Initial Front End Package NCAP response was derived from a 2-level L-64 D.O.E study (Ref. 6). The responses included were crush and the entire LH and RH B-pillar acceleration pulse.

Initial Front End Package - Static Stiffness

The performance matrix for the Initial Front End Package static stiffness

response was derived from a 3-level L-81 D.O.E study (Ref. 5). The responses included were bending and torsional stiffness.

Initial Front End Package - Dynamic Stiffness

The performance matrix for the Initial Front End Package NCAP dynamic stiffness response was derived from a 3-level L-27 D.O.E study (Ref. 5). The responses included were bending and torsional frequencies.

Upgraded Front End Package - NCAP

The performance matrix for the Upgraded Front End Package NCAP response was derived from a 2-level L-64 D.O.E study (Ref. 8). The responses included were crush and the entire LH and RH B-pillar acceleration pulse.

Upgraded Front End Package - IIHS

The performance matrix for the Upgraded Powertrain IIHS response was derived from a 2-level D.O.E study (Ref. 8). The responses included were left, right and center footwell intrusions.

Upgraded Front End Package - Static Stiffness

The performance matrix for the Upgraded Front End Package static stiffness response was derived from a mixed levels, modified L-81 D.O.E study (Ref. 8). The responses included were bending and torsional stiffness.

Upgraded Front End Package Dynamic Stiffness

The performance matrix for the Upgraded Front End Package dynamic stiffness response was derived from a mixed levels, modified L-81 D.O.E study (Ref. 8). The responses included were bending and torsional frequencies.

Conclusions

The performance matrix for predicting the structural performances of the Initial Front End Package and the Upgraded Front End Package models was obtained from the regression analyses of the results of the D.O.E. based parametric studies. The performance matrix is utilized by the knowledge base tool, Proteus, and can be used to perform trade-off studies for these two packages. The performance matrix was also used to generate the response surfaces employed for the computer-aided optimization of the two front end packages.

References

1) *Phase I Structural Performance Targets Report*.

2) *Baseline Model for CAO Report, Milestone 3*.

3) *First Bumper Design Report, Milestone 5*.

4) *Parametric Design Combinations Report, Milestone 7.*

5) *ULSAB Static and Dynamic Stiffness Study, Milestone 8*.

6) *NCAP 35mph Study, Milestone 11*.

7) *ULSAB Model with Upgraded Powertrain Report, Milestone 14*.

8) *Upgraded Powertrain DOE Study, Milestone 15*.

9) *Fourth Bumper Design Report, Milestone 26*.

10) *System of Experimental Design*, *Volume 1*, Taguchi Genichi, 1987, Kraus International Publications.

11) *System of Experimental Design*, *Volume 2*, Taguchi Genichi, 1987, Kraus International Publications.

12) *Taguchi Techniques for Quality Engineering*, Phillip J. Ross, 1988, McGraw -Hill Book Co.

13) *Linear and Nonlinear Programming*, Luenberger D.G., 1984, Addison Wesley.

Library of Designs

Objective

The objective of the library of designs was to generate design variations of the Initial and Upgraded front end packages, in order to improve their crash performance with minimum mass penalty, through computer-aided optimization (CAO) of the response surfaces generated from the D.O.E. studies.

Initial Front End Package

The crash performance of the optimized design of the Initial Front End package was far superior to any of the best-in-class vehicles. The optimized design (Design 7) achieved a **double 5-star NHTSA** rating and an overall **"good" rating in IIHS** footwell intrusions. Furthermore, it met the more stringent NCAP and IIHS targets set up for the current light-weighting project. The optimized design had **mass savings** of more than **12kg**, as compared to the baseline design (Design 0).

Comparison with Best-in-Class Vehicles

The baseline design (Design 0) and the optimized design (Design 7) were compared with the best-in-class vehicles (Ref. 1). The best-in-class vehicles had obtained a 5-star NHTSA rating in the 35mph rigid barrier test (NCAP). In addition, some of these vehicles secured an overall "good" rating from IIHS in the 40mph, 40% offset, deformable barrier test (IIHS). The IIHS intrusions and the NCAP B-pillar pulse (Ref. 1) served as the criteria for evaluating the crash performance of the vehicles.

Figure 1 depicts the NCAP Driver's Side B-pillar pulse of the baseline design, the optimized design and the best-in-class vehicles, in relation to the target pulse established for the current light-weighting project (Ref. 1). No best-in-class vehicle met the target pulse, as the peak accelerations were greater than 30g. The optimized design met the target pulse, as the peak acceleration was 25g. Furthermore, the vehicle stop time was the least for the optimized design, indicating an optimally tuned front-end stiffness. In addition, the B-pillar pulse had an initial peak that was the earliest and the highest of all vehicles (with the exception of Buick LeSabre, which subsequently had a steep drop in acceleration). This high peak is attributed to an efficient bumper design and complementary rail stiffness.

Figure 2 depicts the IIHS intrusions of the baseline design, the optimized design and the best-in-class vehicles, in relation to the standard IIHS The

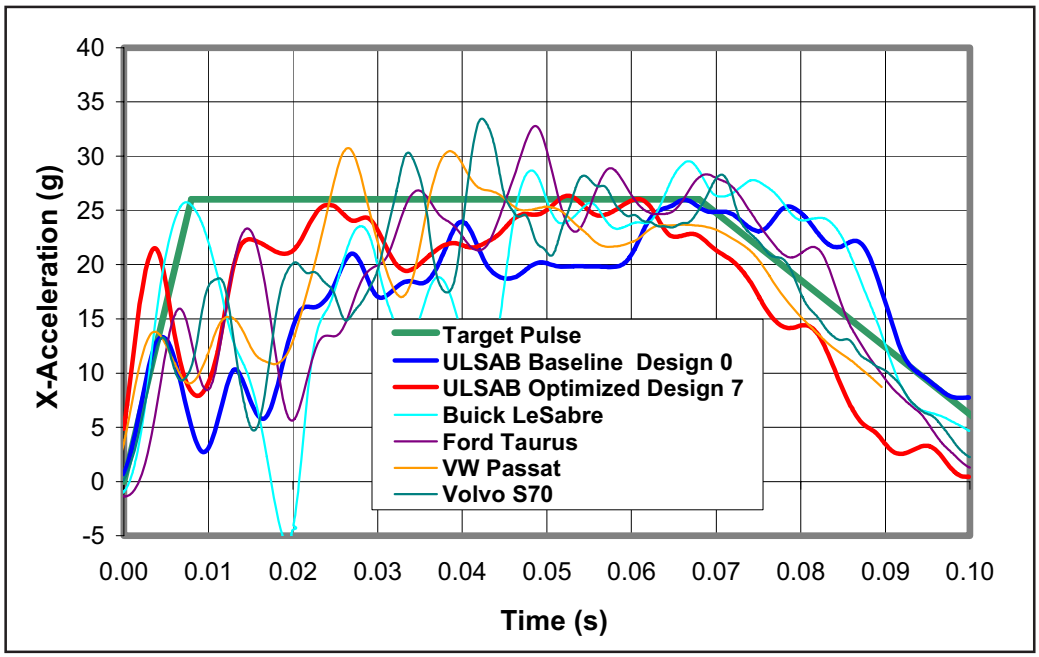


Figure 7.1: Initial Front End Package: Comparison of NCAP Driver's Side B-Pillar Pulse

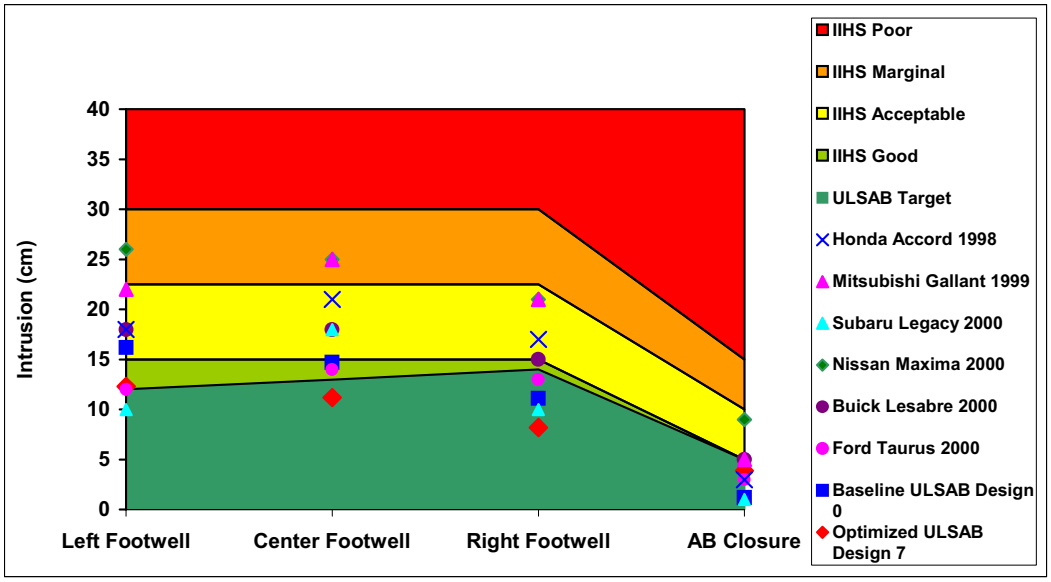


Figure 7.2: Comparison of IIHS Intrusions

ratings, as well as the target intrusions established for the current light-weighting project (Ref. 1). Ford Taurus was the only vehicle that achieved a rating of "good". However, it did not meet all of the targets intrusions. The optimized design had lower intrusions than the Ford Taurus and met all of the target intrusions.

Summary of Designs

Table 7.1 summarizes the library of designs with Bumper 1 design (Ref. 10). Table 7.2 summarizes the library of designs with Bumper 3 design (Ref. 10). The procedure of generating the designs is discussed briefly under each section of this report. The designs either constituted one of the NCAP D.O.E. runs or were derived using CAO. The objective function and constraints were varied in many ways, in order to obtain several designs with improved performance and mass savings. Modifying the constraints changed the search direction, resulting in alternative solutions. The search region was also modified in the quest for better designs. However, the response surface was more accurate close to the DOE boundary (Ref. 6). Consequently, the predictions of optimized designs were more accurate when the design variables had the same range as in the DOE study.

The details of the baseline design (Design 0) and the optimized design (Design 7) are presented below. The details of the remaining designs can be obtained from Ref. 10.

The NCAP B-pillar pulse and the IIHS intrusions of the designs were compared with the targets (Ref. 1). The mass reduction of each design with respect to the baseline model was also documented. The mass savings were broken up into three categories – bumper, cradle and BIW.

The IIHS DOE study was not performed for the baseline design, due to a lack of time. Therefore, response surfaces could not be developed for the IIHS footwell intrusions. The crush response in NCAP had been employed as a measure of IIHS performance. However, there was no one-to-one correspondence between NCAP crush and IIHS intrusions. Consequently, some of the designs that had low crush were found to have high intrusions. Nevertheless, several good designs were obtained by using crush as an estimator of IIHS performance. The D.O.E. study for the Upgraded Front End package included both NCAP and IIHS load case. This enabled response surfaces to be developed for both the B-pillar pulse and the intrusions. Hence, the library of designs for the upgraded design was obtained more efficiently.

Initial Front End Package - Library of Designs with Bumper 1													
		NCAP								IIHS			
Design	Mass Saving (Kg)	Initial B-Pillar Acc.Peak (g)		Peak B-Pillar Acc. in 10-40ms (g)		Peak B-Pillar Acc. in 40-100ms (g)		Crush (mm)	Time to Zero Vel. (ms)	Left Footwell (cm)	Center Footwell (cm)	Right Footwell (cm)	AB Closure (cm)
		LH	RH	LH	RH	LH	RH						
0	-	13.32 (4.5)*	14.14 (4.6)	23.95 (39.9)	26.3 (39.9)	25.97 (66.3)	25.97 (66.3)	795.93	87.2	16.2	14.7	11.1	1.2
1	6.53	17.47 (4.5)	15.77 (4.5)	24.9 (39.9)	21.75 (21.3)	26.10 (78.4)	30.8 (54)	779.36	87.4	17.6	15.9	12.3	1.7
2	6.90	15.47 (5.1)	17.22 (4.3)	22.1 (32.3)	23.34 (28.1)	26.73 (61)	26.42 (70.3)	789.33	87.9	21.4	18.4	13.7	2.0
3	8.24	8.9 (3.6)	10.31 (3.8)	27.68 (33)	26.66 (35)	26.0 (56)	30.20 (58.8)	728.48	81.2	12.9	11.6	8.3	1.8
4	6.98	13.75 (4.2)	14.67 (4.3)	27.84 (37)	27.83 (31.9)	26.01 (50.7)	28.46 (61.3)	754.68	84.1	16.6	14.2	10.3	1.6
5	7.08	18.35 (4.5)	17.85 (4.5)	24.59 (39.9)	26.9 5(35)	28.73 (60)	30.16 (56.9)	723.76	81	17.9	15.6	11.7	2.0
6	2.59	17.39 (4.5)	18.65 (4.6)	27.8 (31.9)	26.46 (24.8)	28.67 (71.4)	27.03 (58.8)	696.51	77.3	15.9	14.7	11.5	1.2

Table 7.1: Initial Front End Package - Library of Designs with Bumper 1

Initial Front End Package - Library of Designs with Bumper 3													
		NCAP								IIHS			
Design	Mass Saving (Kg)	Initial B-Pillar Acc.Peak (g)		Peak B-Pillar Acc. in 10-40ms (g)		Peak B-Pillar Acc. in 40-100ms (g)		Crush (mm)	Time to Zero Vel. (ms)	Left Footwell (cm)	Center Footwell (cm)	Right Footwell (cm)	AB Closure (cm)
		LH	RH	LH	RH	LH	RH						
0	-	13.32 (4.5)*	14.14 (4.6)	23.95 (39.9)	26.3 (39.9)	25.97 (66.3)	25.97 (66.3)	795.93	87.2	16.2	14.7	11.1	1.2
7	12.02	21.5 (3.7)	23.66 (4.0)	25.5(24)	24.25 (23.1)	26.36 (52.5)	29.12 (52)	632.34	74.6	12.3	11.2	8.2	3.9
8	13.49	22.1 (3.69)	19.23 (3.39)	25.09 (33.1)	26.37 (36.5)	27.91 (58.9)	27.26 (57.2)	658.09	77.7	15.0	13.1	9.7	2.6
9	13.59	19.92 (3.6)	19.33 (3.3)	28.21 (30.1)	30.62	26.61 (62.2)	27.22 (64.6)	665.38	78.5	12.2	10.9	8.0	5.3
10	8.94	21.11 (3.3)	20.82 (3.9)	30.53 (38.4)	28.48 (37.5)	27.51 (52.3)	27.26 (50.8)	633.35	75.3	14.5	13.3	10.3	2.8
11	9.74	21.04 (3.6)	20.46 (3.8)	24.89 (14.6)	24.34 (16)	27.64 (49.1)	26.69 (50.6)	662.0	76.8	13.6	12.9	10.0	2.9
12	6.84	23.19 (3.8)	20.07 (3.4)	25.77 (14.8)	26.63 (15.1)	27.61 (53.3)	29.87 (60.1)	658.68	76.3	10.6	10.4	7.8	2.1
13	2.34	23.83 (3.69)	21.30 (3.6)	27.22 (15.0)	21.30 (37.5)	28.83 (41.6)	28.63 (63.7)	651.39	75.3	8.1	8.2	6.1	1.7

Baseline Design 0

This design was the baseline model with Bumper 1 design (Ref. 2). This was used as the baseline for the NCAP L64 DOE Parametric Study (Ref. 6).

Table 7.3 shows the thickness and material values for this design. Figure 3 shows the NCAP B-Pillar acceleration pulse for this design along with the target pulse. Table 7.4 shows the IIHS intrusion values for this design. The table also indicates the target and good performance ratings. Tables 7.5 and 7.6 give the mass distribution in various components.

S. No	Part Name	Part ID	Thickness (mm)	Material
1a	Bumper C-Section [1]	400021	2.0	AISI HSLA 350/450
1.5	Bumper C-Section [2]	400023	1.50	AISI DP 585/965 Post Bake
1.5	Rail Front Inner	60021*	1.50	AISI DP 500/800
1.6	Rail Front Outer	60011*	1.50	AISI HSLA 350/450
1.6	Rail Mid Inner	60022*	1.60	AISI DP 500/800
1.8	Rail Mid Outer	60012*	1.60	AISI HSLA 350/450
2.0	Rail Rear Inner	60023*	1.80	AISI DP 500/800
1.2	Rail Rear Outer	60013*	1.30	AISI HSLA 350/450
0.9	Shot Gun Inner	60049*	1.20	ORNL HSLA 425/770
1.3	Shot Gun Outer	60051*	0.90	AISI DP 500/800
1.6	Cradle Cross Mbr 1st Ubar[1]	60701	1.30	AISI DP 500/800
2.0	Cradle Cross Mbr 2nd Ubar[2]	60702	1.60	AISI DP 500/800
1.5	Cradle	60703	1.30	AISI DP 500/800
1.2	Cradle Extension	60705*	1.00	AISI DP 500/800
13	1st Cross Member	60031	1.20	AISI DP 700/1000

1,2 – Combined Parameters

* corresponds to LH part id. RH part ids are not given in the table for clarity sake. It should be noted that both the LH and RH parts must be set to the thickness and material levels shown in the table.

Table 7.3: Grade/Gauge for Baseline Design 0 (Initial Front End Package)

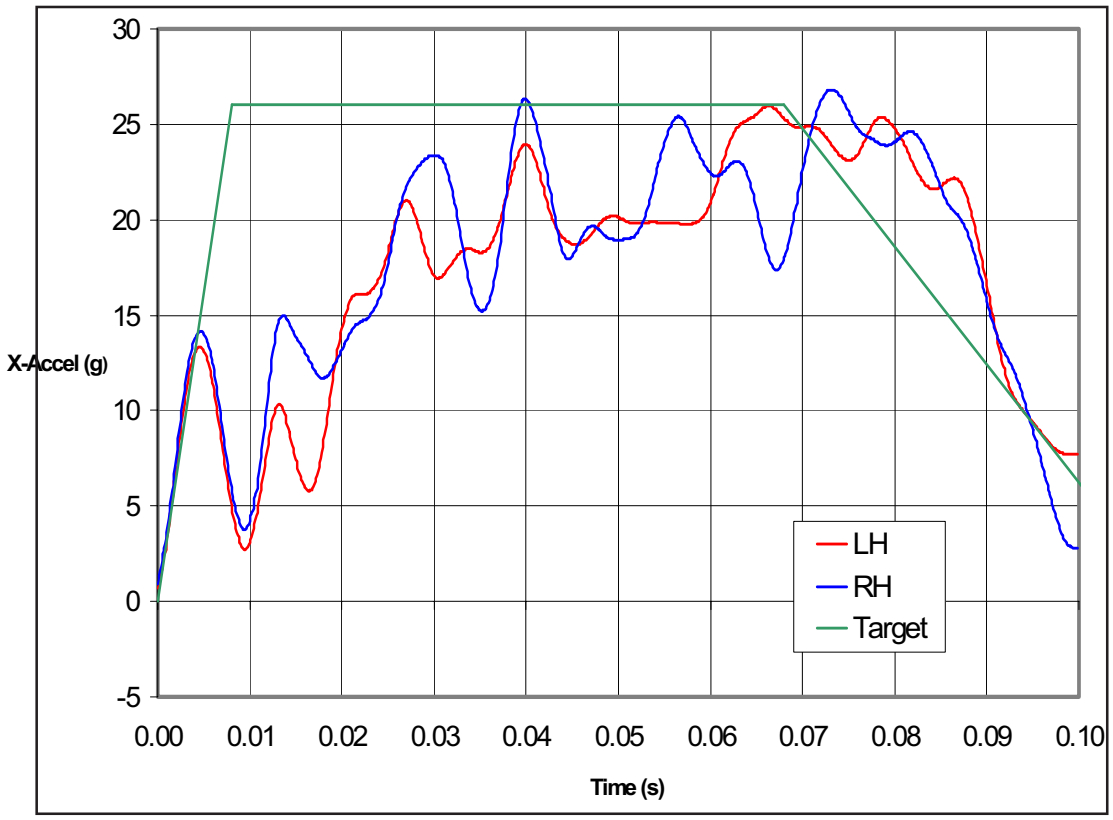


Figure 7.3: NCAP B-Pillar Pulse for Baseline Design 0 (Initial Front End Package)

Description	IIHS Intrusions			
	Footwell Left (cm)	Footwell Center (cm)	Footwell Right (cm)	AB Closure (cm)
Target	12.0	14.0	13.0	5.0
Good Performance	*15.0*	*15.0*	*15.0*	-
Current Design	**16.2**	**14.7**	**11.1**	**1.2**

Table 7.4: IIHS Intrusions for Baseline Design 0 (Initial Front End Package)

S. No	Part Name	Thickness		Mass (Kg)			
		DOE Baseline	Current Design	Doe Baseline	Current Design	Mass Savings	% Mass Savings
1a	Bumper C-Section[1]	2.0	2.0	7.806	7.806	0	0
1b	Bumper C-Section[2]						
2	Rail Front Inner	1.5	1.5	2.127	2.127	0	0
3	Rail Front Outer	1.5	1.5	1.509	1.509	0	0
4	Rail Mid Inner	1.6	1.6	2.929	2.929	0	0
5	Rail Mid Outer	1.6	1.6	1.851	1.851	0	0
6	Rail Rear Inner	1.8	1.8	6.225	6.225	0	0
7	Rail Rear Outer	2.0	2.0	2.867	2.867	0	0
8	Shot Gun Inner	1.2	1.2	5.491	5.491	0	0
9	Shot Gun Outer	0.9	0.9	2.574	2.574	0	0
10a	Cradle Cross Mbr 1st Ubar[1]	1.3	1.3	2.253	2.253	0	0
10b	Cradle Cross Mbr 2nd Ubar[2]	1.6	1.6	2.929	2.929	0	0
11	Cradle	2.0	2.0	8.697	8.697	0	0
12	Cradle Extension	1.5	1.5	4.376	4.376	0	0
13	1st Cross Member	1.2	1.2	2.115	2.115	0	0

Table 7.5 Part Mass for Baseline Design 0 (Initial Front End Package)

S. No	Description	Mass (Kg)			
		DOE Baseline Design	Current Design	Mass Saving	% Mass Saving
1	Bumper / EA	14.080	14.080	0	0
2	Cradle Components	18.26	18.26	0	0
3	BIW Components *	27.69	27.69	0	0
	Total	60.03	60.03	0	0

** Only parts included in DOE Study*

Table 7.6 Mass Summary for Baseline Design 0 (Initial Front End Package)

Optimal Design 7

The design was obtained by minimizing the peak LH acceleration using the analysis of means method.

Table 7.7 shows the thickness and material values for this design. Figure 4 shows the NCAP B-Pillar acceleration pulse for this design along with the target pulse. Table 7.8 shows the IIHS intrusion values for this design. The table also indicates the target and good performance ratings. Tables 7.9 and 7.10 give the mass distribution in various components.

This design was with Bumper 3 and had mass savings of 12.02kg compared to the baseline design.

S. No	Part Name	Part ID	Thickness	Material
1a	Bumper C-Section [1]	400021	1.50	AISI DP 585/965 Post Bake
1b	Bumper C-Section [2]	400023	1.50	AISI DP 585/965 Post Bake
2	Rail Front Inner	60021*	1.50	AISI DP 500/800
3	Rail Front Outer	60011*	1.50	AISI HSLA 350/450
4	Rail Mid Inner	60022*	1.60	AISI DP 500/800
5	Rail Mid Outer	60012*	1.60	AISI HSLA 350/450
6	Rail Rear Inner	60023*	1.80	AISI DP 500/800
7	Rail Rear Outer	60013*	1.30	AISI HSLA 350/450
8	Shot Gun Inner	60049*	1.20	ORNL HSLA 425/770
9	Shot Gun Outer	60051*	0.90	AISI DP 500/800
10a	Cradle Cross Mbr 1st Ubar[1]	60701	1.30	AISI DP 500/800
10b	Cradle Cross Mbr 2nd Ubar[2]	60702	1.60	AISI DP 500/800
11	Cradle	60703	1.30	AISI DP 500/800
12	Cradle Extension	60705*	1.00	AISI DP 500/800
13	1st Cross Member	60031	1.20	AISI DP 700/1000

1,2 – Combined Parameters

* corresponds to LH part id. RH part ids are not given in the table for clarity sake. It should be noted that both the LH and RH parts must be set to the thickness and material levels shown in the table.

Table 7.7: Grade/Gauge for Optimal Design 7 (Initial Front End Package)

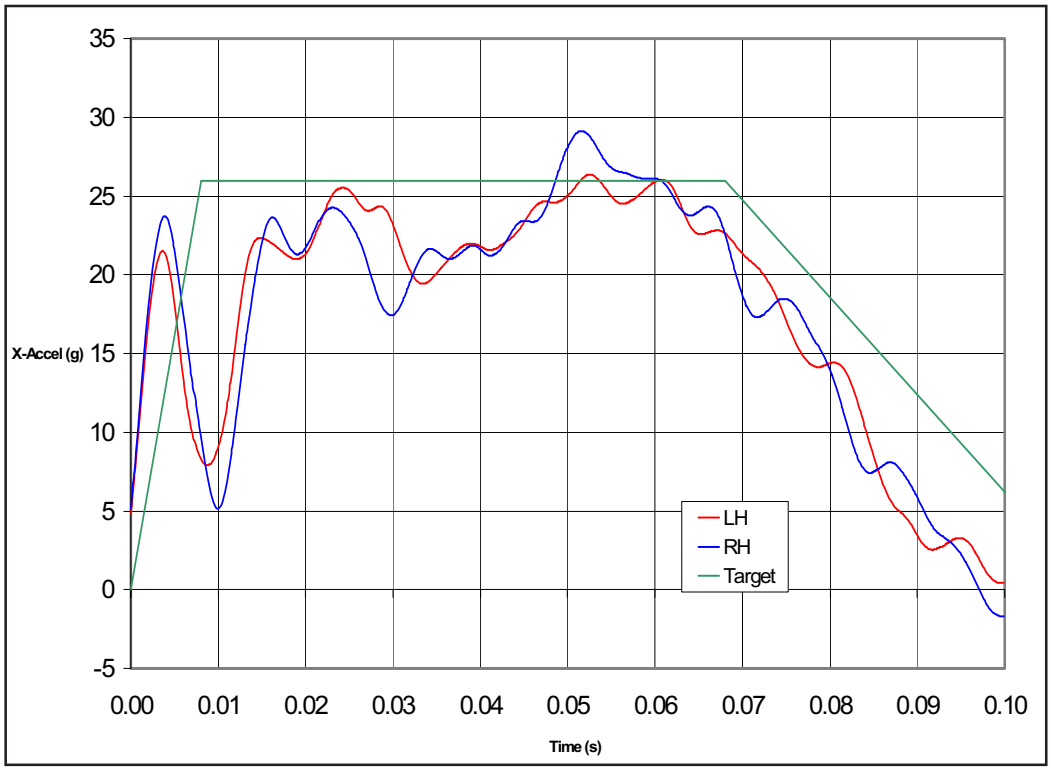


Figure 7.4: NCAP B-Pillar Pulse for Optimal Design 7 (Initial Front End Package)

Description	IIHS Intrusions			
	Footwell Left (cm)	Footwell Center (cm)	Footwell Right (cm)	AB Closure (cm)
Target	12.0	14.0	13.0	5.0
Good Performance	*15.0*	*15.0*	*15.0*	-
Current Design	12.3	11.2	8.2	3.9

Table 7.8: IIHS Intrusions for Optimal Design 7 (Initial Front End Package)

S. No	Part Name	Thickness		Mass (Kg)			
		DOE Baseline	Current Design	Doe Baseline	Current Design	Mass Savings	% Mass Saving-s
1a	Bumper C-Section[1]	2.0	1.5	7.806	2.066	5.74	73.533
1b	Bumper C-Section[2]	-	1.5	0	4.275	-4.275	-
2	Rail Front Inner	1.5	1.5	2.127	2.106	0.02	0.9407
3	Rail Front Outer	1.5	1.5	1.509	1.496	0.013	0.8285
4	Rail Mid Inner	1.6	1.6	2.929	2.929	0	0
5	Rail Mid Outer	1.6	1.6	1.851	1.851	0	0
6	Rail Rear Inner	1.8	1.8	6.225	6.224	0	0
7	Rail Rear Outer	2.0	1.3	2.867	1.863	1.003	35.01
8	Shot Gun Inner	1.2	1.2	5.491	5.491	0	0
9	Shot Gun Outer	0.9	0.9	2.574	2.574	0	0
10a	Cradle Cross Mbr 1st Ubar[1]	1.3	1.3	2.253	2.253	0	0
10b	Cradle Cross Mbr 2nd Ubar[2]	1.6	1.6	2.929	2.929	0	0
11	Cradle	2.0	1.3	8.697	5.653	3.044	35.001
12	Cradle Extension	1.5	1.0	4.376	2.917	1.459	33.341
13	1st Cross Member	1.2	1.2	2.115	2.115	0	0

Table 7.9: Part Mass for Optimal Design 7 (Initial Front End Package)

S. No	Description	Mass (Kg)			
		DOE Baseline Design	Current Design	Mass Saving	% Mass Saving
1	Bumper / EA	14.080	7.606	6.477	45.992
2	Cradle Components	18.26	13.752	4.503	24.667
3	BIW Components *	27.69	26.652	1.036	3.741
	Total	60.03	48.010	12.02	20.018

** Only parts included in DOE Study*

Table 7.10: Mass Summary for Optimal Design 7 (Initial Front End Package)

Upgraded Front End Package

The crash performance of the optimized Upgraded Front End package compared favorably to the best-in-class vehicles. The optimized design (Design 8) achieved a **double 5-star NHTSA** rating and an **overall "good" rating in IIHS** footwell intrusions. Furthermore, it nearly achieved the more stringent NCAP and IIHS targets set up for the current light-weighting project. The optimized design had a mass penalty of 16kg, as compared to the baseline design (Design 0). The mass penalty was minimized through computer-aided optimization and was necessary in order to meet the structural targets.

Comparison with Best-in-Class Vehicles

The baseline design (Design 0) and the optimized design (Design 8) were compared with the best-in-class vehicles in the 3500-4000lb weight class, for which NCAP and IIHS data were available (Ref. 1). The best-in-class vehicles had obtained a 5-star NHTSA rating in the 35mph rigid barrier test (NCAP). In addition, some of these vehicles had secured an overall "good" rating from IIHS in the 40mph, 40% offset, deformable barrier test (IIHS). The IIHS intrusions and the NCAP B-pillar pulse served as the criteria for evaluating the crash performance of the vehicles (Ref. 1).

Figure 5 depicts the NCAP Driver's Side B-pillar pulse of the baseline design, the optimized design and the best-in-class vehicles, in relation to the target pulse established for the current light-weighting project . No best-in-class vehicle met the target pulse, as the peak accelerations were greater than 30g. The optimized Upgraded Powertrain design met the target pulse, as the peak acceleration was 25g (except for an early peak of 32g at 18ms). Furthermore, the vehicle stop time was the least for the design, indicating an optimally tuned front-end stiffness. In addition, the design pulse had an initial peak that was the earliest and the highest of all vehicles. This high peak is attributed to an efficient bumper design and complementary rail stiffness.

Figure 6 depicts the IIHS intrusions of the baseline design, the optimized design and the best-in-class vehicles, in relation to the standard IIHS ratings, as well as the target intrusions established for the current light-weighting project. The optimized Upgraded Powertrain design achieved an overall good intrusion rating and was quite close to the targets intrusions.

It may be worthwhile to mention that the mass of the optimized Upgraded Front End package should not be compared to the baseline mass. The baseline Upgraded Front End model essentially had the same gauges as the Initial Front End model with the low-end powertrain package, which was designed for a vehicle in the 3000-3500lb weight class. However, the

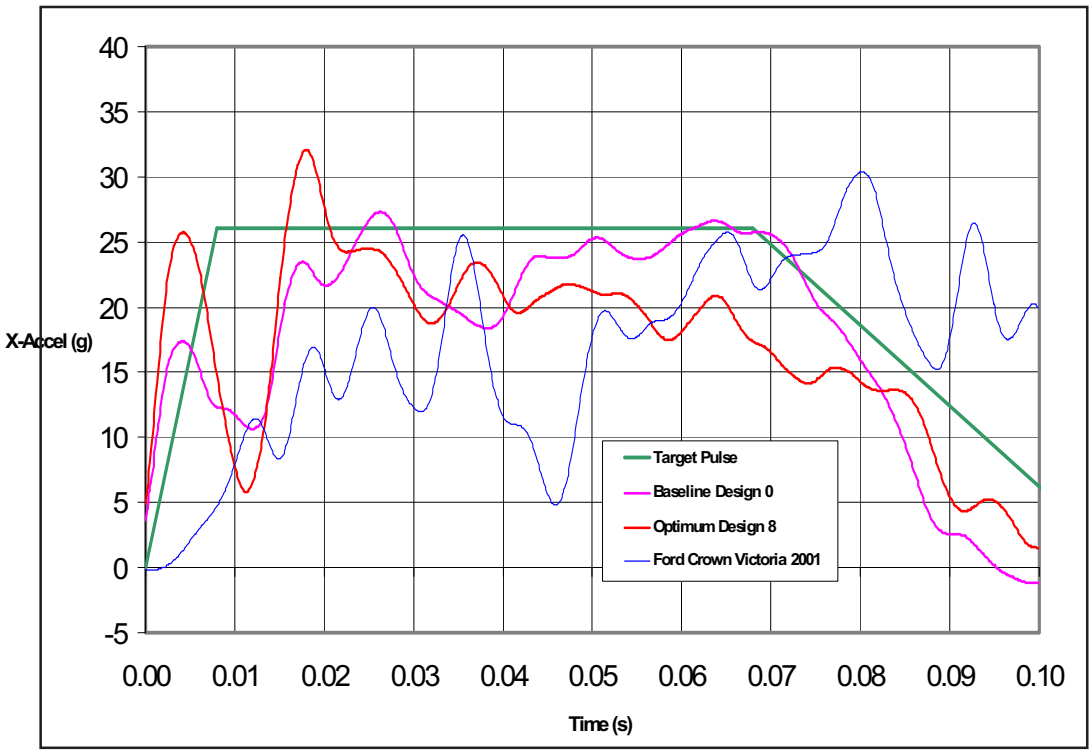


Figure 7.5: Upgraded Front End Package - Comparison of NCAP Driver's Side B-Pillar Pulse

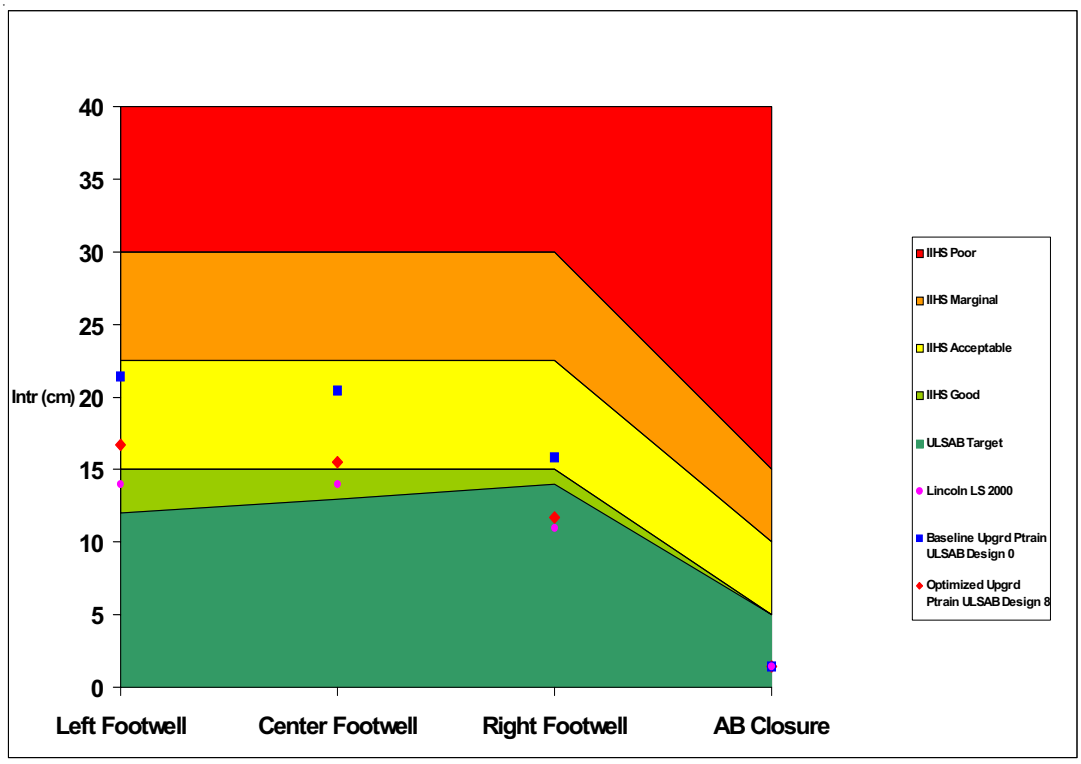


Figure 7.6: Comparison of IIHS Intrusions

upgraded powertrain package was designed for a vehicle in the 3500-4000lb weight class. Hence, the BIW components had to be substantially upgauged, in order to accommodate the high-end powertrain package.

Summary of Designs

Table 7.11 summarizes the library of designs for the Upgraded Powertrain design with the baseline topology (Ref. 11). Table 7.12 summarizes the library of designs with an increased rail length and shotgun width. The procedure of generating the designs is discussed briefly under each section of this report. The designs either constituted one of the D.O.E. runs or had been derived using CAO. The objective function and constraints were varied in many ways, in order to obtain several designs with improved performance and mass savings. Modifying the constraints changed the search direction, resulting in alternative solutions. The search region was also modified in the quest for better designs. However, the response surface was more accurate close to the DOE boundary (Ref. 8). Consequently, the predictions of optimized designs were more accurate when the design variables had the same range as in the DOE study.

The details of the baseline design (Design 0) and the optimized design (Design 8) are presented below. The details of the remaining designs can be obtained from Ref. 11.

Upgraded Front End Package - Library of Designs with Baseline Topology													
		NCAP								IIHS			
Design	Mass Delta (Kg)	Initial B-Pillar Acc.Peak (g)		Peak B-Pillar Acc. in 10-40ms (g)		Peak B-Pillar Acc. in 40-100ms (g)		Crush (mm)	Time to Zero Vel. (ms)	Left Footwell (cm)	Center Footwell (cm)	Right Footwell (cm)	AB Closure (cm)
		LH	RH	LH	RH	LH	RH						
0	-	17.36	17.54	27.29	29.25	26.62	29.93	648.91	72.4	21.4	20.4	15.8	1.4
1	9.5	20.71	16.23	32.03	26.42	26.29	29.44	615.65	71.9	18.4	16.7	12.8	1.9
2	13.6	17.22	15.84	32.35	28.70	27.49	31.72	616.20	74.8	17.5	16.0	12.2	1.6
3	12.6	25.52	23.52	30.13	32.36	29.50	27.26	618.57	68.8	16.1	15.0	11.0	1.2
4	13.5	32.78	33.28	29.43	29.62	30.45	31.05	559.93	75.3	17.7	15.5	10.3	1.9
5	16.4	23.47	25.28	35.10	31.42	26.59	29.99	612.69	68.8	15.4	14.7	11.5	0.5
6	23.8	19.85	25.92	31.98	29.68	27.69	33.31	551.14	75.9	12.7	12.6	9.0	0.8

Table 7.11: Upgraded Front End Package - Library of Designs with Baseline Topology

Upgraded Front End Package - Library of Designs with Longer Rails and Wider Shotgun													
		NCAP								IIHS			
Design	Mass Delta (Kg)	Initial B-Pillar Acc.Peak (g)		Peak B-Pillar Acc. in 10-40ms (g)		Peak B-Pillar Acc. in 40-100ms (g)		Crush (mm)	Time to Zero Vel. (ms)	Left Footwell (cm)	Center Footwell (cm)	Right Footwell (cm)	AB Closure (cm)
		LH	RH	LH	RH	LH	RH						
0	-	17.36	17.54	27.29	29.24	26.62	29.93	648.91	72.4	21.4	20.4	15.8	1.4
7	5.9	19.83	21.60	27.57	30.11	28.13	27.01	637.33	75.9	21.6	18.7	12.8	1.4
8	16.0	25.71	26.23	32.07	31.11	21.74	24.36	614.30	77.2	16.7	15.5	11.7	1.4
9	10.1	22.27	25.89	24.68	26.57	25.25	24.95	650.97	79.2	15.9	14.6	10.9	0.6
10	25.2	20.84	19.17	32.62	35.32	32.63	32.06	570.68	67.0	10.6	11.1	8.8	0.7
11	24.1	22.36	18.11	30.45	30.62	25.04	27.89	642.06	76.6	15.2	15.2	11.7	1.2

Table 7.12: Upgraded Front End Package - Library of Designs with Longer Rails and Wider Shotgun

The NCAP B-pillar pulse and the IIHS intrusions of the designs were compared with the targets (Ref. 1). The mass increment of each design with respect to the baseline model (Ref. 7) were also documented. The mass increment was broken up into three categories – bumper, cradle and BIW.

Baseline Design 0

This design was the Upgraded Powertrain model (Ref. 7) with Bumper 4 design (Ref. 9). This was used as the baseline for the NCAP, IIHS, Static and Dynamic DOE Parametric Studies (Ref. 8).

Table 7.13 shows the topological parameters for this design. Table 7.14 shows the thickness and material parameters. Figure 7 shows the NCAP B-

	Description	Level
1	XZ Bump	Baseline
2	XY Curve	Baseline
3	Rail Length	Baseline
4	Shot Gun Width	Baseline

Table 7.13: Topological ParametersFigure for Baseline Design 0 (Upgraded Front End Package)

S. No.	Part Name	Part ID LH	Part ID RH	Thickness (mm)	Material
1	Bumper Middle Section	400021	-	1.3	DP 585/965 Post Bake
2	Bumper End Sections	400023	-	1.3	DP 585/965 Post Bake
3	Bumper Middle Plate	400022	-	1.3	DP 585/965 Post Bake
4	Rail Front Outer	60011	65011	1.5	AISI DP 500/800
5	Rail Front Inner	60021	65021	1.5	AISI DP 500/800
6	Rail Mid Outer	60012	65012	1.8	AISI DP 500/800
7	Rail Mid Inner	60022	65022	1.8	AISI DP 500/800
8	Rail Rear Outer	60013	65013	2.0	AISI DP 500/800
9	Rail Rear Inner	60023	65023	2.0	AISI DP 500/800
10	Rail Extension Reinforcement	60033	65033	1.8	AISI HSLA 350/450
11	Rail Extension	60035	65035	1.8	AISI HSLA 350/450
12	Shot Gun Inner	60049	65049	1.2	ORNL HSLA 425/770
13	Shot Gun Outer	60051	65051	0.9	AISI HSLA 350/450
14	Cradle CM Ubar 1	60701	-	1.3	AISI HSLA 350/450
15	Cradle CM Ubar 2	60702	-	1.6	AISI HSLA 350/450
16	Cradle	60703	-	2.0	AISI HSLA 350/450
17	Cradle Extension	60705	65705	1.5	AISI DP 280/600
18	1st Cross Member	60031	-	1.6	AISIDP 700/1000
19	Skirt 1	60039	65039	1.6	ORNL AKDQ 160/525
20	Skirt 2	60040	65040	2.0	ORNL AKDQ 160/525
21	Roof Rail	60241	65041	1.0	AISI DP 280/600
22	A-Pillar Upper	60225	65225	1.5	AISI HSLA 350/450
23	A-Pillar Hinge Pillar	60226	65226	1.0	AISI HSLA 350/450
24	A-Pillar Body Side Outer	60277	65277	1.5	AISI HSLA 350/450
25	A-Pillar Body Side Outer	60278	65278	1.7	AISI HSLA 350/450
26	B-Pillar Inner	60261	65261	1.5	AISI HSLA 350/450
27	B-Pillar Body Side Outer	60273	65273	1.3	AISI DP 280/600
28	B-Pillar Body Side Outer	60274	65274	0.9	AISI DP 280/600
29	Rocker Inner	60221	65221	1.7	AISI HSLA 350/450
30	Rocker Inner	60222	65222	1.3	AISI HSLA 350/450
31	Dash Panel	60071	-	0.7	AISI BH 210/340

Table 7.14: Grade/Gauge for Baseline Design 0 (Upgraded Front End Package)

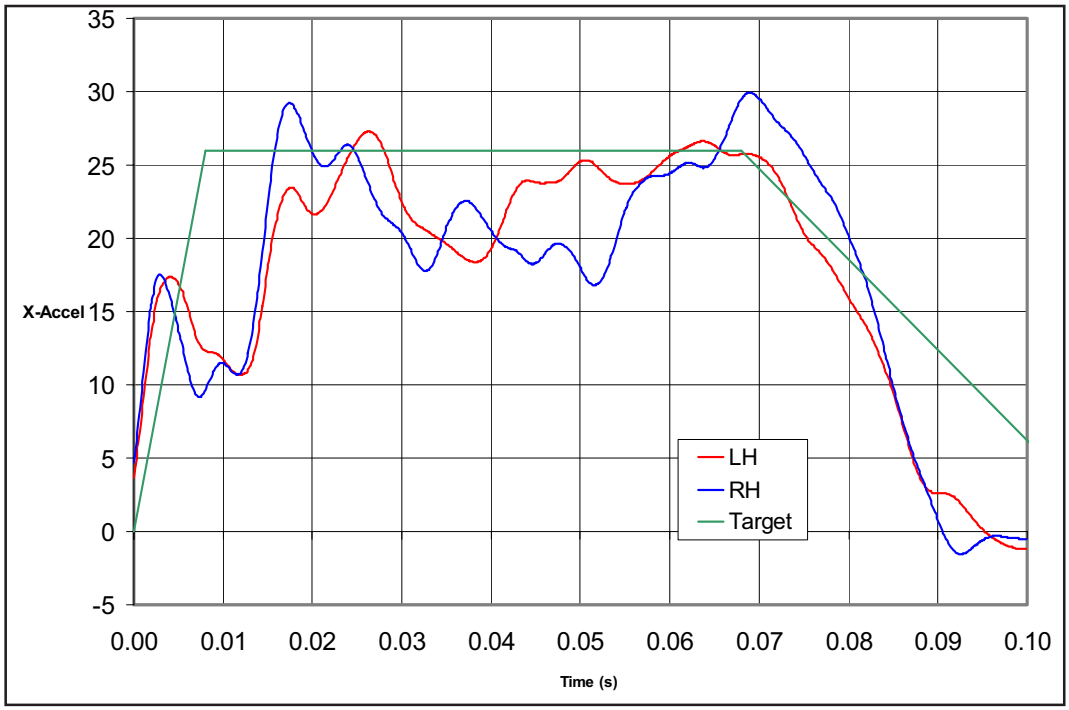


Figure 7.7: NCAP B-Pillar Pulse for Baseline Design 0 (Upgraded Front End Package)

Description	IIHS Intrusions			
	Footwell Left (cm)	Footwell Center (cm)	Footwell Right (cm)	AB Closure (cm)
Target	12.0	14.0	13.0	5.0
Good Performance	*15.0*	*15.0*	*15.0*	-
Current Design	21.4	20.4	15.8	1.4

Table 7.15: IIHS Intrusions for Baseline Design 0 (Upgraded Front End Package)

Description	Static / Dynamic Stiffness Values			
	Torsional Stiffness (N-m/deg)	Bending Stiffness (N/mm)	First Global Torsion Mode (Hz)	First Global Bending Mode (HZ)
Baseline	16295.3	15929.9	59.4	51.8
Current Design	-	-	-	-

Table 7.16: Static and Dynamic Stiffness for Baseline Design 0 (Upgraded Front End Package)

S. No	Description	Mass (Kg)			
		DOE Baseline Design	Current Design	Mass Saving	% Mass Saving
1	Bumper / EA	8.439	8.439	0.000	0.00
2	Cradle Components	17.753	17.753	0.000	0.00
3	BIW Components *	100.732	100.732	0.000	0.00
	Total	126.924	126.924	0.000	0.00

** Only parts included in DOE Study*

Table 7.17: Mass Summary for Baseline Design 0 (Upgraded Front End Package)

		Thickness	Mass (Kg)
S. No	Part Name	DOE Baseline	Doe Baseline
1	Bumper Middle Section	1.3	2.317
2	Bumper End Sections	1.3	4.601
3	Bumper Middle Plate	1.3	1.521
4	Rail Front Outer	1.5	1.435
5	Rail Front Inner	1.5	1.983
6	Rail Mid Outer	1.8	1.895
7	Rail Mid Inner	1.8	
8	Rail Rear Outer	2.0	3.382
9	Rail Rear Inner	2.0	7.094
10	Rail Extension Reinf.	1.8	0.786
11	Rail Extension	1.8	4.586
12	Shot Gun Inner	1.2	4.792
13	Shot Gun Outer	0.9	2.206
14	Cradle CM Ubar 1	1.3	2.252
15	Cradle CM Ubar 2	1.6	3.038
16	Cradle	2.0	8.697
17	Cradle Extension	1.5	3.766
18	1st Cross Member	1.6	3.107
19	Skirt 1	1.6	3.509
20	Skirt 2	2.0	4.154
21	Roof Rail	1.0	3.274
22	A-Pillar Upper	1.5	2.874
23	A-Pillar Hinge Pillar	1.0	2.735
24	A-Pillar Body Side Outer	1.5	3.653
25	A-Pillar Body Side Outer	1.7	8.002
26	B-Pillar Inner	1.5	7.284
27	B-Pillar Body Side Outer	1.3	9.887
28	B-Pillar Body Side Outer	0.9	2.524
29	Rocker Inner	1.7	6.986
30	Rocker Inner	1.3	6.142
31	Dash Panel	0.7	6.035

Table 7.18: Part Mass for Baseline Design 0 (Upgraded Front End Package)

Pillar acceleration pulse for this design along with the target pulse. Table 7.15 shows the IIHS intrusion values for this design. The table also indicates the target and good performance ratings. Table 7.16 shows the static/ dynamic stiffness values. Tables 7.17 and 7.18 give the mass distribution in various components.

Optimal Design 8

The design was obtained using the computer-aided optimization (CAO). This design had **increased rail length and shotgun** width as compared to upgraded power train baseline design. The problem was formulated as given below.

CAO Details:

Objective: Minimize Peak Crush

Constraints: Peak B-Pillar Acceleration in 0-10ms > 15g

Peak B-Pillar Acceleration in 10-100 ms < 23g

Design Space:

-1 < Thickness < +1

-1 < Material < +1

Initial Design:

x0 = -1

Increased Length and Shotgun Width.

In addition, the following components were upgauged by **30 %** over baseline in order to lower the intrusions.

A-Pillar Upper

Hinge Pillar

Rocker Inner

Body Side Otr A-Plr

The CAO was based on response surfaces obtained from NCAP DOE Study.

	Description	Level
1	XZ Bump	Baseline
2	XY Curve	Baseline
3	Rail Length	Baseline + 50 mm
4	Shot Gun Width	Baseline + 10 mm

Table 7.19: Topological ParametersFigure for Optimal Design 8 (Upgraded Front End Package)

S. No.	Part Name	Part ID LH	Part ID RH	Thickness (mm)	Material
1	Bumper Middle Section	400021	-	1.6	AISI DP 700/1000
2	Bumper End Sections	400023	-	1.6	AISI DP 700/1000
3	Bumper Middle Plate	400022	-	1.6	AISI DP 700/1000
4	Rail Front Outer	60011	65011	1.9	AISI DP 500/800
5	Rail Front Inner	60021	65021	1.9	AISI DP 500/800
6	Rail Mid Outer	60012	65012	2.0	AISI DP 500/800
7	Rail Mid Inner	60022	65022	2.0	AISI DP 500/800
8	Rail Rear Outer	60013	65013	2.4	AISI DP 500/800
9	Rail Rear Inner	60023	65023	1.6	AISI DP 500/800
10	Rail Extension Reinforcement	60033	65033	1.3	AISI DP 500/800
11	Rail Extension	60035	65035	1.3	AISI DP 500/800
12	Shot Gun Inner	60049	65049	1.5	ORNL HSLA 425/770
13	Shot Gun Outer	60051	65051	1.1	AISI DP 280/600
14	Cradle CM Ubar 1	60701	-	1.6	AISI DP 500/800
15	Cradle CM Ubar 2	60702	-	2.0	AISI DP 500/800
16	Cradle	60703	-	2.4	AISI DP 500/800
17	Cradle Extension	60705	65705	1.4	AISI DP 500/800
18	1st Cross Member	60031	-	1.5	ORNL HSLA 425/770
19	Skirt 1	60039	65039	2.0	AISI DP 280/600
20	Skirt 2	60040	65040	2.4	AISI DP 280/600
21	Roof Rail	60241	65041	1.0	AISI DP 280/600
22	A-Pillar Upper	60225	65225	2.0	AISI HSLA 350/450
23	A-Pillar Hinge Pillar	60226	65226	1.3	AISI HSLA 350/450
24	A-Pillar Body Side Outer	60277	65277	2.0	AISI HSLA 350/450
25	A-Pillar Body Side Outer	60278	65278	2.2	AISI HSLA 350/450
26	B-Pillar Inner	60261	65261	1.5	AISI HSLA 350/450
27	B-Pillar Body Side Outer	60273	65273	1.3	AISI DP 280/600
28	B-Pillar Body Side Outer	60274	65274	0.9	AISI DP 280/600
29	Rocker Inner	60221	65221	2.2	AISI HSLA 350/450
30	Rocker Inner	60222	65222	1.3	AISI HSLA 350/450
31	Dash Panel	60071	-	0.7	AISI BH 210/340

Table 7.20: Grade/Gauge for Optimal Design 8 (Upgraded Front End Package)

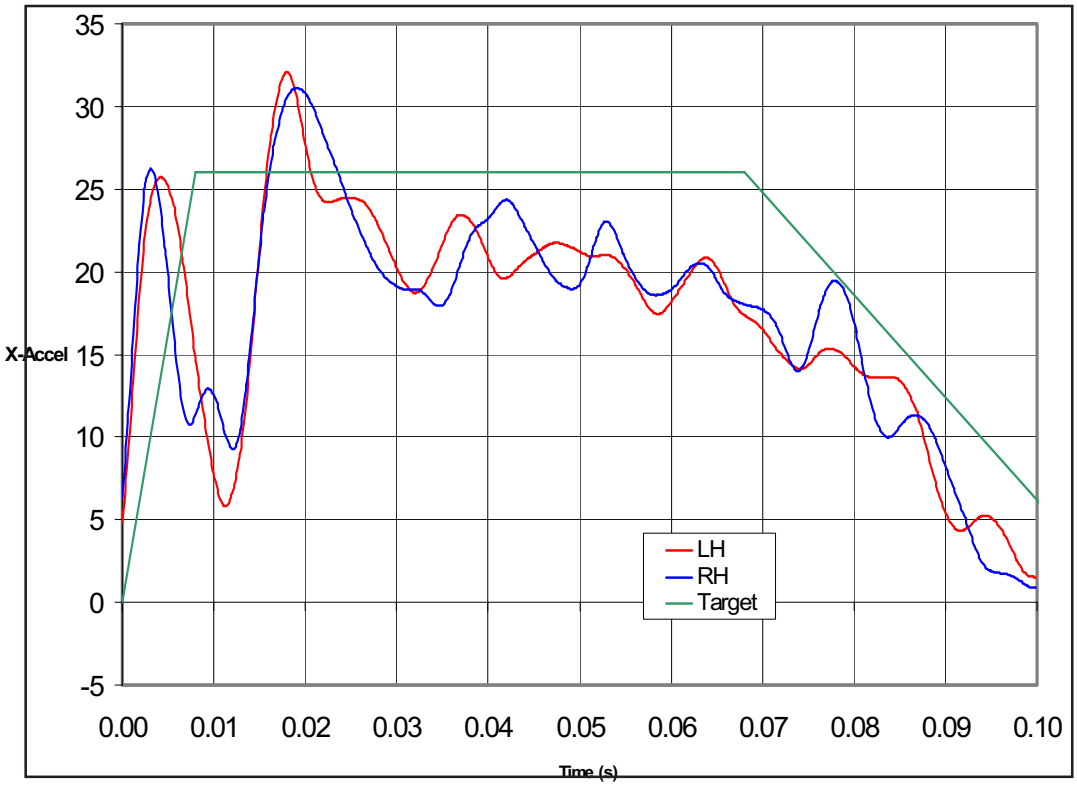


Figure 7.8: NCAP B-Pillar Pulse for Optimal Design 8 (Upgraded Front End Package)

Description	IIHS Intrusions			
	Footwell Left (cm)	Footwell Center (cm)	Footwell Right (cm)	AB Closure (cm)
Target	12.0	14.0	13.0	5.0
Good Performance	*15.0*	*15.0*	*15.0*	-
Current Design	**16.7**	**15.5**	**11.7**	**1.4**

Table 7.21: IIHS Intrusions for Optimal Design 8 (Upgraded Front End Package)

Description	Static / Dynamic Stiffness Values			
	Torsional Stiffness (N-m/deg)	Bending Stiffness (N/mm)	First Global Torsion Mode (Hz)	First Global Bending Mode (HZ)
Baseline	16295.3	15929.9	59.4	51.8
Current Design *	17028.74	16644.65	59.8	52.5

** Static/dynamic stiffnes values are over targets as performance is dictated by crash requirements*

Table 7.22: Static and Dynamic Stiffness for Optimal Design 8 (Upgraded Front End Package)

S. No	Description	Mass (Kg)			
		DOE Baseline Design	Current Design	Mass Saving	% Mass Saving
1	Bumper / EA	8.439	10.386	1.947	23.08
2	Cradle Components	17.753	20.810	3.057	17.22
3	BIW Components *	100.732	111.709	10.977	10.90
	Total	126.924	142.905	15.981	12.59

** Only parts included in DOE Study*

Table 7.23: Mass Summary for Optimal Design 8 (Upgraded Front End Package)

		Thickness		Mass (Kg)			
S. No	Part Name	DOE Baseline	Current Design	Doe Baseline	Current Design	Change in Mass	% Change in Mass
1	Bumper Middle Section	1.3	1.6	2.317	2.852	0.535	23.08
2	Bumper End Sections	1.3	1.6	4.601	5.663	1.062	23.08
3	Bumper Middle Plate	1.3	1.6	1.521	1.872	0.351	23.08
4	Rail Front Outer	1.5	1.9	1.435	2.058	0.623	43.44
5	Rail Front Inner	1.5	1.9	1.983	2.849	0.866	43.66
6	Rail Mid Outer	1.8	2.0	1.895	2.106	0.211	11.11
7	Rail Mid Inner	1.8	2.0	2.407	2.674	0.267	11.11
8	Rail Rear Outer	2.0	2.4	3.382	4.058	0.676	20.00
9	Rail Rear Inner	2.0	1.6	7.094	5.675	-1.419	-20.00
10	Rail Extension Reinf.	1.8	1.3	0.786	0.568	-0.218	-27.78
11	Rail Extension	1.8	1.3	4.586	3.312	-1.274	-27.78
12	Shot Gun Inner	1.2	1.5	4.792	6.206	1.414	29.51
13	Shot Gun Outer	0.9	1.1	2.206	3.114	0.908	41.17
14	Cradle CM Ubar 1	1.3	1.6	2.252	2.772	0.520	23.08
15	Cradle CM Ubar 2	1.6	2.0	3.038	3.798	0.760	25.00
16	Cradle	2.0	2.4	8.697	10.436	1.739	20.00
17	Cradle Extension	1.5	1.4	3.766	3.804	0.038	1.02
18	1st Cross Member	1.6	1.5	3.107	2.913	-0.194	-6.25
19	Skirt 1	1.6	2.0	3.509	4.386	0.877	25.00
20	Skirt 2	2.0	2.4	4.154	4.988	0.834	20.09
21	Roof Rail	1.0	1.0	3.274	3.274	0.000	0.00
22	A-Pillar Upper	1.5	2.0	2.874	3.832	0.958	33.33
23	A-Pillar Hinge Pillar	1.0	1.3	2.735	3.556	0.821	30.00
24	A-Pillar Body Side Outer	1.5	2.0	3.653	4.871	1.218	33.33
25	A-Pillar Body Side Outer	1.7	2.2	8.002	10.356	2.354	29.41
26	B-Pillar Inner	1.5	1.5	7.284	7.284	0.000	0.00
27	B-Pillar Body Side Outer	1.3	1.3	9.887	9.887	0.000	0.00
28	B-Pillar Body Side Outer	0.9	0.9	2.524	2.524	0.000	0.00
29	Rocker Inner	1.7	2.2	6.986	9.041	2.055	29.41
30	Rocker Inner	1.3	1.3	6.142	6.142	0.000	0.00
31	Dash Panel	0.7	0.7	6.035	6.035	0.000	0.00

Table 7.24: Part Mass for Optimal Design 8 (Upgraded Front End Package)

Table 7.19 shows the topological parameters for this design. Table 7.20 shows the thickness and material parameters. Figure 8 shows the NCAP B-Pillar acceleration pulse for this design along with the target pulse. Table 7.21 shows the IIHS intrusion values for this design. The table also indicates the target and good performance ratings. Table 7.22 shows the static/ dynamic stiffness values . Tables 7.23 and 7.24 give the mass distribution in various components.

Conclusions

The DOE based parametric studies of the Initial and Upgraded front end package were successfully employed to generate a library of designs that were close to targets and had a minimum mass penalty. These designs constituted a small set of designs obtained by using a few combinations of objective function, constraints and design space. We obtained several designs by changing these design parameters, according to the performance desired.

The crash performance of the optimized design of the Initial Front End package was far superior to any of the best-in-class vehicles. The optimized design (Design 7) achieved a **double 5-star NHTSA** rating and an overall **"good" rating in IIHS** footwell intrusions. Furthermore, it met the more stringent NCAP and IIHS targets set up for the current light-weighting project. The optimized design had **mass savings** of more than **12kg**, as compared to the baseline design (Design 0).

The crash performance of the optimized Upgraded Front End package compared favorably to the best-in-class vehicles. The optimized design (Design 8) achieved a **double 5-star NHTSA** rating and an **overall "good" rating in IIHS** footwell intrusions. Furthermore, it nearly achieved the more stringent NCAP and IIHS targets set up for the current light-weighting project. The optimized design had a mass penalty of 16kg, as compared to the baseline design (Design 0). The mass penalty was minimized through computer-aided optimization and was necessary in order to meet the structural targets.

The library of designs are archived in the knowledge base tool, Proteus.

References

1) *Phase I Structural Performance Targets Report*.

2) *Baseline Model for CAO Report, Milestone 3*.

3) *First Bumper Design Report, Milestone 5*.

4) *Parametric Design Combinations Report, Milestone 7*.

5) *ULSAB Static and Dynamic Stiffness Study, Milestone 8*.

6) *NCAP 35 mph Study, Milestone 11*.

7) *ULSAB Model with Upgraded Powertrain Report, Milestone 14*.

8) *Upgraded Powertrain DOE Study, Milestone 15*.

9) *Fourth Bumper Design Report, Milestone 26*.

10) *Library of Designs for KB, Baseline ULSAB, Milestone 23*.

11) *Library of Designs for KB, Upgraded Powertrain, Milestone 24*.

Formability

Objective

The purpose of the formability study was to explore the possibility of using high strength/ultra high strength steels towards existing or modified critical components in the front end structure. As more high strength steels were proposed for future automobile structure, it was very beneficial to have an early examination of the impacts they would bring on parts manufacturing.

Another objective of the study was to identify the limiting combinations of high strength steel and minimum thickness from a forming standpoint. The combinations could serve as one of the many criteria for best material selection at the early stage of design.

A one-step forming simulation was selected for the first set of studies (Ref. 1). It provided quick and reasonably good feedback when limited tooling and process information was available. The disadvantage of using one-step, however, lied in less accuracy in simulation results and limitations on resolving forming problems from tooling or process design. Since the purpose of the study was to identify any serious problem that might happen due to new material usage, one-step simulation sufficed as an indicator. Incremental analysis with more tooling and process information was performed on difficult parts identified by one-step analysis later in the project (Ref. 2).

Approach

Formability of the parts was examined using FLD (Forming Limit Diagram). FLC (Forming Limit Curve) was generated based on thickness and ‘n ‘ value (hardening exponent coefficient) of the material following Keeler’s approach. Depending on how well a stress-strain curve could be represented by power law, the accuracy of the conclusion varied.

The part meshes were extracted from an existing model. The mesh was cleaned and flanging area was laid out. Tipping was then calculated based on the geometry of the part and the mesh was tipped to the desired orientation in space. Iterations usually were required to arrive at the optimized outcome for a given part. They could be achieved by modifying boundary conditions for another round of simulation. In the scenario where problems persisted after several iterations, alternate design parameters were suggested for better manufacturability.

All of the following parts were studied using one-step simulation:

Rails inner

Rails outer

Shotgun inner

Shotgun outer

Panel A-pillar inner lower

Panel A-Pillar Inner upper

Front crash member dash

Body side outer

Panel rocker inner

Panel dash

Panel B-pillar inner

The following parts were studied using incremental simulation:

Cross Member

Front Rail Inner

Front Rail Outer

One-Step Simulation

In this study (Ref. 1), analyses were performed in Hyperform as well as other one-step simulation tools. Manufacturing processes were optimized within the capability of one-step simulation to achieve best products. In cases where failures could not be avoided by simply changing material and modifying stamping processes, minimized changes in product were suggested. Besides the examination of suggested grade/gauge combination, various grade/gauge combinations were explored for design alternatives.

A list of limiting values were arrived at, for each components studied. The limiting values, although some of which were too large to be used in practice, were intended for quick evaluation of part designs using high strength steels.

Part I: Forming using suggested material and thickness

This section contains the simulation results for parts with suggested material and thickness combination. The formability contour and Forming Limit Diagram (FLD) were the results of the optimized results from iterations of different tipping angles and drawbead forces.

B-Pillar

Tipped B-pillar geometry is shown in Fig. 8.1. Material suggested for B-pillar was HSLA350/450, with a thickness of 1.5 mm. Drawbeads were prescribed at the circumference to control material flow (Fig. 8.2).

Figures 8.3 and 8.4 indicated there were problems at the corners where large stretches were expected. Wrinkling tendency was predicted by one-step software at the corners of the geometry. The wrinkling prediction was not a realistic forecast partly because much of the tooling geometry close to the corners was not present in the simulation. Providing sensible binder and addendum design information, the wrinkles were easily eliminated in real process.

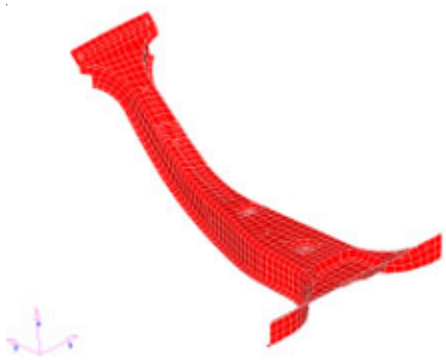


Figure 8.1: Part Geometry and Tipping

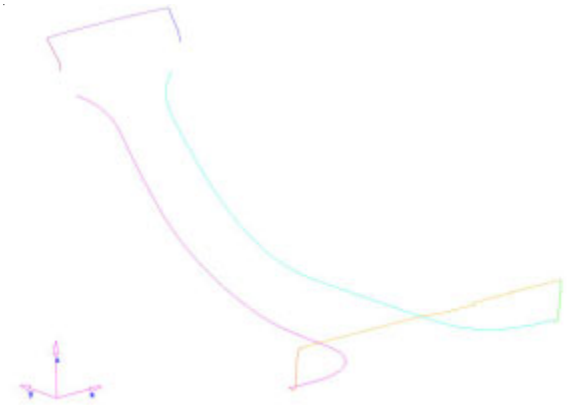


Figure 8.2: Drawbeads Location

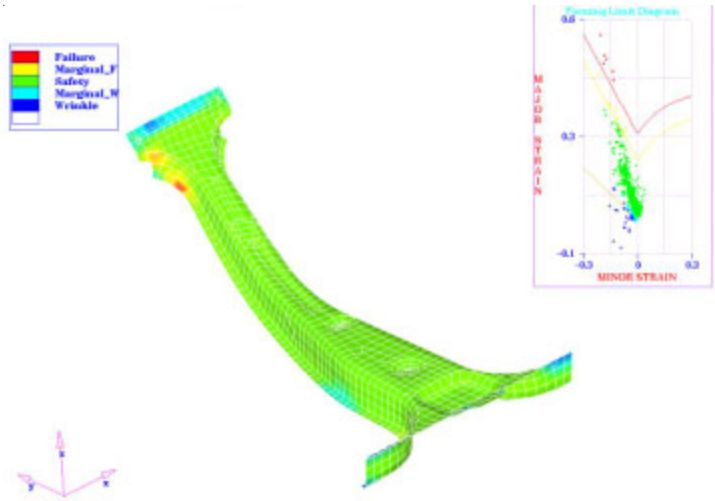


Figure 8.3: Formability - B Pillar I

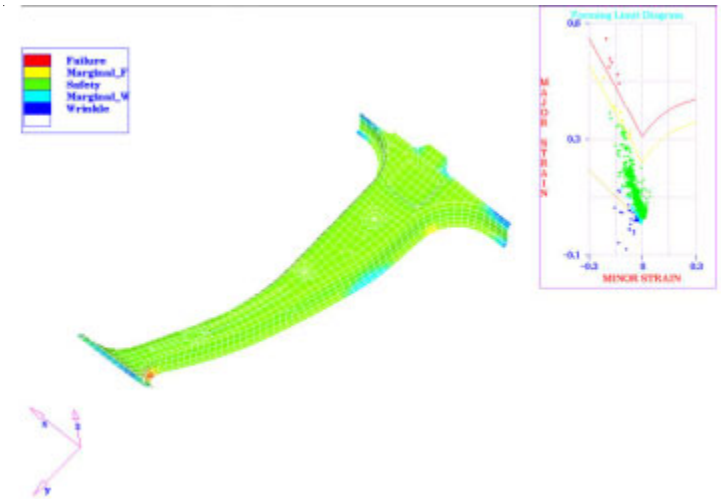


Figure 8.4: Formability - B Pillar II

Dash Panel

Tipped dash panel geometry is shown in Fig. 8.5. Material suggested to make dash panel was BH210 with a thickness of 0.7mm. Drawbeads were prescribed at the circumference to control material flow as shown in Fig. 8.6.

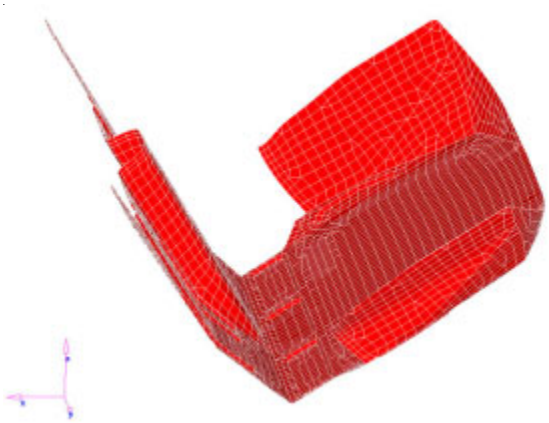


Figure 8.5: Dash Panel Geometry and Tipping



Figure 8.6: Drawbeads Location

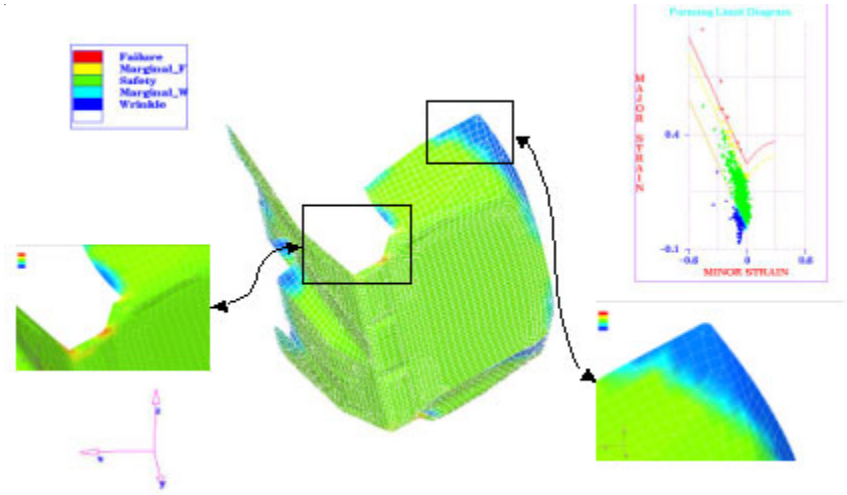


Figure 8.7: Formability - Dash Panel I

Red zones were observed from Fig. 8.7, indicating possible failure. Closer examination suggested the failure was caused by “notch” shapes in part geometry. The notch was only in part geometry to be made by subsequent trimming process. Within the scope of forming, the notch did not exist thus the failure due to the notch would not happen in reality.

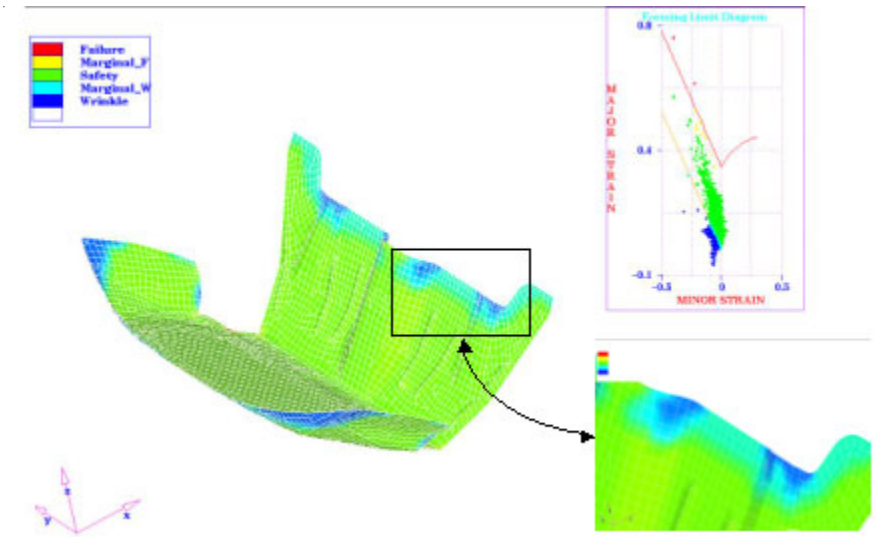


Figure 8.8: Formability - Dash Panel II

Wrinkling tendency highlighted in Figs. 8.7 and 8.8 were, again, caused by insufficient tooling information. They could be eliminated with proper addendum and binder geometry. With suggested grade/gauge, the part was formable although there was not much room left for further down gauging.

Rocker Inner

Tipped rocker inner panel geometry is shown in Fig. 8.9. It was tailor-welded of two parts. Both parts were made of HSLA350/450 but of different thickness as marked. Drawbeads were prescribed at the circumference to control material flow as shown in Fig. 8.10.

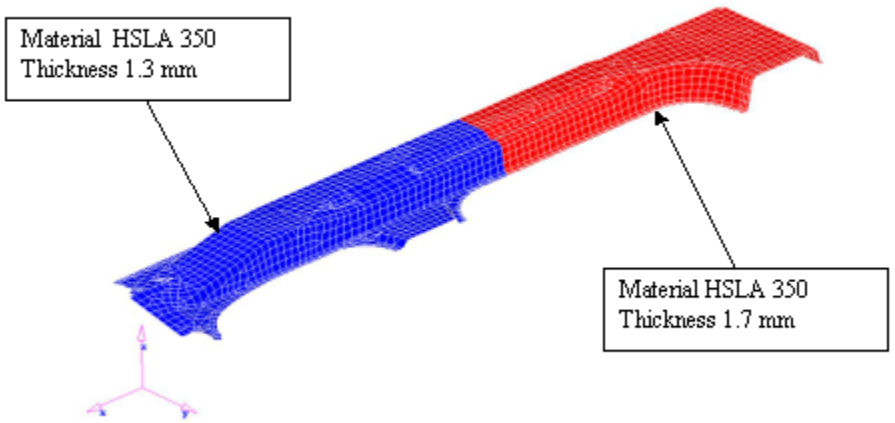


Figure 8.9: Rocker Inner Panel - Geometry and Tipping

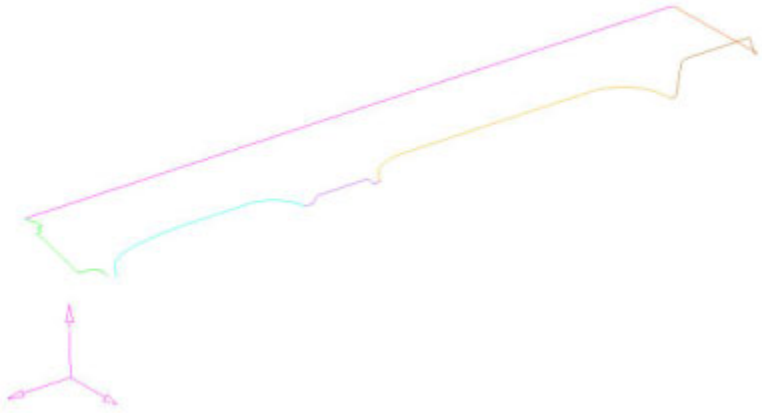


Figure 8.10: Location of Drawbeads

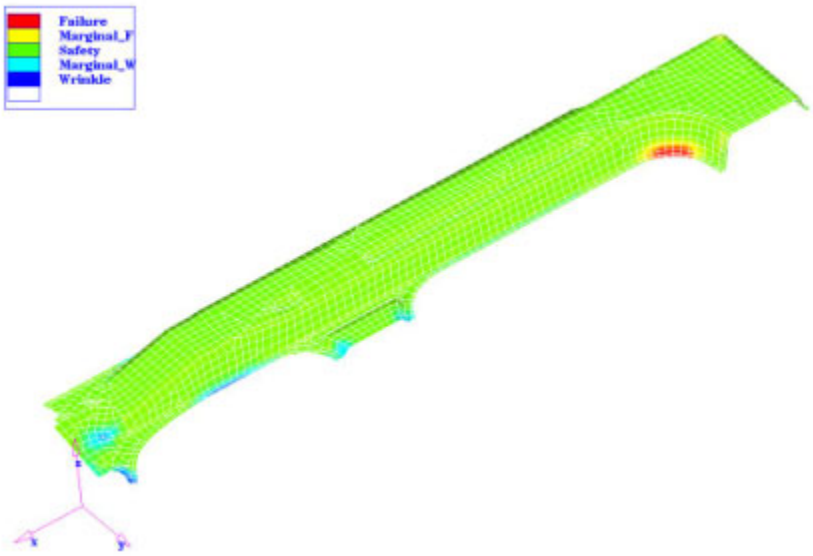


Figure 8.11: Formability - Rocker Inner Panel I

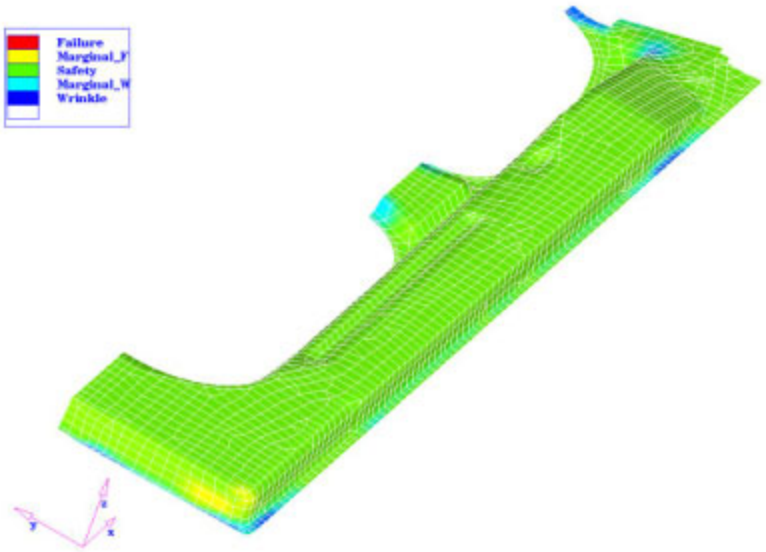


Figure 8.12: Formability - Rocker Inner Panel II

Splitting/splitting tendency was observed at corners from Figs. 8.11 and 8.12 due to excessive thinning. Better fillet radii and opening angles could be used in those areas to ease the situation. Wrinkling area at the rear end of the part in Fig. 8.11 was introduced by the joint of feature surfaces. The magnitude of wrinkles could be reduced to an acceptable level by tightening up drawbeads in neighboring elements.

Bodyside Outer Panel

Tipped bodyside outer panel geometry is shown in Fig. 13. It was a tailor-welded part. It was composed of five sections of different material and thickness as labeled in Fig. 13. Drawbeads were prescribed at the circumference to control material flow as shown in Fig. 14.

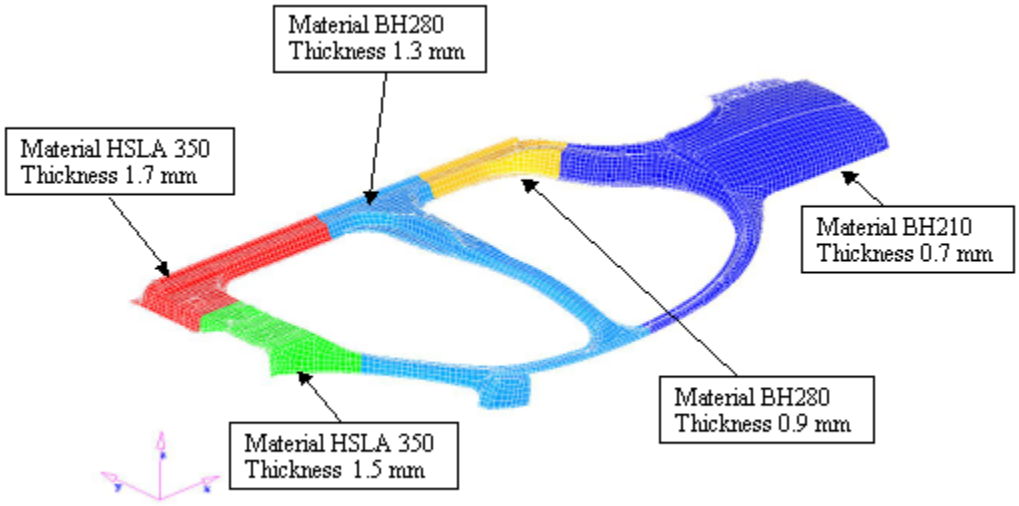


Figure 8.13: Part Geometry and Tipping - Body Side Outer Panel

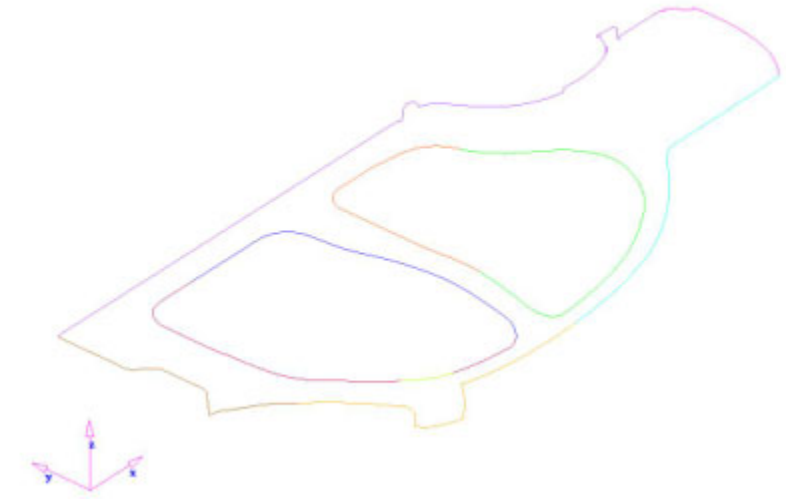


Figure 8.14: Drawbeads Location

Formability contour of bodyside outer panel shown in Fig. 8.15 identified several problem areas. Failures at the lower corners as well as the latch area of the rear door were results of excessive stretching in the area. Wrinkles were also observed at the upper corner where the front roof rail was connected to bodyside outer panel. Modifications in the process design were proposed to solve them. The stretching could be reduced by supplying more material to the area using appropriate binder and addendum design. The magnitude of wrinkles could be reduced by prescribing tighter control of material flow during the stamping processes. Due to incomplete processing information, one-step analysis fell short of providing a solution because of the limitations in implementing tooling information in analysis. Incremental simulations was needed to investigate the part further and develop a remedy for the problems from process design.

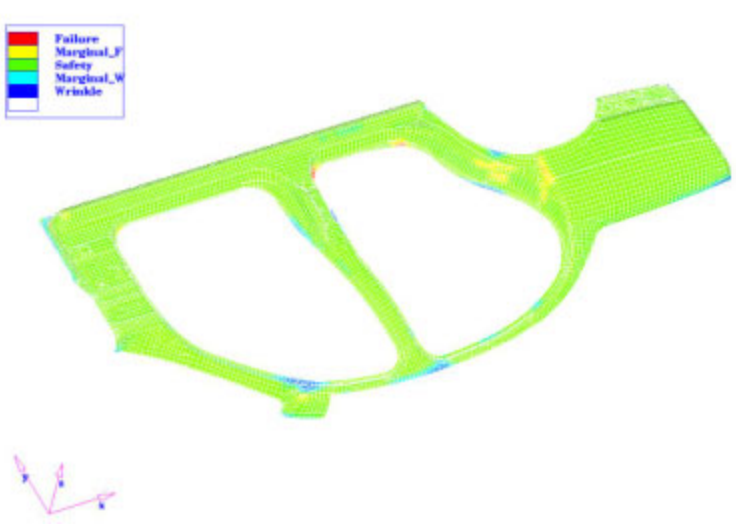


Figure 8.15: Formability - Bodyside Outer Panel

Rail Inner

Tipped rail inner panel geometry is shown in Fig. 8.16. It was still designed as a tailor-welded part composed of three pieces of same material but different thickness. Drawbeads were prescribed at the circumference to control material flow as shown in Fig. 8.17.

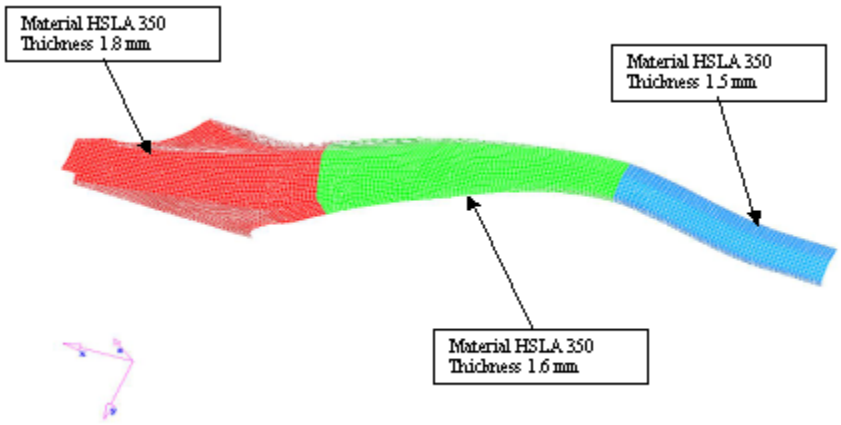


Figure 8.16: Rail Inner - Geometry and Tipping

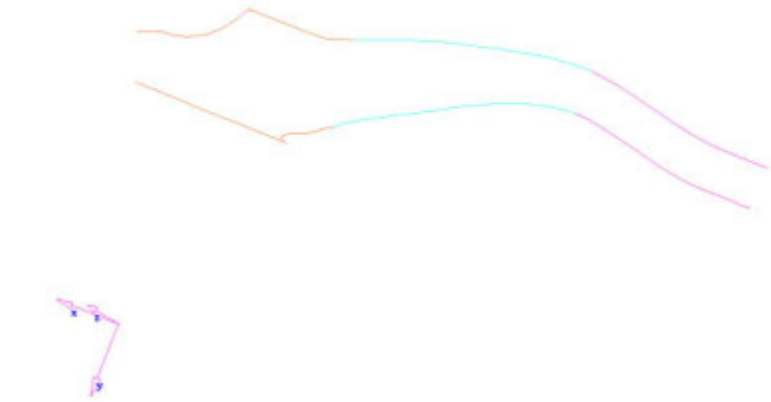


Figure 8.17: Drawbeads Location

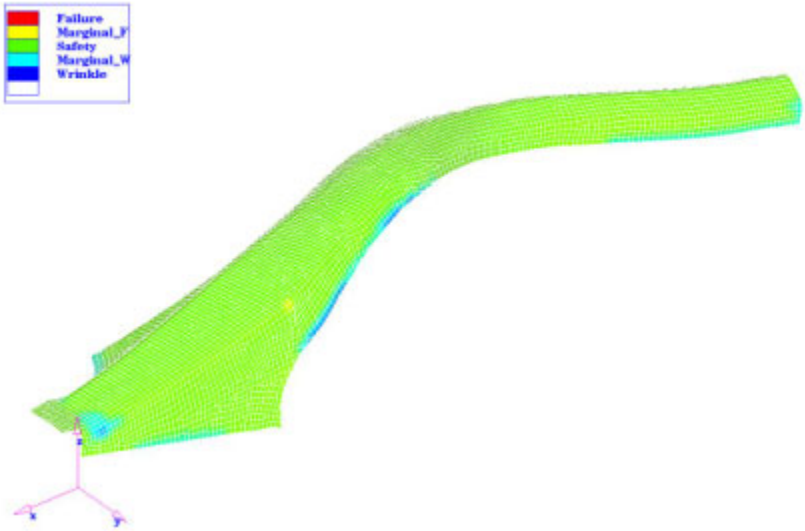


Figure 8.18: Formability - Rail Inner I

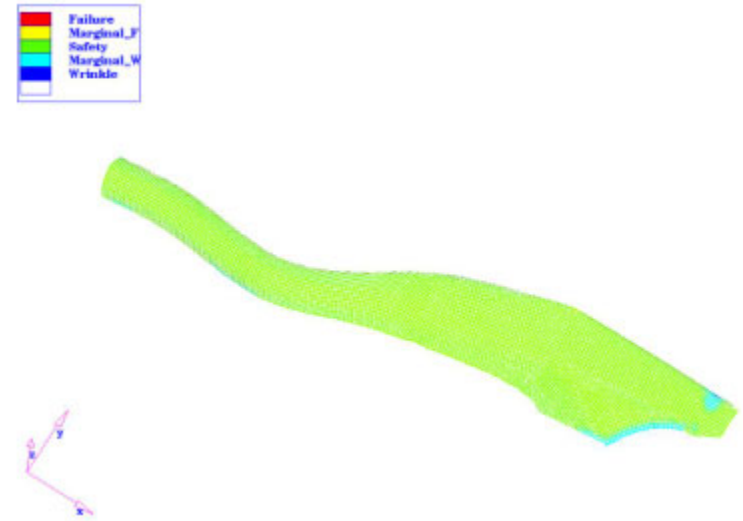


Figure 8.19: Formability - Rail Inner II

Figs. 8.18 and 8.19 suggested the formability for modified rail would not become a problem for given material and thickness combination. The wrinkling tendency shown in the plots were due to lack of tooling information and could be avoided easily otherwise.

Rail Outer

Tipped rail outer panel geometry is shown in Fig. 20. Corresponding to rail inner part, it was designed as a tailor-welded part composed of three pieces of same material but different thickness.

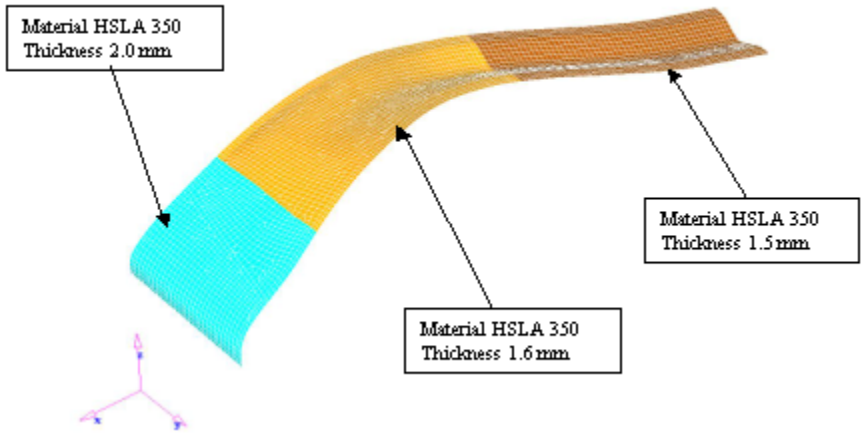


Figure 8.20: Rail Outer - Geometry and Tipping

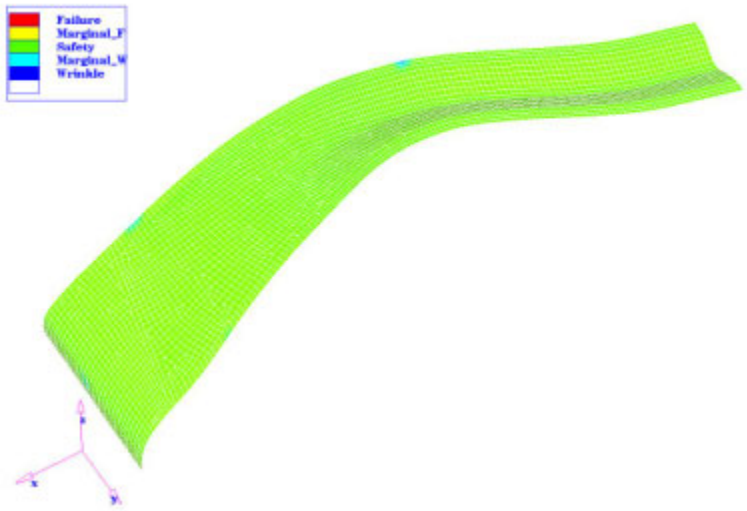


Figure 8.21: Drawbeads Location

As expected, formability contour in Fig. 8.21 did not indicate any forming problems. The modified geometry was formable with suggested grade/ gauge combination.

Shotgun Inner

Tipped shotgun inner geometry is shown in Fig. 8.22. The material suggested to make the part was HSLA425/770 and the thickness, 1.2mm.



Figure 8.22: Shotgun Inner - Geometry and Tipping

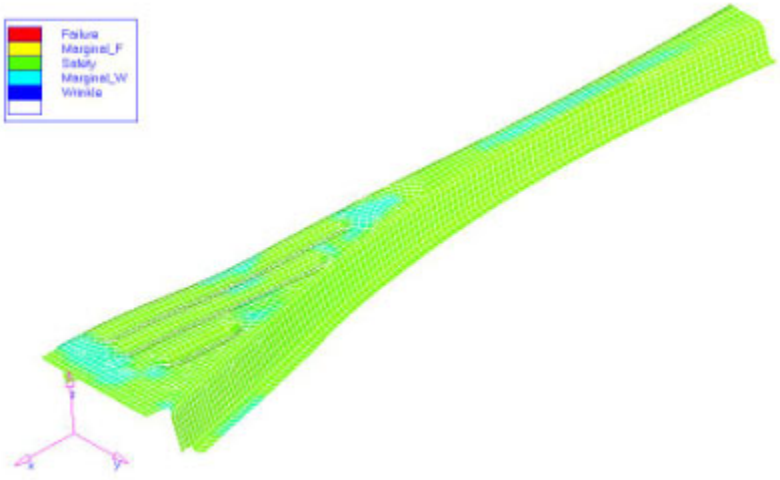


Figure 8.23: Formability - Shotgun Inner I

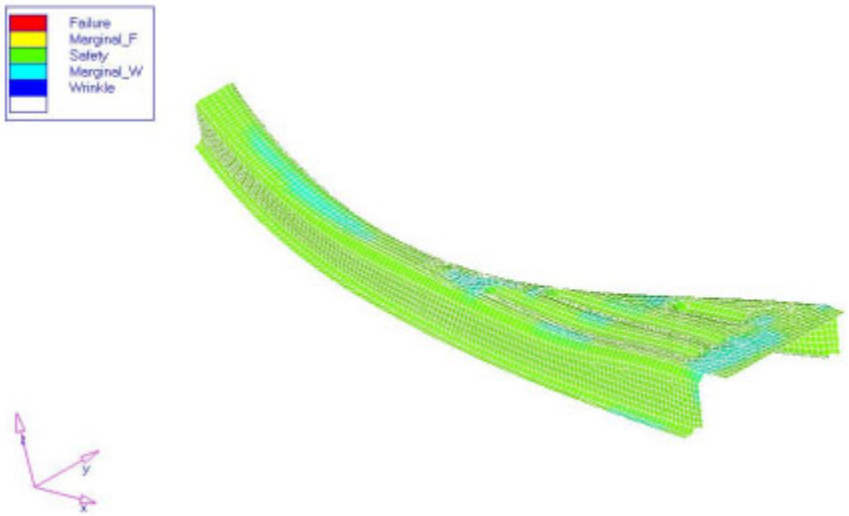


Figure 8.24: Formability - Shotgun Inner !I

Formability contours (Figs. 8.23 and 8.24) showed the part was formed well except some wrinkles at the upper face of the part. The wrinkles were natural happenings given the reinforcement designs in the part. Actions could be taken to minimize the magnitude; and because the wrinkles were not on the mating surface, they would not pose problem for assembly, the presence of the wrinkles would not be a concern.

Shotgun Outer

Tipped shotgun outer geometry is shown in Fig. 25. The material suggested to make the part was HSLA350/450 and the thickness, 0.9mm.



Figure 8.25: Shotgun Outer - Geometry and Tipping



Figure 8.26: Drawbeads Location

Figure 8.26 gives the formability of shotgun outer. Because the part is quite flat, except for the wrinkling tendency at the end of reinforcing features, the rest of the part is perfectly formable. The wrinkling tendency, although present, would probably not affect assembly and structure integrity.

Part II: Limiting Combinations

Limiting combinations of highest grade and minimum gauge were found out for eight parts investigated. The order of the materials being tried was DP700/1000, DP500/800, and HSLA425/770. Minimum thickness that could be used to successfully form the part for each material was identified. Only the practical combinations are presented below.

B-Pillar

The limiting combinations to form B-pillar were: 5.9mm for DP700/1000, 2.8mm for DP500/800 and 1.5mm for HSLA425/770.

Figure 8.27 shows the forming limit contour and forming limit diagram of forming B-pillar with HSLA425/770 at 1.5mm thickness. The yellow region indicates the location where failure would happen if thinner gauge was used.

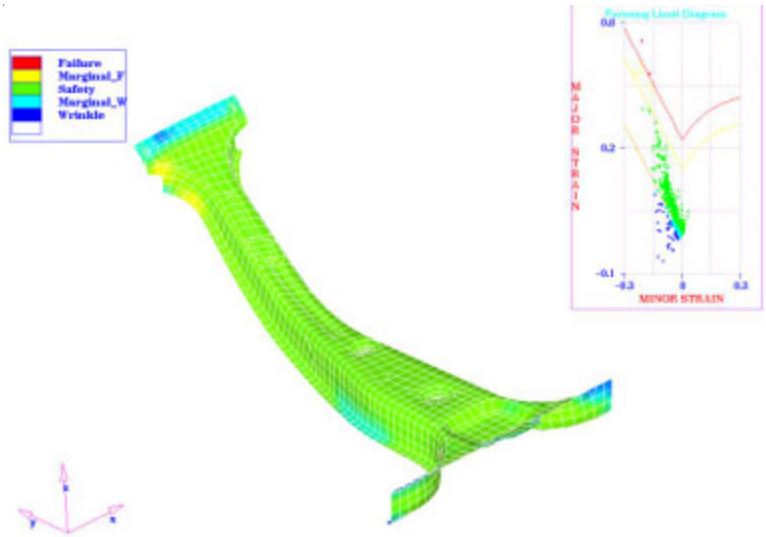


Figure 8.27: Forming Limit for B-PIllar

Dash Panel

The limiting combinations to form dash panel were: 1.2mm for DP700/1000, 0.9mm for DP500/800 and 0.7mm for HSLA425/770.

Figure 8.28 shows the forming limit contour and forming limit diagram of forming dash panel with HSLA425/770 at 0.7mm thickness. The yellow region indicates the location where failure would happen if thinner gauge was used.

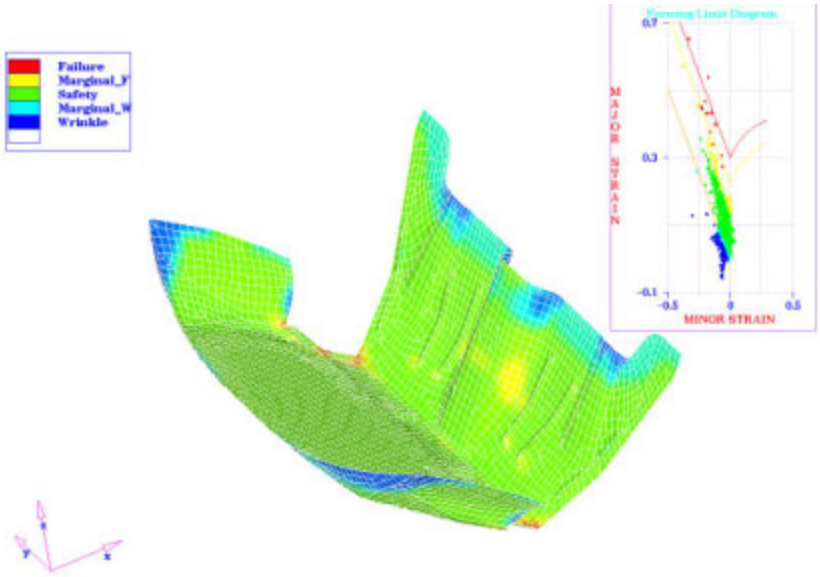


Figure 8.28: Forming Limit for Dash Panel

Rocker Inner

The limiting combinations to form rocker inner were: 5.7mm for DP700/1000, 3.3mm for DP500/800 and 1.6mm for HSLA425/770.

Figure 8.29 shows the forming limit contour and forming limit diagram of forming rocker inner with HSLA425/770 at 1.6mm thickness. The region highlighted indicates the location where failure would happen if thinner gauge was used.

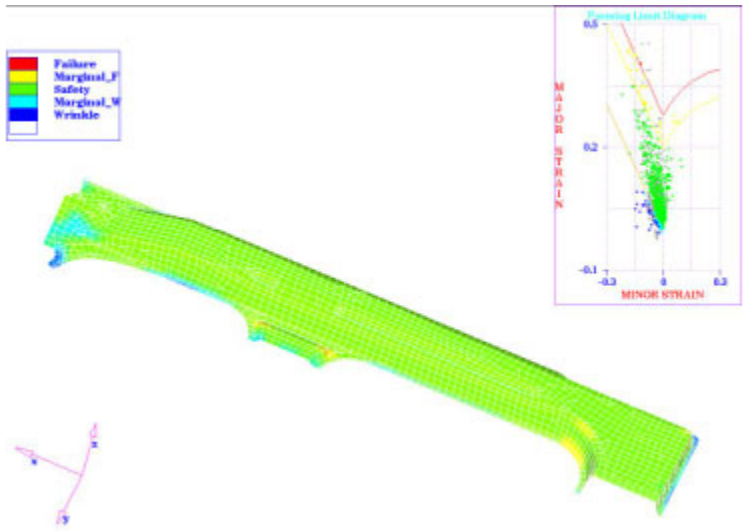


Figure 8.29: Forming Limit for Rocker Inner

Bodyside Outer

The limiting combinations to form bodyside outer panel were: 5.3mm for DP700/1000, 2.6 mm for DP500/800 and 1.4mm for HSLA425/770.

Figure 8.30 shows the forming limit contour and forming limit diagram of forming bodyside outer with HSLA425/770 at 1.4mm thickness. The red/ yellow regions indicate the location where failure would happen if thinner gauge was used.

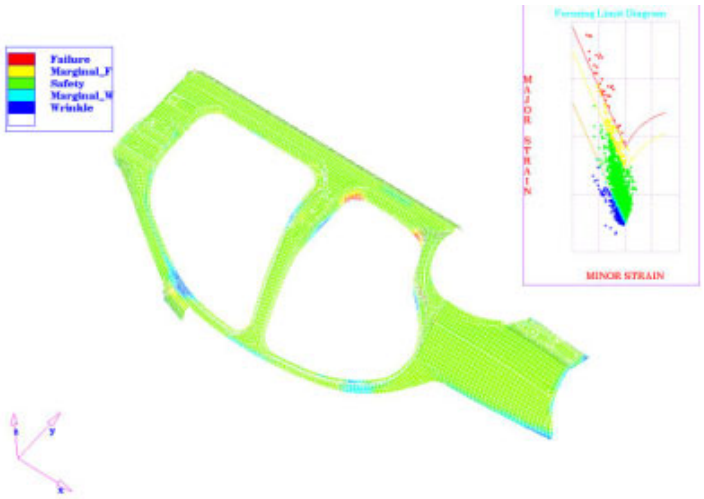


Figure 8.30: Formability Limit for Rocker Inner

Left Rail Inner

The limiting combinations to form modified left rail inner were: 3.0mm for DP700/1000, 2.0mm for DP500/800 and 1.5mm for HSLA425/770.

Figure 8.31 shows the forming limit contour and forming limit diagram of forming left rail inner with HSLA425/770 at 1.5mm thickness. The region highlighted indicates the location where failure would happen if thinner gauge was used.

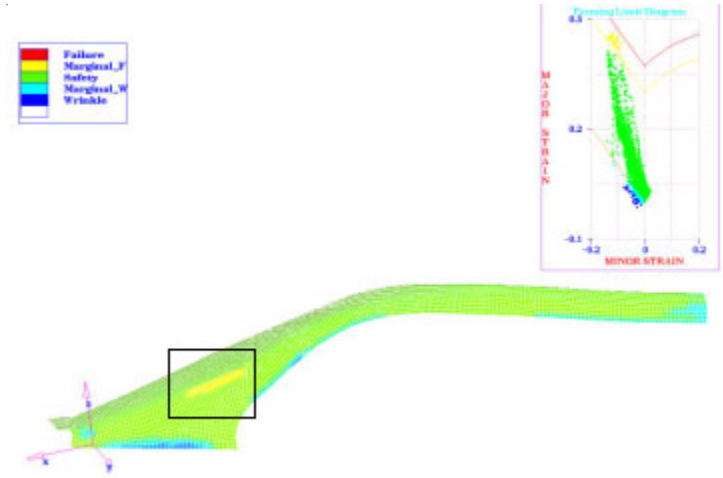


Figure 8.31: Formability of Left Rail Inner

Left Rail Outer

The limiting combination to form modified left rail inner was: 0.8mm for DP700/1000.

Figure 8.32 shows the forming limit contour and forming limit diagram of forming left rail outer with DP700/1000 at 0.8mm thickness. The region highlighted indicates the location where failure would happen if thinner gauge was used.

Because the part is formable with the highest grade at a reasonable thickness, further study on lower grade material was not conducted.

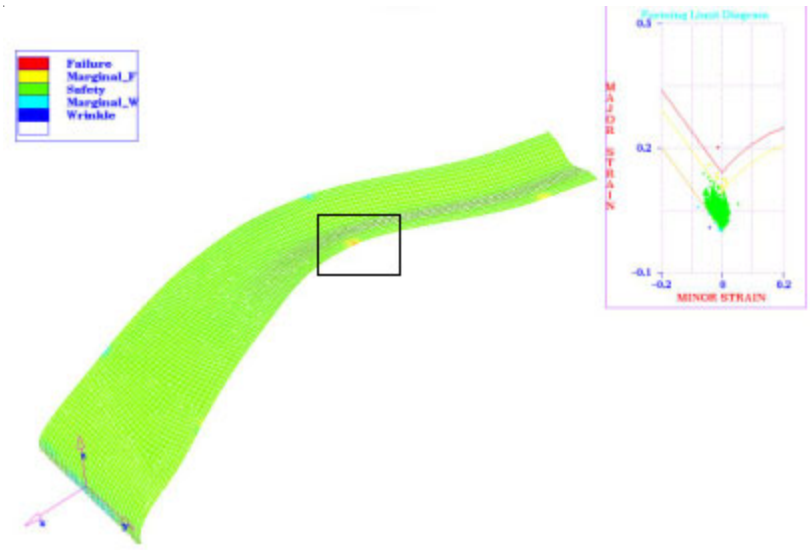


Figure 8.32: Formability of Rail Outer

Shotgun Inner

The limiting combination to form modified shotgun inner was: 1.2mm for DP700/1000.

Figure 8.33 shows the forming limit contour and forming limit diagram of forming shotgun inner with DP700/1000 at 1.2mm thickness. The region highlighted indicates the location where failure would happen if thinner gauge was used.

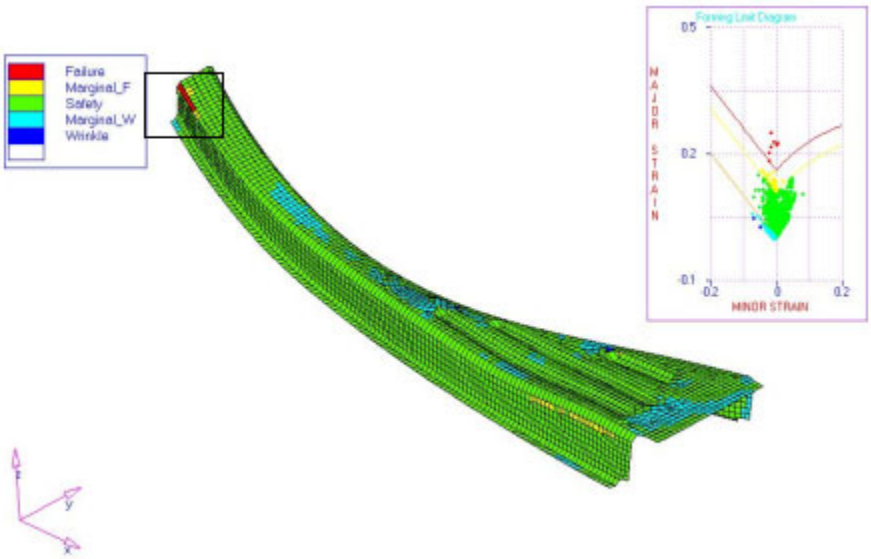


Figure 8.33: Formability of Shotgun Inner

Shotgun Outer

The limiting combination to form modified shotgun outer was: 0.1mm for DP700/1000.

Understanding that 0.1mm was by no means a practical thickness to be used in reality, the intention here was to demonstrate that the part was formable for any practical grade/gauge combination. Figure 8.34 shows the forming limit contour and forming limit diagram of forming left rail inner with DP700/1000 at 0.1mm thickness.

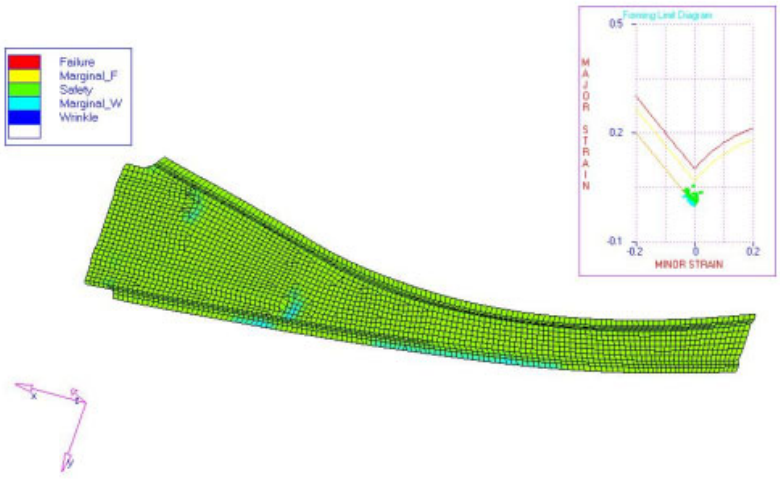


Figure 8.34: Formability of ShotgunOuter

Cases Studied by Steel Companies

Several other critical components in front-end structure were studied by steel companies from formability standpoint. Components analyzed are list as follows. Results of the simulations and discussions can be obtained from Ref. 1.

Panel A-pillar inner lower	by LTV steel
Front Crash member dash	by Ispat Inland
Rails inner	by US steel
Shotgun inner	by US steel
Rails outer	by Dofasco
Shotgun outer	by Dofasco
Panel A-Pillar Inner upper	By Rouge Steel

Incremental Simulation

This study (Ref. 2) documents the results of the formability analyses using die development concept, of the front-end structure using incremental code. Three parts in the front-end structure: Cross Member, Front Rail Inner, and Front Rail Outer were simulated with realistic draw die development. No incremental analysis was performed for the skirt as the DOE-based parametric study showed that there was no significant improvement in NCAP performance by upgrading the skirt material. A brief discussion on the forming issues of the skirt is included in this report.

Four critical parts were selected from the front end structure in order to fully evaluate their formability with dual-phase materials, and to provide possible solutions should the parts fail the formability criteria. The four parts were: 1st cross-member, front rail inner, front rail outer, and skirt. Incremental formability analyses were performed on all the parts, with the exception of the skirt.

All FEA incremental simulations in this report were performed using DYNA3D, which could predict all forming problems such as wrinkling and cracking accurately.

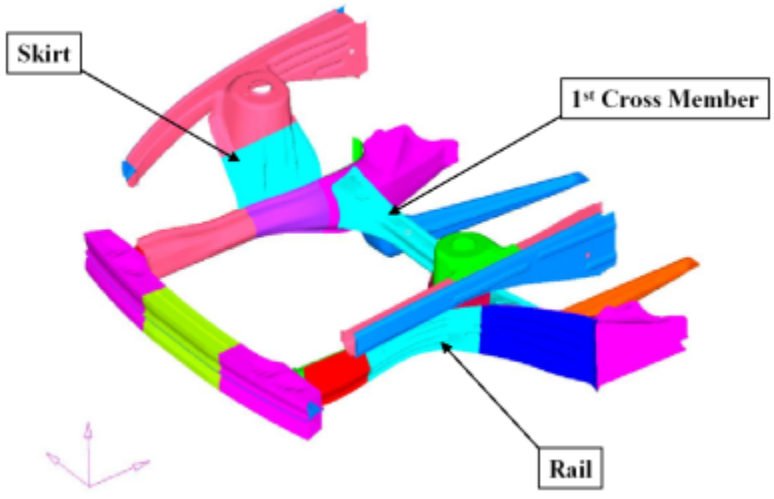


Figure 8.35: Baseline Model Front End Structure

Cross Member

Due to part symmetry, a half-model was used in the simulation, and symmetry boundary conditions were imposed along the centerline. This part was made of DP700/1000 material. The material property is listed in Table 1.

Component Name	Thickness (mm)	Material Code	Material Parameters					
			Y.S. (MPa)	UTS (MPa)	r-bar	n 5-15%	K (MPa)	u
1st Cross Member	1.1	AISI DP700/1000	700	1000	0.9	0.09	1521	0.12
Rail Inner	1.4/1.5/1.6 (F/M/R)	AISI DP500/800	500	800	1.0	0.14	1303	0.12
Rail Outer	1.4/1.5/1.8 (F/M/R)	AISI DP500/800	500	800	1.0	0.14	1303	0.12
Skirt	1.5/1.8	AISI DP280/600	280	600	1.0	0.21	1082	0.12

Table 1: Material Specification

Cross-Member Original Design

The design model that was extracted was prescribed by a coarse element mesh (8mm X 8mm element size). Figure 8.36 illustrates the part design.



Figure 8.36: Cross Member Original Design

In order to fully evaluate the product formability, different forming processes and die concepts were developed and simulated. Some of the key results are described below.

Version 1: Unified draw depth with the flange laid out on wall

The concept of the binder development is illustrated below.

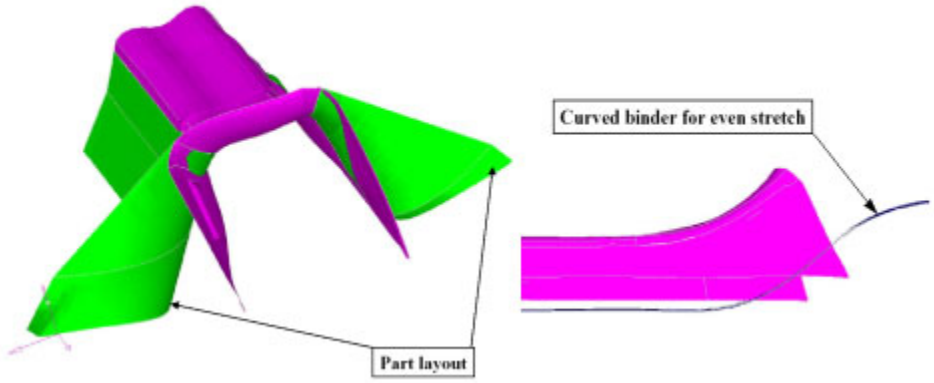


Figure 8.37: Binder Development with Unified Draw Depth

The FLD plot in Figure 8.38 shows both wrinkling and splitting at the same area, and presents a significant problem for stamping panel. Wrinkling was clearly observed on the panel during the forming process.

Due to the severe wrinkling and splitting problem, this die concept failed to form the panel.

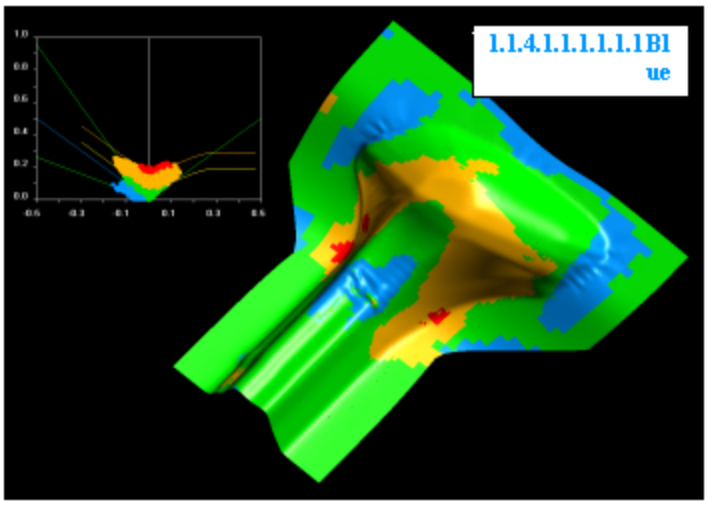


Figure 8.38: Cross Member FLD (Forming Limit Diagram)

Version 2: Revised binder to shorten blank length

In order to eliminate the wrinkling, the binder geometry was modified by



Figure 8.39: Revised Binder Shape with Die Surface

shortening the blank length. This increased the stretch at the top of the part.

Although wrinkling was reduced on the top, the FLD (Figure 8.40) still shows significant wrinkling and splitting.

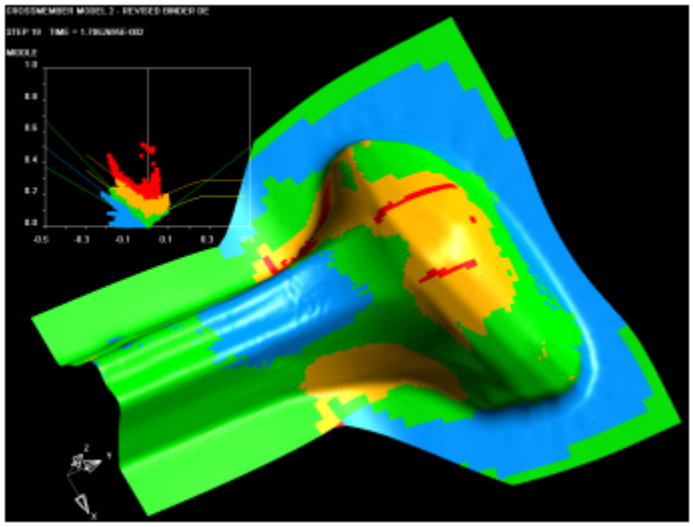


Figure 8.40: Cross Member FLD for Revised Binder

Hence, the part failed with this revised binder concept .

Version 5: Two operations with fully developable blank

Figure 8.41 shows the forming process and the developable blank shape. Figure 8.42 depicts the FLD on operation 1, showing double metal on the ends of the panel.

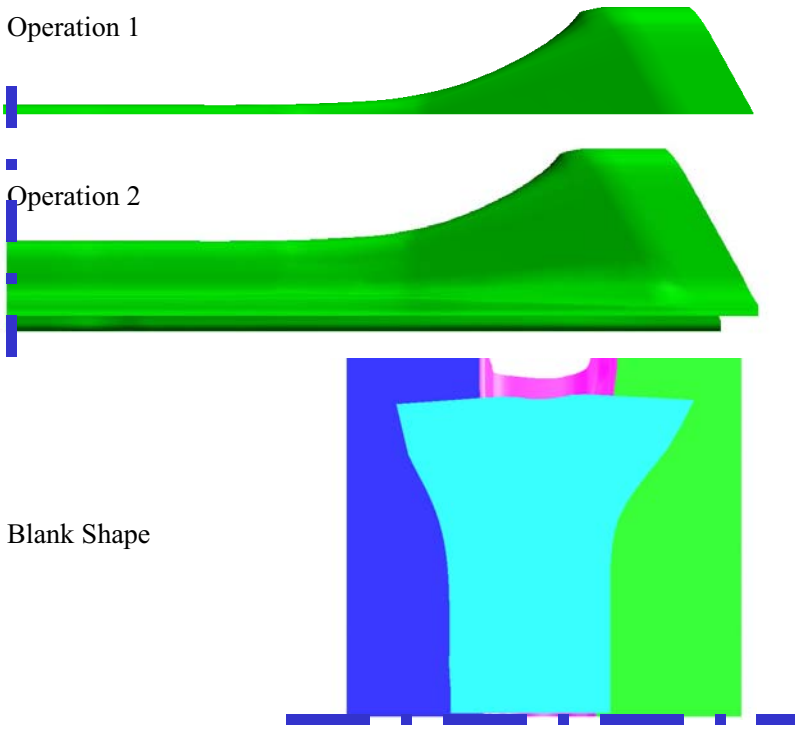


Figure 8.41: Two Operations with Developable Blank

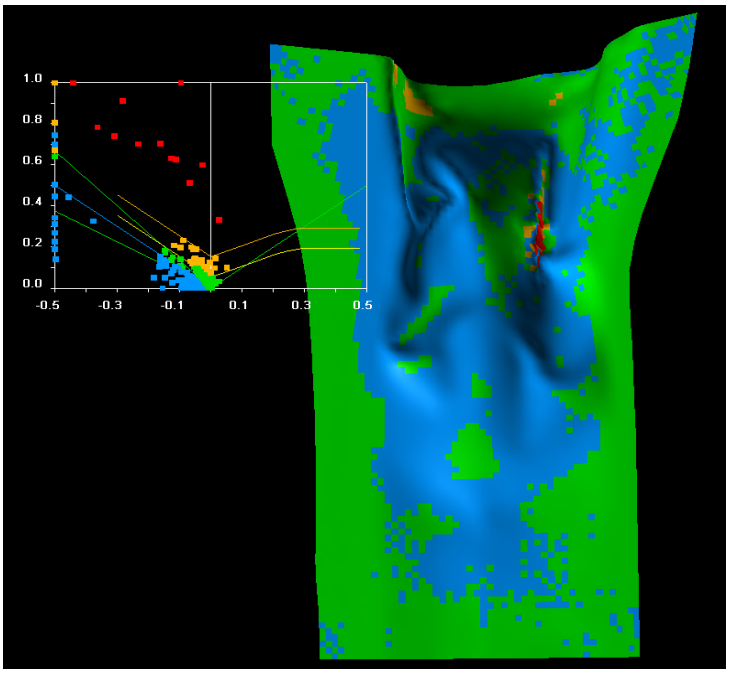


Figure 8.42: FLD for Operation 1

Conclusions

In spite of forming process optimization and die concept optimization, significant wrinkling and splitting still existed on the cross member panel, and the part failed with the current design. Product concession was needed to eliminate the forming problems.

Cross-Member with Product Concession

The product concession was introduced by enlarging the transition zone, which resulted in a gradual increase in depth. The back angle in original design was removed, as it can increase forming cost and equipment investment. Figure 8.43 illustrates the change in the product design.

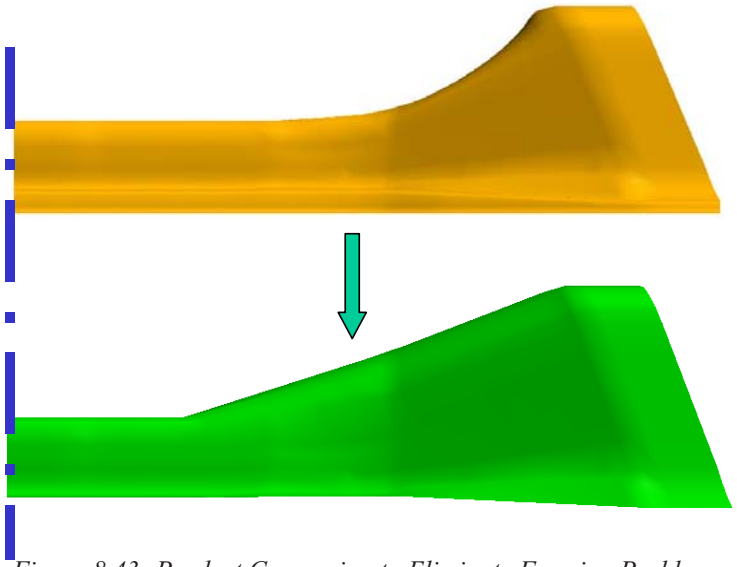


Figure 8.43: Product Concession to Eliminate Forming Problems

Version 14: Unified draw depth with product concession

In the first operation, the panel was evenly drawn to home, in order to reduce the wrinkling and splitting at the top of the panel. In the second operation, the flange was trimmed all around the panel. The final operation brought the entire flange to home. Figure 8.44 illustrates the forming process. Figures 8.44-8.48 show the simulation results.

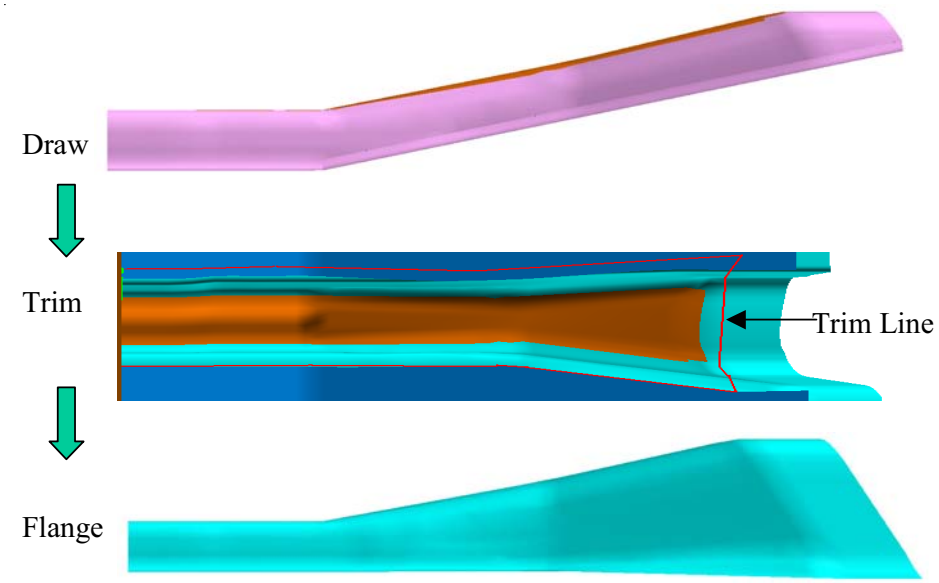


Figure 8.44: Forming Process and Die Concept

Blue – wrinkle red – split orange – marginal

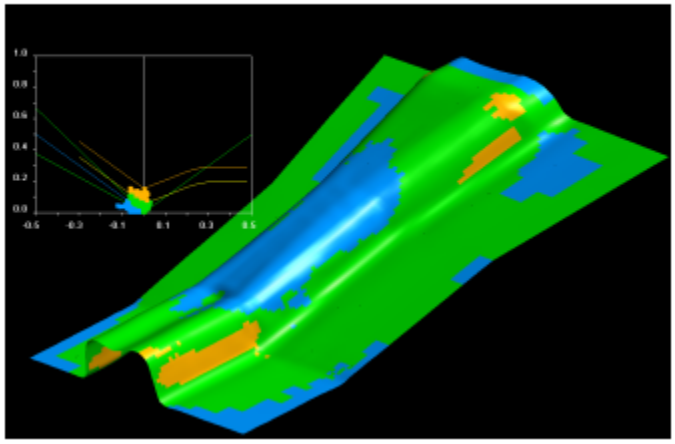


Figure 8.45: Cross Member Mod Design FLD - Forming Stage

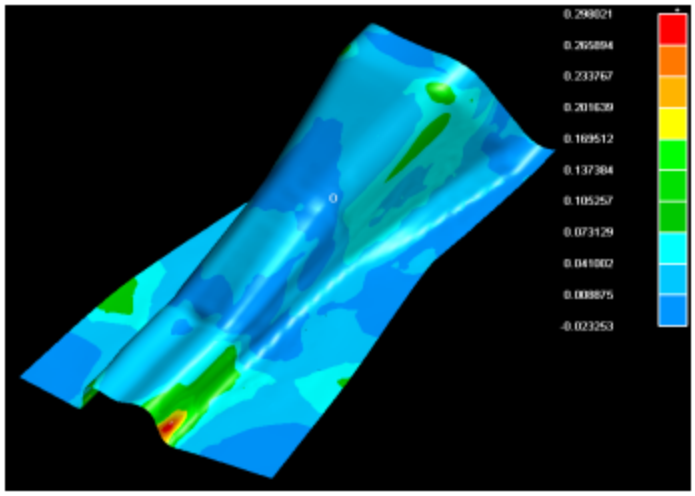


Figure 8.46: Major Strain

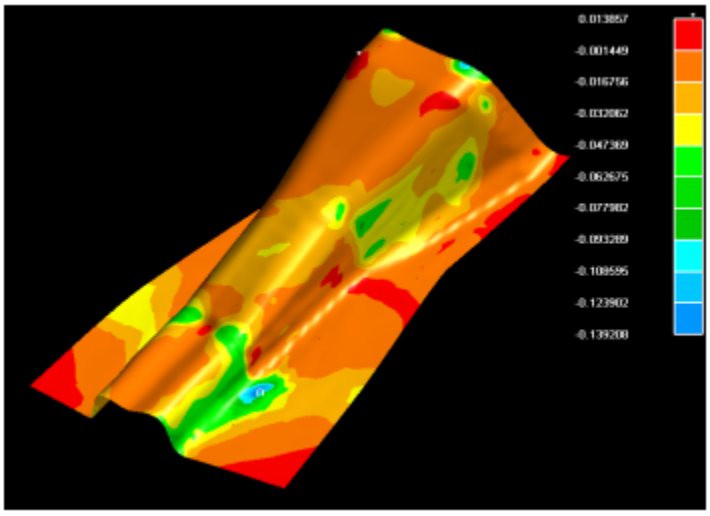


Figure 8.47: Minor Strain

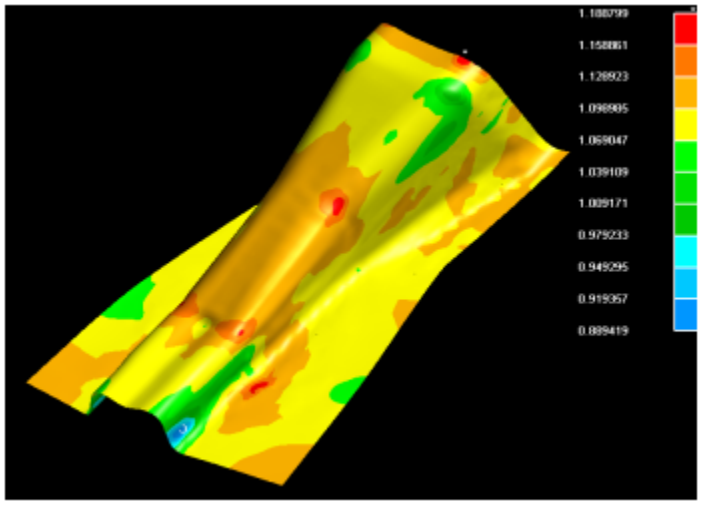


Figure 8.48: Thickness Distribution

Two small hot spots were observed in the FLD plot (Figure 8.49). One reason for this problem was the back angle in the middle of the part along the sidewall. Another reason was the coarse element mesh - there were only 3 elements on a 20mm radius arc (Figure 8.50). If the back angle was removed and the corner smoothened, the hot spot shown on FLD plot would be alleviated.

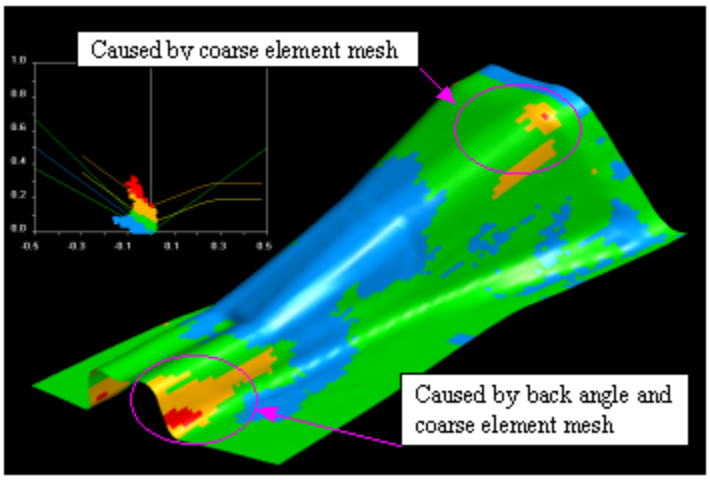


Figure 8.49: Cross Member Mod Design - FLD

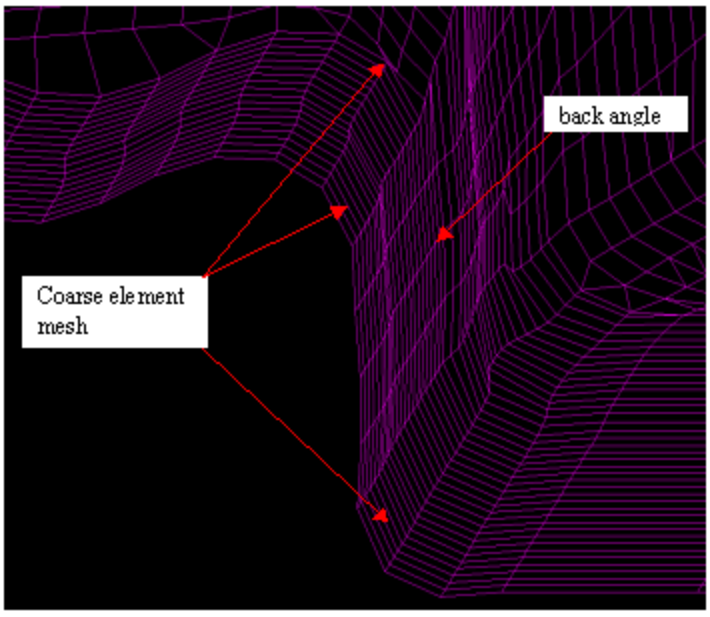


Figure 8.50: Element Mesh Quality

Conclusion

With the product concession and optimized forming process, the 1st cross member was rendered formable.

Front Rail Inner

The panel was made of tailor-welded blank with DP500/800 material. Blank thickness was 1.4mm/1.5mm/1.6mm. The material information is listed in Table 1. The product geometry is shown below (Figure 8.51).

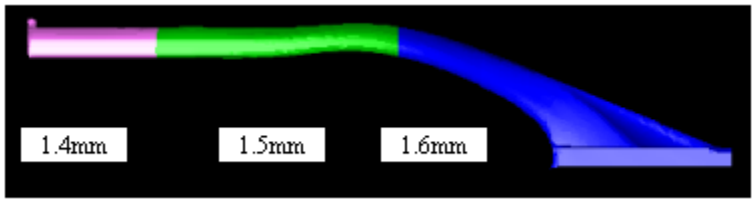


Figure 8.51: Front Rail Inner

Die Development

The draw type was regular three-piece stretch draw. Most flanges were drawn to home except for the small corner shown in Figures 8.52 and 8.53. An open-end was needed on the right side in order to eliminate splitting.

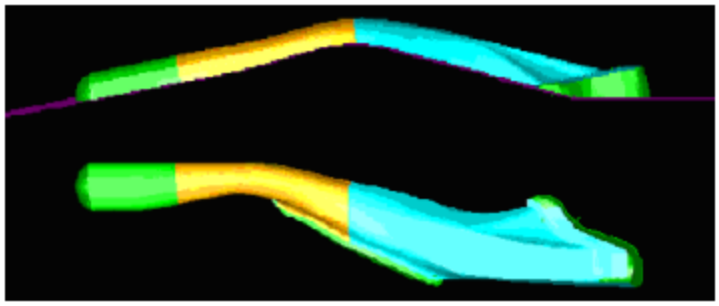


Figure 8.52: Front Rail Inner - Die Surface

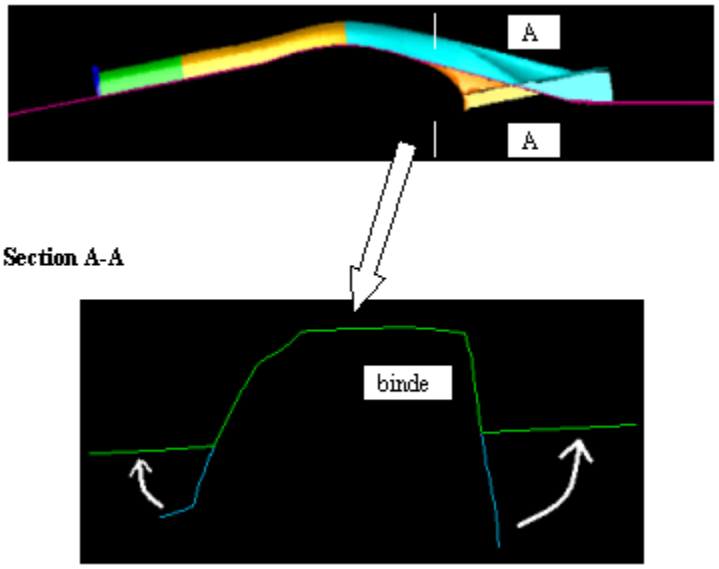


Figure 8.53: Front Rail Inner - Corner Layout

Simulation Results

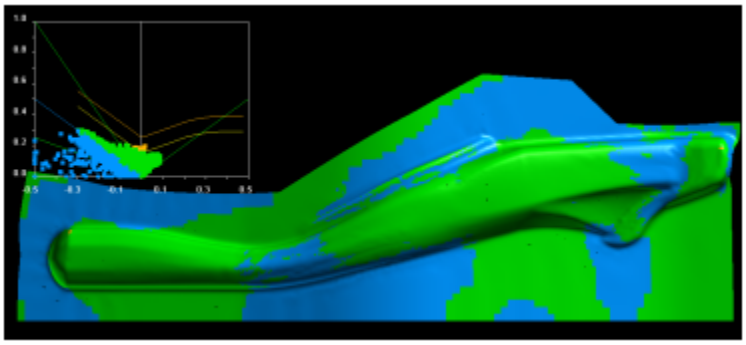


Figure 8:54: Front Rail Inner - FLD

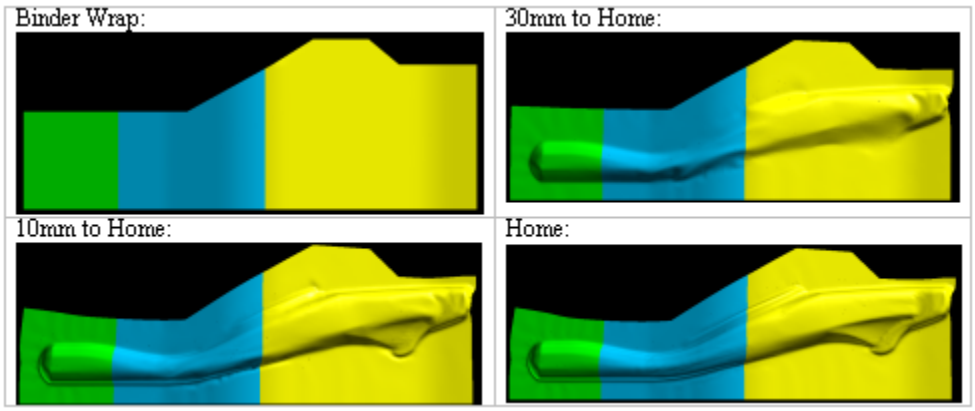


Figure 8.55: Front Rail Inner - Breakdown

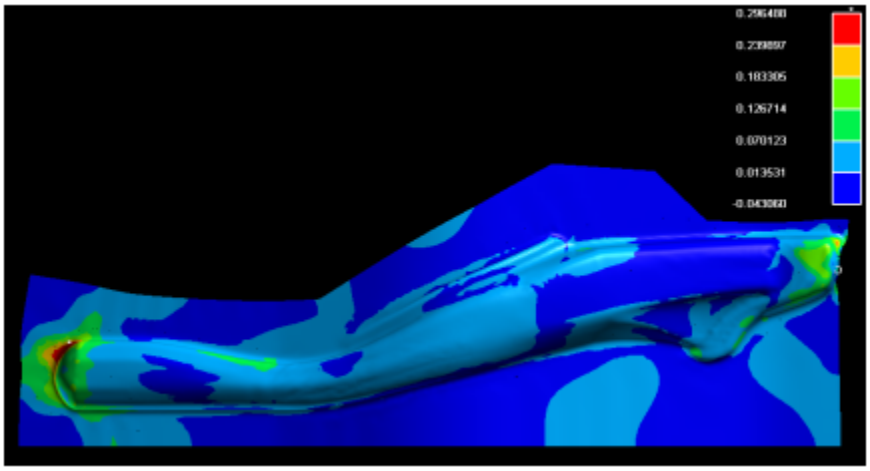


Figure 8.56: Front Rail Inner - Major Strain

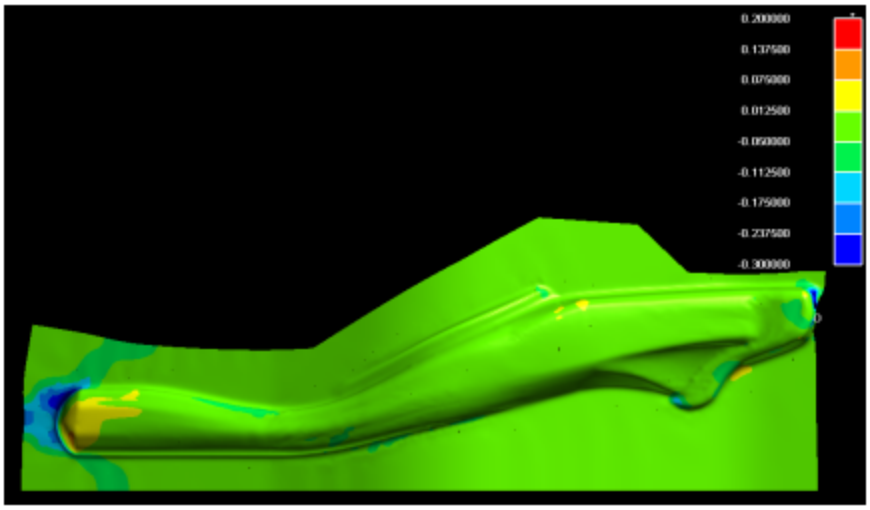


Figure 8.57: Front Rail Inner - Minor Strain

Conclusion

Using a three-piece stretch draw, the front rail inner was essentially formable with an open-end required to eliminate splitting at the end.

Front Rail Outer

The panel was made of tailor-welded blank with DP500/800 material. Blank thickness was 1.4mm/1.5mm/1.8mm. The material information is listed in Table 1. The product geometry is shown below (Figure 8.58).

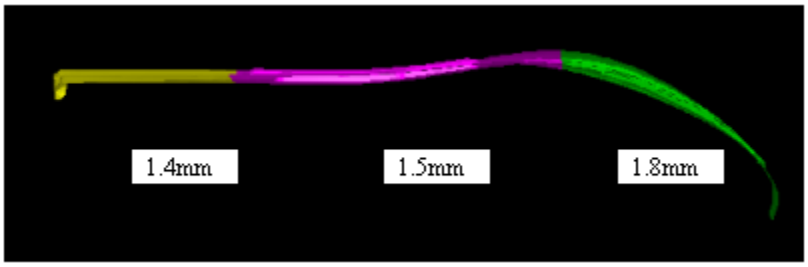


Figure 8.58: Front Rail Outer

Die Development

Three-piece stretch draw was used in order to gain enough stretch to prevent higher spring-back.

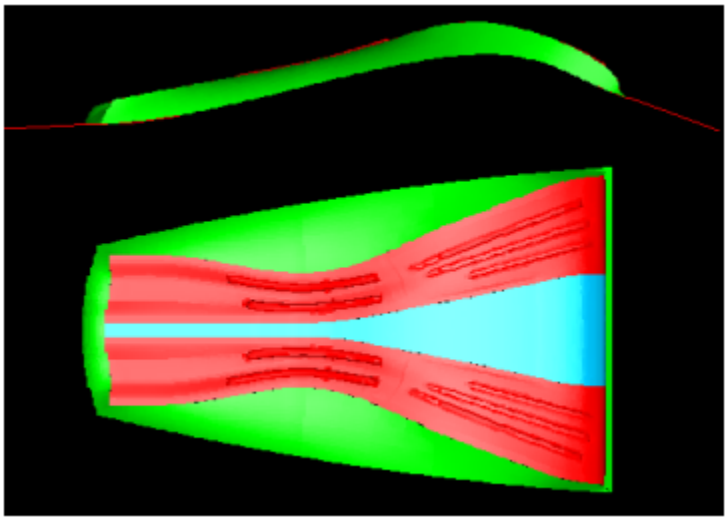


Figure 8.59: Front Rail Outer - Die Surface

Simulation Results

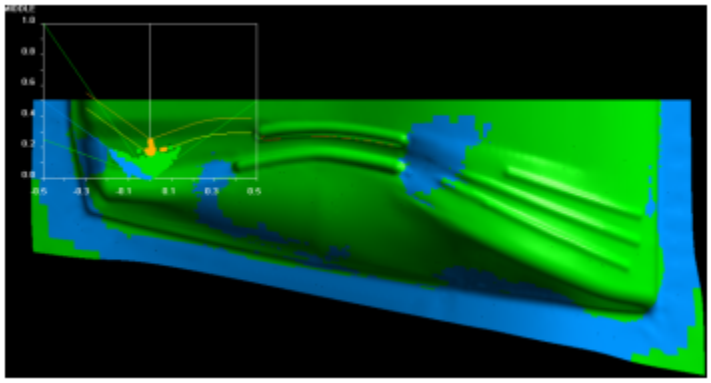


Figure 8.60: Front Rail Outer - FLD

Extending the stiffening beads could eliminate the wrinkling observed in Figure 8.61.

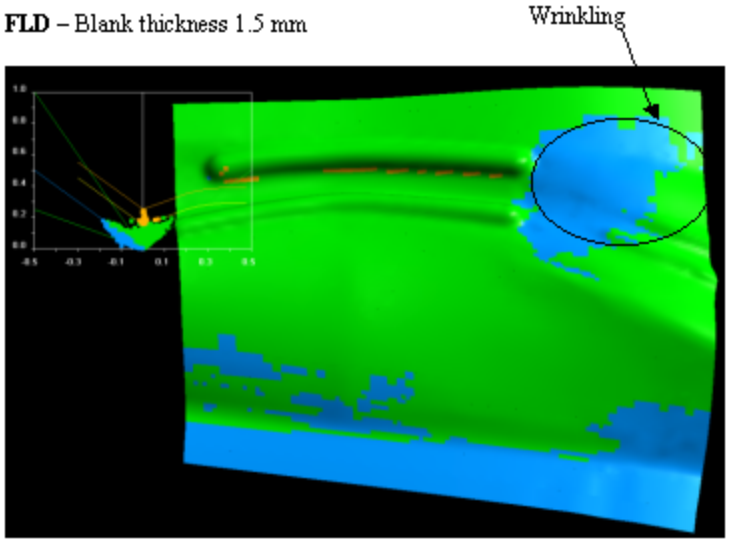


Figure 8.61: Front Rail Outer Center Piece - FLD

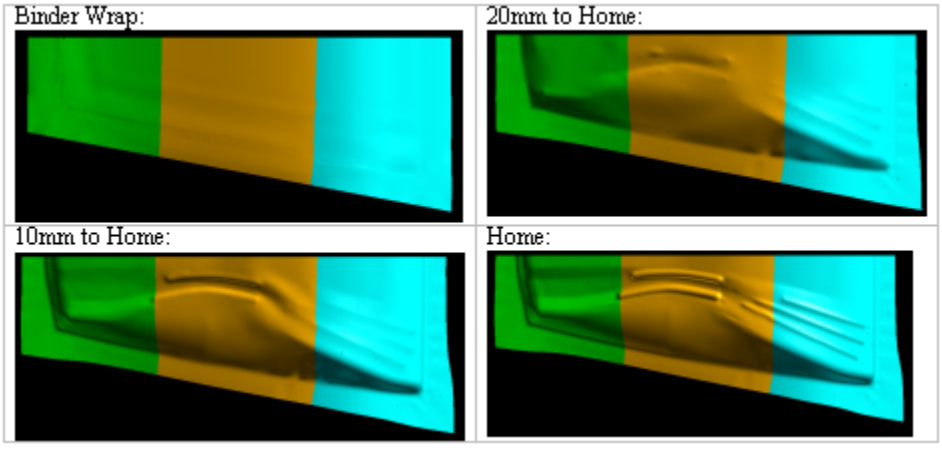


Figure 8.62: Front Rail Outer - Breakdown

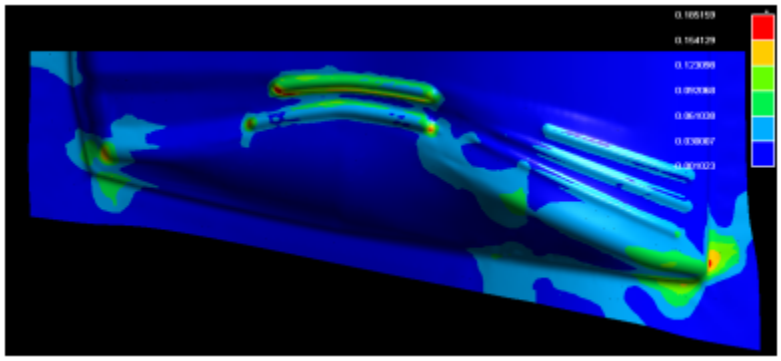


Figure 8.63: Front Rail Outer - Major Strain

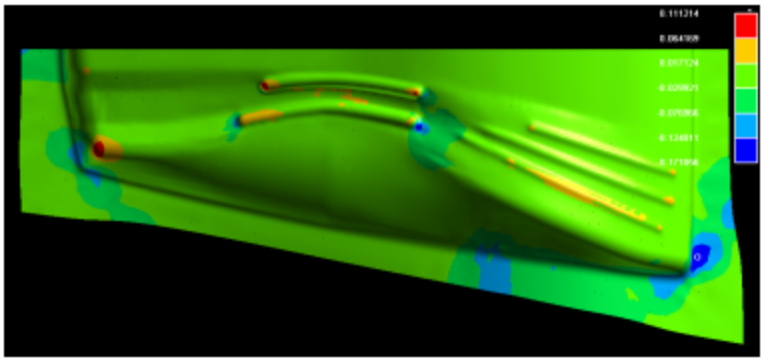


Figure 8.64: Front Rail Outer - Minor Strain

Conclusion

Based on the forming simulation result, the front rail outer was essentially formable.

Linking the two stiffening beads together reduced the loose metal and improved the forming quality.

Skirt

The material of the skirt was DP280/600 (Table 1). The part shape resembled a cup (Figure 8.65).

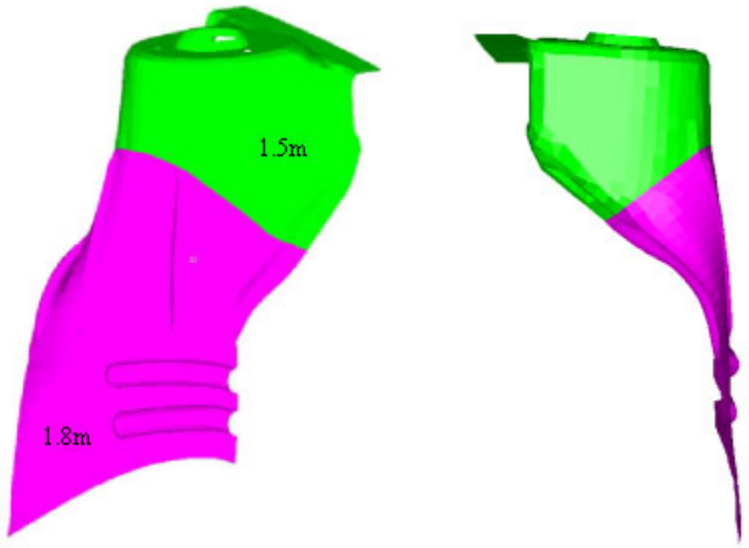


Figure 8.65: Skirt

With tailor-welded blanks of 1.5mm/1.8mm thickness, the right hand and left hand parts were double attached (Figure 8.66). Due to a deep draw depth (200mm) and small sweep radius (20mm), there were excessive wrinkles at the corner and splitting occurred at the bottom along the radii.

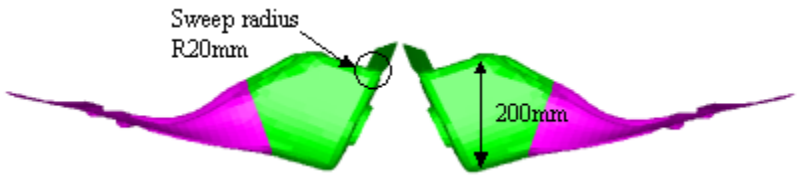


Figure 8.66: Skirt Double Attached (part in one piece)

Proposal

Hence, it was suggested that the part be cut into two pieces, as shown in Figure 8.67, and welded together. The right hand and left hand parts were double attached as shown in Figure 8.68.



Figure 8.67: Skirt Cut into Two Pieces

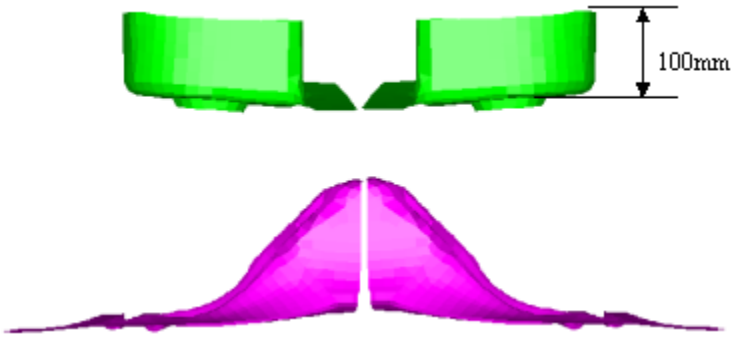


Figure 8.68: Skirt Double Attached (Cut into Two Pieces)

Conclusion

The proposed concept of cutting the skirt into two pieces reduced the draw depth significantly and easily balanced the shape of the die.

DOE-based parametric study showed that there was no significant improvement in NCAP performance by upgrading the skirt material. Hence, incremental analysis was not performed on the skirt.

Conclusions

The **1st cross-member** was the most difficult part to form with DP700/1000 material. The initial product design was evaluated with several different forming processes and draw die designs. Significant wrinkling and splitting was observed on all the try-outs. It was concluded that **product modification** was needed in order to improve the formability of the part. With product concession and process optimization, the part was rendered **formable**.

Front rail inner/outer were **formable** using a regular three-piece-stretch draw. Minor product modification was needed on rail outer in order to improve the panel quality.

DOE-based parametric study showed that there was no significant improvement in NCAP performance by upgrading the **skirt** material. A brief discussion on the forming issue of the skirt is included in this report.

Both equipment cost and spring-back condition were taken into account when developing the forming process and die concept.

References

1) *One-Step Formability Analyses Report, Milestone 17.*

2) *Incremental Formability Analyses Report, Milestone 31.*

Cost Model

Objective

This chapter documents the enhancements made to the original cost model as per the recommendations of the Cost Committee (Ref. 1-2), as well as to include more sophisticated algorithms for the costs of tooling and hydroformed tubes. The original cost model was obtained from the previous ULSAB program. The cost model was also modified in order to interface with the knowledge base tool, *Proteus* (Ref. 3). The cost model enables the users to estimate cost when modifying grade, gauge and architecture.

Enhancements to Cost Model

The following items were selected by the Cost Committee for modifications:

- Blank Size
- Stamping Costs
- Welding Costs
- Assembly Costs
- Hydroformed Tube Costs
- Tooling Costs
- Interface with KB

Blanking and General costs were not modified at all.

Blank Size

The blank size is now a function of the part dimensions. The change in blank dimension was equal to the change in the extreme dimension of the part. For example, if the rails were modified from straight to having a bump, the blank width would increase by an amount that was equal to the height of the bump.

For channel sections, the total change in blank dimension were equal to the sum of the changes of the dimensions of each section.

There was no provision of variable blank dimensions for non-rectangular parts. Such parts had a fixed weight associated with them.

The changes in blank dimensions were input on columns N and O of User Inputs sheet.

Stamping Cost

The only stamping cost that was modified was the Material Reject Rate. The reject rate was doubled if the material was upgraded. Otherwise, it remained unchanged .

The Material Reject Rate factor was input on column Q of User Inputs sheet.

Welding Costs

The only welding cost that was modified was the Weld Line Length for tailor-blanked parts. The weld line length was a function of the blank dimensions. However for non-rectangular parts, the weld line length was fixed, as blank dimensions were not available.

Assembly Costs

The assembly costs were modified to reflect the use of spotwelds in place of laserwelds. The concept of point estimates using existing modeling techniques was used to estimate assembly costs.

Hydroformed Tube Costs

The material costs for hydroformed parts were modified so as to be a function of tube diameter ,gauge and grade. A tube-making cost algorithm was employed to estimate the costs .

Tooling Costs

The tooling costs were modified, by utilizing a tooling cost algorithm that

calibrated the costs to the existing tooling cost model. This approach was easy to implement and concerns regarding data consistency were addressed by validating the cost model.

Interface with KB.

The cost model was modified for easy interface to the KB. All parameters that were varied in the front-end optimization study were now input at one location, the User Inputs sheet. Only two sheets in the cost model were modified – Part Inputs and User Inputs (old name - Blank Sizes). The basic structure of the cost model remained unchanged. No rows or columns were deleted. Only extra rows and columns were added. The cells were color coded for easy reference.

No Fill	Unmodified cells
Green Fill	Modifications/additions
Black Text	Calculated values
Blue Text	Entries that can be modified
Red Text	Entries that should not be modified

Conclusions

The cost model was enhanced according to the recommendations of the Cost Committee and for easy interface with the KB tool.

References

1) *Modified Cost Model, Milestone 12.*

2) *Cost Model for KB, Milestone 28.*

3) *Proteus, KB Version 2, Milestone 32.*

Knowledge Base

Introduction

The *Parametric Study of Front-End Structure Sensitivity* (PSFSS) project has studied the effect, on cost and mass, of practical variations in the design of the front-end structure of ULSAB. The deliverable of this project is a web-enabled knowledge base tool, ***Proteus*** (Ref. 4). It allows for early cost, mass, and options trade-off decisions to be made in support of vehicle development timing reductions, for a given vehicle performance. Proteus incorporates a knowledge base from the Design of Experiments (DoE) optimization study done during the course of the project. It takes a set of design parameters as input, and estimates the corresponding responses - mass, cost, and performance. Three kinds of parameters are taken into consideration: gauge, grade, and topological. Some of the design variables that the current Proteus understands are - rail, panel, and bumper. Some of the responses calculated are - mass, cost, stiffness, NCAP, and IIHS. Proteus is secure, extensible, and user friendly. Currently it has two architectures in its knowledge base- **Initial Front End Package** and **Upgraded Front End Package**. Additional architectures can be easily added in the knowledge base. Access to Proteus is restricted through login and passwords. It can be accessed from anywhere on the Internet or intranet using a web browser.

Architecture

Proteus has two components (Ref. 3) - Proteus Estimation Engine (PEE) and Proteus Web Component (PWC). PEE is the core of Proteus; it estimates the values of responses for a given set of design parameters. Results from the DOE and Cost studies are used to build PEE. PWC provides a user-friendly, web-based interface to PEE.

PEE is implemented as a Microsoft Excel Workbook. This implementation of PEE is called Proteus Workbook (PW). The PSFSS study has looked at two ULSAB architectures: **Initial Front End Package** (*baseline)* and **Upgraded Front End Package** (*upgraded)*. The *upgraded* ULSAB has a bigger engine. The optimizations of the two architectures are similar but differ in the number of parameters, responses, and performance characteristics. Each ULSAB-architecture is modeled as a Proteus Workbook.

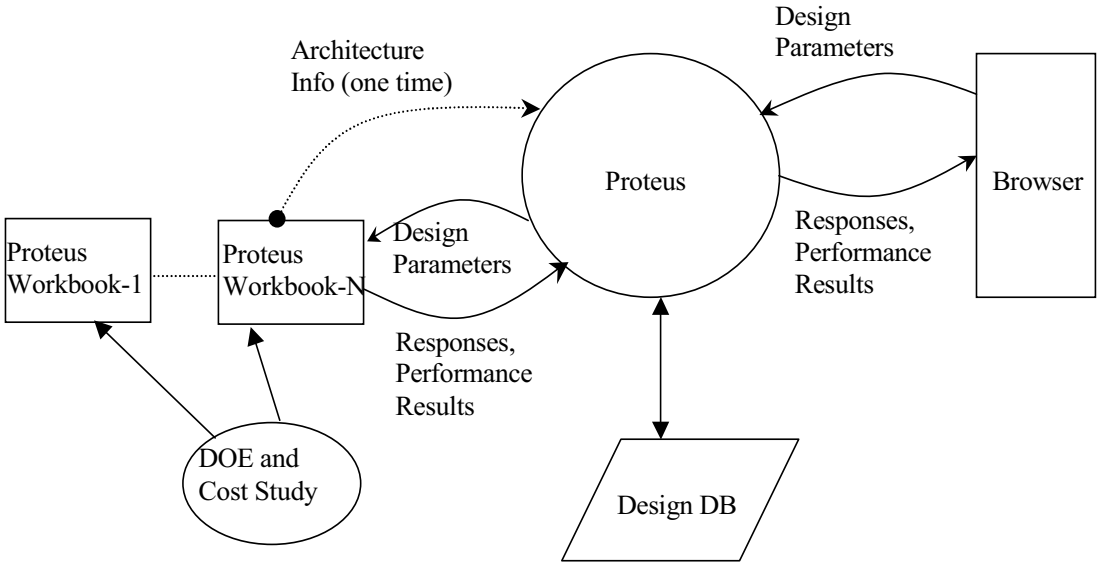


Figure 10.1: Proteus Interfaces

Figure 10.1 depicts the interfaces to Proteus. The DOE and Cost studies help in forming the Proteus Workbooks, one for each ULSAB architecture. Proteus reads each workbook to get information about the architecture, such as, the design parameters, the responses, and library of designs. Users access Proteus from a web browser. They choose an ULSAB architecture, and then input a set of design parameters. Proteus consults the corresponding PW to obtain the results - the responses, and performance characteristics (in the form of graphs). Proteus stores information about architectures, users, and user designs in a database, the Design DB.

Features

Design Variables

Values of design parameters are entered through the Estimation Page, shown in Figure 10.2.

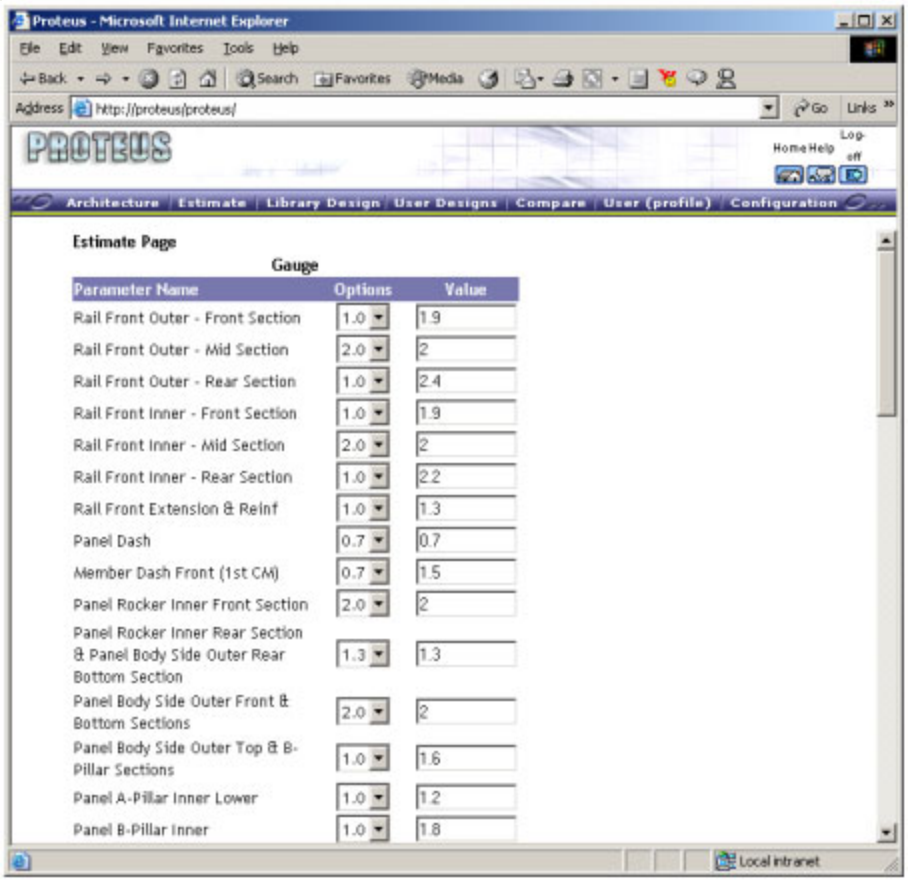


Figure 10.2: Proteus Estimate Page

About 50 design parameters are incorporated in the current Proteus knowledge base. Approximately 25 of them are for gauge, 20 for grade, and the rest for topology. Some of the design parameters are:

Rail Front Outer / Inner	Bumper
Panel A Pillar	Panel Skirt
Panel Rocker Outer / Inner	Roof Rail
Panel B Pillar	XZ Bumper
Rail Fender	XY Curve

The number of design parameters is dependent on the architecture; Proteus does not impose any limit of the number of parameters that it can handle.

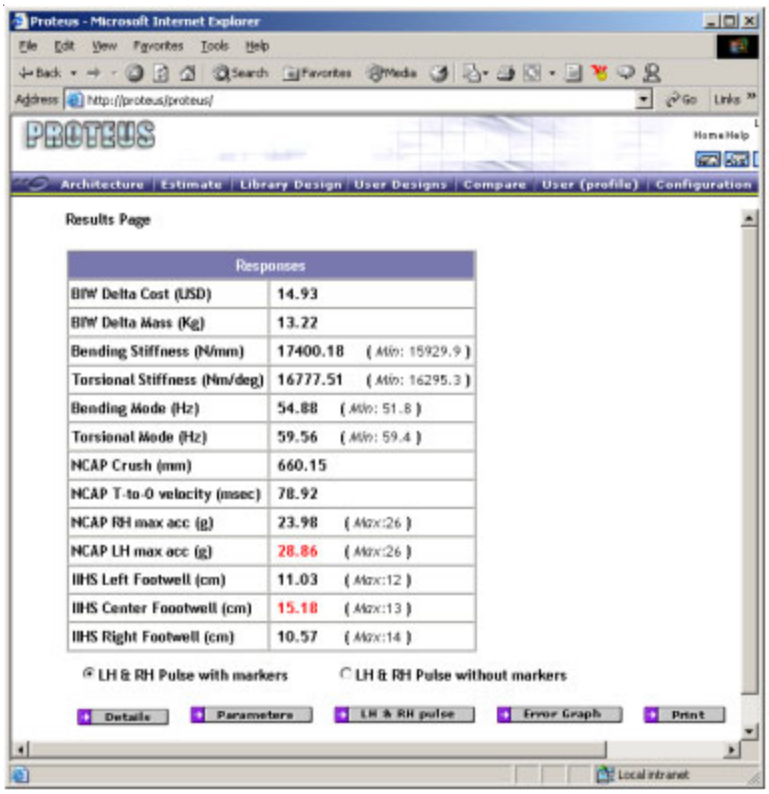


Figure 10.3: Responses

Estimation

Mass and cost estimations of the front-end of ULSAB form the basis of Proteus. Once the design parameters are chosen, Proteus determines the corresponding change in mass and cost. It also calculates the values for various responses. Some of the responses are:

Bending Stiffness	NCAP RH Max Acc
Torsional Stiffness	NCAP LH Max Acc
Bending Mode	IIHS Left Footwell
Torsional Mode	IIHS Center Footwell
NCAP Crush	IIHS Right Footwell

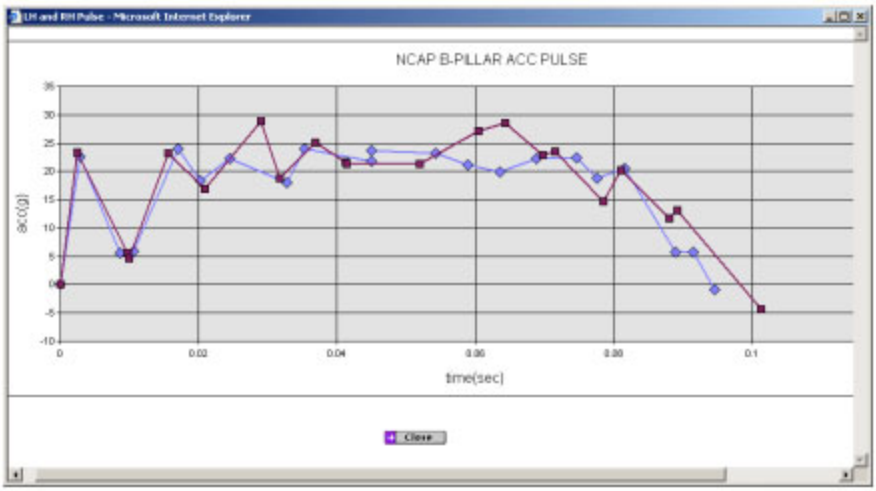


Figure 10.4: LH and RH Pulse

The responses for the design parameters of Figure 10.2 are shown in Figure 10.3. The corresponding B-Pillar acceleration pulses are show in Figure 10.4. The breakdown of mass and cost is shown in Figure 10.6.

User Designs

Users can save their designs, and recall them later. The designs are saved on the Proteus server, hence they can be accessed from anywhere on the network. User designs are linked to an architecture, and are visible only when that architecture is loaded.

Library of Designs

Proteus estimates the responses for a design through its estimation engine. However, its knowledge base also has designs whose responses were computed from actual finite element analyses. Such designs form the library

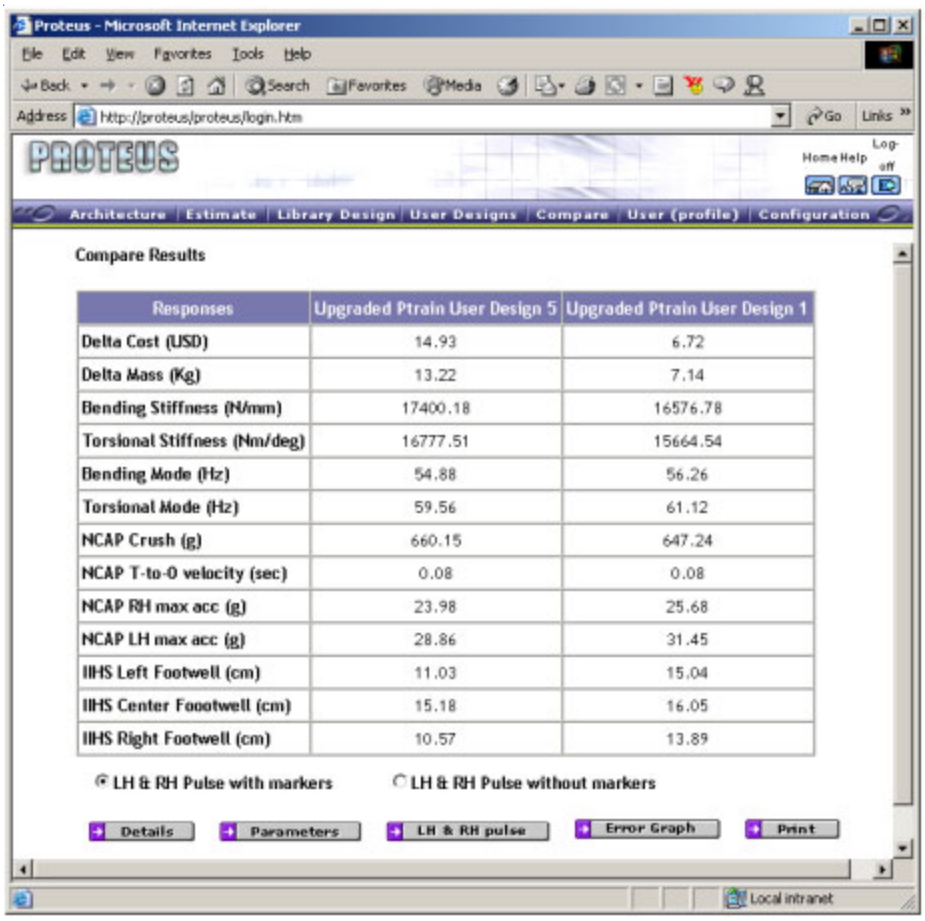
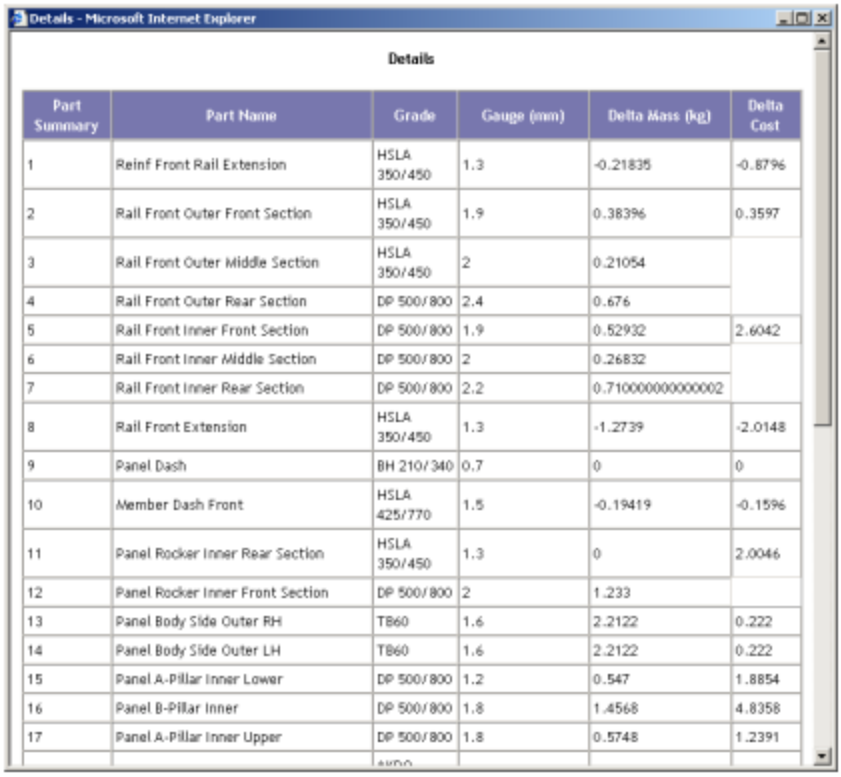


Figure 10.5: Design Comparison

of designs. When a design from this library is chosen, Proteus displays the results directly; it does not estimate the responses through its estimation engine.

Design Comparison

Any two saved designs, from the user designs or from the library of designs, can be compared using Proteus. Figure 10.5 shows the responses from two user designs. Similarly the acceleration pulses from the two designs are displayed in Figure 10.7.



Part Summary	Part Name	Grade	Gauge (mm)	Delta Mass (kg)	Delta Cost
1	Reinf Front Rail Extension	HSLA 350/450	1.3	-0.21835	-0.8796
2	Rail Front Outer Front Section	HSLA 350/450	1.9	0.38396	0.3597
3	Rail Front Outer Middle Section	HSLA 350/450	2	0.21054	
4	Rail Front Outer Rear Section	DP 500/800	2.4	0.676	
5	Rail Front Inner Front Section	DP 500/800	1.9	0.52932	2.6042
6	Rail Front Inner Middle Section	DP 500/800	2	0.26832	
7	Rail Front Inner Rear Section	DP 500/800	2.2	0.710000000000002	
8	Rail Front Extension	HSLA 350/450	1.3	-1.2739	-2.0148
9	Panel Dash	BH 210/340	0.7	0	0
10	Member Dash Front	HSLA 425/770	1.5	-0.19419	-0.1596
11	Panel Rocker Inner Rear Section	HSLA 350/450	1.3	0	2.0046
12	Panel Rocker Inner Front Section	DP 500/800	2	1.233	
13	Panel Body Side Outer RH	TB60	1.6	2.2122	0.222
14	Panel Body Side Outer LH	TB60	1.6	2.2122	0.222
15	Panel A-Pillar Inner Lower	DP 500/800	1.2	0.547	1.8854
16	Panel B-Pillar Inner	DP 500/800	1.8	1.4568	4.8358
17	Panel A-Pillar Inner Upper	DP 500/800	1.8	0.5748	1.2391

Figure 10.6: Mass and Cost Breakdown

Extensible

Even though the PSFSS project dealt with only two ULSAB architectures, Proteus can incorporate multiple architectures. An administrator can add, edit, or remove the architectures. An architecture is modeled as a Proteus Workbook. A Proteus Workbook contains an Input sheet, an Output sheet, and a Files sheet. Design parameters are entered into the input sheet; responses are read from the output sheet; locations of the library of designs and error graphs are kept in the Files sheet.

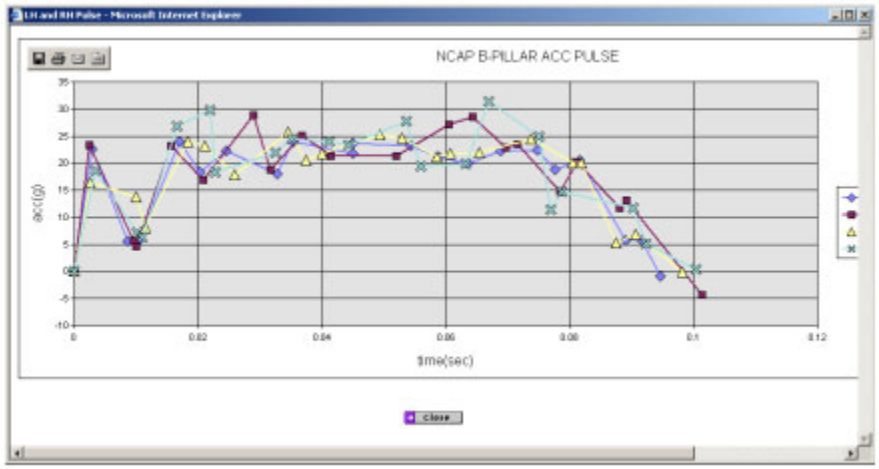


Figure 10.7: Design Comparison - Pulse

Secure

Access to Proteus is restricted through user login and password. There are two classes of users: normal users and administrators. Normal users are restricted from adding new architectures and users, whereas administrators are not.

Glossary

- **A/SP**: Auto/Steel Partnership
- **DoE**: Design of Experiments
- **IIHS**: Insurance Institute for Highway Safety
- **NCAP**: New Car Assessment Program
- **PEE**: Proteus Estimate Engine
- **PSFSS**: Parametric Study of Front-end Structure Sensitivity
- **PW**: Proteus Workbook
- **QGS**: Quantech Global Services Inc
- **SPInE**: Site for PSFSS' Information Exchange
- **ULSAB**: Ultra Light Steel Auto Body

References

1) *Proposal for Parametric Study of Front-End Structure Sensitivity,* Quantech Global Services, Inc.

2) *Proteus: Software Requirement Specification,* Quantech Global Services, Inc.

3) *Proteus Architecture, Milestone 4.*

4) *Proteus Knowledge Base, Milestone 32*

Milestone Reports

1) *Phase I Structural Performance Targets Report.*
2) *Phase I Bumper Design Report.*
3) *First Bumper Design Report, Milestone 5.*
4) *Second Bumper Design Report, Milestone 9.*
5) *Third Bumper Design Report, Milestone 18.*
6) *Fourth Bumper Design Report, Milestone 26.*
7) *Cost and Manufacturability of Bumper Systems Report, Milestone 25.*
8) *Original Sequential Model Analysis Report, Milestone 1.*
9) *Baseline Model for CAO Report, Milestone 3.*
10) *Parametric Design Combinations Report, Milestone 7.*
11) *ULSAB Static and Dynamic Stiffness Study Report, Milestone 8.*
12) *NCAP 35mph Study Report, Milestone 11.*
13) *ULSAB Model with Upgraded Powertrain Report, Milestone 14.*
14) *Upgraded Powertrain DOE Study Report, Milestone 15.*
15) *Library for KB - Baseline Engine Package, Milestone 23.*
16) *Library for KB - Upgraded Powertrain, Milestone 24.*
17) *Performance Matrix for KB, Milestone 27.*
18) *One-Step Formability Analyses Report, Milestone 17.*
19) *Incremental Formability Analyses Report, Milestone 31.*
20) *Modified Cost Model, Milestone 12.*
21) *Cost Model for KB, Milestone 28.*
22) *Proteus Architecture, Milestone 4.*

23) Proteus Knowledge Base, Milestone 32.

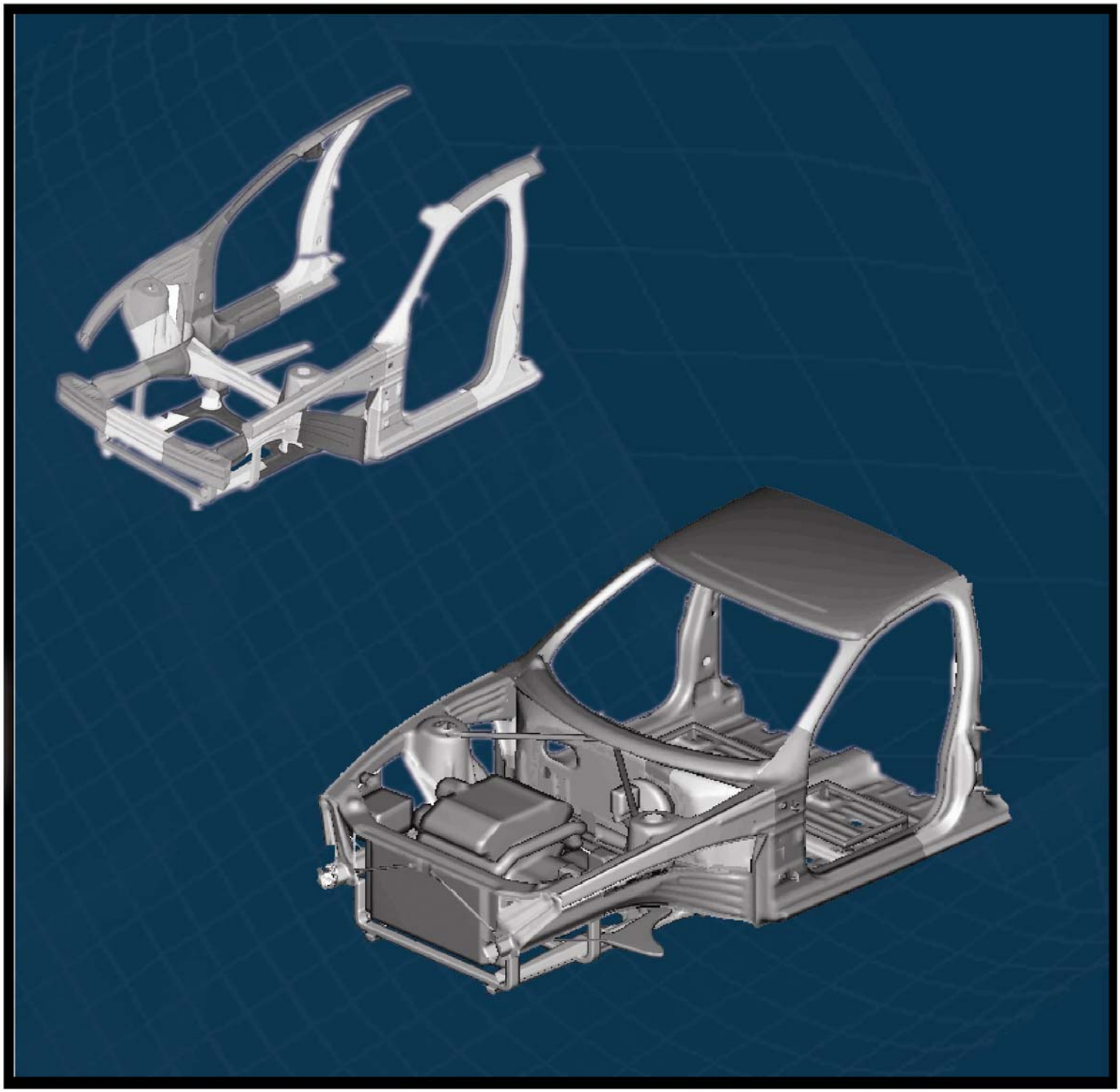
24) SPInE Website, Milestone 33.

25) Weld Study Report, Milestone 2.

26) Spotweld Study Phase I, Milestone 21a.

27) Spotweld Study Phase II, Milestone 21b.

28) Spotweld Study Phase III, Milestone 21c.



Lightweight Front End Structure

Phase I & II - Final Report

A parametric study of automotive front end structure design sensitivities

A/S P Auto/Steel Partnership

Abstract

This report documents the tasks accomplished in *Phase II* of the *Lightweight Front End Structure Project* undertaken by *Quantech Global Services* on behalf of the *Auto/Steel Partnership*.

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1. Introduction

Light-weighting initiatives have demonstrated that *Advanced High Strength Steels* (AHSS) can be effectively utilized for mass avoidance strategies, providing required performance and lower overall cost. Constraints in implementing AHSS scenarios are joining and forming and high volume manufacture and assembly.

A methodology to optimize mass and cost of a structure, subject to performance and manufacturing criteria was developed in *Phase I* of the *Lightweight Front End Structure Project.* This methodology was employed effectively in *Phase II* of the *Lightweight Front End Structure Project.*

2. Objectives

The objective of the *Phase II* of the *Lightweight Front End Structure Project* was to accelerate the introduction of the higher grades of *Advanced High Strength Steels* (DP800 and above) into vehicles, at little or no cost, and consequently accelerate efforts in vehicular light weighting. The project focused on benchmarking, developing and documenting proven solutions that balanced the interaction of material, manufacturing and performance. The study focused on the automotive front-end system solutions that address high volume manufacturing and assembly. The AHSS solutions developed in *Phase II* will provide choices and consequences that address real world challenges faced in the vehicle development process.

3. Approach

Front rail and bumper assemblies of a 5-passenger mid-size vehicle were selected for mass reduction. The parts were designed and manufactured using AHSS materials (DP800 and above), subject to packaging constraints. The parts were assembled into the donor vehicle and physical testing was performed in order to evaluate the AHSS designs. A compressive knowledge-base design tool was developed that capitalizes on a set of robust AHSS automotive design guidelines relating choices to consequences.

The design targets for *Phase II* can be summarized as follows.

- The *AHSS Design* must achieve at least 20% mass reduction.
- *AHSS Design* must meet or exceed performance of *Baseline Design* (6) in the following load cases.
    - NCAP 35mph rigid barrier impact
    - IIHS 55mph deformable barrier offset impact
    - Static stiffness
    - Dynamic stiffness
- The *AHSS design* must be validated by a physical NCAP test.

4. Results Summary

Front rail assembly (DP800) and front bumper assembly (DP980) were designed, manufactured and assembled into a donor vehicle. The *AHSS Design* was validated by conducting an NCAP 35mph rigid barrier crash test. The ***AHSS Design*** (*Figure 1*) achieved a mass reduction of **8.77kg (22.36%)** compared to the *Baseline Design* (*Figure 2*). The NCAP performance of the *AHSS Design* (20) was superior to that of the *Baseline Design* (6). The IIHS, static and dynamic stiffness performances were similar to those of the *Baseline Design*.

The *AHSS Design* has the following features.

- Octagonal 3-piece tailor-welded rail inner and outer pieces with symmetric flanges and tapered front section.
- Two-piece rail tailor-welded extension design with a reinforcement.
- Rail inner reinforcement.
- Symmetric LH/RH rail assemblies.
- Two-piece double box bumper design with energy absorbing features.

Mass comparison of the *AHSS Design* and the *Baseline Design* is shown in *Table 1*. The grades and gauges of the *AHSS Design* are summarized in *Table 2*. The NCAP, IIHS, static and dynamic stiffness results are summarized in *Table 3*, *Table 4, Table 5* and *Table 6* respectively.

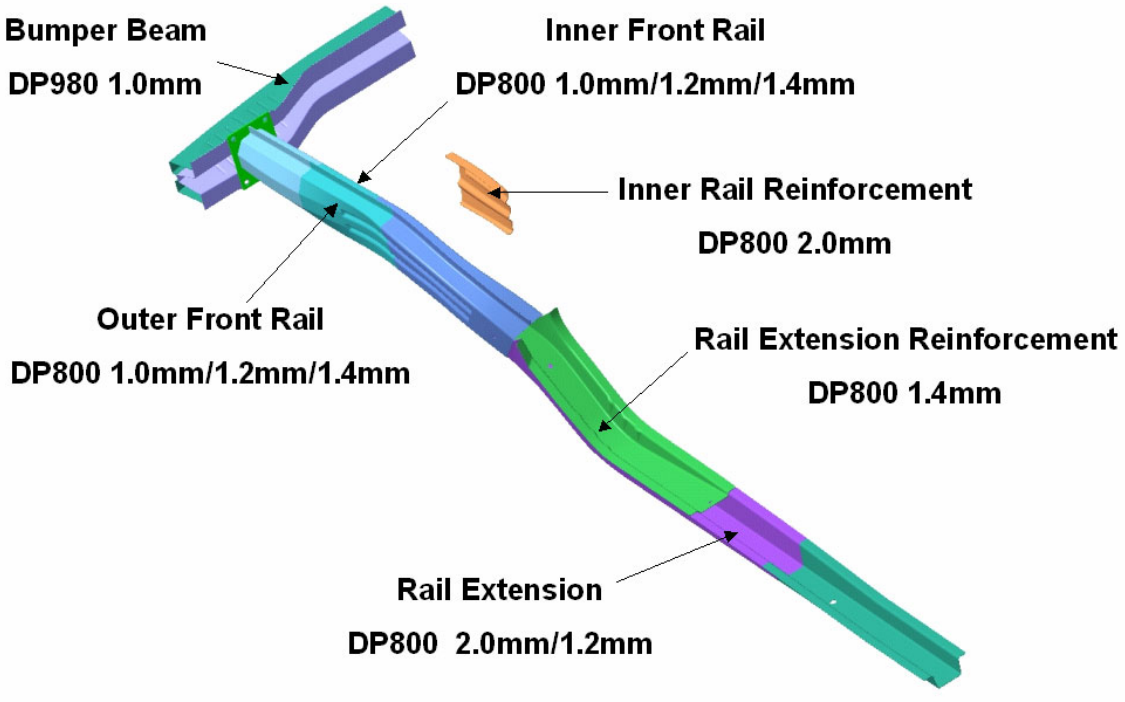


Figure 1: AHSS LH Rail Assembly

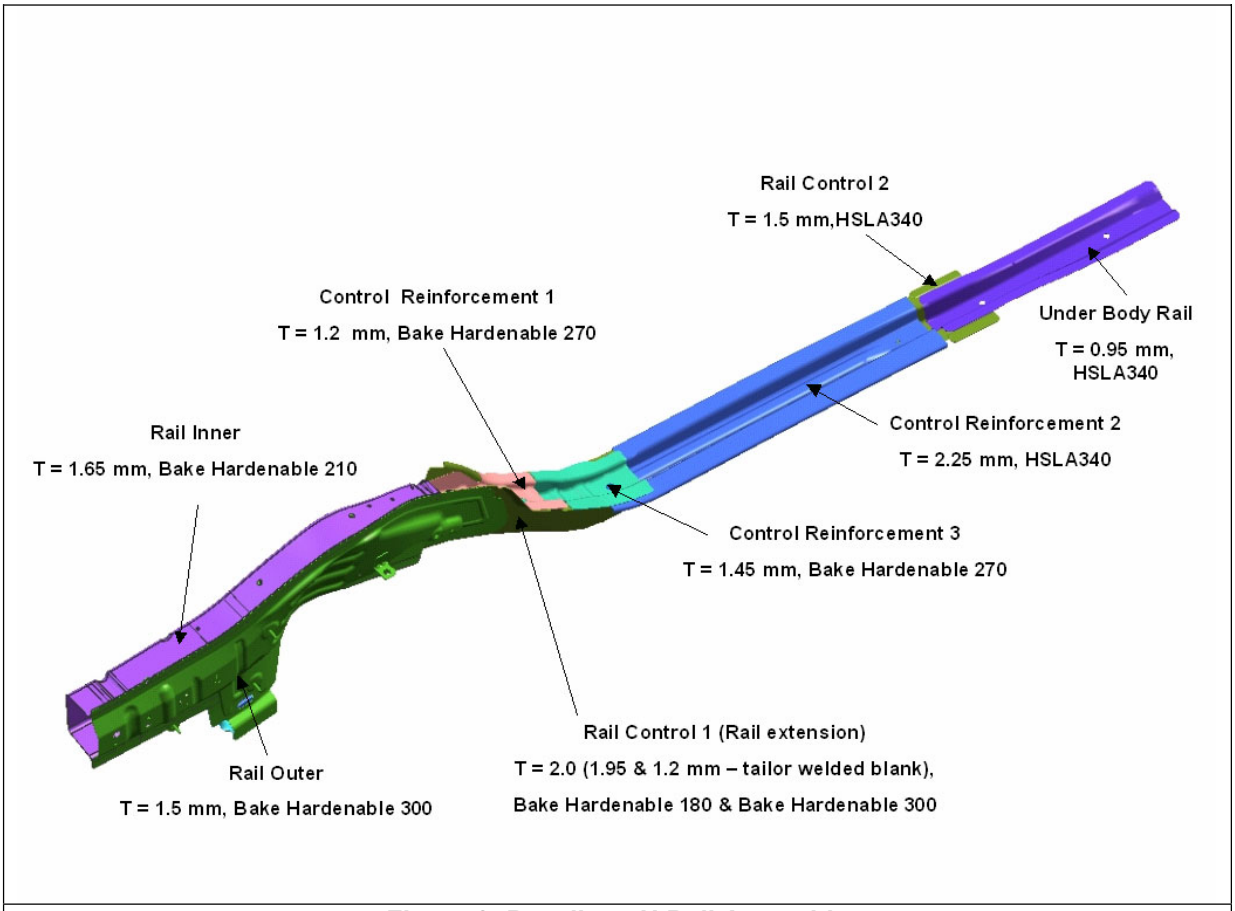


Figure 2: Baseline LH Rail Assembly

Table 1: Mass Summary

Part	Mass (kg)	
	Baseline Design	AHSS Design
LH Rail Assembly	16.52	12.25
RH Rail Assembly	16.15	12.25
Bumper (without foam)	6.56	5.96
Total	39.23	30.46*

* 22.36% mass reduction with respect to *Baseline*

Table 2: Grade and Gauge Summary of AHSS Design

Part	AHSS Design	
	Grade	Gauge (mm)
Rail Front Inner	DP 450/800	1.0
Rail Front Outer	DP 450/800	1.0
Rail Mid Inner	DP 450/800	1.2
Rail Mid Outer	DP 450/800	1.2
Rail Rear Inner	DP 450/800	1.4
Rail Rear Outer	DP 450/800	1.4
Rail Extension Front	DP 450/800	2.0
Rail Extension Rear	DP 450/800	1.2
Rail Extension Reinforcement	DP 450/800	1.4
Rail Inner Reinforcement	DP 450/800	2.0
Bumper Beam	DP 700/980	1.0

Table 3: NCAP Results

	Peak Acceleration	
B-Pillar Pulse	Baseline	AHSS Design
LH	36.7 g @ 58.7 ms	35.4 g @ 48.5 ms
RH	35.3 g @ 58.6 ms	35.6 g @ 57.2 ms

Table 4: IIHS Results

Location	Peak Intrusions (cm)	
	Baseline	AHSS Design
Left Toepan	18.2	15.1
Center Toepan	18.4	19.5
Right Toepan	19.4	19.5
A-B Pillar Closure	14.4	14.1

Table 5: Static Stiffness Results

Static Stiffness	Baseline	AHSS Design
Bending Stiffness (N/mm)	12638.9	12468.7
Torsional Stiffness (Nm/deg)	21002.3	20957.5

Table 6: Dynamic Stiffness Results

Mode	Frequency (Hz)	
	Baseline	AHSS Design
First Torsional Mode	21.06	25.25
First Bending Mode	24.38	22.73

5. Tasks

The process flow chart in *Figure 3* illustrates the design approach and the following sections describe each task in detail.

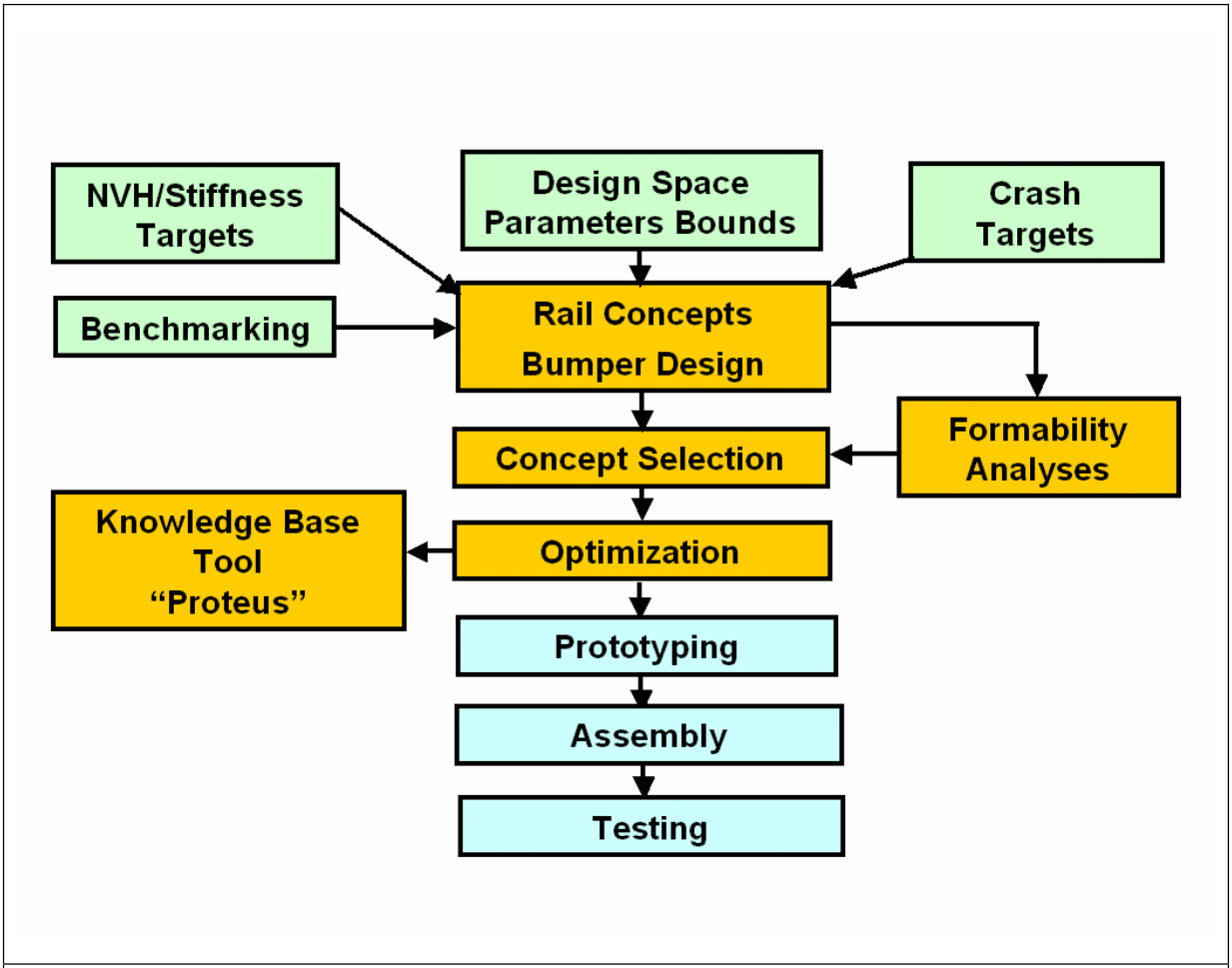


Figure 3: Process Flow Chart

Subsystem Design (1)
A reduced subsystem was developed in order to simulate the NCAP performance of a full vehicle finite element model in the first 40ms. The subsystem predicted accurately the full vehicle response in the first 40 ms of the NCAP load case, and achieved a 50% reduction in the simulation time. The subsystem achieved the same crush pattern for rail and bumper, as in the full vehicle. The subsystem was used to make quick assessments of various rail and bumper concepts.

Competitive Benchmarking Study (2)
The benchmarking study was undertaken to examine rail designs and architectures of competitive vehicles with good NCAP and IIHS performance. The benchmarking study provided useful information for developing design concepts. A total of 14 competitive vehicles were benchmarked for rail design and architecture.

FE Model Validation (4), (5), (6)

The FE models for the Donor vehicle were validated and changes were made to render them suitable for DOE studies. A comprehensive model checking was undertaken and appropriate modifications were made. These FE models served as the baseline for DOE studies and for assessing various rail and bumper concepts developed in *Phase II* of the *Lightweight Front End Structure Project*.

Rail Concept Development (3)
Initial AHSS rail concepts were developed and examined for performance potential, manufacturability and assembly. The concepts developed in this study were further developed into concrete designs and evaluated for performance, manufacturability and ease of assembly. Three concepts were developed during the course of this study:

Baseline Rail Design (8), (9), (10)
- Minimum modifications to the current rail design
- Filled holes and removed notches
- Reduced flange width
- Tailor-welded DP800 rails
- Gauge change
- New bumper design
- Provided design direction

Best Hydroformed Rail Design (14), (15), (16)
- Alternative to stamped design
- Optimum sections
- Part integration
- Reduced welding
- Mass reduction by elimination of flanges
- Superior material properties
- Improved crush

Best Stamped Rail Design (11), (12), (13)
- Part integration
- Octagonal front rail section
- Straight centroidal line and load path
- Improved performance and mass savings

New Bumper Design (17)
- Designed to contribute to high speed crash events
- DP1000T 1.0mm thick
- Two piece stamped design
- Feasibility confirmed with bumper supplier
- Common to all the three designs (with minor changes)

DOE and Optimization (18), (19), (27), (28)
The final design selected for prototyping was optimized by conducting NCAP, IIHS, static and dynamic stiffness DOE studies. The *Final Optimized Design* was derived from the computer-aided optimization (CAO) of the response surfaces obtained from the *DOE* studies.

Knowledge Base (24)
The DOE response surfaces were archived into the knowledge base Proteus. Several enhancements were made to Proteus, including the addition of an *Optimization* module. Proteus can now be employed for optimizing any architecture in its database subject to user-defined constraints. Mass, cost and any DOE response can be selected as objective function and design constraint.

Manufacturing (29)
The *Final Optimized Design* was prototyped using AHSS (DP800 and DP980). Tolerance guidelines for tooling and assembly were provided through *Geometric Tolerance and Dimensional Analyses* undertaken in the project.

Assembly (29)
An appropriate assembly sequence, weld pattern and weld schedules were developed prior to assembly. The weld schedules were tested during assembly on sample sheet metals. The existing rails, bumper and attached components were removed and replaced with the new AHSS parts.

Testing (22)
The vehicle with the new AHSS rail and bumper assemblies was crash tested in order to validate the AHSS design. A 35mph rigid barrier NCAP test was performed for the purpose. The test results of the vehicle with the baseline rails/bumper were compared with the vehicle with the new rails/bumper.

6. Rail Concept Development

Three rail concepts were developed in Phase II.

- Baseline Rail Architecture (10)
- Best Hydroformed Design (16)
- Best Stamped Design (13)

Existing Rail Architecture

The *Baseline* LH rail assembly and bumper (10) are shown in *Figure 4*, *Figure 5,* and *Figure 6*. An attempt was made to reduce the rail/bumper mass (maintaining baseline vehicle performance) by modifying gauges and the use of AHSS, and with minimum changes to the rail architecture. The existing roll-formed bumper was replaced by a new stamped design (similar to the bumper in the final *AHSS Stamped Design*). However, it was not possible to achieve mass reduction without deteriorating the vehicle performance. Hence, it was concluded that rail architecture modification was required in order to achieve the 20% mass reduction target.

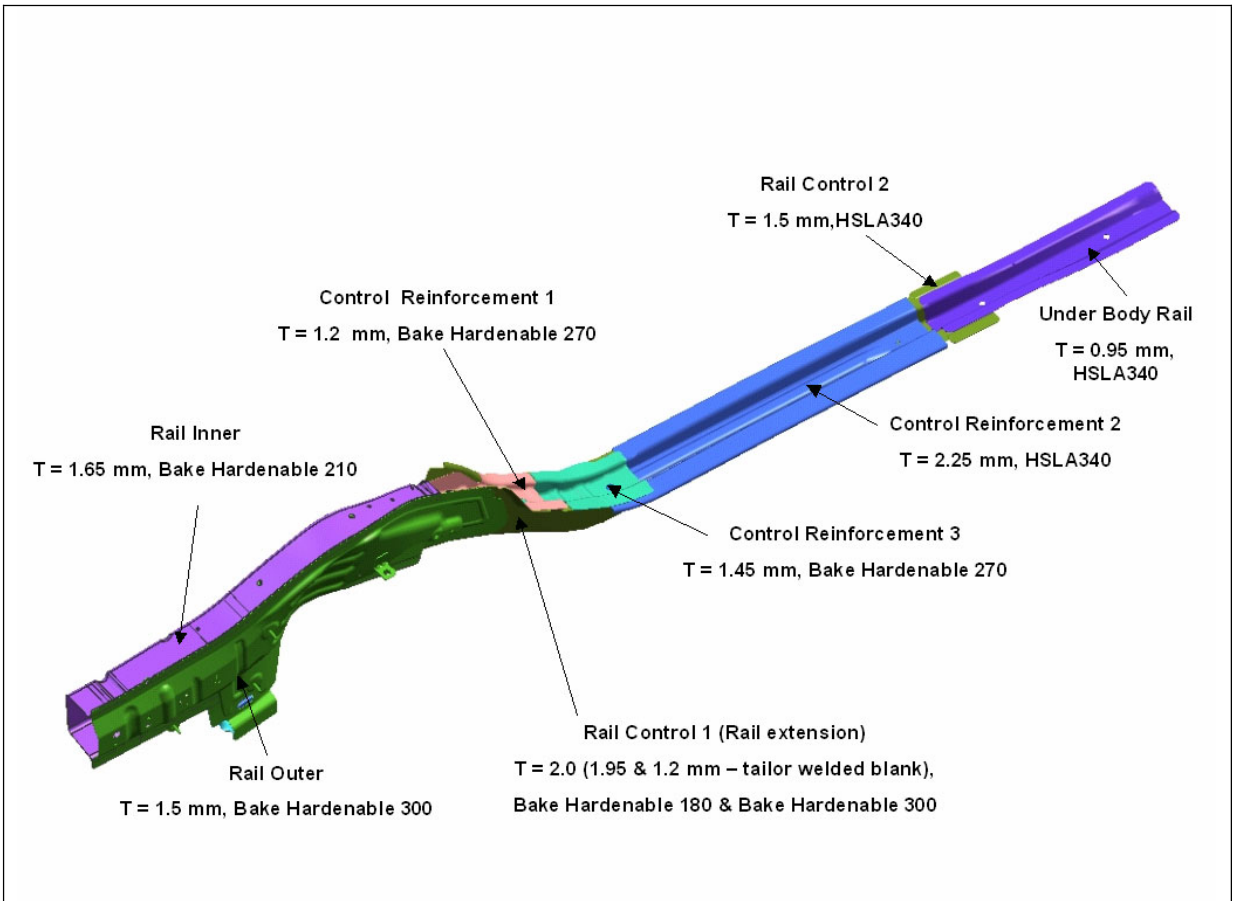


Figure 4: Baseline LH Rail Assembly

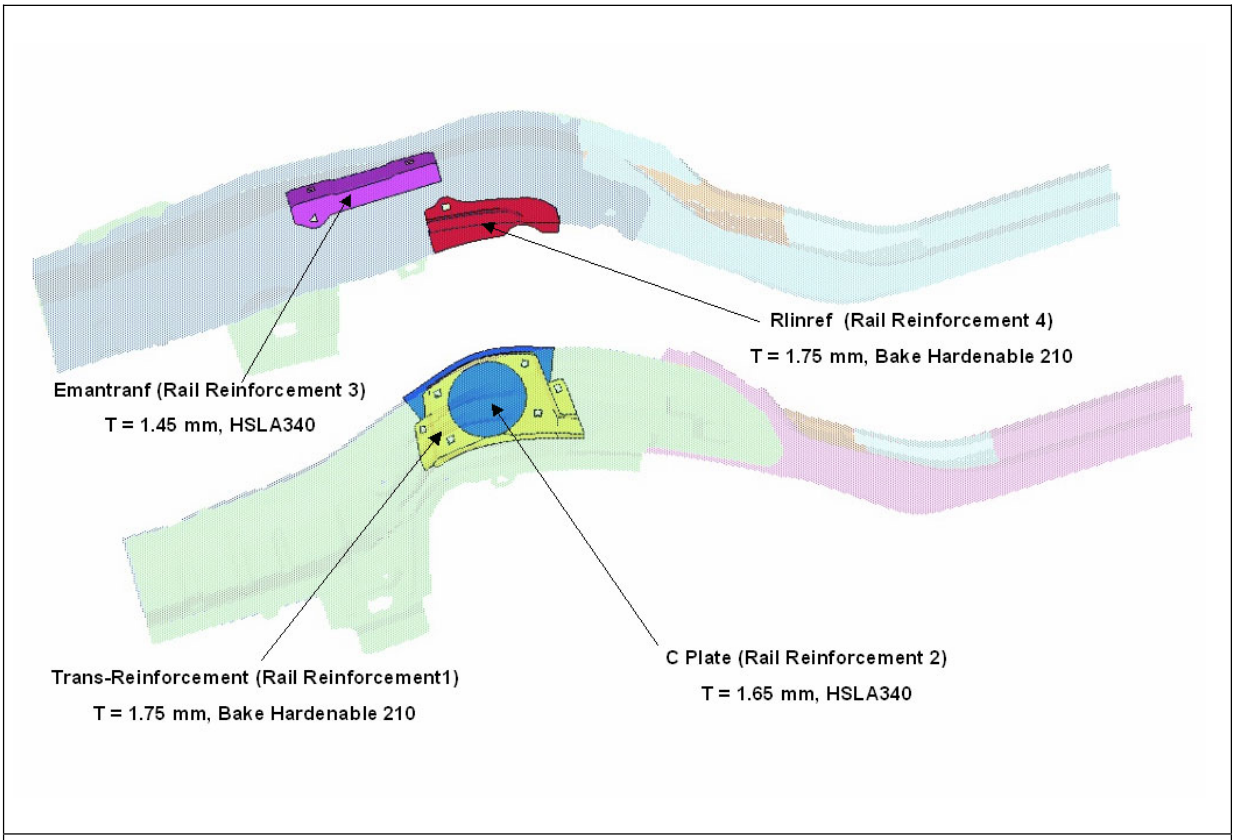


Figure 5: Baseline LH Rail Reinforcements

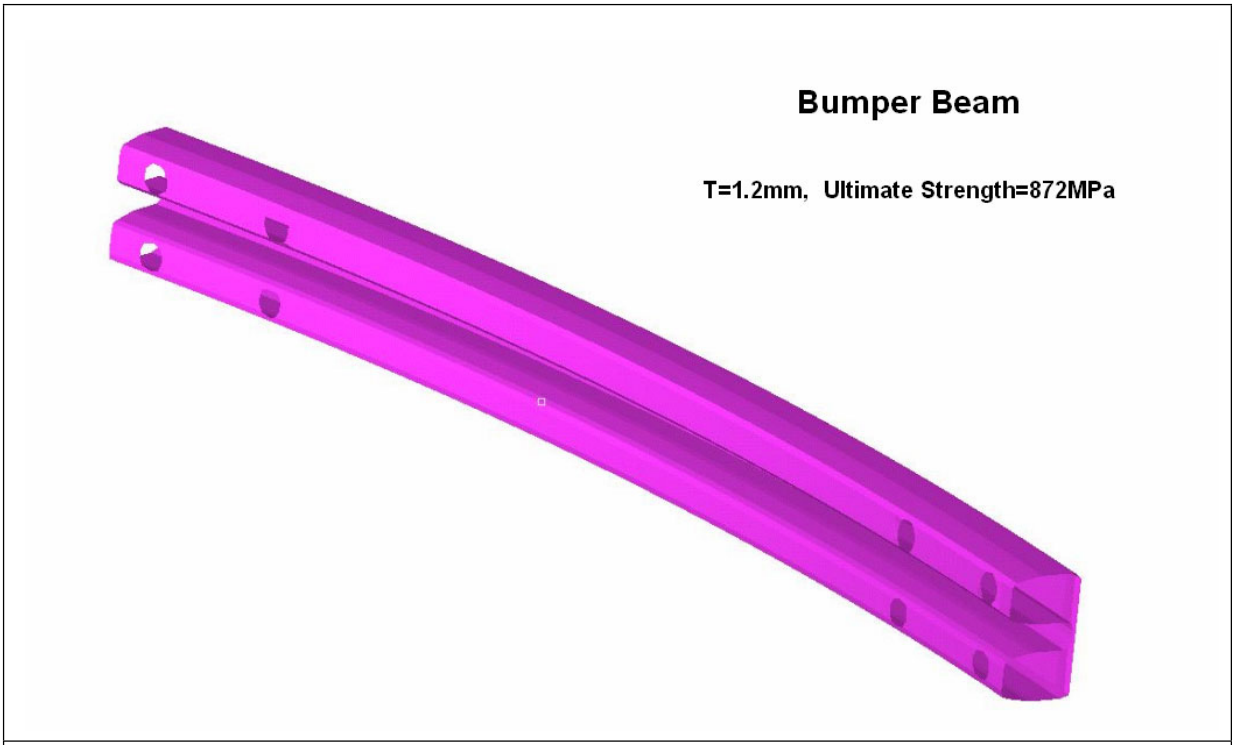


Figure 6: Baseline Bumper

Best Hydroformed Design

The *Hydroformed Design* (16) has the following salient features.

- Symmetric LH/RH rail assemblies.
- One-piece tailor-welded rail design (*Figure 7*).
- Octagonal front sections and rectangular rear sections.
- Two-piece double box bumper design with energy absorbing features.

The *Hydroformed Design* achieved a mass reduction of **12.1kg (31%)** compared to the *Baseline Design*. The *NCAP performance* was essentially the same as that of the baseline design. The *IIHS performance* was slightly inferior to that of the baseline design. There was scope for further improvement in IIHS performance considering the fact that the mass reduction of 31% was well above the target of 20% reduction. However, at that point it was decided to prototype the stamped rail design and to discontinue further design on the hydroformed rails. The stamped design was selected due to its ease of manufacturability and suitability to current production environment.

The *Hydroformed Design* was derived using section optimization. The cross-sections were designed so to maintain a straight centroidal line within the packaging constraints (*Figure 9*) and therefore an axial load path. The initial design was then further evolved (*Figure 8*) in order to improve performance.

The *Hydroformed Design* was instrumental in achieving a sound stamped design. The technique employed for optimizing the cross-sections for the *Hydroformed Design* was later utilized for arriving at similar cross-sections for the *Stamped Design*.

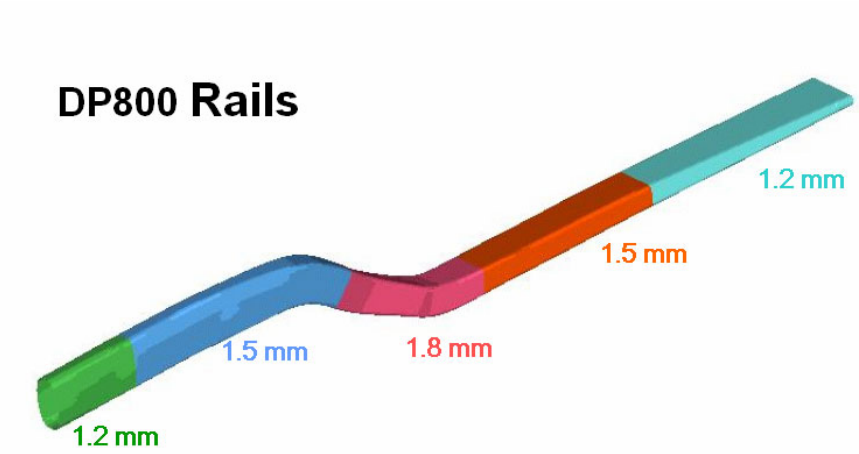


Figure 7: Hydroformed LH Rail

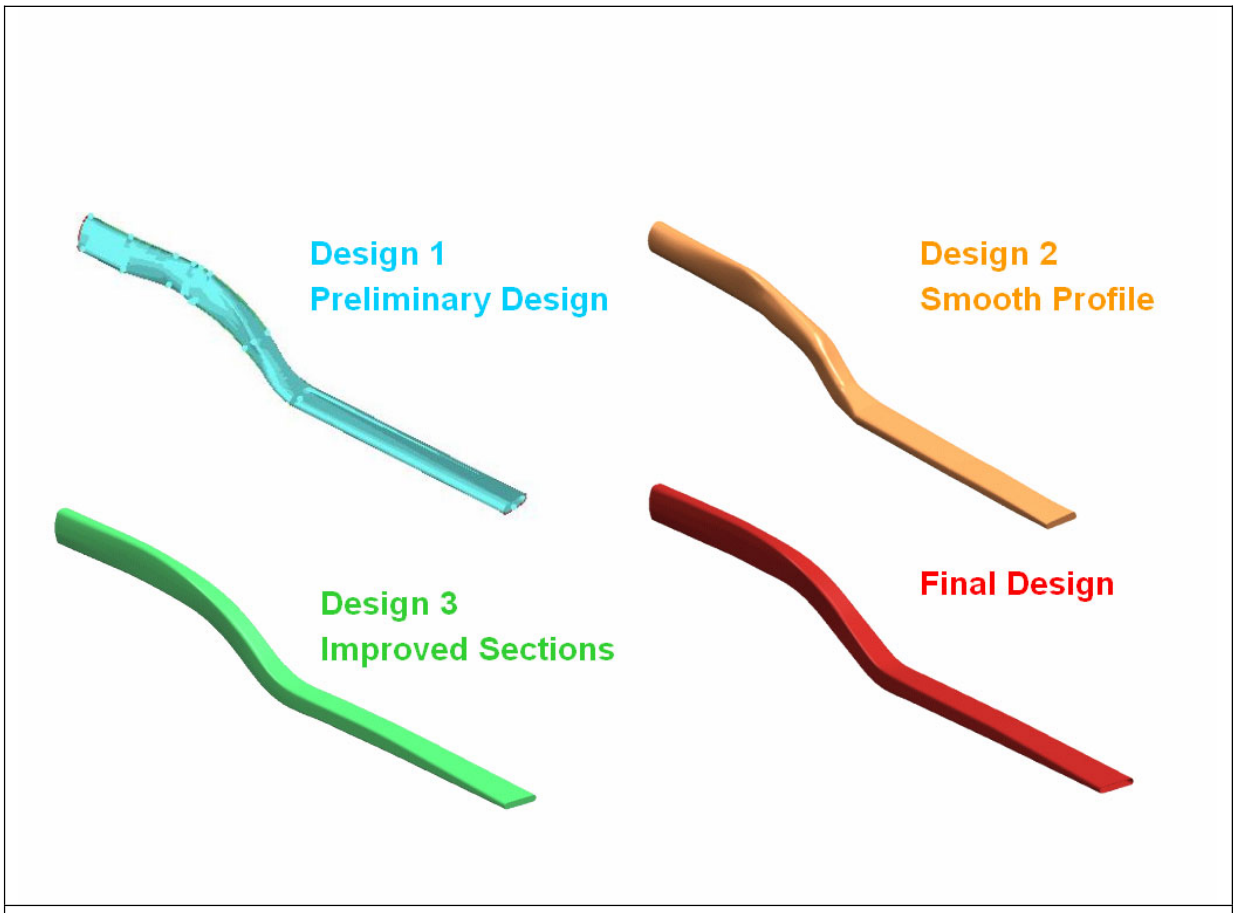


Figure 8: Hydroformed Rail Design Progression

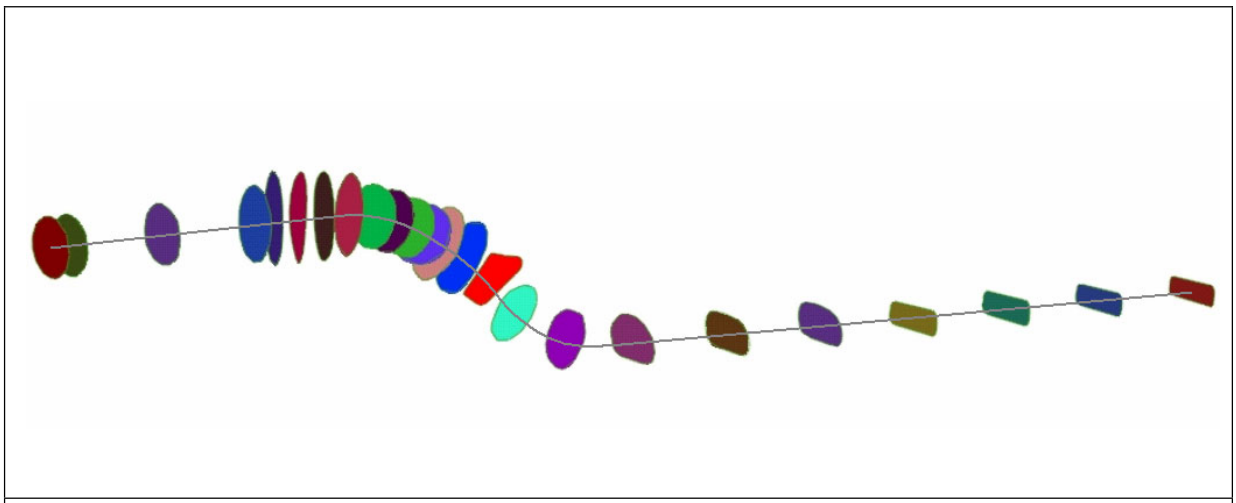


Figure 9: Hydroformed Rail Sections and Centroidal Line

Best Stamped Design

The *Stamped Design* (13) has the following features.

- Octagonal 3-piece tailor-welded rail inner and outer pieces with symmetric flanges and tapered front section (*Figure 10*).
- Two-piece rail tailor-welded extension design with a reinforcement.
- Rail inner reinforcement.
- Symmetric LH/RH rail assemblies.
- Two-piece double box bumper design with energy absorbing features (*Figure 11*).

The *Stamped Design* was derived using section optimization. The cross-sections were designed so to maintain a straight centroidal line within the packaging constraints (*Figure 13*) and therefore an axial load path. The initial design was then further evolved (*Figure 8*) in order to improve performance.

Sheet metal parts attached to the rails (*Figure 14*) were modified in order to connect the rails with the rest of the vehicle.

The *Stamped Design* was selected as the *Final AHSS Design* for prototyping, due to its ease of manufacturability and suitability to current production environment.

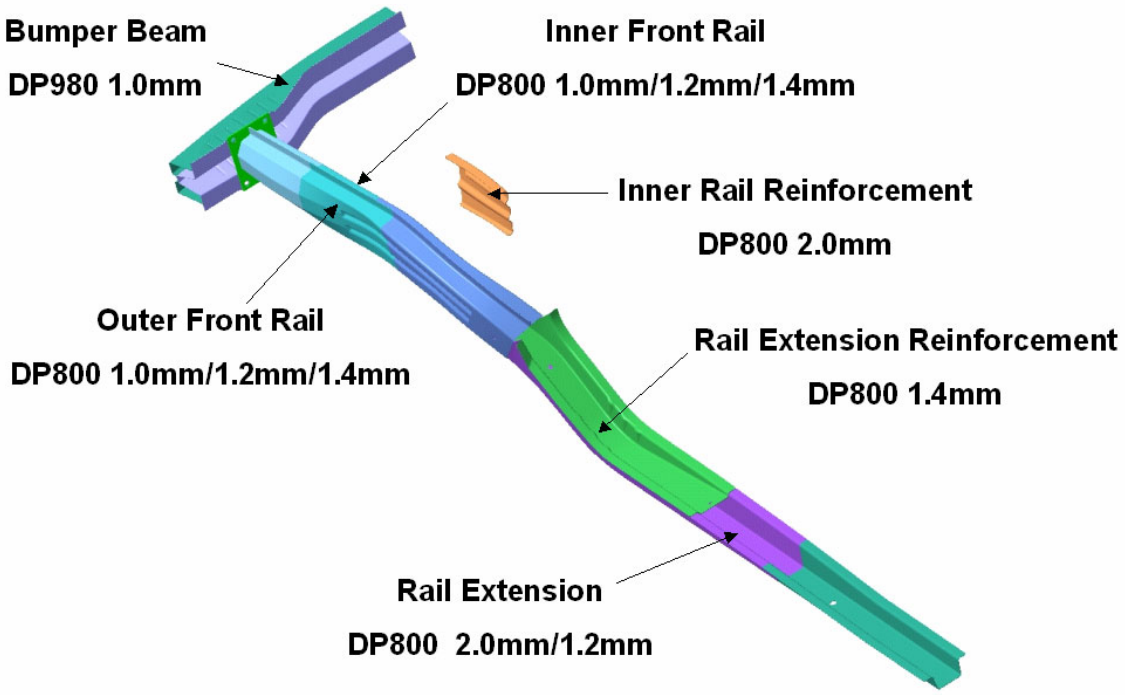


Figure 10: Stamped LH Rail and Bumper Assemblies

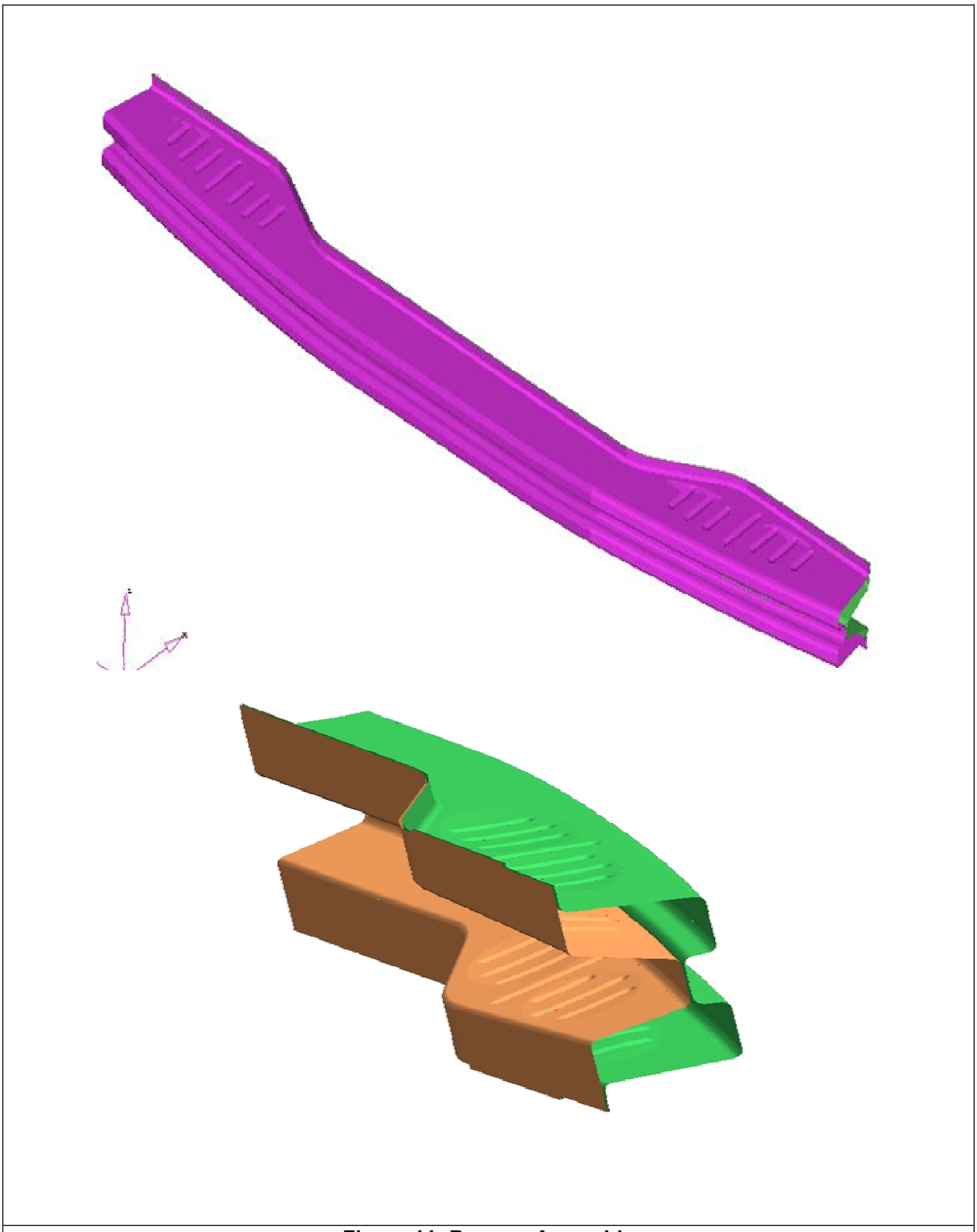


Figure 11: Bumper Assembly

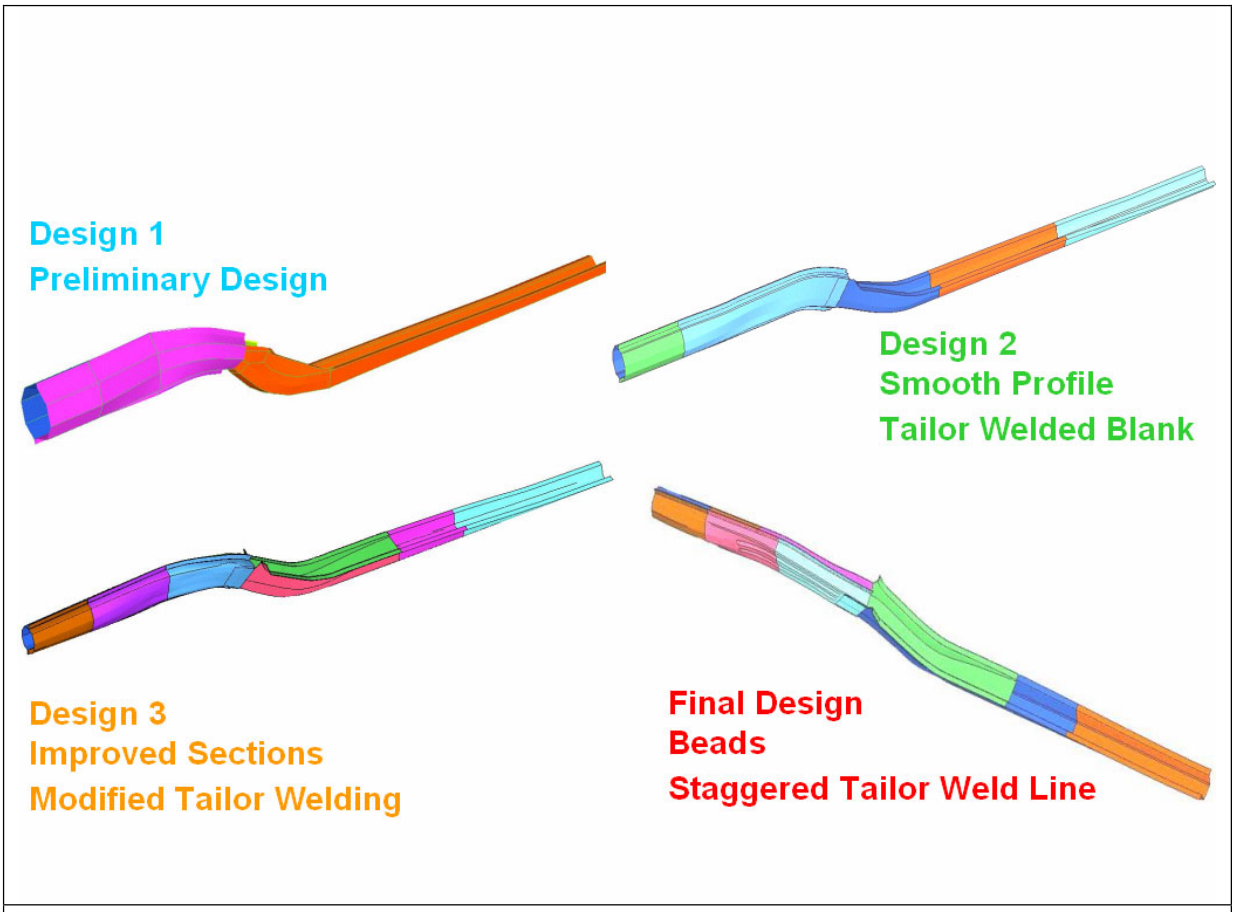


Figure 12: Stamped Rail Design Progression

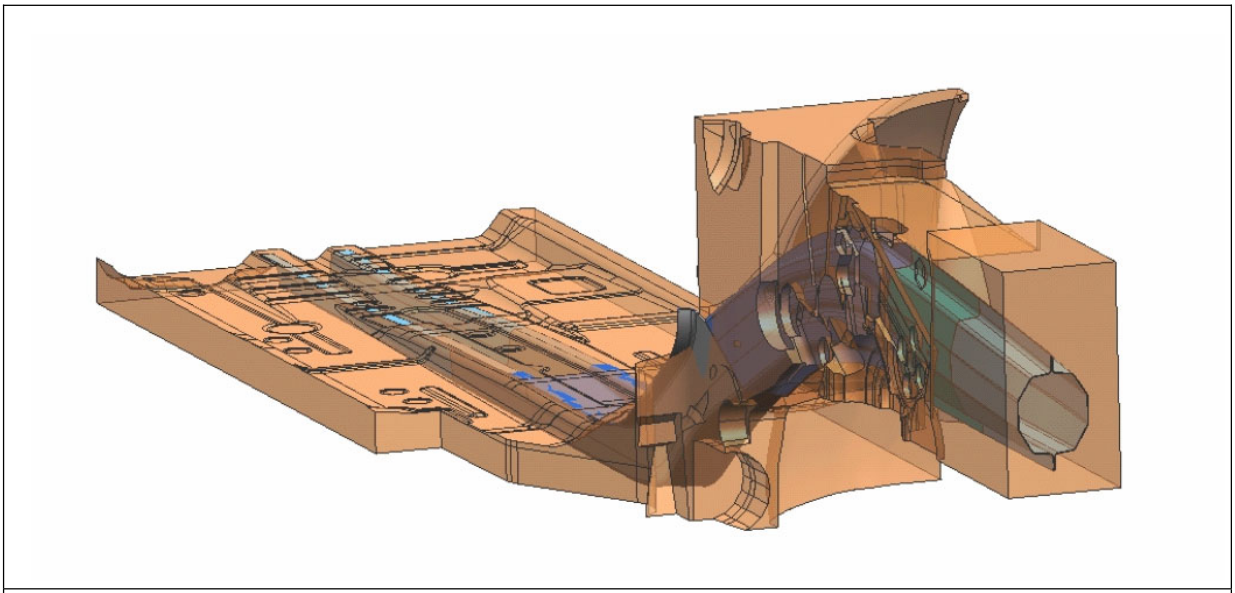


Figure 13: Stamped Rail within Design Envelope

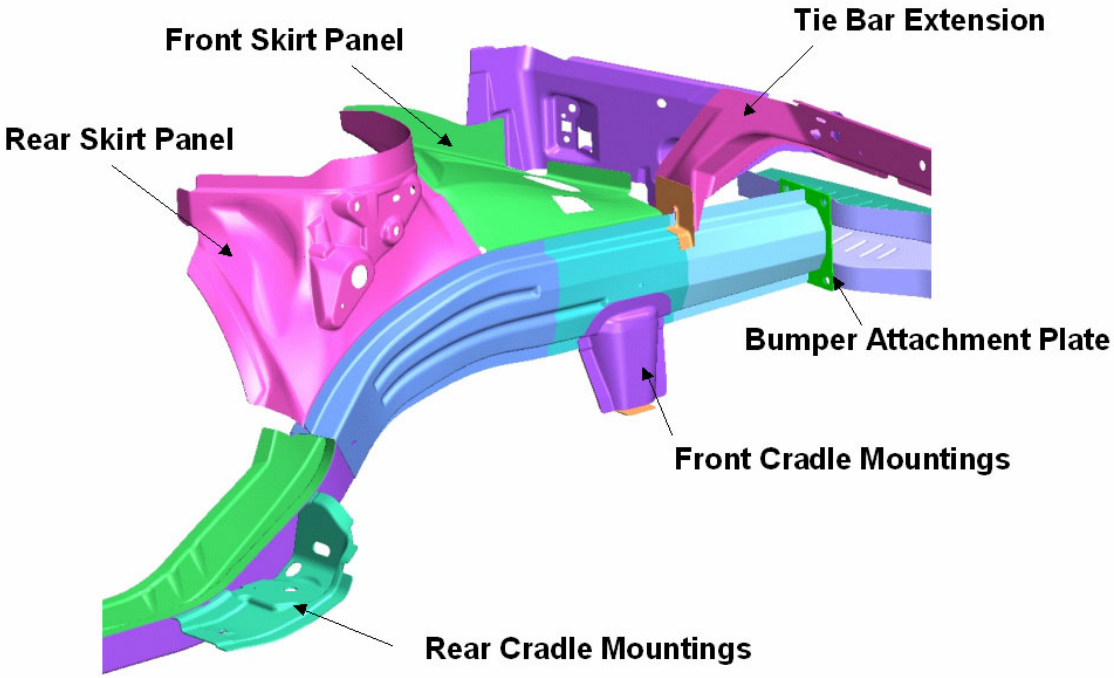


Figure 14: Stamped Rail and Attached Parts

7. DOE and Optimization

The ***Final AHSS Design*** (20) was derived from the *Stamped Design* (13) through computer-aided optimization (CAO) of the response surfaces obtained through Design of Experiments (DOE) studies ((18), (19), (27), (28)).

The NCAP DOE study (18) and IIHS DOE study (19) incorporated the following features.

- NCAP and IIHS load cases up to 100 ms and 150ms respectively.
- 2-level L32 Orthogonal Array.
- Bumper and rail grades/gauges as design parameters.
- 16 factors and 16 interactions.
- NCAP B-pillar accelerations and IIHS intrusions as responses.

NCAP/IIHS DOE parameters and their levels are summarized in *Table 7*.

Table 7: NCAP/IIHS DOE Model

	Part	Level 1 Gauge (mm)	Level 2 Gauge (mm)
1	Bumper	1.0	1.3
2	Rail Front Inner/Outer	1.0	1.3
3	Rail Mid Inner/Outer	1.2	1.6
4	Rail Rear Inner	1.4	2.0
5	Rail Rear Outer	1.4	2.0
6	Rail Reinforcement	1.4	2.0
7	Rail Extension Front	1.4	2.0
8	Rail Extension Rear	1.2	1.6
9	Rail Extension Reinf	1.4	2.0
	Part	**Level 1 Grade**	**Level 2 Grade**
10	Bumper	DP800	DP980
11	Rail Front Inner/Outer	DP600	DP800
12	Rail Mid Inner/Outer	DP600	DP800
13	Rail Rear Inner/Outer	DP600	DP800
14	Rail Reinforcement	DP600	DP800
15	Rail Extension Front/Rear	DP600	DP800
16	Rail Extension Reinf	DP600	DP800

Level 1 gauges correspond to 30% mass reduction compared to the *Donor Vehicle*.

- Level 2 gauges are 130% of Level 1 gauges.

The Static Stiffness DOE study (27) and Dynamic Stiffness (28) DOE study incorporated the following features.

- Static bending/torsional stiffness load cases and free-free modal analysis.
- 2-level L32 Orthogonal Array.
- Bumper and rail gauges as design parameters.
- 9 factors and 22 interactions.
- Bending/torsional stiffness and modes as responses.

Stiffness DOE parameters and their levels are summarized in *Table 8*.

Table 8: Stiffness DOE Model

	Part	Level 1 Gauge (mm)	Level 2 Gauge (mm)
1	Bumper	1.0	1.3
2	Rail Front Inner/Outer	1.0	1.3
3	Rail Mid Inner/Outer	1.2	1.6
4	Rail Rear Inner	1.4	2.0
5	Rail Rear Outer	1.4	2.0
6	Rail Reinforcement	1.4	2.0
7	Rail Extension Front	1.4	2.0
8	Rail Extension Rear	1.2	1.6
9	Rail Extension Reinf	1.4	2.0

- Level 1 gauges correspond to 30% mass reduction compared to the *Donor Vehicle*.
- Level 2 gauges are 130% of Level 1 gauges.

Mass comparison of the optimized *AHSS Design* (20) and the *Baseline Design* (6) is shown in *Table 9*. The grades and gauges of the *AHSS Design* are summarized in *Table 10*.

Table 9: Mass Summary

Part	Mass (kg)	
	Baseline Design	Final AHSS Design
LH Rail Assembly	16.52	12.25
RH Rail Assembly	16.15	12.25
Bumper (without foam)	6.56	5.96
Total	39.23	30.46*

* 22.36% mass reduction with respect to *Baseline*

Table 10: Grade and Gauge Summary

Part	Final AHSS Design	
	Grade	Gauge (mm)
Rail Front Inner	DP 450/800	1.0
Rail Front Outer	DP 450/800	1.0
Rail Mid Inner	DP 450/800	1.2
Rail Mid Outer	DP 450/800	1.2
Rail Rear Inner	DP 450/800	1.4
Rail Rear Outer	DP 450/800	1.4
Rail Extension Front	DP 450/800	2.0
Rail Extension Rear	DP 450/800	1.2
Rail Extension Reinforcement	DP 450/800	1.4
Rail Inner Reinforcement	DP 450/800	2.0
Bumper Beam	DP 700/980	1.0

NCAP Response

The figures below summarize the NCAP response of the *Final AHSS Design* (20). The *Final AHSS Design* possesses a superior NCAP performance compared to the *Baseline Design* (6). The initial peak is higher and the global peak is lower than the *Baseline Design.* Furthermore, the front of the rail (forward of the front cradle mount) crushes axially, resulting in good energy absorption.

IIHS Response

IIHS intrusions are summarized in Table 4. Toepan, brake pedal and A-B closure intrusions oscillate after 200ms about a mean value. Hence, the peak intrusion values are used for comparison (*Table 4*). The left toepan and A-B closure intrusions of the *Final AHSS Design* (20) are lower than the *Baseline Design* values (6). The center and right toepan intrusions of the *Final AHSS Design* are slightly higher than the *Baseline Design* values.

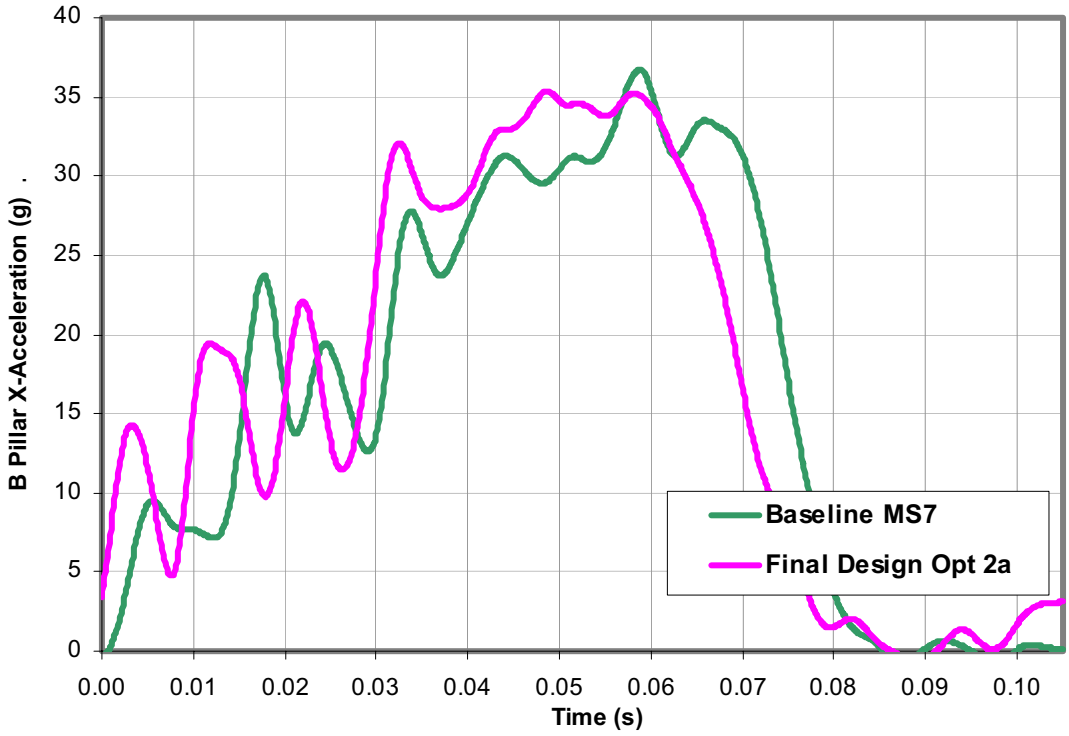


Figure 15: LH B-Pillar Pulse – Final Design Vs. Baseline

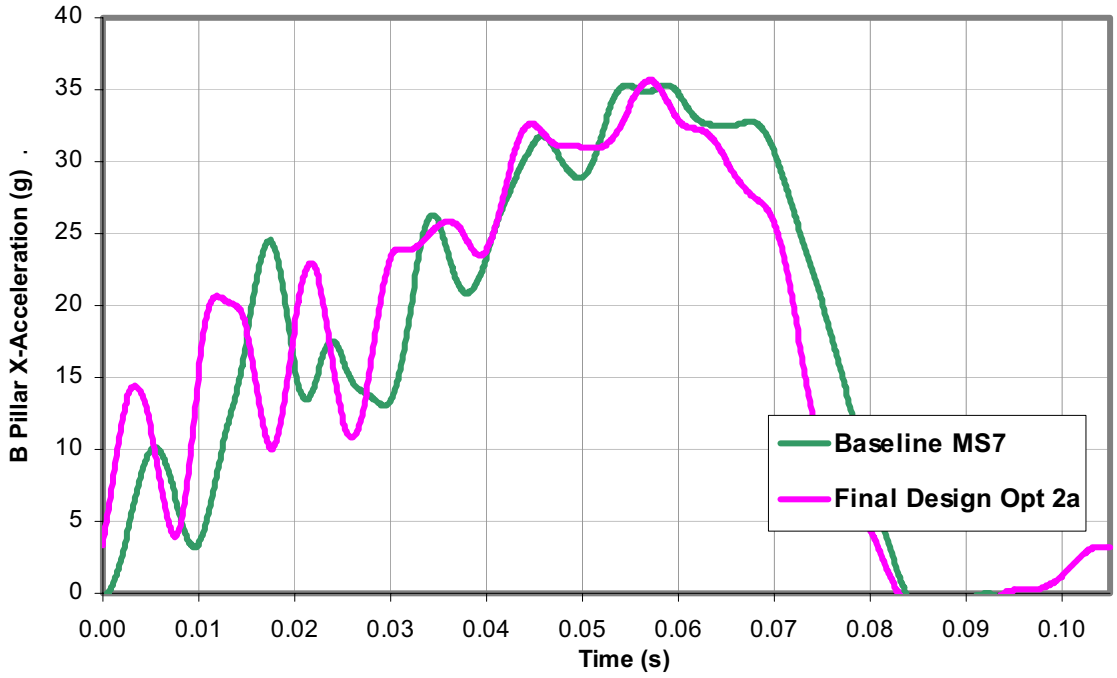


Figure 16: RH B-Pillar Pulse – Final Design Vs. Baseline

8. Knowledge Base

The knowledge base tool ***Proteus*** that was developed in *Phase I*, was enhanced considerably in *Phase II* (24). The main addition to ***Proteus*** was the Optimizer module (*Figure 17, Figure 18*). ***Proteus*** can now be employed for optimizing any architecture in its database subject to user-defined constraints. Mass, cost and any DOE response can be selected as objective function and design constraint. The DOE response surfaces obtained in *Phase II* were archived into the knowledge base Proteus. Please refer to (24) for instructions on using ***Proteus*** as well as all available databases.

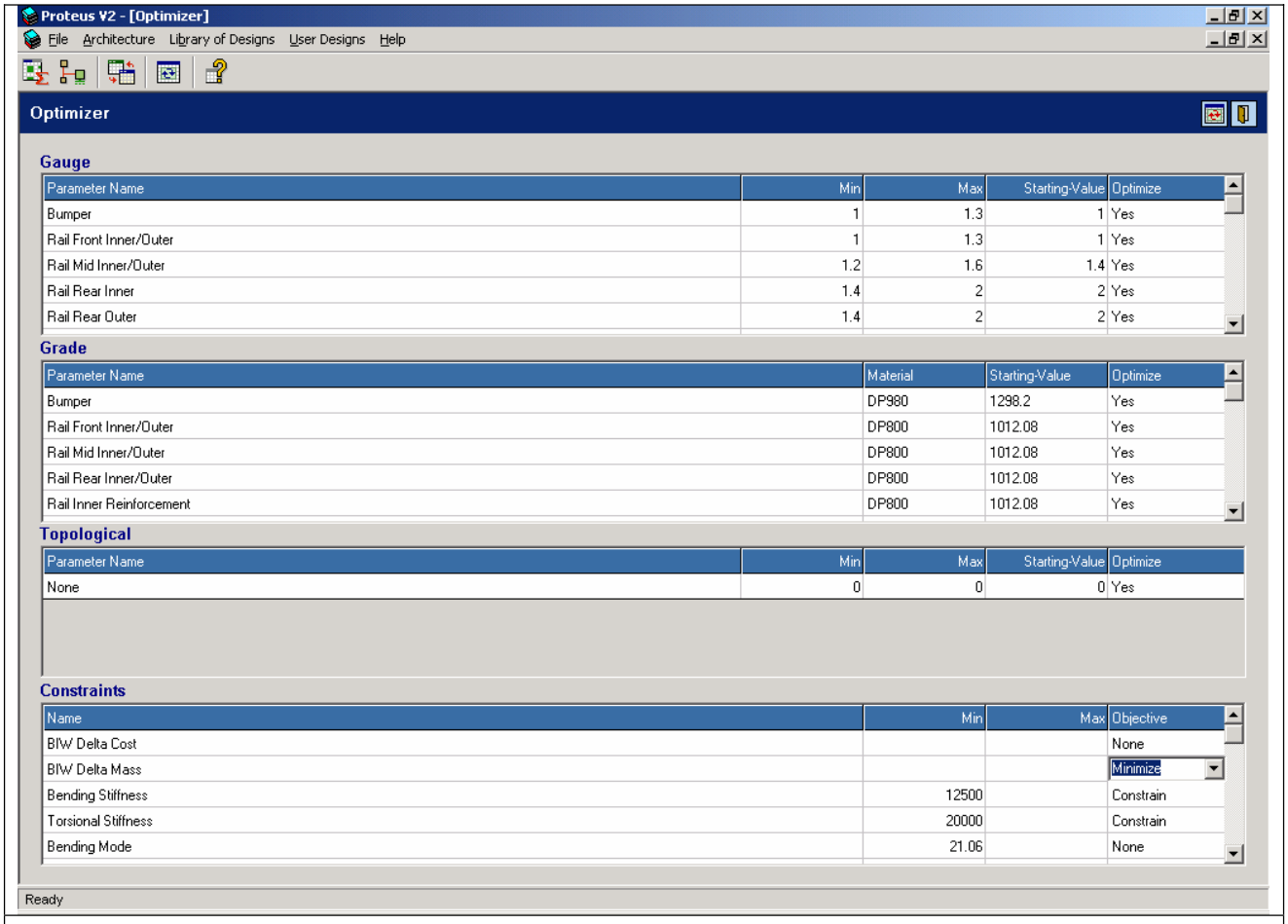
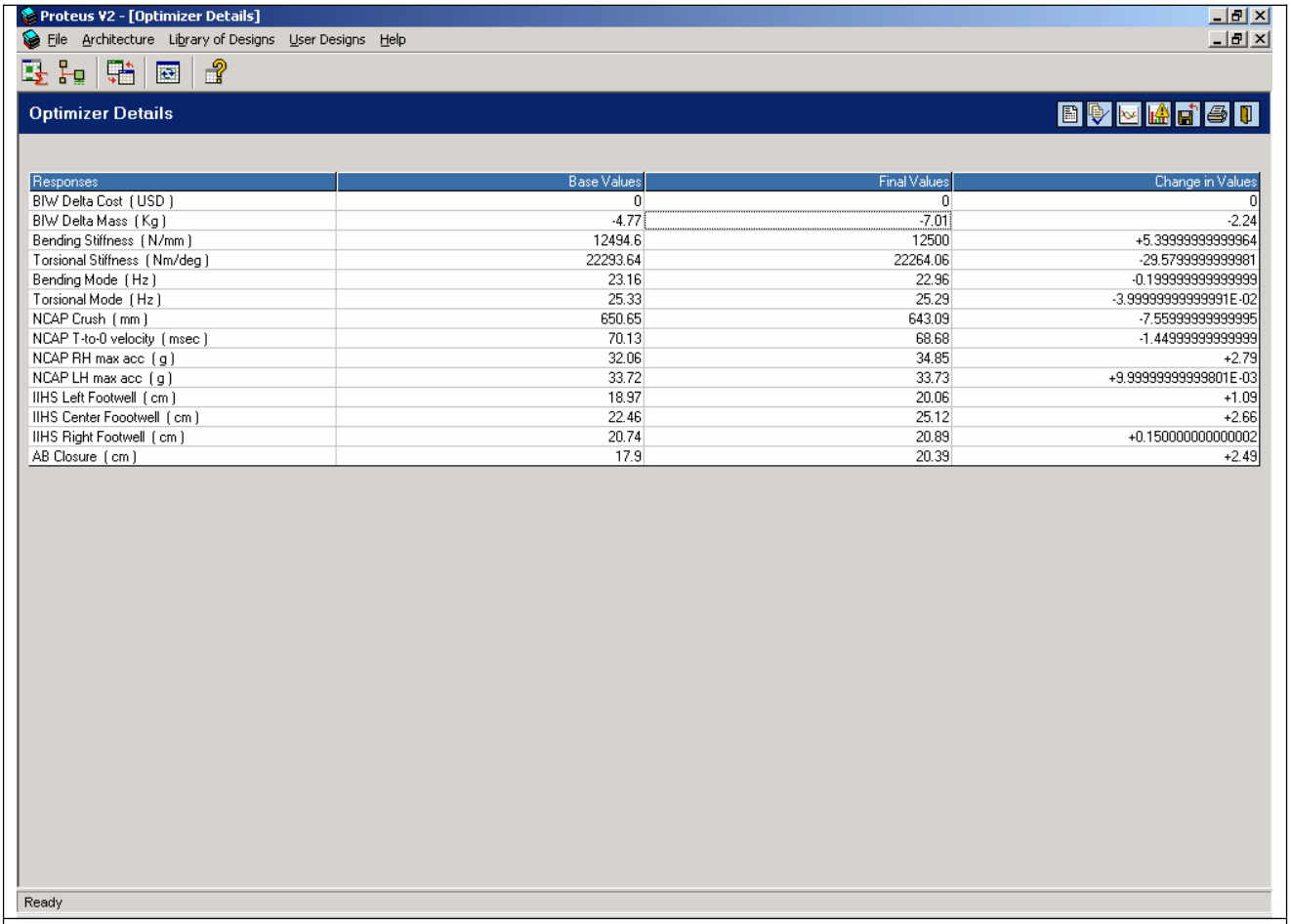


Figure 17: Proteus Optimizer Page

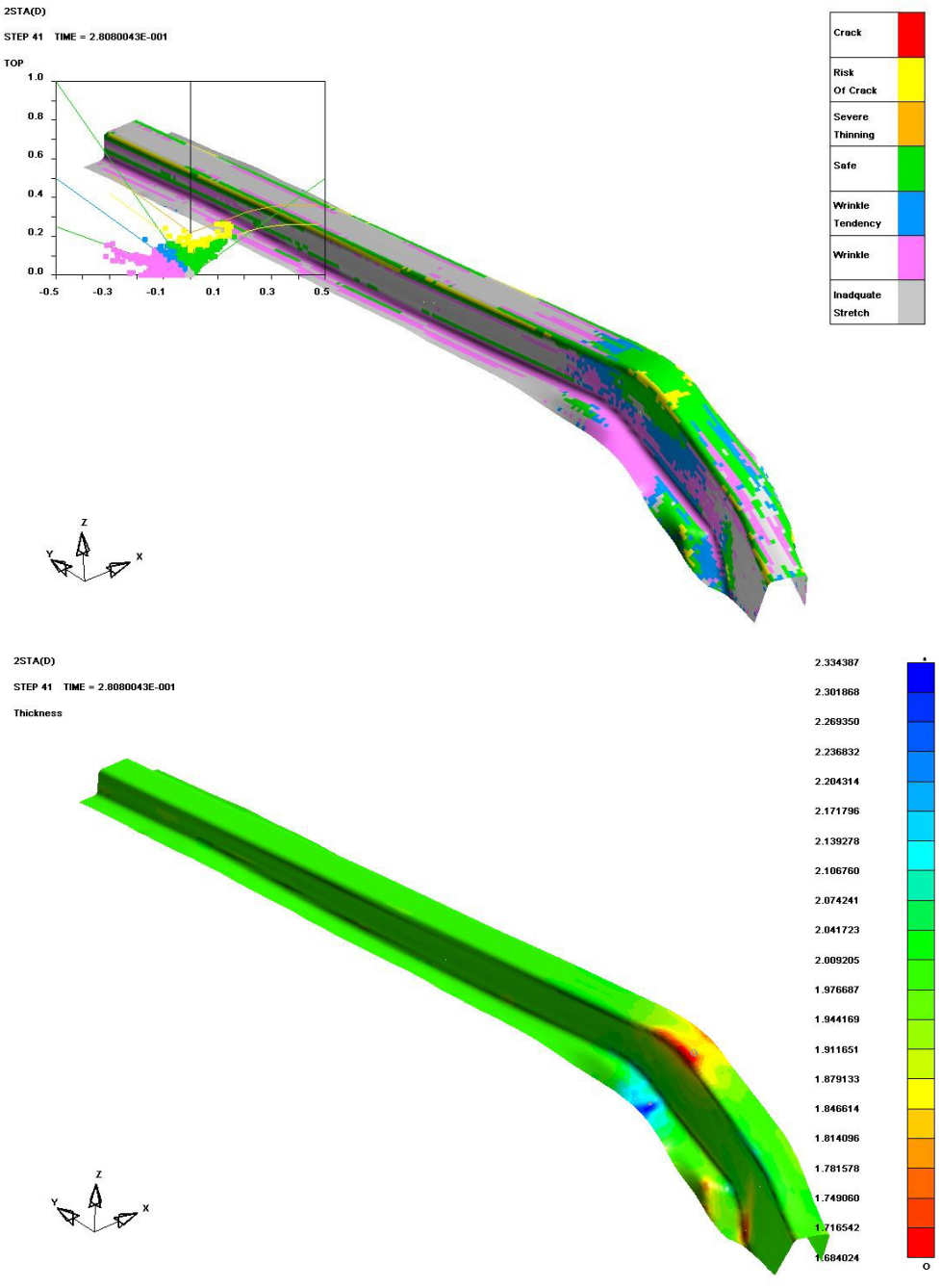


Responses	Base Values	Final Values	Change in Values
BIW Delta Cost (USD)	0	0	0
BIW Delta Mass (Kg)	-4.77	-7.01	-2.24
Bending Stiffness (N/mm)	12494.6	12500	+5.39999999999964
Torsional Stiffness (Nm/deg)	22293.64	22264.06	-29.5799999999981
Bending Mode (Hz)	23.16	22.96	-0.199999999999999
Torsional Mode (Hz)	25.33	25.29	-3.99999999999991E-02
NCAP Crush (mm)	650.65	643.09	-7.55999999999995
NCAP T-to-0 velocity (msec)	70.13	68.68	-1.44999999999999
NCAP RH max acc (g)	32.06	34.85	+2.79
NCAP LH max acc (g)	33.72	33.73	+9.99999999999801E-03
IIHS Left Footwell (cm)	18.97	20.06	+1.09
IIHS Center Foootwell (cm)	22.46	25.12	+2.66
IIHS Right Footwell (cm)	20.74	20.89	+0.150000000000002
AB Closure (cm)	17.9	20.39	+2.49

Figure 18: Proteus Optimizer Details Page

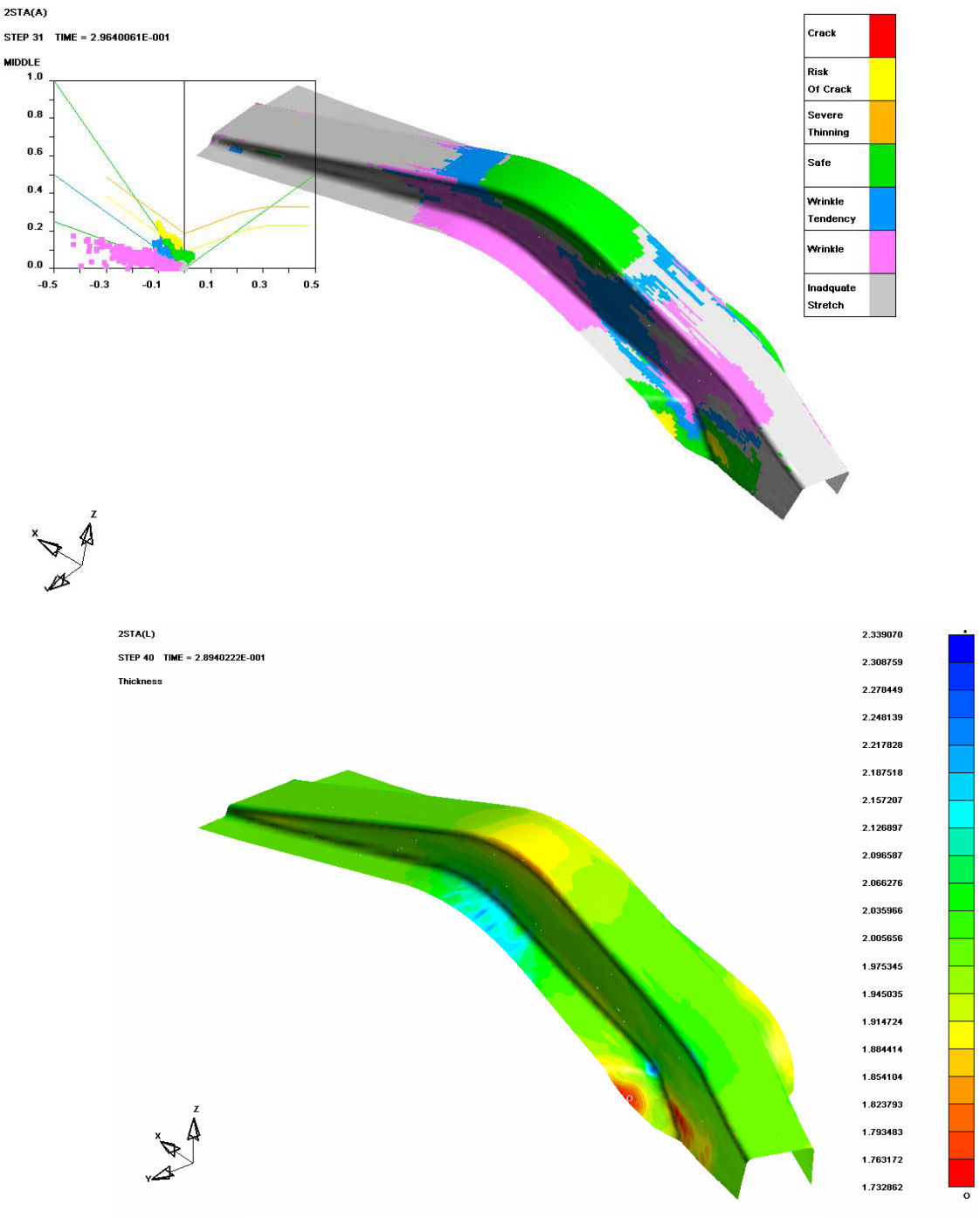
9. Manufacturing

The ***Stamped Design*** (20) was selected as the ***Final AHSS Design*** for prototyping. Forming simulations were carried out for difficult parts to confirm design feasibility. Incremental analyses were undertaken and FLD curves and thinning contours were generated to identify critical areas. Thinning criterion of less than 15% was used to establish design feasibility.



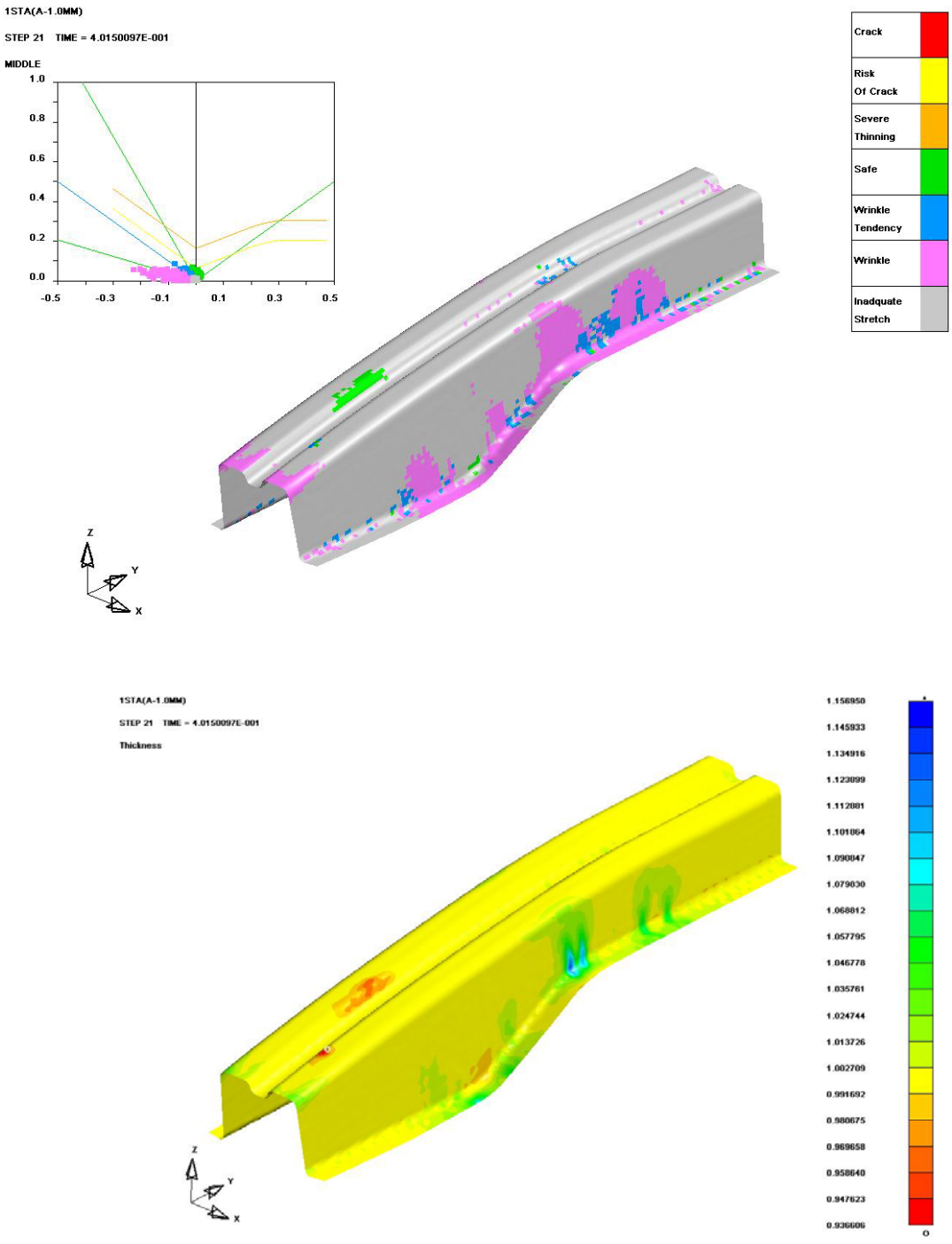
Thinning < 15% : Design Feasible with Minor Adjustments

Figure 19: Rail Extension - FLD (top) and Thinning Plot (Bottom)



Thinning < 13% : Design Feasible

Figure 20: Rail Extension Reinforcement - FLD (top) and Thinning Plot (Bottom)



Thinning < 10% : Design Feasible

Figure 21: Bumper Inner - FLD (top) and Thinning Plot (Bottom)

The original prototyping processes designed at the prior to prototyping were later modified to ensure better manufacturability. Production processes were also recommended, based on the lessons learned from prototyping.

The manufacturing processes for the rail and bumper parts are summarized *Table 11* through *Table 16*. The final prototyped parts are shown in *Figure 22* through *Figure 26*.

Table 11: Front Rail Inner/Outer Manufacturing Processes

Original Prototyping Processes	**Develop Oversize Profile Blank** **Single Hit Crash Form Operation** **Laser Trim** **Machined Construction Holes**
Final Prototyping Processes	**Develop Reshaped Profile Blank** **Single Hit Crash Form Operation with Pinch Flanges** **Saw Trim** **Machined Construction Holes** **Restrike Operation using Original Form**
Recommended Production Processes	**Oversize Developed Flat Blank** **Draw-form Part Complete to Part Shape (Using Pressure Pad to Secure Blank)** **Pierce Construction Holes and Trim Outside Finish Shape** **Final Form Operation**

Table 12: Front Rail Reinforcement Manufacturing Processes

Original Prototyping Processes	**First Form: Draw Tool** **Second Form: Restrike Tool** **Laser Trim**
Final Prototyping Processes	**Developed trim profile** **Single Hit Crash Form Operation** **Laser Trim**
Recommended Production Processes	**Developed Trim Profile** **Single Hit Form Operation** **Finish Trim**

Table 13: Rail Extension Reinforcement Manufacturing Processes

Original Prototyping Processes	**Developed Flat Blank with Oversize Profile** **First Form** **Second Form** **Laser Trim** **Machine Construction Holes**
Final Prototyping Processes	**Develop Reshaped Profile Blank** **First Form: Pre Form** **Second Form: Finish Form** **Laser Trim** **Machine Construction Holes** **Restrike Operation Using Second Form Die**
Recommended Production Processes	**Oversize Flat Developed Blank** **First Form** **Pierce and Trim Outside Profile** **Final Form Operation**

Table 14: Rail Extension Manufacturing Processes

Original Prototyping Processes	**Rough Oversize Profile Flat Blank** **Single 3 Piece Draw Die** **Pierce Construction Holes** **Laser Trim Finish**
Final Prototyping Processes	**Rough Oversize Profile Flat Blank** **Single 3 Piece Draw Die** **Restrike Operation using Second Form Die** **Laser Trim Finish**
Recommended Production Processes	**Oversized Flat Developed Blank** **First Draw Form** **Second Form** **Pierce and Trim Outside Profile** **Final Form Operation**

Table 15: Inner Bumper Manufacturing Processes

Original Prototyping Processes	Developed Flat Blank with Oversize Profile Single Hit Draw Die Weld Fixture Pierce Mounting Holes Into Bumper Assembly Laser Trim
Final Prototyping Processes	Developed Flat Blank with Oversize Profile First Form Die Restrike in the First Form Tool Weld Fixture Pierce Mounting Holes Into Bumper Assembly Laser Trim
Recommended Production Processes	Developed Flat Blank With Oversize Profile Pierce Manufacturing Construction Holes First Form Finish Form Spot Weld Outer Inner Bumpers Together Pierce Mounting Holes and Trim Outside Profile After Assembling

Table 16: Outer Bumper Manufacturing Processes

Original Prototyping Processes	Developed Flat Blank with Oversize Profile First Hit: Draw Center Channel Second Hit: “W-Shape” To Form Part in Open Position Third Hit: Finish Form – Kirksite Tool Weld Fixture Pierce Mounting Holes Into Bumper Assembly Laser Trim
Final Prototyping Processes	Developed Flat Blank with Oversize Profile First Hit: Draw Center Channel Second Hit: “W-Shape” To Form Part in Open Position Third Hit: Finish Form – Kirksite Tool Weld Fixture Pierce Mounting Holes Into Bumper Assembly Laser Trim
Recommended Production Processes	Developed Flat Blank with Oversize Profile Pierce Manufacturing Construction Holes First Form: Draw Center Channel Second Form: “W-Shape” To Form Part in Open Position Third Form: Finish Form Spot Weld Inner and Outer Bumpers Together Pierce Mounting Holes and Trim Outside Profile After Assembling

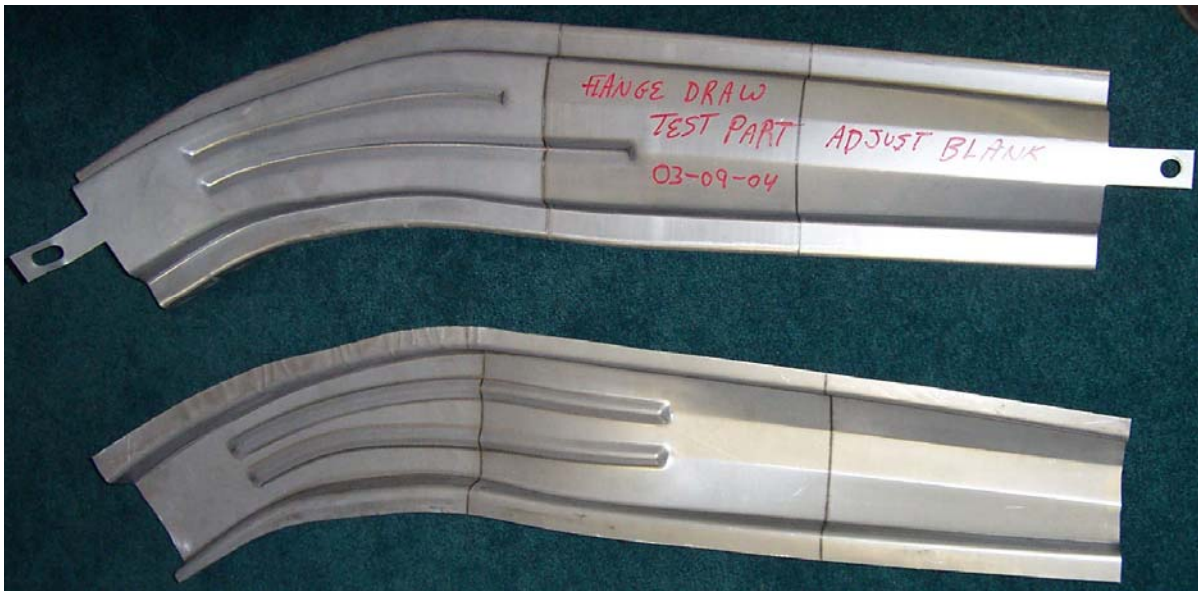


Figure 22: Front Rail Inner/Outer



Figure 23: Rail Inner Reinforcement



Figure 24: Rail Extension Reinforcement



Figure 25: Rail Extension



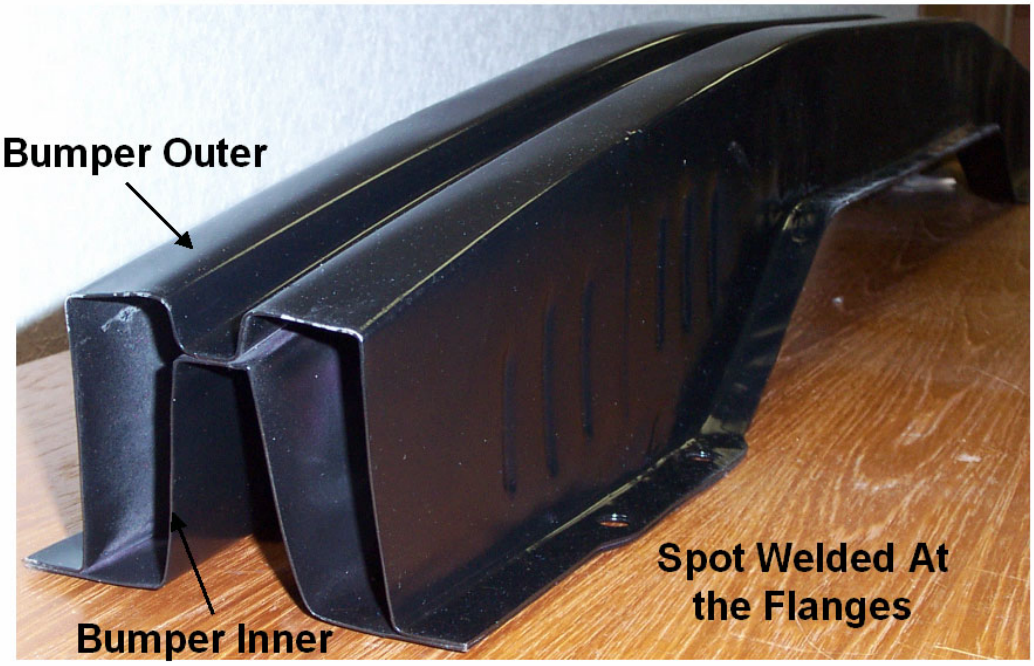


Figure 26: Bumper Assembly

10. Assembly

Assembly Sequence

The sequence of assembling the prototyped parts into the vehicle was generated (*Figure 27*). This formed the basis of arriving at dimensional tolerances and stickups for prototyping as well as for assembly.

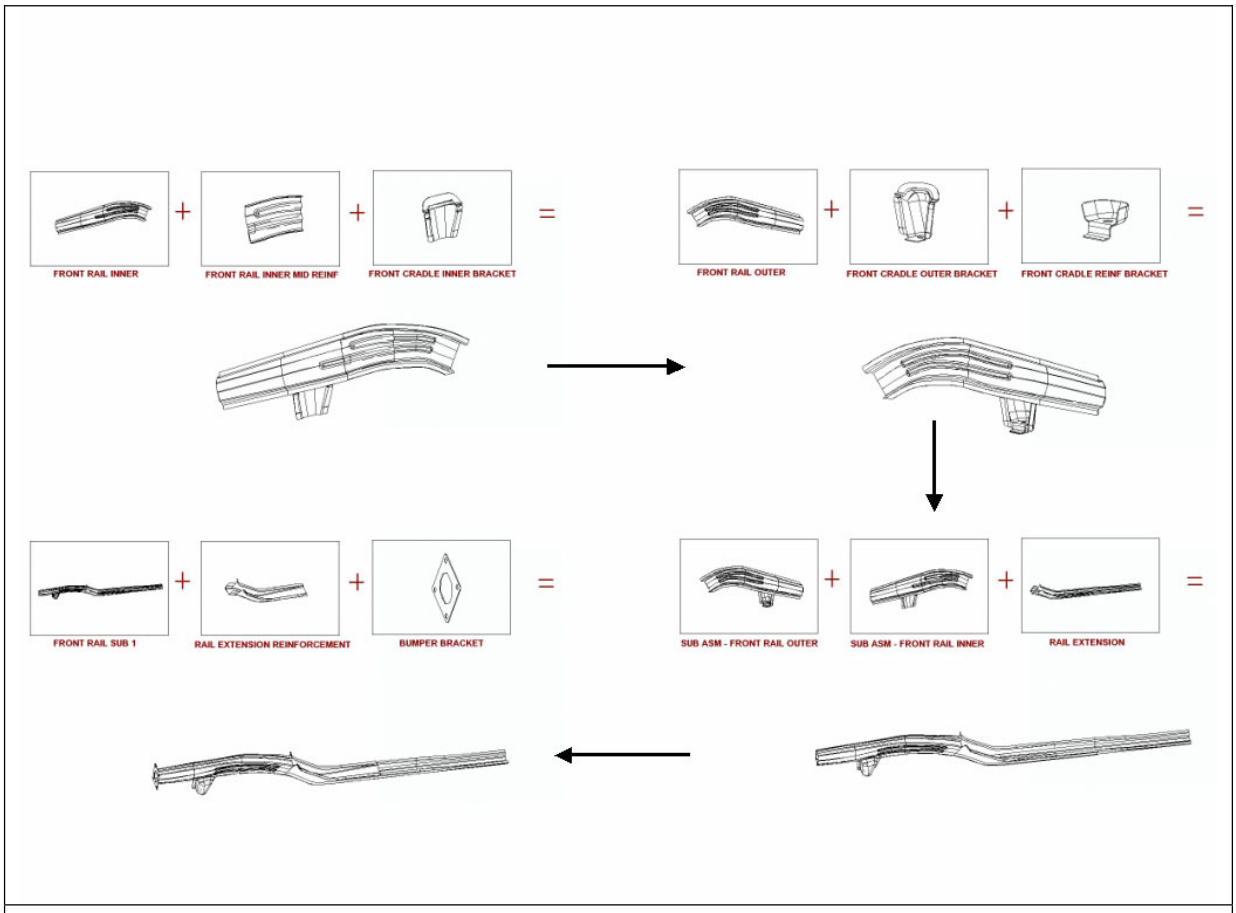


Figure 27: Assembly Sequence

Dimensional Tolerance Analyses

A detailed dimensional tolerance analyses was undertaken to provide tolerances for prototyping and assembly (*Figure 28* through *Figure 32*).

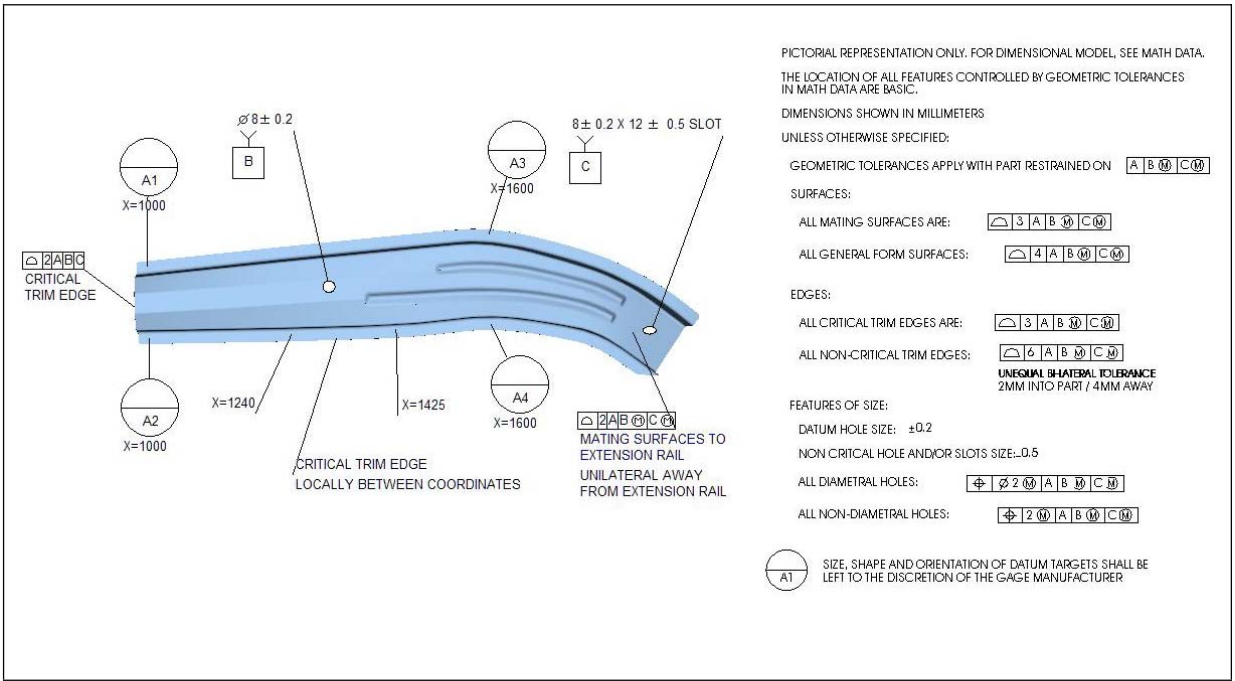


Figure 28: Rail Inner Tolerances

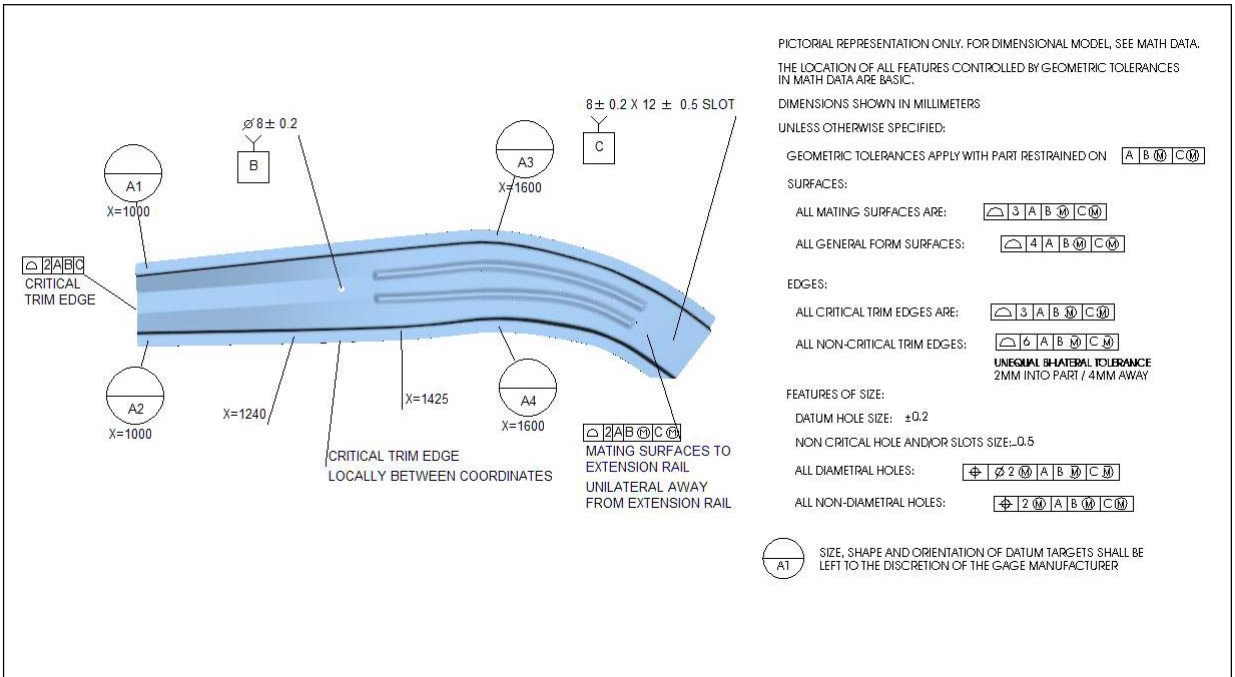


Figure 29: Rail Outer Tolerances

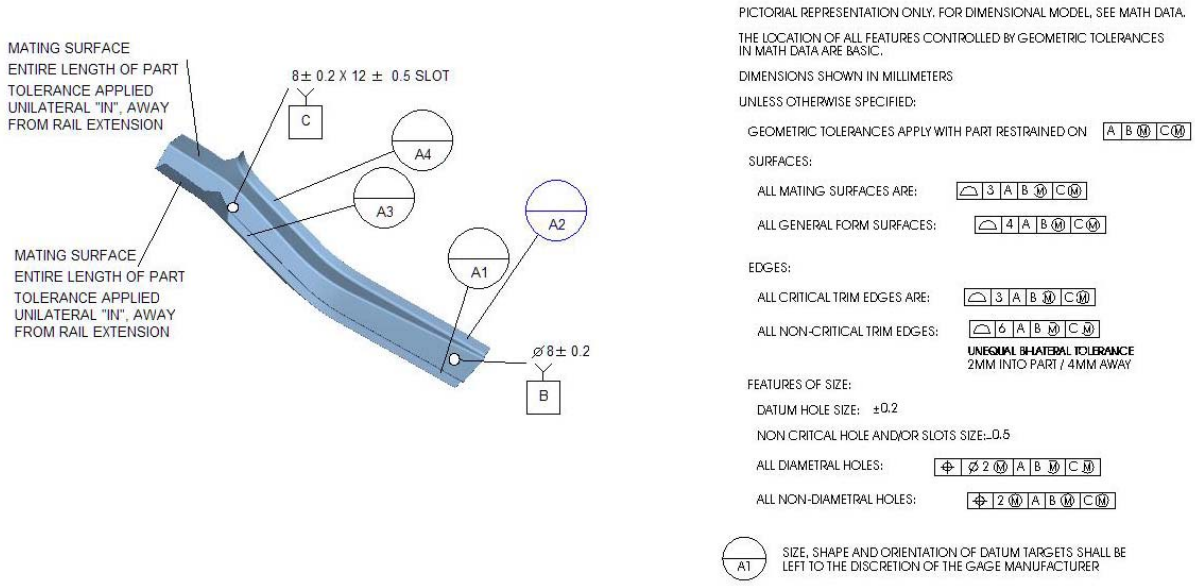


Figure 30: Rail Extension Reinforcement Tolerances

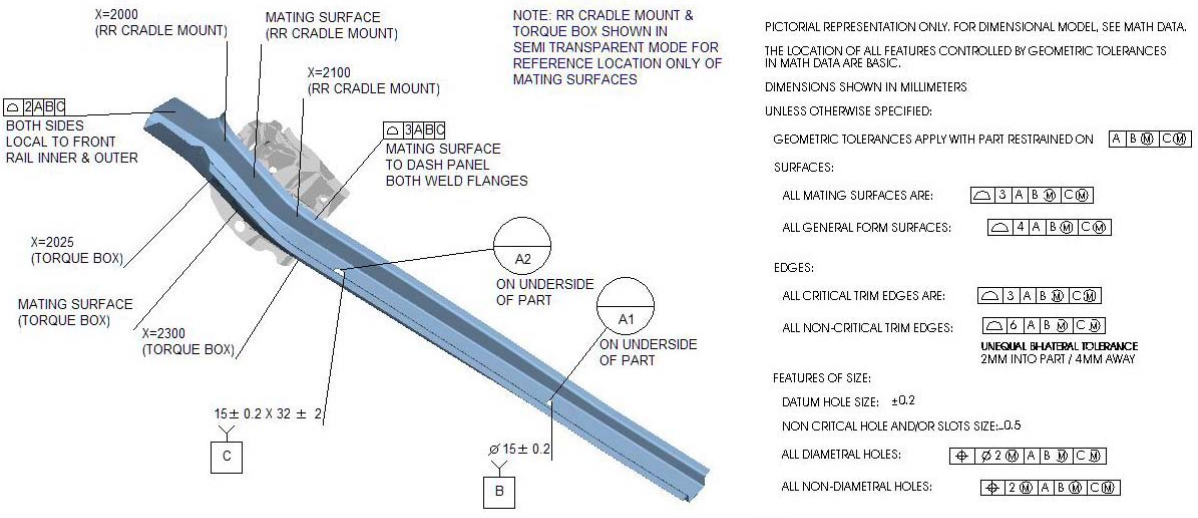
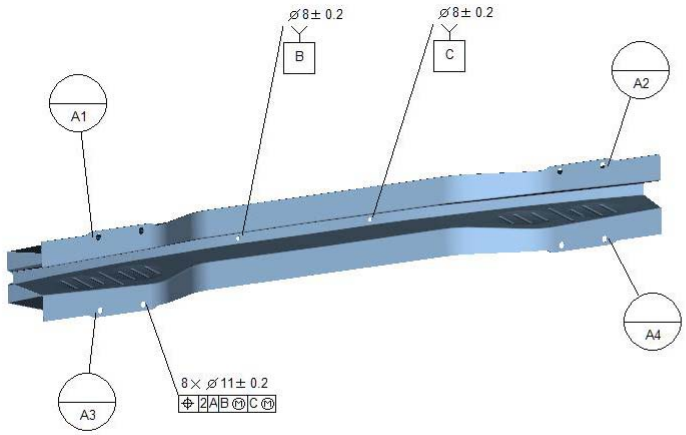


Figure 31: Rail Extension Tolerances



PICTORIAL REPRESENTATION ONLY. FOR DIMENSIONAL MODEL, SEE MATH DATA.

THE LOCATION OF ALL FEATURES CONTROLLED BY GEOMETRIC TOLERANCES IN MATH DATA ARE BASIC.

DIMENSIONS SHOWN IN MILLIMETERS

UNLESS OTHERWISE SPECIFIED:

GEOMETRIC TOLERANCES APPLY WITH PART RESTRAINED ON A B M C M

SURFACES:

ALL MATING SURFACES ARE: ⌓ 3 A B M C M

ALL GENERAL FORM SURFACES: ⌓ 4 A B M C M

EDGES:

ALL CRITICAL TRIM EDGES ARE: ⌓ 3 A B M C M

ALL NON-CRITICAL TRIM EDGES: ⌓ 6 A B M C M

FEATURES OF SIZE:

DATUM HOLE SIZE: ±0.2

NON CRITCAL HOLE AND/OR SLOTS SIZE: $^{+0.6}_{-}$

ALL DIAMETRAL HOLES: ⌖ ⌀ 2 M A B M C M

ALL NON-DIAMETRAL HOLES: ⌖ 2 M A B M C M

A1 SIZE, SHAPE AND ORIENTATION OF DATUM TARGETS SHALL BE LEFT TO THE DISCRETION OF THE GAGE MANUFACTURER

Figure 32: Bumper Tolerances

Weld Schedule Development

Weld schedule was developed by the ***A/SP Joining Group*** prior to assembly for all the metal stickups (*Figure 33*). The weld schedule was tested on sample sheet metal in the assembly shop to confirm that the same weld schedule would apply to the assembly shop welding equipment.

RES STACK-UP ID	RES MATERIAL ID		STACK-UP	WELD TIME	WELDING RANGE (kAmps)	VALIDATED CURRENT
114	TOP MAT'L		BARE 1.03 DP980	16 CYC.	8.7-11.8	
			TO	16 CYC.	8.6-12.0	
	BOT MAT'L		BARE 1.03 DP980	22 CYC.	8.8-11.6	10.5
				28 CYC.	8.7-11.6	
115	TOP MAT'L		GN 1.00 DP800	16 CYC.	9.4-11.7	
			TO	22 CYC.	8.8-12.4	11.0***
	BOT MAT'L		GN 1.00 DP800	28 CYC.	9.1-11.1	
116	TOP MAT'L	AISI 208	GN 1.20 DP800	16 CYC.	9.4-11.2	
			TO	22 CYC.	9.0-10.8	10.0
	BOT MAT'L	AISI 208	GN 1.20 DP800	28 CYC.	8.7-10.5	
117	TOP MAT'L	AISI 209	GN 1.40 DP800	16 CYC.	9.6-11.0	
			TO	22 CYC.	9.0-10.4	10.5***
	BOT MAT'L	AISI 209	GN 1.40 DP800	28 CYC.	8.5-10.1	
118	TOP MAT'L	AISI 210	HDG 2.00 DP800	16 CYC.	10.6-11.6	
			TO	22 CYC.	10.0-11.5	10.8
	BOT MAT'L	AISI 209	GN 1.40 DP800	28 CYC.	8.7-10.4	
119	TOP MAT'L	AISI 208	GN 1.20 DP800	16 CYC.	10.2-12.0	
			TO	22 CYC.	10.0-12.0	11.0***
	BOT MAT'L	AISI 210	HDG 2.00 DP800	28 CYC.	8.7-10.4	
120	TOP MAT'L	AISI 209	GN 1.40 DP800	16 CYC.	10.6-11.6	
			TO	22 CYC.	10.0-11.5	10.8
	BOT MAT'L	AISI 210	HDG 2.00 DP800	28 CYC.	8.7-10.4	
121	TOP MAT'L	AISI 209	GN 1.40 DP800 to	~~16 CYC.~~		
	MID MAT'L	AISI 210	HDG 2.00 DP800 to	22 CYC.	9.8-11.0	10.8***
	BOT MAT'L	AISI 209	GN 1.40 DP800	28 CYC.	9.3-10.8	
				34 CYC.	8.9-10.4	

WELD SCHEDULE: 1500 Lbs. with 30 cyc. HOLD TIME; CAPS: 45° TRUNCATED 7.0 mm TIP
* = WELDED WITHOUT STABILIZATION
VALIDATED CURRENT TEST IS AT LEAST 66 GOOD WELDS OUT OF 68 WELDS WITHOUT STABILIZATION
** = 400 AMPS LOWER THAN EXPULSION, ALSO TEST RESULTS FOR THIS MATERIAL COMPLETED UNDER JOB # 1768
***= REQUIRED CONDITIONING WELDS TO ATTAIN BUTTON ON POINT EVALUATION TEST

Figure 33: Weld Schedule

Assembly Welding

Assembly fixtures were developed for fixturing the parts during welding (*Figure 34*). The existing parts from the donor vehicle were removed and the new AHSS parts were retrofitted into the vehicle using the weld schedules and weld patterns developed earlier (*Figure 35*).



Figure 34: Weld Fixtures



Figure 35: Rail Assembly

11. Testing

The AHSS rail and bumper design was validated by conducting an NCAP 35mph rigid barrier impact test at Transportation Research Center, Ohio (22).

The bumper and the front section of the rails crushed completely and there was no significant deformation of the A-Pillar, B-Pillar, roof rails and rail extension rear (*Figure 36* through *Figure 42*).

The B-pillar acceleration peak of the new *AHSS Design* was lower than that of the *Baseline Design* (*Figure 43*, *Figure 44*). However, the time-to-stop of the new *AHSS Design* was longer than that of the *Baseline Design.*

There were two observations related to the condition of the *Test Vehicle*.

- The test vehicle had been driven prior to the test.
- Engine and engine mounts from a previously crashed vehicle were used in the *Test Vehicle*.

Overall, the new *AHSS Design had an NCAP performance similar to that of the Baseline Design.*



Figure 36: NCAP Test - LH Side View



Figure 37: NCAP Test - Front View

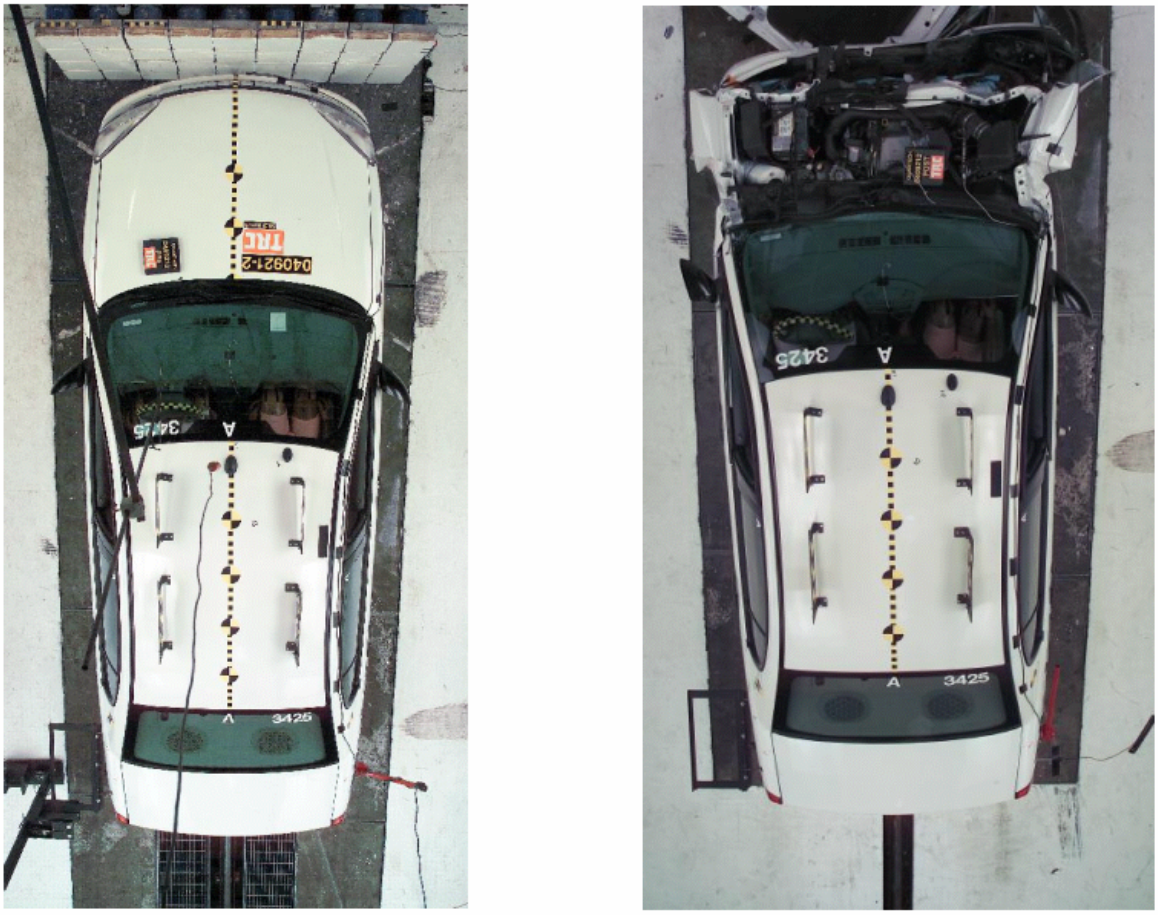


Figure 38: NCAP Test - Top View



Figure 39Figure 38: NCAP Test - Underbody View



Figure 40: NCAP Test - Bumper



Figure 41: NCAP Test - Bumper Close-up

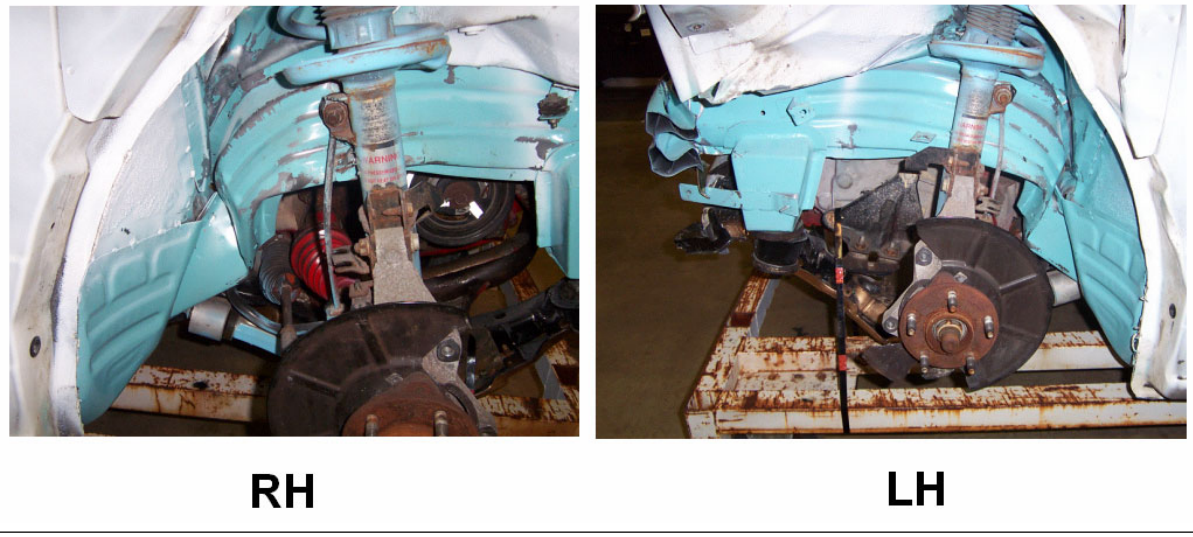


Figure 42: NCAP Test - Front Rails

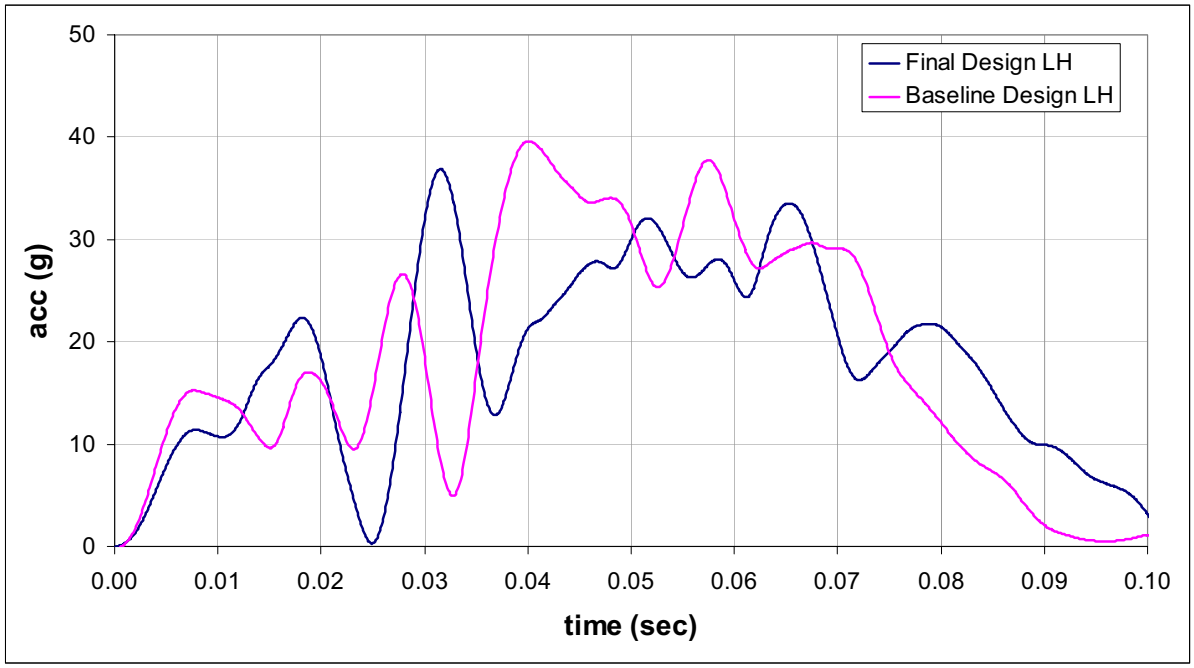


Figure 43: NCAP Test - LH B-Pillar Acceleration Pulse

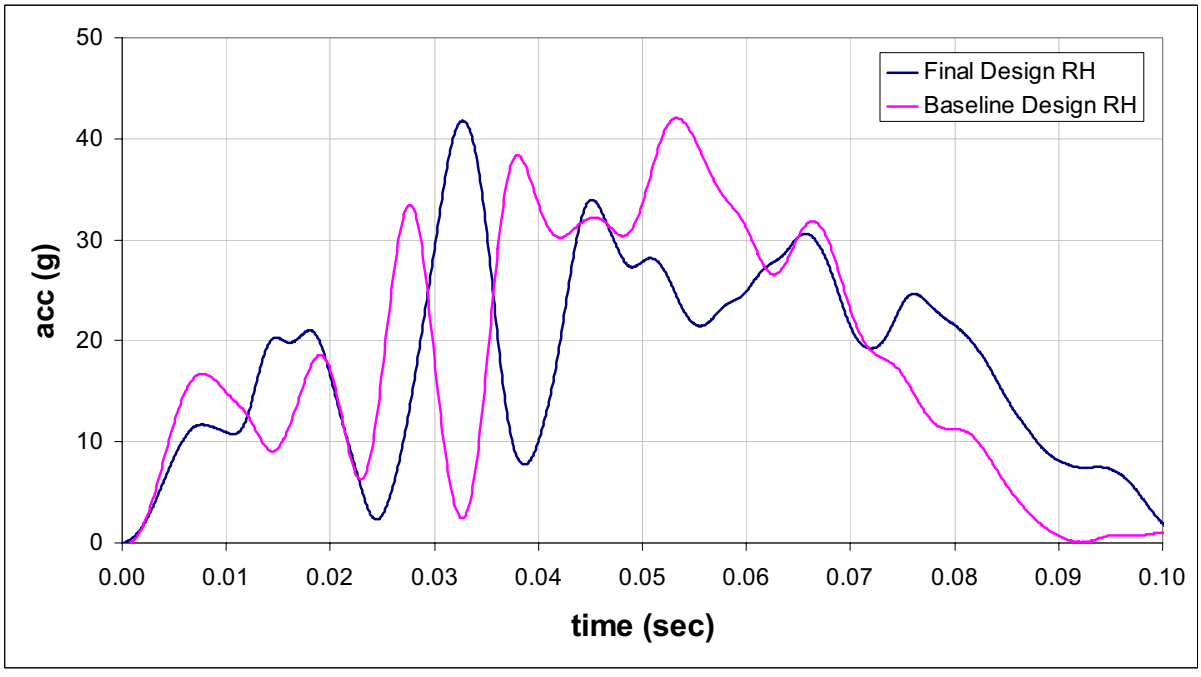


Figure 44: NCAP Test - RH B-Pillar Acceleration Pulse

12. Conclusions

Front rails and bumper were designed and fabricated using ***Advanced High Strength Steels*** (DP800 and DP980). The ***AHSS Design*** achieved a mass reduction of **8.77kg (22.36%)** compared to the *Baseline Design*. The performance of the *AHSS Design* was similar to that of the *Baseline Design*. The *AHSS Design* was validated by conducting an **NCAP** 35mph rigid barrier impact test on the donor vehicle fitted with the AHSS rails and bumper.

It can be concluded that the use of AHSS in conjunction with effective part design can result in significant mass reductions in crash applications. Priority should be given to design stability and load path, as opposed to maximizing sections. Parts can be manufactured using DP800 and DP980 steels, provided due attention is given to manufacturing constraints early in the design process.

13. References

1) *Laboratory Test Procedure for New Car Assessment Program (NCAP), September 1996,* NHTSA.

2) *Offset Barrier Crash Test Protocol (Version IX), October 2002,* IIHS.

3) *FMVSS Part 581 Bumper Standard,* NHTSA.

4) *Milestone Reports,* SPHINX, Phase I.

14. Appendix A: FE Model

Model Mass	1.778 tons

Model mass is from LS-DYNA3D d3hsp file.

The nodes at which the desired NCAP and IIHS outputs were obtained are listed in *Table 17*.

The intrusions are measured at the nodes as specified in *Reference 3*.

The acceleration and intrusion node locations are shown in *Figure 45* and *Figure 46* below.

Table 17: Summary of Output Locations

Parameter	Location	Node Number
Accelerations	B-Pillar / Rocker - LH	5000001
	B-Pillar / Rocker - RH	5000002
Intrusions	Origin	6000000
	Plane Y-axis	6000001
	Plane Z-axis	6000002
	Steering Column	7000001
	Brake Pedal	7000002
	Toepan - Left	7000003
	Toepan - Center	7000004
	Toepan - Right	7000005
	Left Front Seat Bolt	7000006
	Right Front Seat Bolt	7000007
	Left Rear Seat Bolt	7000008
	Right Rear Seat Bolt	7000009
	AB Closure - A Pillar	7000010
	AB Closure - B Pillar	7000011

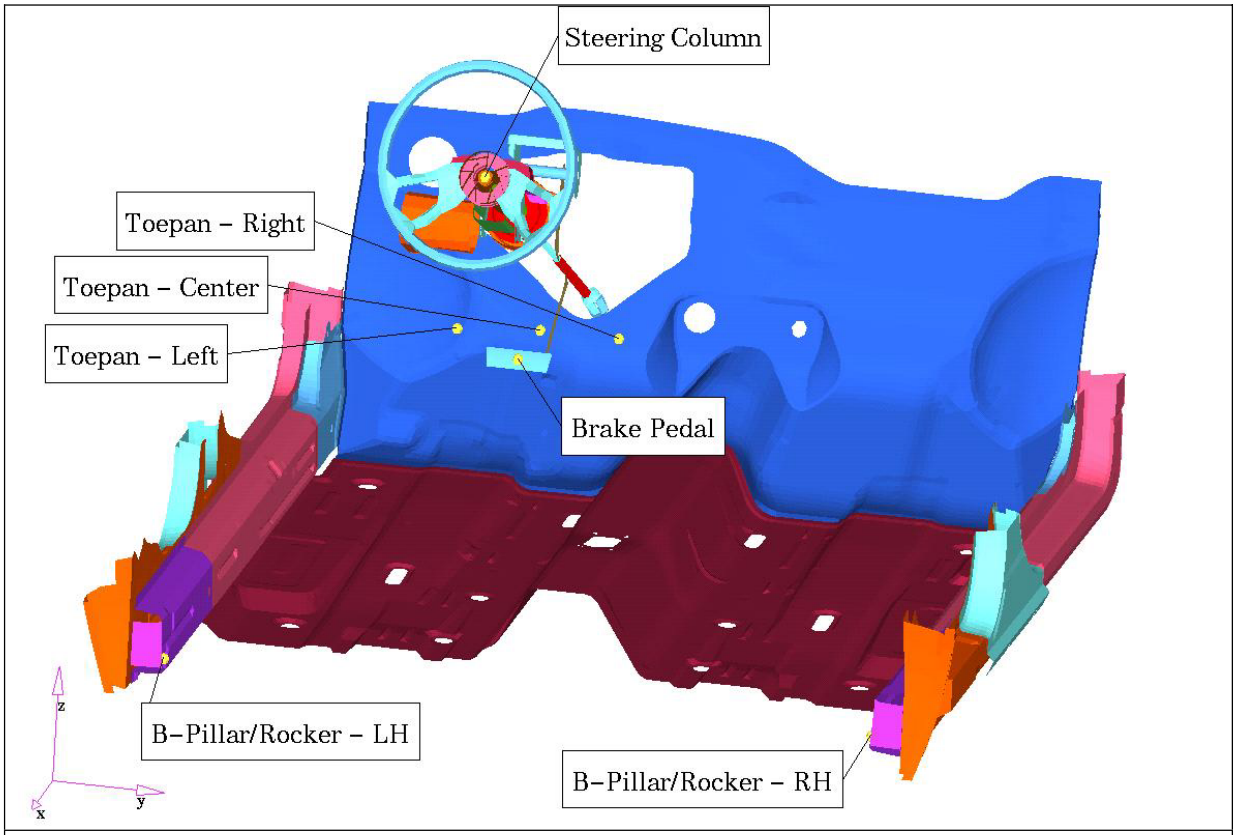


Figure 45: Output Locations for NCAP/IIHS



Figure 46: Output Locations for IIHS- AB Closure

15. Appendix B: Milestone Reports

1) *Preliminary Subsystem Design, Milestone 1*, SPHINX, Phase II.
2) *Competitive Benchmarking, Milestone 2*, SPHINX, Phase II.
3) *Rail Concept Development, Milestone 3*, SPHINX, Phase II.
4) *Validated FE Models, Milestone 5*, SPHINX, Phase II.
5) *Enhanced FE Models, Milestone 6*, SPHINX, Phase II.
6) *DOE FE Models, Milestone 7*, SPHINX, Phase II.
7) *Concept 1 Subsystem Design, Milestone 8,* SPHINX, Phase II.
8) *Concept 1: Preliminary Design, Milestone 10*, SPHINX, Phase II.
9) *Concept 1: DOE, Milestone 11*, SPHINX, Phase II.
10) *Concept 1: Final Design, Milestone 12*, SPHINX, Phase II.
11) *Concept 2: Preliminary Design, Milestone 13*, SPHINX, Phase II.
12) *Concept 2: DOE, Milestone 14*, SPHINX, Phase II.
13) *Concept 2: Final Design, Milestone 15*, SPHINX, Phase II.
14) *Concept 3: Preliminary Design, Milestone 16*, SPHINX, Phase II.
15) *Concept 3: DOE, Milestone 17*, SPHINX, Phase II.
16) *Concept 3: Final Design, Milestone 18*, SPHINX, Phase II.
17) *Bumper Formability, Milestone 19*, SPHINX, Phase II.
18) *NCAP DOE Response Surface, Milestone 20*, SPHINX, Phase II.
19) *IIHS DOE Response Surface, Milestone 21*, SPHINX, Phase II.
20) *Final Optimized Design, Milestone 22*, SPHINX, Phase II.
21) *Analysis of Vehicle with New Rail System, Milestone 34*, SPHINX, Phase II.
22) *NCAP Test Results of Vehicle with New Rails and Bumper*, *Milestone 35*, SPHINX, Phase II.
23) *Correlation of Vehicle with New Rails and Bumper, Milestone 36*, SPHINX, Phase II.
24) *Final KB: Proteus Version 4, Milestone 39*, SPHINX, Phase II.
25) *Final Report, Milestone 44*, SPHINX, Phase II.
26) *Static/Dynamic Stiffness DOE FE Models, Milestone 45*, SPHINX, Phase II.
27) *Static Stiffness DOE Response Surface, Milestone 46*, SPHINX, Phase II.

28) *Dynamic Stiffness DOE Response Surface, Milestone 47*, SPHINX, Phase II.

29) *Geometric Tolerance and Dimensional Analyses, Milestone 48*, SPHINX, Phase II.

30) *Rollout of Application Methodology, Milestone 49*, SPHINX, Phase II.

16. Appendix C: A/SP Reports

A/SP Enabling Groups generated the following reports.

1) *Manufacturing Feasibility Report, Stamping Group.*

Preliminary Subsystem Design

Milestone 1

Lightweight Front End Structure Phase II

December 17, 2002



Auto/Steel Partnership

Abstract

This report documents the preliminary design of a subsystem that can simulate the NCAP performance of a full vehicle finite element model, in the first 40ms. The subsystem predicts accurately the full vehicle response in the first 40 ms of the NCAP load case, and achieves a 50% reduction in the simulation time. The subsystem achieves the same crush pattern for rail and bumper, as in the full vehicle. The subsystem will be employed to assess various rail and bumper concepts developed in Phase II of the Lightweight Front End Structure Project.

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1. Objectives

The goal of this study is to design a subsystem that can simulate the NCAP performance of a full vehicle finite element model, in the first 40ms. The subsystem should predict accurately the full vehicle response in the first 40 ms of the NCAP load case, and also reduce the simulation time significantly. The subsystem should achieve the same crush pattern for rail and bumper, as in the full vehicle. The subsystem will be employed to assess various rail and bumper concepts developed in Phase II of the Lightweight Front End Structure Project.

2. Results Summary

It was concluded from the study that the following subsystem design (*Figure 1*) would predict accurately the full vehicle response in the first 40 ms of the NCAP load case (*Figure 3* through *Figure 19*, *Table 2* and *Table 3*), and also reduce the simulation time by 50%.

- **All parts forward of A-pillar**
  - Bumper
  - Rail Assembly
  - Shotgun & Fender
  - First Cross Member
  - Cradle Assembly
  - Engine, Battery and Radiator

- **A-pillar**
  - Rocker portion, to simulate tire hit
  - Upper A-pillar, for connecting shotgun, dash panel and IP cross member

- **Dash area**
  - Dash panel
  - IP cross member
  - Floor, up to B-pillar
  - Floor cross members

A rigid body with equivalent inertia properties represents the parts not included in the subsystem. Data collection points in the subsystem are identical to those in the full vehicle model.

This subsystem corresponds to level 2a in *Table 1*

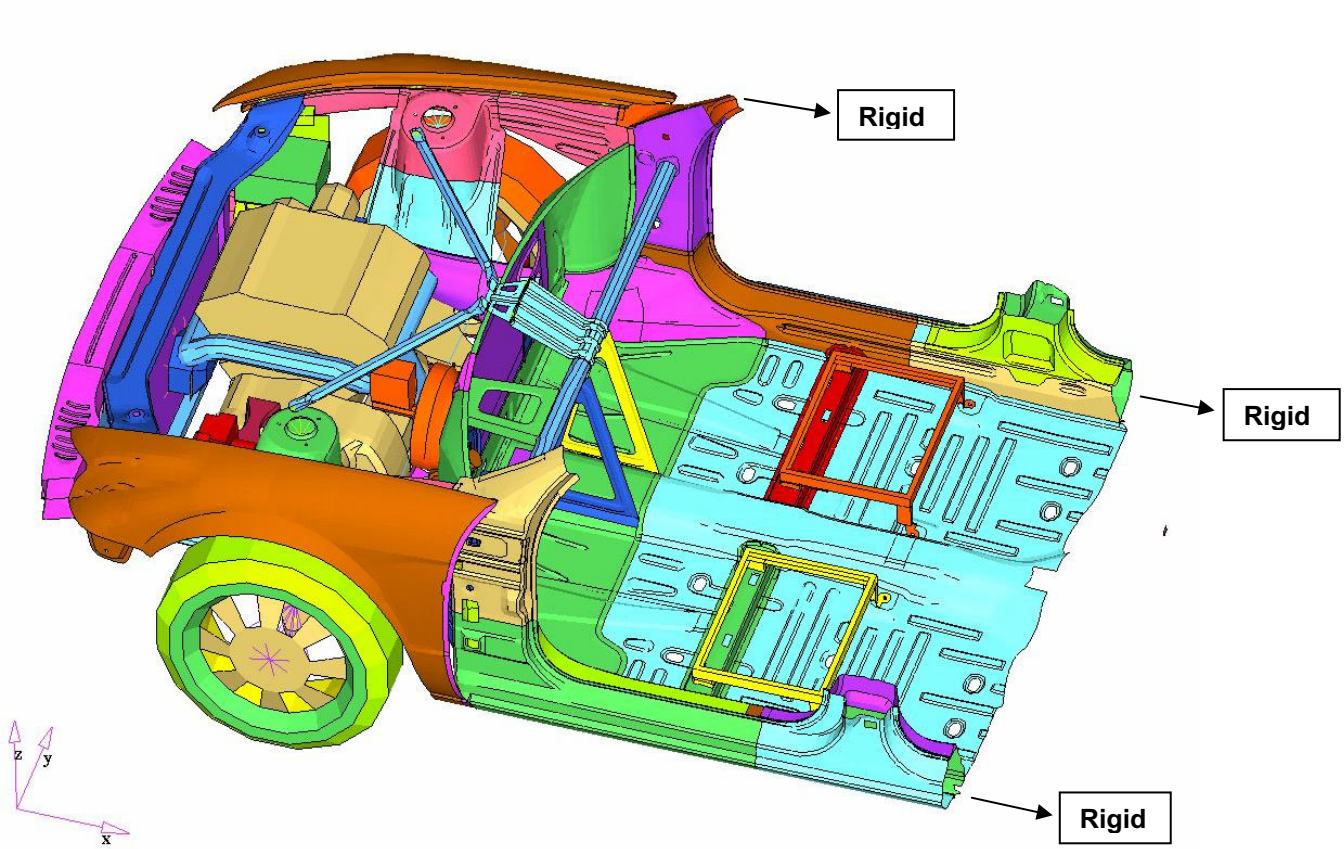


Figure 1: Subsystem of Design 0 (Baseline Upgraded Powertrain)

3. Subsystem Development

The Upgraded Powertrain architecture (Ref. 1) served as the basis for developing the subsystem design. This architecture is similar to the architectures existing in several OEM vehicles. Three design versions (Ref. 3) of the Upgraded Powertrain were used to develop and verify the subsystem concept.

1. Baseline Design 0 (*Figure 2*)

2. Design 5

3. Optimized Design 8

The subsystem accurately predicted the full vehicle NCAP performance in the first 40 ms, for all the three designs (*Figure 15, Figure 16, Figure 17*). The three designs had diverse NCAP responses. Hence, there is a considerable confidence in the subsystem concept for predicting the NCAP performance of a typical OEM vehicle.

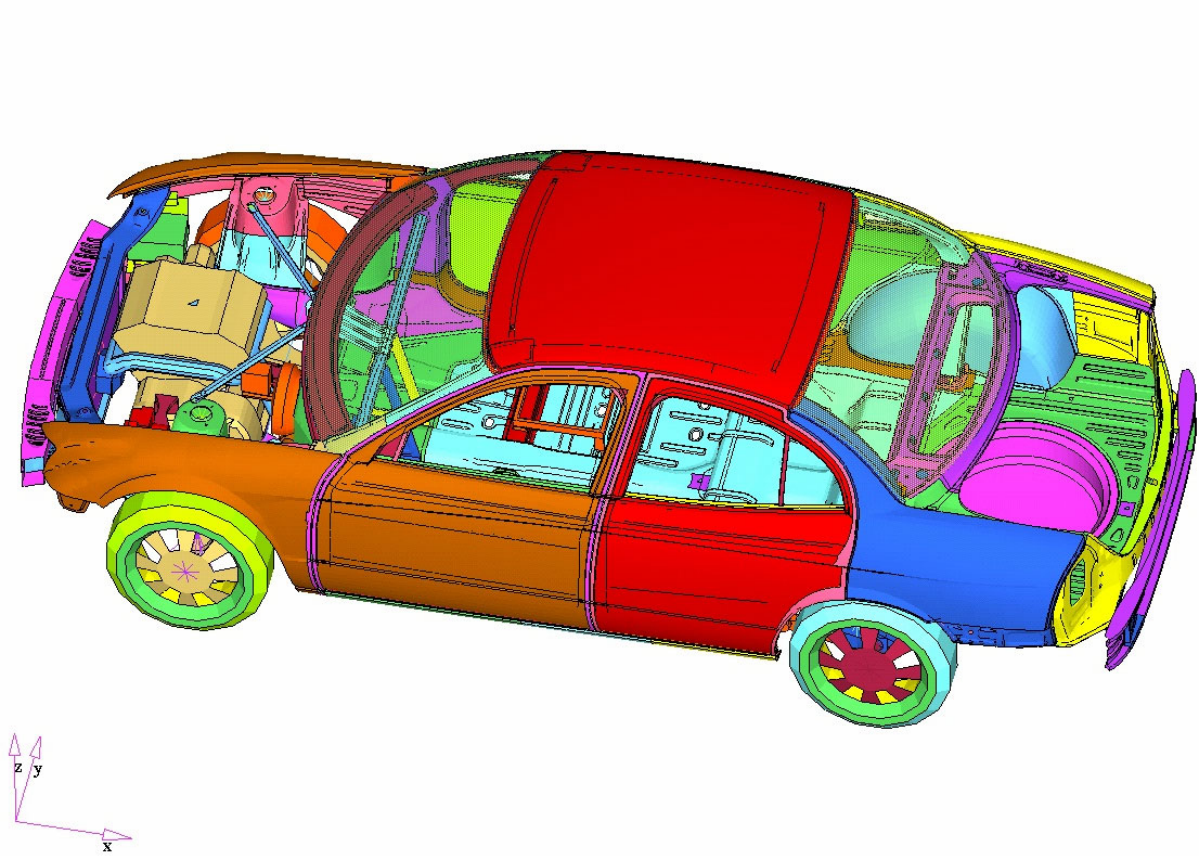


Figure 2: Full Vehicle Model of Design 0 (Baseline Upgraded Powertrain)

The following levels of subsystem were considered for the design development (*Table 1*).

1. Level 1
2. Level 2a with rocker and dash panel
3. Level 2b without rocker/dash
4. Level 3
5. Level 4
6. Level 5

The accuracy of the subsystem decreases and the simulation increases, as the level of the subsystem increases (*Figure 3, Figure 4*). Since the subsystem design is to be employed only for simulation, and not for actual crash testing, it was determined that **Level 2a** design was the **optimum subsystem**. It predicted accurately the full vehicle response in the first 40 ms of the NCAP load case, and also reduced the simulation time by 50%. Level 4 represents the limit of simplification, as any level higher than Level 4 cannot predict NCAP performance in the first 40ms.

Table 1: Description of Subsystem Levels

Level	Description	Model size	Relative Run Time
Baseline	Full Vehicle Model	Elements 252359, Nodes 215347	1.00
1	Parts rearwards of B-Pillar are removed (half vehicle).	Elements 151570, Nodes 135012	0.58
2a	**With Dash panel- Parts rearwards of A-pillar are removed.**	**Elements 140110, Nodes 122288**	**0.53**
2b	Without Dash panel- Parts rearwards of A-pillar are removed.	Elements 91682, Nodes 86277	0.37
3	Level 2b without Dash panel+ Front Tires and suspensions are removed.	Elements 87163, Nodes 81648	0.34
4	Level 3 + Radiator and Battery are removed.	Elements 84613, Nodes 77786	0.32
5	Level 4 + Shotgun and Radiator mounting cross member are removed.	Elements 68919, Nodes 57670	0.23

Level 4 subsystem is the simplest subsystem that can yield meaningful comparison with the full vehicle model response (*Figure 3, Figure 4*). All of the important front-end parts are retained in Level 4. Level 5 subsystem, which has the shotgun and radiator removed, fails to predict the second and third peaks.

Level 2a captures the load path into the rocker, floor and hinge pillar quite accurately. The effects of engine and tire hit are simulated well, along with the distribution of load into the floor through the rail

extension. The deformation of the bumper and rails (*Figure 5* through *Figure 12*) are predicted very well by the subsystem.

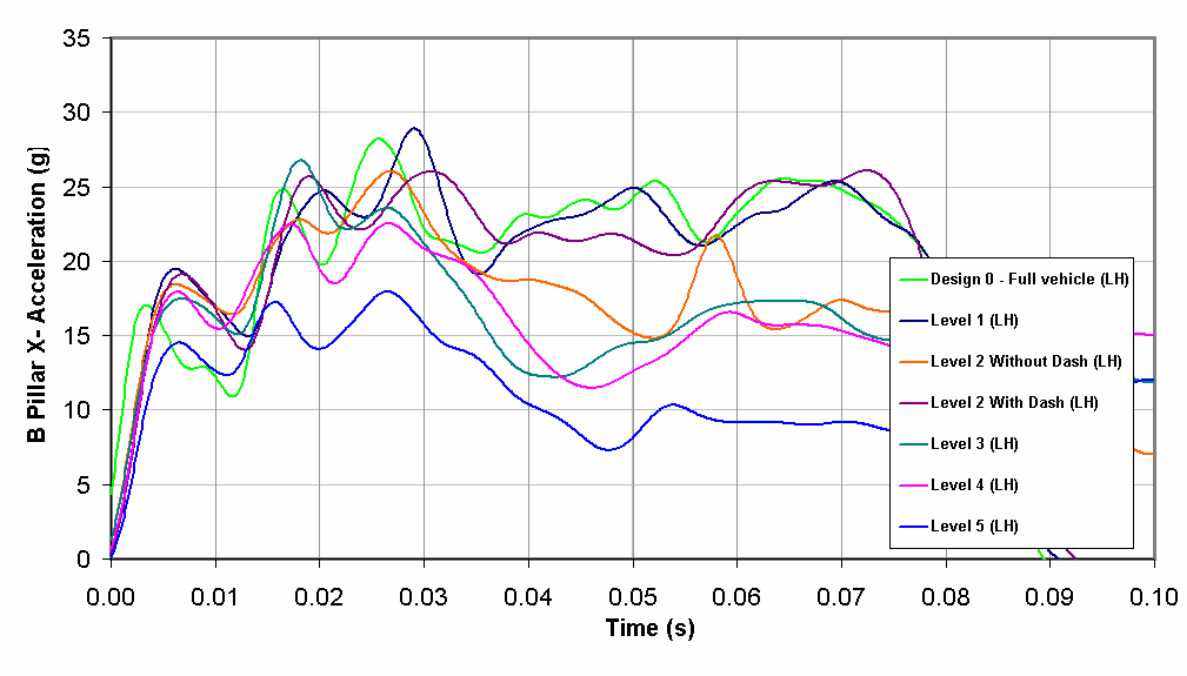


Figure 3: LH B-Pillar Pulse of Full Vehicle Model and Subsystems (Design 0)

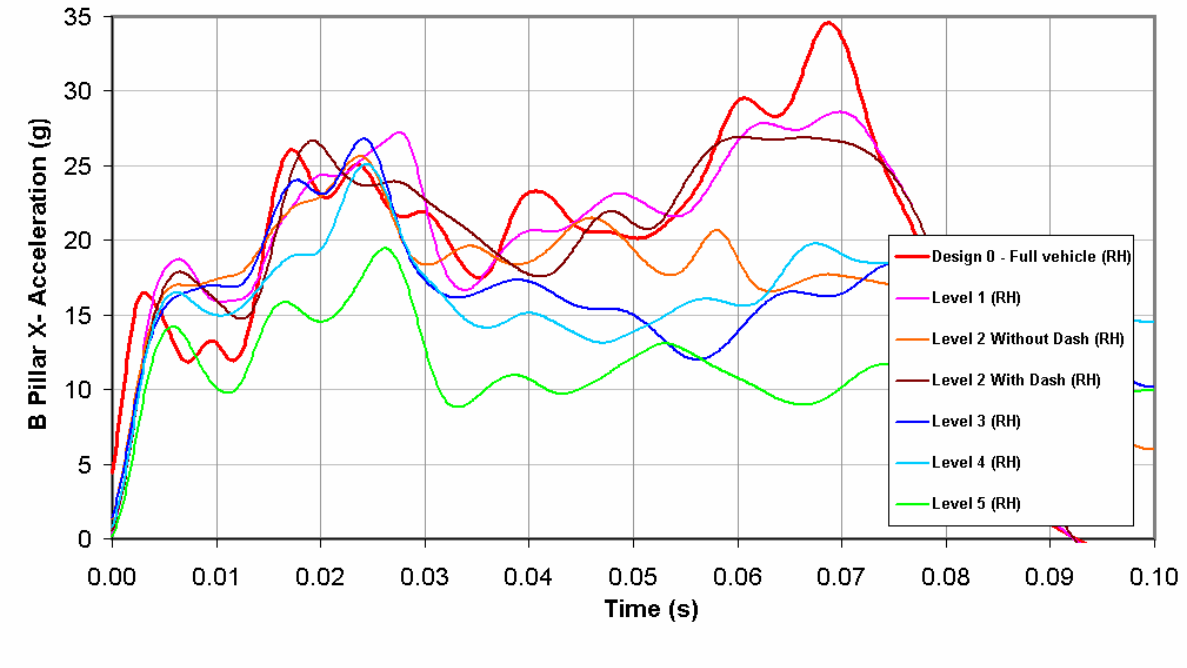


Figure 4: RH B-Pillar Pulse of Full Vehicle Model and Subsystems (Design 0)

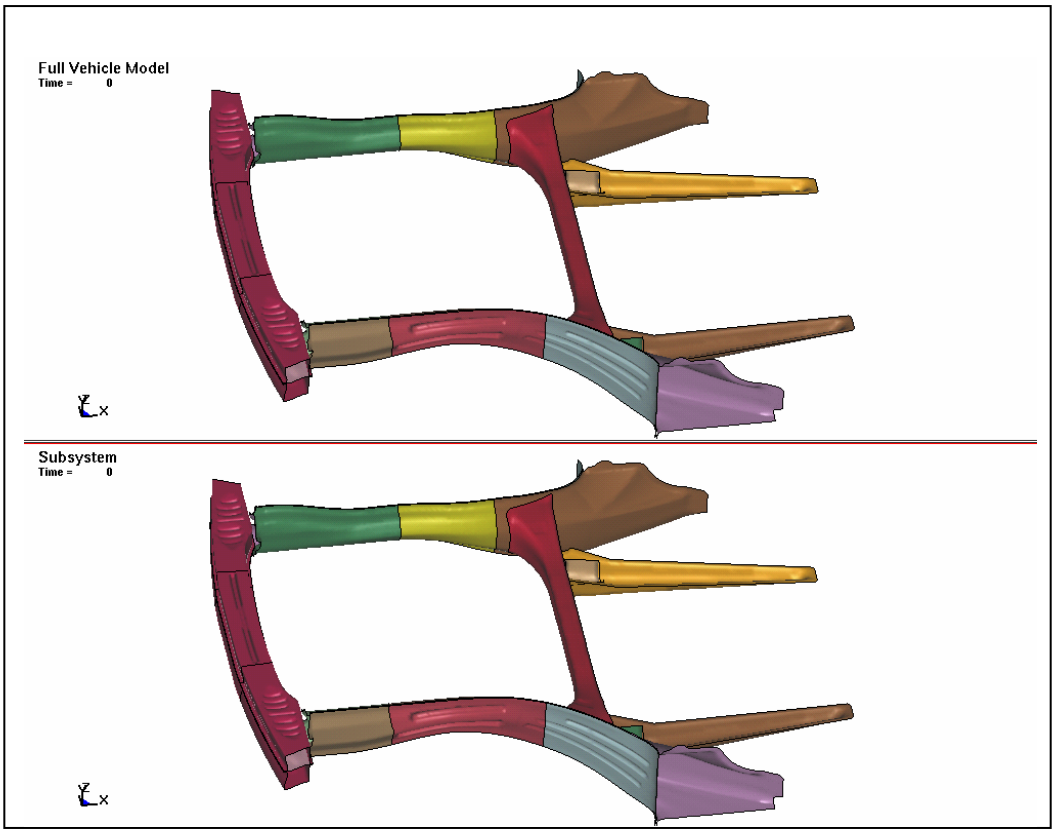


Figure 5: Rail Deformations at 0ms: Design 0 Subsystem Level 2a

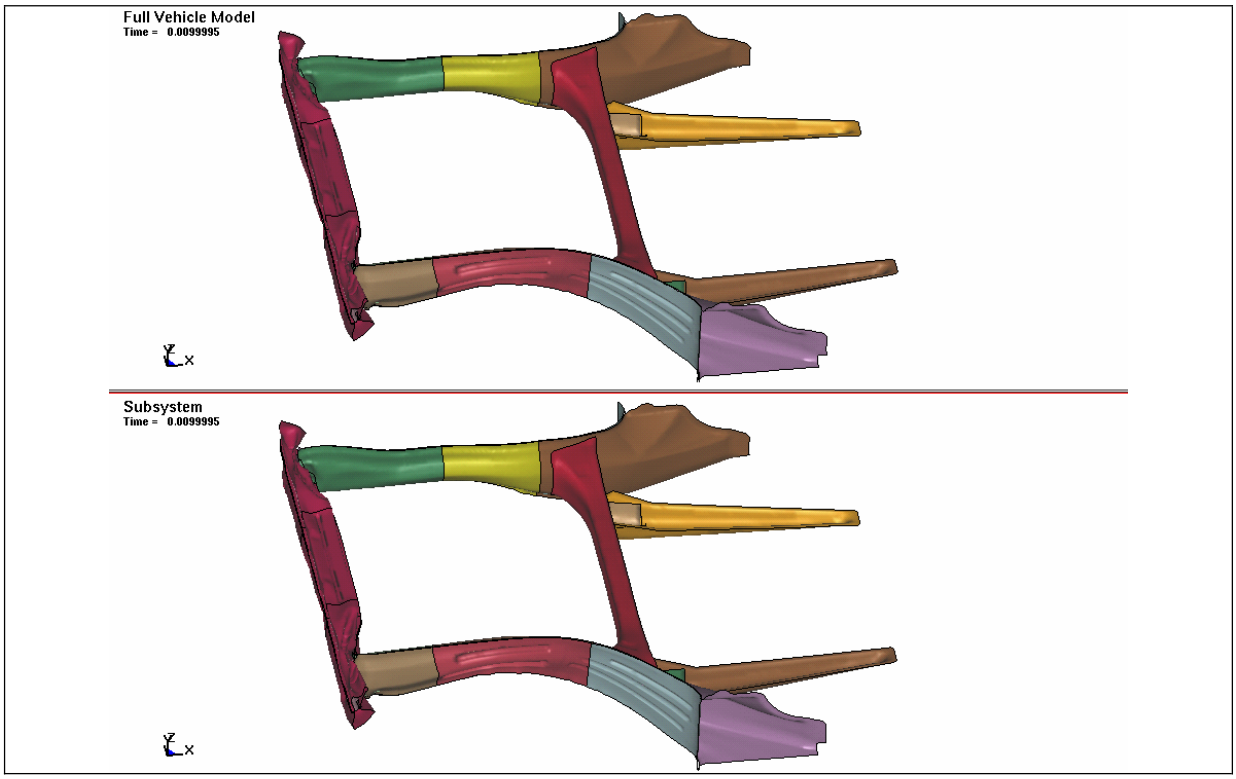


Figure 6: Rail Deformations at 10ms: Design 0 Subsystem Level 2a

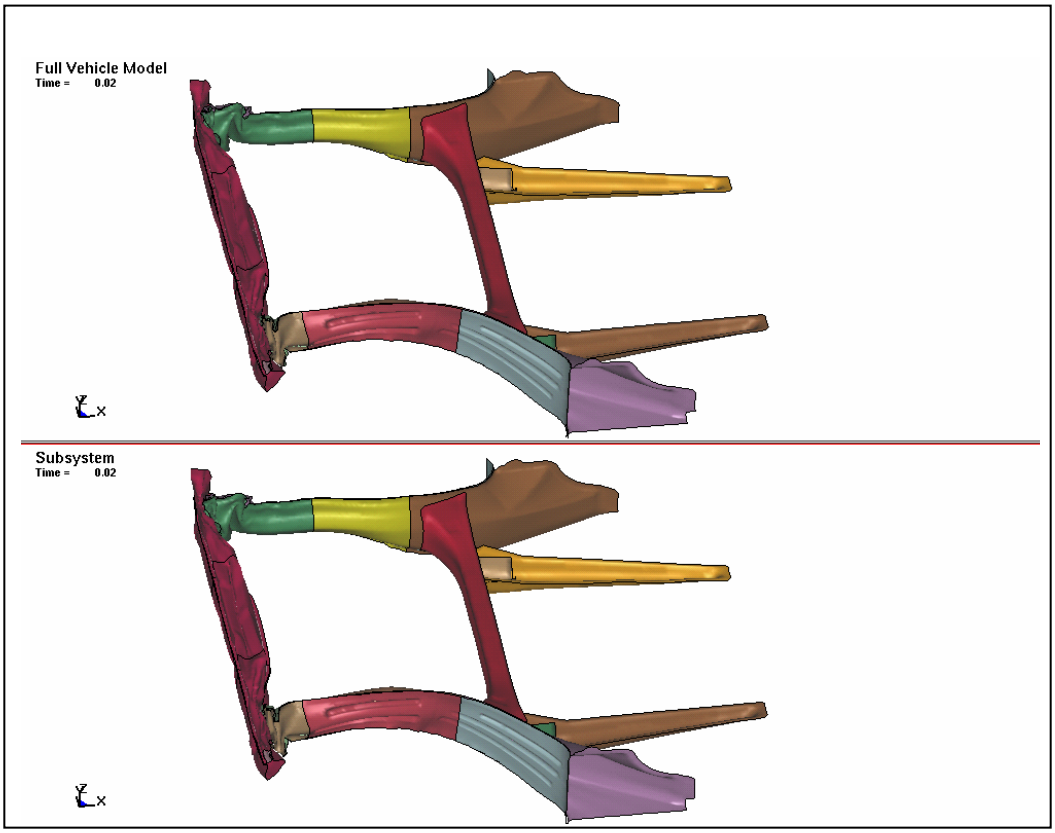


Figure 7: Rail Deformations at 20ms: Design 0 Subsystem Level 2a

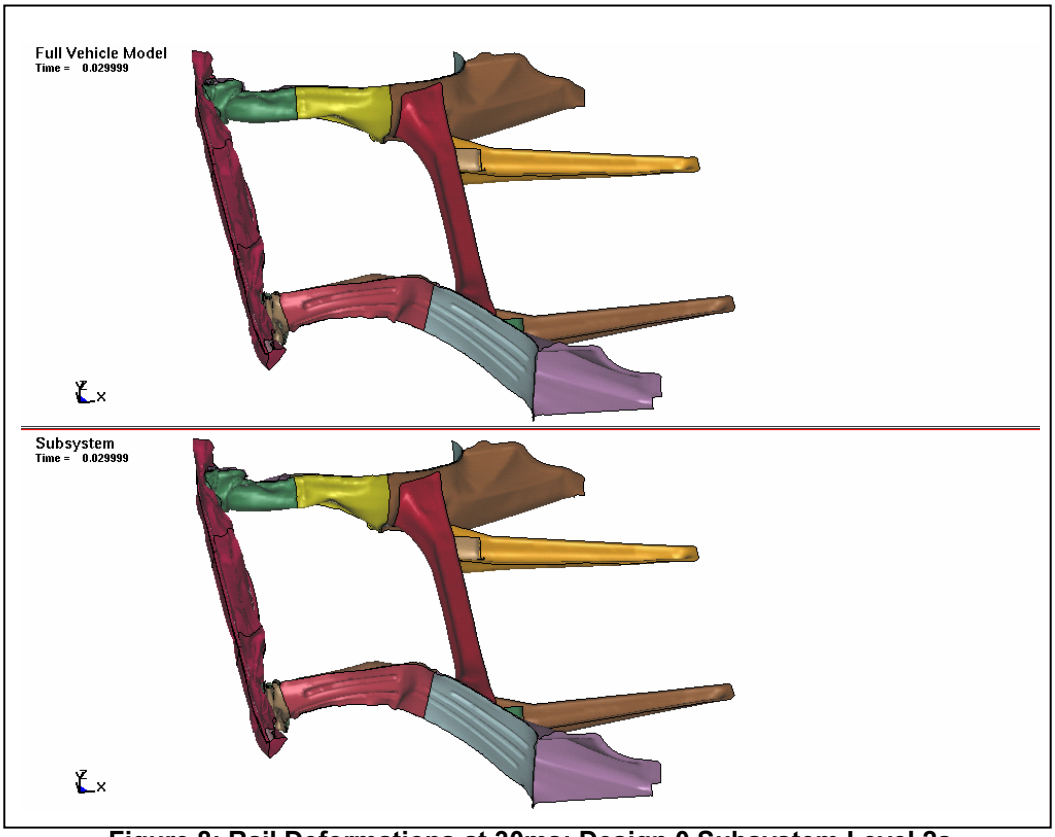


Figure 8: Rail Deformations at 30ms: Design 0 Subsystem Level 2a

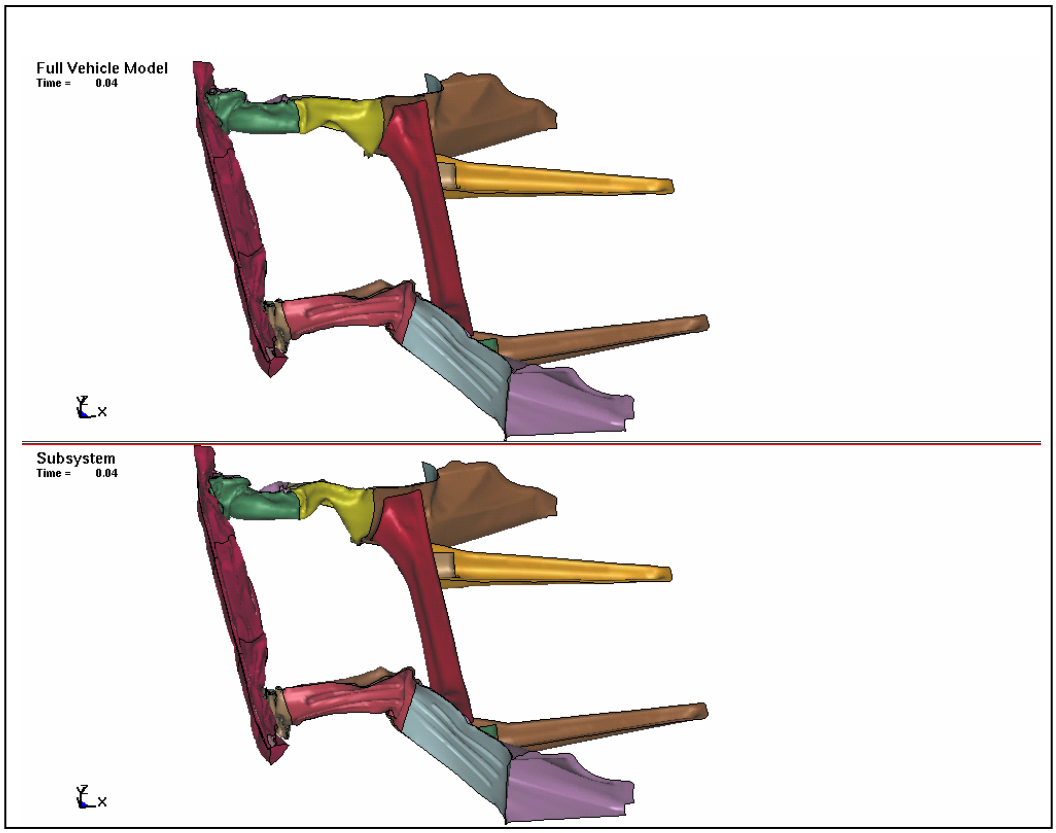


Figure 9: Rail Deformations at 40ms: Design 0 Subsystem Level 2a

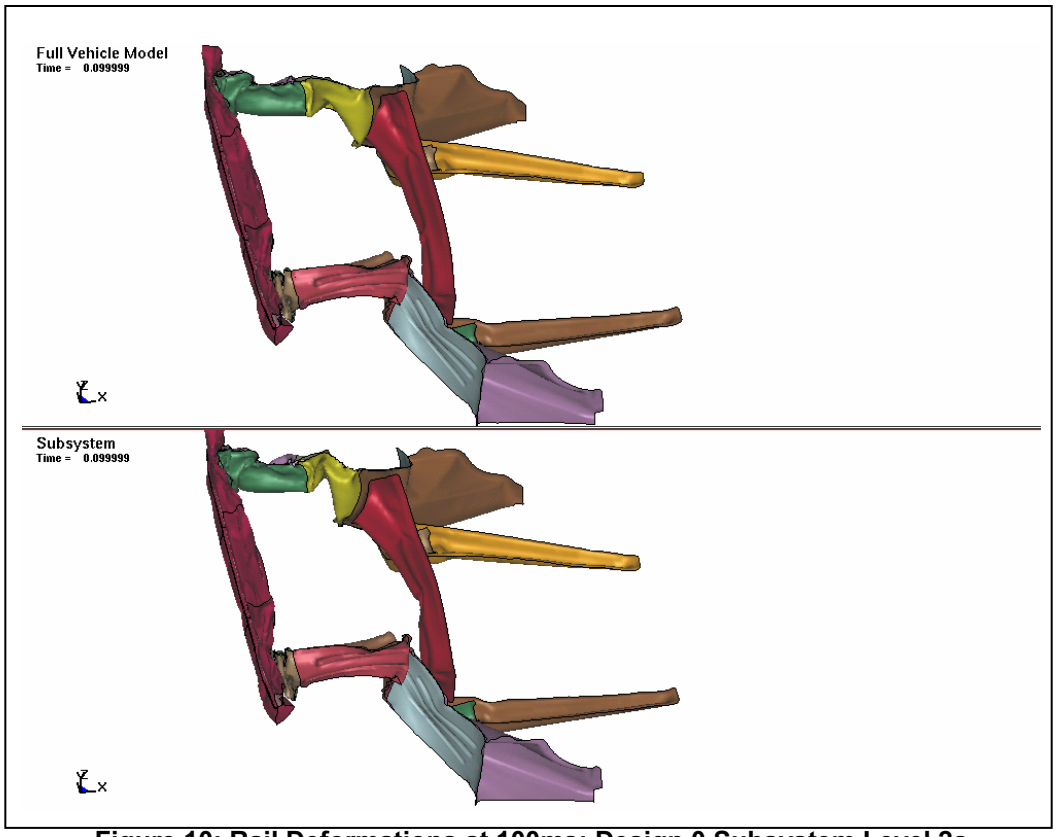


Figure 10: Rail Deformations at 100ms: Design 0 Subsystem Level 2a

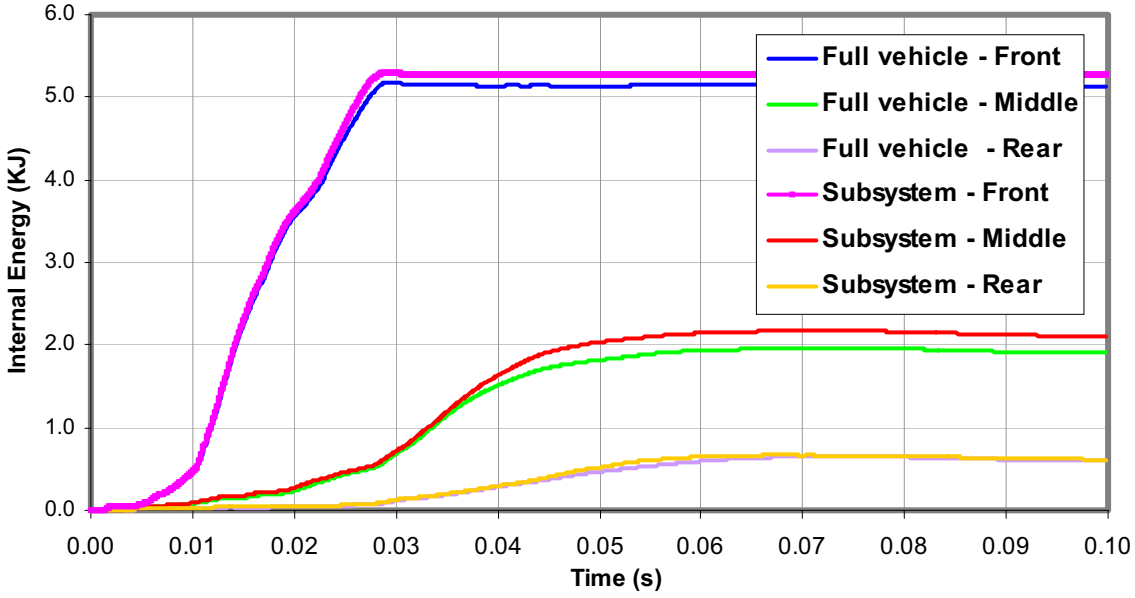


Figure 11: Internal Energy of LH Outer Rails: Design 0 Full Vehicle and Subsystem Level 2a

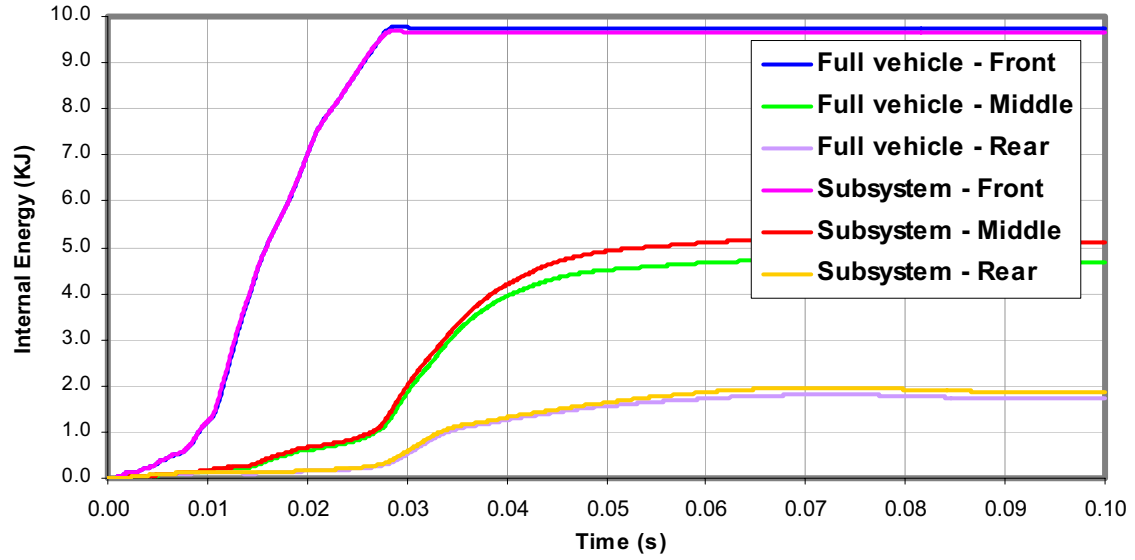


Figure 12: Internal Energy of LH Inner Rails: Design 0 Full Vehicle and Subsystem Level 2a

3.1. Design 0

This design served as the basis of all studies on the Upgraded Powertrain (Ref 1).

3.2. Design 5

This design had the same topological levels as the baseline design, but different levels of grades and gauges. It was one of the designs obtained by the computer-aided optimization of the response surfaces obtained from the D.O.E. study (Ref. 3).

3.3. Design 8

This design had increased rail length and shotgun width, as compared to the baseline design, in addition to different levels of grades and gauges. It was the final optimized design obtained by the computer-aided optimization of the response surfaces obtained from the D.O.E. study (Ref. 3).

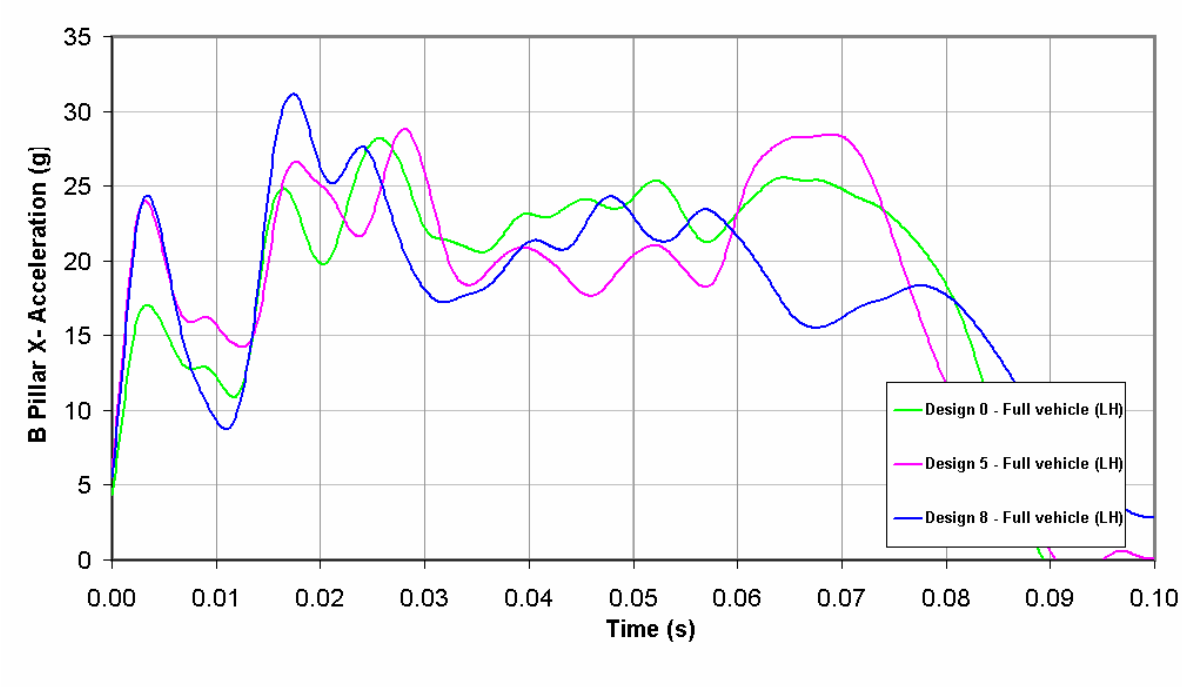


Figure 13: LH B-Pillar Pulse of Full Vehicle Models

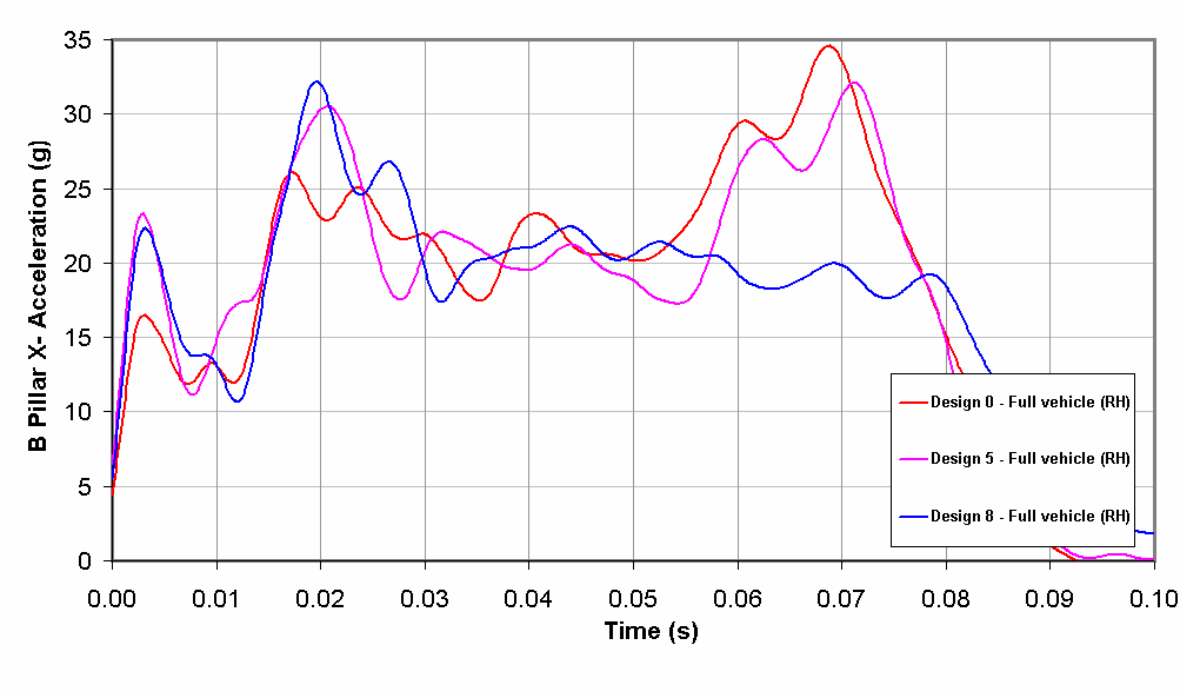


Figure 14: RH B-Pillar Pulse of Full Vehicle Models

4. Subsystem Comparison

The Level 2a subsystems predict the NCAP response fairly accurately for all the three designs. There is an excellent correlation of vehicle crush between the full vehicle and subsystem models (*Table 3*). The B-pillar pulse prediction is quite accurate as well (*Table 2, Figure 15, Figure 16, Figure 17*).

The first peak is the most accurately predicted peak. There is a slight delay and over-prediction of the level of the first peak, for all the three designs. The first peak represents the initial deformation of the bumper system.

The second peak is also predicted fairly accurately for all the three designs. No generalization can be made about the peak phase or level, as compared to the full vehicle response.

The third peak level is not predicted as accurately as the first and second peaks. However, the essential character of the pulse is predicted reasonably well. Design 8 pulse does not possess a third peak. This is correctly predicted by the subsystem response.

The subsystems yield reasonable predictions of the vehicle response after 40 ms. For Designs 0 and 5, the rise in pulse after 50ms is predicted correctly by the subsystems. The pulse decreases continuously for Design 8, after 50ms. This is indeed predicted quite well by the subsystem.

The pulse prediction is the best for Design 8. A possible explanation is that in Design 8, the engine does not hit the 1st cross-member. Hence, the effect of hinge pillar, dash and floor is the least for Design 8. This is also suggests a good front-end design – one in which the engine hit is avoided.

Table 2: Comparison of B-Pillar Peak Accelerations: Full Vehicle vs. Subsystem Level 2a

Design	Location	Model	B -Pillar Pulse (g)		
			First Peak	Second Peak	Third Peak
Design 0	LH *(Figure 15)*	Full vehicle	17 g @ 4 ms	25 g @ 17 ms	28 g @ 26 ms
		Subsystem	19 g @ 7 ms	26 g @ 19 ms	26 g @ 31 ms
	RH *(Figure 15)*	Full vehicle	16 g @ 4 ms	26 g @ 18 ms	25 g @ 24 ms
		Subsystem	18 g @ 7 ms	27 g @ 20 ms	24 g @ 28 ms
Design 5	LH *(Figure 16)*	Full vehicle	24 g @ 4 ms	27 g @ 18 ms	29 g @ 28 ms
		Subsystem	24 g @ 7 ms	27 g @ 20 ms	24 g @ 32 ms
	RH *(Figure 16)*	Full vehicle	23 g @ 3 ms	31 g @ 21 ms	22 g @ 31 ms
		Subsystem	23 g @ 6 ms	29 g @ 20 ms	23 g @ 34 ms
Design 8	LH *(Figure 17)*	Full vehicle	24 g @ 4 ms	31 g @ 18 ms	28 g @ 24 ms
		Subsystem	25 g @ 6 ms	30 g @ 19 ms	22 g @ 36 ms
	RH *(Figure 17)*	Full vehicle	22 g @ 4 ms	32 g @ 20 ms	27 g @ 27 ms
		Subsystem	23 g @ 6 ms	31 g @ 20 ms	22 g @ 37 ms

Table 3: Comparison of Vehicle Crush: Full Vehicle vs. Subsystem Level 2a

Design	Model	Vehicle Crush (mm)
Design 0	Full vehicle	647
	Subsystem	640
Design 5	Full vehicle	618
	Subsystem	611
Design 8	Full vehicle	625
	Subsystem	630

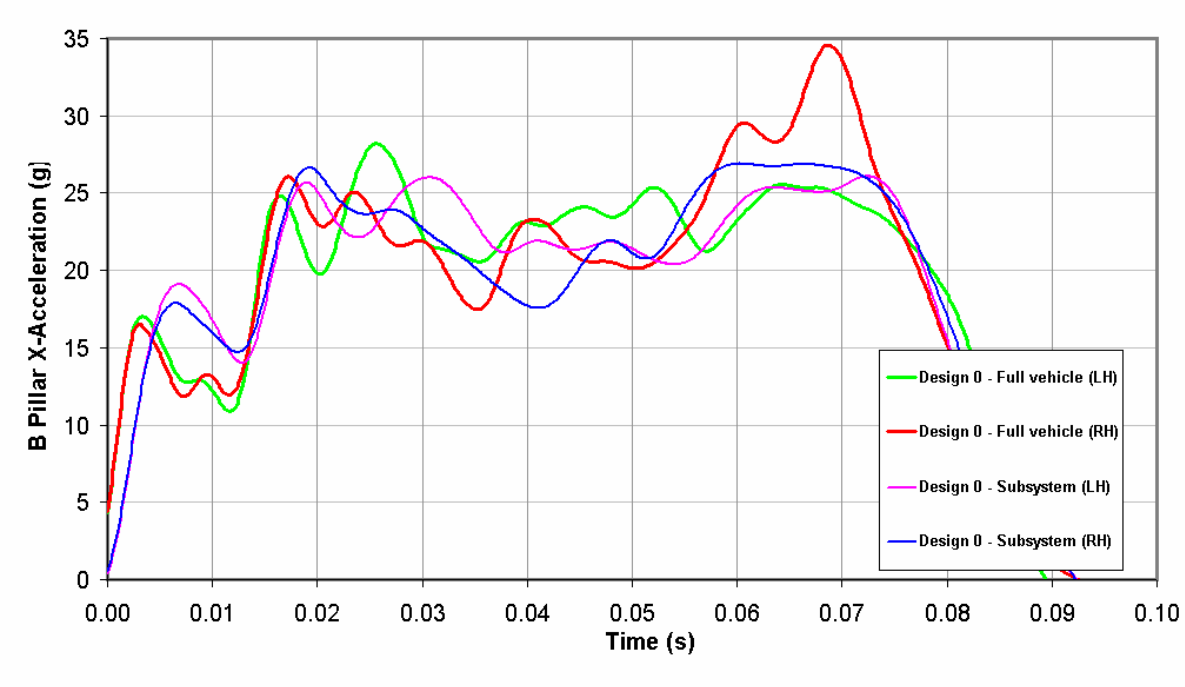


Figure 15: B-Pillar Pulse of Full Vehicle Model and Subsystem Level 2a (Design 0)

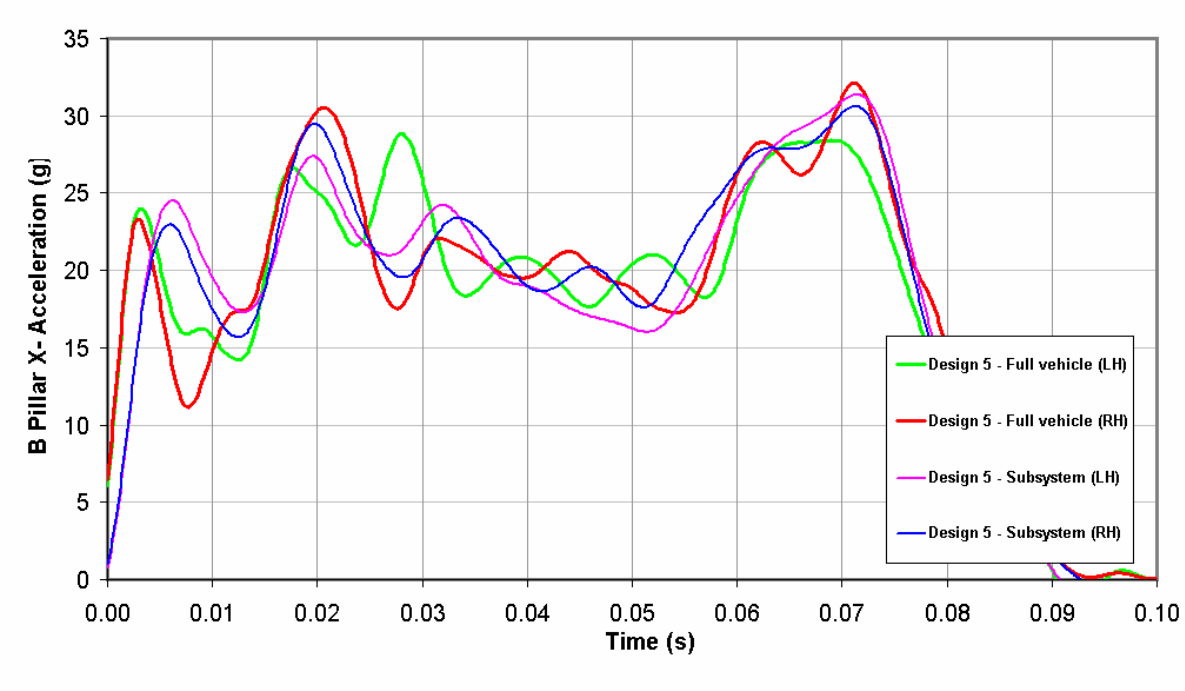


Figure 16: B Pillar Pulse of Full Vehicle Model and Subsystem Level 2a (Design 5)

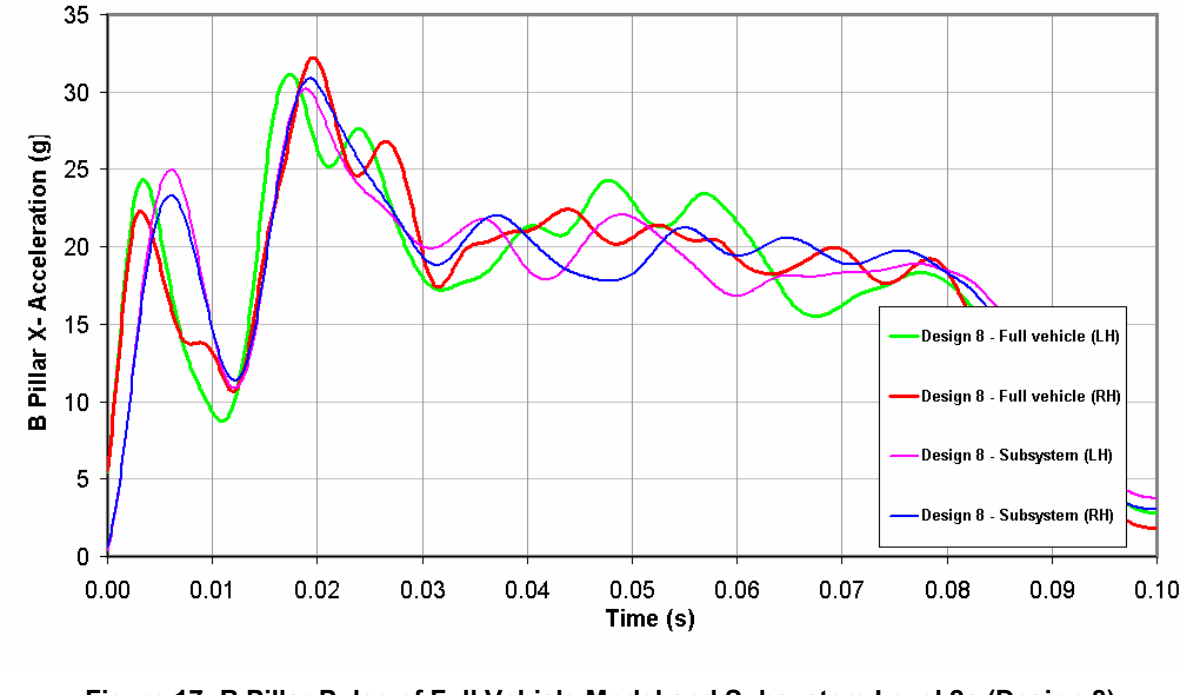


Figure 17: B Pillar Pulse of Full Vehicle Model and Subsystem Level 2a (Design 8)

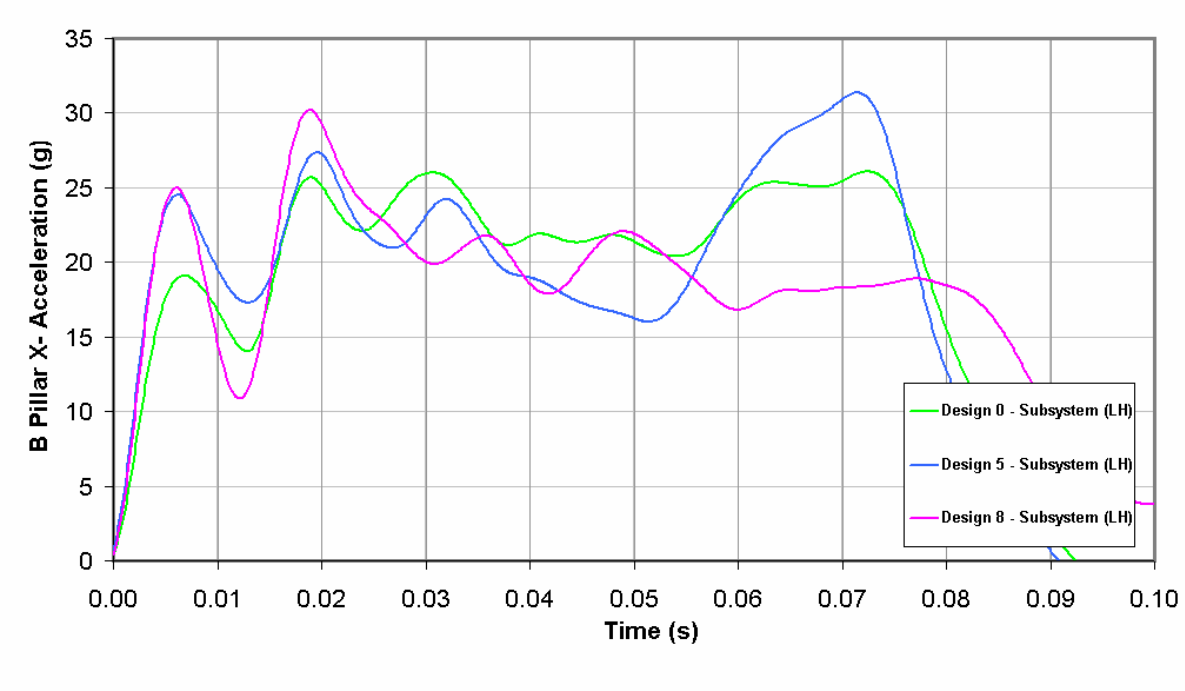


Figure 18: LH B-Pillar Pulse of Subsystems (Level 2a)

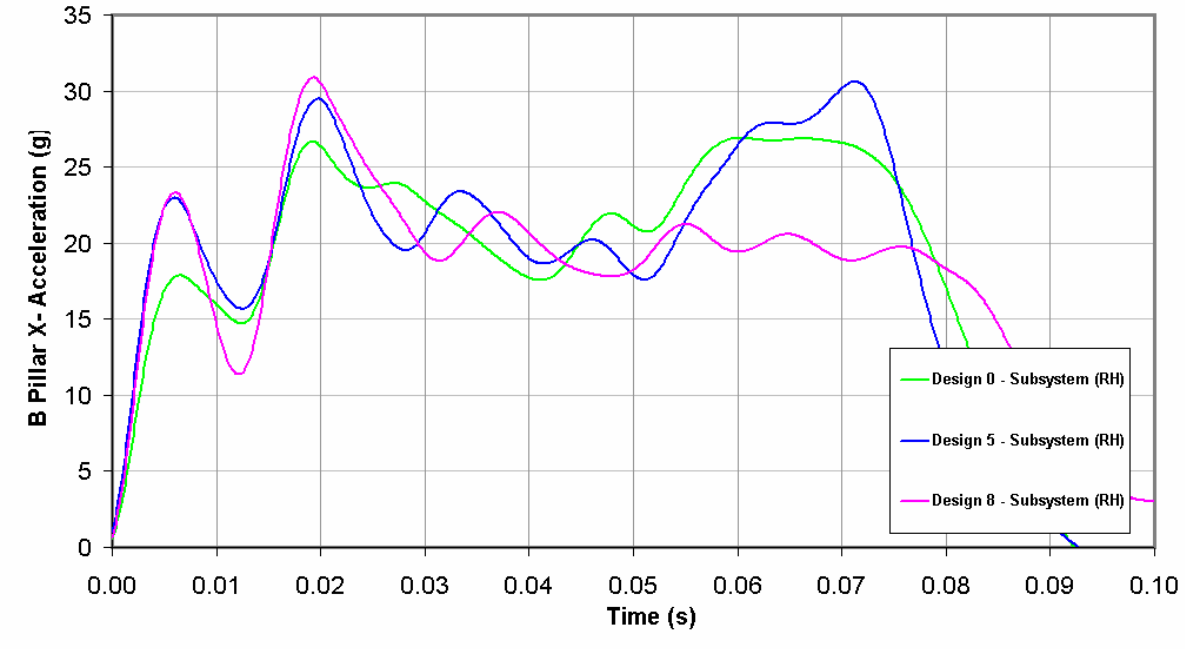


Figure 19: RH B-Pillar Pulse of Subsystems (Level 2a)

5. Conclusions

It was concluded from the study that the following subsystem design (*Figure 1*) would predict accurately the full vehicle response in the first 40 ms of the NCAP load case (*Figure 3* through *Figure 19*, *Table 2* and *Table 3*), and also reduce the simulation time by 50%.

- **All parts forward of A-pillar**
  - Bumper
  - Rail Assembly
  - Shotgun & Fender
  - First Cross Member
  - Cradle Assembly
  - Engine, Battery and Radiator

- **A-pillar**
  - Rocker portion, to simulate tire hit
  - Upper A-pillar, for connecting shotgun, dash panel and IP cross member

- **Dash area**
  - Dash panel
  - IP cross member
  - Floor, up to B-pillar
  - Floor cross members

A rigid body with equivalent inertia properties represents the parts not included in the subsystem. Data collection points in the subsystem are identical to those in the full vehicle model.

6. Future Work

The subsystem design developed in this study will be employed to create a subsystem for the OEM vehicle selected for the Phase II study. The subsystem will be employed to assess various rail and bumper concepts developed in Phase II of the Lightweight Front End Structure Project. The range of subsystems developed in this study would help understand the effect of distributing crash loads amongst the various load paths.

7. References

1) *ULSAB Model with Upgraded Powertrain, Milestone 14*, SPHINX, Phase I.

2) *Upgraded Powertrain: D.O.E. Parametric Study, Milestone 15*, SPHINX, Phase I.

3) *Library of Designs for KB: Upgraded Powertrain, Milestone 24*, SPHINX, Phase I.

8. Appendix A: Animations

The following animation files for the subsystem development can be viewed at the Auto/Steel Partnership website, www.a-sp.org.

You will need a Hyperview Player in order to view these animations at the site. You can download this free software at www.altair.com.

1. Design 0: Full Vehicle
2. Design 0: Subsystem Level 2a
3. Design 5: Full Vehicle
4. Design 5: Subsystem Level 2a
5. Design 8: Full Vehicle
6. Design 8: Subsystem Level 2a

Competitive Benchmarking

Milestone 2

Lightweight Front End Structure Phase II

January 17, 2003

Abstract

This report documents the study of rail designs and architectures of competitive vehicles with good NCAP and IIHS performance. The knowledge from this study will be useful in designing AHSS rails for the donor vehicle in Phase II of the Lightweight Front End Structure Project.

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1. Objectives

The aim of the benchmarking study was to examine rail designs and architectures of competitive vehicles with good NCAP and IIHS performance. The knowledge from this study will be useful in designing AHSS rails for the donor vehicle in Phase II of the Lightweight Front End Structure Project (Ref. 1).

2. Results Summary

The following salient features were observed in the benchmarking study.

- Most vehicles had nearly straight rails or rails with very smooth curvature (instead of a sharp hump).
- Most vehicles had box section rails. Notable exceptions were:
  - Octagonal section: 2001 Audi A-6, Cadillac CTS
  - Hexagonal section: Lexus LS430, Toyota Corolla
- In all the vehicles, the rails did not tie in to the rocker.
- In most of the vehicles, the rails extended up to the rear seat. The only exceptions were:
  - VW Passat
  - VW Golf
  - Honda Civic - featured extra middle rails beyond the first cross-member
- Some vehicles lacked a first cross-member (forward of dash panel).
  - Golf
  - Passat
  - Camry
- Some use of AHSS was observed.
  - LS430
  - Cadillac CTS
- Significant use of tailor-welded blanks was observed.
  - Audi A6
  - Golf
  - Passat
  - Mercedes S500
  - Corolla

Vehicle performance is tabulated in *Table 1*. A summary of rail sections and architecture can be obtained from *Table 2* and *Table 3*.

Table 1: Vehicle Ratings

Category	Model/Make	Weight (lbs)	NCAP Star Rating		IIHS Rating	
			Driver Side	Passenger Side	Overall	Structure Cage
Compact Passenger Car	2002 Honda Civic	2522	5	5	Good	Good
	2001 VW Golf	2934	5	5	Good	Acceptable
Medium Passenger Car	2001 Audi A6	-	-	-	Acceptable	Acceptable
	2002 Honda Accord	3078	5	5	Acceptable	Acceptable
	2002 Toyota Camry	3098	5	4	Good	Good
	2002 VW Passat	3168	5	5	Good	Good
Heavy Passenger Car	2002 Lincoln LS	3735	5	5	Good	Good
Van	2002 Honda Odyssey	4370	5	5	Good	Acceptable
	2002 Toyota Sienna	3973	5	5	Good	Good

Table 2: Rail Sections

Model/Make	Front Rail Cross-Section	Front Rail Gauge (mm)		Front Rail Grade
		Inner	Outer	
2002 Honda Civic	Box	1.50	1.50	-
2001 VW Golf	Box	2.0/2.9/1.4	-	IF Mild Steel
2001 Audi A6	Octagonal	-	-	Bake Hardened 210-270 Isotropic 280/340
2002 Honda Accord	Box	2.00	2.00	Bake Hardened 180/210
2002 Toyota Camry	Box	1.75	1.80	Japanese Style High Tensile Steel 440/590 MPa
2002 VW Passat	-	1.25	2.0/1.6	-
2002 Lincoln LS	-	-	-	-
2002 Honda Odyssey	Box	-	-	-
2002 Toyota Sienna	Box	1.80	2.00	-

Table 3: Rail Architectures

Model/Make	Front Rail Cross-Section	Front Rail Gauge (mm)		Rail Architecture	
		Inner	Outer	Front Rail Plan Curvature	Front Rail Extension
2002 Honda Civic	Box	1.50	1.50	Inboard kick	Not merged with rear rails Extra middle rails from 1st CM up to rear rail
2001 VW Golf	Box	2.0/2.9/1.4	-	Inboard kick	Not merged with rear rails
2001 Audi A6	Octagon	-	-	-	-
2002 Honda Accord	Box	2.00	2.00	Inboard kick relatively small	Not merged but run up to rear rail
2002 Toyota Camry	Box	1.75	1.80	Straight rails up to rear rail	Not merged but run up to rear rail
2002 VW Passat	-	1.25	2.0/1.6	Inboard kick relatively large	Not merged with rear rails
2002 Lincoln LS	-	-	-	Straight rails up to rear rail	Not merged with rear rails
2002 Honda Odyssey	Box	-	-	Inboard kick	Merged with rear rails
2002 Toyota Sienna	Box	1.80	2.00	Straight, inboard kick under dash panel	Merged with rear rails Multiple cross members under dash and floor

3. Benchmarked Vehicles

2001 Audi A2

- Shorter Rails
- Rail with Al material
- Box type with longitudinal stiffeners
- Rails manufactured by extrusion method
- Rails have two crush initiators

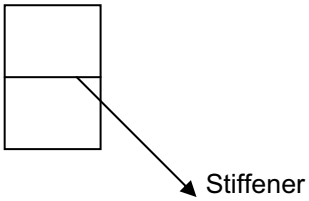


Figure 1: Audi A2 - Front Rails Cross-Section (one piece with middle stiffener)

2001 Audi A6

- Octagonal rails, tailor welded
- EA welded directly to the front rail
- X-Z curvature: almost straight
- X-Y curvature: curvature towards the rear

2001 VW Golf

- 3-piece tailor-welded rails

2001 VW Passat

- Outer rails - 3-piece tailor-welded
- Inner rails - single piece
- Rails do not extend to rear of vehicle

2001 Mercedes Benz S-500

- Box section, tailor-welded, straight
- Upper Rails: box section

2002 Honda Accord

- Straight rails, small inboard bend at dash panel junction.
- Box type rails
- Size of bumper beam relatively small

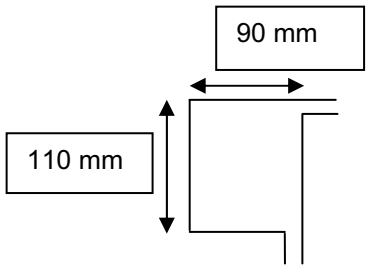


Figure 2: Honda Accord - Front Rails Cross-Section

2002 Honda Civic

- Box type rails
- Straight rails

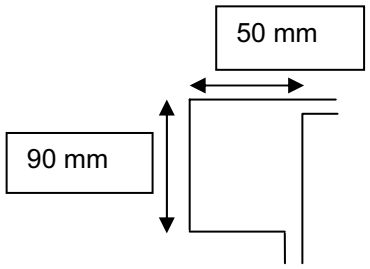


Figure 3: Honda Civic - Front Rails Cross-Section

2002 Honda Odyssey

- Box type rails
- Slight curvature in rails

2003 Honda Pilot

- Roll formed HSS bumper with ERW

2001 Lexus LS 430

- Rails are made of High Strength Steel
- Hexagonal cross-section
- Front rails are relatively straight, with large cross section at the junction of toe pan and #1 bar
- Rails go up to #4 Bar
- Crush initiators
- Upper rails: box section, high strength steel, spot welded to FBHP (Front Board Hinge Pillar)
- Large one piece Shock Tower
- Diagonal support at bottom of upper rails (shot gun) from FBHP

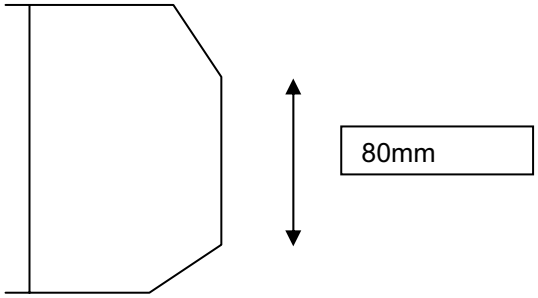


Figure 4: Lexus LS 430 - Front LH Rail Cross-Section

2002 Toyota Camry

- Box type rails, small height of bumper

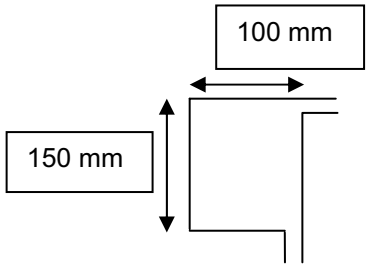


Figure 5: Toyota Camry - Front LH rail Cross-Section

- Smooth XY rail curvature (not a bump)

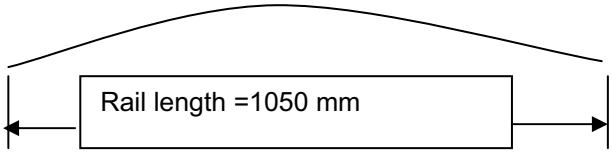


Figure 6: Toyota Camry - Front Rails Curvature (side view)

2003 Toyota Corolla 4 Dr Sedan

- Straight rails: small bump on LH
- Hexagonal cross-section
- Non-symmetrical LH and RH Rails
- 2-piece tailor welded
- No Upper Rails (shotgun) beyond the shock cap
- Body assembly mass= 256.64 Kg

2000 Hyundai Elantra

- Box type rails

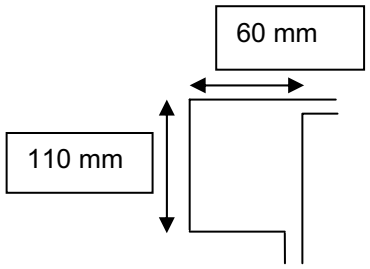


Figure 7: Hyundai Elantra – Front Rails Cross-Section

2003 Cadillac CTS

- One piece bumper
- Octagonal front rails
- Tailor-welded rails
- Front rail extension - Al extrusion
- Rest of the rail - HSS

2001 Daewoo Lanos: Post-IIHS Crash Test

- No crushing of rails/shotgun – they buckle
- Roof, door damage

4. Design Assessment

All the vehicles with NCAP 5-star rating and IIHS overall good rating had very slight curvature in the rails. Thus, it is of paramount importance to reduce the plan and elevation curvatures as much as possible, in order to avoid buckling of rails.

A large number of vehicles with good performance had regular box-type rails. However, hexagonal or octagonal rails do exhibit better formability characteristics. Hexagonal and box sections provide better mounting surfaces. Octagonal rails are recommended for good buckling characteristics. Mass savings could be achieved by employing a section that fills up the packaging envelope the most, thereby enabling the highest section modulus and the minimum gauge.

Another feature that may affect performance is the length of rail extension and tying of the rails to the rocker. None of the benchmarked rails were tied to the rocker, unlike the ULSAB architecture (Ref. 2). Most of the vehicles, except for Golf, Passat and Civic, had long rails extending up to the rear seat. This feature of rail design should be studied in the development of rail concepts.

The use of tailor-welded rails was observed in several vehicles. Tailor-welded rails enable mass reduction, as the requirements of stiffness vary along the rail length (Ref. 2).

No extensive use of AHSS materials was observed. However, the use of AHSS will result in significant mass reduction and improved performance. Formability and welding does pose a challenge for designing rails using AHSS.

The use of laser welding was found to be minimal. However, Phase 1 work (Ref. 3) has indicated that mass savings could be achieved by laser welding, as laser-welded sections possess higher stiffness. Thus, there is a possibility of reducing the rail gauge and achieving the same stiffness by laser welding. However, spotwelds do act as crush initiators and initiate early crush, thereby avoiding buckling of rails.

5. Conclusions

The following design guidelines can be formulated, based on the benchmarking study.

- Plan and elevation curvatures should be reduced as much as possible, in order to avoid buckling of rails.
- Octagonal and hexagonal sections exhibit superior formability, as compared to box sections. Octagonal sections have better buckling characteristics, where as hexagonal sections provide better mounting surfaces. Packaging space-filling cross-sections will enable mass reduction.
- The optimum length of the rail extension and tying of the rails to the rocker should be explored.
- Use of tailor-welded blanks should result in mass reduction and better crash performance.
- Laser welding may provide scope for mass reduction and improved crash performance.

6. Future Work

The information gathered from the benchmarking study will be employed to develop rail concepts in Phase II of the Lightweight Front End Structure Project. Eventually, the best rail concept will be designed, optimized and verified analytically. The new AHSS rail design will be manufactured and assembled into the full vehicle, along with the new bumper design. The full vehicle will then be physically tested for the NCAP load case, and its performance will be compared to the vehicle with the original rail and bumper designs.

7. References

1) *Phase II Proposal: Automotive Lightweight Structure Design Utilizing Advanced High Strength Steels.*

2) *Lightweight Front-End Structure, Final Report, SPHINX Phase 1.*

3) *ULSAB Weld DOE Study,* Milestone 21c*, SPHINX Phase 1.*

8. Appendix A: Photographs of Vehicle Front-Ends

2001 Audi A6

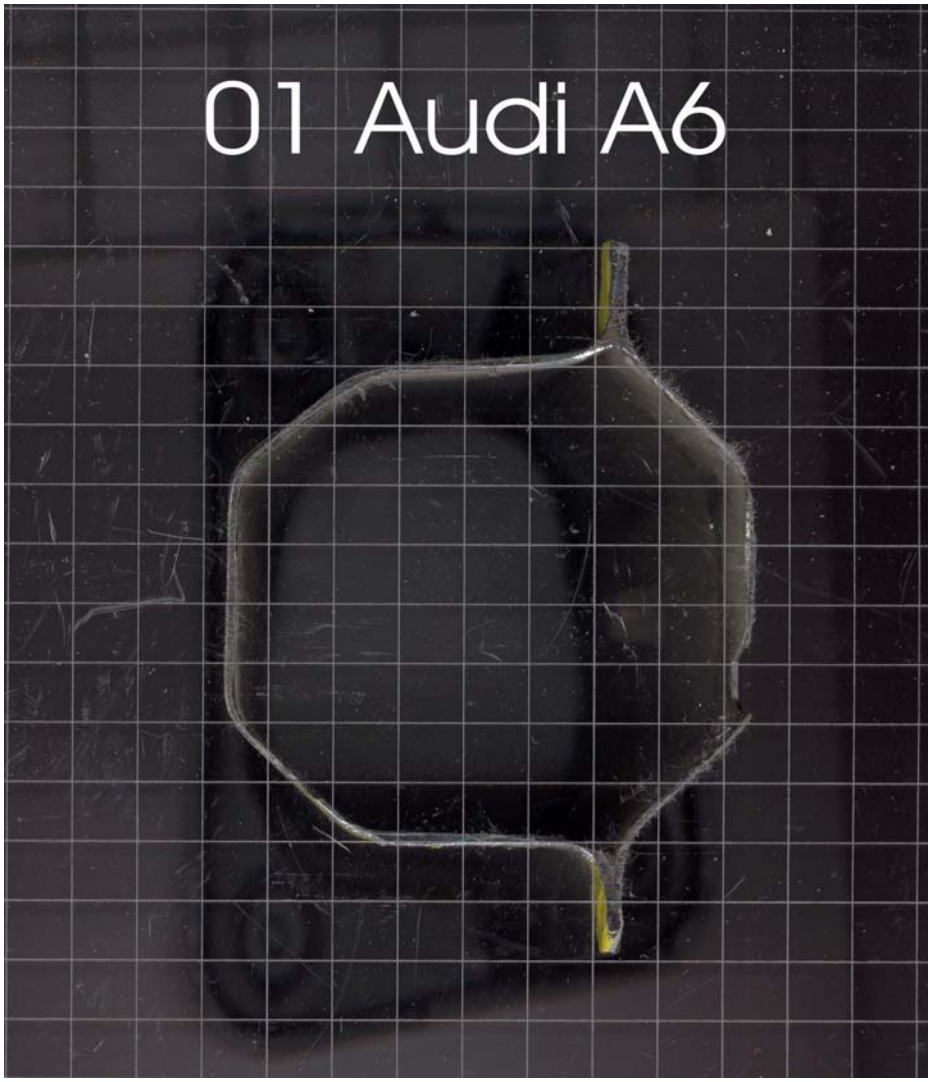


Figure 8: Audi A6 - Front Rails Cross-Section

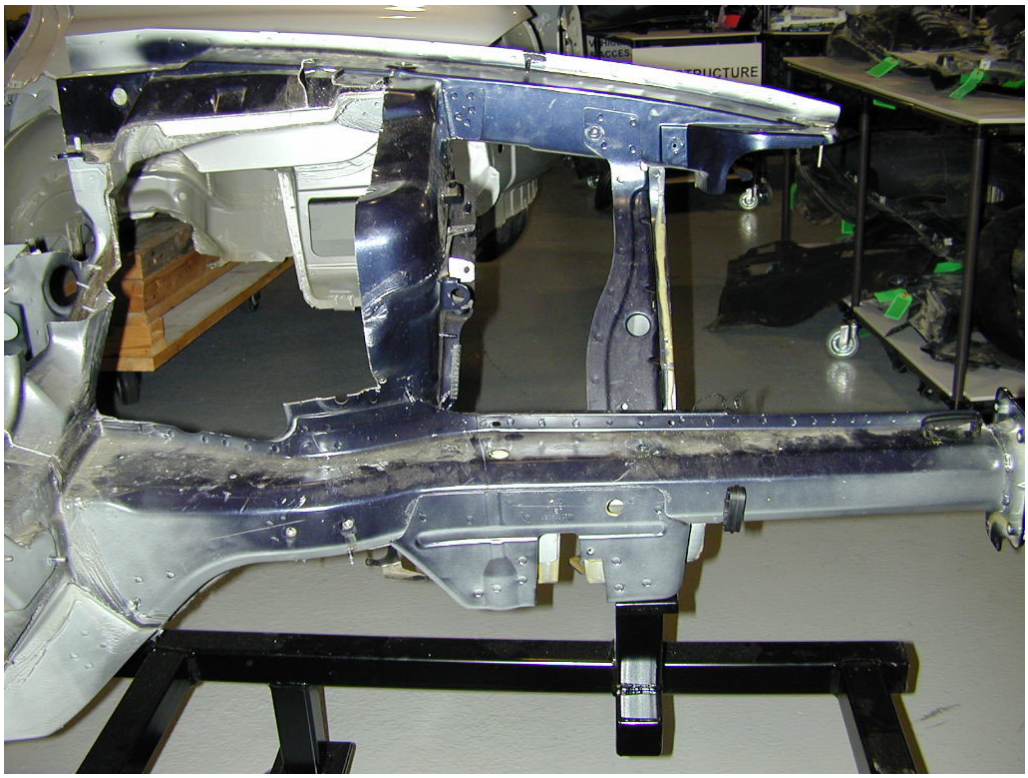


Figure 9: Audi A6 - LH Front Rail (inboard side view)

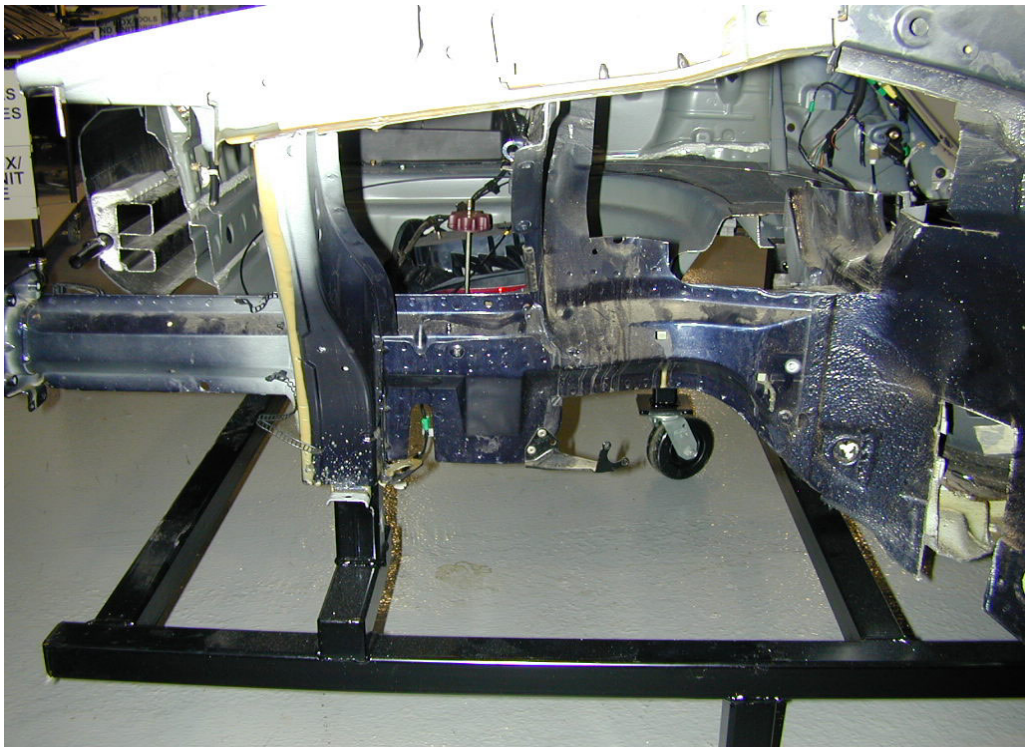


Figure 10 Audi A6 - LH Front Rail (outboard side view)

2001 VW Golf

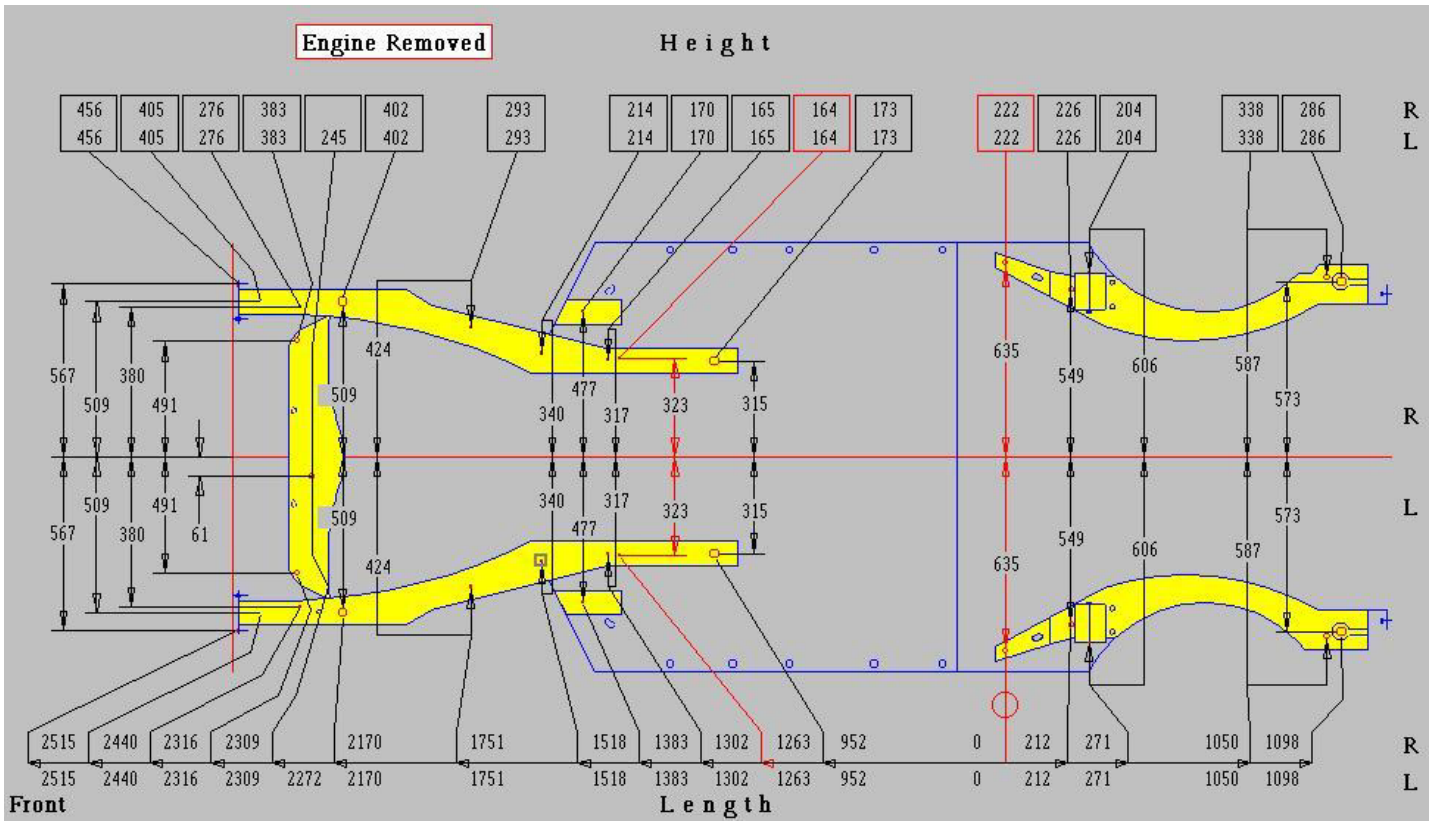


Figure 11: VW Golf - Rail Architecture

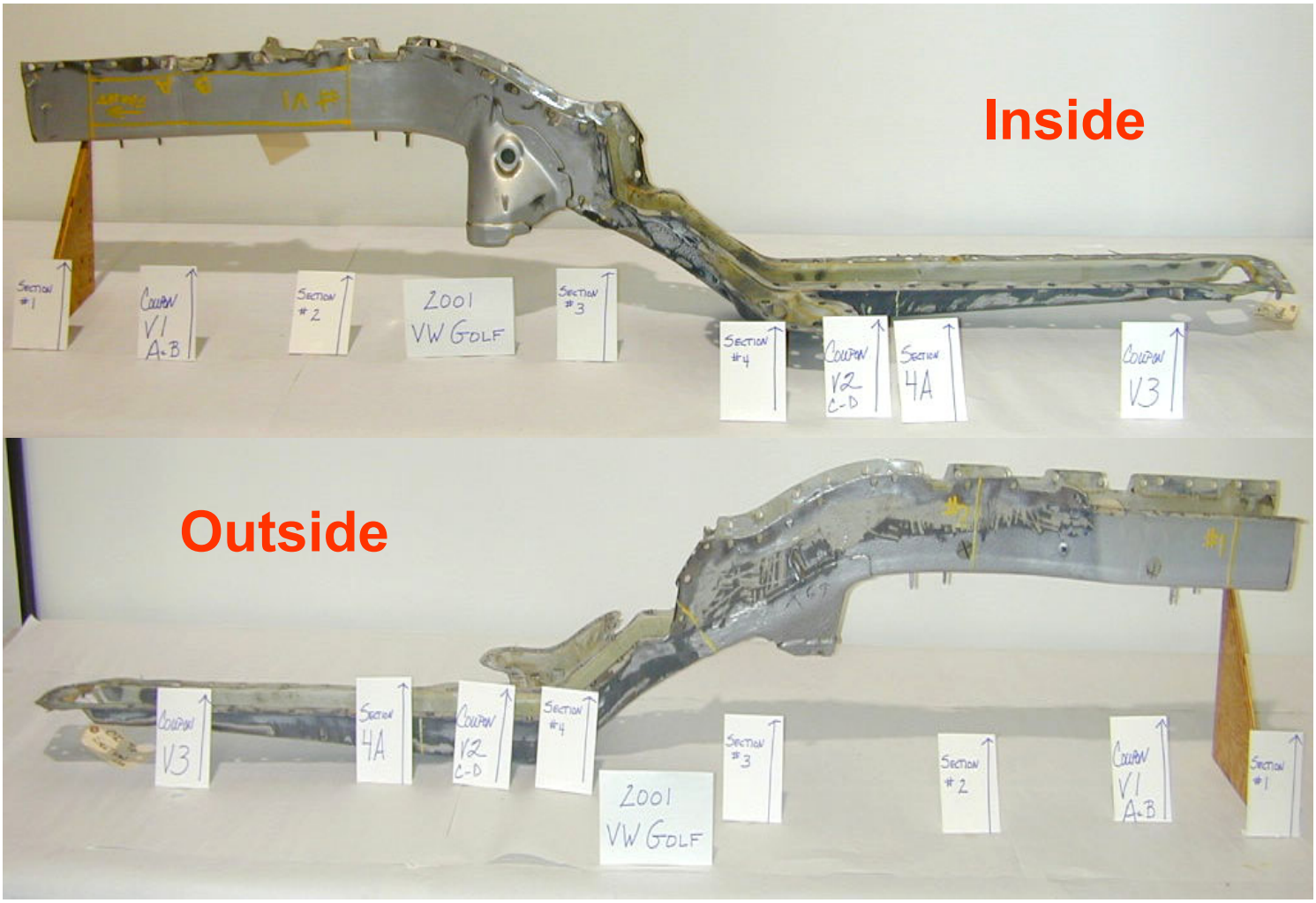


Figure 12: VW Golf - Front Rails



Figure 13: VW Golf - Front Rails (inside view)

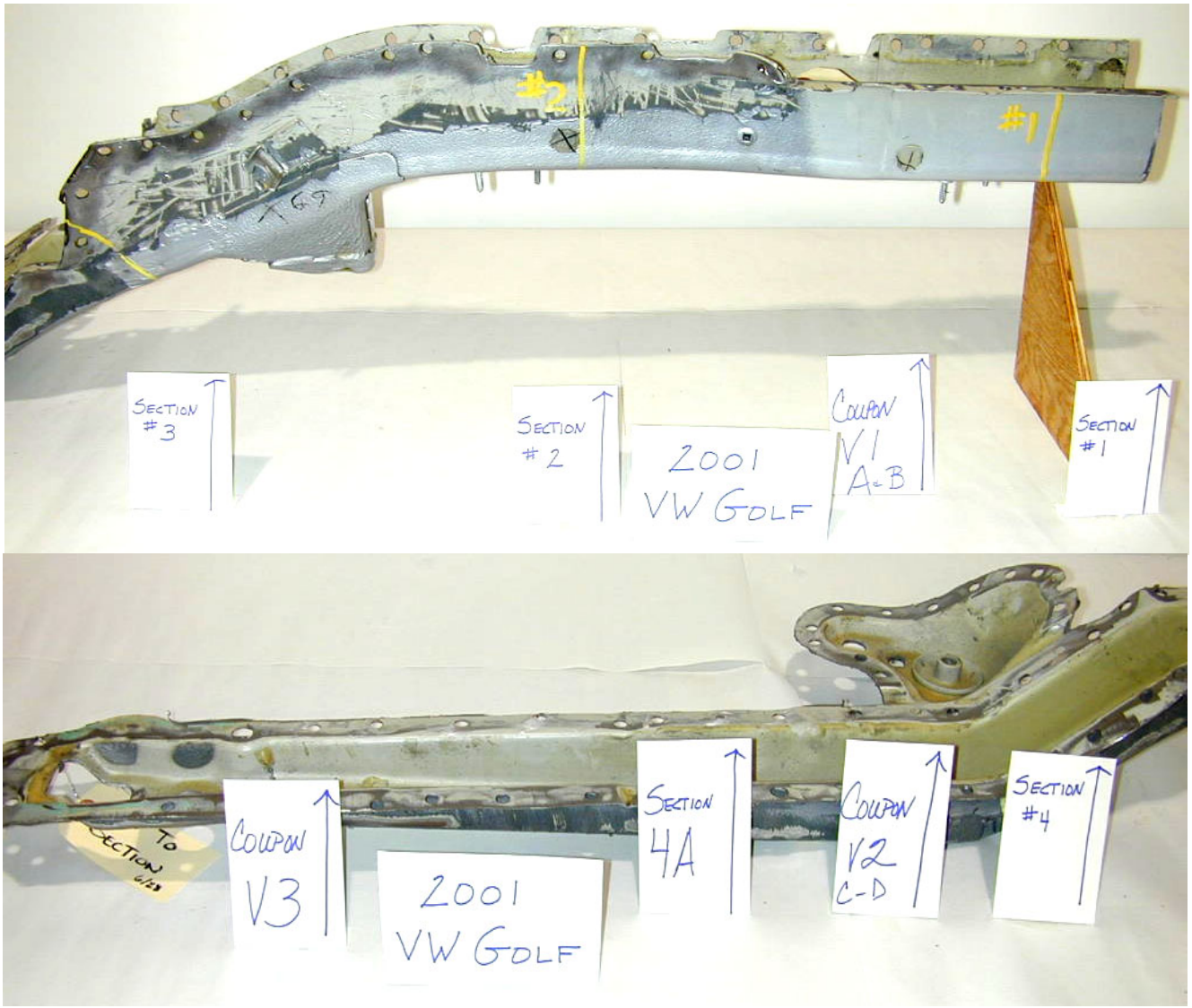


Figure 14: VW Golf - Front Rails (outside view)

2002 VW Passat

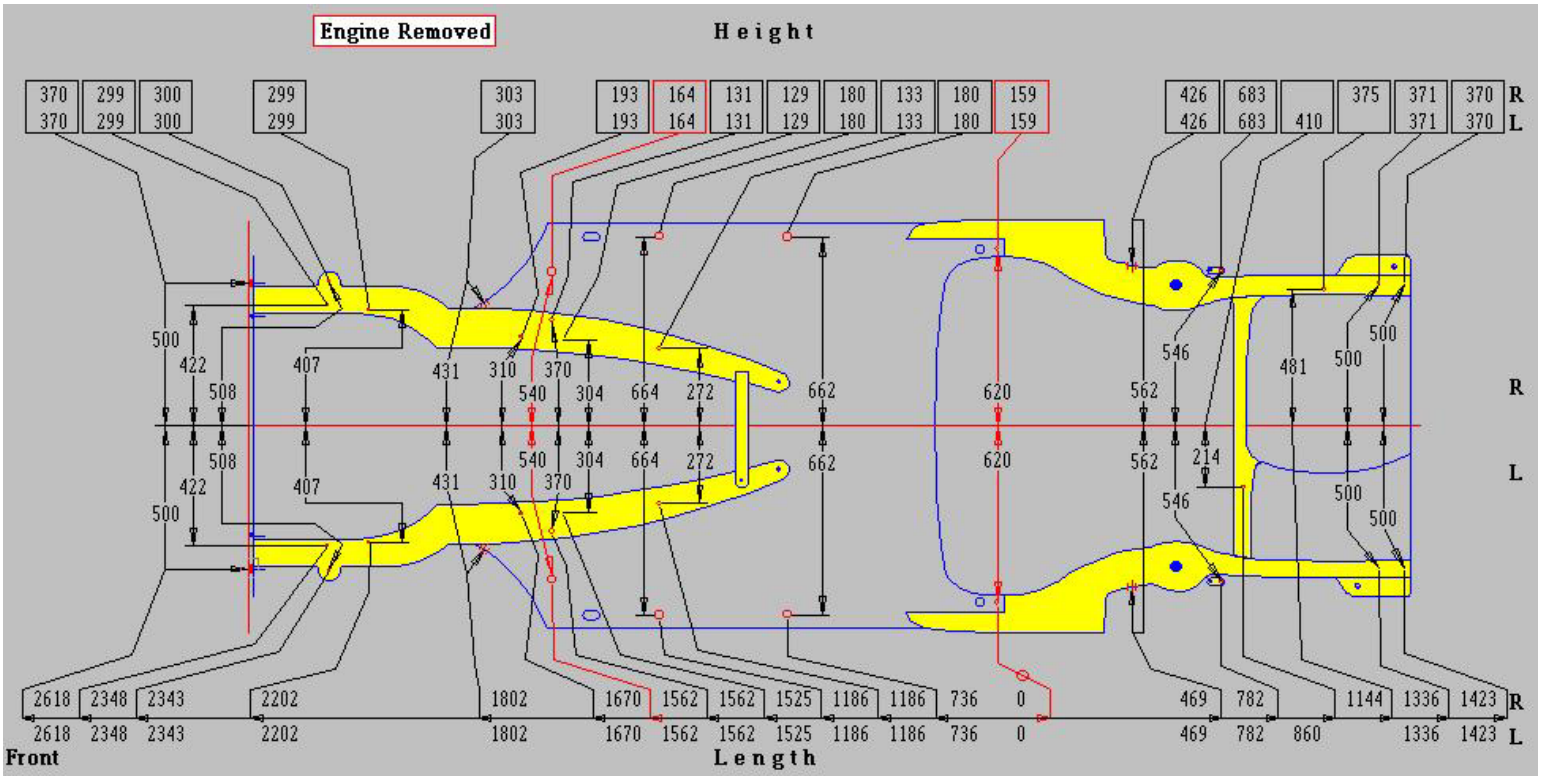


Figure 15: VW Passat - Rail Architecture

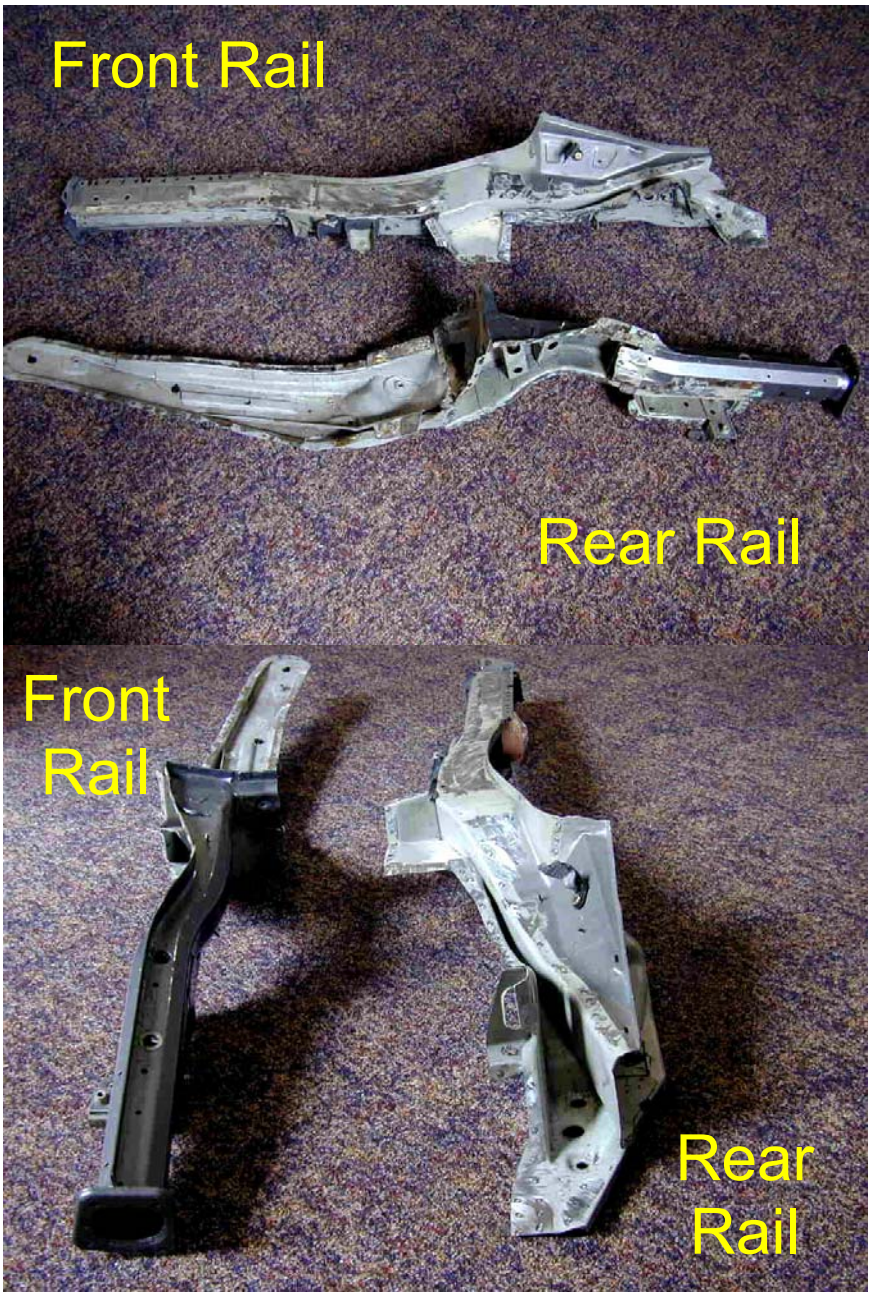


Figure 16: VW Passat - Front and Rear Rails

2001 Mercedes Benz S-500

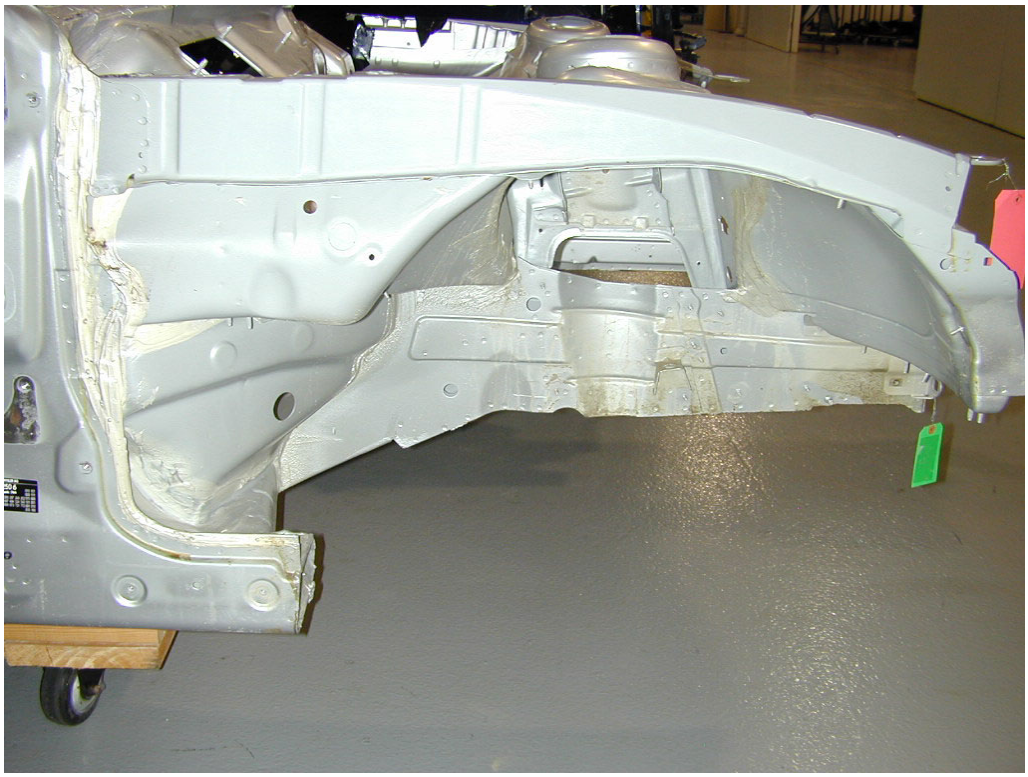


Figure 17: Mercedes Benz S-500 - RH Front Rail (outboard side view)



Figure 18: Mercedes Benz S-500 - RH Front Rail (inboard side view)

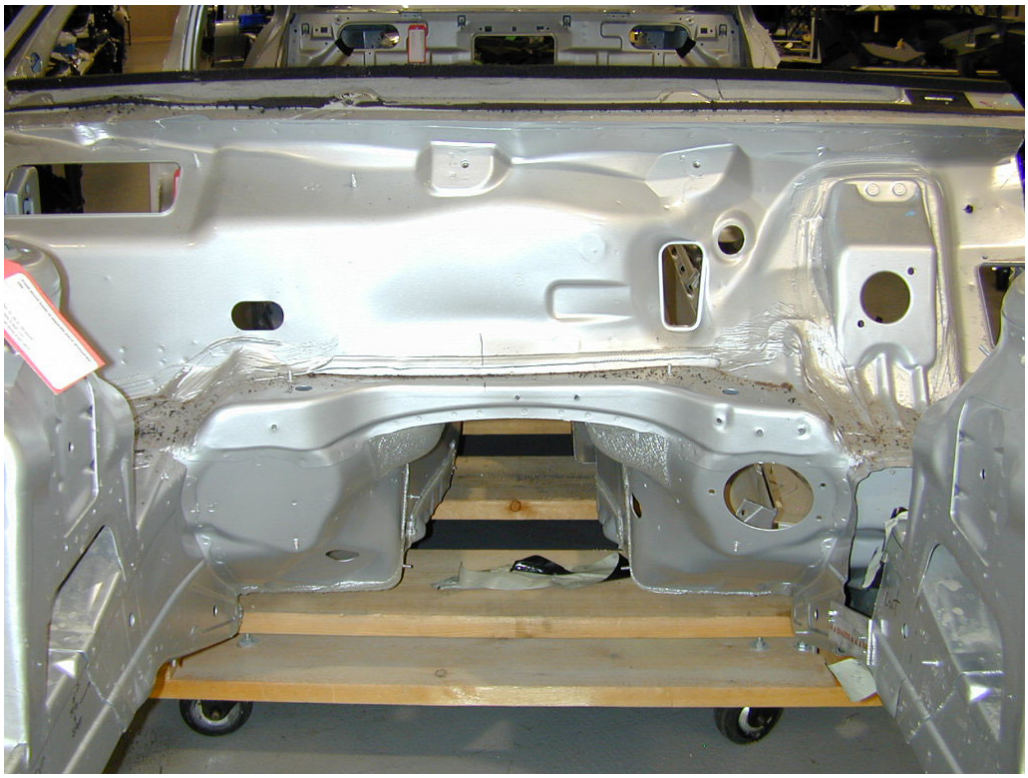


Figure 19: Mercedes Benz S-500 - First Cross Member

2002 Honda Accord

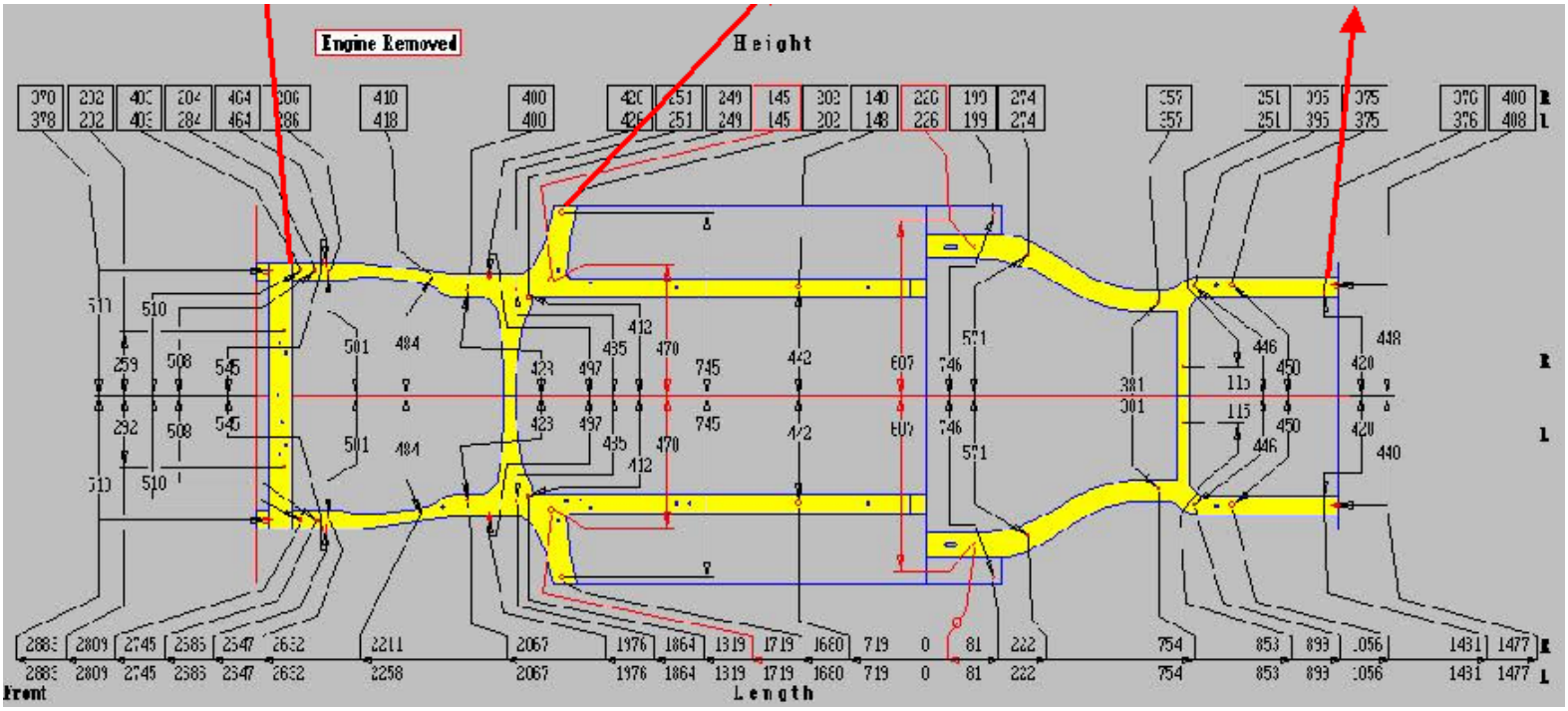


Figure 20: Honda Accord - Rail Architecture

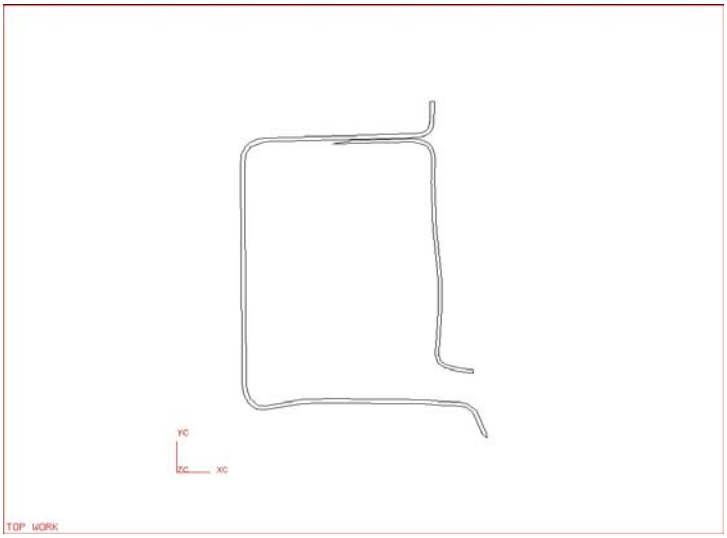


Figure 21: Honda Accord - Front Rails Cross-Section



Figure 22: Honda Accord - Front Rails (outside view)



Figure 23: Honda Accord - Front Rails (inside view)

2002 Honda Civic

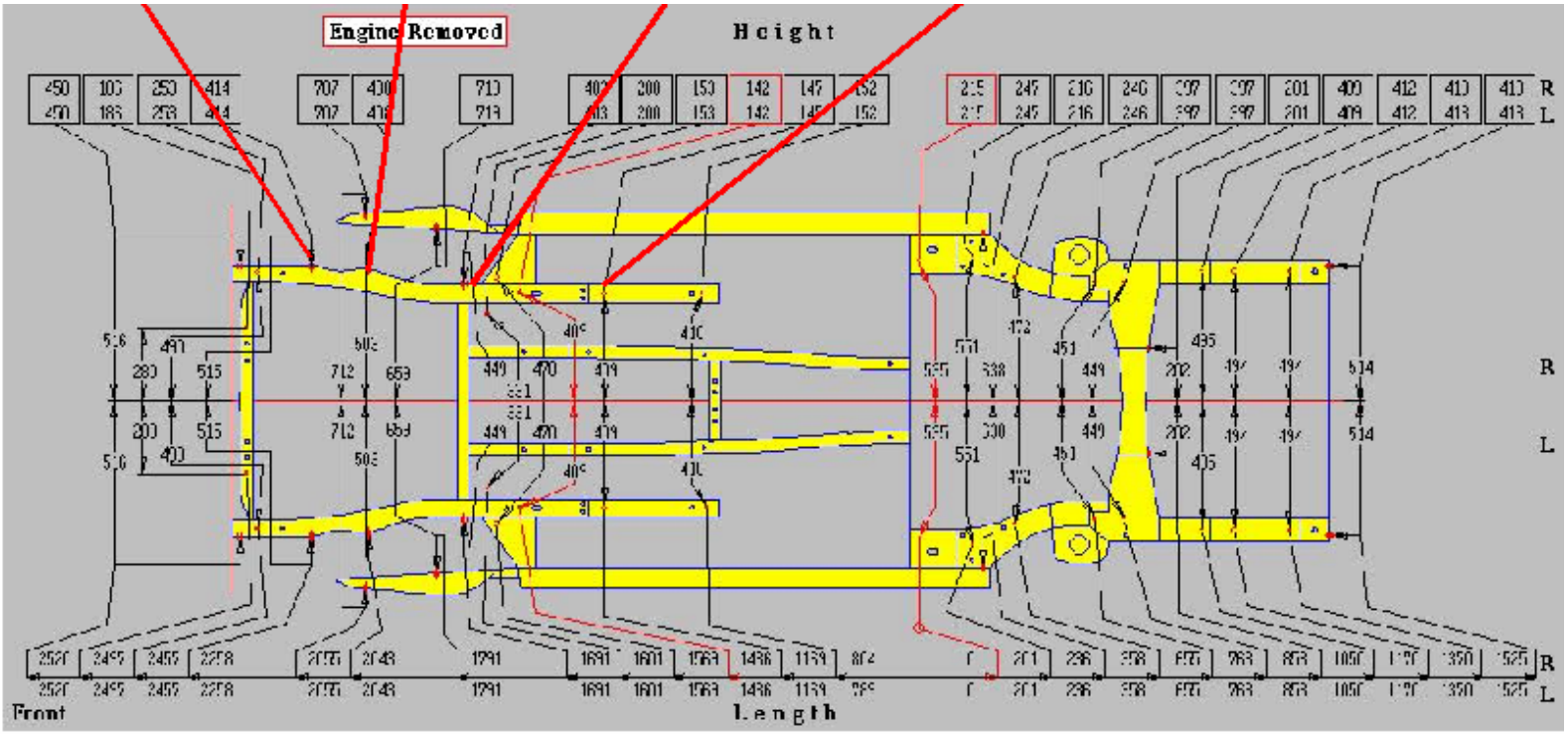


Figure 24: Honda Civic - Rail Architecture

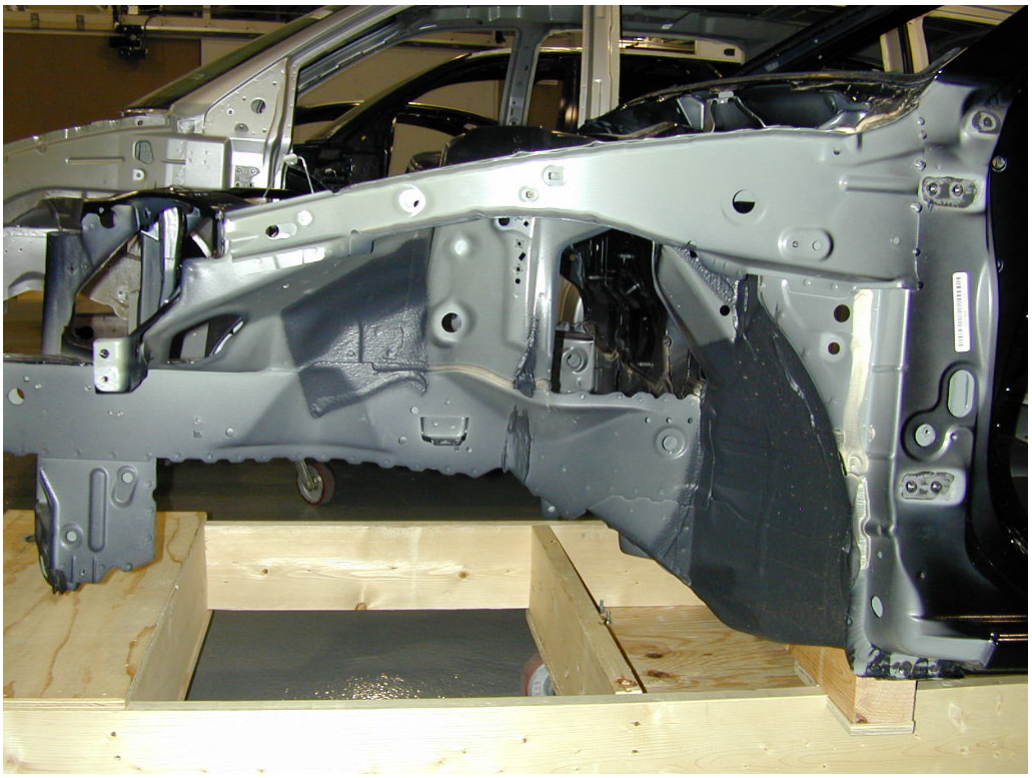


Figure 25: Honda Civic - LH Front Rail (outboard side view)

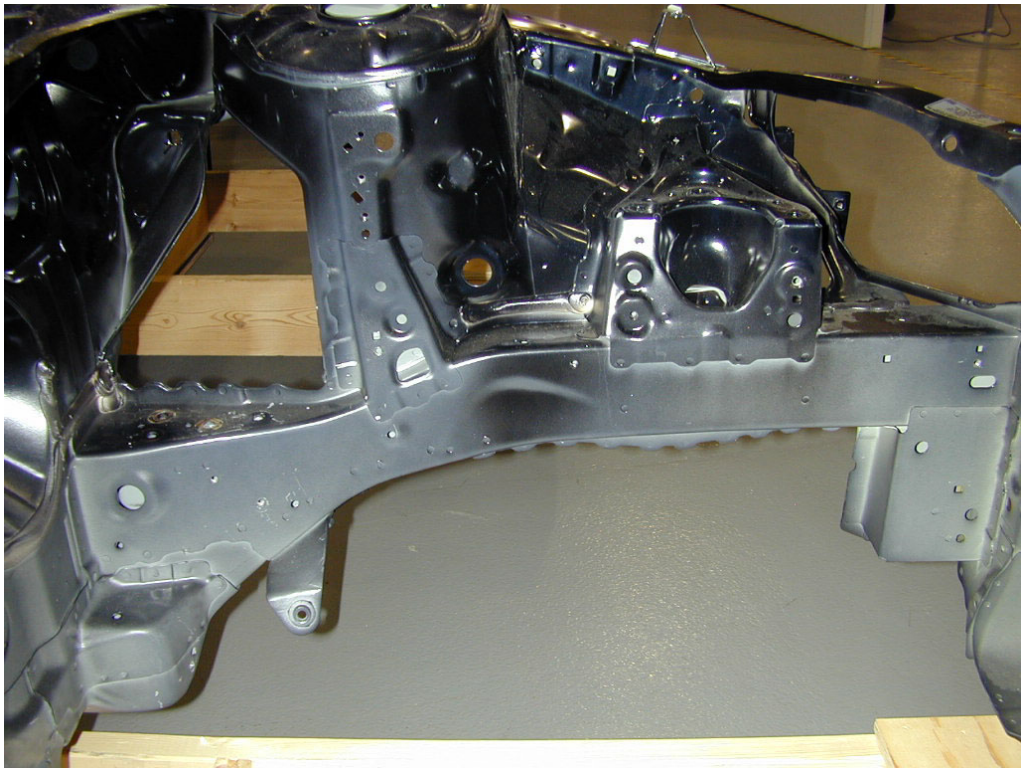


Figure 26: Honda Civic - LH Front Rail (inboard side view)

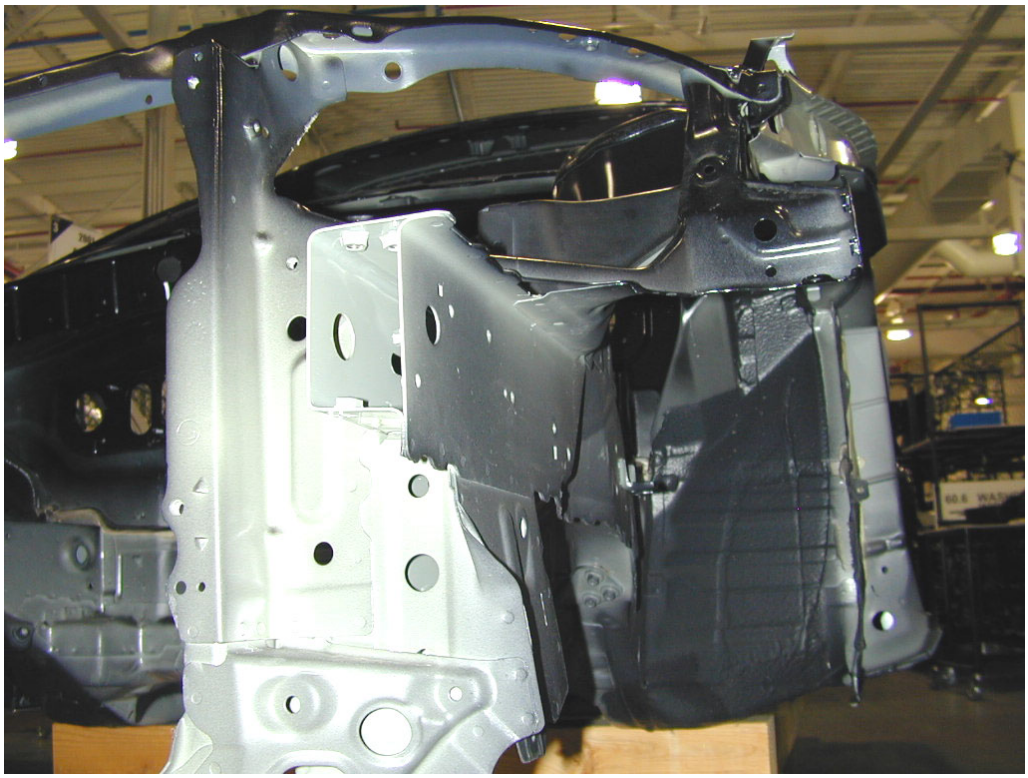


Figure 27: Honda Civic - Front Rail Cross-Section

2002 Honda Odyssey

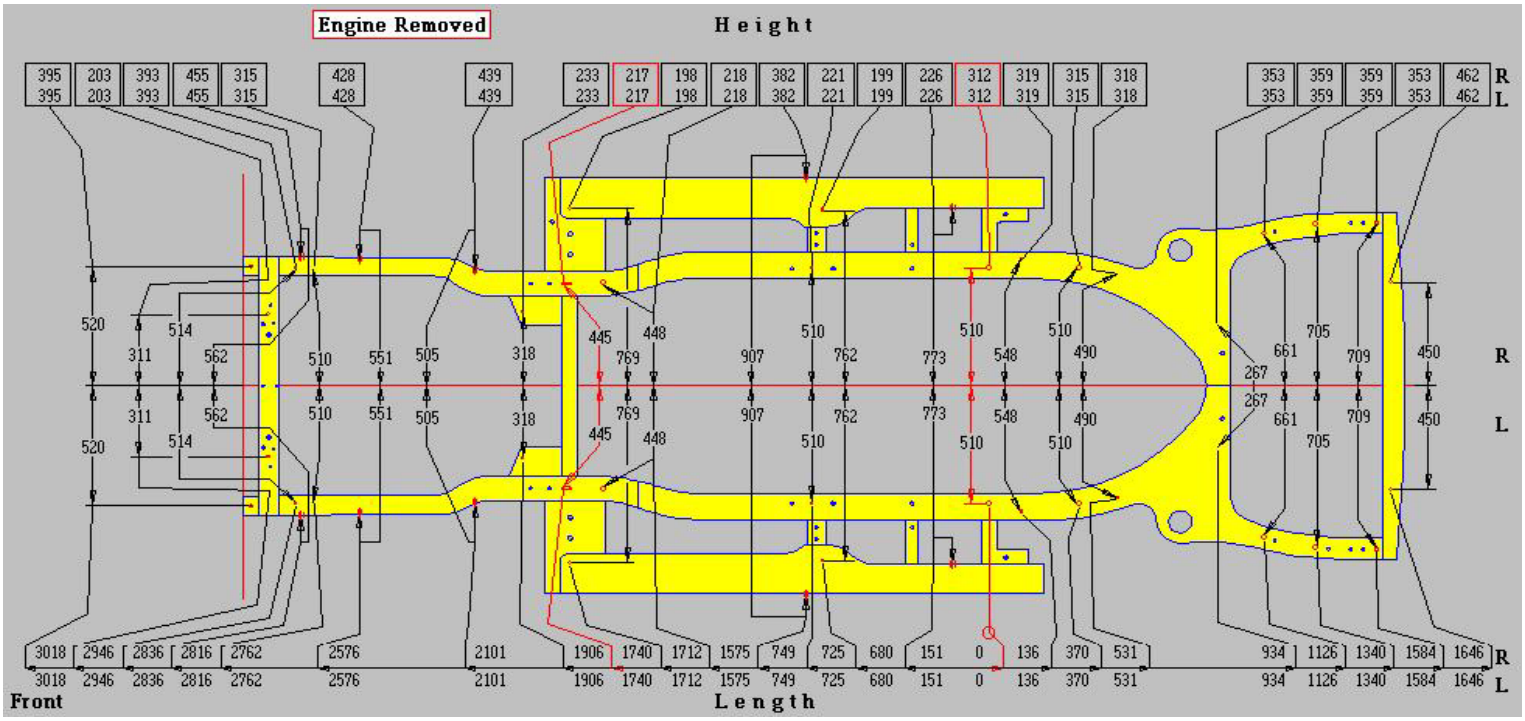


Figure 28: Honda Odyssey - Rail Architecture

2003 Honda Pilot



Figure 29: Honda Pilot - LH Front Rail (outboard side view)

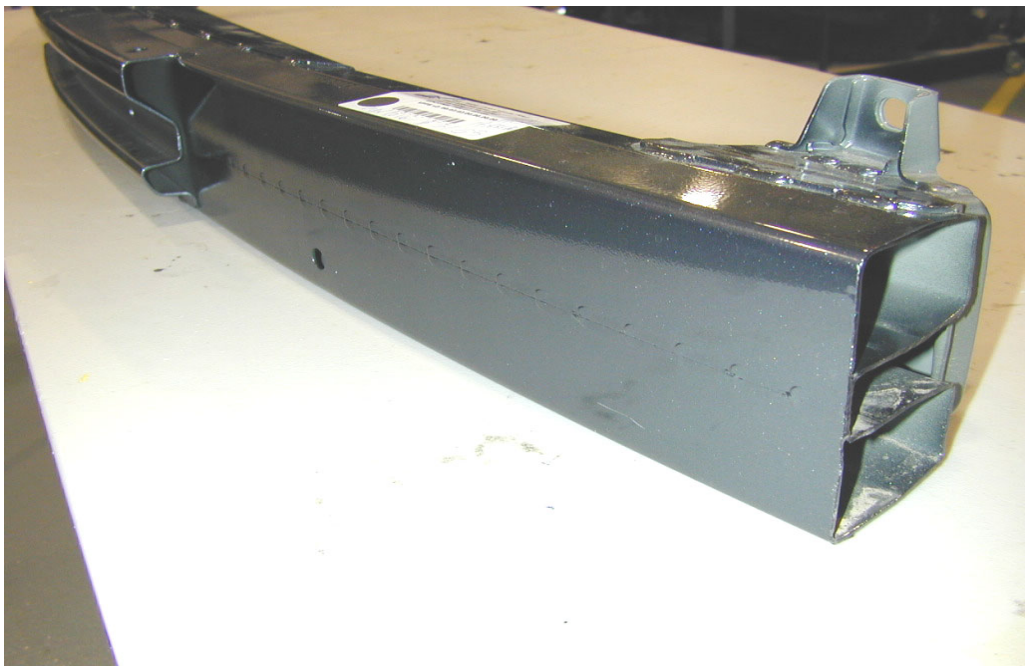


Figure 30: Honda Pilot - Bumper Cross-Section

2001 Lexus LS430

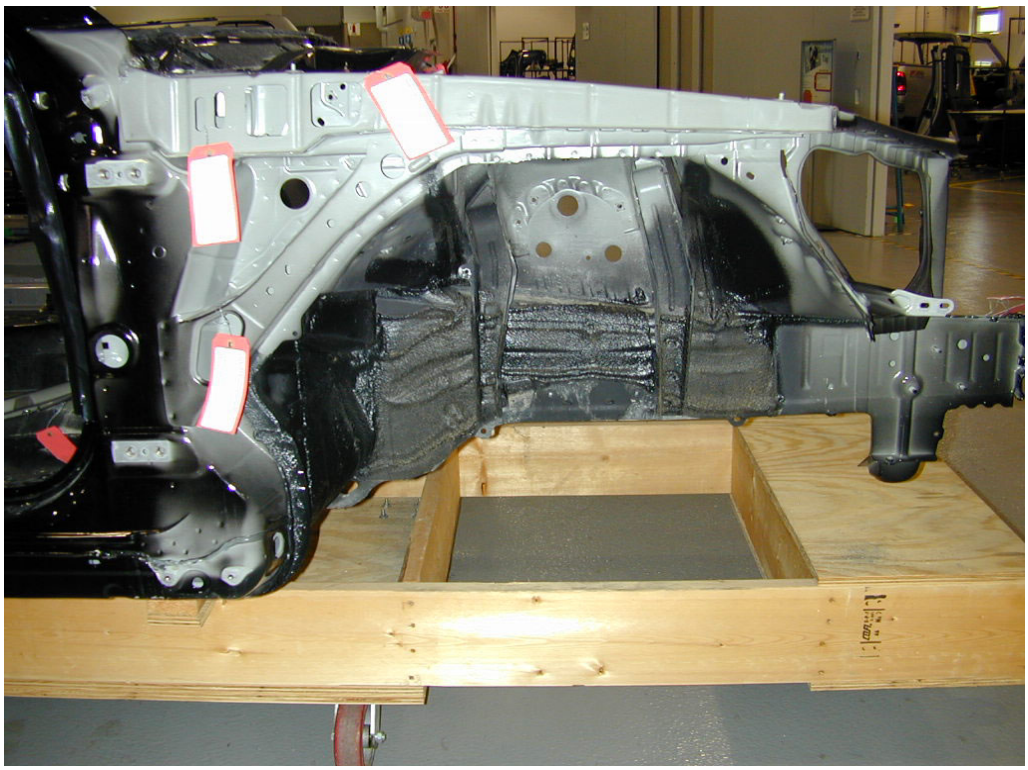


Figure 31: Lexus LS430 - RH Front Rail (outboard side view)

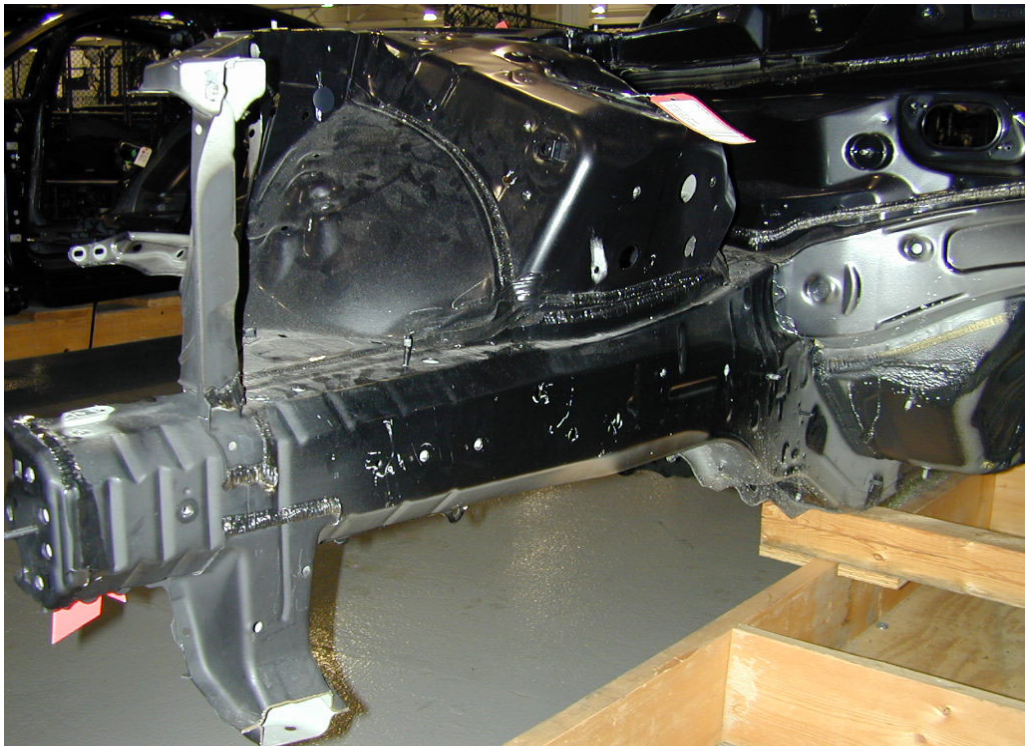


Figure 32: Lexus LS430 - RH Front Rail (inboard side view)



Figure 33: Lexus LS430 - First Cross Member

2002 Toyota Camry

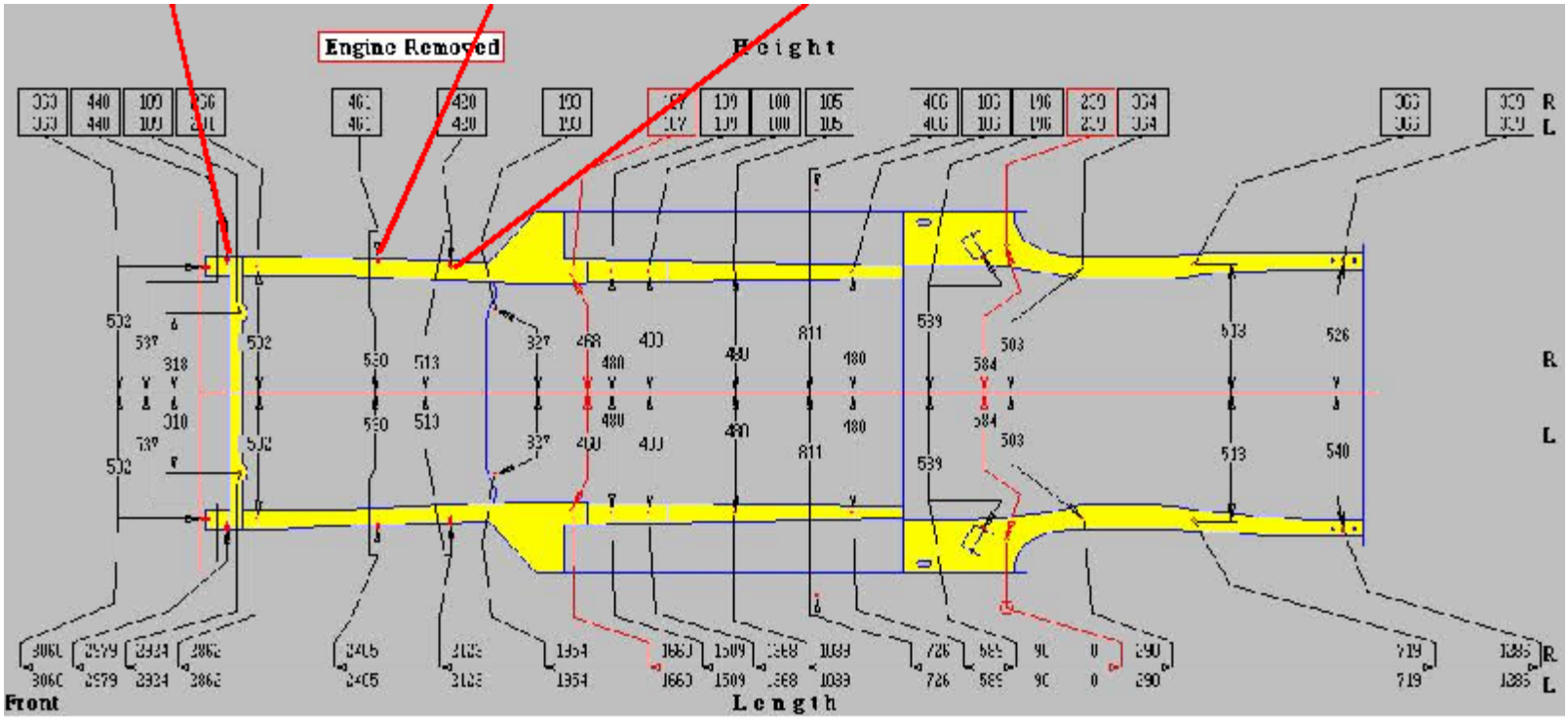


Figure 34: Toyota Camry - Rail Architecture



Figure 35: Toyota Camry - Front Rails Cross-Section

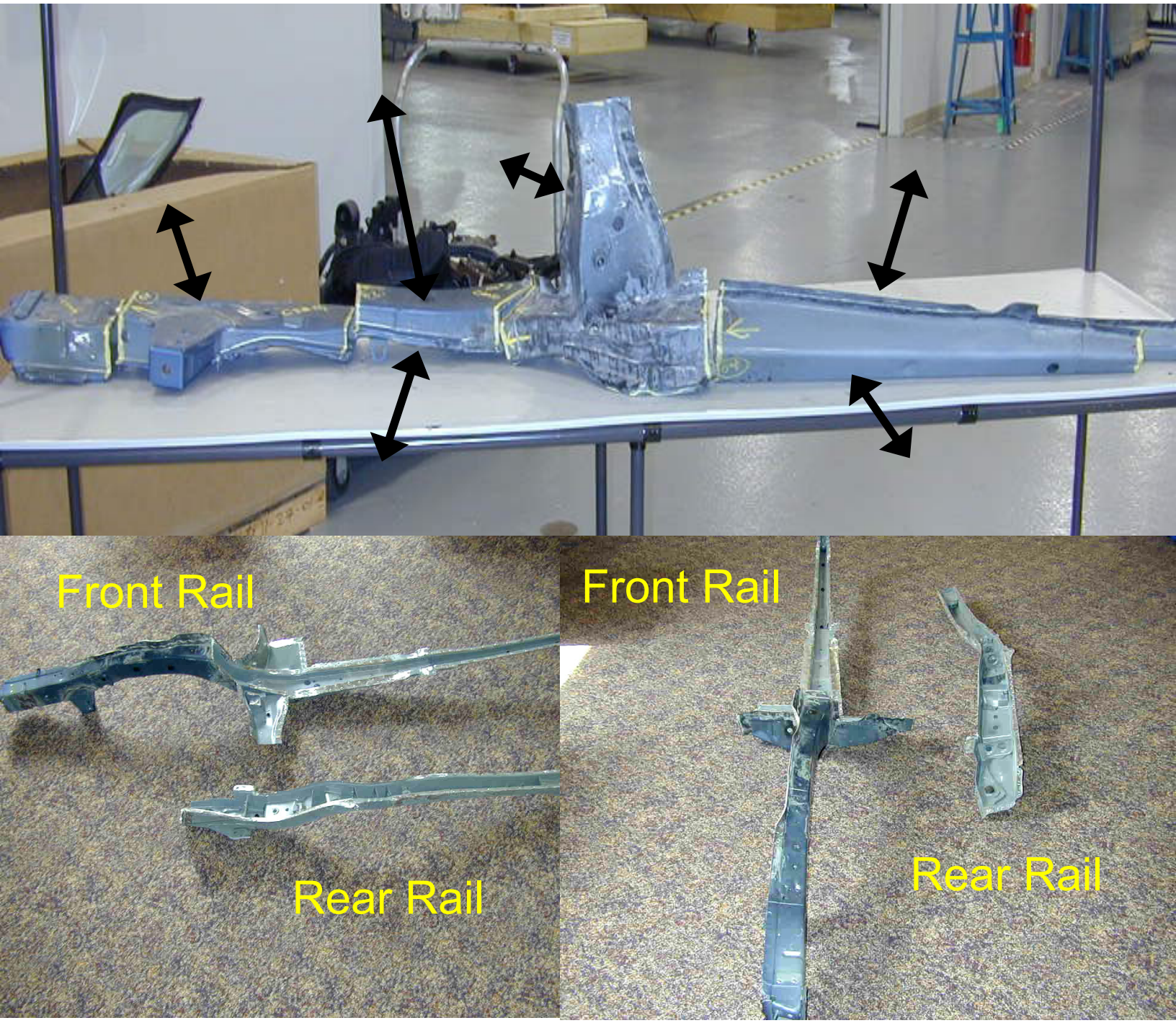


Figure 36: Toyota Camry - Front and Rear Rails

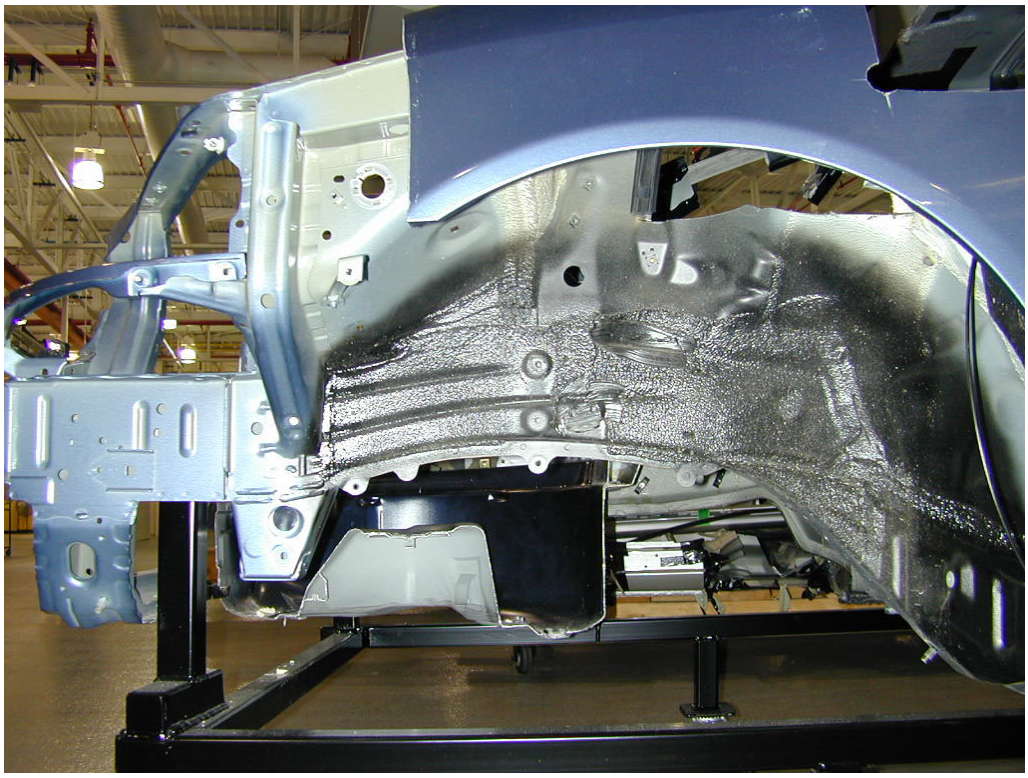


Figure 37: Toyota Camry - LH Front Rail (outboard side view)



Figure 38: Toyota Camry - LH Front Rail (inboard side view)

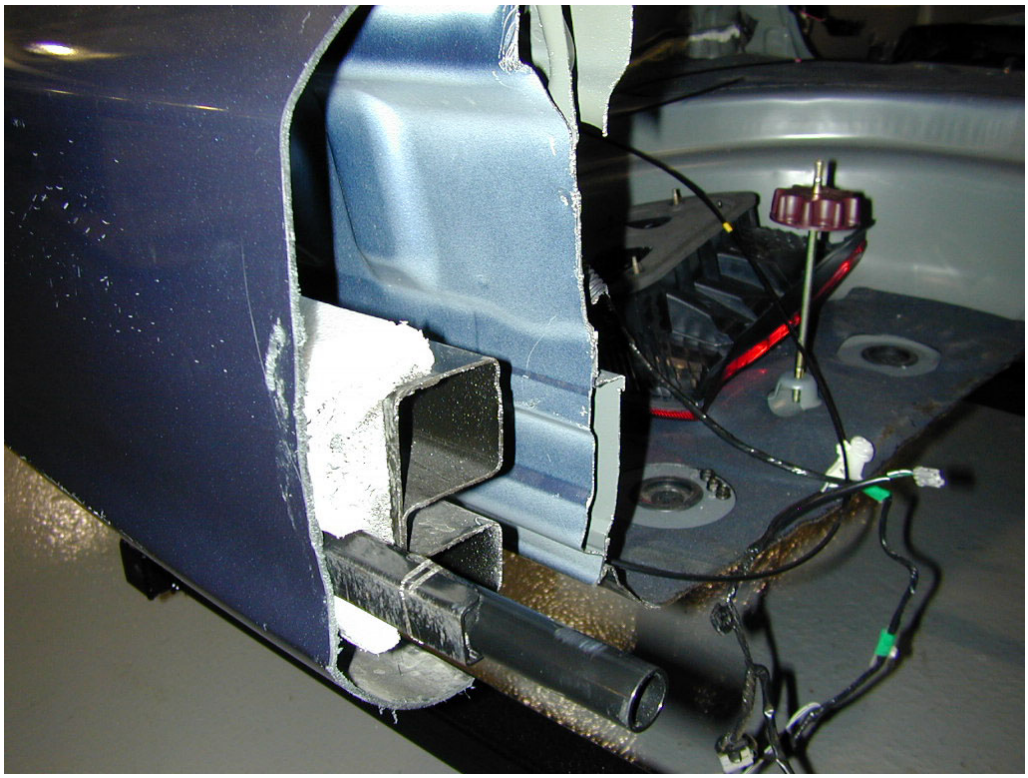


Figure 39: Toyota Camry - Bumper Cross-Section

2003 Toyota Corolla

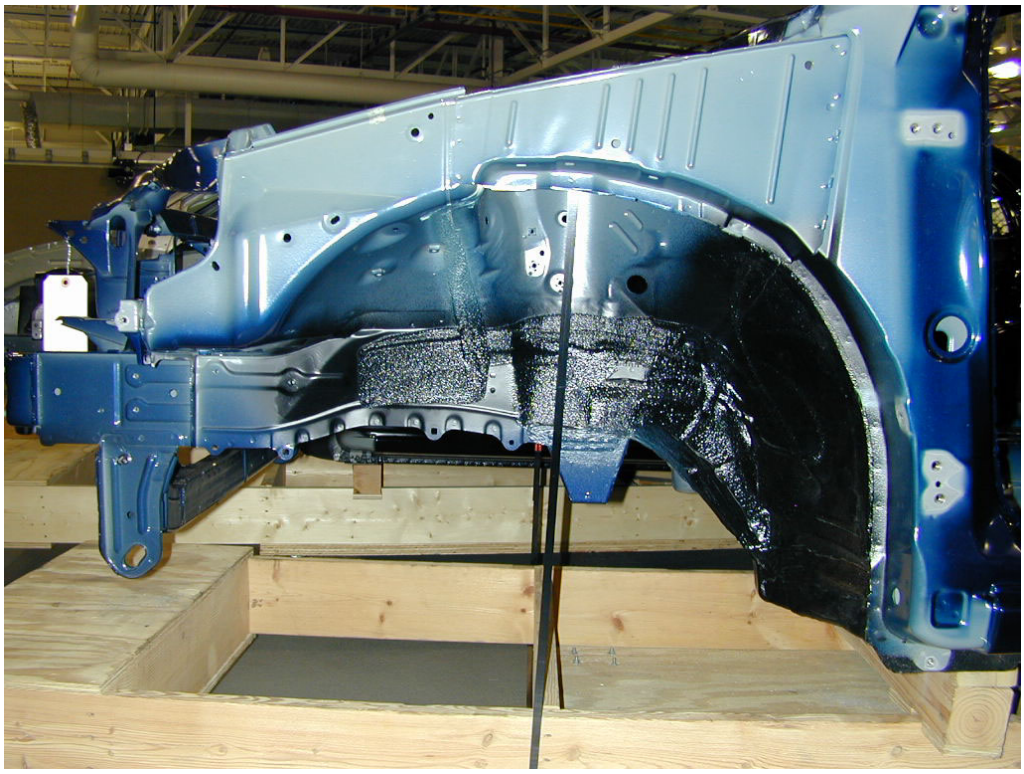


Figure 40: Toyota Corolla - LH Front Rail (outboard side view)

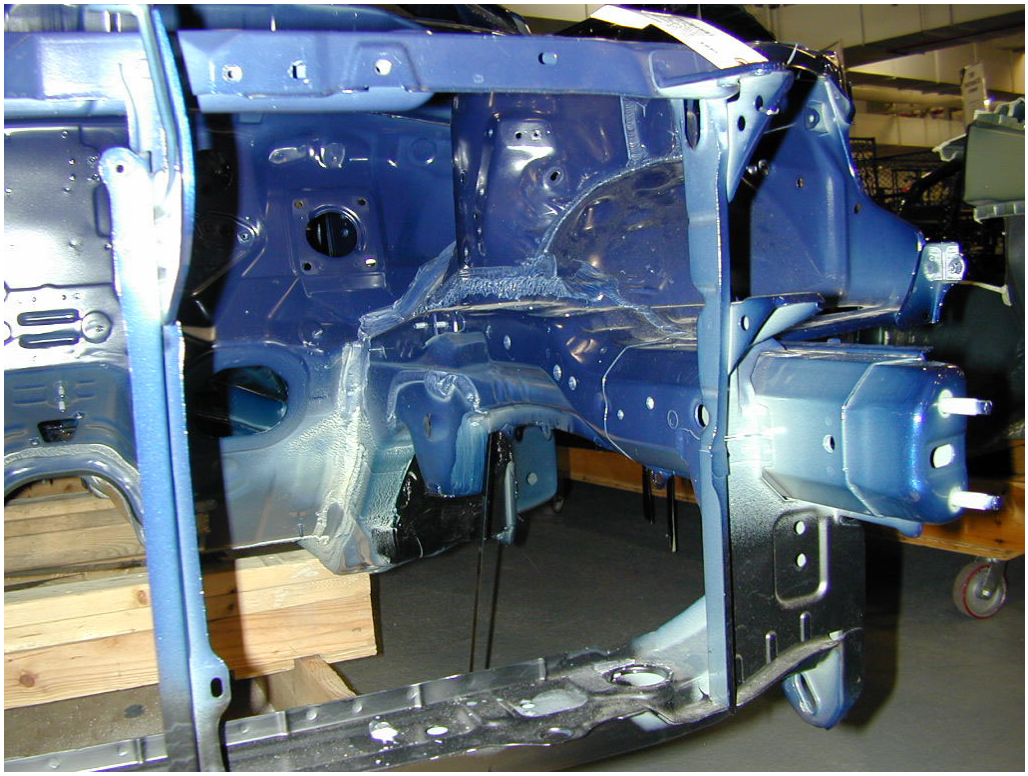


Figure 41: LH Front Rail Inboard Side View (2003 Toyota Corolla)

2003 Saturn Ion



Figure 42 LH front Rail Outboard Side View (2003 Saturn Ion)



Figure 43: LH Front Rail Inboard Side View (2003 Saturn Ion)

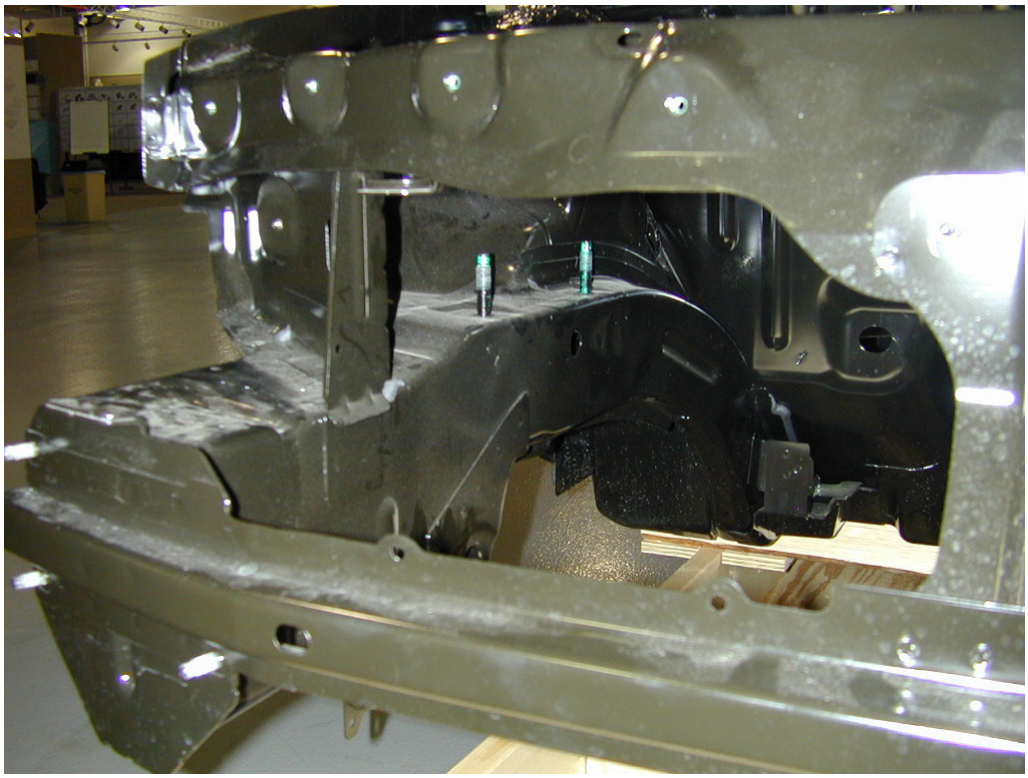


Figure 44: RH Front Rail Inboard Side View (2003 Saturn Ion)

2002 Saturn VUE



Figure 45: LH front Rail Outboard Side View (2002 Saturn VUE)

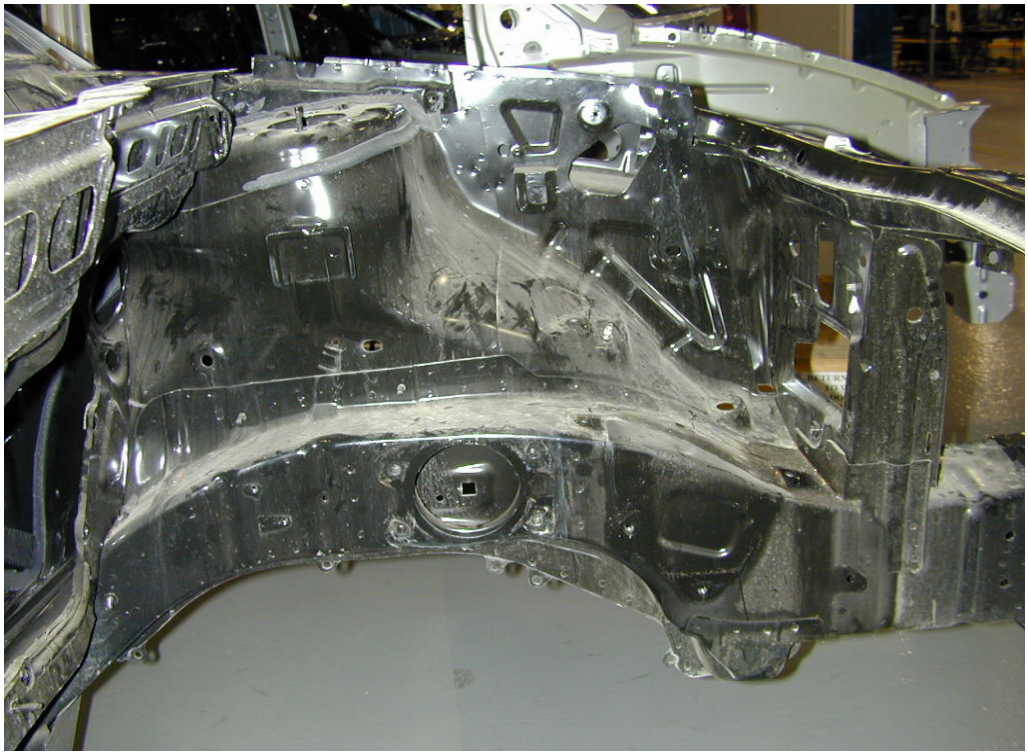


Figure 46: LH Front Rail Inboard Side View (2002 Saturn VUE)



Figure 47: RH Front Rail Inboard Side View (2002 Saturn VUE)

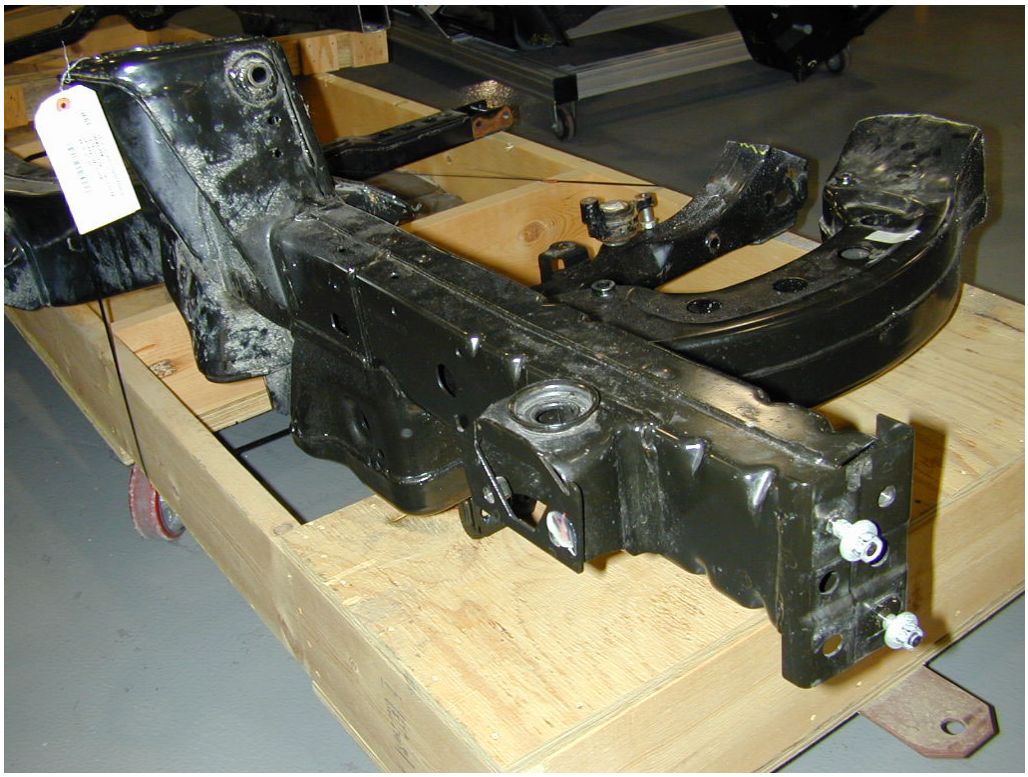


Figure 48: RH Front Rail Outboard Side View (2002 Saturn VUE)

2002 Lincoln LS

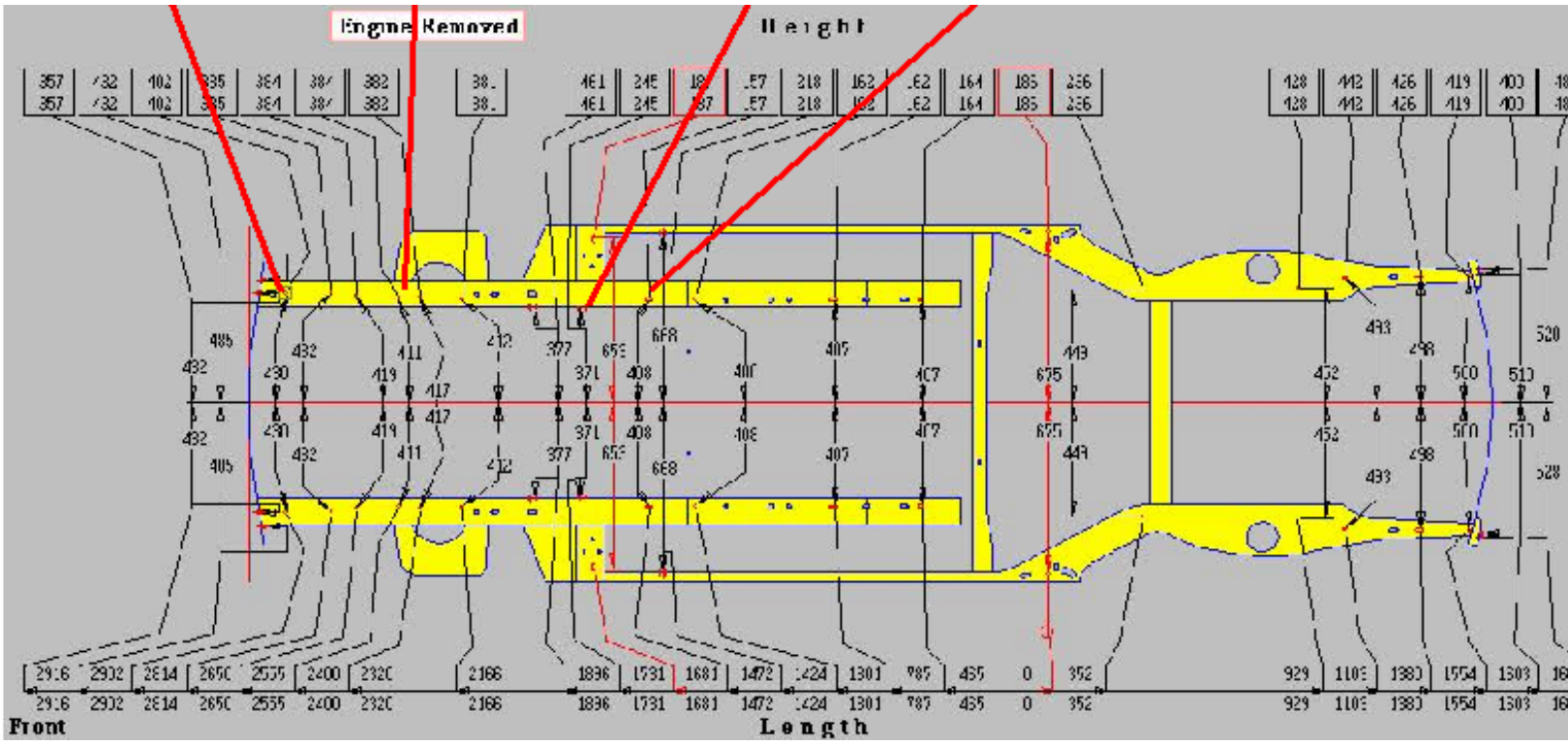


Figure 49: Lincoln LS - Rail Architecture

Rail Concept Development

Milestone 3

Lightweight Front End Structure Phase II

February 21, 2003

Auto/Steel Partnership

Abstract

This report documents the development of rail concepts for the Phase II donor vehicle, employing Advanced High Strength Steel materials (AHSS). These concepts would be further developed into concrete designs and would be evaluated for performance, cost and manufacturability. The most feasible design will eventually be prototyped, assembled into the donor vehicle and tested for NCAP performance. This is the ultimate goal of Phase II of the Lightweight Front End Structure Project.

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1. Objectives

This report documents the development of rail concepts for the Phase II donor vehicle, employing Advanced High Strength Steel materials (AHSS). These concepts would be further developed into concrete designs and would be evaluated for performance, cost and manufacturability. The most feasible design will eventually be prototyped, assembled into the donor vehicle and tested for NCAP performance. This is the ultimate goal of Phase II of the Lightweight Front End Structure Project.

The concepts were developed by holding discussions with the Lightweight Structures Project Team, and were guided by the knowledge gathered from Phase I of the Lightweight Front End Structure Project.

The concepts do not include design details, but focus primarily on preferred cross-section shapes, architectures, materials, manufacturing and assembly methods.

2. Rail Concepts Summary

Three concepts were developed during the course of this study:

- **Concept 1: Existing Rail Architecture**
  - Minimum modifications to the current rail design
  - Provide design direction
  - Filling holes and removing notches
  - Reducing flange width
  - Tailor-welded rails
  - AHSS materials
  - Gauge change
  - New bumper: Bumper 3 design from Phase I study

- **Concept 2: Best Stamped Design**
  - Improved performance and mass savings
  - Hexagonal rails
  - Modifying rail curvatures in side view (XZ) and plan (XY) view.
  - Modifying rail extension
  - Possibility of tying rails to rocker and cradle

- **Concept 3: Best Hydroformed Design**
  - Alternative to stamped design
  - Integrating parts
  - Hexagonal/octagonal rails
  - Reduce welding
  - Mass reduction by elimination of flanges
  - Superior material properties
  - Improved crush

3. Existing Rail Architecture

The front-end of the donor vehicle (*Figure 1*) has asymmetrical rails composed of HSLA steel with yield strength in the range of 314MPa to 359MPa. The LH rail has a significant bump in the XZ side view, due to powertrain clearance requirements (*Figure 2*). Both LH and RH rails have an inward bend in the XY plan view, due to tire flop clearance requirements. These bumps and bends promote buckling of the rails, as opposed to the desired axial crushing.

The front portion of the rails is comprised of inner and outer stampings that connect to the front bumper. The rear portion of the rails, called rail extension, is made up of several parts and extends beyond the front seats (*Figure 3*).

The cradle has a front attachment to the rails, but is not connected to the rails at the rear. The rails are weakly tied to the rocker through the torque box (*Figure 16*).

The bumper beam (*Figure 5*) is a roll-formed C-section with a yield of 848MPa.

A summary of grade and gauge for the rail and bumper assembly is included in *Table 1*.

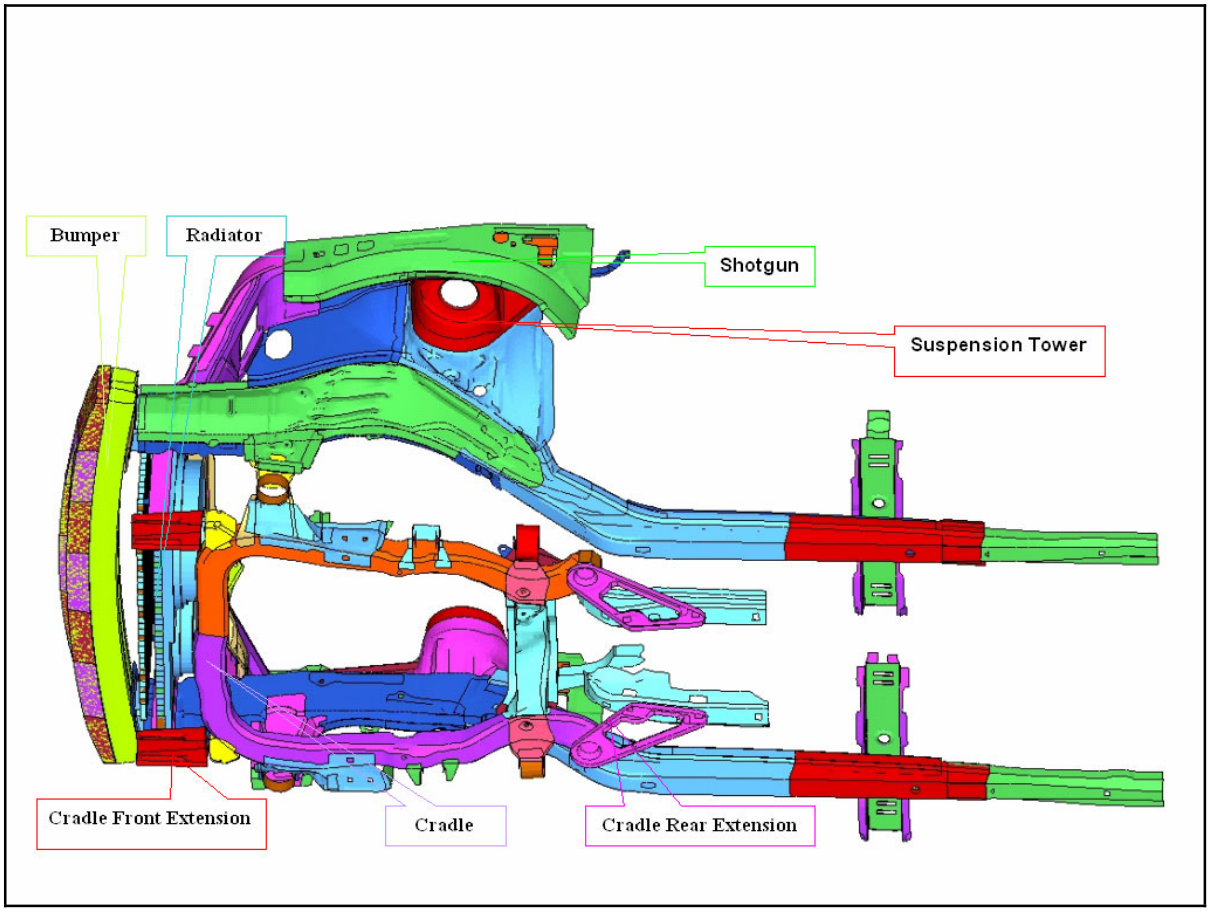


Figure 1: Front-End of Donor Vehicle

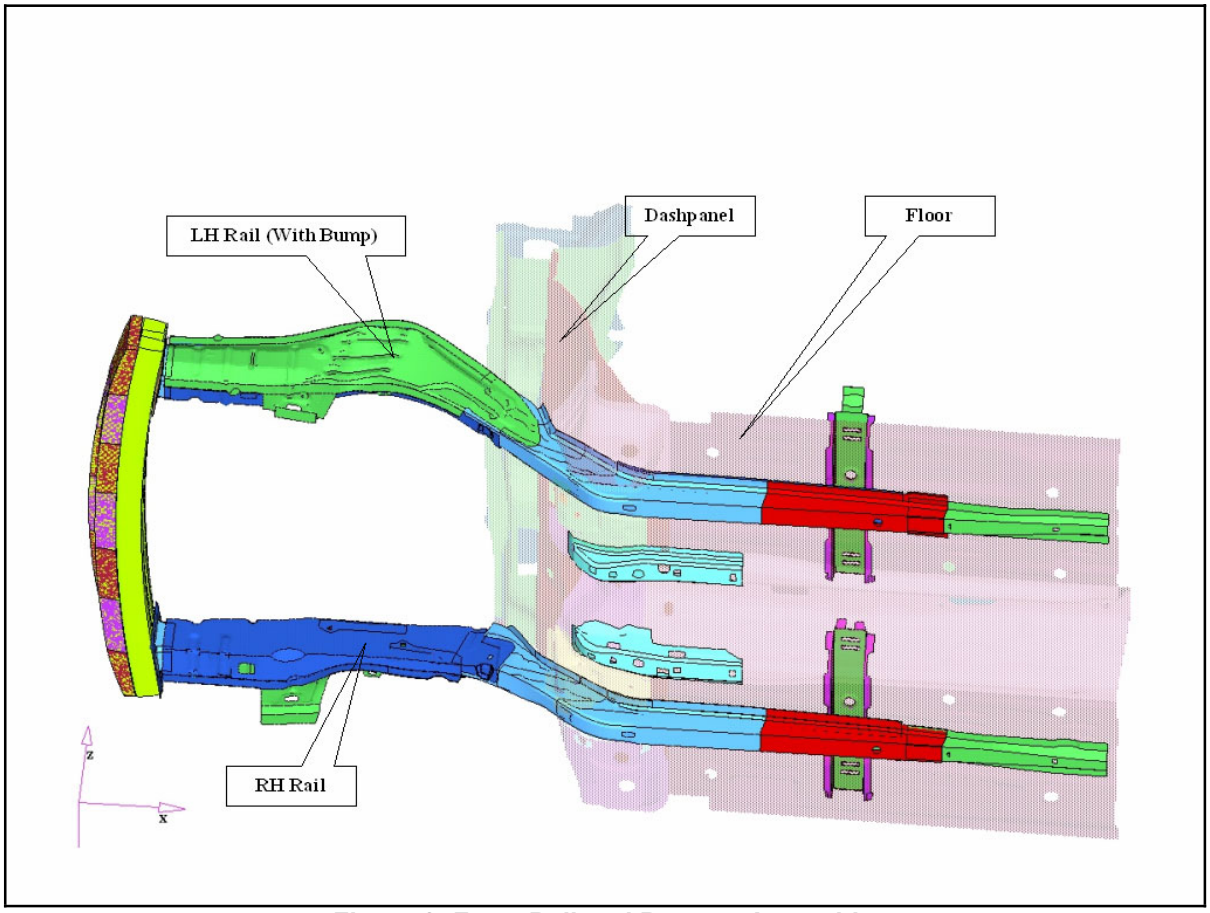


Figure 2: Front Rail and Bumper Assembly

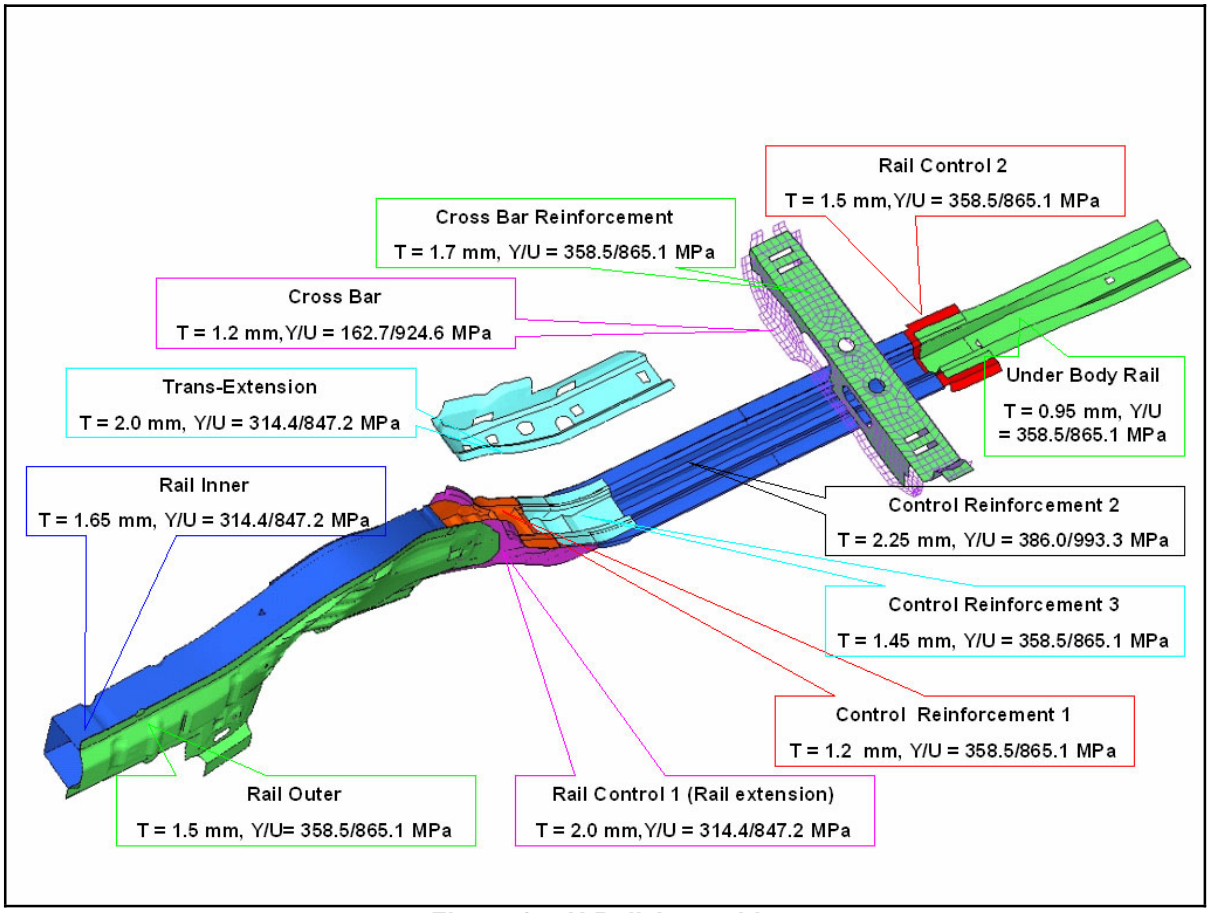


Figure 3: LH Rail Assembly

The front rail assembly has several reinforcements to alleviate the effect of narrowing of cross-section

and buckling due to curvatures. The reinforcements in the front portion of the rails are shown in *Figure 4*.

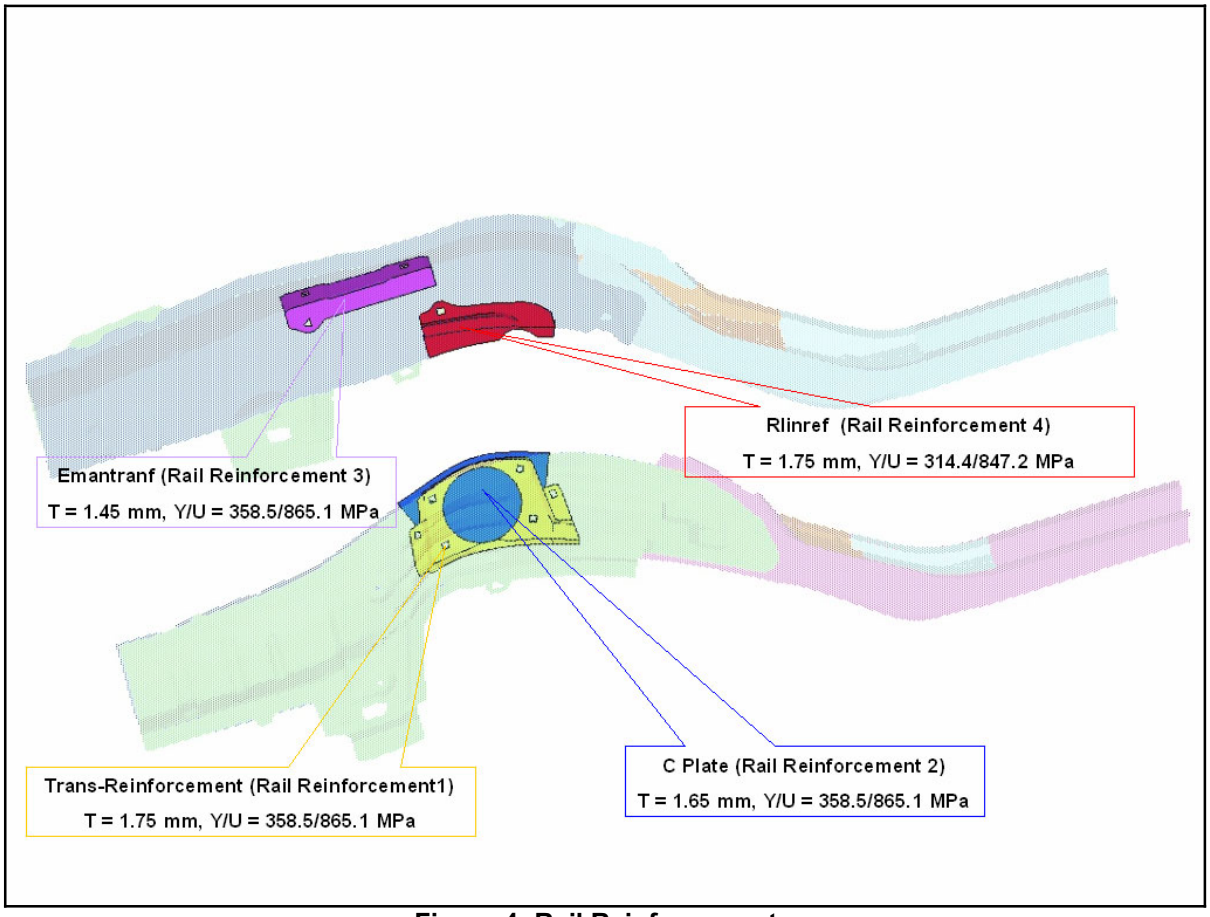


Figure 4: Rail Reinforcements

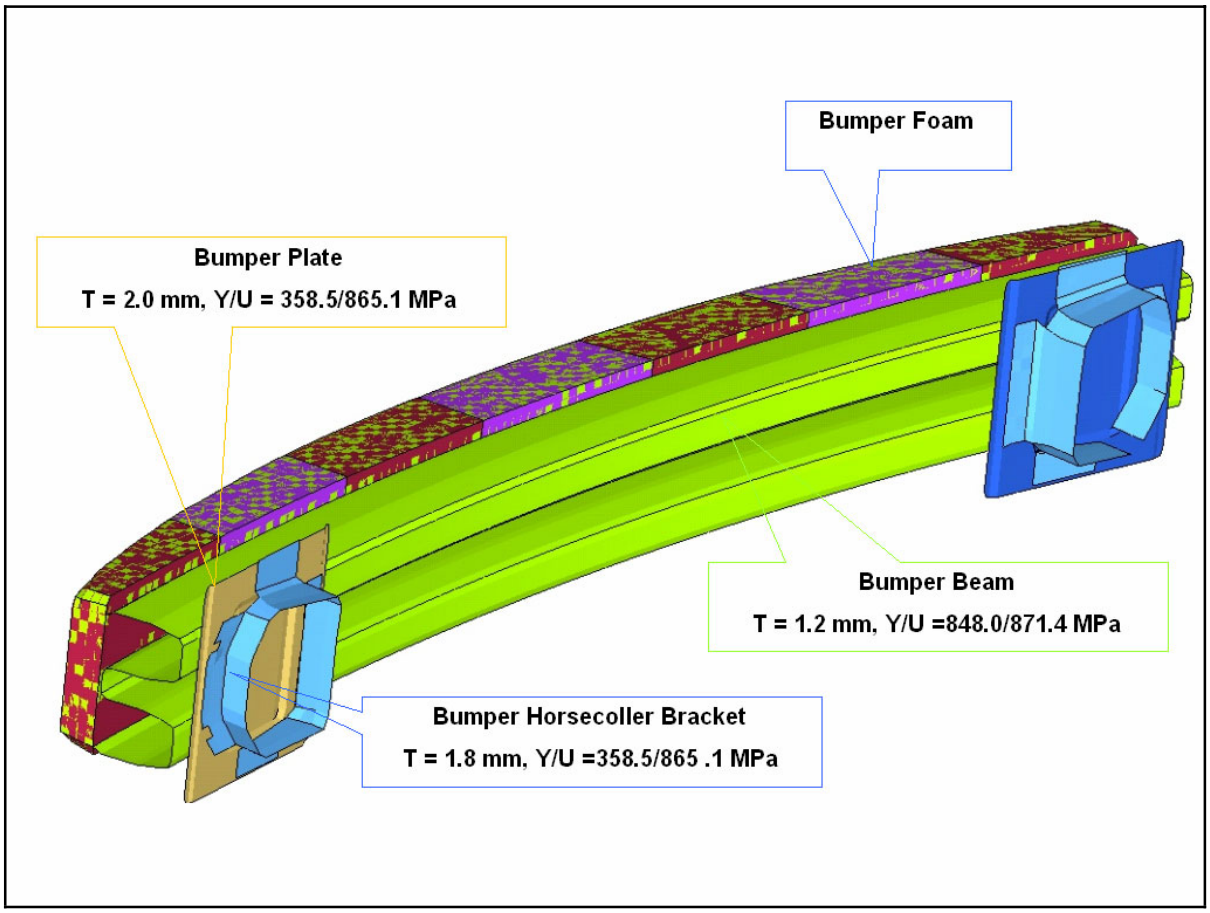


Figure 5: Bumper Assembly

Table 1: Summary of Grade and Gauge

Components	Thickness (mm)	Yield Strength (MPa)	Mass (Kg)
Rail Components (LH)			
Rail Inner	1.65	314.4	3.81
Rail Outer	1.5	358.5	1.50
Rail Control 1	2.0	314.4	3.83
Control Reinforcement 1	1.2	358.5	0.45
Control Reinforcement 2	2.25	386	2.82
Control Reinforcement 3	1.45	358.5	0.73
Rail Control 2	1.5	358.5	1.02
Under Body Rail	0.95	358.5	0.60
Cross Bar	1.2	162.7	1.38
Cross Bar Reinforcement	1.7	358.5	1.26
Trans-Extension	2.0	314.4	1.25
Rail Reinforcement 1	1.75	358.5	0.30
Rail Reinforcement 2	1.65	358.5	0.35
Rail Reinforcement 3	1.45	358.5	0.24
Rail Reinforcement 4	1.75	314.4	0.28
Bumper Components			
Bumper Beam	1.2	848	5.41
Bumper Horsecoller Bracket (LH	1.8	358.5	0.29
Bumper Plate (LH)	2.0	358.5	0.52
RH and LH Rails have the same material and thicknesses. Yield strength corresponds to quasi-static values			

A large hole in LH inner rail can be filled up (Hole 1, *Figure 6*), as it exists only to accommodate a

European powertrain package that will not be used in North America. A tooling hole on both LH and RH inner rails (Hole 2, *Figure 4*) can be reduced in size and can also be shifted, provided it is easily accessible. A notch on the LH inner rail flange can also be removed.

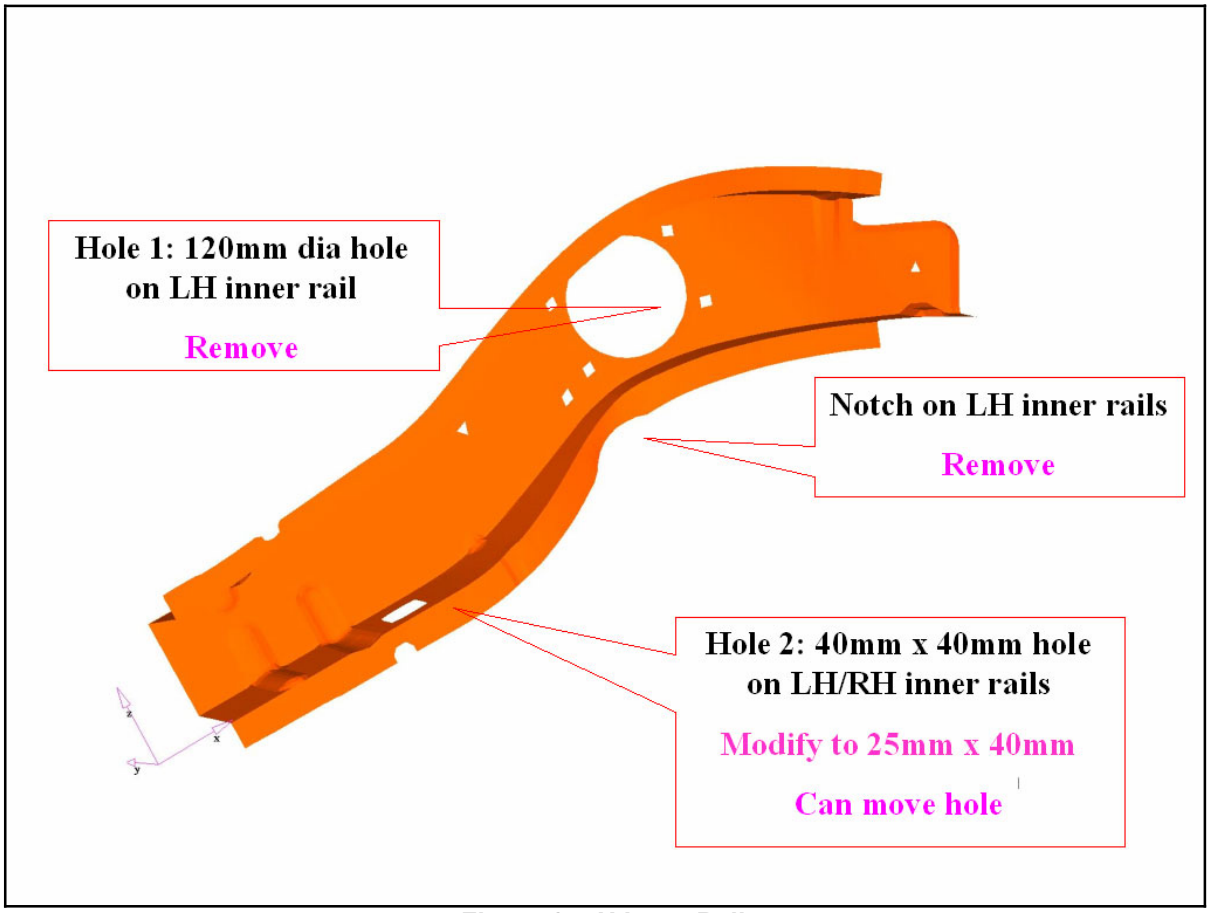


Figure 6: LH Inner Rail

The front portion of the rails will be assumed to be two-piece tailor-welded stampings (*Figure 7*). Weld

line A-A is preferred for better formability. The potential candidates for rail material are DP480/800 and DP700/1000.

All flanges will be reduced by 5mm such that the flat region of the flange is 16mm (*Figure 7*). This would result in a total flange width of about 21mm. This same width was employed in the flanges of the ULSAB rails.

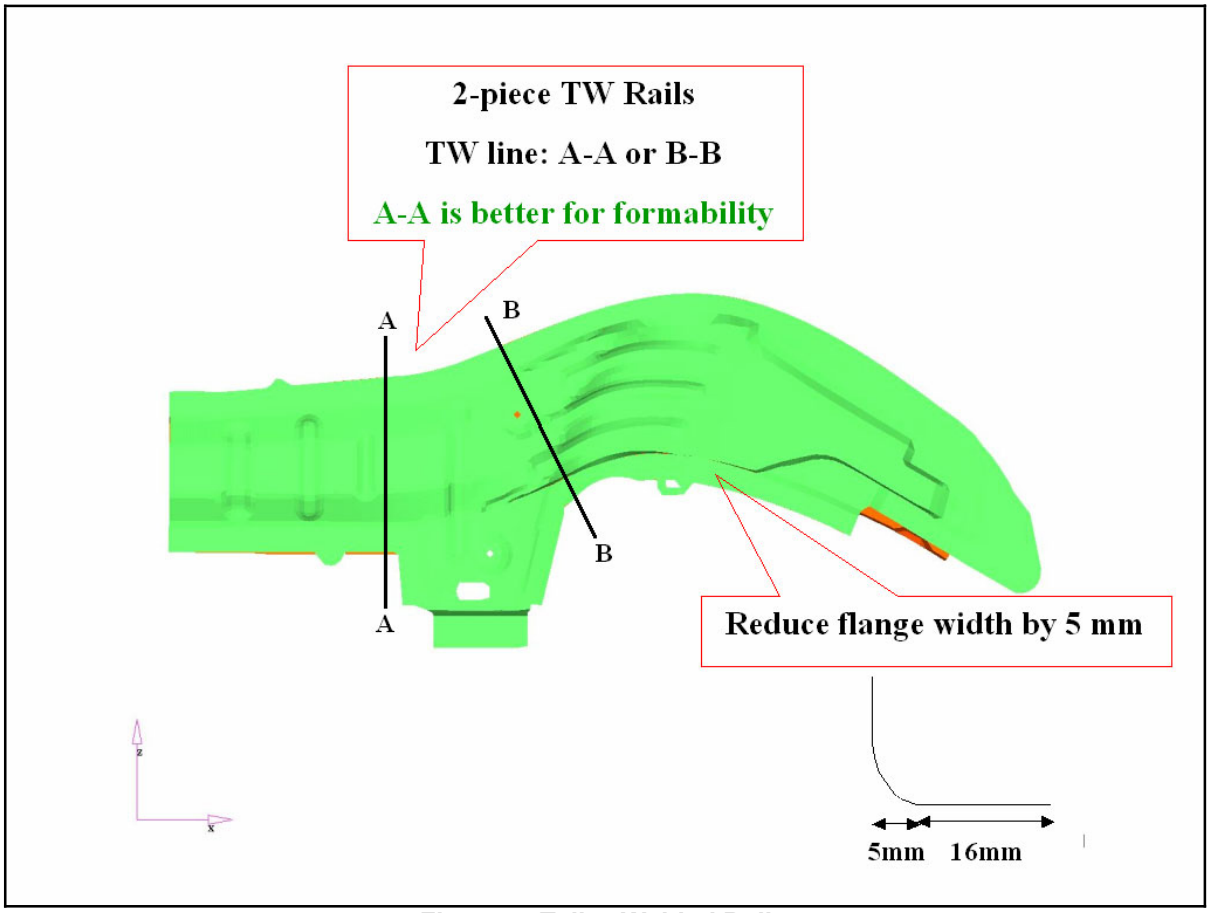


Figure 7: Tailor-Welded Rails

The existing bumper assembly will be replaced by the Bumper 3 design from Phase I. The bumper

sweep, width and height will be adjusted to optimize the performance of the front-end and to minimize mass. Potential candidates for bumper materials are DP700/100 and Martensite 950/1200. Martensite 1250/1520 and Boron steel may also be explored. Martensite 1250/1520 possesses higher yield, but displays limited formability. Intricate parts of high yield may be formed out of Boron steel. However, there are some concerns regarding oxidation and lack of uniformity in properties of Boron steel parts.

The current Bumper 3 design cannot be roll formed. If it is desired to roll-form the bumper, modifications will have to be made in order to create a constant cross-section. For the purpose of stamping, vertical flanges would be beneficial for formability (*Figure 9*). However, this would require a change in the bead pattern. Reducing the bumper sweep would also improve formability.

The front flange may be eliminated by employing single-sided welding (*Figure 9*). This would straighten the front profile and reduce the foam width.

Continuous welding is required for efficient performance of Bumper 3 design. Laserwelding and MIG welding are possible methods.

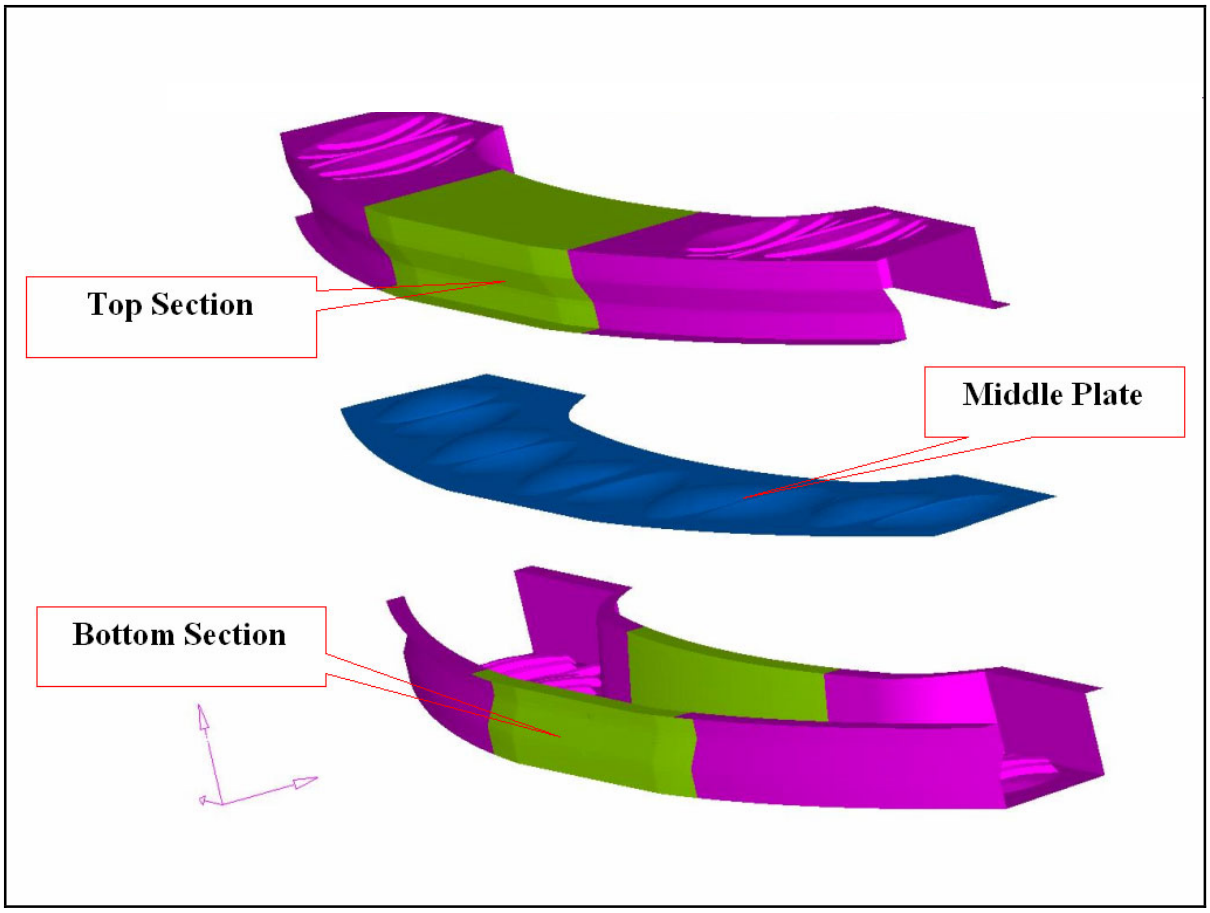


Figure 8: Bumper 3 Design (Phase I)

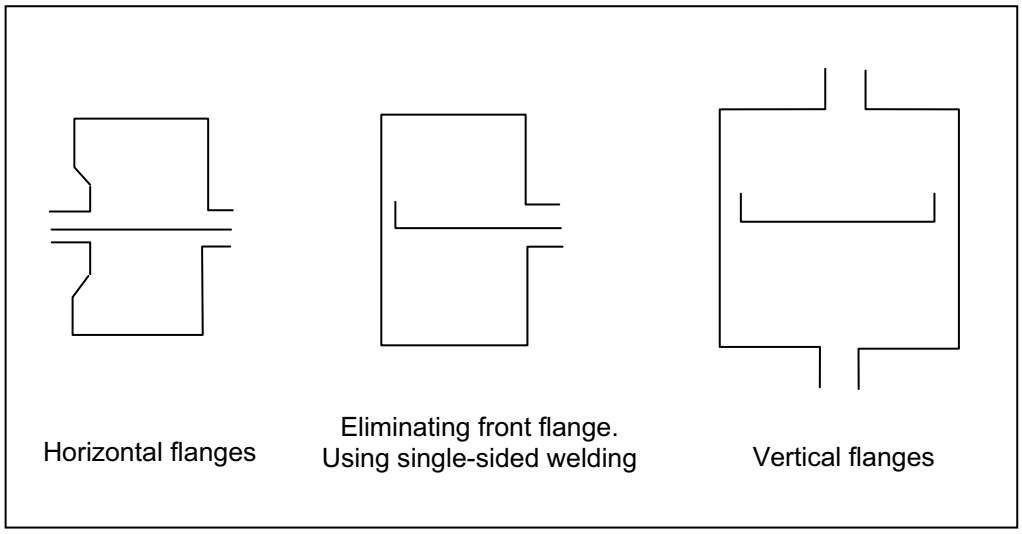


Figure 9: Bumper Beam Flanges

4. Best Stamped Design

The rail architecture will be modified in order to obtain the best-stamped design possible, subject to design packaging constraints. The potential candidates for rail material are DP480/800 and DP700/1000.

The LH rail XZ curvature will be modified (*Figure 10*), in order to reduce the buckling of the rails. Phase I study showed that lowering the top surface at the bump improved the crush characteristics of the rails, even though the rail cross-section decreased at the bump. The possibility of lowering the bottom surface at the bump will also be explored, as it will straighten the bottom profile.

The top surface of the front crush section of the rail will be raised, in order to bring it in line with the surface at the bump. The possibility of raising the bottom surface will also be examined, subject to the pendulum impact criterion restrictions.

Appropriate changes will have to be made to the front section of the RH rail, for the purpose of attachment to the bumper.

The effect of these changes will be to straighten and lower the rail profile at the bump, resulting in improved axial crush.

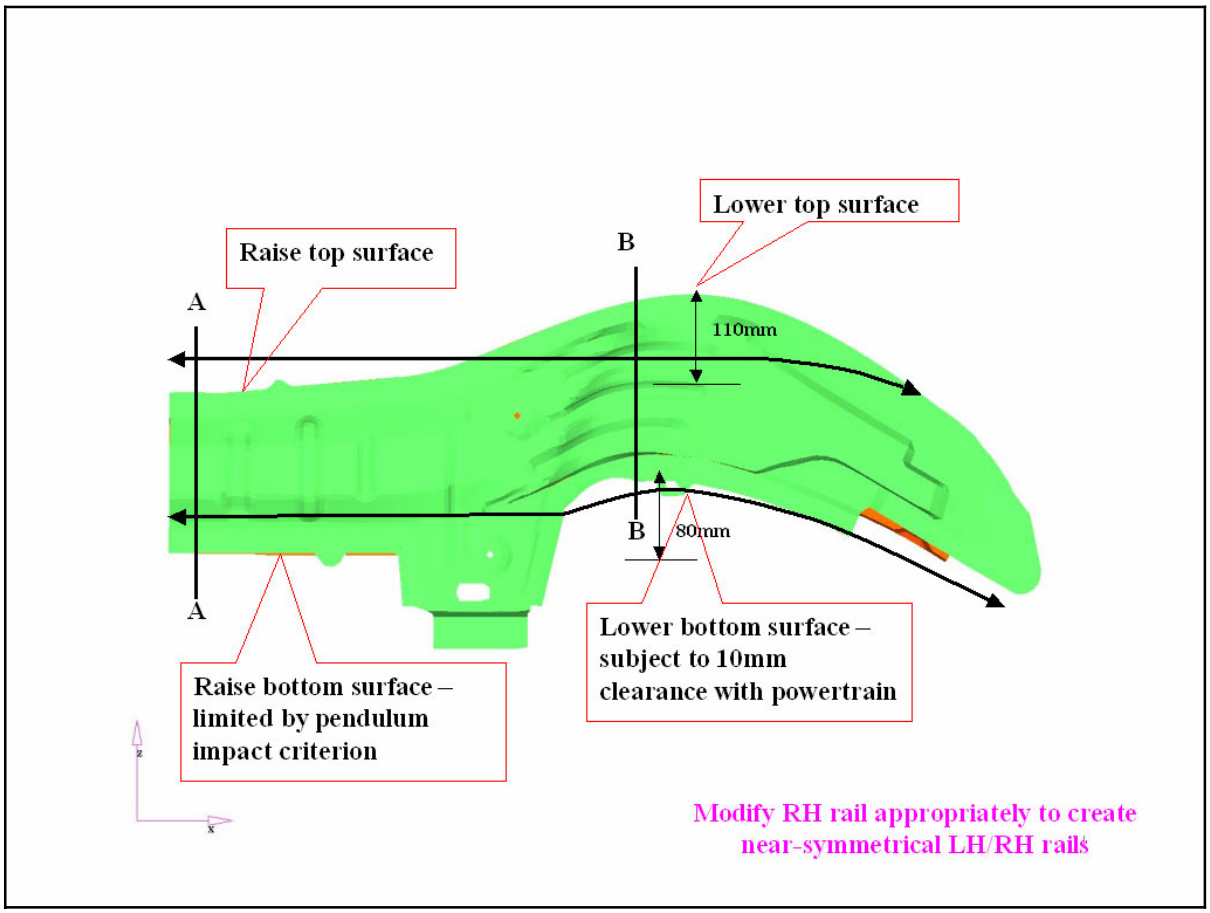


Figure 10: LH Rail - XZ Bump

The possibility of reducing the XY curvatures for both LH and RH rails will be explored (*Figure 11*).

The rails will be moved inboards, subject to clearance requirements. The rail section may be widened at the V-shaped grove in the tire flop.

Reducing the inboard bend will substantially decrease the lateral buckling of the rails, and will promote axial crush.

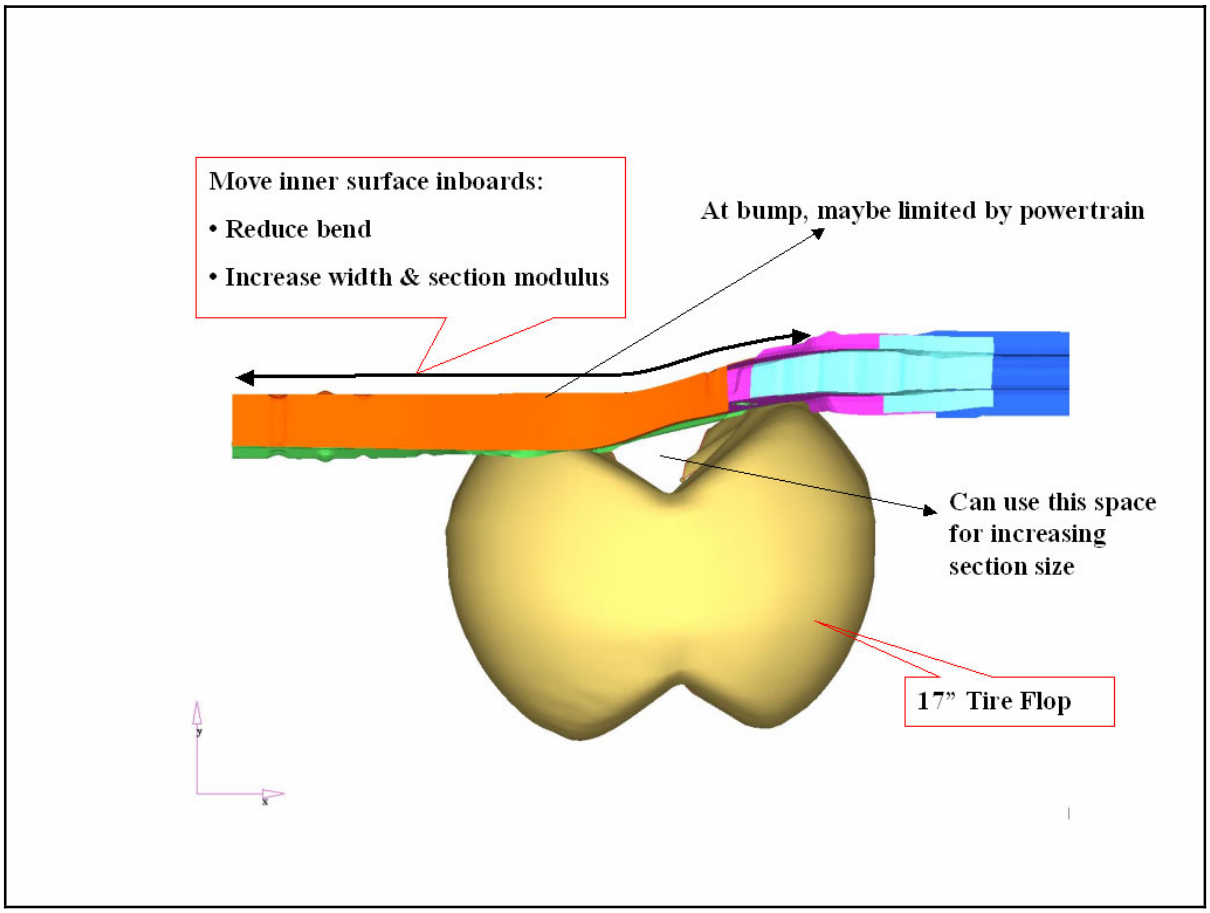


Figure 11: LH/RH Rail - XY Bend

The rail cross-section will be modified to a regular hexagon, so as to obtain a design that is better for formability and exhibits superior crush characteristics (Ref. 5). Flange positions will have to be changed, both for improving formability and crush performance (*Figure 12*). This would require some modifications in attaching the wheelhouse and the cradle. The flanges will be angled to improve formability. They maybe straightened in a re-strike operation, as straight flanges provide better surfaces for attachment.

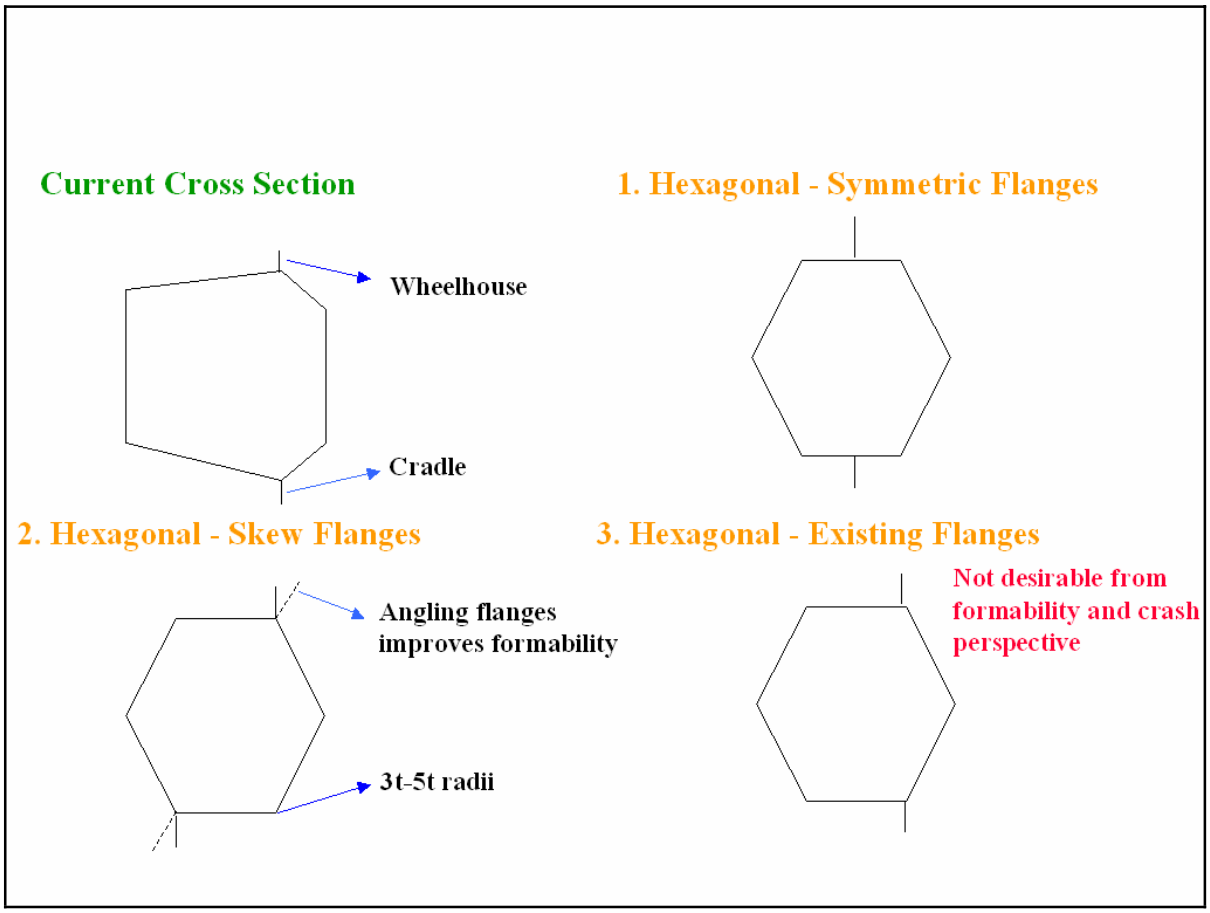


Figure 12: Rail Cross-Section and Flanges

The rail extension portion of the rails has 7 parts (*Figure 13*). This part of the rail assembly will be redesigned, so as to reduce the number of parts.

The rail extension section in front of the dash panel is a difficult part to manufacture, due to the inboard and upward curvatures. It is desirable to have a constant draw depth, in order to improve formability. The height of the rail extension can be increased in front of the dash, but not rearwards (*Figure 13*). However, the width may be increased, rearwards of dash panel. The length of the rail extension may also be reduced.

The possibility of 3-piece tailor-welded rails up to the dash and a roll-formed rail extension rearward of dash will also be explored.

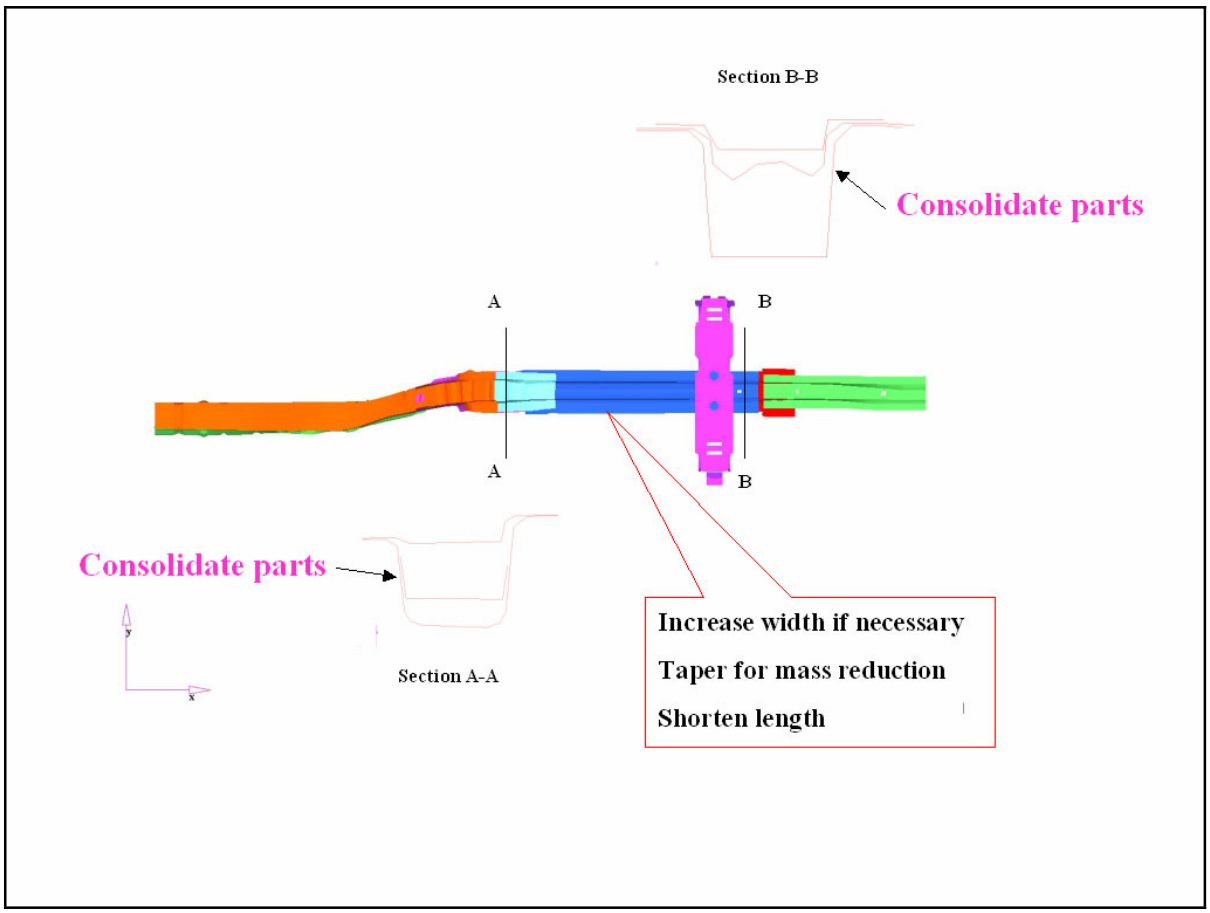


Figure 13: Rail Extension - Plan View

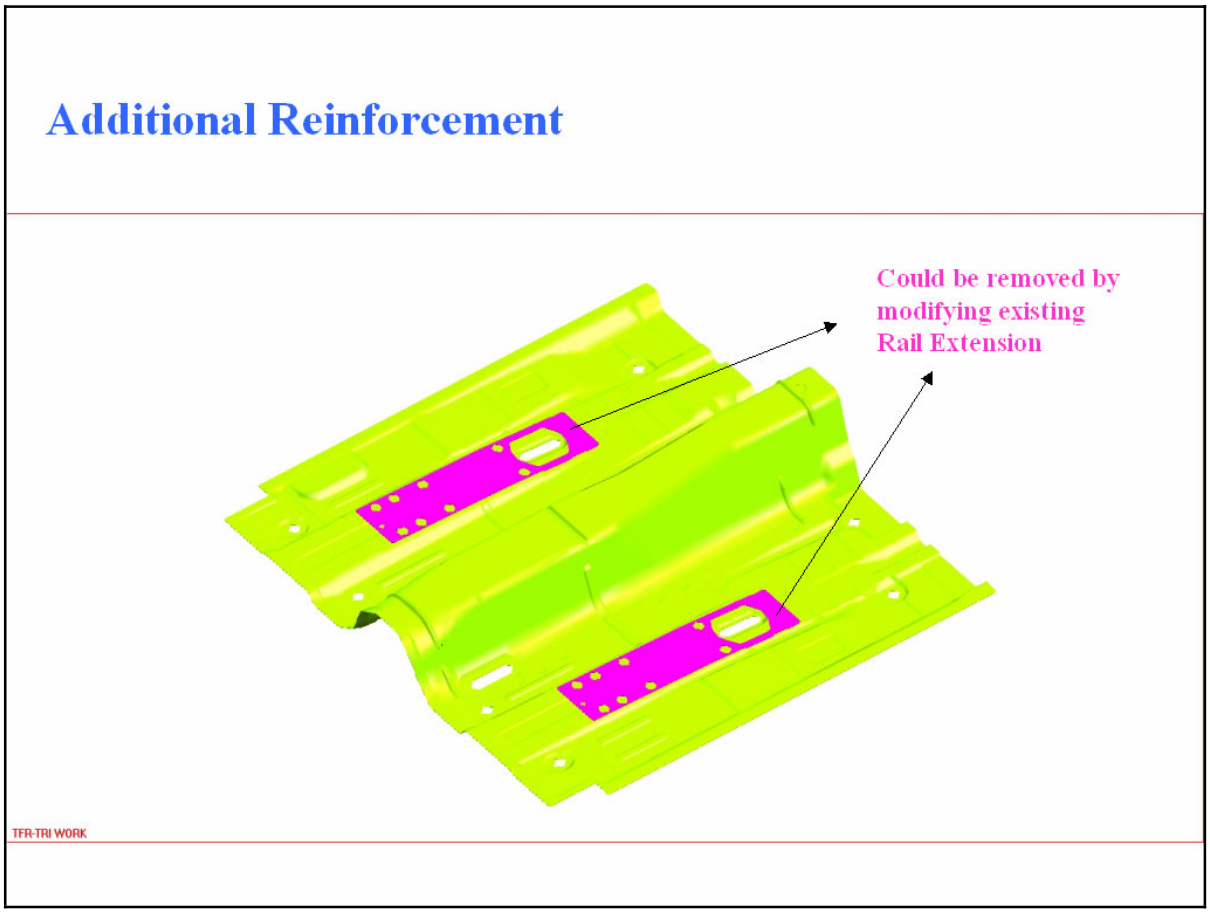


Figure 14: Additional Reinforcement

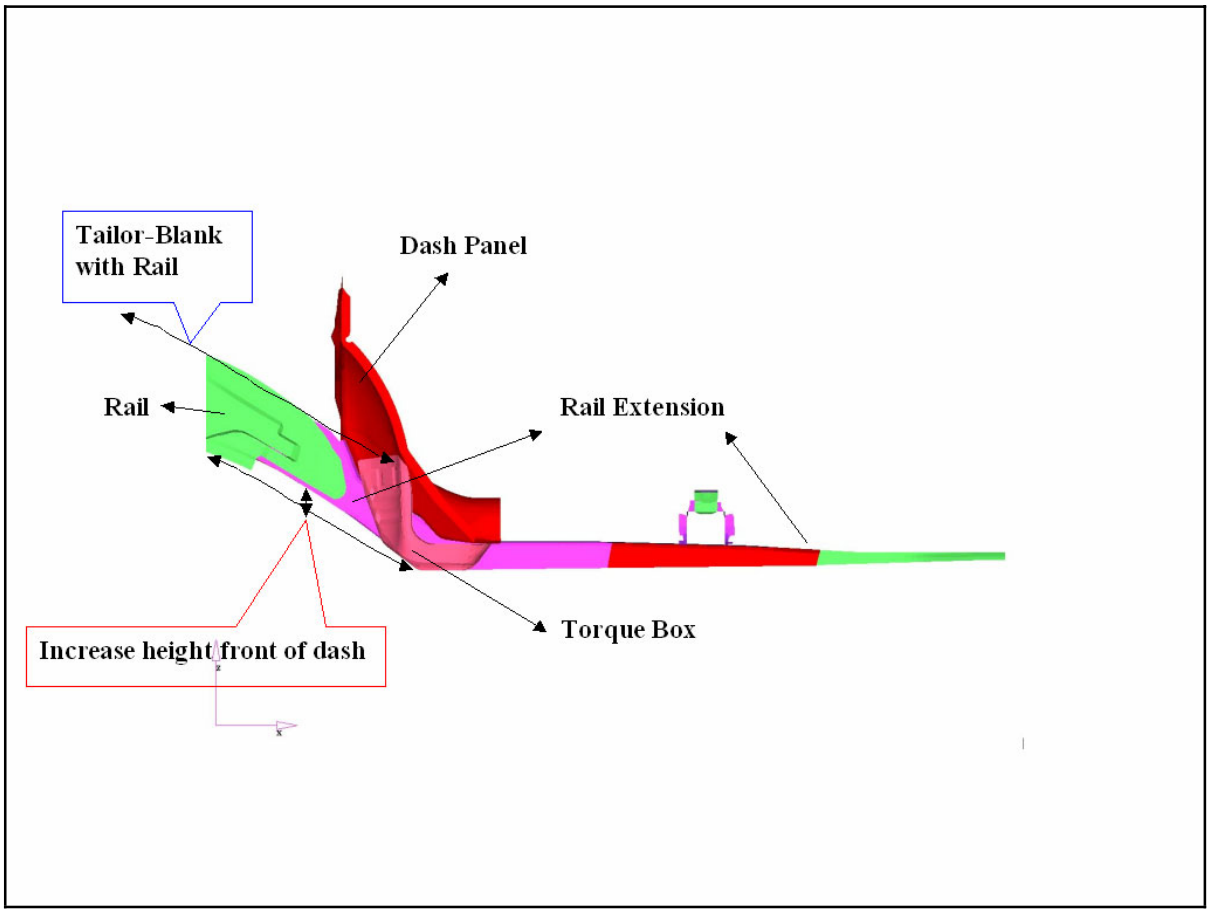


Figure 15: Rail Extension - Side View

Phase I study demonstrated that having a dual load path – one through the rail extension and another through the rocker, promotes a good front-end performance. In the current design, the rails are tied weakly to the rocker, through the torque box. The possibility of an improved rail-rocker connection will be examined. This would require a re-tooling of the torque box (*Figure 16*).

The front-end performance may also be improved by connecting the cradle to the rails, at the rear. This would require a modification to the cradle mount bracket only (*Figure 16*).

An additional cross member would reduce the lateral buckling of the rails. However, this would incur extra tooling costs. There may also be clearance issues that may rule out a cross member in the desired location.

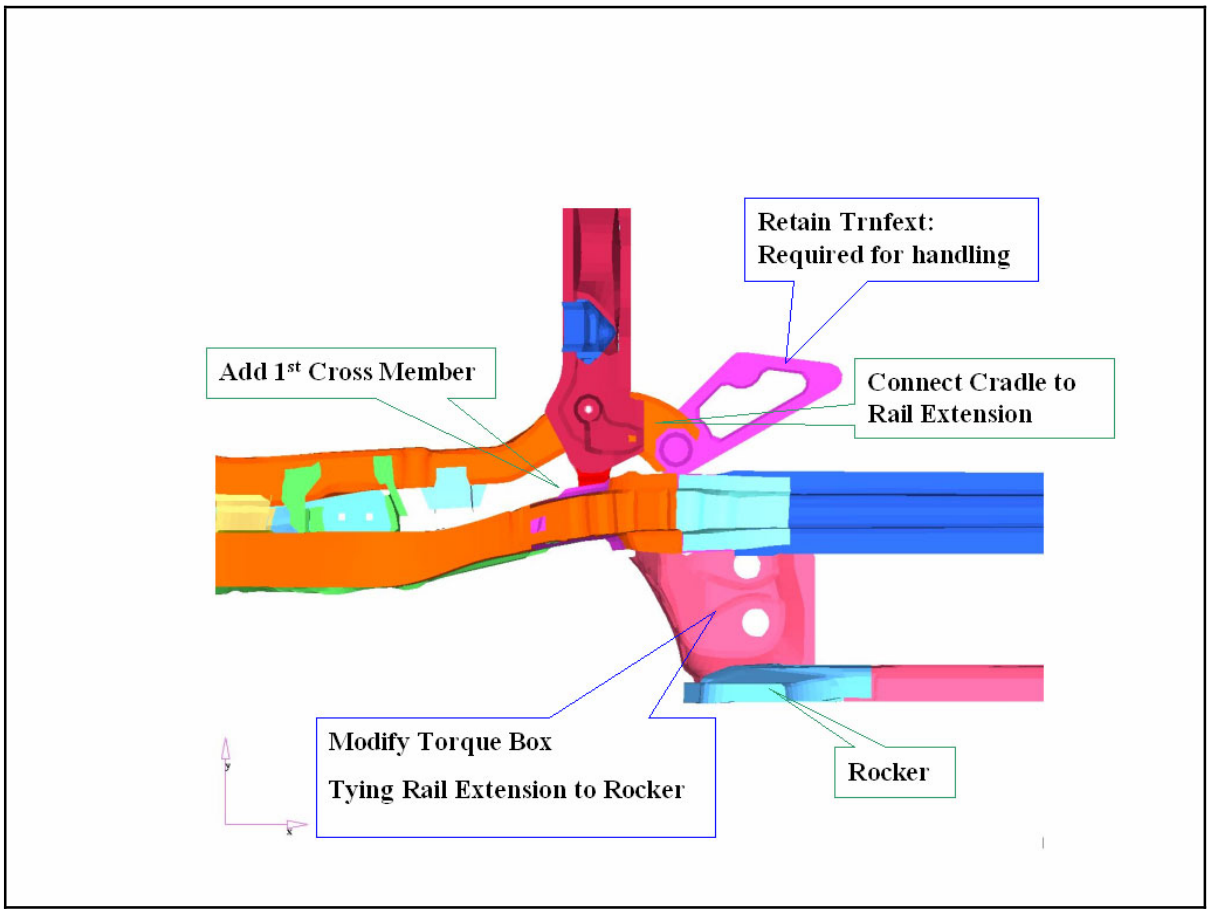


Figure 16: Tying Rails to Rocker and Cradle

The front crush portion of the cradle, called the cradle extension, may be re-designed for improved

energy absorption (*Figure 17*). The cradle extension was found to be a major energy absorption component in the Phase I study. This would require a re-tooling of the part. However, the cradle extension is very simple in design and it may be possible to prototype the part with a minimum cost penalty.

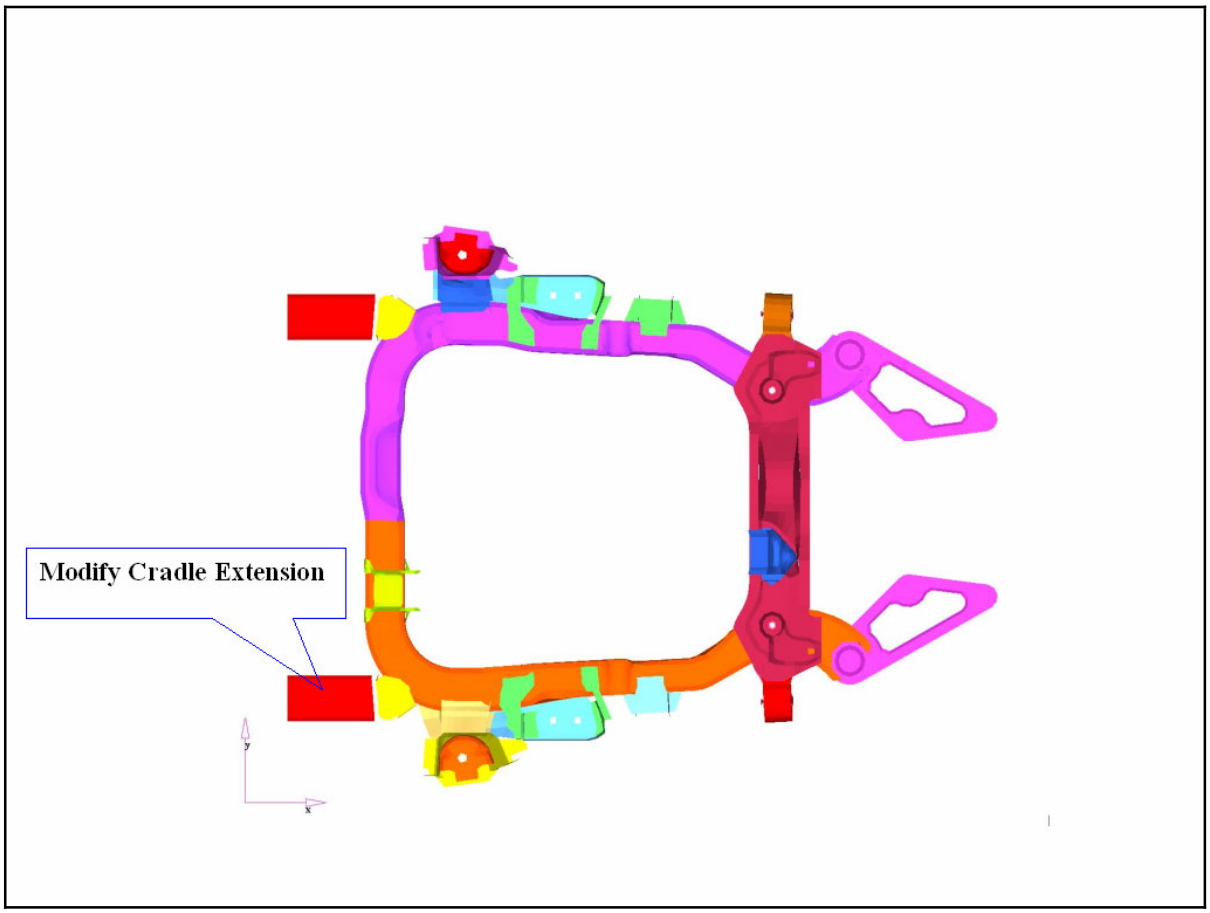


Figure 17: Cradle Extension

5. Best Hydroformed Design

Tube hydroforming is an alternative method of manufacturing front rails. Hydroforming has been used widely in cradles and side rails for frames. It has not been used in side rails for BIW vehicles, the chief limitation being the integration of a hydroformed part into a stamped front-end. The problem appears to be more of a reluctance to change the design paradigm, rather than of process limitation. Hydroforming does offer several advantages, both in manufacturing and in performance (Ref. 5). Hence, the third concept will focus on developing hydroformed rails.

The main restriction of the hydroformed process is the perimeter change limitation. Typically, the perimeter cannot vary more than 5%, along the length of the part. Larger increases are only possible at the ends and require more elaborate tooling.

A preliminary look into the packaging space indicates that the limiting perimeter occurs at the top of the XZ bump (*Figure 18*). This minimum perimeter would determine the rail design. However, it will be required to increase the perimeter in the front crush section of the rails, and the portion of the rail extension in front of the dash. End feeding may allow for this increase in perimeter.

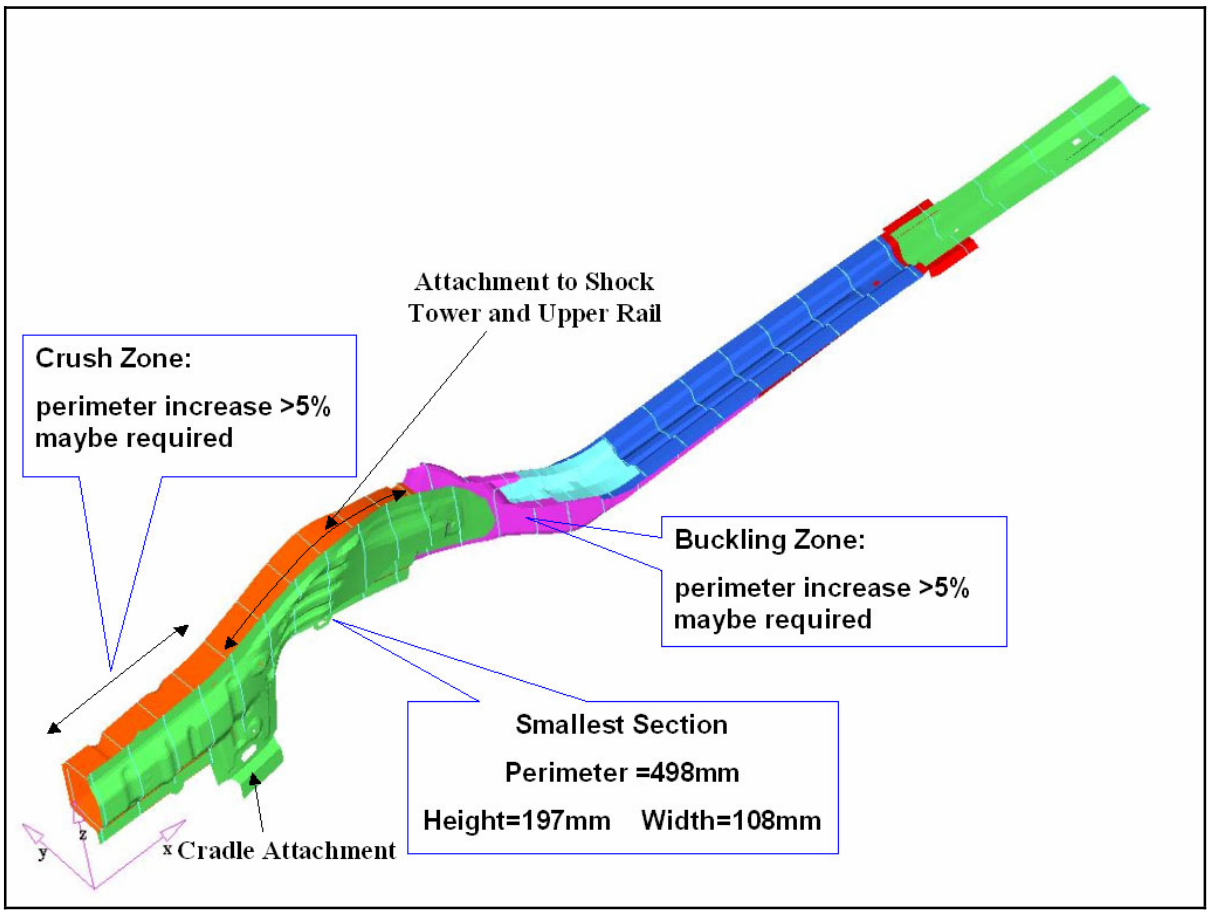


Figure 18: LH Rail - Perimeter Requirements

Another limitation for hydroforming is part curvature. Typically, bend radii should be greater than two times the tube diameter. Curvatures in two planes complicate the design, and should be kept equal.

Corner radii should be greater than four times the tube thickness. This is not a potential problem as the rail cross section will be hexagonal and there is no design requirement of tight corners.

The possibility of using tailor-welded tubes will be explored. It is possible to implement a gauge change of 1.3mm to 1.7mm at ends, without the use of tailor-welded tubes.

The portion of the rails rearwards of dash will be stamped or roll-formed, as there is no advantage of using hydroforming for C-sections (*Figure 13*).

The potential candidates for rail material are DP480/800 and DP700/1000. Since hydroforming can result in significant work hardening, it may be desirable to use a lower grade material for the tube, such as DP350/600 in place of DP480/800. The finished part would exhibit higher yield than the base metal.

Parts that have to be attached to the rails will have be joined using single-sided welding such as laser or MIG welding. Some small modifications in the flanges of those parts will also be required.

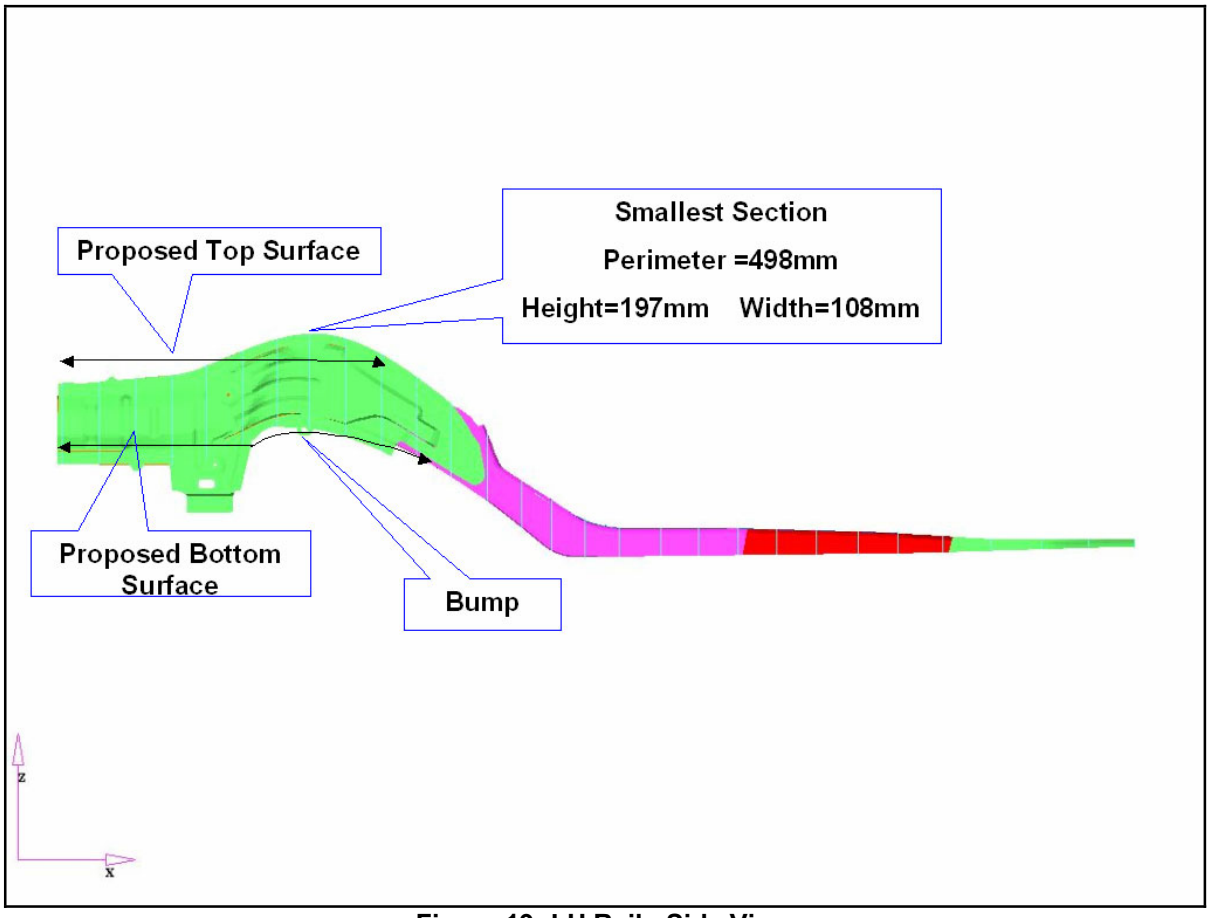


Figure 19: LH Rail - Side View

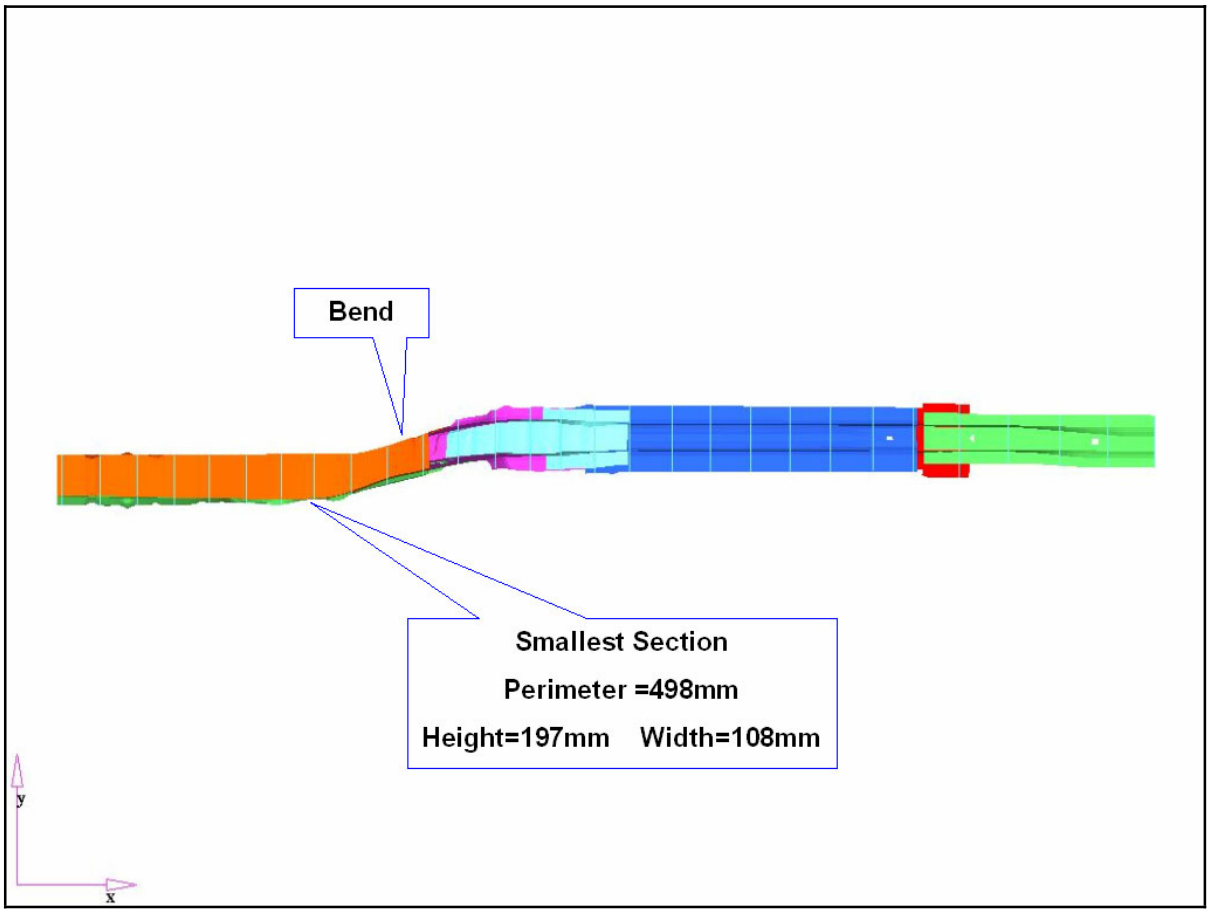


Figure 20: LH Rail - Plan View

6. Design Comparisons

The main utility of **Concept 1** is to evaluate the potentials of the existing architecture and provide a design direction to the development of Concepts 2 and 3. The effect of filling holes and reducing flange widths will be evaluated. Furthermore, the advantages of using AHSS and tailor-welded blanks will also be ascertained. The Bumper 3 design from Phase 1 will be interfaced in Concept 1.

Concept 2 represents the best possible stamped design that would result in improved performance and mass savings. Optimum rail curvatures and cross-sections will be developed, subject to packaging constraints. Multiple rail extension parts will be consolidated into fewer parts. Extensive formability studies will be required to prove design feasibility.

Concept 3 takes advantage of the hydroforming process to yield a design that has superior material properties, better crush behavior, reduced mass and fewer parts. It would also reduce significantly welding requirements. However, attaching mating stamped parts to the hydroformed rail assembly will be an issue.

In terms of manufacturability, both Concept 2 and 3 present challenges with AHSS materials. Ultimately, the feasibility of prototyping a rail design will dictate which of the two concepts would eventually be selected.

The **Bumper 3** design presents some challenges for stamping, and may require suitable modifications in order to achieve a feasible design. Roll forming is also possible, if certain design concessions are made. The possibility of using Boron steel will also explored, as its use may allow all design features to be included, without compromising performance. However, there are some concerns regarding oxidation and lack of uniformity in properties of Boron steel parts.

7. Conclusions

Three rail concepts, employing AHSS materials, have been developed for the Phase II donor vehicle. **Concept 1** merely provides design direction, whereas **Concept 2** (best-stamped design) and **Concept 3** (best-hydrofromed design) are the two candidates for the final design that will eventually be prototyped.

8. Future Work

The three concepts created in this study would be further developed into concrete designs and would be evaluated for performance, cost and manufacturability. The most suitable design will eventually be prototyped, assembled into the donor vehicle and tested for NCAP performance. This is the ultimate goal of Phase II of the Lightweight Front End Structure Project.

9. References

1) *ULSAB Model with Upgraded Powertrain*, Milestone 14, SPHINX, Phase I.

2) *Upgraded Powertrain: D.O.E. Parametric Study*, Milestone 15, SPHINX, Phase I.

3) *Library of Designs for KB: Upgraded Powertrain*, Milestone 24, SPHINX, Phase I.

4) *Third Bumper Design*, Milestone 18, SPHINX, Phase I.

5) *Automotive Steel Design Manual*, AISI and A/SP.

6) *Phase II Proposal: Automotive Lightweight Structure Design Utilizing Advanced High Strength Steels,* Quantech Global Services.

Validated FE Models

Milestone 5

Lightweight Front End Structure Phase II

May 6, 2003



Auto/Steel Partnership

Abstract

This report documents the validation of the donor vehicle FE models obtained from the OEM. These FE models will be employed to assess various rail and bumper concepts developed in Phase II of the Lightweight Front End Structure Project.

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1. Objectives

The aim of this study was to document the responses of the donor vehicle FE models, as received from the OEM. The FE models obtained from the OEM were analyzed with minimum changes, and the results compared with the available test results. These FE models will be employed to assess various rail and bumper concepts developed in Phase II of the Lightweight Front End Structure Project.

2. Results Summary

The following modifications were made to the original crash FE model.

- **Mass**
  - The lumped masses were adjusted so as to match the test vehicle mass.
- **Seat model**
  - The LH seat model was reflected to obtain the RH seat model, which was missing from the original FE model.
- **Units change**
  - The units of the crash model were changed from mm-kg-msec to mm-tonnes-sec, in order to match the IIHS deformable barrier units
- **Miscellaneous changes**
  - The original FE model resulted in some warnings and errors, and was suitably corrected.

The NCAP and IIHS results are summarized in *Table 1* and *Table 2*.

Table 1: NCAP Results

B Pillar Pulse	FE Model	Test Data
LH	35.7 g @ 58.3 ms	39.6 g @ 40.1 ms
RH	34.3 g @ 63.1 ms	42.1 g @ 53.3 ms

Table 2: IIHS Results

Location	Intrusion @ 250ms (cm)
Left Toepan	11.6
Center Toepan	15.4
Right Toepan	16.7
Brake Pedal	6.9
A-B Pillar Closure	10.0
Steering Column Upward Movement	11.2
Steering Column Rearward Movement	4.6

3. Model Modifications

The mass and CG of the FE model obtained from the OEM (*Figure 1* and *Figure 2*) was adjusted so as to match the test vehicle mass. Only the lumped masses were modified for this purpose. *Table 3* and *Table 4* give a summary of the test vehicle data.

The RH seat model was missing in the FE model. The LH seat model was reflected in order to obtain the RH seat model (*Figure 3*).

The units of the crash model were changed from mm-kg-msec to mm-tonnes-sec, in order to match the IIHS deformable barrier units. The units of the crash model were modified, as it was easier to verify the change in the vehicle model as compared to the barrier.

Table 3: Test Vehicle Data

Vehicle Parameter	Value		
Engine	V6 3.4 liters		
Transmission	4-speed automatic		
Body Type	Sedan		
Test Vehicle Mass (including dummies)	1778 kg		
Dummy Mass	156 kg		
Vehicle CG (car coordinates, mm)	2737.0	5.8	478.0
Vehicle Length	4665MM + FASCIA		
Vehicle Width	1775 MM		
Vehicle Speed	56.4 kph		
Principal Force Direction	90 degrees		

Table 4: Accelerometer Location

Location	Sensor Axis	Car Coordinates (mm)		
		X	Y	Z
Rear rocker on left side of vehicle	X-Global	3977	-678	209
Rear rocker on right side of vehicle	X-Global	3977	678	209
Top of engine block	X-Global	1483	104	788
Bottom of engine block	X-Global	1483	104	131

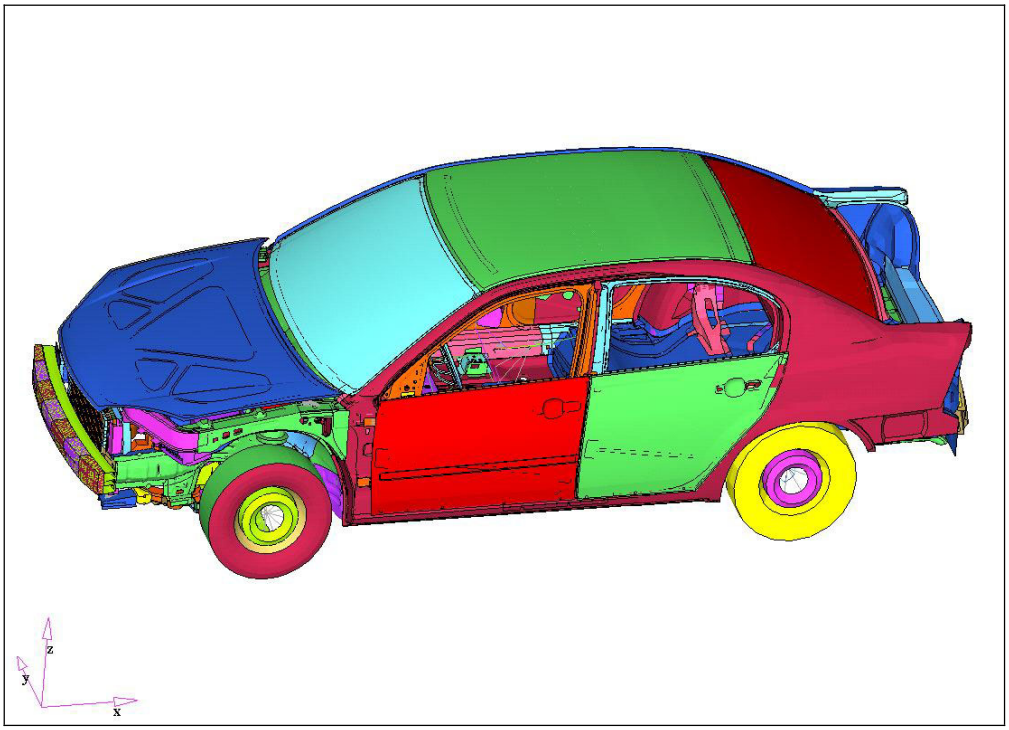


Figure 1: NCAP Full Vehicle FE Model

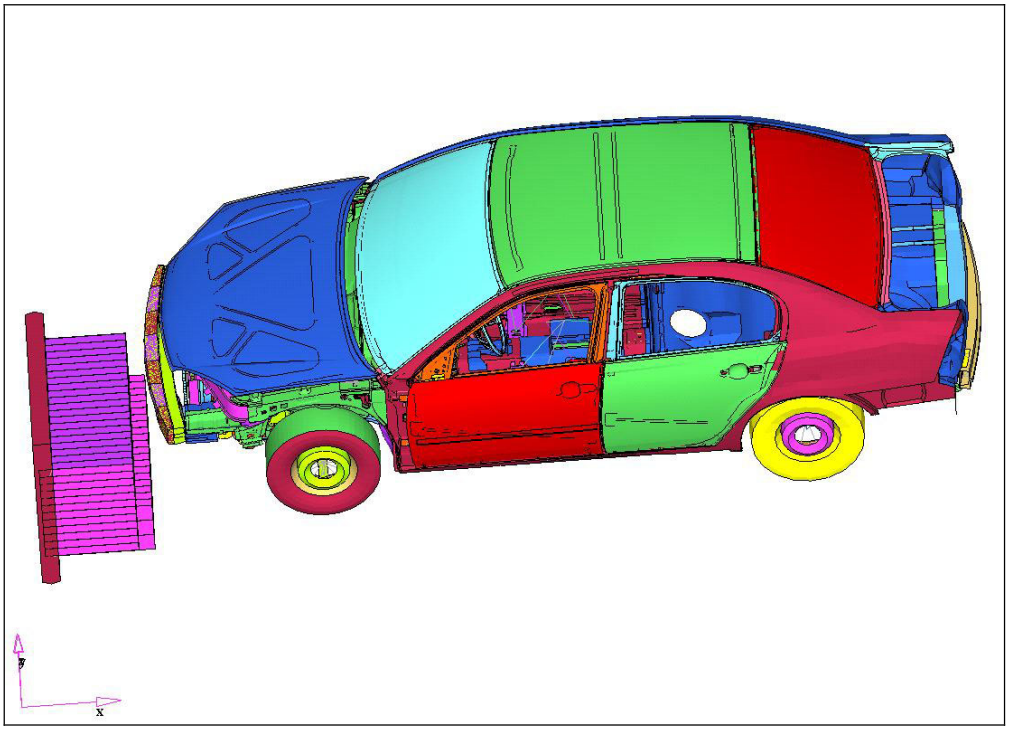
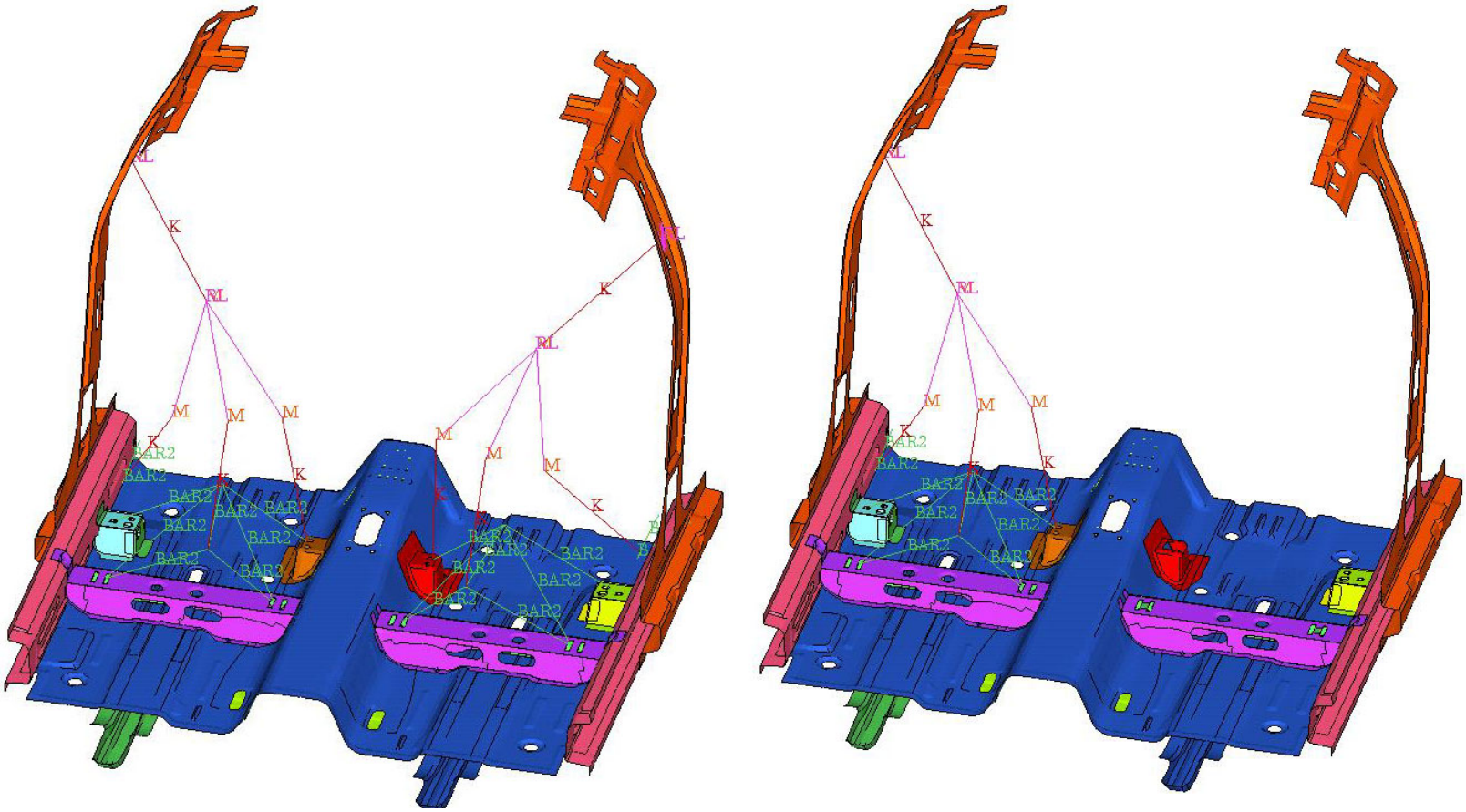


Figure 2: IIHS Full Vehicle FE Model



Original Seat Model **Modified Seat Model**

Figure 3: Seat Model

4. NCAP Response

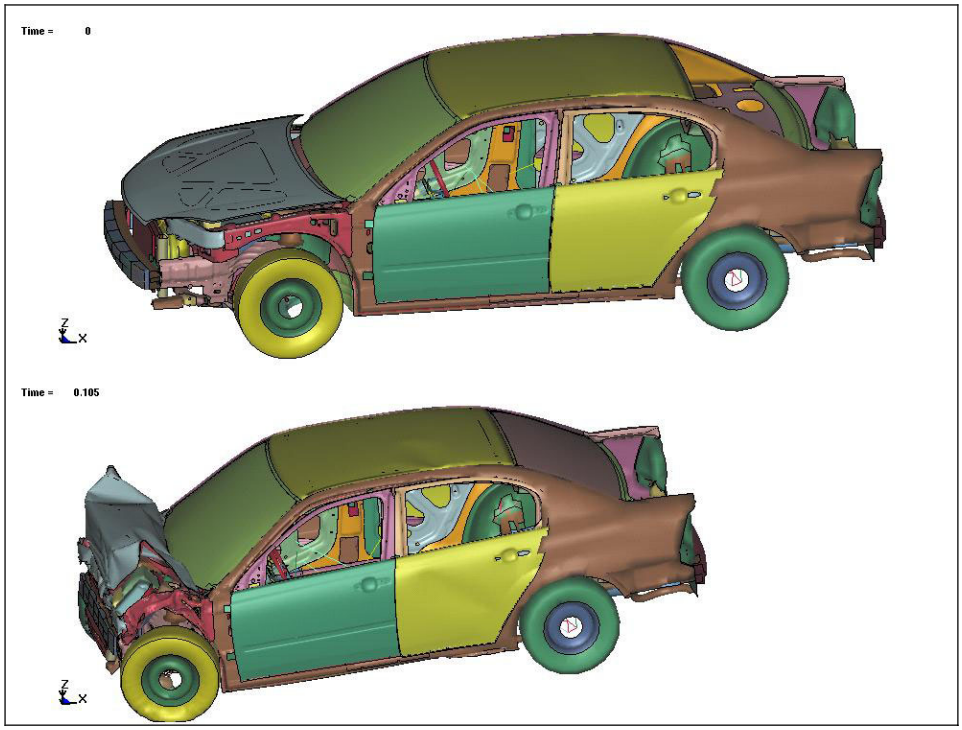


Figure 4: Deformation of Full Vehicle

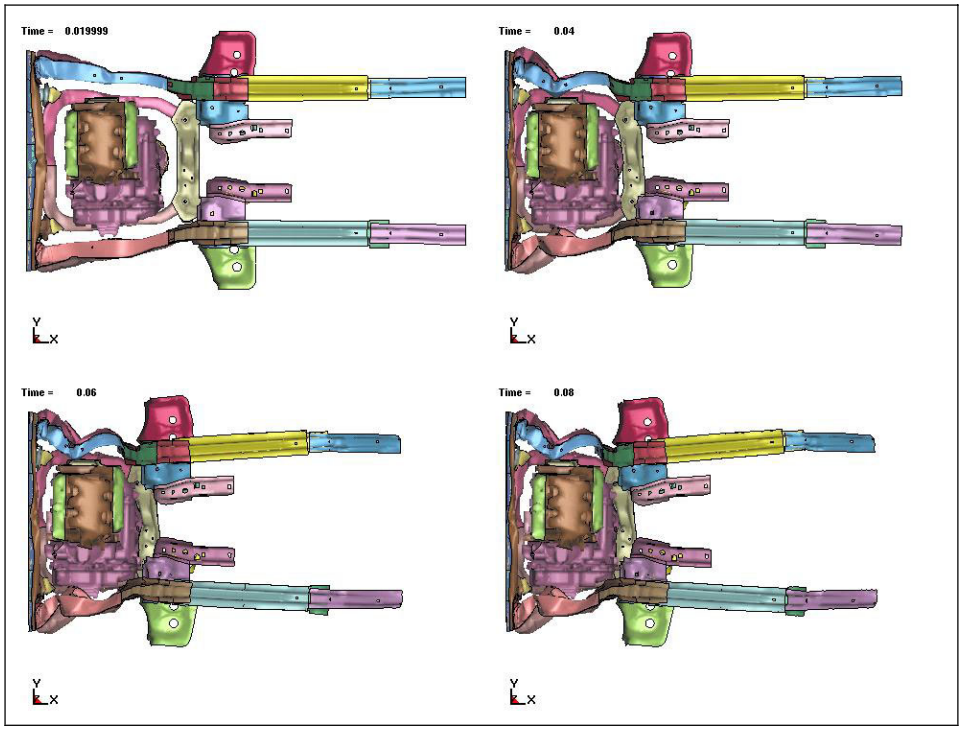


Figure 5 Deformation of Front End (Top View)

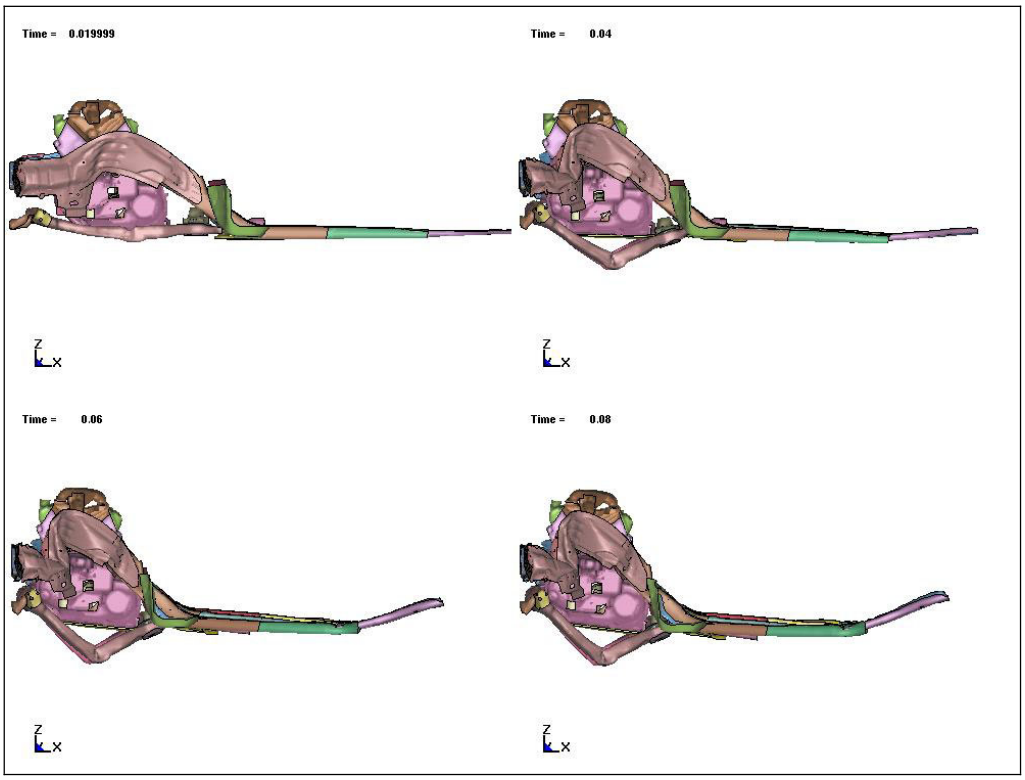


Figure 6: Deformation of Front End (Left Side View)

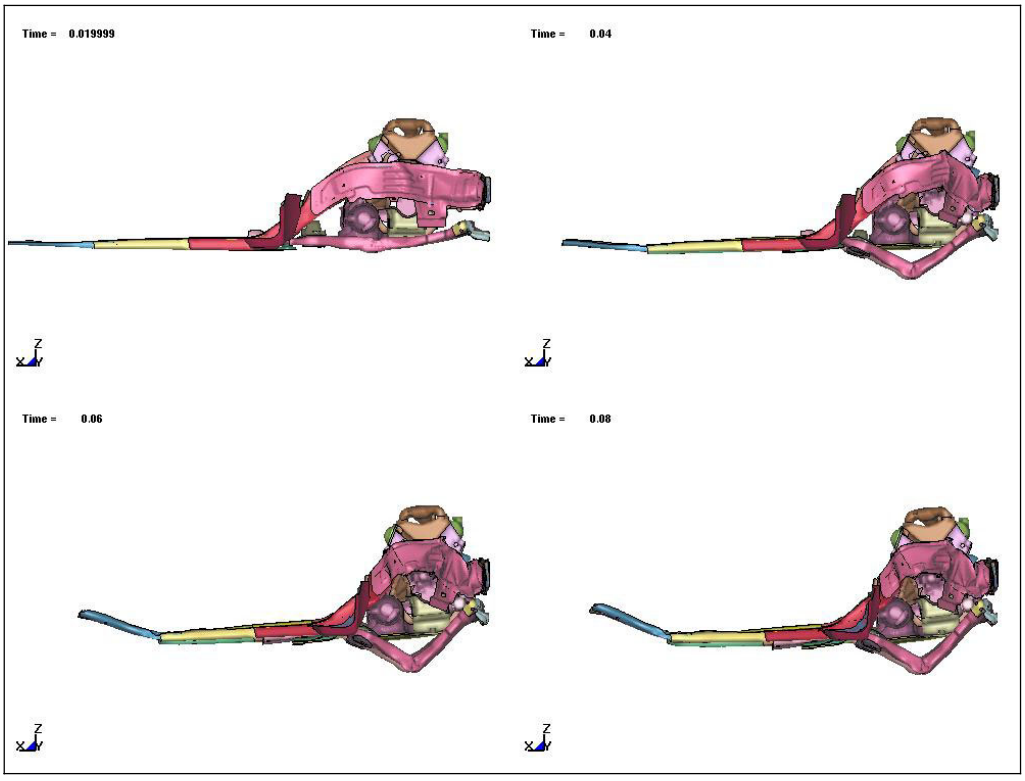


Figure 7: Deformation of Front End (Right Side View)

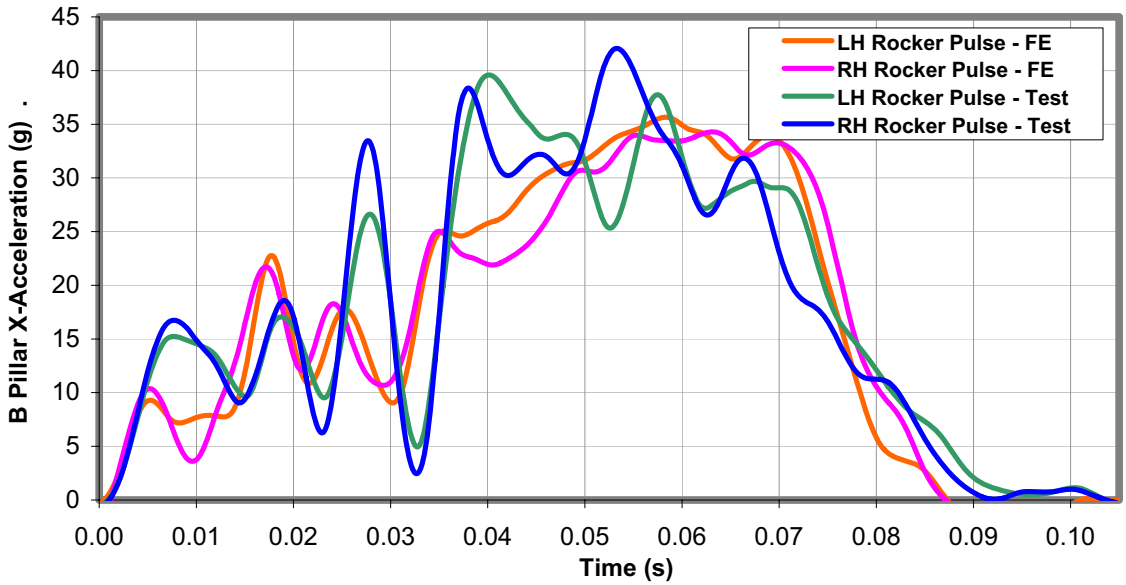


Figure 8: Comparison of B Pillar Pulse – FE and Test

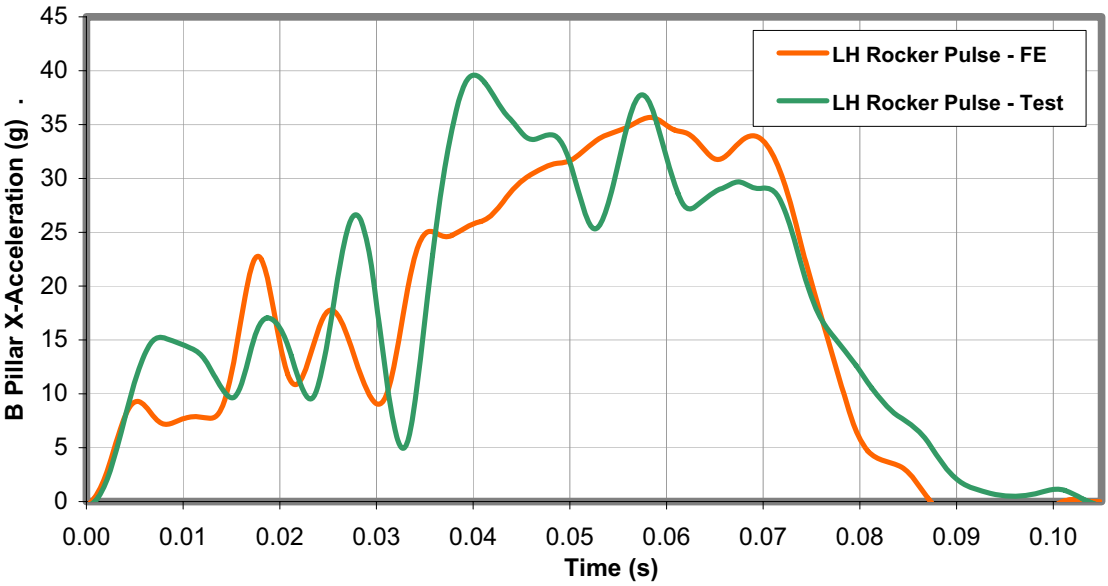


Figure 9: B Pillar Pulse – LH

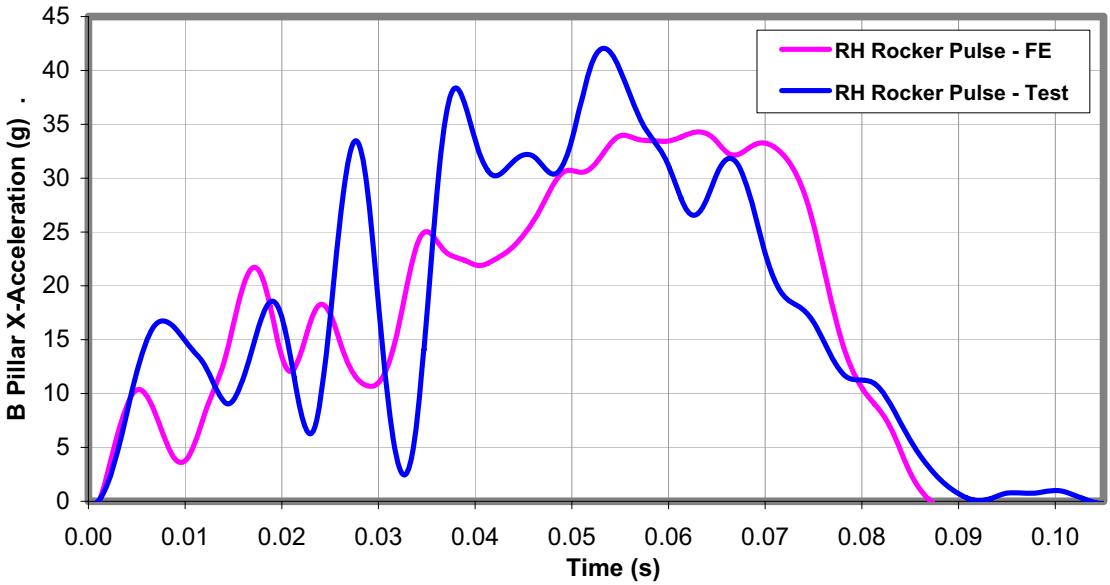


Figure 10: B Pillar Pulse – RH

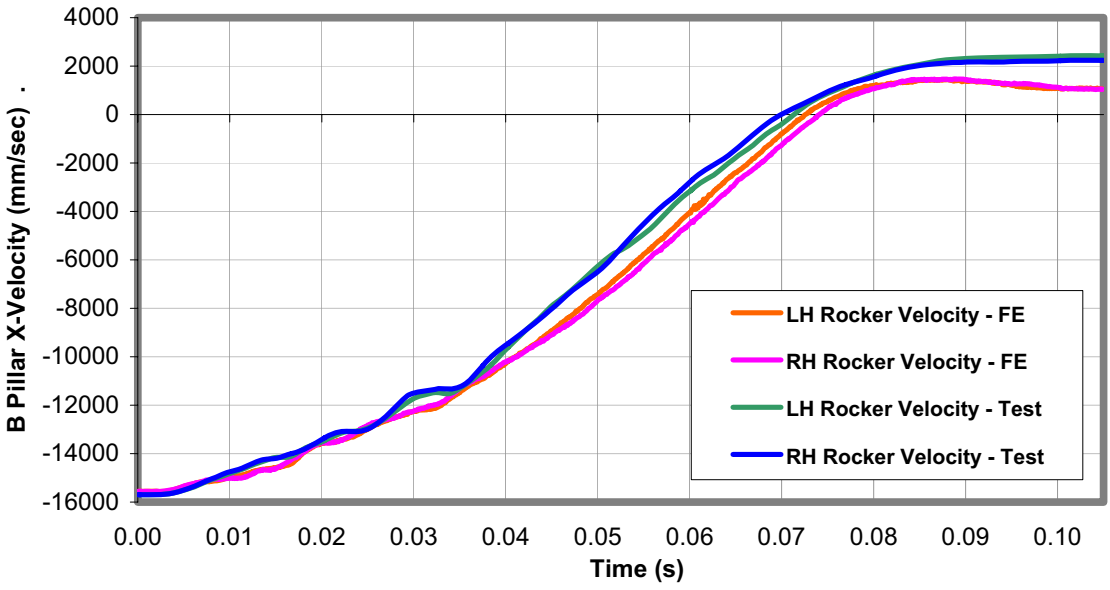


Figure 11: Comparison of B Pillar Velocity – FE and Test

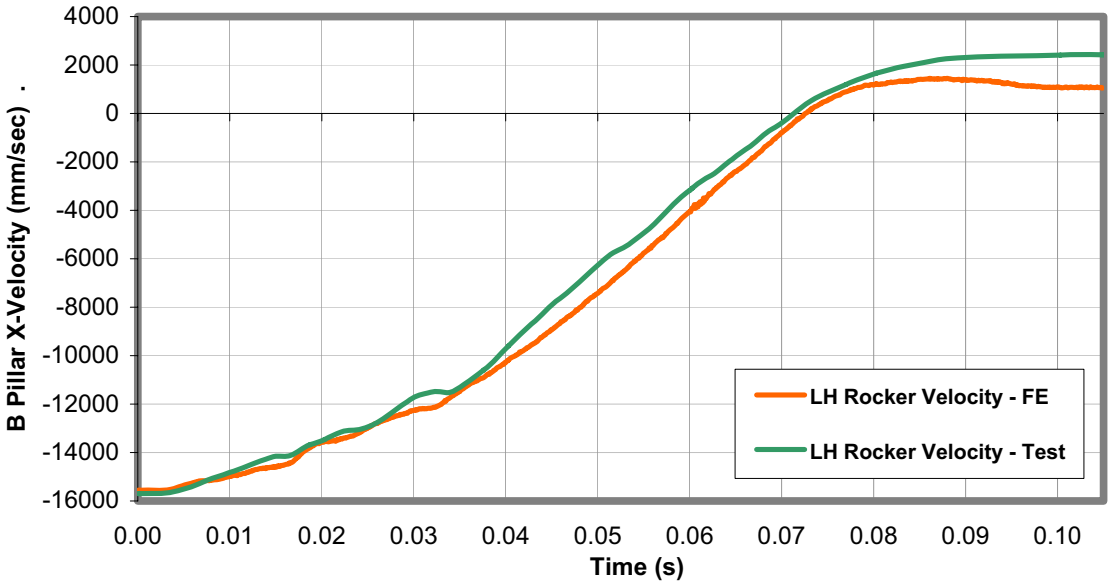


Figure 12: B Pillar Velocity - LH

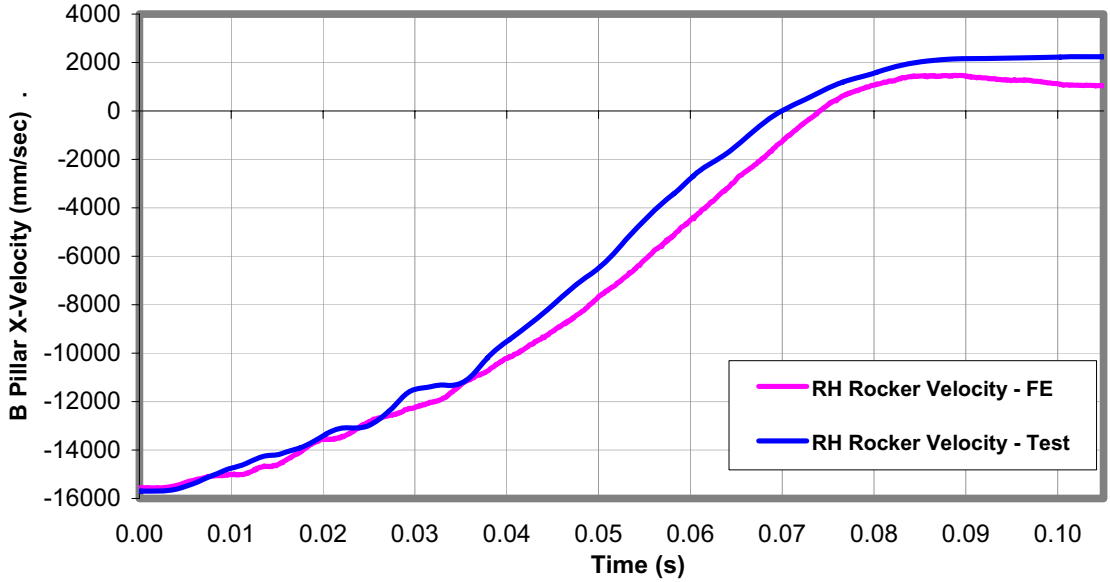


Figure 13: B-Pillar Velocity - RH

Table 5: NCAP Crash Events

Time (ms)	Crash Events
0-15	Bumper absorbs energy
15-20	Cradle engaged and engine hits the radiator
25-30	Cradle and LH rail buckling started
35-40	LH front wheel hits the LH rail
40-45	Engine hits to dash
45-50	RH front wheel hits the RH rail
55-60	LH wheel hits the front rigid wall
60-65	RH wheel hits the front rigid wall, LH wheel hits the rocker
75-80	RH wheel hits the rocker

5. IIHS Response

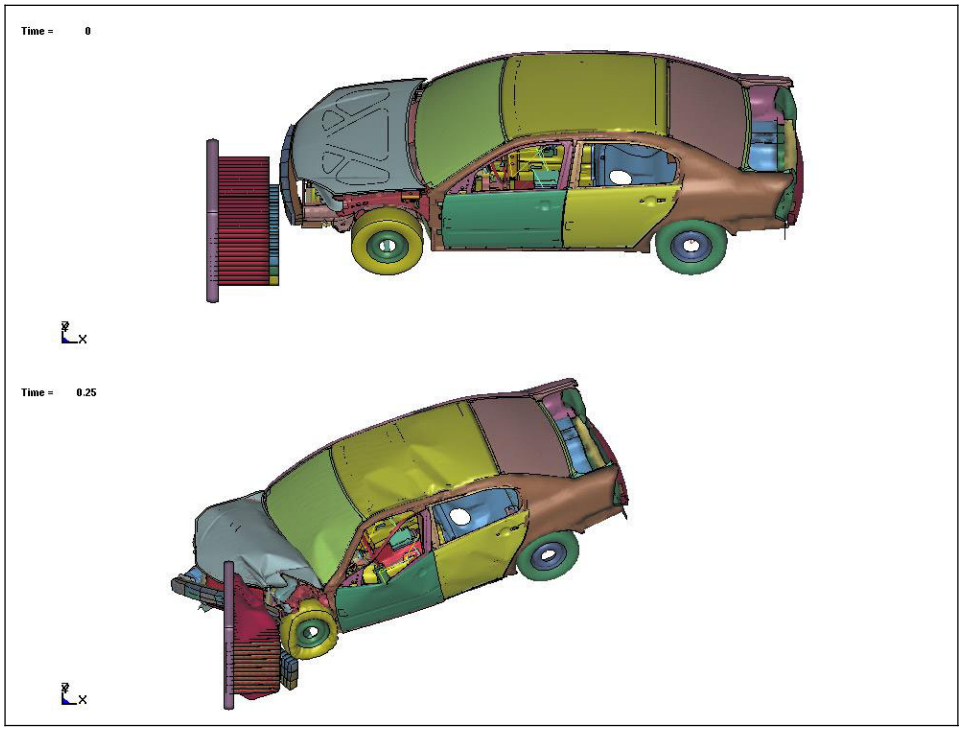


Figure 14: Deformation of Full Vehicle

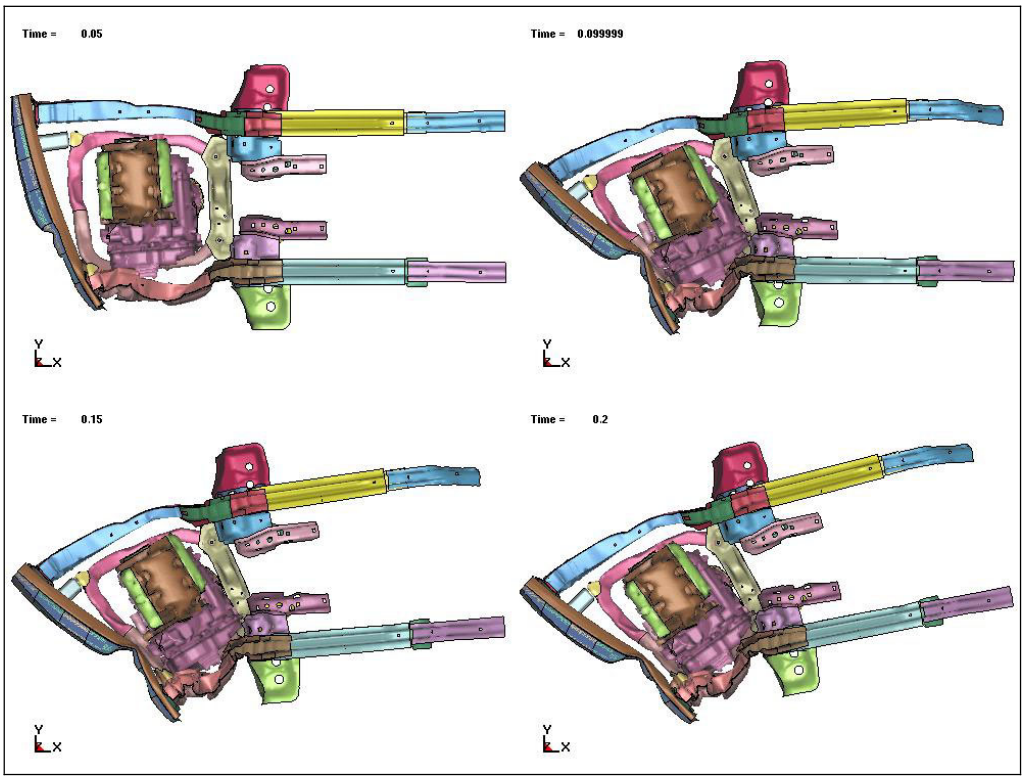


Figure 15: Deformation of Front End (Top View)

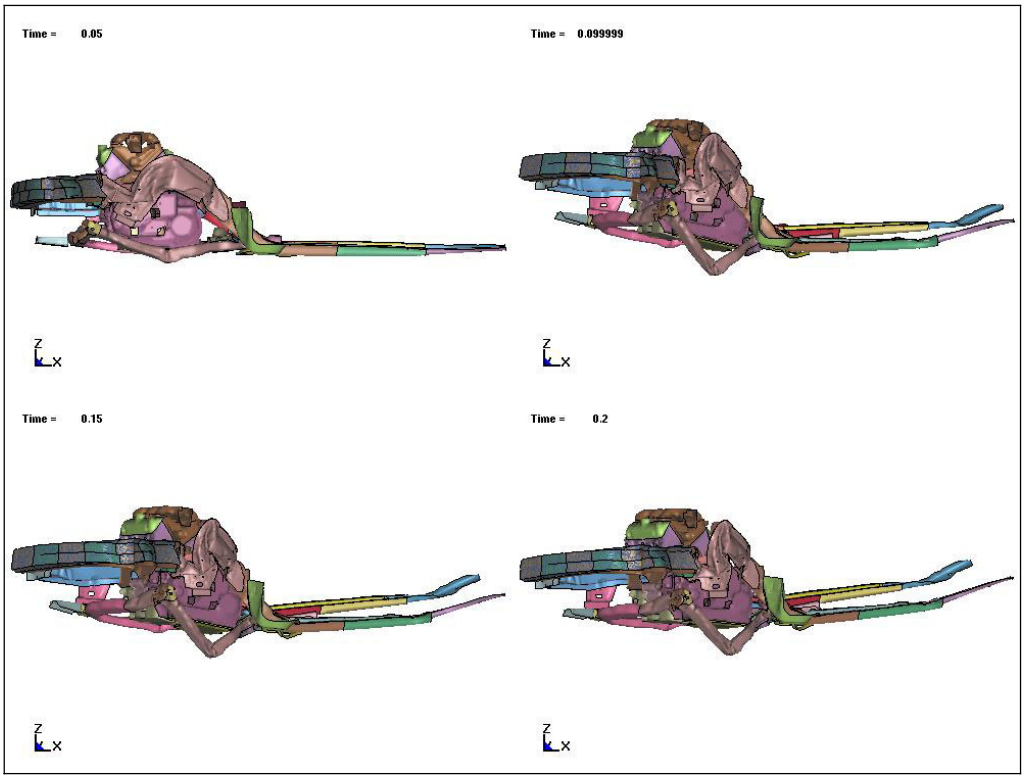


Figure 16: Deformation of Front End (Left Side View)

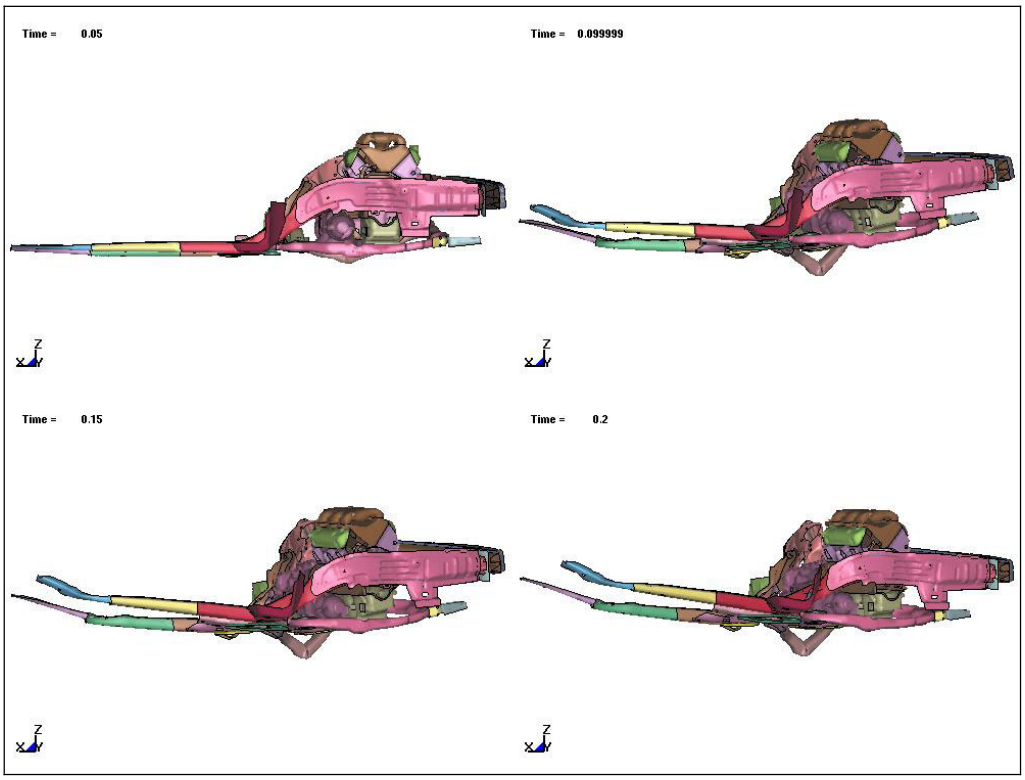


Figure 17: Deformation of Front End (Right Side View)

6. Conclusions

The FE models obtained from the OEM were analyzed with minimum changes, and the results compared with the available test results. The results were also verified by OEM engineers. Hence, the validated FE models can serve as the basis for all Phase II analytical work.

7. Future Work

The validated FE models will be modified appropriately, in order to make them suitable for DOE studies. These FE models will be employed to assess various rail and bumper concepts developed in Phase II of the Lightweight Front End Structure Project.

8. Appendix A: Animations

The following animation files for the subsystem development can be viewed at the Auto/Steel Partnership website, www.a-sp.org.

You will need a Hyperview Player in order to view these animations at the site. You can download this free software at www.altair.com.

1. NCAP: Full Vehicle
2. NCAP: Front-End
3. IIHS: Full Vehicle
4. IIHS: Front-End

9. Appendix B: Summary of FE Model

Component Name	ID	Property Name	ID	Material Name	ID	MASS (ton)	Thickness (mm)
Part_2	60002	SectShll10.1	60010	MATL9_2	60002	0.014989	1
part.42	61161	SectDisc779	60779	MATSpr1_779	60779	0	0
part.43	61162	SectDisc780	60780	MATDmp2_780	60780	0	0
part.44	61163	SectDisc781	60781	MATSpr4_781	60781	0	0
part.47	61166	SectDisc783	60783	MATDmp2_784	60784	0	0
part.9	61365	SectShll20.1	60020	MAT9_704	60704	1.11E-04	2
part.10	61366	SectShll20.1	60020	MAT9_705	60705	4.58E-05	2
part.11	61367	SectShll5.3	60005	MAT20_706	60706	5.98E-05	0.5
part.12	61368	SectBeam707	60707	MAT24_707	60707	7.69E-04	0
part.14	61411	SectShll20.1	60020	MAT20_750	60750	0.001699	2
part.15	61412	SectShll10.1	60010	MAT20_751	60751	8.05E-05	1
part.16	61413	SectShll34	60034	MAT20_752	60752	1.83E-04	3.4
part.17	61414	SectShll25	60025	MAT20_753	60753	5.23E-04	2.5
part.18	61415	SectShll25	60025	MAT20_754	60754	6.50E-04	2.5
part.19	61416	SectShll20.1	60020	MAT20_755	60755	5.14E-04	2
part.20	61417	SectShll30	60030	MAT20_756	60756	4.70E-04	3
part.21	61418	SectShll34	60034	MAT20_757	60757	2.55E-04	3.4
part.22	61419	SectShll20.1	60020	MAT20_758	60758	5.61E-05	2
part.24	61421	SectShll20.1	60020	MAT20_760	60760	1.14E-04	2
part.25	61422	SectShll20.1	60020	MAT20_761	60761	8.86E-05	2
part.28	61425	SectShll20.1	60020	MAT20_764	60764	2.43E-05	2
part.29	61426	SectShll20.1	60020	MAT20_765	60765	2.32E-05	2
part.30	61427	SectShll40	60040	MAT20_766	60766	3.95E-06	4
part.31	61428	SectShll40	60040	MAT20_767	60767	3.95E-06	4
part.34	61432	SectShll40	60040	MAT24_771	60771	2.43E-05	4
part.40	61438	SectShll30	60030	MAT20_777	60777	3.28E-04	3
part.41	61439	SectShll30	60030	MAT20_778	60778	3.69E-04	3
railinr.l	70662	Sectshll16.5	60165	MATL24_250	60250	0.003805	1.65
railotr.l	70663	SectShll15.3	60015	MATL24_340	60340	0.002781	1.5
trnsrnf	70664	Sectshll17.5	60175	MATL24_340	60340	2.91E-04	1.75
ailctr1.l	70665	SectShll20.1	60020	MATL24_210	60210	0.00383	2
ubrail.l	70666	SectShll95	60095	MATL24_340	60340	5.89E-04	0.95
ailrnf1.l	70667	SectShll12.1	60012	MATL24_340	60340	4.46E-04	1.2
ailrnf2.l	70668	SectShll225	60225	MATL24_3404	63404	0.00282	2.25
trqbox1.l	70670	Sectshll14.5	60145	MATL24_210	60210	0.001434	1.45
trqbox2.l	70671	Sectshll14.5	60145	MATL24_160	60160	2.73E-04	1.45
btray1	70674	SectShll15.3	60015	MATL24_160	60160	0.003147	1.5
btray2	70675	SectShll10.1	60010	MATL24_160	60160	2.19E-04	1
frtflr	70677	SectShll085	60085	MATL24_160	60160	0.013015	0.85
rkrinr.l	70680	sectshll16	60016	MATL24_3404	63404	0.003811	1.6
bar2.l	70681	SectShll12.1	60012	MATL24_160	60160	0.00138	1.2

Component Name	ID	Property Name	ID	Material Name	ID	MASS (ton)	Thickness (mm)
eatrein.l	70684	SectShll12.1	60012	MATL24_160	60160	3.44E-04	1.2
bar1	70687	SectShll20.1	60020	MATL24_3404	63404	0.002622	2
tnl1	70688	SectShll18.1	60018	MATL24_340	60340	0.001311	1.8
trnfext.l	70689	SectShll20.1	60020	MATL24_250	60250	0.001246	2
tnl2	70690	SectShll12.1	60012	MATL24_250	60250	0.006463	1.2
rdlmnt1.l	70693	Sectshll19.5	60195	MATL24_160	60160	8.12E-04	1.95
rdlmnt2.l	70694	Sectshll14.5	60145	MATL24_210	60210	1.37E-04	1.45
rdlmnt1.l	70695	SectShll25	60025	MATL24_210	60210	0.001234	2.5
rdlmnt2.l	70696	SectShll19.1	60190	MATL24_210	60210	2.84E-04	1.9
rearflr	70700	SectShll8.3	60008	MATL24_160	60160	0.017539	0.8
bar3	70709	SectShll10.1	60010	MATL24_211	60211	0.002442	1
bar4ctr	70710	SectShll10.1	60010	MATL24_340	60340	0.001438	1
bar4lft	70711	SectShll15.3	60015	MATL24_160	60160	0.001168	1.5
rrrail.l	70712	SectShll15.3	60015	MATL24_251	60251	0.005535	1.5
ailrnf1.l	70715	SectShll10.1	60010	MATL24_160	60160	1.93E-04	1
ailrnf2.l	70717	SectShll10.1	60010	MATL24_160	60160	2.10E-04	1
gusset.l	70720	SectShll15.3	60015	MATL24_160	60160	7.13E-04	1.5
gusset2.l	70721	SectShll15.3	60015	MATL24_160	60160	8.44E-04	1.5
gusset3.l	70722	SectShll15.3	60015	MATL24_160	60160	5.19E-04	1.5
gusset4.l	70723	SectShll15.3	60015	MATL24_160	60160	5.89E-04	1.5
tiebar2	70732	SectShll9.1	60009	MATL24_160	60160	0.001152	0.9
pnlfrt1.l	70738	Sectshll75	60075	MATL24_210	60210	5.44E-04	0.75
pnlfrt2.l	70739	SectShll12.1	60012	MATL24_210	60210	0.001237	1.2
urail_l	70742	SectShll8.3	60008	MATL24_160	60160	0.001457	0.8
tiebar	70743	SectShll9.1	60009	MATL24_210	60210	0.002278	0.9
shock.l	70746	Sectshll17.5	60175	MATL24_160	60160	0.001518	1.75
dash	70749	SectShll95	60095	MATL24_160	60160	0.008027	0.95
cowlupr	70754	SectShll8.3	60008	MATL24_210	60210	0.001526	0.8
plrrnf1.l	70763	SectShll10.1	60010	MATL24_210	60210	0.001632	1
hlhsinr.l	70812	SectShll10.1	60010	MATL24_160	60160	0.002906	1
barrnf1.l	70814	SectShll20.1	60020	MATL24_160	60160	0.001399	2
barrnf2.l	70815	SectShll25	60025	MATL24_160	60160	7.24E-04	2.5
backpanel	70826	SectShll8.3	60008	MATL24_160	60160	0.005311	0.8
bpnlrnf	70827	Sectshll75	60075	MATL24_160	60160	0.001933	0.75
roof	70832	Sectshll75	60075	MATL24_160	60160	0.010195	0.75
frthdr	70834	SectShll7.2	60007	MATL24_160	60160	9.30E-04	0.7
rrhdr	70836	SectShll9.1	60009	MATL24_160	60160	0.001134	0.9
rfbow2	70837	SectShll9.1	60009	MATL24_340	60340	9.29E-04	0.9
suspshk.l	70854	SectShll225	60225	MATL24_160	60160	3.05E-04	2.25
wshield	70873	SectShll48	60048	laminatedglass	60101	0.015413	4.8
gbox1	70963	SectShll10.1	60010	MATL24_160	60160	0	1
gbox1rnf	70964	SectShll15.3	60015	MATL24_160	60160	0	1.5
flrlvrrnf	70981	SectShll15.3	60015	MATL24_160	60160	7.10E-04	1.5
rclnmend3	70983	SectShll50	60050	rigid	60103	3.64E-04	5

strngrack	70986	SectShll60	60060	MAT24_1111	61111	0.002617	6
Component Name	**ID**	**Property Name**	**ID**	**Material Name**	**ID**	**MASS (ton)**	**Thickness (mm)**
rrackends	70987	SectShll60	60060	MATL24_160	60160	0.001162	6
pedal2	70993	SectShll30	60030	MATL24_160	60160	0.001364	3
crdl.l	71011	SectShll26	60026	MATL24_340	60340	0.006018	2.6
rdlmnt3.l	71012	SectShll25	60025	MATL24_340	60340	4.35E-04	2.5
tcrdlmnt5	71013	SectShll15.3	60015	MATL24_160	60160	4.31E-04	1.5
rdlrrxlwr	71014	SectShll23	60023	MATL24_340	60340	0.001291	2.3
rdlrrxupr	71015	SectShll25	60025	MATL24_340	60340	0.002183	2.5
crdlblt	71016	SectShll20.1	60020	MATL24_160	60160	2.41E-04	2
rdlbltrnf	71018	SectShll275.1	60275	MATL24_160	60160	3.23E-04	2.75
stabbar	71019	SectShll40	60040	MATL24_160	60160	0.004576	4
lcarnf.l	71020	SectShll30	60030	MATL24_340	60340	3.19E-04	3
ntrlarm.l	71021	SectShll30	60030	MATL24_160	60160	0.002294	3
lcacyl.l	71023	SectShll50	60050	MATL24_160	60160	0.001295	5
bdattch.l	71025	SectShll35	60305	MATL24_160	60160	0.001148	3.5
spstrut.l	71026	SectShll50	60050	MATL24_160	60160	0.005601	5
frtmnt1	71027	SectShll20.1	60020	MATL24_160	60160	1.04E-03	2
frtmnt2	71029	SectShll225	60225	MATL24_160	60160	3.87E-04	2.25
crdlfbrkt	71030	SectShll30	60030	MATL24_600	60600	8.68E-04	3
pt2	71064	SectShll10.1	60010	rigid	60103	0.001123	1
pt3	71066	SectShll10.1	60010	rigid	60103	0.006404	1
driveline	71069	SectShll70	60070	MATL24_340	60340	0.005373	7
pt6	71071	SectShll10.1	60010	rigid	60103	0.304199	1
pt7	71072	SectShll10.1	60010	rigid	60103	0.001243	1
pt8	71073	SectShll20.1	60020	rigid	60103	0.005085	2
pt9	71075	SectShll100	60102	rigid	60103	0.005278	10
pt10	71076	SectShll10.1	60010	rigid	60103	9.92E-04	1
pt11	71077	SectShll225	60225	rigid	60103	0.001336	2.25
pt12	71078	SectShll80	60080	rigid	60103	0.007011	8
pt13	71079	SectShll10.1	60010	rigid	60103	1.07E-04	1
pt14	71080	SectShll10.1	60010	rigid	60103	0.001639	1
pt19	71081	SectShll10.1	60010	rigid	60103	4.08E-04	1
pt16	71082	SectShll40	60040	rigid	60103	0.003234	4
pt17	71083	SectShll30	60030	MATL24_160	60160	0.007696	3
pt18	71084	SectShll40	60040	rigid	60103	0.007255	4
expipefrt	71086	SectShll15.3	60015	MATL24_160	60160	0.003601	1.5
battery1	71099	SectShll5.3	60005	MATL24_160	60160	8.66E-04	0.5
adsupport	71102	SectShll10.1	60010	MATL24_160	60160	0.001261	1
ECM	71103	SectShll10.1	60010	MATL24_160	60160	1.07E-03	1
rad4	71104	SectShll10.1	60010	MATL24_160	60160	8.32E-06	1
rad3	71106	SectSld300	60300	MATL24_160	60160	0	0
rad2	71107	SectSld900	60900	MAT57rad&cond	60102	0.002656	0
rad1	71108	SectSld900	60900	MAT57rad&cond	60102	0.003782	0
rim.l	71111	SectShll35	60305	MATL24_600	60600	0.008136	3.5
tire1.l	71112	SectShll20.1	60020	mat1.tirerubber	60104	0.00197	2

tir2.l	71113	SectShll7.2	60007	MATL24_160	60160	0.002042	0.7
Component Name	**ID**	**Property Name**	**ID**	**Material Name**	**ID**	**MASS (ton)**	**Thickness (mm)**
tire3.l	71114	SectShll3.3	60306	MATL24_160	60160	1.00E-03	0.3
rearrim	71115	SectShll35	60305	MATL24_160	60160	0.015933	3.5
rtire.l	71116	SectShll10.1	60010	MATL24_160	60160	0.007576	1
rclnmend4	71118	SectShll50	60050	rigid	60103	2.10E-04	5
bar1fsusp	71161	Sectbeam10500	60307	MATBEAM	60969	0.00188	0
bar2fsusp	71162	Sectbeam10501	60308	MATBEAM	60969	4.12E-05	0
bar3fsusp	71163	Sectbeam10500	60307	MATBEAM	60969	1.65E-04	0
rsubframe	71164	Sectbeam10503	60309	MATBEAM	60969	0	0
BARDLINE	71165	Sectbeam10504	60310	MATBEAM	60969	7.06E-05	0
bar4fsusp	71166	Sectbeam10500	60307	MATBEAM	60969	9.48E-04	0
bar2dline	71167	Sectbeam10500	60307	MATBEAM	60969	0.001306	0
bar3dline	71168	Sectbeam10504	60310	MATBEAM	60969	1.16E-04	0
bar4dline	71169	Sectbeam10504	60310	MATBEAM	60969	0	0
bar5dline	71170	Sectbeam10509	60311	MATBEAM	60969	8.50E-05	0
bar6dline	71171	Sectbeam10509	60311	MATBEAM	60969	0	0
bar1rrsus	71176	Sectbeam10500	60307	MATBEAM	60969	0.007365	0
ar2rrsusp	71177	Sectbeam10516	60313	MATBEAM	60969	0.019679	0
ar3rrsusp	71178	Sectbeam10516	60313	MATBEAM	60969	0.0026	0
ar4rrsusp	71179	Sectbeam10516	60313	MATBEAM	60969	0.002841	0
ardummies	71180	Sectbeam10519	60314	MATBEAM	60969	0.003373	0
barseat	71181	Sectbeam10519	60314	MATBEAM	60969	3.34E-04	0
rradiator	71183	Sectbeam10522	60316	MATBEAM	60969	1.82E-04	0
driveline	71186	Sectbeam10504	60310	MATBEAM	60969	2.57E-04	0
riveline8	71187	Sectbeam10504	60310	MATBEAM	60969	7.05E-05	0
prdrvline	71266	SectDisc1	60600	Matsprstr14	60605	0	0
prengmnt3	71280	SectDisc1	60600	Matsprstr113	60619	0	0
sprdummy	71282	SectDisc1	60600	Matsprstr114	60621	0	0
spr2dummy	71285	SectDisc1	60600	Matsprstr116	60623	0	0
spr3dummy	71286	SectDisc1	60600	Matsprstr116	60623	0	0
bumpbeam	71461	SectShll12.1	60012	MATL24_848	60848	0.005409	1.2
bumpnull	71463	SectShll10.1	60010	null	60100	0.002833	1
ldfoam	71464	SectSld900	60900	foam2.8pcf	60831	1.91E-04	0
hdfoam	71466	SectSld900	60900	foam6.6pcf	60834	4.93E-04	0
llar_brkt	71467	SectShll18.1	60018	MATL24_340	60340	6.28E-04	1.8
per_plate	71468	SectShll20.1	60020	MATL24_340	60340	5.18E-04	2
per_plate	71469	SectShll20.1	60020	MATL24_340	60340	5.17E-04	2
fanshroud	71470	SectShll20.1	60020	MATL24_181	60181	0.007298	2
hfanmotor	71471	SectShll20.1	60020	MATL24_181	60181	5.60E-04	2
hfanmotor	71472	SectShll20.1	60020	MATL24_181	60181	5.40E-04	2
ep_7685	73662	SectShll10.1	60010	rigid	60103	2.83E-04	1
flywheel	73663	SectShll10.1	60010	rigid	60103	7.92E-04	1
ep_4776	73664	SectShll10.1	60010	rigid	60103	4.99E-04	1
ep_7498	73665	SectShll10.1	60010	rigid	60103	0.002606	1
ep_0939	73666	SectShll10.1	60010	rigid	60103	5.82E-04	1

ep_0017	73667	SectShll10.1	60010	rigid	60103	4.50E-04	1
Component Name	**ID**	**Property Name**	**ID**	**Material Name**	**ID**	**MASS (ton)**	**Thickness (mm)**
ep_70842	73668	SectShll10.1	60010	rigid	60103	1.84E-04	1
tery_fill	73669	SectShll10.1	60010	MATL24_160	60160	0.001326	1
g_mnt_l_e	73670	SectShll80	60080	MATL24_160	60160	0.002636	8
p_bkt_l_e	73671	SectShll80	60080	MAT24_1111	61111	5.72E-04	8
t_bkt_l_e	73672	SectShll30	60030	MATL24_340	60340	9.58E-04	3
g_mnt_r_e	73673	SectShll80	60080	MATL24_160	60160	0.002631	8
p_bkt_r_e	73674	SectShll80	60080	MAT24_1111	61111	1.01E-03	8
t_bkt_r_e	73675	SectShll30	60030	MATL24_340	60340	9.29E-04	3
eformable	73676	SectShll80	60080	MATL24_160	60160	0.001725	8
tiebar4.l	73677	Sectshll75	60075	MATL24_180	60180	4.27E-05	0.75
.supt.upr	73678	Sectshll75	60075	MATL24_160	60160	0.002601	0.75
mltintjnt	73679	Sectshll75	60075	MATL24_160	60160	0.00405	0.75
dpnlotr.l	73681	Sectshll75	60075	MATL24_160	60160	0.014307	0.75
dpnlinr.l	73682	SectShll10.1	60010	MATL24_160	60160	0.00962	1
rkrblkhds	73684	SectShll12.1	60012	MATL24_340	60340	7.59E-04	1.2
rdeck	73685	SectShll10.1	60010	MATL24_160	60160	0.005446	1
rnkgtrfrt	73686	SectShll10.1	60010	MATL24_160	60160	0.00209	1
deckbrkt1	73687	SectShll10.1	60010	MATL24_160	60160	9.01E-04	1
deckbrkt2	73688	SectShll10.1	60010	MATL24_160	60160	2.49E-04	1
trnkgtr.l	73689	SectShll9.1	60009	MATL24_160	60160	3.97E-04	0.9
ckbrkt3.l	73690	SectShll10.1	60010	MATL24_160	60160	8.76E-04	1
ckbrkt4.l	73691	SectShll10.1	60010	MATL24_160	60160	7.68E-04	1
rhtchbrkt	73692	SectShll10.1	60010	MATL24_160	60160	0.001306	1
railext.l	73693	SectShll15.3	60015	MATL24_160	60160	7.29E-04	1.5
pbmbrkt.l	73694	SectShll15.3	60015	MATL24_160	60160	4.35E-04	1.5
rbumpbeam	73695	SectShll10.1	60010	MATL24_160	60160	0.003708	1
bplrrnf.l	73697	SectShll225	60225	MATL24_250	60250	0.003029	2.25
tiebar3.l	73700	Sectshll75	60075	MATL24_180	60180	6.78E-04	0.75
il_rnf2.l	73701	SectShll9.1	60009	MATL24_160	60160	4.72E-04	0.9
62109a_e1	73702	SectShll37	60037	MATL24_160	60160	3.62E-04	3.7
62109a_e2	73703	SectShll37	60037	MATL24_160	60160	1.22E-04	3.7
62109a_e3	73704	SectShll37	60037	MATL24_160	60160	4.00E-04	3.7
62109b_e1	73705	SectShll10.1	60010	MATL24_160	60160	4.06E-04	1
lar_rnf_l	73706	SectShll10.1	60010	MATL24_160	60160	9.04E-04	1
t_bushing	73707	SectShll20.1	60020	MATL24_160	60160	5.79E-04	2
r_wndshld	73708	SectShll48	60048	laminatedglass	60101	0.011646	4.8
part.49	81712	SectShll15.3	60015	MAT20_20015	100022	1.06E-05	1.5
railinr.r	110662	Sectshll16.5	60165	MATL24_250	60250	0.003652	1.65
railotr.r	110663	SectShll15.3	60015	MATL24_340	60340	0.002653	1.5
emntrnf	110664	Sectshll14.5	60145	MATL24_340	60340	2.40E-04	1.45
ailctr1.r	110665	SectShll20.1	60020	MATL24_210	60210	0.003998	2
ubrail.r	110666	SectShll95	60095	MATL24_340	60340	5.92E-04	0.95
ailrnf1.r	110667	SectShll12.1	60012	MATL24_340	60340	4.28E-04	1.2
ailrnf2.r	110668	SectShll225	60225	MATL24_3404	63404	0.002855	2.25

trqbox1.r	110670	Sectshll14.5	60145	MATL24_210	60210	0.001625	1.45
Component Name	**ID**	**Property Name**	**ID**	**Material Name**	**ID**	**MASS (ton)**	**Thickness (mm)**
trqbox2.r	110671	Sectshll14.5	60145	MATL24_160	60160	2.73E-04	1.45
rkrinr.r	110680	sectshll16	60016	MATL24_3404	63404	0.003811	1.6
bar2.r	110681	SectShll12.1	60012	MATL24_160	60160	0.001379	1.2
eatrein.r	110684	SectShll12.1	60012	MATL24_160	60160	3.46E-04	1.2
trnfext.r	110689	SectShll20.1	60020	MATL24_250	60250	0.001225	2
rdlmnt1.r	110693	Sectshll19.5	60195	MATL24_160	60160	7.34E-04	1.95
rdlmnt2.r	110694	Sectshll14.5	60145	MATL24_210	60210	1.38E-04	1.45
rdlmnt1.r	110695	SectShll25	60025	MATL24_210	60210	0.001389	2.5
rdlmnt2.r	110696	SectShll19.1	60190	MATL24_210	60210	2.84E-04	1.9
bar4rt	110711	SectShll15.3	60015	MATL24_160	60160	0.001168	1.5
rrrail.r	110712	SectShll15.3	60015	MATL24_251	60251	0.005519	1.5
ailrnf1.r	110715	SectShll10.1	60010	MATL24_160	60160	1.93E-04	1
ailrnf2.r	110717	SectShll10.1	60010	MATL24_160	60160	2.10E-04	1
gusset.r	110720	SectShll15.3	60015	MATL24_160	60160	7.13E-04	1.5
gusset2.r	110721	SectShll15.3	60015	MATL24_160	60160	8.44E-04	1.5
gusset3.r	110722	SectShll15.3	60015	MATL24_160	60160	5.19E-04	1.5
gusset4.r	110723	SectShll15.3	60015	MATL24_160	60160	5.87E-04	1.5
pnlfrt1.r	110738	Sectshll75	60075	MATL24_210	60210	6.27E-04	0.75
pnlfrt2.r	110739	SectShll12.1	60012	MATL24_210	60210	0.001294	1.2
urail_r	110742	SectShll8.3	60008	MATL24_160	60160	0.001456	0.8
shock.r	110746	Sectshll17.5	60175	MATL24_160	60160	0.001546	1.75
plrrnf1.r	110763	SectShll10.1	60010	MATL24_210	60210	0.001634	1
hlhsinr.r	110812	SectShll10.1	60010	MATL24_160	60160	0.003046	1
barrnf1.r	110814	SectShll20.1	60020	MATL24_160	60160	0.001459	2
barrnf2.r	110815	SectShll25	60025	MATL24_160	60160	6.97E-04	2.5
suspshk.r	110854	SectShll225	60225	MATL24_160	60160	3.05E-04	2.25
crdl.r	111011	SectShll26	60026	MATL24_340	60340	0.006321	2.6
rdlmnt3.r	111012	SectShll25	60025	MATL24_340	60340	3.45E-04	2.5
lcarnf.r	111020	SectShll30	60030	MATL24_340	60340	3.41E-04	3
ntrlarm.r	111021	SectShll30	60030	MATL24_160	60160	0.002289	3
lcacyl.r	111023	SectShll50	60050	MATL24_160	60160	0.001295	5
bdattch.r	111025	SectShll35	60305	MATL24_160	60160	0.001147	3.5
spstrut.r	111026	SectShll50	60050	MATL24_160	60160	0.005601	5
rim.r	111111	SectShll35	60305	MATL24_600	60600	0.008136	3.5
tire1.r	111112	SectShll20.1	60020	mat1.tirerubber	60104	0.00197	2
tire3.r	111113	SectShll7.2	60007	MATL24_160	60160	0.002042	0.7
tire2.r	111114	SectShll3.3	60306	MATL24_160	60160	1.00E-03	0.3
rtire.r	111117	SectShll10.1	60010	MATL24_160	60160	0.007576	1
il_rnf1.r	113662	SectShll9.1	60009	MATL24_160	60160	4.72E-04	0.9
tiebar3.r	113663	Sectshll75	60075	MATL24_180	60180	7.24E-04	0.75
nldshext2	113665	SectShll8.3	60008	MATL24_210	60210	1.91E-04	0.8
bplrrnf.r	113666	SectShll225	60225	MATL24_250	60250	0.003029	2.25
dpnlotr.r	113667	Sectshll75	60075	MATL24_160	60160	0.014309	0.75
dpnlinr.r	113668	SectShll10.1	60010	MATL24_160	60160	0.009567	1

railinr.r	113669	SectShll20.1	60020	MATL24_160	60160	7.85E-04	2
Component Name	**ID**	**Property Name**	**ID**	**Material Name**	**ID**	**MASS (ton)**	**Thickness (mm)**
trnkgtr.r	113670	SectShll9.1	60009	MATL24_160	60160	4.00E-04	0.9
ckbrkt3.r	113671	SectShll10.1	60010	MATL24_160	60160	8.78E-04	1
ckbrkt4.r	113672	SectShll10.1	60010	MATL24_160	60160	7.63E-04	1
pbmbrkt.r	113673	SectShll15.3	60015	MATL24_160	60160	4.35E-04	1.5
railext.r	113674	SectShll15.3	60015	MATL24_160	60160	7.27E-04	1.5
tiebar4.r	113675	Sectshll75	60075	MATL24_180	60180	4.44E-05	0.75
lar_rnf_r	113676	SectShll10.1	60010	MATL24_160	60160	9.05E-04	1
rinrpnl.l	115663	Sectshll75	60075	MATL24_160	60160	0.003644	0.75
rlwrhng.l	115664	SectShll50	60050	MATL24_160	60160	1.30E-04	5
rotrpnl.l	115665	Sectshll75	60075	MATL24_180	60180	0.004412	0.75
z-brkt.l	115666	SectShll10.1	60010	MATL24_160	60160	5.49E-05	1
r_frame.l	115668	SectShll10.1	60010	MATL24_160	60160	0.002017	1
drbeam.l	115669	SectShll20.1	60020	MATL24_600	60600	0.001988	2
ruprhng.l	115670	SectShll50	60050	MATL24_160	60160	1.31E-04	5
rinrpnl.r	115672	Sectshll75	60075	MATL24_160	60160	0.003644	0.75
rotrpnl.r	115673	Sectshll75	60075	MATL24_180	60180	0.004412	0.75
z-brkt.r	115674	SectShll10.1	60010	MATL24_160	60160	5.49E-05	1
r_frame.r	115676	SectShll10.1	60010	MATL24_160	60160	0.002017	1
drbeam.r	115677	SectShll20.1	60020	MATL24_600	60600	0.001988	2
druphng.r	115678	SectShll50	60050	MATL24_160	60160	1.36E-04	5
drlwhng.r	115679	SectShll50	60050	MATL24_160	60160	1.27E-04	5
fdrbdhng	115681	SectShll50	60050	MATL24_210	60210	2.09E-04	5
fdrbdhng2	115682	SectShll20.1	60020	rigid	60103	1.95E-05	2
fdrbdhng3	115683	SectShll20.1	60020	rigid	60103	2.47E-05	2
fdrbdhng4	115684	SectShll50	60050	MATL24_210	60210	2.04E-04	5
fdrbdhng5	115685	SectShll20.1	60020	rigid	60103	2.06E-05	2
fdrbdhng6	115686	SectShll20.1	60020	rigid	60103	2.50E-05	2
fdrbdhng7	115687	SectShll50	60050	MATL24_210	60210	2.60E-04	5
fdrbdhng8	115688	SectShll20.1	60020	rigid	60103	2.01E-05	2
fdrbdhng9	115689	SectShll20.1	60020	rigid	60103	2.42E-05	2
drbdhng10	115690	SectShll50	60050	MATL24_210	60210	2.06E-04	5
drbdhng11	115691	SectShll20.1	60020	rigid	60103	2.06E-05	2
drbdhng12	115692	SectShll20.1	60020	rigid	60103	2.50E-05	2
comptrnf2	115694	SectShll40	60040	MATL24_160	60160	0.002901	4
rlsrwld.l	115699	SectShll18.1	60018	MATL24_160	60160	0.003576	1.8
rlsrwld.r	115700	SectShll18.1	60018	MATL24_160	60160	0.003576	1.8
cradbrkt1	120662	SectShll10.1	60010	MATL24_180	60180	2.36E-04	1
cradbrkt	120665	SectShll30	60030	MATL24_340	60340	4.46E-04	3
cradbrkt2	120666	SectShll30	60030	MATL24_340	60340	3.58E-04	3
2barreinf	120667	SectShll17	60017	MATL24_340	60340	0.002514	1.7
cplate	120669	Sectshll16.5	60165	MATL24_340	60340	3.54E-04	1.65
sideinr.l	120670	SectShll21	60021	MATL24_160	60160	0.009052	2.1
sideinr.r	120671	SectShll21	60021	MATL24_160	60160	0.009056	2.1
plnmbrkt	128851	SectShll8.3	60008	MATL24_210	60210	1.51E-04	0.8

ailctr2.l	128913	SectShll12.1	60012	MATL24_340	60340	1.02E-03	1.2
Component Name	**ID**	**Property Name**	**ID**	**Material Name**	**ID**	**MASS (ton)**	**Thickness (mm)**
ailctr2.r	128914	SectShll12.1	60012	MATL24_340	60340	9.75E-04	1.2
ailrnf3.l	128915	Sectshll14.5	60145	MATL24_340	60340	7.25E-04	1.45
ailrnf3.r	128916	Sectshll14.5	60145	MATL24_340	60340	7.46E-04	1.45
rkrx_l	128961	Sectshll13	60013	MATL24_340	60340	1.02E-03	1.3
pbulkhd.l	128962	SectShll20.1	60020	MATL24_340	60340	6.10E-04	2
rblkhds.1	128963	SectShll12.1	60012	MATL24_340	60340	2.83E-04	1.2
rkrx_r	128964	Sectshll13	60013	MATL24_340	60340	1.02E-03	1.3
B_plr_rnf	128969	SectShll10.1	60010	MATL24_160	60160	6.01E-04	1
drfrail.l	198077	SectShll14.1	60014	MATL24_160	60160	0	1.4
drfrail.r	198078	SectShll14.1	60014	MATL24_160	60160	0	1.4
rlinrnf.r	198090	Sectshll17.5	60175	MATL24_210	60210	2.77E-04	1.75
ldB-plr.r	198091	SectShll18.1	60018	MATL24_250	60250	0.003041	1.8
ldB-plr.l	198092	SectShll18.1	60018	MATL24_250	60250	0.003041	1.8
accl.r	198093	SectShll10.1	60010	rigid	60103	4.29E-05	1
accl.l	198094	SectShll10.1	60010	rigid	60103	4.56E-05	1
refplane	198095	SectShll10.1	60010	rigid	60103	0	1
rein_upr	198126	SectShll15.3	60015	MATL24_210	60210	9.29E-04	1.5
MTG1	198127	SectShll10.1	60010	MATL24_210	60210	4.34E-04	1
KT_Consol	198128	SectShll15.3	60015	MATL24_210	60210	6.89E-04	1.5
_brkt_lwr	198129	SectShll20.1	60020	MATL24_210	60210	0.002868	2
rfmbrkt.r	198140	SectShll20.1	60020	MATL24_340	60340	5.38E-04	2
rfmbrkt.l	198149	SectShll20.1	60020	MATL24_340	60340	5.34E-04	2
frt_hrn	1052382	SectShll20.1	60020	MATL24_160	60160	7.90E-04	2
rr_hrn	1052383	SectShll14.1	60014	MATL24_160	60160	9.17E-04	1.4
rrdrinn.l	1052393	Sectshll75	60075	MATL24_160	60160	0.006906	0.75
rrdrinr.l	1052394	SectShll18.1	60018	MATL24_160	60160	0.005526	1.8
rrdrotr.l	1052395	Sectshll75	60075	MATL24_160	60160	0.007977	0.75
rrdrfrm.l	1052396	SectShll10.1	60010	MATL24_160	60160	0.003505	1
rrdrbm.l	1052397	SectShll20.1	60020	MATL24_600	60600	0.002599	2
bathtub.l	1052398	SectShll20.1	60020	MATL24_160	60160	2.61E-04	2
rrdrhng.l	1052399	SectShll50	60050	MATL24_160	60160	1.06E-03	5
latchjt.l	1052400	SectShll20.1	60020	MATL24_160	60160	2.26E-04	2
rdrhng1.l	1052401	SectShll50	60050	MATL24_160	60160	6.18E-04	5
frailrnfl	1052409	SectShll20.1	60020	MATL24_210	60210	0.002007	2
fbhp_brkt	2044939	SectShll20.1	60020	MATL24_210	60210	1.84E-04	2
rkr_extn	6081245	Sectshll75	60075	MATL24_600	60600	0.001526	0.75
temp	6081246	SectShll7.2	60007	MATL24_600	60600	2.63E-04	0.7
frailrnfr	6081248	SectShll20.1	60020	MATL24_210	60210	0.002007	2
nt_spring	6081270	SectDisc20071.1	121277	MATSpr4_61112	121112	0	0
nt_spring	6081271	SectDisc20071.1	121277	MATSpr4_61113	121113	0	0
atch_spri	6081272	SectDisc20071.1	121277	MATSpr4_61116	121116	0	0
atch_spri	6081273	SectDisc20071.1	121277	MATSpr4_61115	121115	0	0
ajnt_1.L1	6081278	SectShll30	60030	rigid	60103	4.12E-05	3
ajnt_2.L1	6081279	SectShll30	60030	rigid	60103	6.26E-05	3

ajnt_1.R1	6081281	SectShll30	60030	rigid	60103	4.12E-05	3

Component Name	ID	Property Name	ID	Material Name	ID	MASS (ton)	Thickness (mm)
ajnt_2.R1	6081282	SectShll30	60030	rigid	60103	6.33E-05	3
ajnt_1.L2	6081283	SectShll30	60030	rigid	60103	3.16E-05	3
ajnt_2.L2	6081284	SectShll30	60030	rigid	60103	2.76E-05	3
ajnt_1.R2	6081285	SectShll30	60030	rigid	60103	3.16E-05	3
ajnt_2.R2	6081286	SectShll30	60030	rigid	60103	2.76E-05	3
muffler	6110958	SectShll5.3	60005	MATL24_160	60160	0.00133	0.5
exhstpipe	6110959	SectShll5.3	60005	MATL24_160	60160	0.00201	0.5
921_256_1	6111022	SectShll12.1	60012	MATL24_160	60160	2.43E-04	1.2
921_255_1	6111023	SectShll12.1	60012	MATL24_160	60160	1.85E-04	1.2
920_256_1	6111027	SectShll12.1	60012	MATL24_160	60160	2.43E-04	1.2
920_255_1	6111028	SectShll12.1	60012	MATL24_160	60160	1.85E-04	1.2
abs_brkt	6111033	SectShll20.1	60020	MATL24_160	60160	4.33E-04	2
edge	6111035	SectShll2.1.1	1121861	MAT24_3	1161367	1.06E-03	1.35
inner	6111036	SectShll3.2.1	1121862	MAT24_3	1161367	0.005236	0.7
outer	6111037	SectShll4.1.1	1121863	MAT24_3	1161367	0.008255	0.7
MODPLT	90060001	SectShll273	90060005	MAT24_20022	90060020	0.001666	1.5
SUPT_forw	90060002	SectShll274	90060006	MAT24_20022	90060020	5.31E-04	1.22
can	90060003	SectShll276	90060008	MAT24_20022	90060020	6.88E-04	1.2
can1	90060004	SectShll277	90060009	MAT24_20022	90060020	9.93E-05	1.2
can2	90060005	SectShll278	90060010	MAT24_20022	90060020	1.10E-04	1.2
can.1	90060006	SectShll279	90060011	MAT24_20022	90060020	1.44E-04	1.2
inflator	90060007	SectShll280	90060012	MAT24_20022	90060020	0.001499	5.4
Brkt-1	90060008	SectShll2.1	90060063	MAT24_20022	90060020	6.07E-04	3
gaspdel	90060009	SectShll7.1	90060068	MAT24_20022	90060020	1.67E-04	2.5
stelpeice	90060010	SectShll12	90060071	MAT24_20022	90060020	1.55E-04	3
SIPO_p	90060011	SectShll287	90060014	MAT24_20022	90060020	7.36E-04	2
SIPO_d2	90060012	SectShll288	90060015	MAT24_20022	90060020	7.50E-04	2
eel_strip	90060013	SectShll294	90060016	MAT24_20022	90060020	1.39E-04	1.5
oor_Brkt2	90060014	SectShll315	90060037	MAT24_20022	90060020	9.82E-04	2.5
_Stk_brkt	90060015	SectShll316	90060038	MAT24_20022	90060020	3.25E-04	1.5
lower	90060016	SectShll5	90060044	HVAC_MATERIAL_PP	90060013	0.001208	2.43
upper	90060017	SectShll7	90060045	HVAC_MATERIAL_PP	90060013	0.001283	2.36
cbrkt_add	90060018	SectShll8	90060046	HVAC_MATERIAL_PP	90060013	1.95E-05	2.36
heatercvr	90060019	SectShll9	90060047	HVAC_MATERIAL_PP	90060013	3.84E-04	2.38
ai	90060020	SectShll10	90060048	HVAC_MATERIAL_PP	90060013	5.34E-04	2.1
ai_icebox	90060021	SectShll11	90060049	HVAC_MATERIAL_PP	90060013	1.52E-05	2.1
_actuator	90060022	SectShll13	90060050	HVAC_MATERIAL_PP	90060013	3.37E-05	2
_actuator	90060023	SectShll14	90060051	HVAC_MATERIAL_PP	90060013	2.98E-05	2
foamplate	90060024	SectShll15	90060052	MAT24_20022	90060020	5.74E-05	1
filmvalve	90060025	SectShll16	90060053	HVAC_MATERIAL_PP	90060013	4.93E-04	2
arm1_srib	90060026	SectShll18	90060054	HVAC_MATERIAL_PP	90060013	9.08E-05	2
rib_4_hub	90060027	SectShll19	90060055	HVAC_MATERIAL_PP	90060013	1.42E-04	3.5
ower_add1	90060028	SectShll20	90060056	HVAC_MATERIAL_PP	90060013	1.89E-05	2

foam	90060029	secn_solid_foam	90060125	FOAM_PART_OF_HVA	90060001	1.48E-06	0
evapblock	90060030	secn_solid_evapb	90060126	EVAP_CORE_MATERI	90060003	3.53E-05	0
Component Name	**ID**	**Property Name**	**ID**	**Material Name**	**ID**	**MASS (ton)**	**Thickness (mm)**
IBEC	90060031	SectShll281	90060013	NYLON_MATERIAL	90060005	3.04E-04	2
wer_tube1	90060032	evapcore_heatcor	90060041	ALUMINIUM_PARTOF	90060002	8.77E-06	1
per_tube1	90060033	evapcore_heatcor	90060041	ALUMINIUM_PARTOF	90060002	1.39E-05	1
per_tube1	90060034	evapcore_heatcor	90060041	ALUMINIUM_PARTOF	90060002	4.27E-05	1
wer_tube1	90060035	evapcore_heatcor	90060041	ALUMINIUM_PARTOF	90060002	2.57E-05	1
il	90060036	radio_controller	90060042	IP_1000_MATERIAL	90060014	1.89E-04	1
sidepnl_E	90060037	SectShll304	90060026	DOWC70035N	90060015	1.26E-04	2.5
po_fixed1	90060038	SectShll288	90060015	matl_steel_allfi	90060008	1.39E-06	2
po_fixed2	90060039	SectShll288	90060015	matl_steel_allfi	90060008	1.46E-06	2
po_fixed3	90060040	SectShll288	90060015	matl_steel_allfi	90060008	1.53E-06	2
po_fixed4	90060041	SectShll288	90060015	matl_steel_allfi	90060008	1.13E-06	2
po_fixed5	90060042	SectShll288	90060015	matl_steel_allfi	90060008	1.85E-06	2
po_fixed6	90060043	SectShll288	90060015	matl_steel_allfi	90060008	1.95E-06	2
po_fixed7	90060044	SectShll288	90060015	matl_steel_allfi	90060008	1.83E-06	2
_p_fixed7	90060045	SectShll287	90060014	matl_steel_allfi	90060008	1.24E-06	2
_p_fixed6	90060046	SectShll287	90060014	matl_steel_allfi	90060008	1.59E-06	2
_p_fixed5	90060047	SectShll287	90060014	matl_steel_allfi	90060008	1.71E-06	2
_p_fixed4	90060048	SectShll287	90060014	matl_steel_allfi	90060008	1.13E-06	2
_p_fixed3	90060049	SectShll287	90060014	matl_steel_allfi	90060008	1.85E-06	2
_p_fixed2	90060050	SectShll287	90060014	matl_steel_allfi	90060008	1.95E-06	2
p_fixed12	90060051	SectShll287	90060014	matl_steel_allfi	90060008	1.83E-06	2
te_rigid1	90060052	SectShll273	90060005	matl_steel_allfi	90060008	1.55E-06	1.5
te_rigid2	90060053	SectShll273	90060005	matl_steel_allfi	90060008	2.34E-06	1.5
e_rigid32	90060054	SectShll273	90060005	matl_steel_allfi	90060008	1.45E-06	1.5
te_rigid4	90060055	SectShll273	90060005	matl_steel_allfi	90060008	1.65E-06	1.5
te_rigid5	90060056	SectShll273	90060005	matl_steel_allfi	90060008	1.58E-06	1.5
te_rigid6	90060057	SectShll273	90060005	matl_steel_allfi	90060008	1.98E-06	1.5
te_rigid7	90060058	SectShll273	90060005	matl_steel_allfi	90060008	9.84E-07	1.5
te_rigid8	90060059	SectShll273	90060005	matl_steel_allfi	90060008	1.76E-06	1.5
e.pedal	90060060	SectShll3.2	90060073	STEEL_NON_RIGID_	90060011	8.37E-04	8
e.pad	90060061	SectShll4.2	90060074	STEEL_NON_RIGID_	90060011	1.20E-04	3.5
e.pin	90060062	SectShll6.1	90060075	STEEL_NON_RIGID_	90060011	1.14E-04	2
dalpivout	90060063	SectShll20000.1	90060072	MAT20_20003.1	90060009	8.58E-06	3
dalpivinb	90060064	SectShll20000.1	90060072	MAT20_20003.1	90060009	8.58E-06	3
pedallink	90060065	SectShll20000.1	90060072	MAT20_20003.1	90060009	1.43E-06	3
rkt_boost	90060066	SectShll20000.1	90060072	MAT20_20003.1	90060009	0.00385	3
pivot inb	90060067	SectShll20000.1	90060072	MAT20_20003.1	90060009	4.32E-06	3
pivot out	90060068	SectShll20000.1	90060072	MAT20_20003.1	90060009	1.10E-06	3
:_22026	90060069	SectBeam20101.1	90060003	steel_elastic_fo	90060006	0	0
art221130	90060070	SectShll20000.1	90060072	MAT20_20003.1	90060009	1.09E-06	3
art221131	90060071	SectShll20000.1	90060072	MAT20_20003.1	90060009	1.39E-06	3
art221132	90060072	SectShll20000.1	90060072	MAT20_20003.1	90060009	9.68E-07	3
art221133	90060073	SectShll20000.1	90060072	MAT20_20003.1	90060009	9.69E-07	3

art221134	90060074	SectShll20000.1	90060072	MAT20_20003.1	90060009	6.81E-07	3
art221135	90060075	SectShll20000.1	90060072	MAT20_20003.1	90060009	1.30E-06	3
Component Name	**ID**	**Property Name**	**ID**	**Material Name**	**ID**	**MASS (ton)**	**Thickness (mm)**
art221136	90060076	SectShll20000.1	90060072	MAT20_20003.1	90060009	9.62E-07	3
dr_ealf	90060077	SectShll591	90060077	STEEL_NON_RIGID_	90060011	2.29E-04	1.5
dr_eart	90060078	SectShll591	90060077	MAT24_20022	90060020	2.29E-04	1.5
ps_eart	90060079	SectShll560	90060076	MAT24_20022	90060020	1.64E-04	1.5
ps_eart.1	90060080	SectShll560	90060076	MAT24_20022	90060020	1.64E-04	1.5
ttachment	90060081	SectShll536	90060078	MAT24_20022	90060020	5.37E-04	2
_fixdeles	90060082	SectShll536	90060078	allfixed_matl20	90060010	1.18E-06	2
_fixdeles	90060083	SectShll536	90060078	allfixed_matl20	90060010	1.27E-06	2
_fixdeles	90060084	SectShll536	90060078	allfixed_matl20	90060010	2.33E-06	2
_fixdeles	90060085	SectShll536	90060078	allfixed_matl20	90060010	1.83E-06	2
_fixdeles	90060086	SectShll536	90060078	allfixed_matl20	90060010	4.47E-06	2
_fixdeles	90060087	SectShll536	90060078	allfixed_matl20	90060010	7.59E-06	2
_fixdeles	90060088	SectShll536	90060078	allfixed_matl20	90060010	2.76E-06	2
_fixdeles	90060089	SectShll536	90060078	allfixed_matl20	90060010	3.89E-06	2
rame_base	90060090	gbx_frm_bs_25thk	90060080	POLYFORT_PP070	90060016	3.96E-04	2.5
gboxframe	90060091	gbx_frm_rib_10th	90060081	POLYFORT_PP070	90060016	5.18E-06	1
gboxframe	90060092	gbx_frm_rib_12th	90060082	POLYFORT_PP070	90060016	2.68E-05	1.2
eam_65dia	90060093	hinge_beam_props	90060004	steel_elastic_fo	90060006	1.07E-04	0
g_6.5.1.1	90060094	SectShll1.1.1	90060100	MAGNESIUM_NON_RI	90060012	3.06E-04	6.5
g_3.0.1.1	90060095	SectShll2.2	90060101	MAGNESIUM_NON_RI	90060012	0.003441	3
g_4.0.1.1	90060096	SectShll3.4	90060102	MAGNESIUM_NON_RI	90060012	4.78E-04	4
_ribs.1.1	90060097	SectShll4.4	90060103	MAGNESIUM_NON_RI	90060012	0.002763	3
g_1.5.1.1	90060098	SectShll5.1.1	90060104	MAGNESIUM_NON_RI	90060012	1.30E-04	1.5
Mag_5.0.1	90060099	SectShll6.2.1	90060105	MAGNESIUM_NON_RI	90060012	1.38E-04	5
Mag_2.5	90060100	SectShll8.2	90060106	MAGNESIUM_NON_RI	90060012	2.66E-04	2.5
inner.1	90060101	newinner	90060107	POLYFORT_PP070	90060016	3.59E-04	3
ergroorve	90060102	innergroove	90060111	POLYFORT_PP070	90060016	8.66E-07	3.3
ribs.1	90060103	innerribs	90060112	POLYFORT_PP070	90060016	1.40E-04	1.25
bin o	90060104	binprop	90060108	DOWC70035N_w6pcf	90060017	2.78E-04	2.5
ribbin	90060105	binrib	90060110	DOWC70035N_w6pcf	90060017	3.47E-07	1.7
bintongue	90060106	bintongue	90060109	DOWC70035N_w6pcf	90060017	5.25E-07	1.1
outer.1	90060107	outer25thk	90060113	POLYFORT_PP070	90060016	2.87E-04	2.5
hub	90060108	outervrib	90060115	POLYFORT_PP070	90060016	1.87E-06	1
outerhrib	90060109	outerrib	90060114	POLYFORT_PP070	90060016	6.91E-06	1.2
outervrib	90060110	outervrib	90060115	POLYFORT_PP070	90060016	3.11E-07	1
hubrib	90060111	hubrib1375	90060116	POLYFORT_PP070	90060016	2.06E-07	1.375
rm_hinge_	90060112	knee_bolster_out	90060117	POLYFORT_PP070	90060016	8.50E-06	3
lster inn	90060113	inner knee bolst	90060118	POLYFORT_PP070	90060016	2.72E-04	2.5
ner rib h	90060114	inner kb rib	90060119	POLYFORT_PP070	90060016	1.36E-04	1.875
rib inner	90060115	inner kb small r	90060120	POLYFORT_PP070	90060016	3.33E-06	2.6
lster out	90060116	outer knee bolst	90060121	POLYFORT_PP070	90060016	4.31E-04	2.5
use outer	90060117	outer kb dog hou	90060122	POLYFORT_PP070	90060016	6.47E-06	1.4
outer rib	90060118	ribs outer kb	90060123	POLYFORT_PP070	90060016	4.70E-06	1.1

tipof bin	90060119	tip off bin	90060124	POLYFORT_PP070	90060016	5.23E-05	2.5
Masses	90060120	N/A	N/A		0	0.002085	N/A
Component Name	**ID**	**Property Name**	**ID**	**Material Name**	**ID**	**MASS (ton)**	**Thickness (mm)**
ElemMass	90060121	N/A	N/A		0	0.633762	N/A
iver_pass	90060122	N/A	N/A		0	0.156	N/A
oint2Node	90060123	N/A	N/A		0	0	N/A
oint4Node	90060124	N/A	N/A		0	0	N/A
oint6Node	90060125	N/A	N/A		0	0	N/A
SpotWelds	90060126	N/A	N/A		0	0	N/A
Rigids.5	90060127	N/A	N/A		0	0	N/A

Total Components	**498**
Model Mass	**1.778 tonnes**

Enhanced FE Models

Milestone 6

Lightweight Front End Structure Phase II

June 2, 2003



Auto/Steel Partnership

Abstract

This report documents the modifications made to the validated donor vehicle FE models (*Milestone 5*). These FE models will be employed to assess various rail and bumper concepts developed in Phase II of the Lightweight Front End Structure Project.

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1. Objectives

The aim of this effort was to modify the validated FE models (*Milestone 5*), in order to render them suitable for DOE studies. The size of several assemblies not critical to crash was reduced. A comprehensive model checking was also initiated. All modifications and enhancements, other than size reduction, will be incorporated in *Milestone 7: NCAP/IIHS DOE FE Models*. These FE models will be employed to assess various rail and bumper concepts developed in Phase II of the Lightweight Front End Structure Project.

2. Results Summary

The following vehicles assemblies were coarsened.

- **IP Assembly**
- **Door Assembly**
- **Hood**
- **Windshield**
- **Roof**

The mesh coarsening resulted in a reduction in run time by 50%, compared to the validated FE models (*Milestone 5*).

The NCAP response did not change significantly due to the mesh coarsening. However, some IIHS intrusions changed considerably. The model will be suitably corrected in *Milestone 7* such that all measurements are consistent. Furthermore, the brake pedal and toepan intrusions for the Validated Model (*Milestone 5*) have been modified, as the brake pedal reference was corrected.

The NCAP and IIHS results are summarized in *Table 1* and *Table 2*.

Table 1: NCAP Results

B Pillar Pulse	Test Data	Validated Model	Enhanced Model
LH	39.6 g @ 40.1 ms	35.7 g @ 58.3 ms	35.4 g @ 57.9 ms
RH	42.1 g @ 53.3 ms	34.3 g @ 63.1 ms	34.3 g @ 65.5 ms

Table 2: IIHS Results

Location	Intrusion @ 250ms (cm)	
	Validated Model	Enhanced Model
Left Toepan	13.4	12.7
Center Toepan	13.8	12.5
Right Toepan	16.0	15.1
Brake Pedal*	8.6	14.8
A-B Pillar Closure	10.0	9.3
Steering Column Upward Movement*	11.2	3.0
Steering Column Rearward Movement*	4.6	4.2

*** Model has to be checked for variance in measurements**

3. Model Modifications

Several assemblies that possessed a large number of degrees of freedom and were not critical to crash were coarsened. *Table 3* and *Table 4* summarize the size of the assemblies and the run times.



Figure 1: Door Assembly Fine Mesh Model

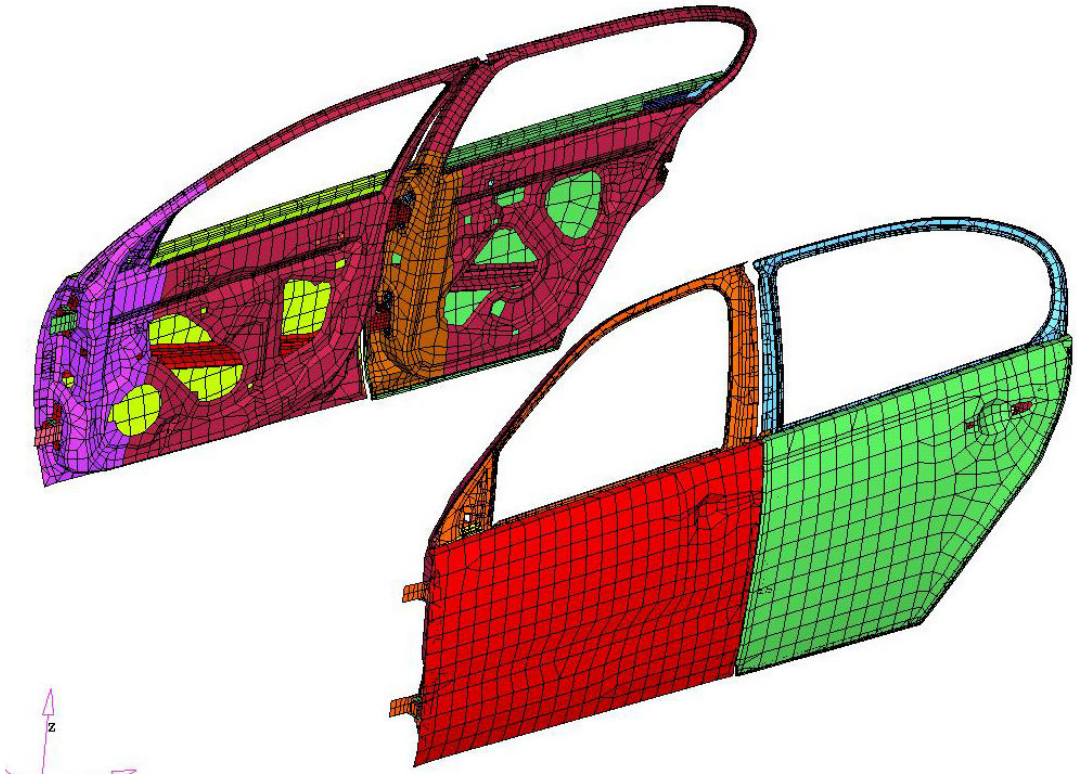


Figure 2: Door Assembly Coarse Mesh Model

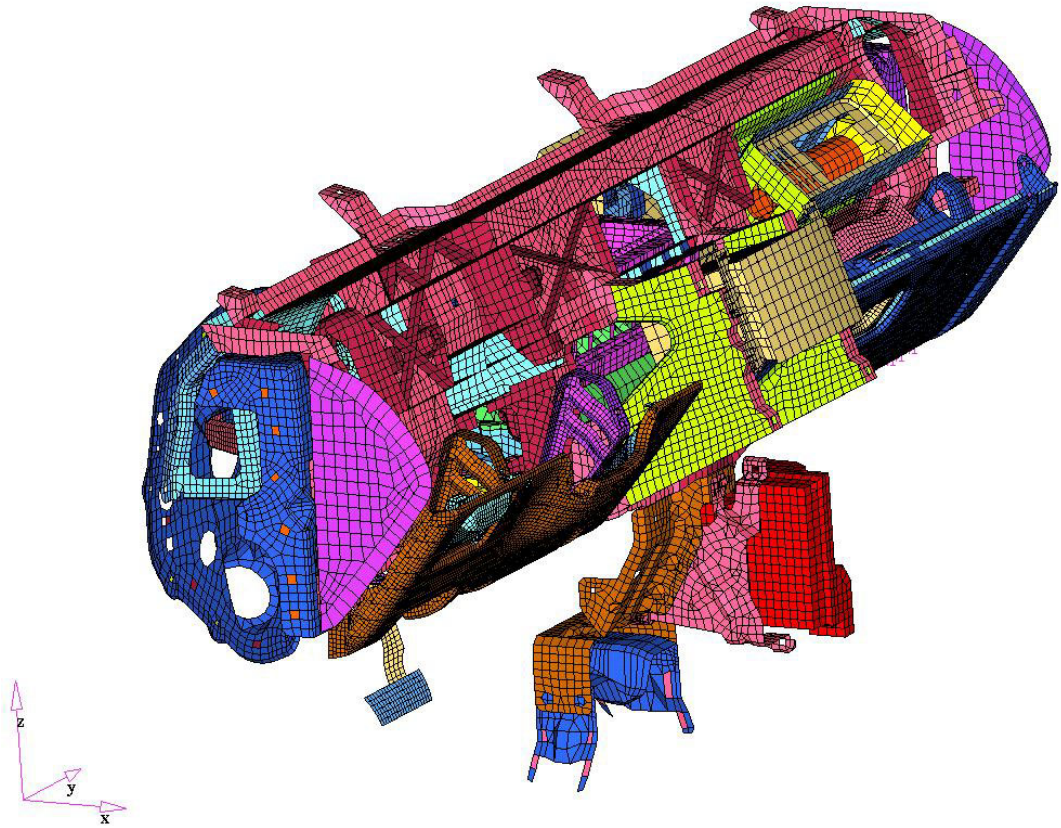


Figure 3: IP Fine Mesh Model

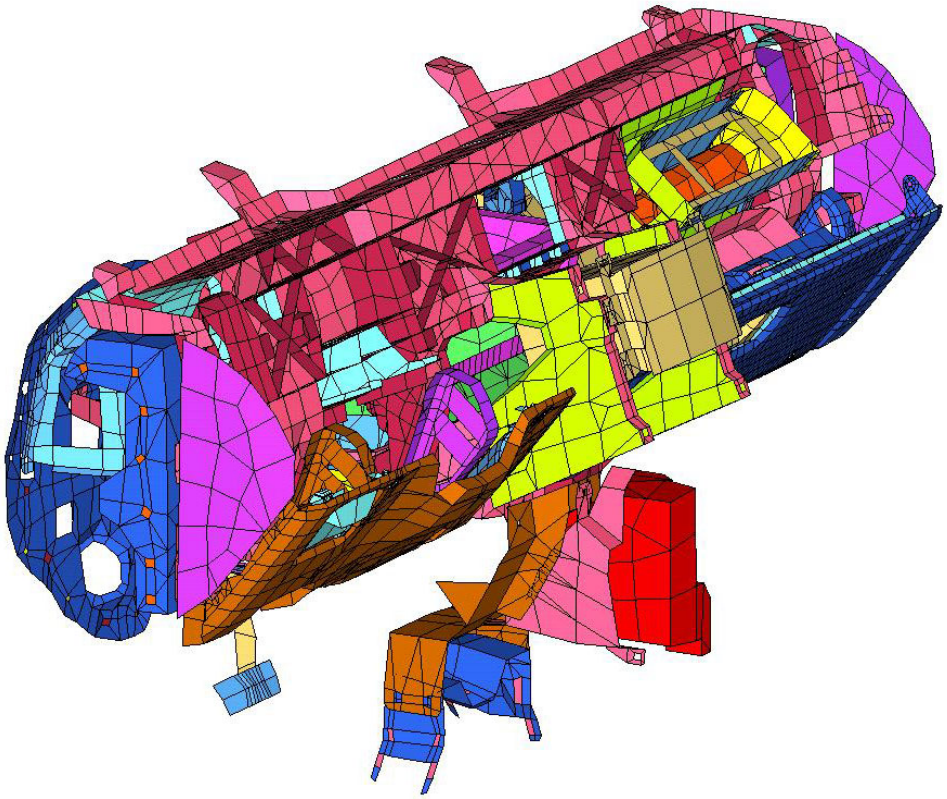


Figure 4: IP Coarse Mesh Model

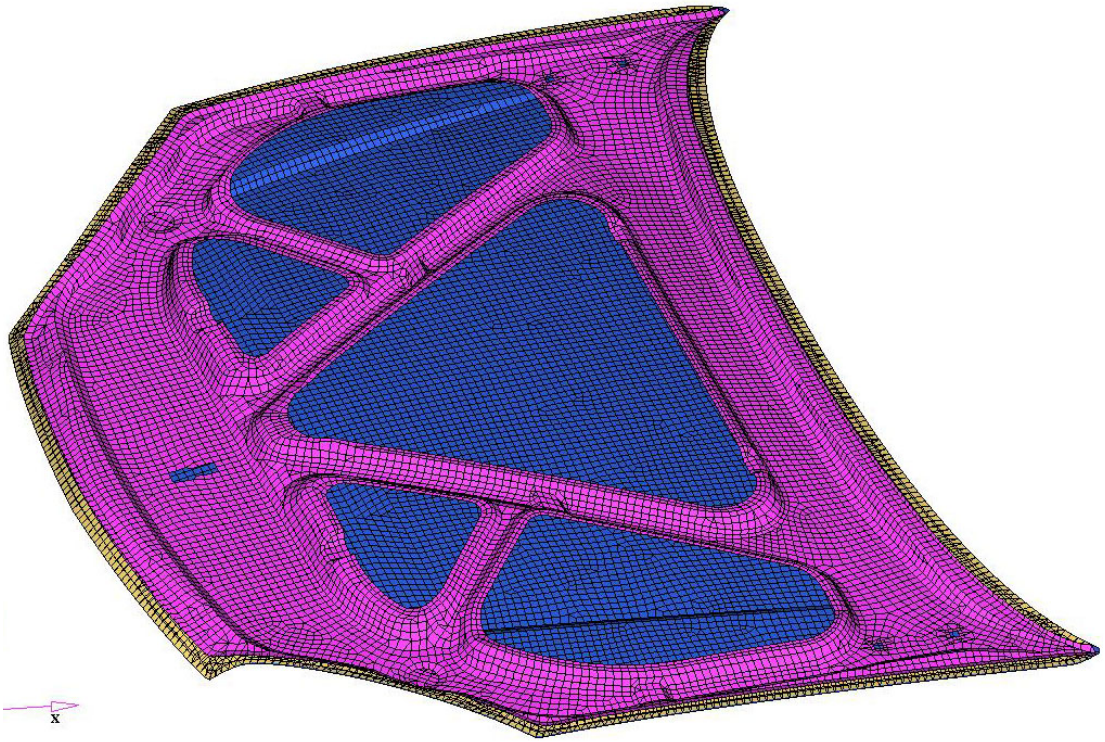


Figure 5: Hood Assembly Fine Mesh Model

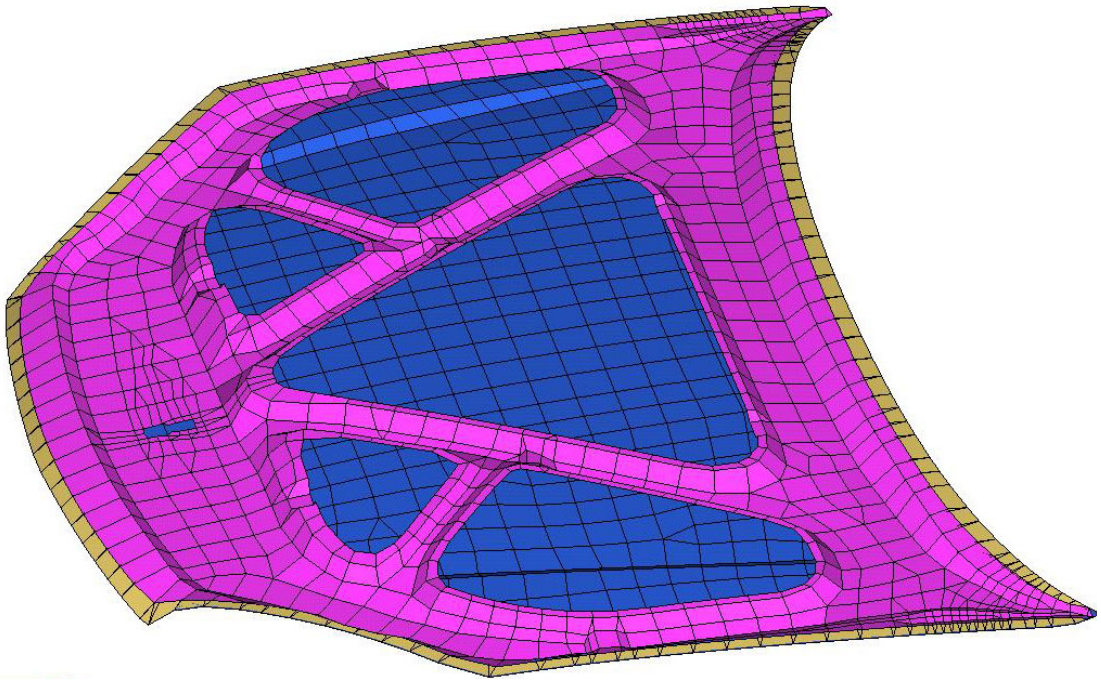


Figure 6: Hood Assembly Coarse Mesh Model

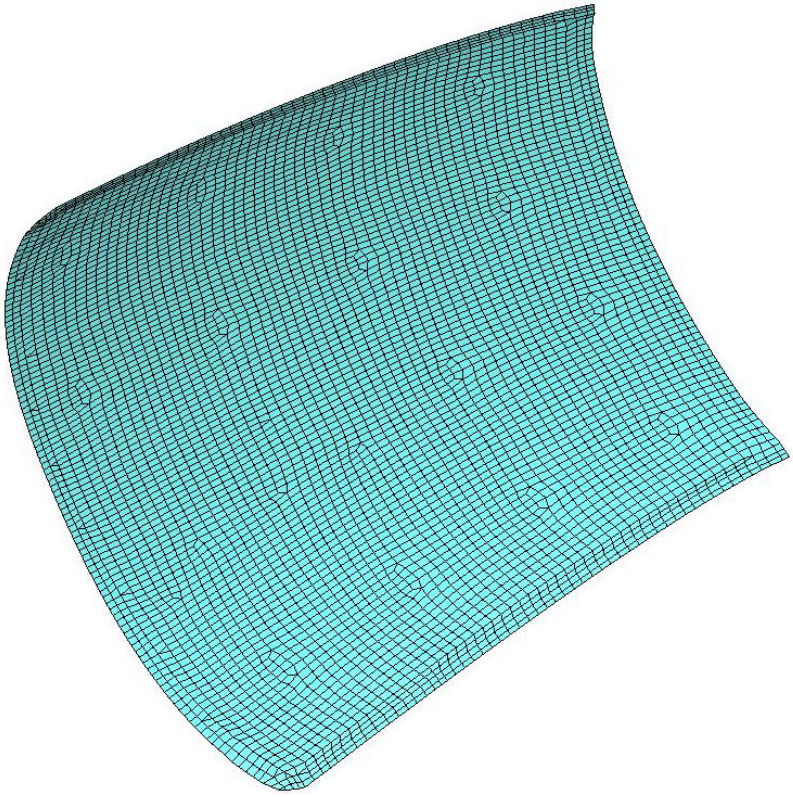


Figure 7: Windshield Fine Mesh Model

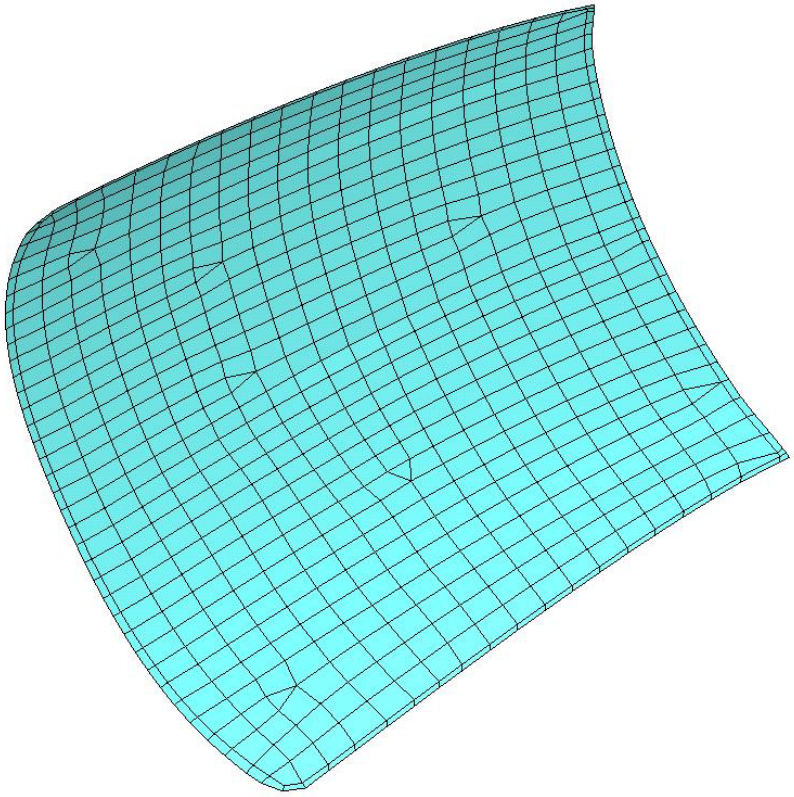


Figure 8: Windshield Coarse Mesh Model

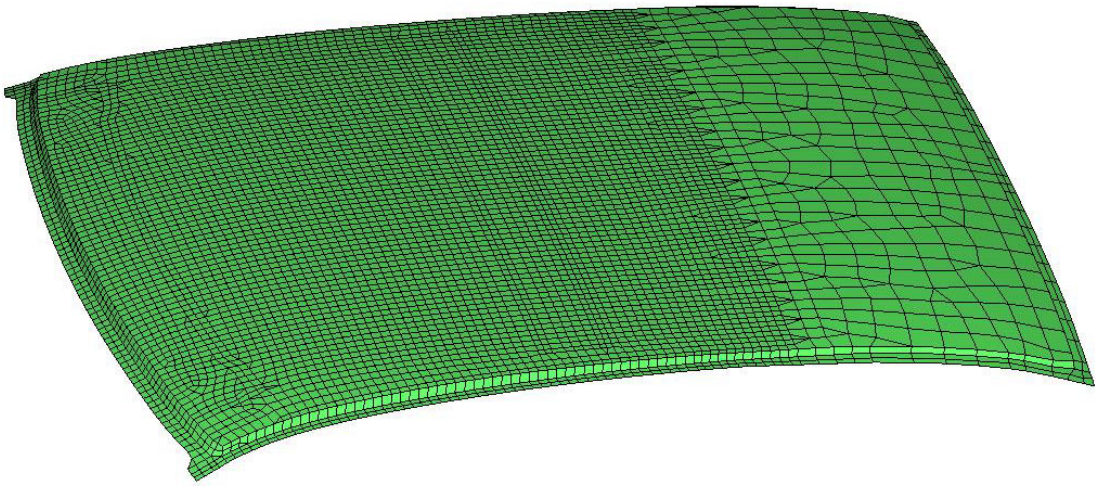


Figure 9: Roof Fine Mesh Model

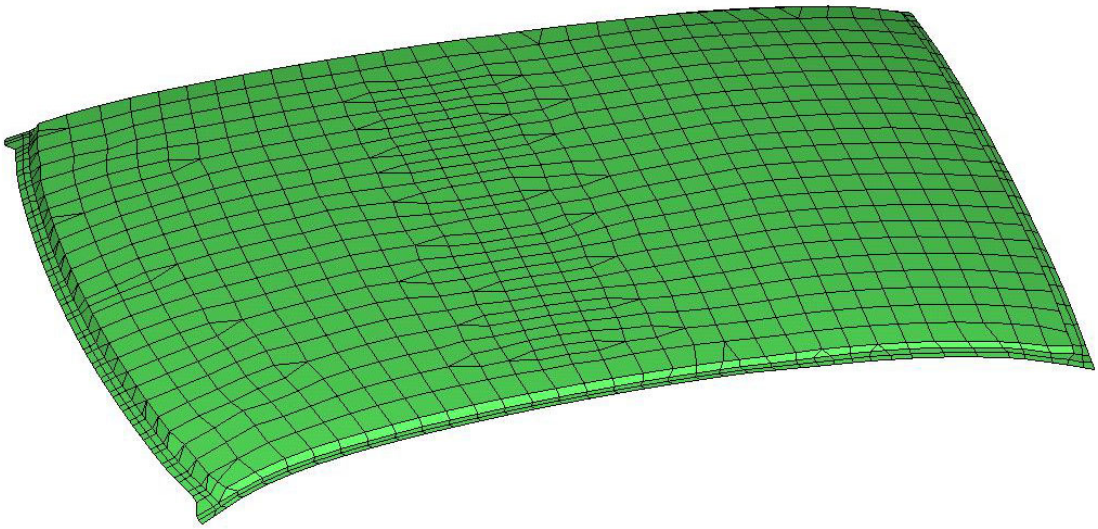


Figure 10: Roof Coarse Mesh Model

Table 3: Size of Assemblies

Assembly	Number of Nodes	
	Validated Model	Enhanced Model
Door	83295 *(Figure 1)*	15787 *(Figure 2)*
IP	81255 *(Figure 3)*	12521 *(Figure 4)*
Hood	23015 *(Figure 5)*	2073 *(Figure 6)*
Roof	6403 *(Figure 7)*	1239 *(Figure 8)*
Windshield	5774 *(Figure 9)*	750 *(Figure 10)*

Table 4: Model Size Comparison

Parameters	Validated Model	Enhanced Model	% Reduction
No. Nodes	439039	271664	38.1
No. Elements	448762	281964	37.2
NCAP CPU Time	85 hrs 51 min	40 hrs 26 min	52.9
IIHS CPU Time	278 hrs 11 min	138 hrs 40 min	50.2

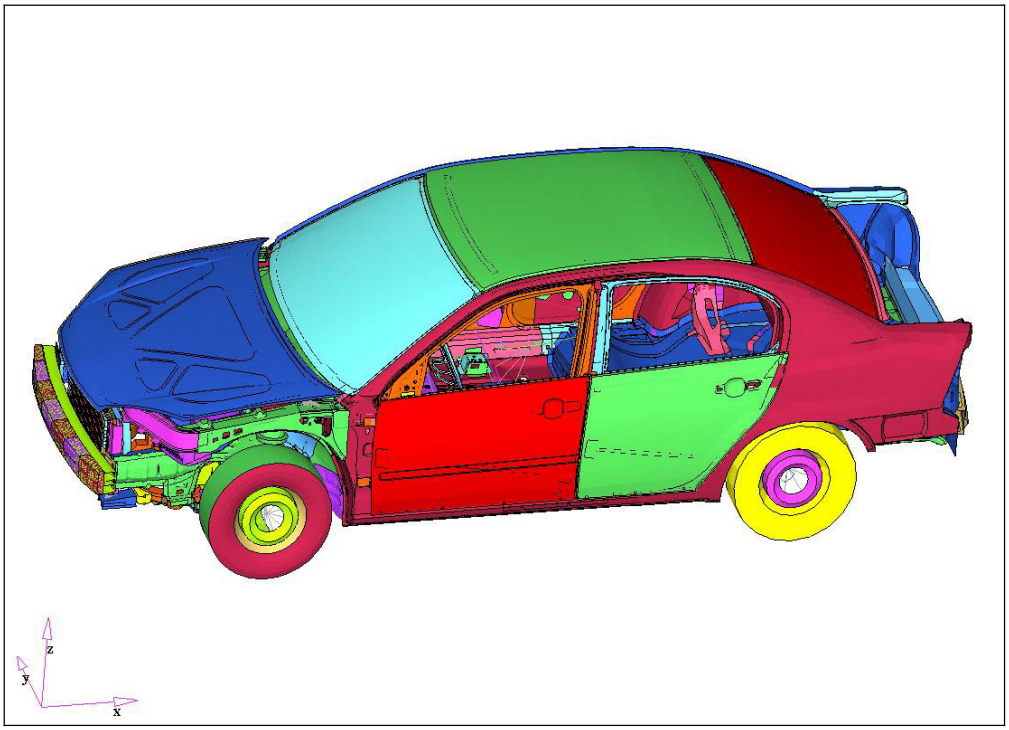


Figure 11: NCAP Full Vehicle FE Model

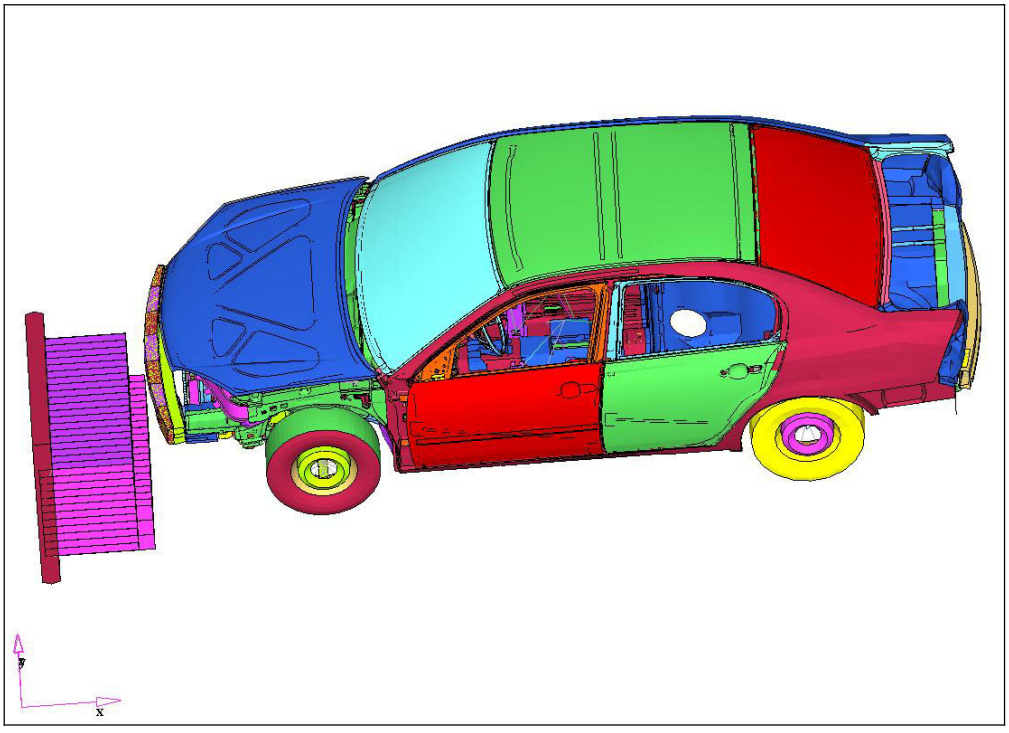


Figure 12: IIHS Full Vehicle FE Model

4. NCAP Response

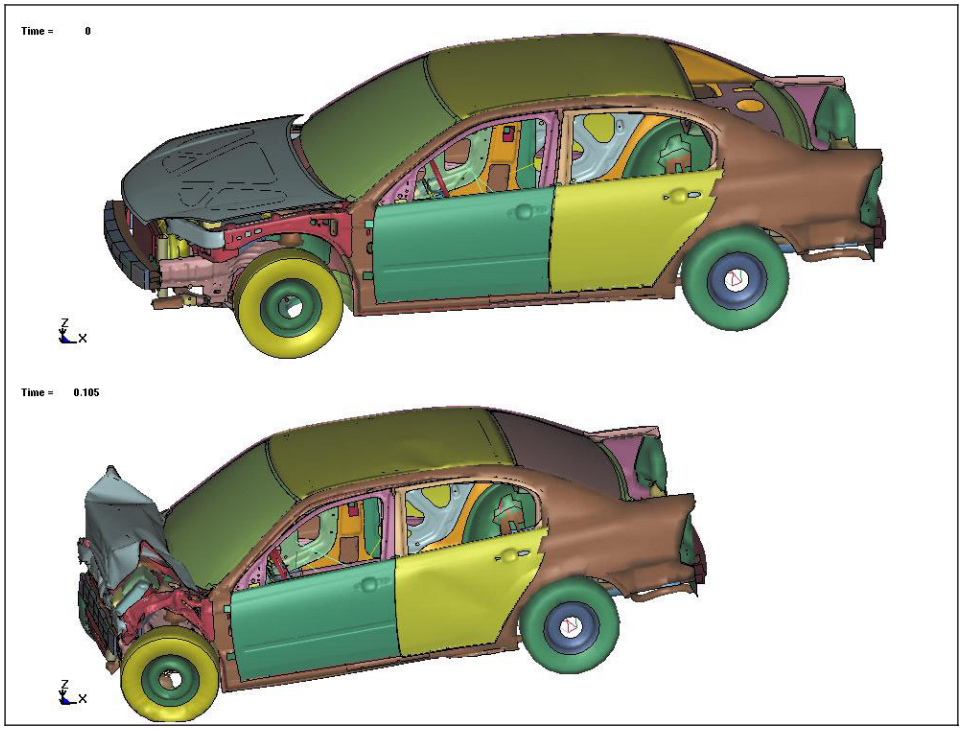


Figure 13: Deformation of Full Vehicle

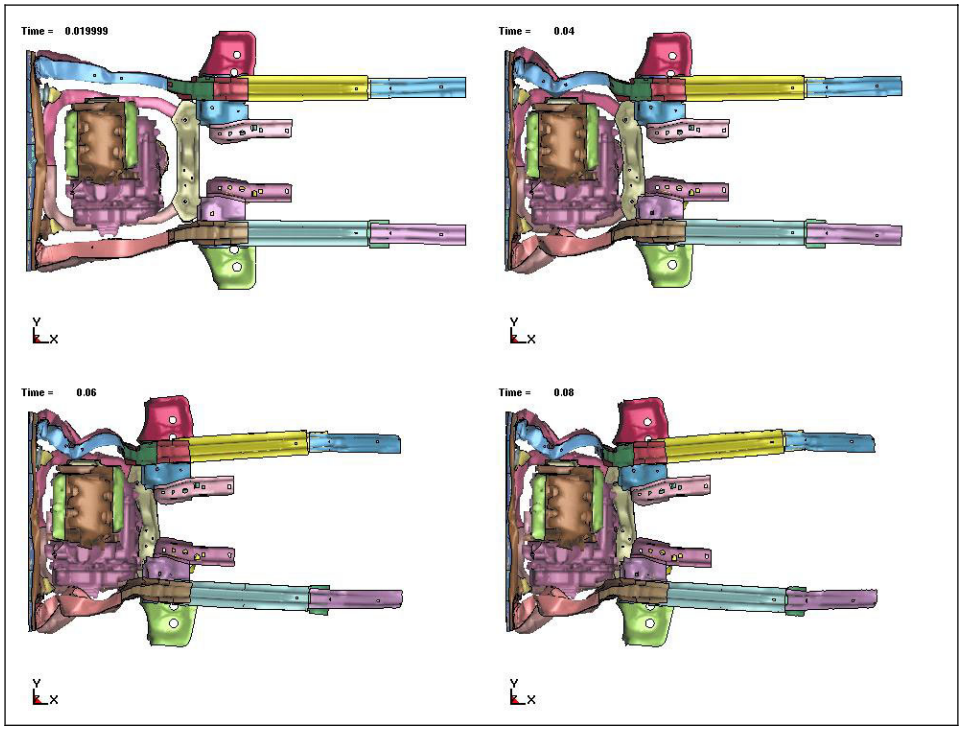


Figure 14: Deformation of Front End (Top View)

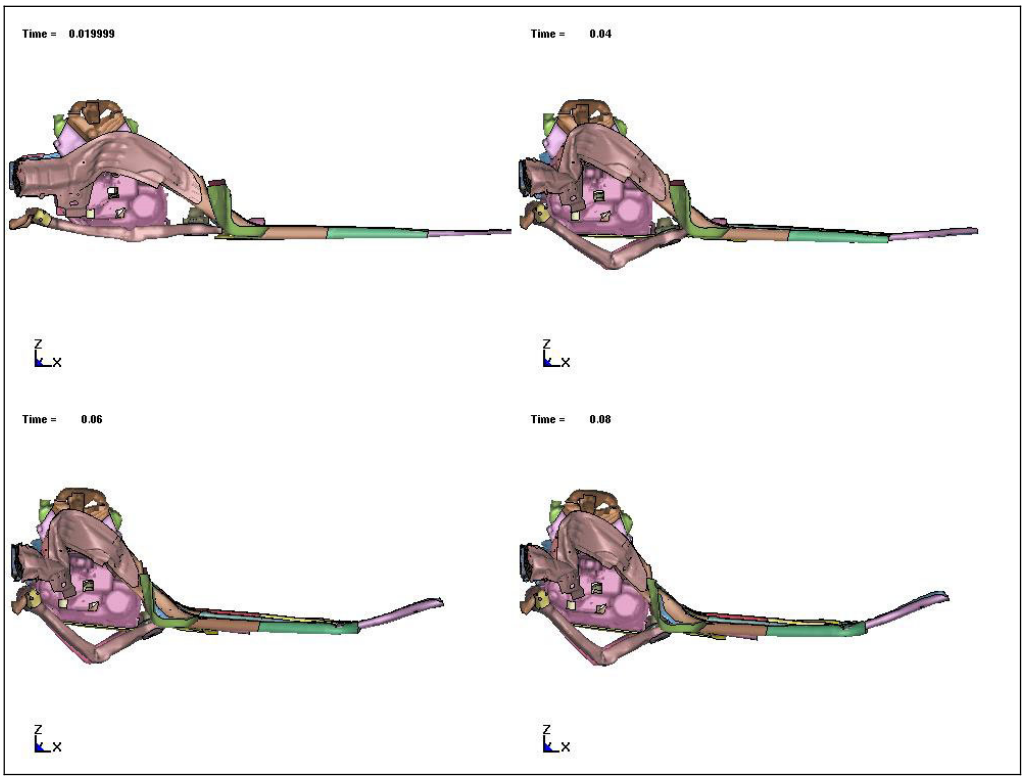


Figure 15: Deformation of Front End (Left Side View)

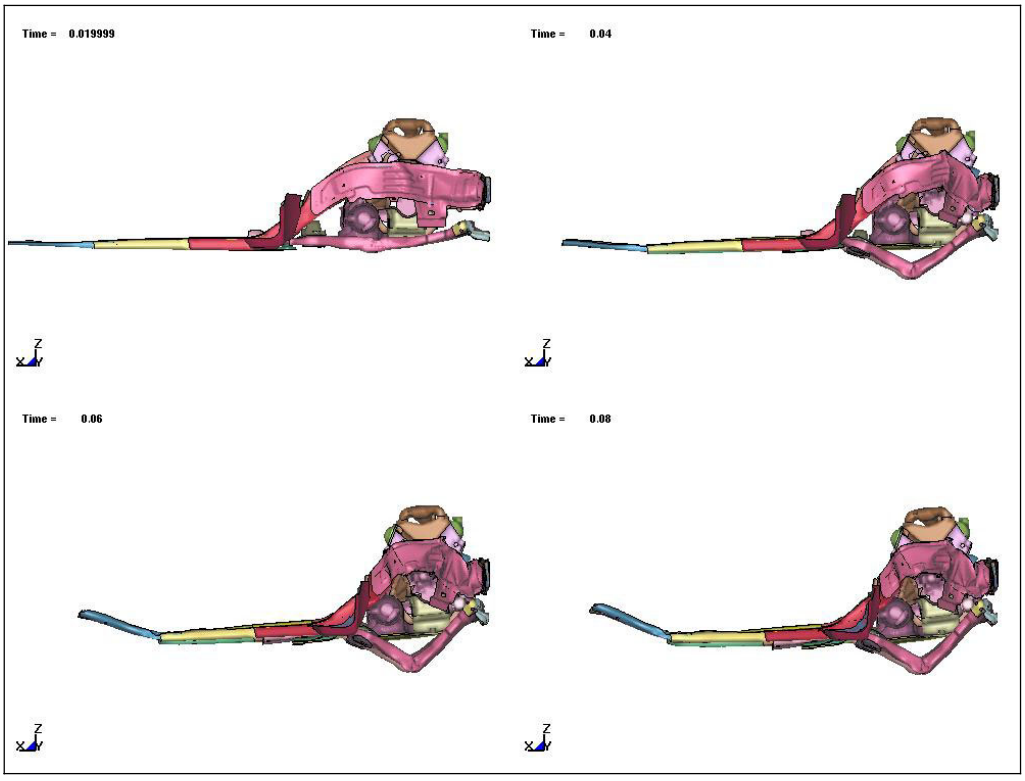


Figure 16: Deformation of Front End (Right Side View)

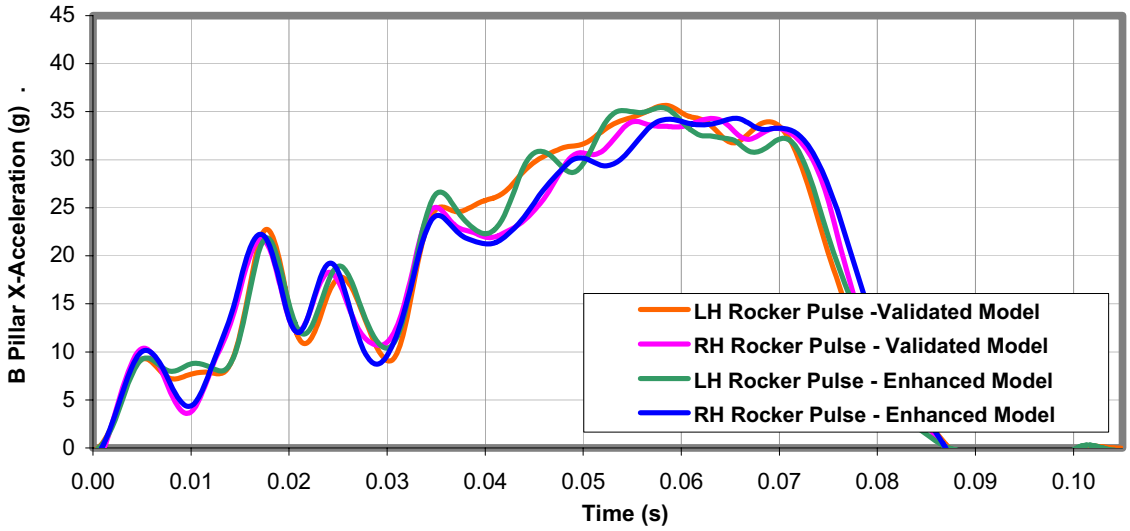


Figure 17: Comparison of B Pillar Pulse - Validated and Enhanced Model

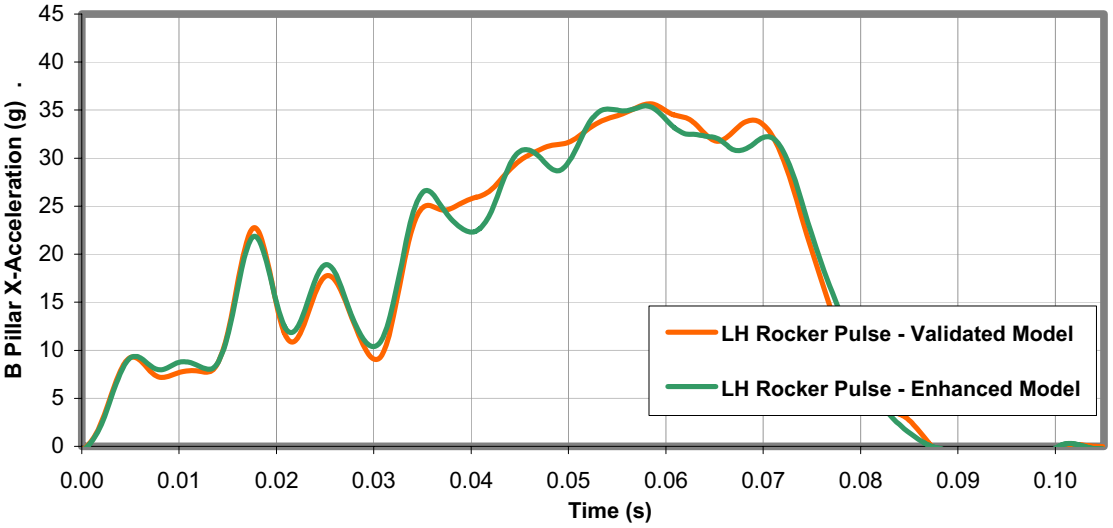


Figure 18: B Pillar Pulse – LH

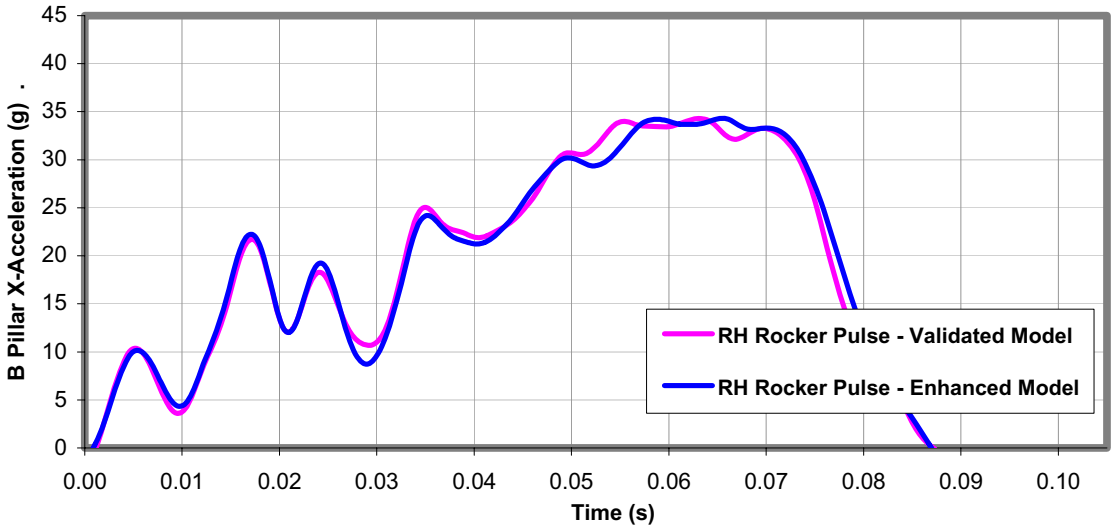


Figure 19: B Pillar Pulse – RH

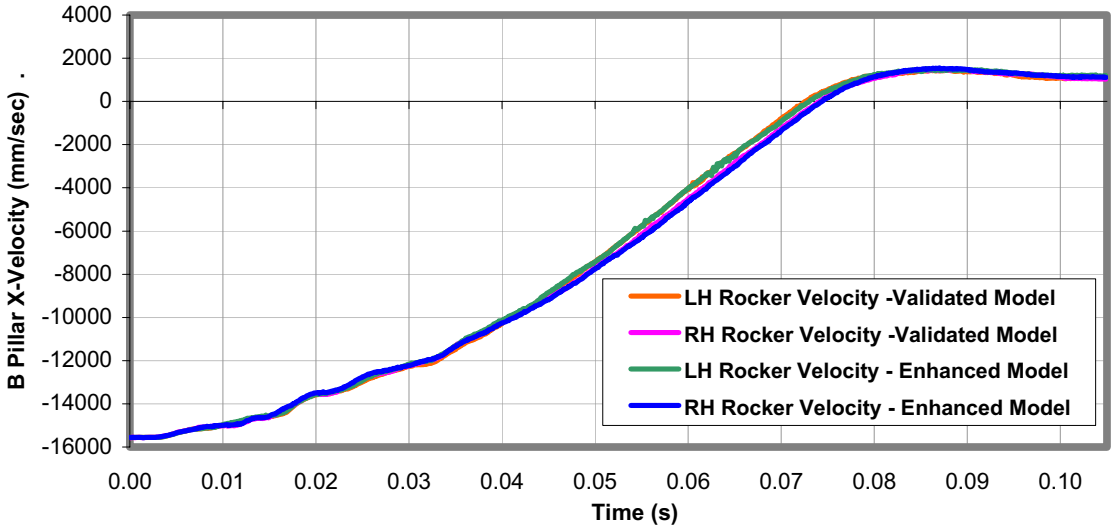


Figure 20: Comparison of B Pillar Velocity – Validated and Enhanced Model

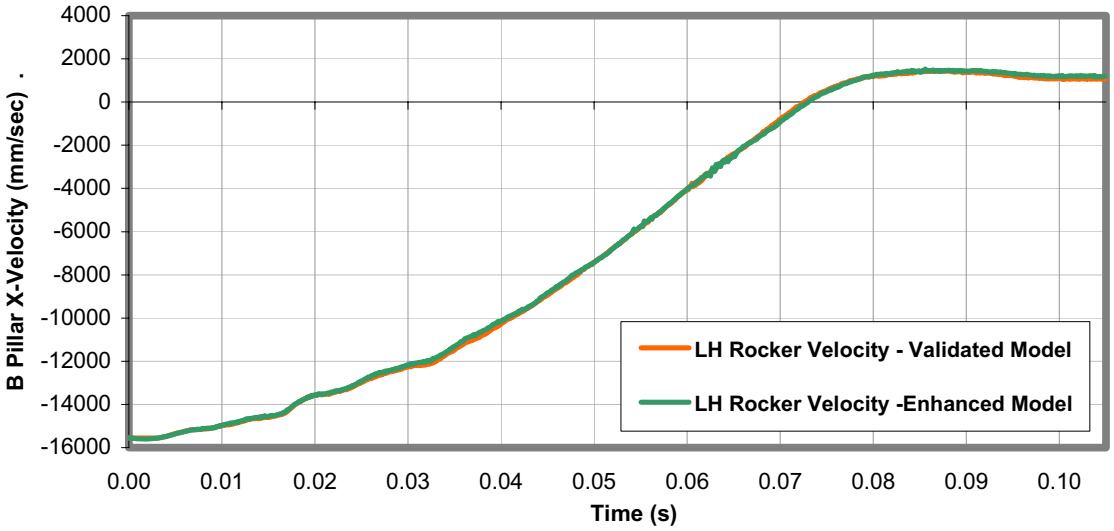


Figure 21: B Pillar Velocity - LH

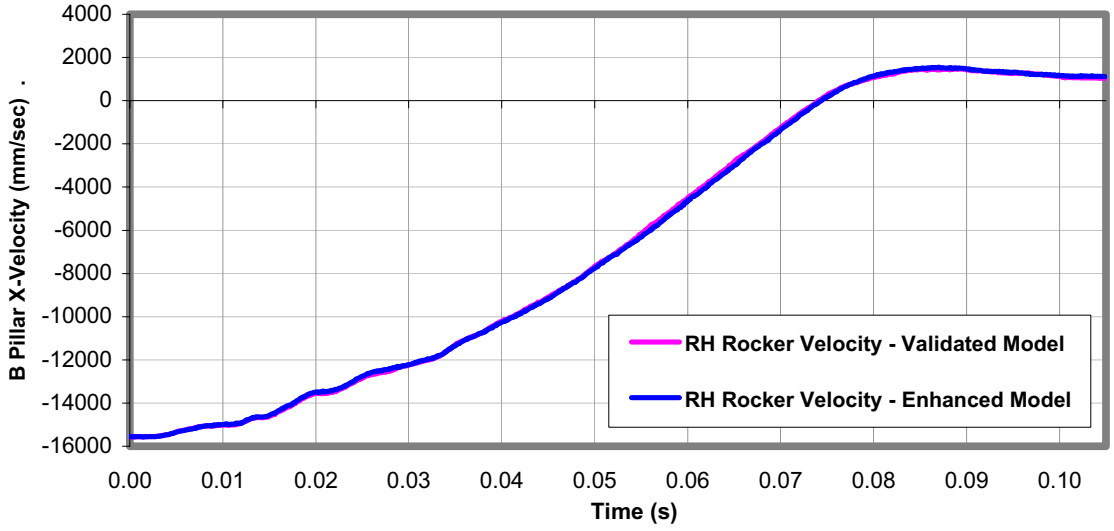


Figure 22: B-Pillar Velocity - RH

Table 5: NCAP Crash Events

Time (ms)	Crash Events
0-15	Bumper absorbs energy
15-20	Cradle engaged and engine hits the radiator
25-30	Cradle and LH rail buckling started
35-40	LH front wheel hits the LH rail
40-45	Engine hits to dash
45-50	RH front wheel hits the RH rail
55-60	LH wheel hits the front rigid wall
60-65	RH wheel hits the front rigid wall, LH wheel hits the rocker
75-80	RH wheel hits the rocker

5. IIHS Response

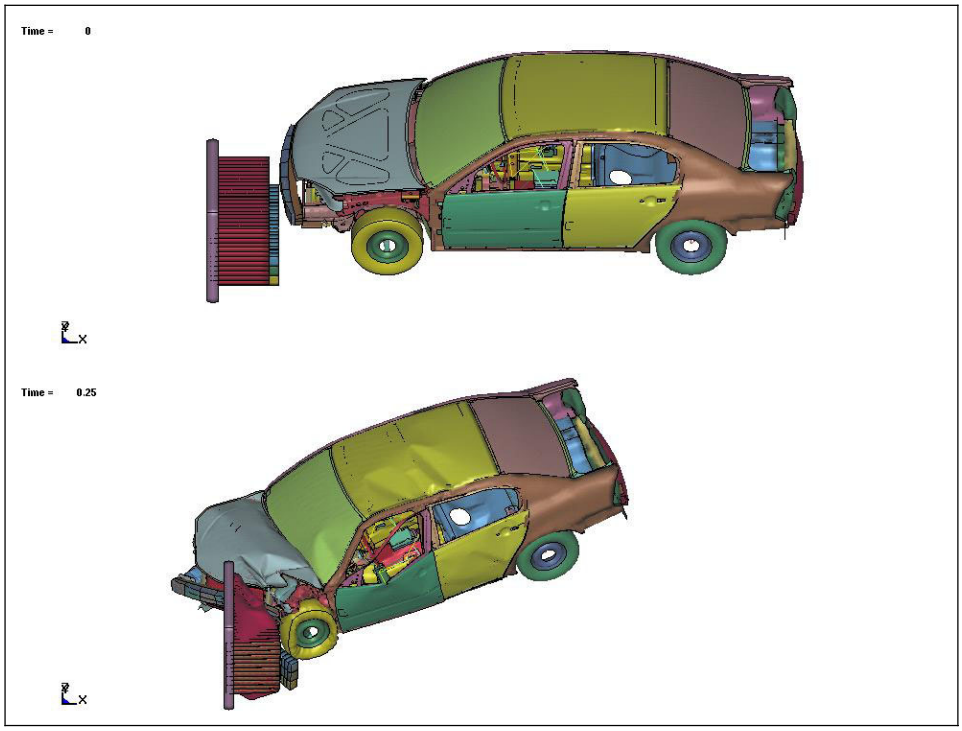


Figure 23: Deformation of Full Vehicle

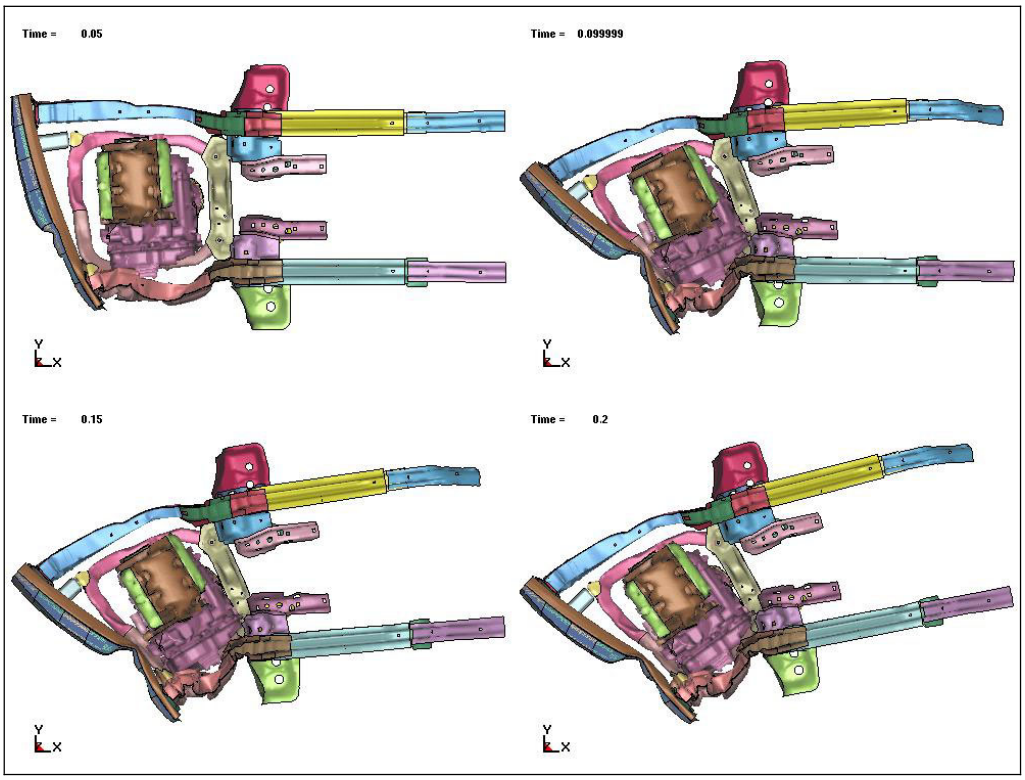


Figure 24: Deformation of Front End (Top View)

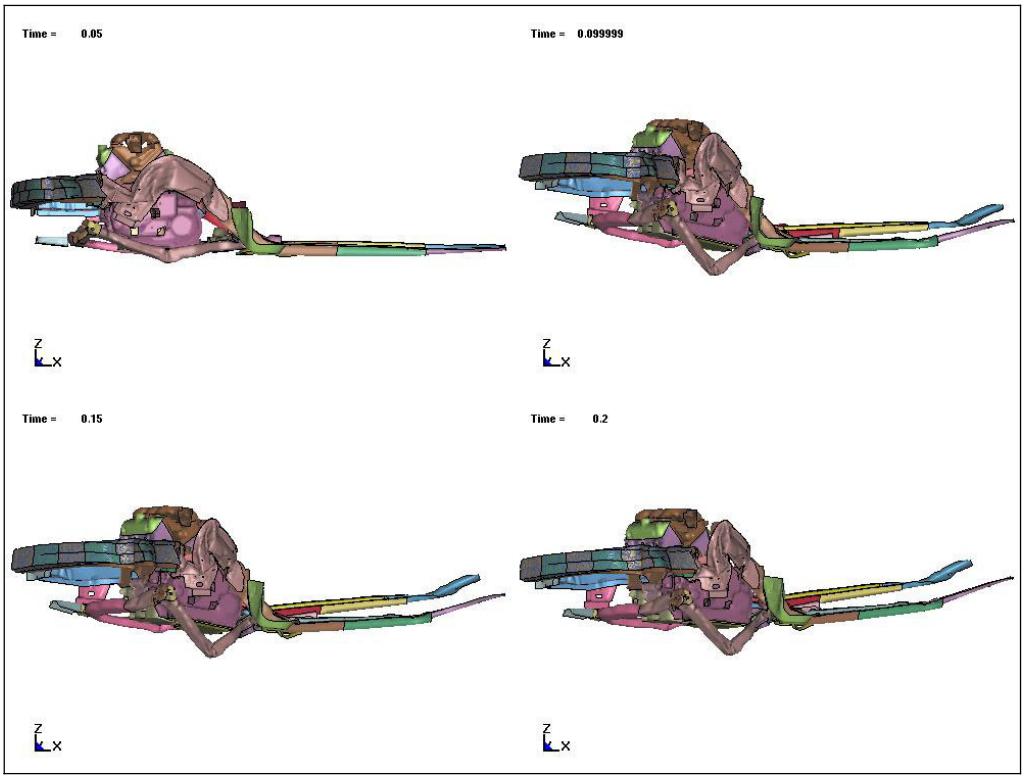


Figure 25: Deformation of Front End (Left Side View)

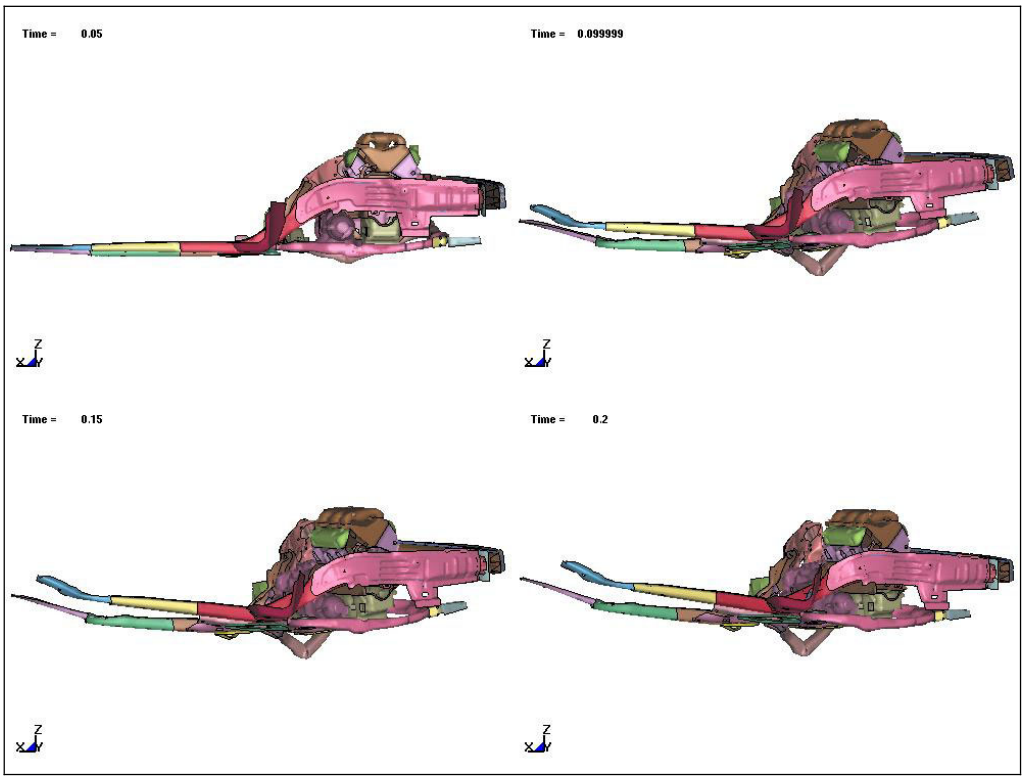


Figure 26: Deformation of Front End (Right Side View)

6. Conclusions

The validated FE models (*Milestone 5*) were modified, in order to render them suitable for DOE studies. The size of several assemblies not critical to crash was reduced. A comprehensive model checking was also initiated. The NCAP response did not change significantly due to the mesh coarsening (*Table 1*). However, some IIHS intrusions changed considerably (*Table 2*). The model will be suitably corrected in *Milestone 7* such that all measurements are consistent.

7. Future Work

The enhanced FE models will be further modified, in order to make them ideal for DOE studies. All modifications and enhancements will be incorporated in *Milestone 7: NCAP/IIHS DOE FE Models*. These FE models will be employed to assess various rail and bumper concepts developed in Phase II of the Lightweight Front End Structure Project.

8. References

1) *Validated FE Models, Milestone 5*, SPHINX, Phase II.

9. Appendix A: Animations

The following animation files for the subsystem development can be viewed at the Auto/Steel Partnership website, www.a-sp.org.

You will need a Hyperview Player in order to view these animations at the site. You can download this free software at www.altair.com.

1. NCAP: Full Vehicle
2. NCAP: Front-End
3. IIHS: Full Vehicle
4. IIHS: Front-End

10. Appendix B: Summary of FE Model

Component Name	ID	Property Name	ID	Material Name	ID	MASS (ton)	Thickness (mm)
Part_2	60002	SectShll10.1	60010	MATL9_2	60002	0.014989	1
part.42	61161	SectDisc779	60779	MATSpr1_779	60779	0	0
part.43	61162	SectDisc780	60780	MATDmp2_780	60780	0	0
part.44	61163	SectDisc781	60781	MATSpr4_781	60781	0	0
part.47	61166	SectDisc783	60783	MATDmp2_784	60784	0	0
part.9	61365	SectShll20.1	60020	MAT9_704	60704	1.11E-04	2
part.10	61366	SectShll20.1	60020	MAT9_705	60705	4.58E-05	2
part.11	61367	SectShll5.3	60005	MAT20_706	60706	5.98E-05	0.5
part.12	61368	SectBeam707	60707	MAT24_707	60707	7.69E-04	0
part.14	61411	SectShll20.1	60020	MAT20_750	60750	0.001699	2
part.15	61412	SectShll10.1	60010	MAT20_751	60751	8.05E-05	1
part.16	61413	SectShll34	60034	MAT20_752	60752	1.83E-04	3.4
part.17	61414	SectShll25	60025	MAT20_753	60753	5.23E-04	2.5
part.18	61415	SectShll25	60025	MAT20_754	60754	6.50E-04	2.5
part.19	61416	SectShll20.1	60020	MAT20_755	60755	5.14E-04	2
part.20	61417	SectShll30	60030	MAT20_756	60756	4.70E-04	3
part.21	61418	SectShll34	60034	MAT20_757	60757	2.55E-04	3.4
part.22	61419	SectShll20.1	60020	MAT20_758	60758	5.61E-05	2
part.24	61421	SectShll20.1	60020	MAT20_760	60760	1.14E-04	2
part.25	61422	SectShll20.1	60020	MAT20_761	60761	8.86E-05	2
part.28	61425	SectShll20.1	60020	MAT20_764	60764	2.43E-05	2
part.29	61426	SectShll20.1	60020	MAT20_765	60765	2.32E-05	2
part.30	61427	SectShll40	60040	MAT20_766	60766	3.95E-06	4
part.31	61428	SectShll40	60040	MAT20_767	60767	3.95E-06	4
part.34	61432	SectShll40	60040	MAT24_771	60771	2.43E-05	4
part.40	61438	SectShll30	60030	MAT20_777	60777	3.28E-04	3
part.41	61439	SectShll30	60030	MAT20_778	60778	3.69E-04	3
railinr.l	70662	Sectshll16.5	60165	MATL24_250	60250	0.003805	1.65
railotr.l	70663	SectShll15.3	60015	MATL24_340	60340	0.002781	1.5
trnsrnf	70664	Sectshll17.5	60175	MATL24_340	60340	2.91E-04	1.75
ailctr1.l	70665	SectShll20.1	60020	MATL24_210	60210	0.00383	2
ubrail.l	70666	SectShll95	60095	MATL24_340	60340	5.89E-04	0.95
ailrnf1.l	70667	SectShll12.1	60012	MATL24_340	60340	4.46E-04	1.2
ailrnf2.l	70668	SectShll225	60225	MATL24_3404	63404	0.00282	2.25
trqbox1.l	70670	Sectshll14.5	60145	MATL24_210	60210	0.001434	1.45
trqbox2.l	70671	Sectshll14.5	60145	MATL24_160	60160	2.73E-04	1.45
btray1	70674	SectShll15.3	60015	MATL24_160	60160	0.003147	1.5
btray2	70675	SectShll10.1	60010	MATL24_160	60160	2.19E-04	1
frtflr	70677	SectShll085	60085	MATL24_160	60160	0.013015	0.85
rkrinr.l	70680	sectshll16	60016	MATL24_3404	63404	0.003811	1.6
bar2.l	70681	SectShll12.1	60012	MATL24_160	60160	0.00138	1.2

Component Name	ID	Property Name	ID	Material Name	ID	MASS (ton)	Thickness (mm)
eatrein.l	70684	SectShll12.1	60012	MATL24_160	60160	3.44E-04	1.2
bar1	70687	SectShll20.1	60020	MATL24_3404	63404	0.002622	2
tnl1	70688	SectShll18.1	60018	MATL24_340	60340	0.001311	1.8
trnfext.l	70689	SectShll20.1	60020	MATL24_250	60250	0.001246	2
tnl2	70690	SectShll12.1	60012	MATL24_250	60250	0.006463	1.2
rdlmnt1.l	70693	Sectshll19.5	60195	MATL24_160	60160	8.12E-04	1.95
rdlmnt2.l	70694	Sectshll14.5	60145	MATL24_210	60210	1.37E-04	1.45
rdlmnt1.l	70695	SectShll25	60025	MATL24_210	60210	0.001234	2.5
rdlmnt2.l	70696	SectShll19.1	60190	MATL24_210	60210	2.84E-04	1.9
rearflr	70700	SectShll8.3	60008	MATL24_160	60160	0.017539	0.8
bar3	70709	SectShll10.1	60010	MATL24_211	60211	0.002442	1
bar4ctr	70710	SectShll10.1	60010	MATL24_340	60340	0.001438	1
bar4lft	70711	SectShll15.3	60015	MATL24_160	60160	0.001168	1.5
rrrail.l	70712	SectShll15.3	60015	MATL24_251	60251	0.005535	1.5
ailrnf1.l	70715	SectShll10.1	60010	MATL24_160	60160	1.93E-04	1
ailrnf2.l	70717	SectShll10.1	60010	MATL24_160	60160	2.10E-04	1
gusset.l	70720	SectShll15.3	60015	MATL24_160	60160	7.13E-04	1.5
gusset2.l	70721	SectShll15.3	60015	MATL24_160	60160	8.44E-04	1.5
gusset3.l	70722	SectShll15.3	60015	MATL24_160	60160	5.19E-04	1.5
gusset4.l	70723	SectShll15.3	60015	MATL24_160	60160	5.89E-04	1.5
tiebar2	70732	SectShll9.1	60009	MATL24_160	60160	0.001152	0.9
pnlfrt1.l	70738	Sectshll75	60075	MATL24_210	60210	5.44E-04	0.75
pnlfrt2.l	70739	SectShll12.1	60012	MATL24_210	60210	0.001237	1.2
urail_l	70742	SectShll8.3	60008	MATL24_160	60160	0.001457	0.8
tiebar	70743	SectShll9.1	60009	MATL24_210	60210	0.002278	0.9
shock.l	70746	Sectshll17.5	60175	MATL24_160	60160	0.001518	1.75
dash	70749	SectShll95	60095	MATL24_160	60160	0.008027	0.95
cowlupr	70754	SectShll8.3	60008	MATL24_210	60210	0.001526	0.8
plrrnf1.l	70763	SectShll10.1	60010	MATL24_210	60210	0.001632	1
hlhsinr.l	70812	SectShll10.1	60010	MATL24_160	60160	0.002906	1
barrnf1.l	70814	SectShll20.1	60020	MATL24_160	60160	0.001399	2
barrnf2.l	70815	SectShll25	60025	MATL24_160	60160	7.24E-04	2.5
backpanel	70826	SectShll8.3	60008	MATL24_160	60160	0.005311	0.8
bpnlrnf	70827	Sectshll75	60075	MATL24_160	60160	0.001933	0.75
roof	70832	Sectshll75	60075	MATL24_160	60160	0.010195	0.75
frthdr	70834	SectShll7.2	60007	MATL24_160	60160	9.30E-04	0.7
rrhdr	70836	SectShll9.1	60009	MATL24_160	60160	0.001134	0.9
rfbow2	70837	SectShll9.1	60009	MATL24_340	60340	9.29E-04	0.9
suspshk.l	70854	SectShll225	60225	MATL24_160	60160	3.05E-04	2.25
wshield	70873	SectShll48	60048	laminatedglass	60101	0.015413	4.8
gbox1	70963	SectShll10.1	60010	MATL24_160	60160	0	1
gbox1rnf	70964	SectShll15.3	60015	MATL24_160	60160	0	1.5
flrlvrrnf	70981	SectShll15.3	60015	MATL24_160	60160	7.10E-04	1.5
rclnmend3	70983	SectShll50	60050	rigid	60103	3.64E-04	5

strngrack	70986	SectShll60	60060	MAT24_1111	61111	0.002617	6
Component Name	**ID**	**Property Name**	**ID**	**Material Name**	**ID**	**MASS (ton)**	**Thickness (mm)**
rrackends	70987	SectShll60	60060	MATL24_160	60160	0.001162	6
pedal2	70993	SectShll30	60030	MATL24_160	60160	0.001364	3
crdl.l	71011	SectShll26	60026	MATL24_340	60340	0.006018	2.6
rdlmnt3.l	71012	SectShll25	60025	MATL24_340	60340	4.35E-04	2.5
tcrdlmnt5	71013	SectShll15.3	60015	MATL24_160	60160	4.31E-04	1.5
rdlrrxlwr	71014	SectShll23	60023	MATL24_340	60340	0.001291	2.3
rdlrrxupr	71015	SectShll25	60025	MATL24_340	60340	0.002183	2.5
crdlblt	71016	SectShll20.1	60020	MATL24_160	60160	2.41E-04	2
rdlbltrnf	71018	SectShll275.1	60275	MATL24_160	60160	3.23E-04	2.75
stabbar	71019	SectShll40	60040	MATL24_160	60160	0.004576	4
lcarnf.l	71020	SectShll30	60030	MATL24_340	60340	3.19E-04	3
ntrlarm.l	71021	SectShll30	60030	MATL24_160	60160	0.002294	3
lcacyl.l	71023	SectShll50	60050	MATL24_160	60160	0.001295	5
bdattch.l	71025	SectShll35	60305	MATL24_160	60160	0.001148	3.5
spstrut.l	71026	SectShll50	60050	MATL24_160	60160	0.005601	5
frtmnt1	71027	SectShll20.1	60020	MATL24_160	60160	1.04E-03	2
frtmnt2	71029	SectShll225	60225	MATL24_160	60160	3.87E-04	2.25
crdlfbrkt	71030	SectShll30	60030	MATL24_600	60600	8.68E-04	3
pt2	71064	SectShll10.1	60010	rigid	60103	0.001123	1
pt3	71066	SectShll10.1	60010	rigid	60103	0.006404	1
driveline	71069	SectShll70	60070	MATL24_340	60340	0.005373	7
pt6	71071	SectShll10.1	60010	rigid	60103	0.304199	1
pt7	71072	SectShll10.1	60010	rigid	60103	0.001243	1
pt8	71073	SectShll20.1	60020	rigid	60103	0.005085	2
pt9	71075	SectShll100	60102	rigid	60103	0.005278	10
pt10	71076	SectShll10.1	60010	rigid	60103	9.92E-04	1
pt11	71077	SectShll225	60225	rigid	60103	0.001336	2.25
pt12	71078	SectShll80	60080	rigid	60103	0.007011	8
pt13	71079	SectShll10.1	60010	rigid	60103	1.07E-04	1
pt14	71080	SectShll10.1	60010	rigid	60103	0.001639	1
pt19	71081	SectShll10.1	60010	rigid	60103	4.08E-04	1
pt16	71082	SectShll40	60040	rigid	60103	0.003234	4
pt17	71083	SectShll30	60030	MATL24_160	60160	0.007696	3
pt18	71084	SectShll40	60040	rigid	60103	0.007255	4
expipefrt	71086	SectShll15.3	60015	MATL24_160	60160	0.003601	1.5
battery1	71099	SectShll5.3	60005	MATL24_160	60160	8.66E-04	0.5
adsupport	71102	SectShll10.1	60010	MATL24_160	60160	0.001261	1
ECM	71103	SectShll10.1	60010	MATL24_160	60160	1.07E-03	1
rad4	71104	SectShll10.1	60010	MATL24_160	60160	8.32E-06	1
rad3	71106	SectSld300	60300	MATL24_160	60160	0	0
rad2	71107	SectSld900	60900	MAT57rad&cond	60102	0.002656	0
rad1	71108	SectSld900	60900	MAT57rad&cond	60102	0.003782	0
rim.l	71111	SectShll35	60305	MATL24_600	60600	0.008136	3.5
tire1.l	71112	SectShll20.1	60020	mat1.tirerubber	60104	0.00197	2

tir2.l	71113	SectShll7.2	60007	MATL24_160	60160	0.002042	0.7
Component Name	**ID**	**Property Name**	**ID**	**Material Name**	**ID**	**MASS (ton)**	**Thickness (mm)**
tire3.l	71114	SectShll3.3	60306	MATL24_160	60160	1.00E-03	0.3
rearrim	71115	SectShll35	60305	MATL24_160	60160	0.015933	3.5
rtire.l	71116	SectShll10.1	60010	MATL24_160	60160	0.007576	1
rclnmend4	71118	SectShll50	60050	rigid	60103	2.10E-04	5
bar1fsusp	71161	Sectbeam10500	60307	MATBEAM	60969	0.00188	0
bar2fsusp	71162	Sectbeam10501	60308	MATBEAM	60969	4.12E-05	0
bar3fsusp	71163	Sectbeam10500	60307	MATBEAM	60969	1.65E-04	0
rsubframe	71164	Sectbeam10503	60309	MATBEAM	60969	0	0
BARDLINE	71165	Sectbeam10504	60310	MATBEAM	60969	7.06E-05	0
bar4fsusp	71166	Sectbeam10500	60307	MATBEAM	60969	9.48E-04	0
bar2dline	71167	Sectbeam10500	60307	MATBEAM	60969	0.001306	0
bar3dline	71168	Sectbeam10504	60310	MATBEAM	60969	1.16E-04	0
bar4dline	71169	Sectbeam10504	60310	MATBEAM	60969	0	0
bar5dline	71170	Sectbeam10509	60311	MATBEAM	60969	8.50E-05	0
bar6dline	71171	Sectbeam10509	60311	MATBEAM	60969	0	0
bar1rrsus	71176	Sectbeam10500	60307	MATBEAM	60969	0.007365	0
ar2rrsusp	71177	Sectbeam10516	60313	MATBEAM	60969	0.019679	0
ar3rrsusp	71178	Sectbeam10516	60313	MATBEAM	60969	0.0026	0
ar4rrsusp	71179	Sectbeam10516	60313	MATBEAM	60969	0.002841	0
ardummies	71180	Sectbeam10519	60314	MATBEAM	60969	0.003373	0
barseat	71181	Sectbeam10519	60314	MATBEAM	60969	3.34E-04	0
rradiator	71183	Sectbeam10522	60316	MATBEAM	60969	1.82E-04	0
driveline	71186	Sectbeam10504	60310	MATBEAM	60969	2.57E-04	0
riveline8	71187	Sectbeam10504	60310	MATBEAM	60969	7.05E-05	0
prdrvline	71266	SectDisc1	60600	Matsprstr14	60605	0	0
prengmnt3	71280	SectDisc1	60600	Matsprstr113	60619	0	0
sprdummy	71282	SectDisc1	60600	Matsprstr114	60621	0	0
spr2dummy	71285	SectDisc1	60600	Matsprstr116	60623	0	0
spr3dummy	71286	SectDisc1	60600	Matsprstr116	60623	0	0
bumpbeam	71461	SectShll12.1	60012	MATL24_848	60848	0.005409	1.2
bumpnull	71463	SectShll10.1	60010	null	60100	0.002833	1
ldfoam	71464	SectSld900	60900	foam2.8pcf	60831	1.91E-04	0
hdfoam	71466	SectSld900	60900	foam6.6pcf	60834	4.93E-04	0
llar_brkt	71467	SectShll18.1	60018	MATL24_340	60340	6.28E-04	1.8
per_plate	71468	SectShll20.1	60020	MATL24_340	60340	5.18E-04	2
per_plate	71469	SectShll20.1	60020	MATL24_340	60340	5.17E-04	2
fanshroud	71470	SectShll20.1	60020	MATL24_181	60181	0.007298	2
hfanmotor	71471	SectShll20.1	60020	MATL24_181	60181	5.60E-04	2
hfanmotor	71472	SectShll20.1	60020	MATL24_181	60181	5.40E-04	2
ep_7685	73662	SectShll10.1	60010	rigid	60103	2.83E-04	1
flywheel	73663	SectShll10.1	60010	rigid	60103	7.92E-04	1
ep_4776	73664	SectShll10.1	60010	rigid	60103	4.99E-04	1
ep_7498	73665	SectShll10.1	60010	rigid	60103	0.002606	1
ep_0939	73666	SectShll10.1	60010	rigid	60103	5.82E-04	1

ep_0017	73667	SectShll10.1	60010	rigid	60103	4.50E-04	1
Component Name	**ID**	**Property Name**	**ID**	**Material Name**	**ID**	**MASS (ton)**	**Thickness (mm)**
ep_70842	73668	SectShll10.1	60010	rigid	60103	1.84E-04	1
tery_fill	73669	SectShll10.1	60010	MATL24_160	60160	0.001326	1
g_mnt_l_e	73670	SectShll80	60080	MATL24_160	60160	0.002636	8
p_bkt_l_e	73671	SectShll80	60080	MAT24_1111	61111	5.72E-04	8
t_bkt_l_e	73672	SectShll30	60030	MATL24_340	60340	9.58E-04	3
g_mnt_r_e	73673	SectShll80	60080	MATL24_160	60160	0.002631	8
p_bkt_r_e	73674	SectShll80	60080	MAT24_1111	61111	1.01E-03	8
t_bkt_r_e	73675	SectShll30	60030	MATL24_340	60340	9.29E-04	3
eformable	73676	SectShll80	60080	MATL24_160	60160	0.001725	8
tiebar4.l	73677	Sectshll75	60075	MATL24_180	60180	4.27E-05	0.75
.supt.upr	73678	Sectshll75	60075	MATL24_160	60160	0.002601	0.75
mltintjnt	73679	Sectshll75	60075	MATL24_160	60160	0.00405	0.75
dpnlotr.l	73681	Sectshll75	60075	MATL24_160	60160	0.014307	0.75
dpnlinr.l	73682	SectShll10.1	60010	MATL24_160	60160	0.00962	1
rkrblkhds	73684	SectShll12.1	60012	MATL24_340	60340	7.59E-04	1.2
rdeck	73685	SectShll10.1	60010	MATL24_160	60160	0.005446	1
rnkgtrfrt	73686	SectShll10.1	60010	MATL24_160	60160	0.00209	1
deckbrkt1	73687	SectShll10.1	60010	MATL24_160	60160	9.01E-04	1
deckbrkt2	73688	SectShll10.1	60010	MATL24_160	60160	2.49E-04	1
trnkgtr.l	73689	SectShll9.1	60009	MATL24_160	60160	3.97E-04	0.9
ckbrkt3.l	73690	SectShll10.1	60010	MATL24_160	60160	8.76E-04	1
ckbrkt4.l	73691	SectShll10.1	60010	MATL24_160	60160	7.68E-04	1
rhtchbrkt	73692	SectShll10.1	60010	MATL24_160	60160	0.001306	1
railext.l	73693	SectShll15.3	60015	MATL24_160	60160	7.29E-04	1.5
pbmbrkt.l	73694	SectShll15.3	60015	MATL24_160	60160	4.35E-04	1.5
rbumpbeam	73695	SectShll10.1	60010	MATL24_160	60160	0.003708	1
bplrrnf.l	73697	SectShll225	60225	MATL24_250	60250	0.003029	2.25
tiebar3.l	73700	Sectshll75	60075	MATL24_180	60180	6.78E-04	0.75
il_rnf2.l	73701	SectShll9.1	60009	MATL24_160	60160	4.72E-04	0.9
62109a_e1	73702	SectShll37	60037	MATL24_160	60160	3.62E-04	3.7
62109a_e2	73703	SectShll37	60037	MATL24_160	60160	1.22E-04	3.7
62109a_e3	73704	SectShll37	60037	MATL24_160	60160	4.00E-04	3.7
62109b_e1	73705	SectShll10.1	60010	MATL24_160	60160	4.06E-04	1
lar_rnf_l	73706	SectShll10.1	60010	MATL24_160	60160	9.04E-04	1
t_bushing	73707	SectShll20.1	60020	MATL24_160	60160	5.79E-04	2
r_wndshld	73708	SectShll48	60048	laminatedglass	60101	0.011646	4.8
part.49	81712	SectShll15.3	60015	MAT20_20015	100022	1.06E-05	1.5
railinr.r	110662	Sectshll16.5	60165	MATL24_250	60250	0.003652	1.65
railotr.r	110663	SectShll15.3	60015	MATL24_340	60340	0.002653	1.5
emntrnf	110664	Sectshll14.5	60145	MATL24_340	60340	2.40E-04	1.45
ailctr1.r	110665	SectShll20.1	60020	MATL24_210	60210	0.003998	2
ubrail.r	110666	SectShll95	60095	MATL24_340	60340	5.92E-04	0.95
ailrnf1.r	110667	SectShll12.1	60012	MATL24_340	60340	4.28E-04	1.2
ailrnf2.r	110668	SectShll225	60225	MATL24_3404	63404	0.002855	2.25

trqbox1.r	110670	Sectshll14.5	60145	MATL24_210	60210	0.001625	1.45
Component Name	**ID**	**Property Name**	**ID**	**Material Name**	**ID**	**MASS (ton)**	**Thickness (mm)**
trqbox2.r	110671	Sectshll14.5	60145	MATL24_160	60160	2.73E-04	1.45
rkrinr.r	110680	sectshll16	60016	MATL24_3404	63404	0.003811	1.6
bar2.r	110681	SectShll12.1	60012	MATL24_160	60160	0.001379	1.2
eatrein.r	110684	SectShll12.1	60012	MATL24_160	60160	3.46E-04	1.2
trnfext.r	110689	SectShll20.1	60020	MATL24_250	60250	0.001225	2
rdlmnt1.r	110693	Sectshll19.5	60195	MATL24_160	60160	7.34E-04	1.95
rdlmnt2.r	110694	Sectshll14.5	60145	MATL24_210	60210	1.38E-04	1.45
rdlmnt1.r	110695	SectShll25	60025	MATL24_210	60210	0.001389	2.5
rdlmnt2.r	110696	SectShll19.1	60190	MATL24_210	60210	2.84E-04	1.9
bar4rt	110711	SectShll15.3	60015	MATL24_160	60160	0.001168	1.5
rrrail.r	110712	SectShll15.3	60015	MATL24_251	60251	0.005519	1.5
ailrnf1.r	110715	SectShll10.1	60010	MATL24_160	60160	1.93E-04	1
ailrnf2.r	110717	SectShll10.1	60010	MATL24_160	60160	2.10E-04	1
gusset.r	110720	SectShll15.3	60015	MATL24_160	60160	7.13E-04	1.5
gusset2.r	110721	SectShll15.3	60015	MATL24_160	60160	8.44E-04	1.5
gusset3.r	110722	SectShll15.3	60015	MATL24_160	60160	5.19E-04	1.5
gusset4.r	110723	SectShll15.3	60015	MATL24_160	60160	5.87E-04	1.5
pnlfrt1.r	110738	Sectshll75	60075	MATL24_210	60210	6.27E-04	0.75
pnlfrt2.r	110739	SectShll12.1	60012	MATL24_210	60210	0.001294	1.2
urail_r	110742	SectShll8.3	60008	MATL24_160	60160	0.001456	0.8
shock.r	110746	Sectshll17.5	60175	MATL24_160	60160	0.001546	1.75
plrrnf1.r	110763	SectShll10.1	60010	MATL24_210	60210	0.001634	1
hlhsinr.r	110812	SectShll10.1	60010	MATL24_160	60160	0.003046	1
barrnf1.r	110814	SectShll20.1	60020	MATL24_160	60160	0.001459	2
barrnf2.r	110815	SectShll25	60025	MATL24_160	60160	6.97E-04	2.5
suspshk.r	110854	SectShll225	60225	MATL24_160	60160	3.05E-04	2.25
crdl.r	111011	SectShll26	60026	MATL24_340	60340	0.006321	2.6
rdlmnt3.r	111012	SectShll25	60025	MATL24_340	60340	3.45E-04	2.5
lcarnf.r	111020	SectShll30	60030	MATL24_340	60340	3.41E-04	3
ntrlarm.r	111021	SectShll30	60030	MATL24_160	60160	0.002289	3
lcacyl.r	111023	SectShll50	60050	MATL24_160	60160	0.001295	5
bdattch.r	111025	SectShll35	60305	MATL24_160	60160	0.001147	3.5
spstrut.r	111026	SectShll50	60050	MATL24_160	60160	0.005601	5
rim.r	111111	SectShll35	60305	MATL24_600	60600	0.008136	3.5
tire1.r	111112	SectShll20.1	60020	mat1.tirerubber	60104	0.00197	2
tire3.r	111113	SectShll7.2	60007	MATL24_160	60160	0.002042	0.7
tire2.r	111114	SectShll3.3	60306	MATL24_160	60160	1.00E-03	0.3
rtire.r	111117	SectShll10.1	60010	MATL24_160	60160	0.007576	1
il_rnf1.r	113662	SectShll9.1	60009	MATL24_160	60160	4.72E-04	0.9
tiebar3.r	113663	Sectshll75	60075	MATL24_180	60180	7.24E-04	0.75
nldshext2	113665	SectShll8.3	60008	MATL24_210	60210	1.91E-04	0.8
bplrrnf.r	113666	SectShll225	60225	MATL24_250	60250	0.003029	2.25
dpnlotr.r	113667	Sectshll75	60075	MATL24_160	60160	0.014309	0.75
dpnlinr.r	113668	SectShll10.1	60010	MATL24_160	60160	0.009567	1

railinr.r	113669	SectShll20.1	60020	MATL24_160	60160	7.85E-04	2
Component Name	**ID**	**Property Name**	**ID**	**Material Name**	**ID**	**MASS (ton)**	**Thickness (mm)**
trnkgtr.r	113670	SectShll9.1	60009	MATL24_160	60160	4.00E-04	0.9
ckbrkt3.r	113671	SectShll10.1	60010	MATL24_160	60160	8.78E-04	1
ckbrkt4.r	113672	SectShll10.1	60010	MATL24_160	60160	7.63E-04	1
pbmbrkt.r	113673	SectShll15.3	60015	MATL24_160	60160	4.35E-04	1.5
railext.r	113674	SectShll15.3	60015	MATL24_160	60160	7.27E-04	1.5
tiebar4.r	113675	Sectshll75	60075	MATL24_180	60180	4.44E-05	0.75
lar_rnf_r	113676	SectShll10.1	60010	MATL24_160	60160	9.05E-04	1
rinrpnl.l	115663	Sectshll75	60075	MATL24_160	60160	0.003644	0.75
rlwrhng.l	115664	SectShll50	60050	MATL24_160	60160	1.30E-04	5
rotrpnl.l	115665	Sectshll75	60075	MATL24_180	60180	0.004412	0.75
z-brkt.l	115666	SectShll10.1	60010	MATL24_160	60160	5.49E-05	1
r_frame.l	115668	SectShll10.1	60010	MATL24_160	60160	0.002017	1
drbeam.l	115669	SectShll20.1	60020	MATL24_600	60600	0.001988	2
ruprhng.l	115670	SectShll50	60050	MATL24_160	60160	1.31E-04	5
rinrpnl.r	115672	Sectshll75	60075	MATL24_160	60160	0.003644	0.75
rotrpnl.r	115673	Sectshll75	60075	MATL24_180	60180	0.004412	0.75
z-brkt.r	115674	SectShll10.1	60010	MATL24_160	60160	5.49E-05	1
r_frame.r	115676	SectShll10.1	60010	MATL24_160	60160	0.002017	1
drbeam.r	115677	SectShll20.1	60020	MATL24_600	60600	0.001988	2
druphng.r	115678	SectShll50	60050	MATL24_160	60160	1.36E-04	5
drlwhng.r	115679	SectShll50	60050	MATL24_160	60160	1.27E-04	5
fdrbdhng	115681	SectShll50	60050	MATL24_210	60210	2.09E-04	5
fdrbdhng2	115682	SectShll20.1	60020	rigid	60103	1.95E-05	2
fdrbdhng3	115683	SectShll20.1	60020	rigid	60103	2.47E-05	2
fdrbdhng4	115684	SectShll50	60050	MATL24_210	60210	2.04E-04	5
fdrbdhng5	115685	SectShll20.1	60020	rigid	60103	2.06E-05	2
fdrbdhng6	115686	SectShll20.1	60020	rigid	60103	2.50E-05	2
fdrbdhng7	115687	SectShll50	60050	MATL24_210	60210	2.60E-04	5
fdrbdhng8	115688	SectShll20.1	60020	rigid	60103	2.01E-05	2
fdrbdhng9	115689	SectShll20.1	60020	rigid	60103	2.42E-05	2
drbdhng10	115690	SectShll50	60050	MATL24_210	60210	2.06E-04	5
drbdhng11	115691	SectShll20.1	60020	rigid	60103	2.06E-05	2
drbdhng12	115692	SectShll20.1	60020	rigid	60103	2.50E-05	2
comptrnf2	115694	SectShll40	60040	MATL24_160	60160	0.002901	4
rlsrwld.l	115699	SectShll18.1	60018	MATL24_160	60160	0.003576	1.8
rlsrwld.r	115700	SectShll18.1	60018	MATL24_160	60160	0.003576	1.8
cradbrkt1	120662	SectShll10.1	60010	MATL24_180	60180	2.36E-04	1
cradbrkt	120665	SectShll30	60030	MATL24_340	60340	4.46E-04	3
cradbrkt2	120666	SectShll30	60030	MATL24_340	60340	3.58E-04	3
2barreinf	120667	SectShll17	60017	MATL24_340	60340	0.002514	1.7
cplate	120669	Sectshll16.5	60165	MATL24_340	60340	3.54E-04	1.65
sideinr.l	120670	SectShll21	60021	MATL24_160	60160	0.009052	2.1
sideinr.r	120671	SectShll21	60021	MATL24_160	60160	0.009056	2.1
plnmbrkt	128851	SectShll8.3	60008	MATL24_210	60210	1.51E-04	0.8

ailctr2.l	128913	SectShll12.1	60012	MATL24_340	60340	1.02E-03	1.2
Component Name	**ID**	**Property Name**	**ID**	**Material Name**	**ID**	**MASS (ton)**	**Thickness (mm)**
ailctr2.r	128914	SectShll12.1	60012	MATL24_340	60340	9.75E-04	1.2
ailrnf3.l	128915	Sectshll14.5	60145	MATL24_340	60340	7.25E-04	1.45
ailrnf3.r	128916	Sectshll14.5	60145	MATL24_340	60340	7.46E-04	1.45
rkrx_l	128961	Sectshll13	60013	MATL24_340	60340	1.02E-03	1.3
pbulkhd.l	128962	SectShll20.1	60020	MATL24_340	60340	6.10E-04	2
rblkhds.1	128963	SectShll12.1	60012	MATL24_340	60340	2.83E-04	1.2
rkrx_r	128964	Sectshll13	60013	MATL24_340	60340	1.02E-03	1.3
B_plr_rnf	128969	SectShll10.1	60010	MATL24_160	60160	6.01E-04	1
drfrail.l	198077	SectShll14.1	60014	MATL24_160	60160	0	1.4
drfrail.r	198078	SectShll14.1	60014	MATL24_160	60160	0	1.4
rlinrnf.r	198090	Sectshll17.5	60175	MATL24_210	60210	2.77E-04	1.75
ldB-plr.r	198091	SectShll18.1	60018	MATL24_250	60250	0.003041	1.8
ldB-plr.l	198092	SectShll18.1	60018	MATL24_250	60250	0.003041	1.8
accl.r	198093	SectShll10.1	60010	rigid	60103	4.29E-05	1
accl.l	198094	SectShll10.1	60010	rigid	60103	4.56E-05	1
refplane	198095	SectShll10.1	60010	rigid	60103	0	1
rein_upr	198126	SectShll15.3	60015	MATL24_210	60210	9.29E-04	1.5
MTG1	198127	SectShll10.1	60010	MATL24_210	60210	4.34E-04	1
KT_Consol	198128	SectShll15.3	60015	MATL24_210	60210	6.89E-04	1.5
_brkt_lwr	198129	SectShll20.1	60020	MATL24_210	60210	0.002868	2
rfmbrkt.r	198140	SectShll20.1	60020	MATL24_340	60340	5.38E-04	2
rfmbrkt.l	198149	SectShll20.1	60020	MATL24_340	60340	5.34E-04	2
frt_hrn	1052382	SectShll20.1	60020	MATL24_160	60160	7.90E-04	2
rr_hrn	1052383	SectShll14.1	60014	MATL24_160	60160	9.17E-04	1.4
rrdrinn.l	1052393	Sectshll75	60075	MATL24_160	60160	0.006906	0.75
rrdrinr.l	1052394	SectShll18.1	60018	MATL24_160	60160	0.005526	1.8
rrdrotr.l	1052395	Sectshll75	60075	MATL24_160	60160	0.007977	0.75
rrdrfrm.l	1052396	SectShll10.1	60010	MATL24_160	60160	0.003505	1
rrdrbm.l	1052397	SectShll20.1	60020	MATL24_600	60600	0.002599	2
bathtub.l	1052398	SectShll20.1	60020	MATL24_160	60160	2.61E-04	2
rrdrhng.l	1052399	SectShll50	60050	MATL24_160	60160	1.06E-03	5
latchjt.l	1052400	SectShll20.1	60020	MATL24_160	60160	2.26E-04	2
rdrhng1.l	1052401	SectShll50	60050	MATL24_160	60160	6.18E-04	5
frailrnfl	1052409	SectShll20.1	60020	MATL24_210	60210	0.002007	2
fbhp_brkt	2044939	SectShll20.1	60020	MATL24_210	60210	1.84E-04	2
rkr_extn	6081245	Sectshll75	60075	MATL24_600	60600	0.001526	0.75
temp	6081246	SectShll7.2	60007	MATL24_600	60600	2.63E-04	0.7
frailrnfr	6081248	SectShll20.1	60020	MATL24_210	60210	0.002007	2
nt_spring	6081270	SectDisc20071.1	121277	MATSpr4_61112	121112	0	0
nt_spring	6081271	SectDisc20071.1	121277	MATSpr4_61113	121113	0	0
atch_spri	6081272	SectDisc20071.1	121277	MATSpr4_61116	121116	0	0
atch_spri	6081273	SectDisc20071.1	121277	MATSpr4_61115	121115	0	0
ajnt_1.L1	6081278	SectShll30	60030	rigid	60103	4.12E-05	3
ajnt_2.L1	6081279	SectShll30	60030	rigid	60103	6.26E-05	3

ajnt_1.R1	6081281	SectShll30	60030	rigid	60103	4.12E-05	3

Component Name	ID	Property Name	ID	Material Name	ID	MASS (ton)	Thickness (mm)
ajnt_2.R1	6081282	SectShll30	60030	rigid	60103	6.33E-05	3
ajnt_1.L2	6081283	SectShll30	60030	rigid	60103	3.16E-05	3
ajnt_2.L2	6081284	SectShll30	60030	rigid	60103	2.76E-05	3
ajnt_1.R2	6081285	SectShll30	60030	rigid	60103	3.16E-05	3
ajnt_2.R2	6081286	SectShll30	60030	rigid	60103	2.76E-05	3
muffler	6110958	SectShll5.3	60005	MATL24_160	60160	0.00133	0.5
exhstpipe	6110959	SectShll5.3	60005	MATL24_160	60160	0.00201	0.5
921_256_1	6111022	SectShll12.1	60012	MATL24_160	60160	2.43E-04	1.2
921_255_1	6111023	SectShll12.1	60012	MATL24_160	60160	1.85E-04	1.2
920_256_1	6111027	SectShll12.1	60012	MATL24_160	60160	2.43E-04	1.2
920_255_1	6111028	SectShll12.1	60012	MATL24_160	60160	1.85E-04	1.2
abs_brkt	6111033	SectShll20.1	60020	MATL24_160	60160	4.33E-04	2
edge	6111035	SectShll2.1.1	1121861	MAT24_3	1161367	1.06E-03	1.35
inner	6111036	SectShll3.2.1	1121862	MAT24_3	1161367	0.005236	0.7
outer	6111037	SectShll4.1.1	1121863	MAT24_3	1161367	0.008255	0.7
MODPLT	90060001	SectShll273	90060005	MAT24_20022	90060020	0.001666	1.5
SUPT_forw	90060002	SectShll274	90060006	MAT24_20022	90060020	5.31E-04	1.22
can	90060003	SectShll276	90060008	MAT24_20022	90060020	6.88E-04	1.2
can1	90060004	SectShll277	90060009	MAT24_20022	90060020	9.93E-05	1.2
can2	90060005	SectShll278	90060010	MAT24_20022	90060020	1.10E-04	1.2
can.1	90060006	SectShll279	90060011	MAT24_20022	90060020	1.44E-04	1.2
inflator	90060007	SectShll280	90060012	MAT24_20022	90060020	0.001499	5.4
Brkt-1	90060008	SectShll2.1	90060063	MAT24_20022	90060020	6.07E-04	3
gaspdel	90060009	SectShll7.1	90060068	MAT24_20022	90060020	1.67E-04	2.5
stelpeice	90060010	SectShll12	90060071	MAT24_20022	90060020	1.55E-04	3
SIPO_p	90060011	SectShll287	90060014	MAT24_20022	90060020	7.36E-04	2
SIPO_d2	90060012	SectShll288	90060015	MAT24_20022	90060020	7.50E-04	2
eel_strip	90060013	SectShll294	90060016	MAT24_20022	90060020	1.39E-04	1.5
oor_Brkt2	90060014	SectShll315	90060037	MAT24_20022	90060020	9.82E-04	2.5
_Stk_brkt	90060015	SectShll316	90060038	MAT24_20022	90060020	3.25E-04	1.5
lower	90060016	SectShll5	90060044	HVAC_MATERIAL_PP	90060013	0.001208	2.43
upper	90060017	SectShll7	90060045	HVAC_MATERIAL_PP	90060013	0.001283	2.36
cbrkt_add	90060018	SectShll8	90060046	HVAC_MATERIAL_PP	90060013	1.95E-05	2.36
heatercvr	90060019	SectShll9	90060047	HVAC_MATERIAL_PP	90060013	3.84E-04	2.38
ai	90060020	SectShll10	90060048	HVAC_MATERIAL_PP	90060013	5.34E-04	2.1
ai_icebox	90060021	SectShll11	90060049	HVAC_MATERIAL_PP	90060013	1.52E-05	2.1
_actuator	90060022	SectShll13	90060050	HVAC_MATERIAL_PP	90060013	3.37E-05	2
_actuator	90060023	SectShll14	90060051	HVAC_MATERIAL_PP	90060013	2.98E-05	2
foamplate	90060024	SectShll15	90060052	MAT24_20022	90060020	5.74E-05	1
filmvalve	90060025	SectShll16	90060053	HVAC_MATERIAL_PP	90060013	4.93E-04	2
arm1_srib	90060026	SectShll18	90060054	HVAC_MATERIAL_PP	90060013	9.08E-05	2
rib_4_hub	90060027	SectShll19	90060055	HVAC_MATERIAL_PP	90060013	1.42E-04	3.5
ower_add1	90060028	SectShll20	90060056	HVAC_MATERIAL_PP	90060013	1.89E-05	2

foam	90060029	secn_solid_foam	90060125	FOAM_PART_OF_HVA	90060001	1.48E-06	0
evapblock	90060030	secn_solid_evapb	90060126	EVAP_CORE_MATERI	90060003	3.53E-05	0
Component Name	**ID**	**Property Name**	**ID**	**Material Name**	**ID**	**MASS (ton)**	**Thickness (mm)**
IBEC	90060031	SectShll281	90060013	NYLON_MATERIAL	90060005	3.04E-04	2
wer_tube1	90060032	evapcore_heatcor	90060041	ALUMINIUM_PARTOF	90060002	8.77E-06	1
per_tube1	90060033	evapcore_heatcor	90060041	ALUMINIUM_PARTOF	90060002	1.39E-05	1
per_tube1	90060034	evapcore_heatcor	90060041	ALUMINIUM_PARTOF	90060002	4.27E-05	1
wer_tube1	90060035	evapcore_heatcor	90060041	ALUMINIUM_PARTOF	90060002	2.57E-05	1
il	90060036	radio_controller	90060042	IP_1000_MATERIAL	90060014	1.89E-04	1
sidepnl_E	90060037	SectShll304	90060026	DOWC70035N	90060015	1.26E-04	2.5
po_fixed1	90060038	SectShll288	90060015	matl_steel_allfi	90060008	1.39E-06	2
po_fixed2	90060039	SectShll288	90060015	matl_steel_allfi	90060008	1.46E-06	2
po_fixed3	90060040	SectShll288	90060015	matl_steel_allfi	90060008	1.53E-06	2
po_fixed4	90060041	SectShll288	90060015	matl_steel_allfi	90060008	1.13E-06	2
po_fixed5	90060042	SectShll288	90060015	matl_steel_allfi	90060008	1.85E-06	2
po_fixed6	90060043	SectShll288	90060015	matl_steel_allfi	90060008	1.95E-06	2
po_fixed7	90060044	SectShll288	90060015	matl_steel_allfi	90060008	1.83E-06	2
_p_fixed7	90060045	SectShll287	90060014	matl_steel_allfi	90060008	1.24E-06	2
_p_fixed6	90060046	SectShll287	90060014	matl_steel_allfi	90060008	1.59E-06	2
_p_fixed5	90060047	SectShll287	90060014	matl_steel_allfi	90060008	1.71E-06	2
_p_fixed4	90060048	SectShll287	90060014	matl_steel_allfi	90060008	1.13E-06	2
_p_fixed3	90060049	SectShll287	90060014	matl_steel_allfi	90060008	1.85E-06	2
_p_fixed2	90060050	SectShll287	90060014	matl_steel_allfi	90060008	1.95E-06	2
p_fixed12	90060051	SectShll287	90060014	matl_steel_allfi	90060008	1.83E-06	2
te_rigid1	90060052	SectShll273	90060005	matl_steel_allfi	90060008	1.55E-06	1.5
te_rigid2	90060053	SectShll273	90060005	matl_steel_allfi	90060008	2.34E-06	1.5
e_rigid32	90060054	SectShll273	90060005	matl_steel_allfi	90060008	1.45E-06	1.5
te_rigid4	90060055	SectShll273	90060005	matl_steel_allfi	90060008	1.65E-06	1.5
te_rigid5	90060056	SectShll273	90060005	matl_steel_allfi	90060008	1.58E-06	1.5
te_rigid6	90060057	SectShll273	90060005	matl_steel_allfi	90060008	1.98E-06	1.5
te_rigid7	90060058	SectShll273	90060005	matl_steel_allfi	90060008	9.84E-07	1.5
te_rigid8	90060059	SectShll273	90060005	matl_steel_allfi	90060008	1.76E-06	1.5
e.pedal	90060060	SectShll3.2	90060073	STEEL_NON_RIGID_	90060011	8.37E-04	8
e.pad	90060061	SectShll4.2	90060074	STEEL_NON_RIGID_	90060011	1.20E-04	3.5
e.pin	90060062	SectShll6.1	90060075	STEEL_NON_RIGID_	90060011	1.14E-04	2
dalpivout	90060063	SectShll20000.1	90060072	MAT20_20003.1	90060009	8.58E-06	3
dalpivinb	90060064	SectShll20000.1	90060072	MAT20_20003.1	90060009	8.58E-06	3
pedallink	90060065	SectShll20000.1	90060072	MAT20_20003.1	90060009	1.43E-06	3
rkt_boost	90060066	SectShll20000.1	90060072	MAT20_20003.1	90060009	0.00385	3
pivot inb	90060067	SectShll20000.1	90060072	MAT20_20003.1	90060009	4.32E-06	3
pivot out	90060068	SectShll20000.1	90060072	MAT20_20003.1	90060009	1.10E-06	3
:_22026	90060069	SectBeam20101.1	90060003	steel_elastic_fo	90060006	0	0
art221130	90060070	SectShll20000.1	90060072	MAT20_20003.1	90060009	1.09E-06	3
art221131	90060071	SectShll20000.1	90060072	MAT20_20003.1	90060009	1.39E-06	3
art221132	90060072	SectShll20000.1	90060072	MAT20_20003.1	90060009	9.68E-07	3
art221133	90060073	SectShll20000.1	90060072	MAT20_20003.1	90060009	9.69E-07	3

art221134	90060074	SectShll20000.1	90060072	MAT20_20003.1	90060009	6.81E-07	3
art221135	90060075	SectShll20000.1	90060072	MAT20_20003.1	90060009	1.30E-06	3
Component Name	**ID**	**Property Name**	**ID**	**Material Name**	**ID**	**MASS (ton)**	**Thickness (mm)**
art221136	90060076	SectShll20000.1	90060072	MAT20_20003.1	90060009	9.62E-07	3
dr_ealf	90060077	SectShll591	90060077	STEEL_NON_RIGID_	90060011	2.29E-04	1.5
dr_eart	90060078	SectShll591	90060077	MAT24_20022	90060020	2.29E-04	1.5
ps_eart	90060079	SectShll560	90060076	MAT24_20022	90060020	1.64E-04	1.5
ps_eart.1	90060080	SectShll560	90060076	MAT24_20022	90060020	1.64E-04	1.5
ttachment	90060081	SectShll536	90060078	MAT24_20022	90060020	5.37E-04	2
_fixdeles	90060082	SectShll536	90060078	allfixed_matl20	90060010	1.18E-06	2
_fixdeles	90060083	SectShll536	90060078	allfixed_matl20	90060010	1.27E-06	2
_fixdeles	90060084	SectShll536	90060078	allfixed_matl20	90060010	2.33E-06	2
_fixdeles	90060085	SectShll536	90060078	allfixed_matl20	90060010	1.83E-06	2
_fixdeles	90060086	SectShll536	90060078	allfixed_matl20	90060010	4.47E-06	2
_fixdeles	90060087	SectShll536	90060078	allfixed_matl20	90060010	7.59E-06	2
_fixdeles	90060088	SectShll536	90060078	allfixed_matl20	90060010	2.76E-06	2
_fixdeles	90060089	SectShll536	90060078	allfixed_matl20	90060010	3.89E-06	2
rame_base	90060090	gbx_frm_bs_25thk	90060080	POLYFORT_PP070	90060016	3.96E-04	2.5
gboxframe	90060091	gbx_frm_rib_10th	90060081	POLYFORT_PP070	90060016	5.18E-06	1
gboxframe	90060092	gbx_frm_rib_12th	90060082	POLYFORT_PP070	90060016	2.68E-05	1.2
eam_65dia	90060093	hinge_beam_props	90060004	steel_elastic_fo	90060006	1.07E-04	0
g_6.5.1.1	90060094	SectShll1.1.1	90060100	MAGNESIUM_NON_RI	90060012	3.06E-04	6.5
g_3.0.1.1	90060095	SectShll2.2	90060101	MAGNESIUM_NON_RI	90060012	0.003441	3
g_4.0.1.1	90060096	SectShll3.4	90060102	MAGNESIUM_NON_RI	90060012	4.78E-04	4
_ribs.1.1	90060097	SectShll4.4	90060103	MAGNESIUM_NON_RI	90060012	0.002763	3
g_1.5.1.1	90060098	SectShll5.1.1	90060104	MAGNESIUM_NON_RI	90060012	1.30E-04	1.5
Mag_5.0.1	90060099	SectShll6.2.1	90060105	MAGNESIUM_NON_RI	90060012	1.38E-04	5
Mag_2.5	90060100	SectShll8.2	90060106	MAGNESIUM_NON_RI	90060012	2.66E-04	2.5
inner.1	90060101	newinner	90060107	POLYFORT_PP070	90060016	3.59E-04	3
ergroorve	90060102	innergroove	90060111	POLYFORT_PP070	90060016	8.66E-07	3.3
ribs.1	90060103	innerribs	90060112	POLYFORT_PP070	90060016	1.40E-04	1.25
bin o	90060104	binprop	90060108	DOWC70035N_w6pcf	90060017	2.78E-04	2.5
ribbin	90060105	binrib	90060110	DOWC70035N_w6pcf	90060017	3.47E-07	1.7
bintongue	90060106	bintongue	90060109	DOWC70035N_w6pcf	90060017	5.25E-07	1.1
outer.1	90060107	outer25thk	90060113	POLYFORT_PP070	90060016	2.87E-04	2.5
hub	90060108	outervrib	90060115	POLYFORT_PP070	90060016	1.87E-06	1
outerhrib	90060109	outerrib	90060114	POLYFORT_PP070	90060016	6.91E-06	1.2
outervrib	90060110	outervrib	90060115	POLYFORT_PP070	90060016	3.11E-07	1
hubrib	90060111	hubrib1375	90060116	POLYFORT_PP070	90060016	2.06E-07	1.375
rm_hinge_	90060112	knee_bolster_out	90060117	POLYFORT_PP070	90060016	8.50E-06	3
lster inn	90060113	inner knee bolst	90060118	POLYFORT_PP070	90060016	2.72E-04	2.5
ner rib h	90060114	inner kb rib	90060119	POLYFORT_PP070	90060016	1.36E-04	1.875
rib inner	90060115	inner kb small r	90060120	POLYFORT_PP070	90060016	3.33E-06	2.6
lster out	90060116	outer knee bolst	90060121	POLYFORT_PP070	90060016	4.31E-04	2.5
use outer	90060117	outer kb dog hou	90060122	POLYFORT_PP070	90060016	6.47E-06	1.4
outer rib	90060118	ribs outer kb	90060123	POLYFORT_PP070	90060016	4.70E-06	1.1

tipof bin	90060119	tip off bin	90060124	POLYFORT_PP070	90060016	5.23E-05	2.5
Masses	90060120	N/A	N/A		0	0.002085	N/A
Component Name	**ID**	**Property Name**	**ID**	**Material Name**	**ID**	**MASS (ton)**	**Thickness (mm)**
ElemMass	90060121	N/A	N/A		0	0.633762	N/A
iver_pass	90060122	N/A	N/A		0	0.156	N/A
oint2Node	90060123	N/A	N/A		0	0	N/A
oint4Node	90060124	N/A	N/A		0	0	N/A
oint6Node	90060125	N/A	N/A		0	0	N/A
SpotWelds	90060126	N/A	N/A		0	0	N/A
Rigids.5	90060127	N/A	N/A		0	0	N/A

Total Components	**498**
Model Mass	**1.778 tonnes**

DOE FE Models

Milestone 7

Revision 1

Lightweight Front End Structure Phase II

August 26, 2003



Auto/Steel Partnership

Abstract

This report documents the modifications made to the donor vehicle FE models (*Milestone 5*). The revised report includes updated results owing to small changes made to the models, as well as dynamic IIHS intrusion plots. The modified FE models will serve as the baseline for DOE studies and for assessing various rail and bumper concepts developed in Phase II of the Lightweight Front End Structure Project.

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1. Objectives

The aim of this effort was to modify the donor vehicle FE models (*Milestone 5*), in order to render them suitable for DOE studies. A comprehensive model checking was undertaken and appropriate modifications were made. These FE models will serve as the baseline for DOE studies and for assessing various rail and bumper concepts developed in Phase II of the Lightweight Front End Structure Project.

2. Results Summary

The following modifications were made to the donor vehicle FE models.

- Several assemblies were coarsened (*Milestone 6*) and the mass, center of gravity and moment of inertias were adjusted so as to match the original values (*Milestone 5*). The assemblies included

  - IP Assembly
  - Front and Rear Door Assemblies
  - Hood
  - Windshield
  - Roof

- Miscellaneous connections were corrected in the following assemblies.

  - IP Assembly
  - Steering Column Assembly
  - Brake Pedal
  - Bulk Heads at Rocker

- Interference of parts was reduced significantly. The following major areas were corrected.

  - Rear Door and Body Panels
  - Brake Pedal Parts
  - IP Assembly
  - Rocker/Hinge Area and Bulk Heads.
  - Steering Wheel
  - Local Penetrations

- Contact thickness scale factors were adjusted. The donor vehicle model has a global absolute contact thickness (SST) of 0.8 in the contact definition (*Milestone 5*). In the DOE model, a global contact thickness scale factor (SFST) of 0.8 is used. In addition, the factor is further adjusted on *PART_CONTACT, as required.

- Contact scale factors for NCAP and IIHS were kept same from consistency point of view. Internal contact of barrier was maintained as obtained from the supplier.

- Explored various contact options like IGNORE, SOFT, Automatic General and Single Edge, in order to determine the best contact algorithm.

- The box size for including slave nodes to the ground rigidwall was increased, as some parts

were penetrating the ground. Friction was also added to the ground.

- The box size was also increased for the barrier rigidwall slave nodes.
- Acceleration due to gravity (LOAD_BODY_Z) was added.
- Corrected shear areas (SA) on the beam properties.
- Nodal Rigid Bodies for welds were replaced by Spotwelds, in order to recover weld forces.
- Few changes in *CONTROL CARDS were made, e.g. BWC=1 on *CONTROL_SHELL.
- Cross-Section Planes and Nodes were created at every 100 mm, in order to recover cross-section forces and displacements.
- IIHS Measurement locations were recreated according to the IIHS Protocol and the new brake pedal reference.

The mesh coarsening resulted in a reduction in run time by 46%, compared to the validated FE models (*Milestone 5*).

The NCAP and IIHS response did not change significantly due to the above changes. However, the DOE FE models would have better stability and yield consistent results, and would be helpful in making accurate design comparisons.

The NCAP and IIHS results are summarized in *Table 1* and *Table 2*.

A positive value of steering column upward movement means that the steering column moves upwards and towards the occupant, and a positive value of steering column rearward movement means that the steering column moves rearwards and towards the occupant.

Table 1: NCAP Results

B Pillar Pulse	Test Data	Validated Model	DOE Model
LH	39.6 g @ 40.1 ms	35.7 g @ 58.3 ms	36.7 g @ 58.7 ms
RH	42.1 g @ 53.3 ms	34.3 g @ 63.1 ms	35.3 g @ 58.6 ms

Table 2: IIHS Results

Location	Intrusions @ 250ms (cm)	
	Validated Model	DOE Model
Brake Pedal	8.1	11.2
Left Toepan	12.9	14.5
Center Toepan	13.7	14.4
Right Toepan	16.2	15.8
A-B Pillar Closure	10.0	11.8
Steering Column Upward Movement*	-10.8	-1.8
Steering Column Rearward Movement*	-4.5	0.0

* In Validated Model some steering column connections were missing. These have been corrected in the DOE Model. However, steering column movement does not stabilize (*Figure 30*).

3. Model Modifications

Several assemblies that possessed a large number of degrees of freedom and were not critical to crash were coarsened in *Milestone 6*. However, their mass distributions were modified slightly, as a result of the coarsening. Lumped masses were therefore added, in order to match the original mass distribution, through computer-aided optimization. The optimization problem was set up as:

Minimize: Standard Deviation of Lumped Masses

Subject: Total mass of assembly = Original mass

CG of assembly = Within 1% of original CG

Inertias of assembly = Within 1% original inertias

Table 3 and *Table 4* summarize the size of the assemblies and the run times.

Table 3: Size of Assemblies

Assembly	Number of Nodes	
	Validated Model	DOE Model
Door	**83295** *(Figure 3)*	**15736** *(Figure 4)*
IP	**81255** *(Figure 5)*	**15836** *(Figure 6)*
Hood	**23015** *(Figure 7)*	**2073** *(Figure 8)*
Roof	**6403** *(Figure 911)*	**1239** *(Figure 1012)*
Windshield	**5774** *(Figure 119)*	**750** *(Figure 1210)*

Table 4: Model Size Comparison

Parameters	Validated Model	DOE Model	% Reduction
No. Nodes	**439039**	**274921**	**37.4**
No. Elements	**448762**	**287285**	**35.4**
NCAP CPU Time	**85 hrs 51 min**	**51 hours 37 min***	**39.4**
IIHS CPU Time	**278 hrs 11 min**	**148 hours 4 min**	**46.8**

* On machine with less RAM. More reduction will result on machine with higher RAM.

Miscellaneous connections were corrected in the following assemblies.

IP Assembly
Steering Column Assembly
Brake Pedal
Bulk Heads at Rocker

Performing free-free modal analyses, using MSC/NASTRAN, identified the problem areas. The crash model was converted to a NASTRAN model, for this purpose.

Interference of parts was reduced significantly. The following major areas were corrected.

Rear Door and Body Panels
Brake Pedal Parts
IP Assembly
Rocker/Hinge Area and Bulk Heads.
Steering Wheel
Local Penetrations

Contact thickness scale factors were also adjusted. The donor vehicle has a global absolute contact thickness (SST) of 0.8 in the contact definition (*Milestone 5*). This results in a uniform thickness of 0.8mm throughout the model, which is not realistic. In the DOE model, a global contact thickness scale factor (SFST) of 0.8 is used. In addition, the factor is further adjusted on *PART_CONTACT, as required. The adjusted scale factors would result in a better contact definition.

Contact scale factors for NCAP and IIHS were kept same from consistency point of view. Internal contact of barrier was maintained as obtained from the supplier.

Various contact options like IGNORE, SOFT, Automatic General and Single Edge were explored, in order to determine the best contact algorithm. Eventually SOFT=1 with the IGNORE option was used. The donor vehicle model used SOFT=0 with the IGNORE option. SOFT=1 results in better contact stiffness between dissimilar materials and mesh densities.

The box size for including slave nodes to the ground rigidwall was increased, as some parts were penetrating the ground. Friction was also added to the ground.

The box size was also increased for the barrier rigidwall slave nodes.

Acceleration due to gravity (LOAD_BODY_Z) was added.

Shear areas (SA) on the beam properties were corrected. Shear areas were not defined for the bolt beams in the donor vehicle.

Nodal Rigid Bodies for welds were replaced by Spotwelds, in order to recover weld forces.

Few changes in *CONTROL CARDS were made, for example, BWC on *CONTROL_SHELL. In the donor vehicle model, shell warping stiffness was not added (BWC=2). Shell warping stiffness was added to the DOE model (BWC=1).

Cross-Section Planes and Nodes were created at every 100 mm, in order to recover cross-section forces and displacements. Section forces can be employed for understanding the crash response and for constructing simplified lumped parameter models.

IIHS measurement locations were recreated according to the IIHS Protocol and the new brake pedal reference. Some of the nodes in the donor vehicle did not correspond to the IIHS locations.

4. F E Model - Output Location Summary

The nodes at which the desired NCAP and IIHS outputs were obtained are listed in *Table 5*.

The intrusions are measured at the nodes as specified in *Reference 3*.

The acceleration and intrusion node locations are shown in *Figure 1* and *Figure 2* below.

Table 5: Summary of Output Locations

Parameter	Location	Node Number
Accelerations	B-Pillar / Rocker - LH	5000001
	B-Pillar / Rocker - RH	5000002
Intrusions	Origin	6000000
	Plane Y-axis	6000001
	Plane Z-axis	6000002
	Steering Column	7000001
	Brake Pedal	7000002
	Toepan - Left	7000003
	Toepan - Center	7000004
	Toepan - Right	7000005
	Left Front Seat Bolt	7000006
	Right Front Seat Bolt	7000007
	Left Rear Seat Bolt	7000008
	Right Rear Seat Bolt	7000009
	AB Closure - A Pillar	7000010
	AB Closure - B Pillar	7000011

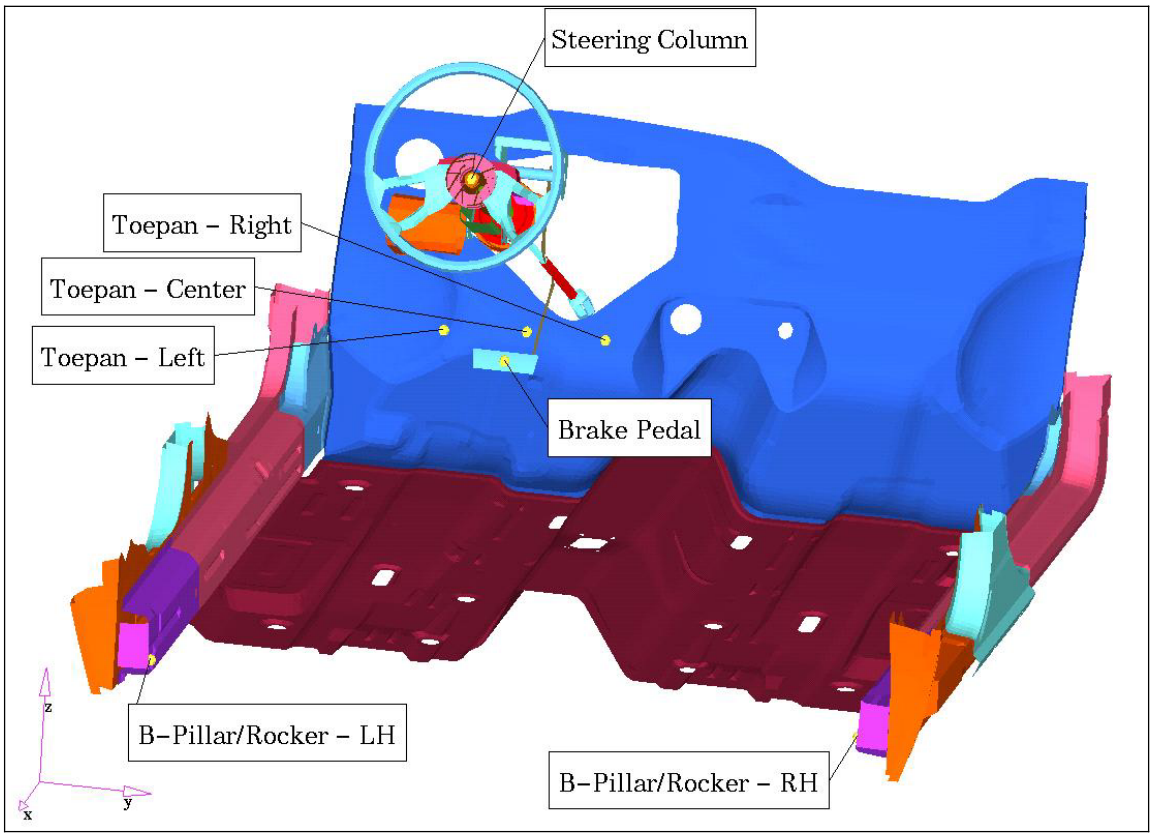


Figure 1: Output Locations for NCAP/IIHS

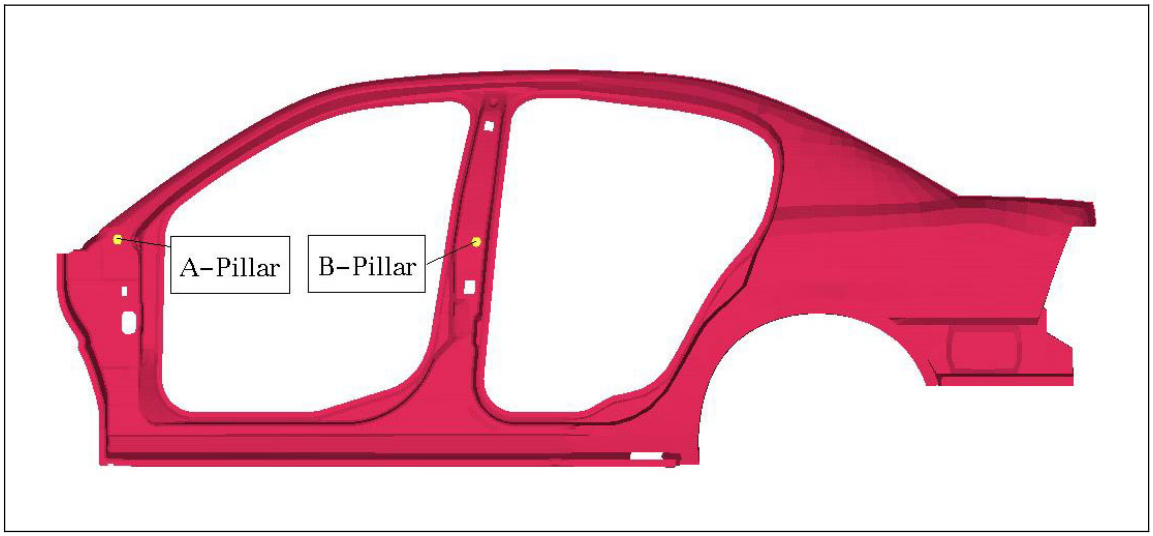


Figure 2: Output Locations for IIHS- AB Closure

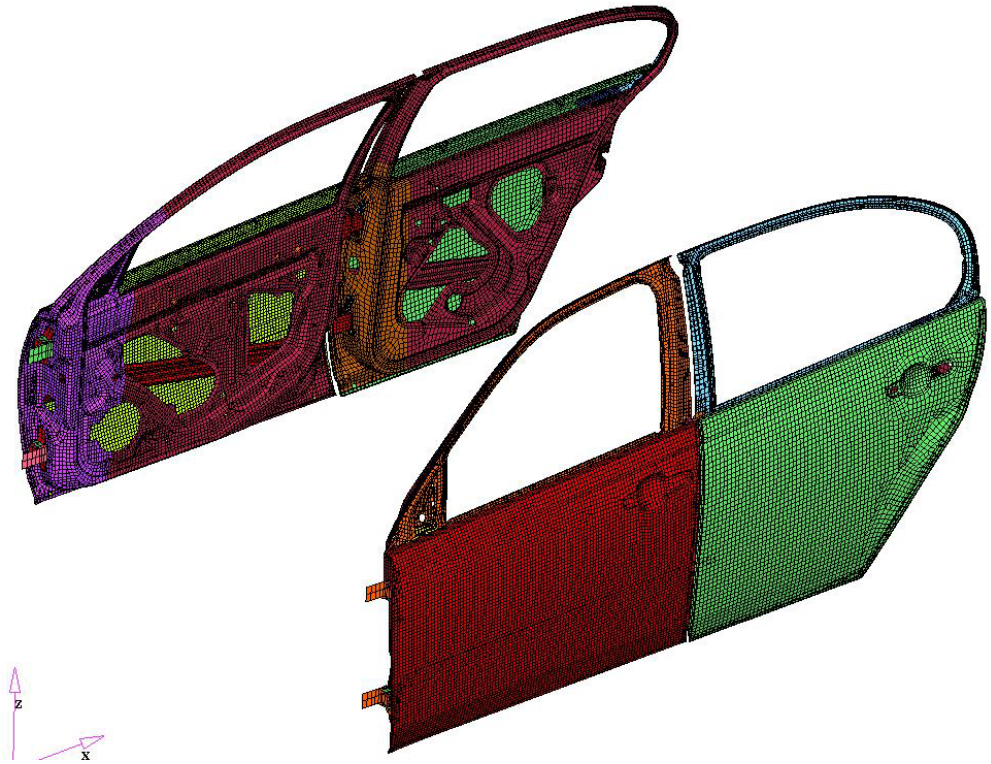


Figure 3: Door Assembly Fine Mesh Model

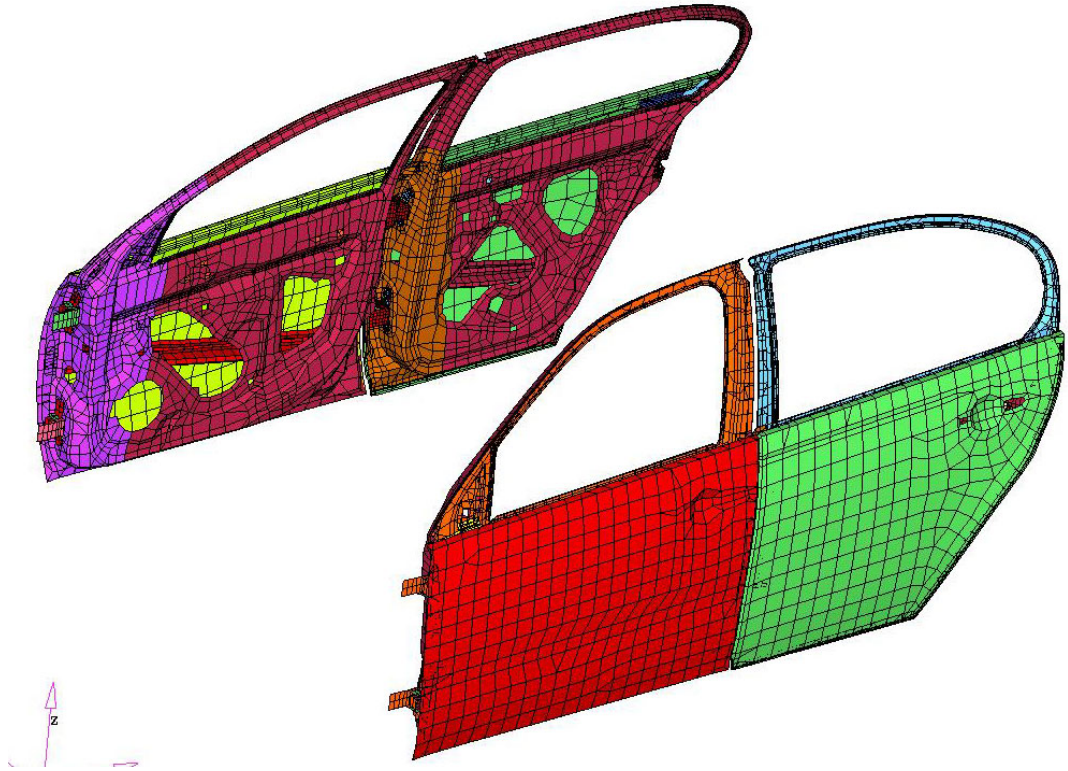


Figure 4: Door Assembly Coarse Mesh Model

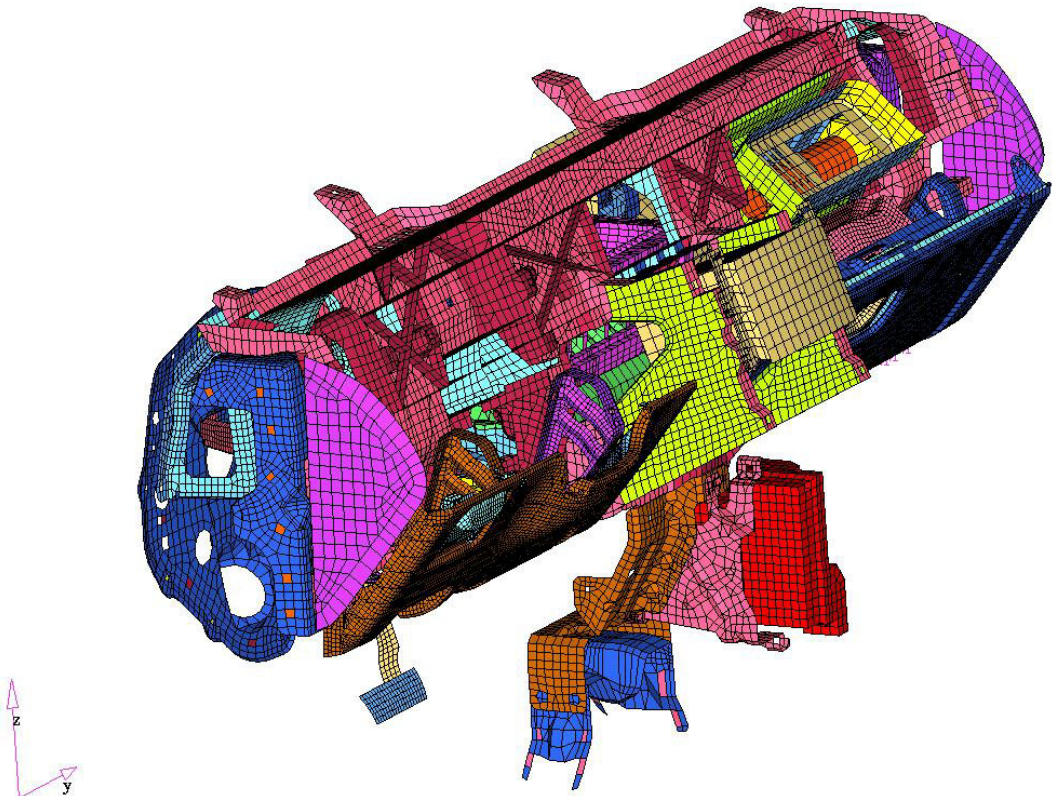


Figure 5: IP Fine Mesh Model

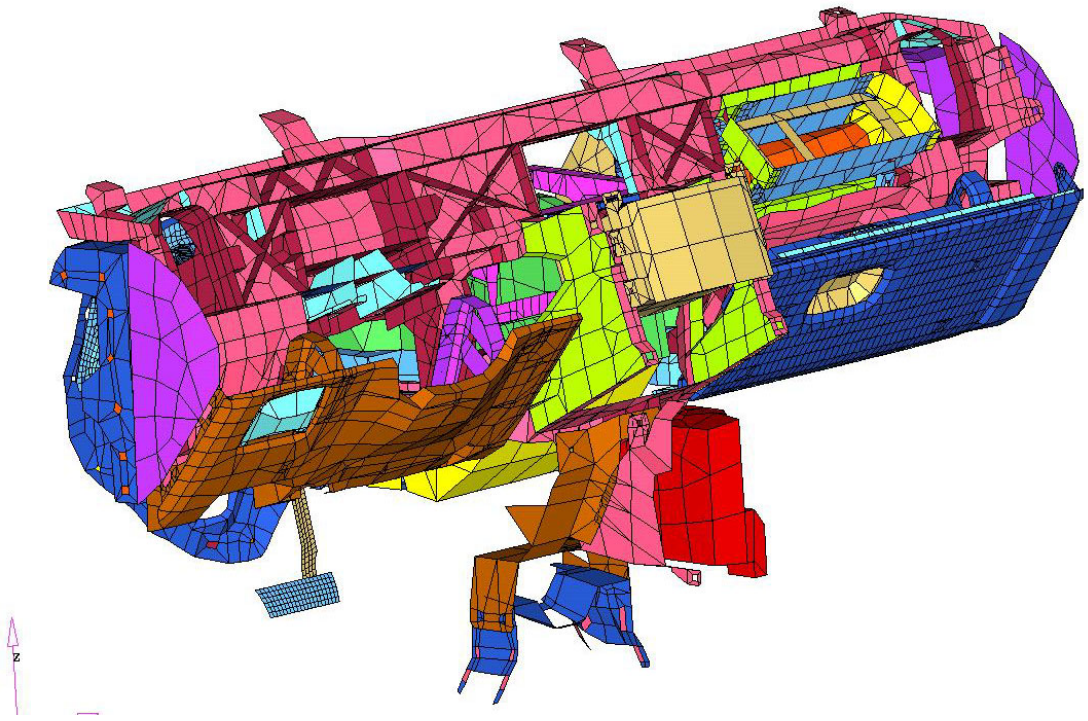


Figure 6: IP Coarse Mesh Model

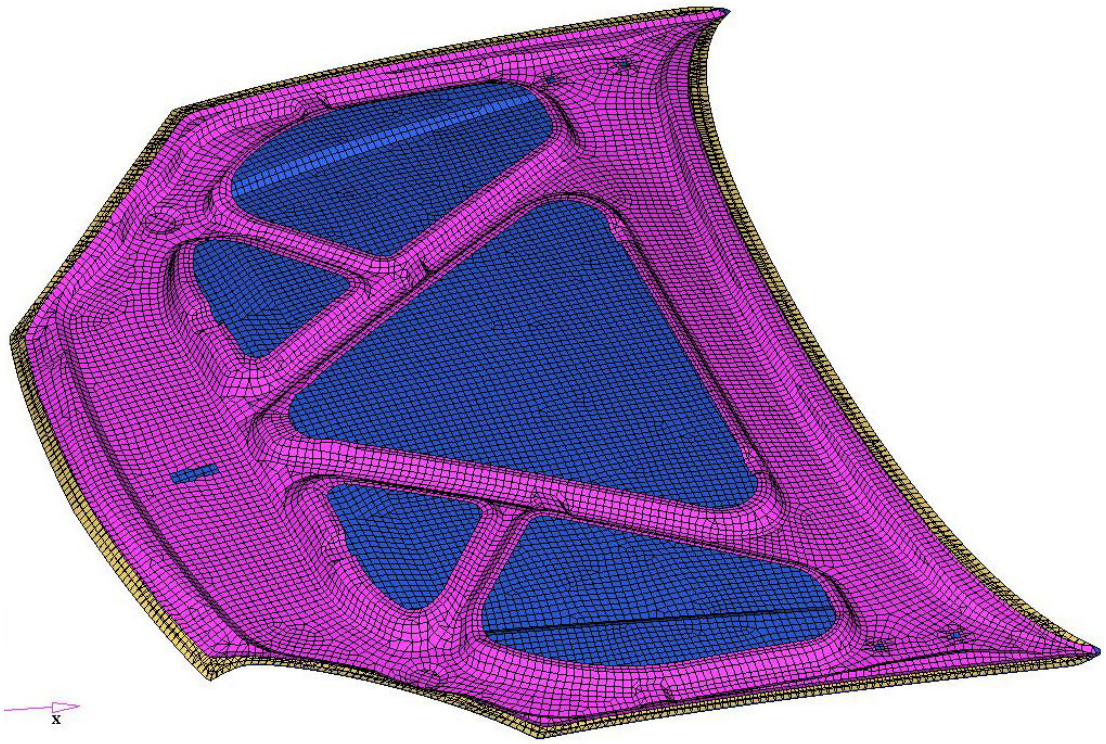


Figure 7: Hood Assembly Fine Mesh Model

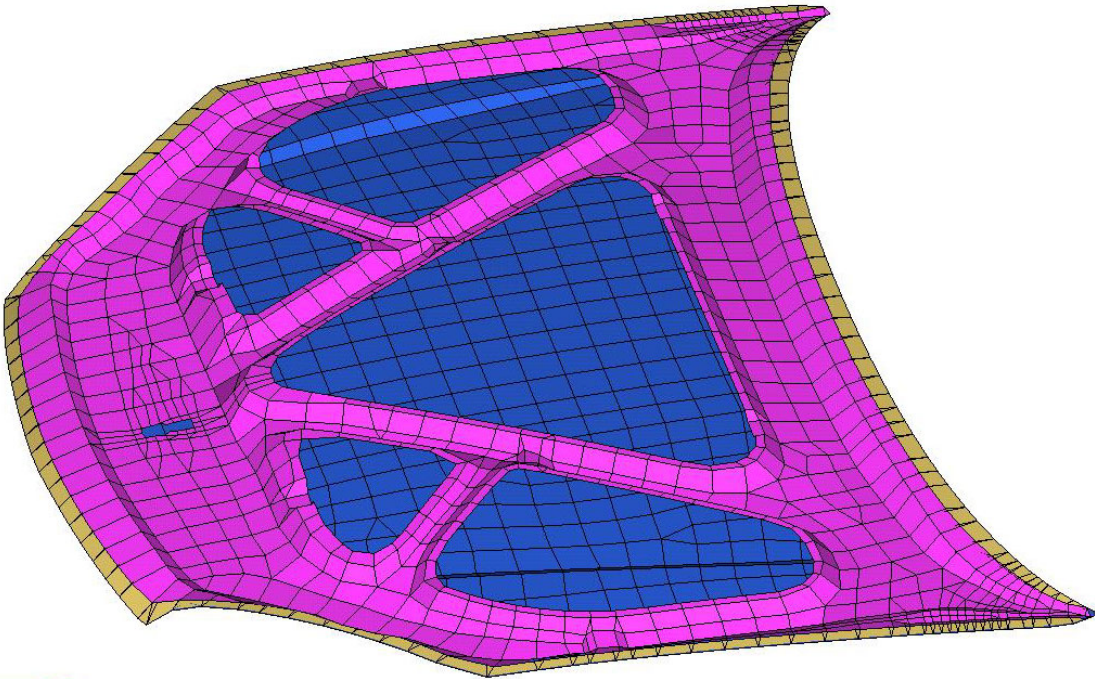


Figure 8: Hood Assembly Coarse Mesh Model

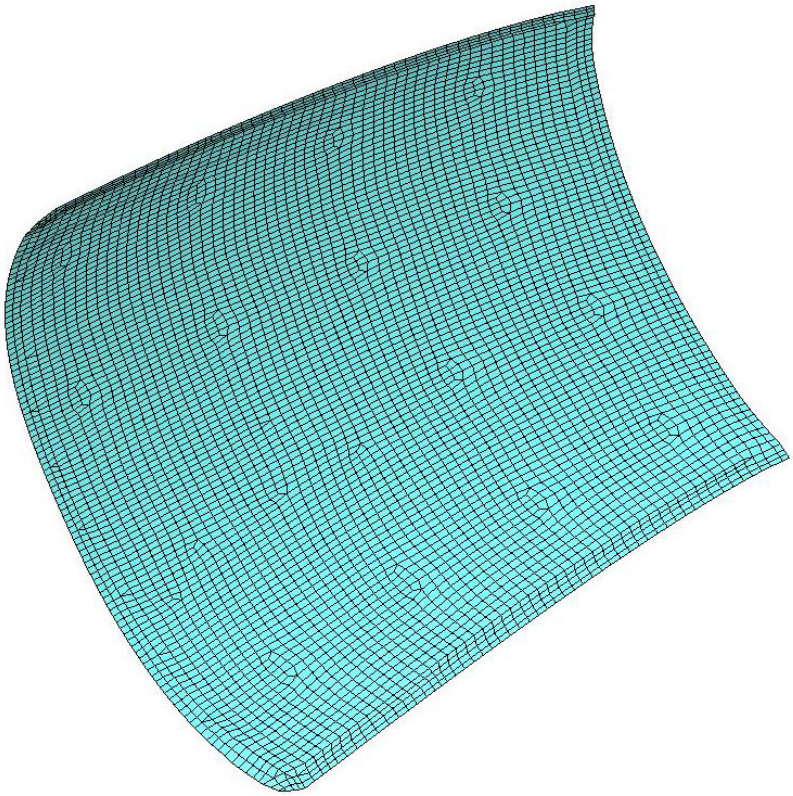


Figure 9: Windshield Fine Mesh Model

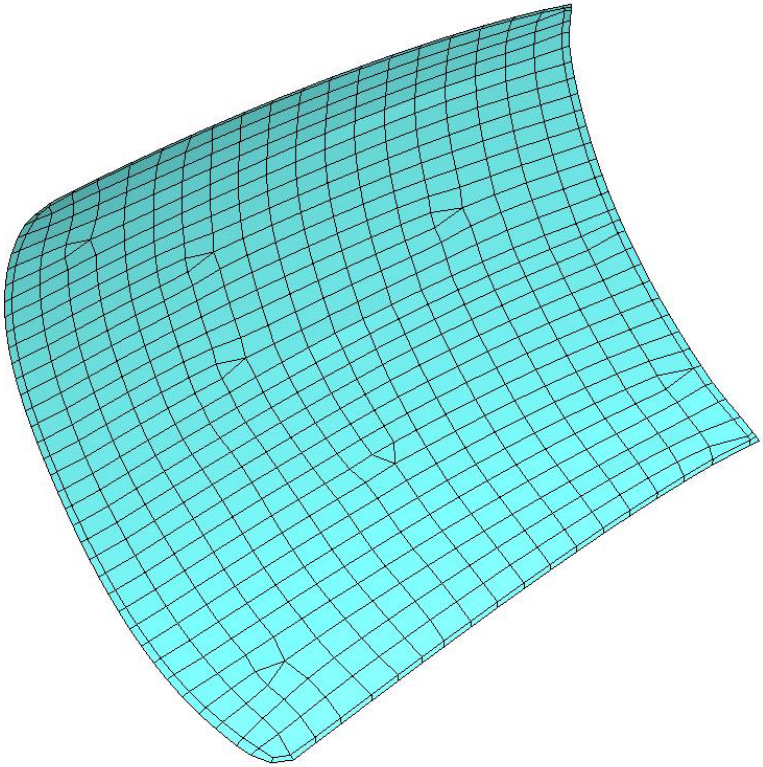


Figure 10: Windshield Coarse Mesh Model

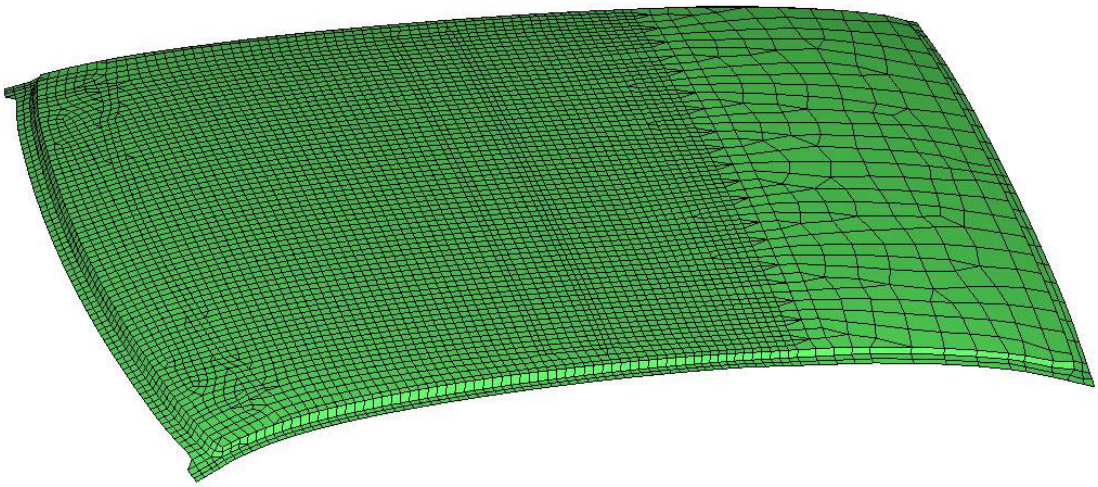


Figure 11: Roof Fine Mesh Model

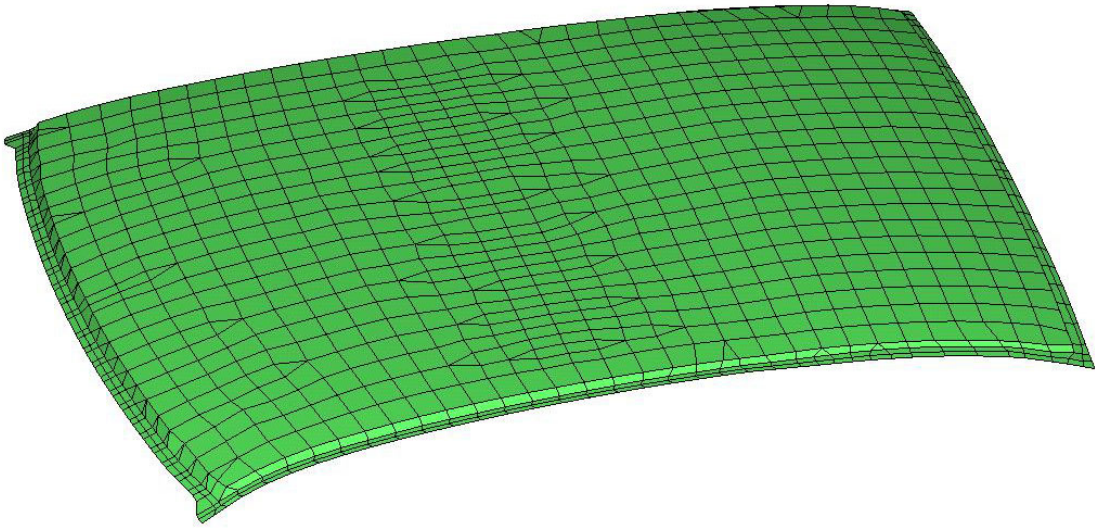


Figure 12: Roof Coarse Mesh Model

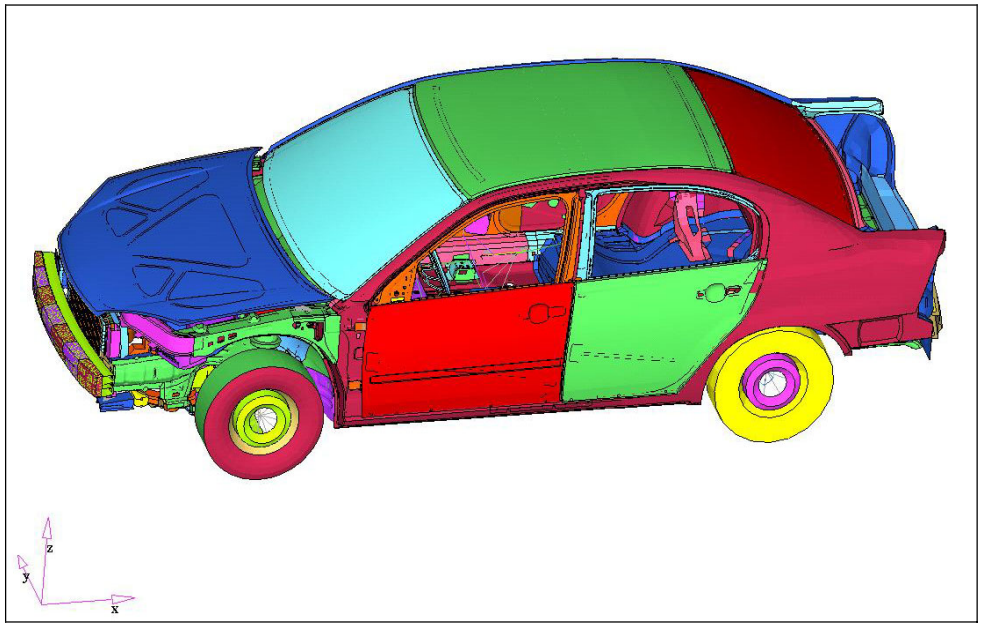


Figure 13: NCAP Full Vehicle FE Model

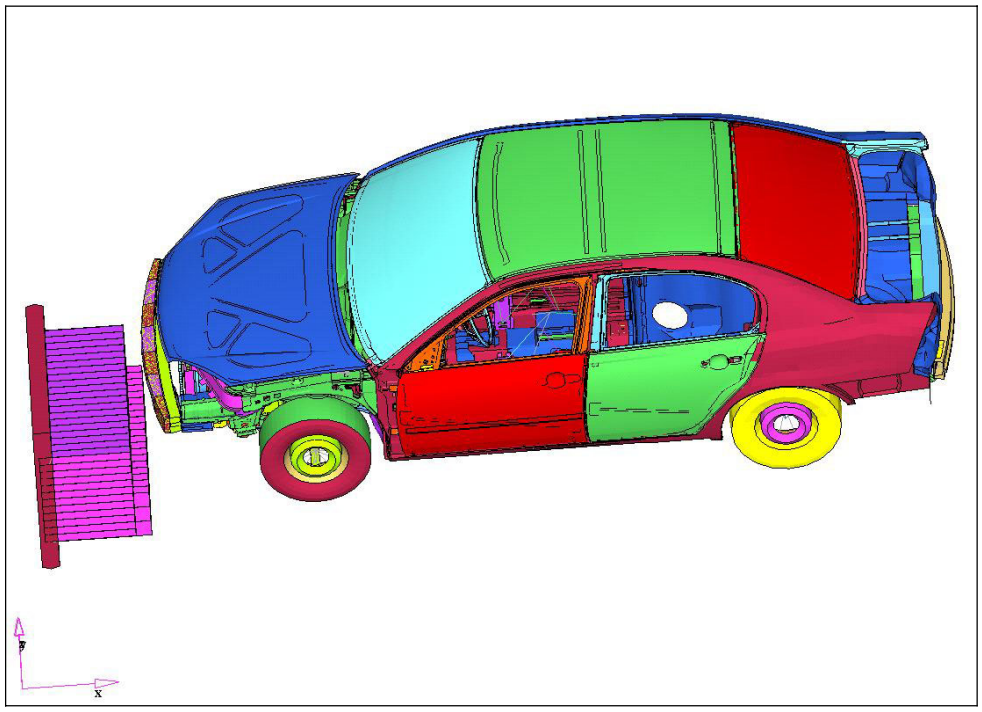


Figure 14: IIHS Full Vehicle FE Model

5. NCAP Response

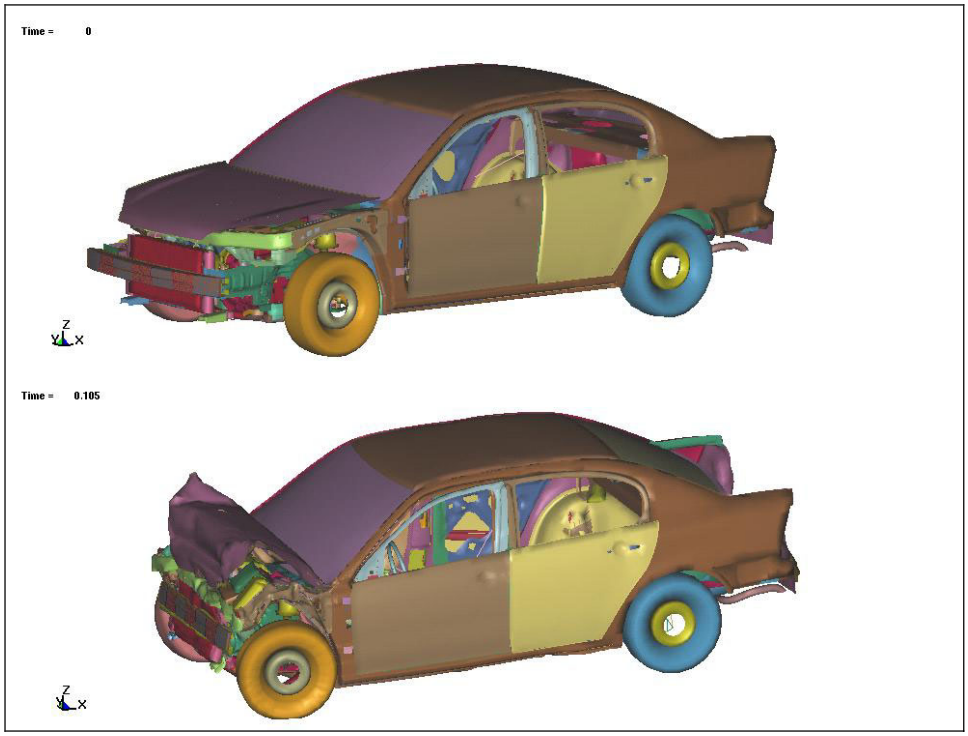


Figure 15: Deformation of Full Vehicle

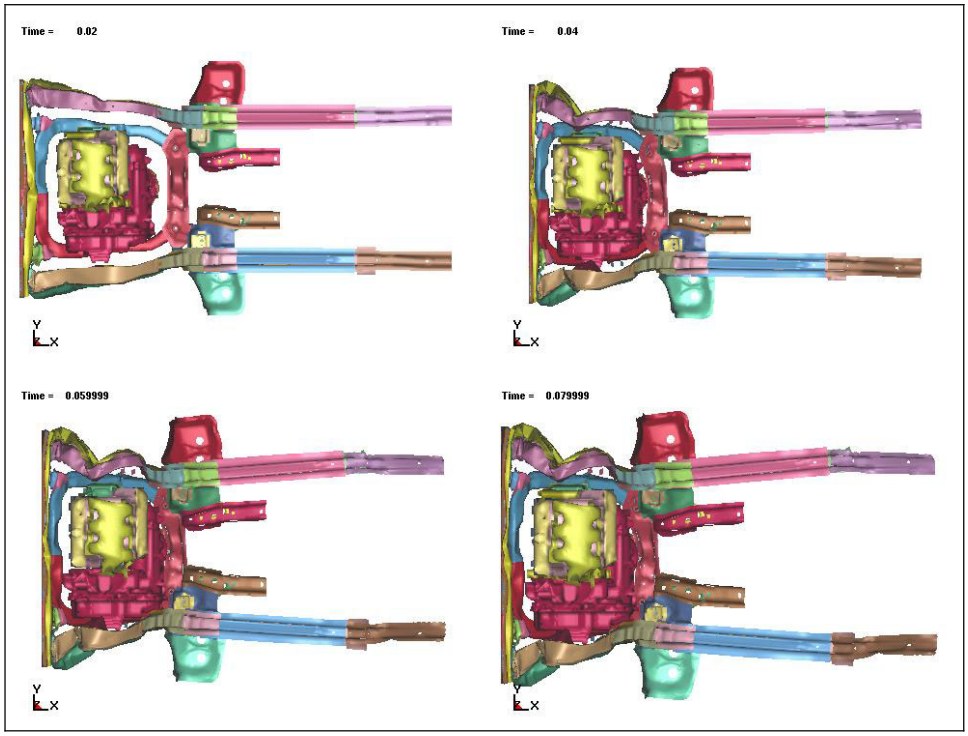


Figure 16: Deformation of Front End (Top View)

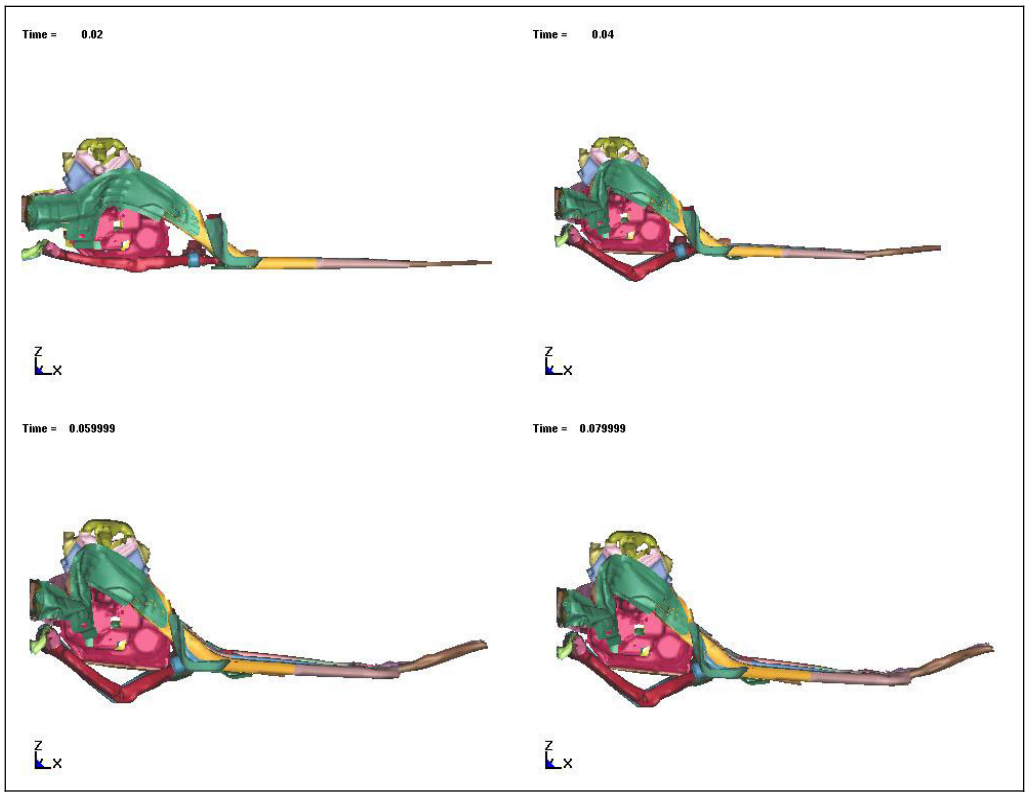


Figure 17: Deformation of Front End (Left Side View)

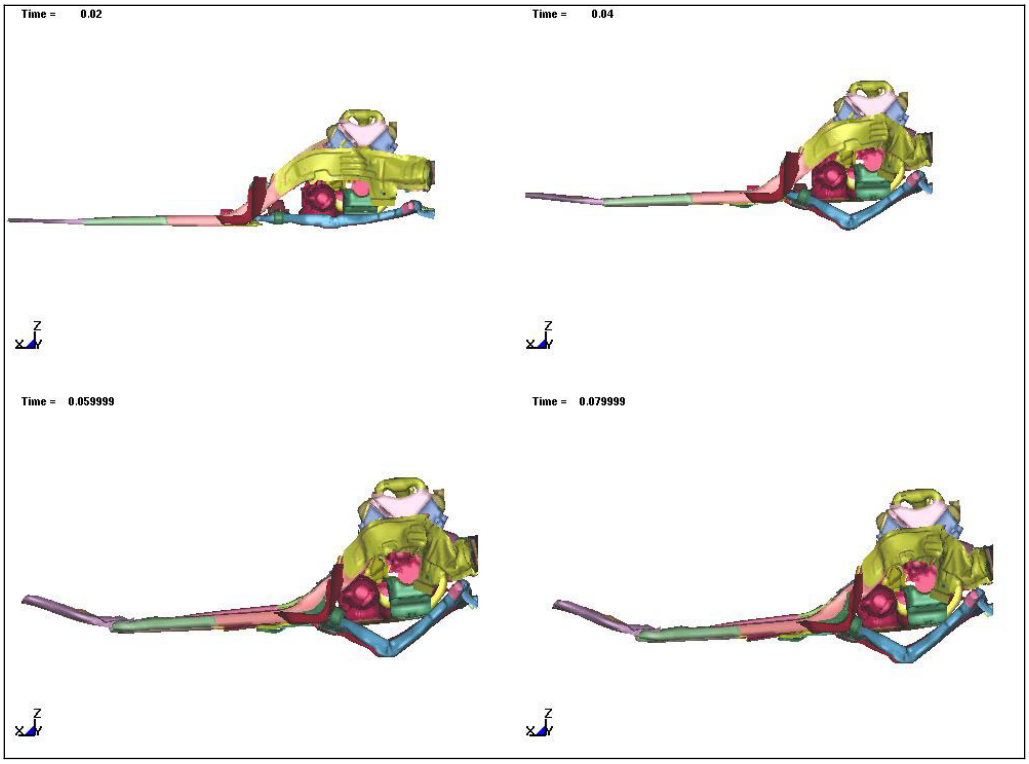


Figure 18: Deformation of Front End (Right Side View)

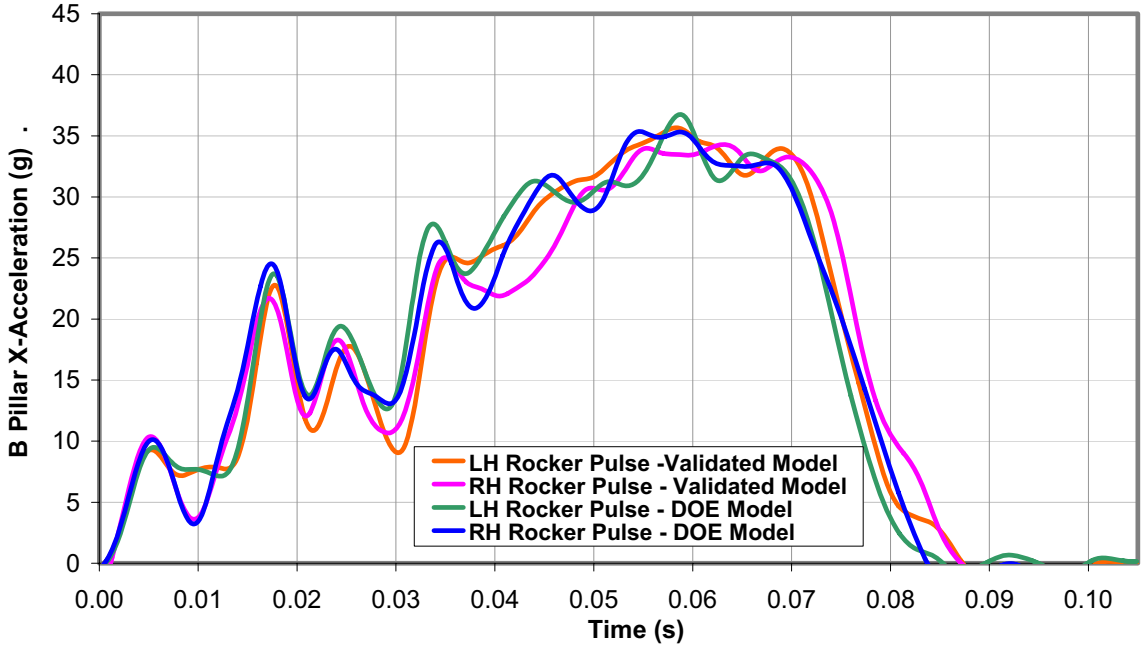


Figure 19: Comparison of B Pillar Pulse - Validated and DOE Model

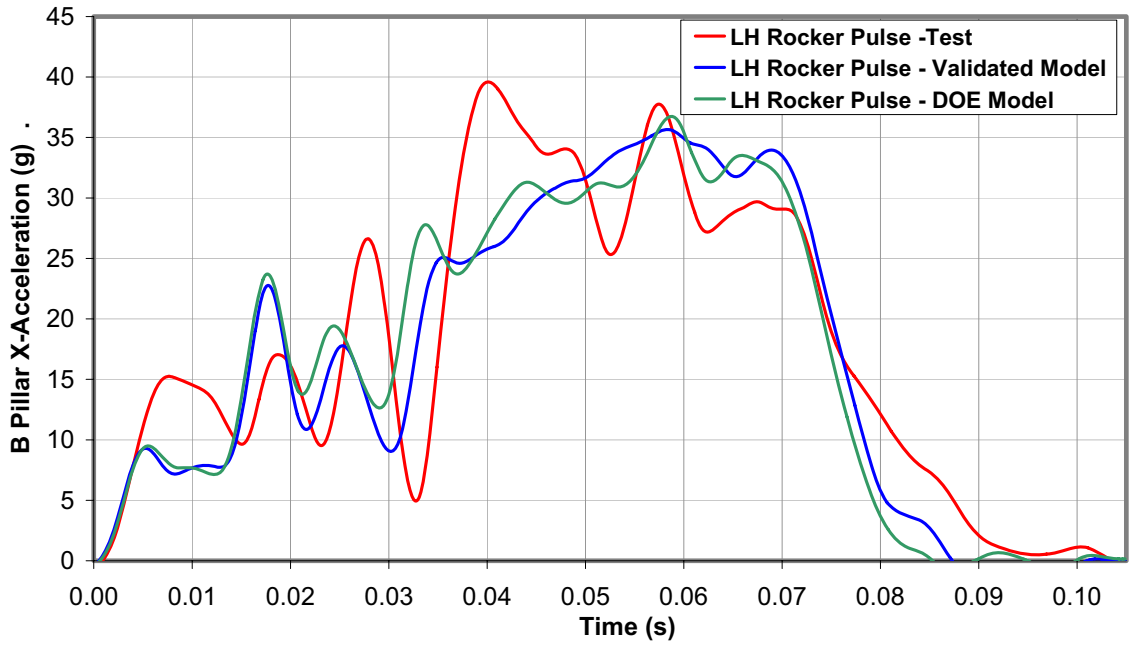


Figure 20: B Pillar Pulse – LH

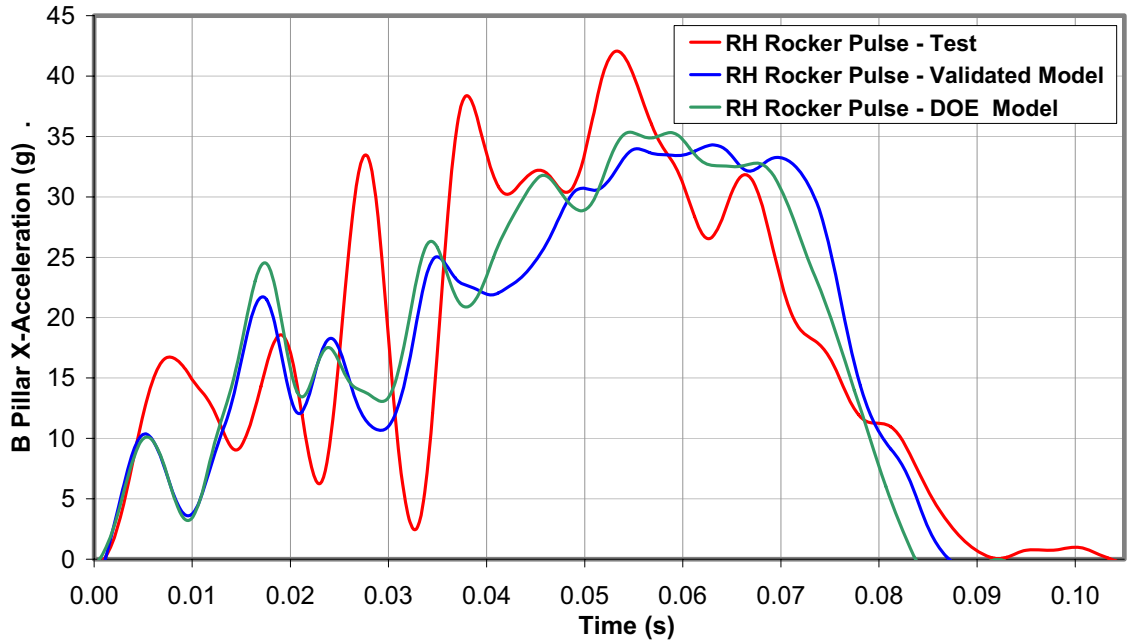


Figure 21: B Pillar Pulse – RH

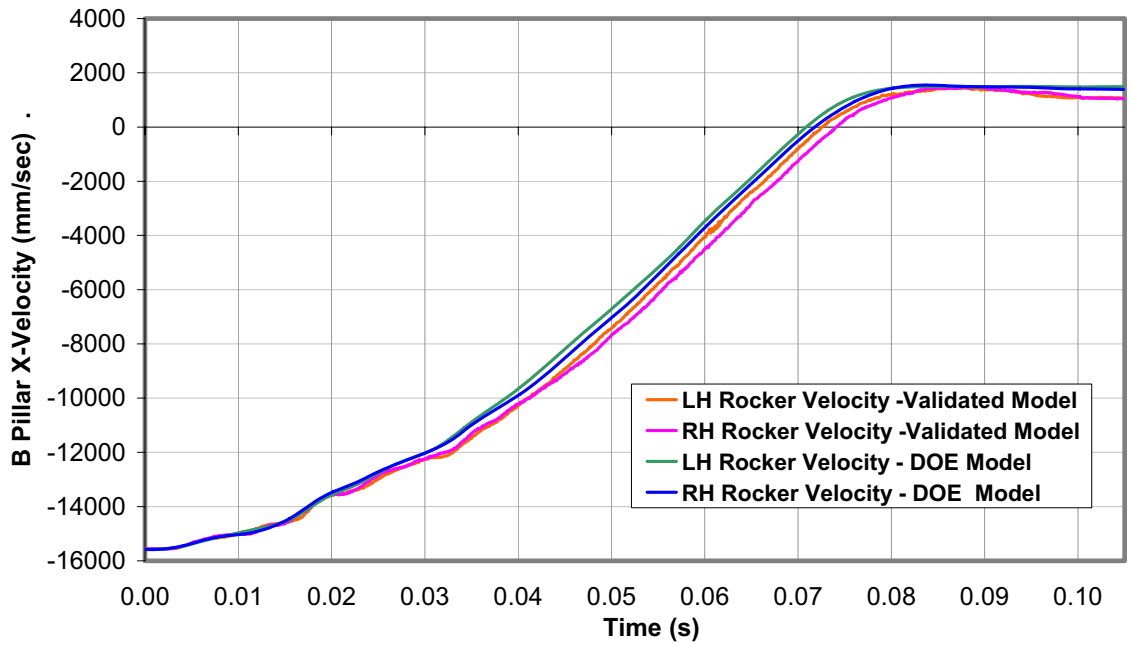


Figure 22: Comparison of B Pillar Velocity – Validated and DOE Model

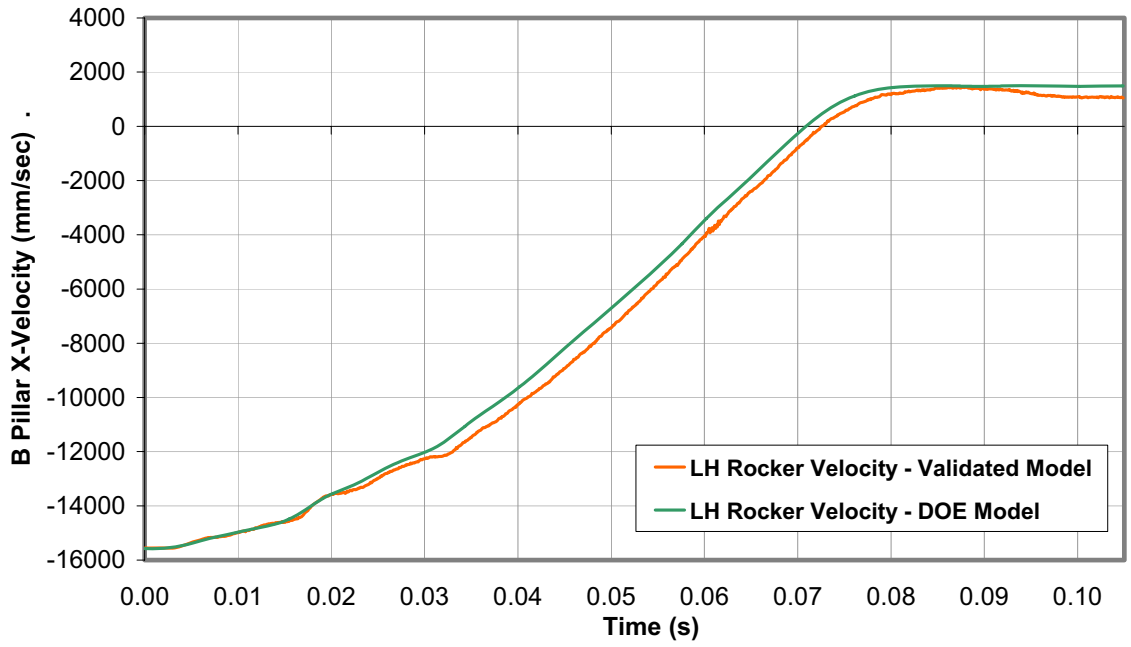


Figure 23: B Pillar Velocity - LH

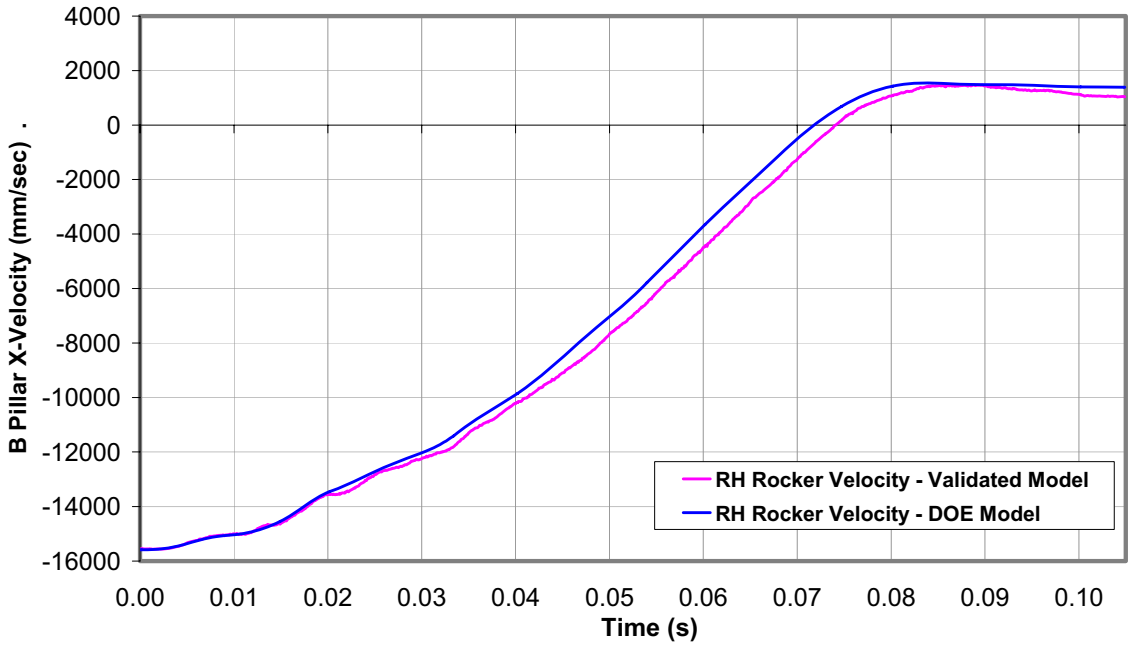


Figure 24: B-Pillar Velocity - RH

Table 6: NCAP Crash Events

Time (ms)	Crash Events
0-15	Bumper absorbs energy
15-20	Engine hits the radiator, Cradle Extension Buckles, Cradle engaged
20-30	Cradle and LH rail buckling started
35-40	LH front wheel hits the LH rail
40-45	Engine hits to dash
45-50	RH front wheel hits the RH rail
55-60	LH wheel hits the front rigid wall
60-70	RH wheel hits the front rigid wall, LH wheel hits the rocker
70-75	RH wheel hits the rocker

6. IIHS Response

IIHS intrusions are summarized in *Table 2*. Deformed plots are included in *Figure 25* through *Figure 28*. Animation files are included in *Appendix A*.

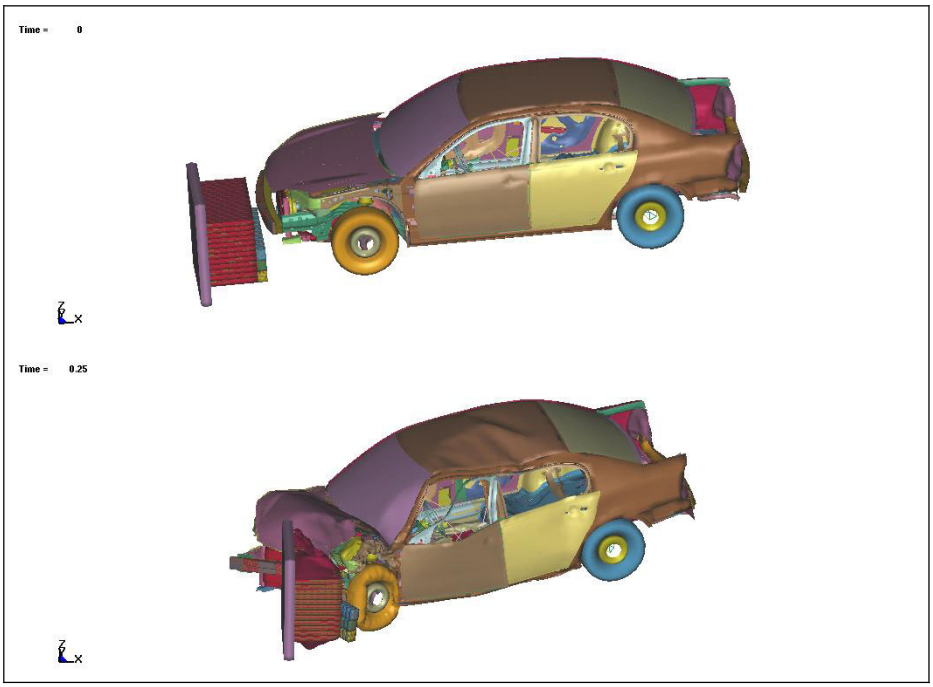


Figure 25: Deformation of Full Vehicle

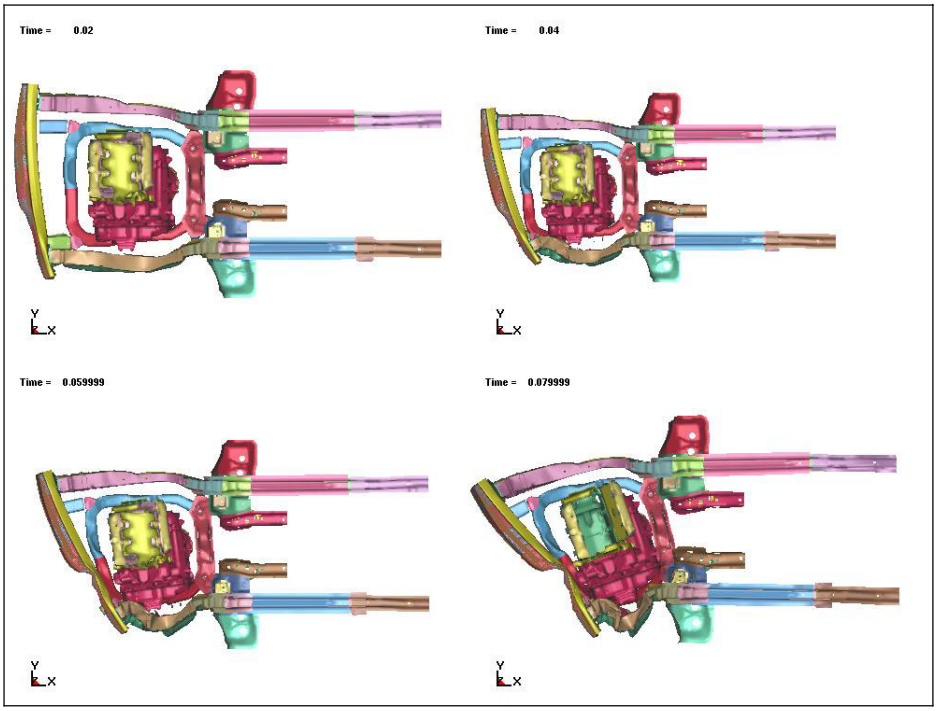


Figure 26: Deformation of Front End (Top View)

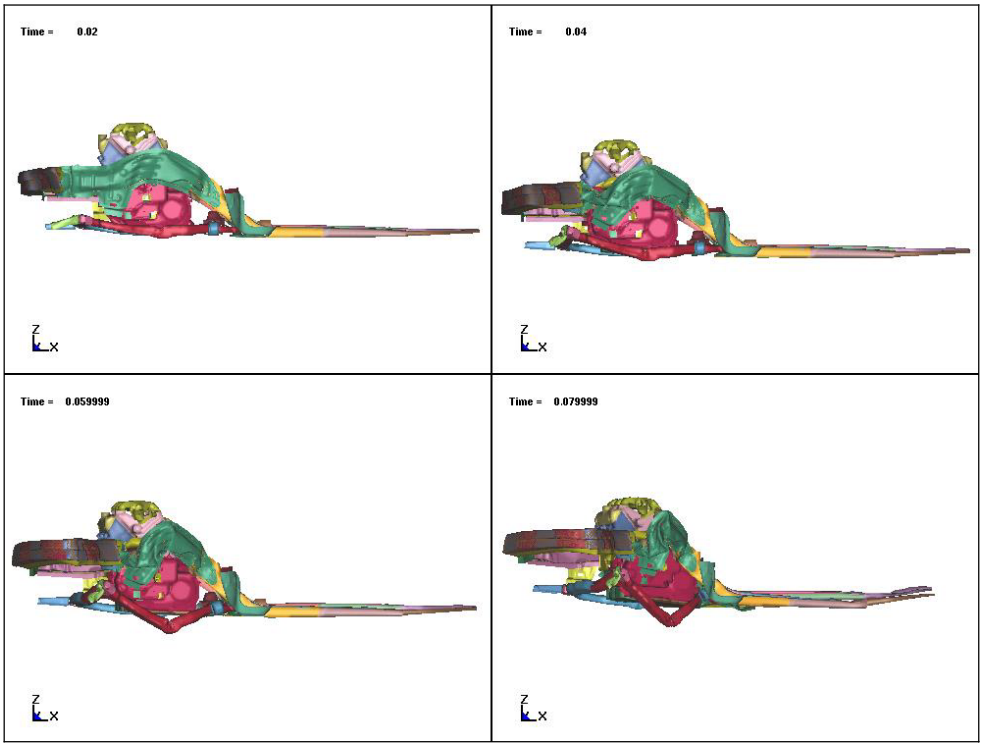


Figure 27: Deformation of Front End (Left Side View)

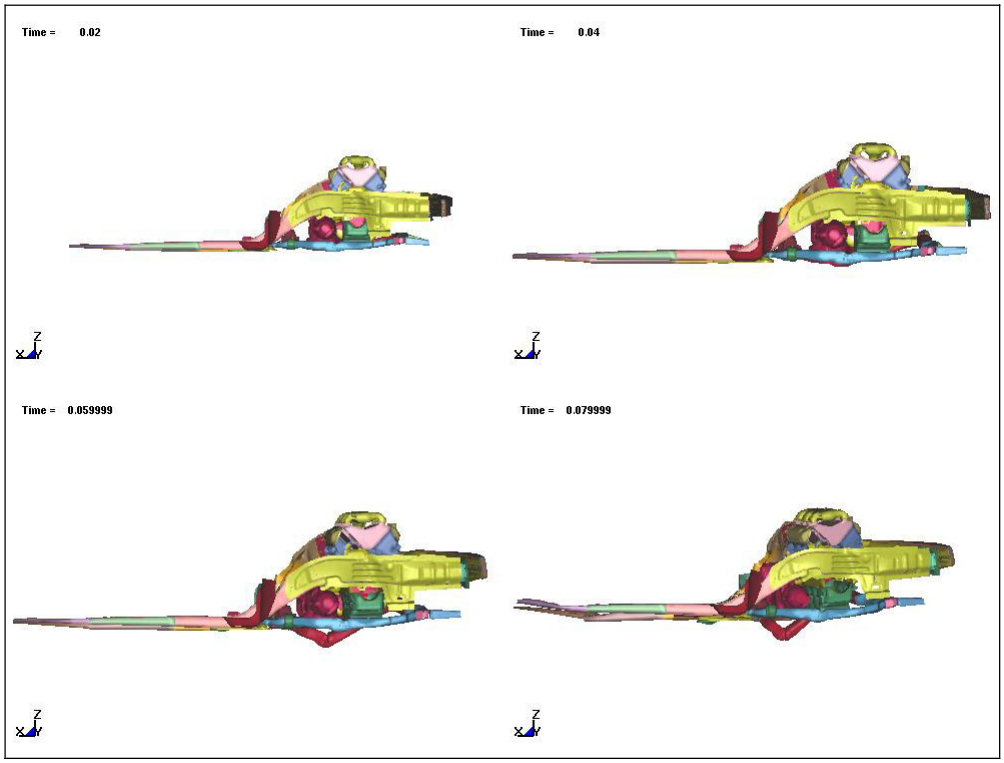


Figure 28: Deformation of Front End (Right Side View)

Toepan, brake pedal and A-B closure intrusions oscillate after 200ms about a mean value. Hence, the mean values should be used for comparison. However, the values reported in *Table 2* are at 250ms.

Steering column movement does not reach any equilibrium. The IIHS simulation would have to be carried out for a longer duration in order to report stable meaningful values. The steering column model may also be deficient, resulting in an unstable movement.

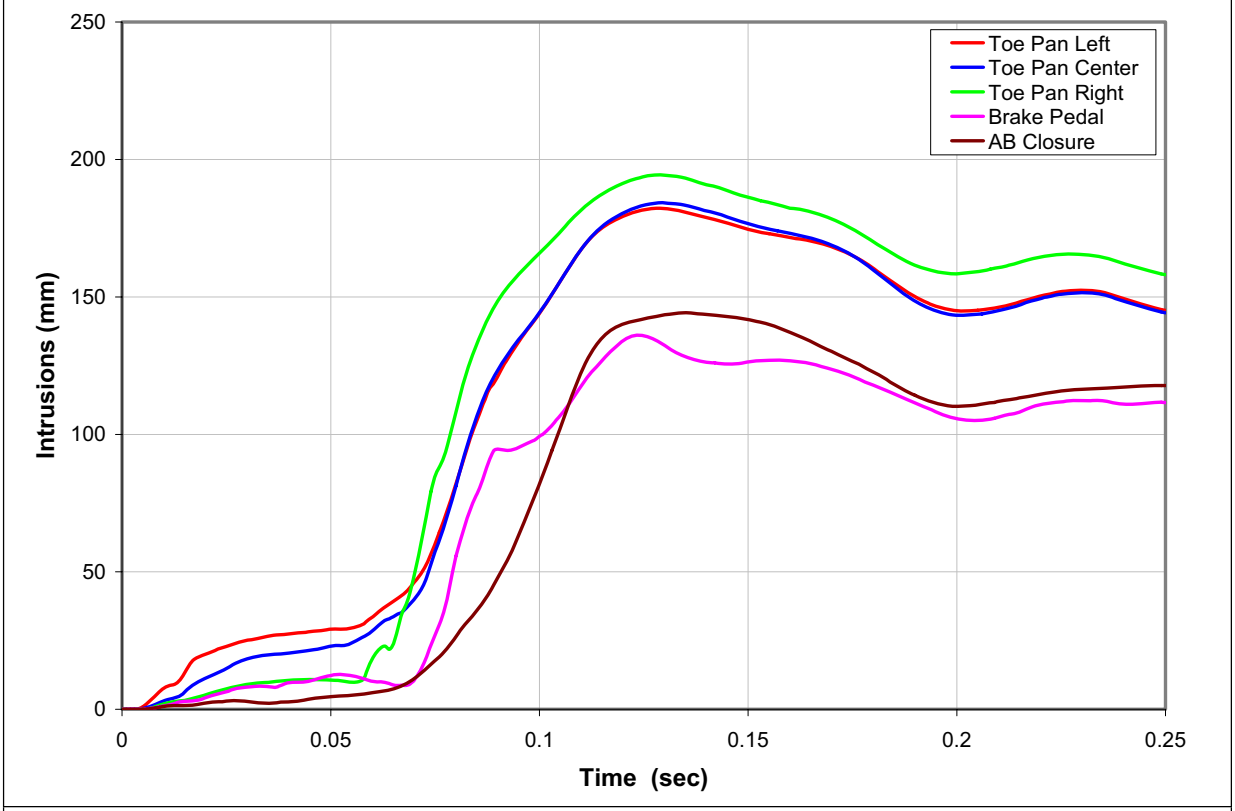


Figure 29: Toepan, Brake Pedal and A-B Closure Intrusions

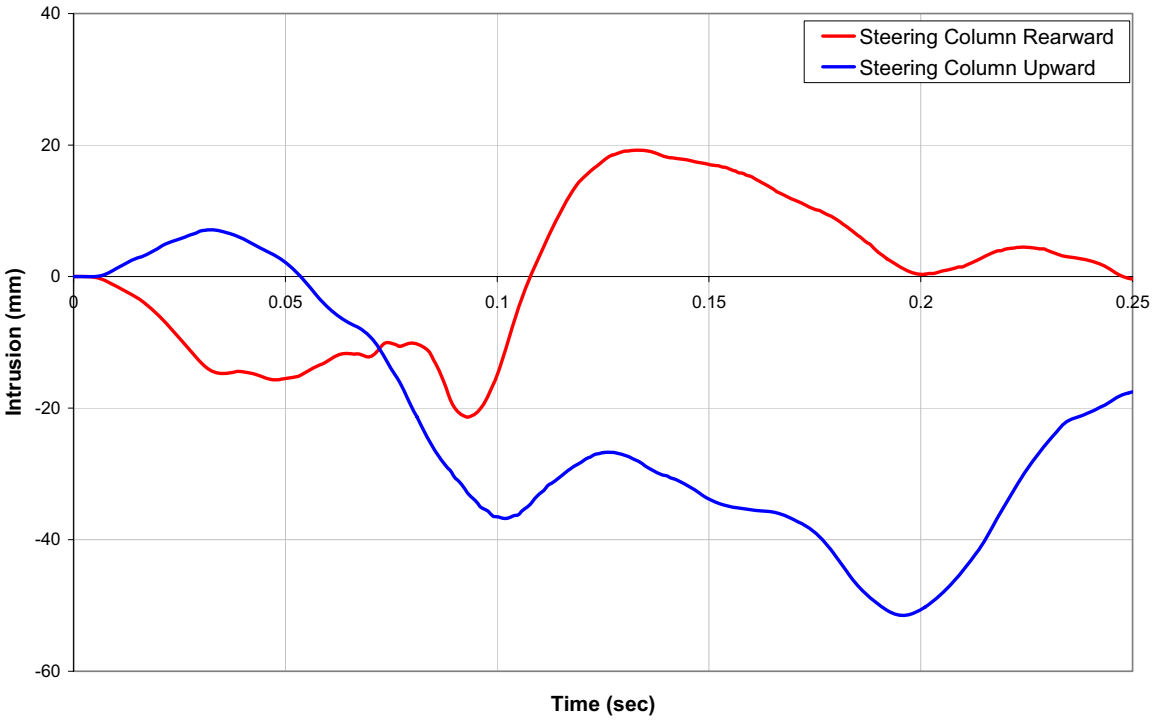


Figure 30: Steering Column Movement

7. Conclusions

The aim of this effort was to modify the donor vehicle FE models (*Milestone 5*), in order to render them suitable for DOE studies. A comprehensive model checking was undertaken and appropriate modifications were made. The NCAP response and IIHS Intrusions did not change significantly. However, the DOE FE models would have better stability and yield consistent results, and would be helpful in making accurate design comparisons.

8. Future Work

The DOE FE models will serve as the baseline for DOE studies and for assessing various rail and bumper concepts developed in Phase II of the Lightweight Front End Structure Project.

9. References

1) *Validated FE Models, Milestone 5*, SPHINX, Phase II.

2) *Enhanced FE Models, Milestone 6*, SPHINX, Phase II.

3) *IIHS Crashworthiness Evaluation Offset Barrier Crash Test Protocol (Version IX), October 2002.*

10. Appendix A: Animations

The following animation files for the subsystem development can be viewed at the Auto/Steel Partnership website, www.a-sp.org.

You will need a Hyperview Player in order to view these animations at the site. You can download this free software at www.altair.com.

1. NCAP: Full Vehicle
2. NCAP: Front-End
3. IIHS: Full Vehicle
4. IIHS: Front-End

11. Appendix B: Summary of FE Model

Component Name	ID	Property Name	ID	Material Name	ID	MASS (ton)	Thickness (mm)
horsecollar_brkt	60001	SectShll18.1	60087	MATL24_340	60049	6.20E-04	1.8
l_bumper_plate	60003	SectShll20.1	60088	MATL24_340	60049	5.17E-04	2
r_bumper_plate	60004	SectShll20.1	60088	MATL24_340	60049	5.18E-04	2
bumpbeam	60005	SectShll12.1	60084	MATL24_848	60050	0.005409	1.2
bumpnull	60006	SectShll10.1	60083	null	60008	0.002833	1
ldfoam	60007	SectSld900	60121	foam2.8pcf	60060	1.91E-04	0
hdfoam	60008	SectSld900	60121	foam6.6pcf	60061	4.93E-04	0
railotr.l	60101	SectShll15.3	60117	MATL24_340	60049	0.002781	1.5
railotr.r	60102	SectShll15.3	60117	MATL24_340	60049	0.002653	1.5
railinr.l	60103	Sectshll16.5	60109	MATL24_250	60054	0.003794	1.65
railinr.r	60104	Sectshll16.5	60109	MATL24_250	60054	0.003652	1.65
railctr1.l	60105	SectShll20.1	60088	MATL24_210	60052	0.00383	2
railctr1.r	60106	SectShll20.1	60088	MATL24_210	60052	0.003998	2
railctr2.l	60107	SectShll12.1	60084	MATL24_340	60049	1.02E-03	1.2
railctr2.r	60108	SectShll12.1	60084	MATL24_340	60049	9.75E-04	1.2
ubrail.l	60109	SectShll95	60113	MATL24_340	60049	5.89E-04	0.95
ubrail.r	60110	SectShll95	60113	MATL24_340	60049	5.93E-04	0.95
ctrrailrnf1.l	60111	SectShll12.1	60084	MATL24_340	60049	4.45E-04	1.2
ctrrailrnf1.r	60112	SectShll12.1	60084	MATL24_340	60049	4.28E-04	1.2
ctrrailrnf3.l	60113	Sectshll14.5	60111	MATL24_340	60049	7.25E-04	1.45
ctrrailrnf3.r	60114	Sectshll14.5	60111	MATL24_340	60049	7.46E-04	1.45
ctrrailrnf2.l	60115	SectShll225	60099	MATL24_3404	60051	0.002819	2.25
ctrrailrnf2.r	60116	SectShll225	60099	MATL24_3404	60051	0.002855	2.25
trqbox1.l	60117	Sectshll14.5	60111	MATL24_210	60052	0.001434	1.45
trqbox1.r	60118	Sectshll14.5	60111	MATL24_210	60052	0.001625	1.45
trqbox2.l	60119	Sectshll14.5	60111	MATL24_160	60048	2.71E-04	1.45
trqbox2.r	60120	Sectshll14.5	60111	MATL24_160	60048	2.72E-04	1.45
trnsrnf	60121	Sectshll17.5	60096	MATL24_340	60049	2.91E-04	1.75
emntrnf	60122	Sectshll14.5	60111	MATL24_340	60049	2.40E-04	1.45
cplate	60123	Sectshll16.5	60109	MATL24_340	60049	3.54E-04	1.65
rlinrnf.r	60124	Sectshll17.5	60096	MATL24_210	60052	2.77E-04	1.75
crfmbrkt.l	60201	SectShll20.1	60088	MATL24_340	60049	5.34E-04	2
crfmbrkt.r	60202	SectShll20.1	60088	MATL24_340	60049	5.38E-04	2
crdlfbrkt	60203	SectShll30	60094	MATL24_600	60056	8.68E-04	3
crdl.l	60205	SectShll26	60116	MATL24_340	60049	0.006018	2.6
crdl.r	60206	SectShll26	60116	MATL24_340	60049	0.006321	2.6
rrcrdlbdattch.l	60207	SectShll35	60106	MATL24_160	60048	0.001148	3.5
rrcrdlbdattch.r	60208	SectShll35	60106	MATL24_160	60048	0.001147	3.5
trnfext.l	60209	SectShll20.1	60088	MATL24_250	60054	0.001243	2
trnfext.r	60210	SectShll20.1	60088	MATL24_250	60054	0.001222	2
rrcrdlmnt1.l	60211	SectShll25	60091	MATL24_210	60052	0.001237	2.5
rrcrdlmnt1.r	60212	SectShll25	60091	MATL24_210	60052	0.001394	2.5

rrcrdlmnt2.l	60213	SectShll19.1	60112	MATL24_210	60052	2.84E-04	1.9
rrcrdlmnt2.r	60214	SectShll19.1	60112	MATL24_210	60052	2.84E-04	1.9
frtcrdlmnt1.l	60215	Sectshll19.5	60110	MATL24_160	60048	8.12E-04	1.95
frtcrdlmnt1.r	60216	Sectshll19.5	60110	MATL24_160	60048	7.34E-04	1.95
frtcrdlmnt2.l	60217	Sectshll14.5	60111	MATL24_210	60052	1.37E-04	1.45
frtcrdlmnt2.r	60218	Sectshll14.5	60111	MATL24_210	60052	1.38E-04	1.45
frtcrdlmnt5	60219	SectShll15.3	60117	MATL24_160	60048	4.31E-04	1.5
frtcrdlmnt3.l	60221	SectShll25	60091	MATL24_340	60049	4.30E-04	2.5
frtcrdlmnt3.r	60222	SectShll25	60091	MATL24_340	60049	3.41E-04	2.5
bot_bkt_l_e	60223	SectShll30	60094	MATL24_340	60049	9.59E-04	3
bot_bkt_r_e	60224	SectShll30	60094	MATL24_340	60049	9.29E-04	3
cradbrkt	60225	SectShll30	60094	MATL24_340	60049	4.46E-04	3
cradbrkt2	60227	SectShll30	60094	MATL24_340	60049	3.58E-04	3
lcarnf.l	60229	SectShll30	60094	MATL24_340	60049	3.19E-04	3
lcarnf.r	60230	SectShll30	60094	MATL24_340	60049	3.41E-04	3
lcajnt_1.L1	60231	SectShll30	60094	rigid	60014	4.12E-05	3
lcajnt_1.R1	60232	SectShll30	60094	rigid	60014	4.12E-05	3
lcacyl.l	60235	SectShll50	60092	MATL24_160	60048	0.001295	5
lcacyl.r	60236	SectShll50	60092	MATL24_160	60048	0.001295	5
lcajnt_1.L2	60239	SectShll30	60094	rigid	60014	3.16E-05	3
lcajnt_1.R2	60240	SectShll30	60094	rigid	60014	3.16E-05	3
cradbrkt1	60241	SectShll10.1	60083	MATL24_180	60046	2.36E-04	1
crdlblt	60243	SectShll20.1	60088	MATL24_160	60048	2.41E-04	2
crdlrrxupr	60244	SectShll25	60091	MATL24_340	60049	0.002183	2.5
crdlrrxlwr	60245	SectShll23	60090	MATL24_340	60049	0.00129	2.3
urail_l	60301	SectShll8.3	60081	MATL24_160	60048	0.001457	0.8
urail_r	60302	SectShll8.3	60081	MATL24_160	60048	0.001456	0.8
urail_rnf2.l	60303	SectShll9.1	60082	MATL24_160	60048	4.72E-04	0.9
urail_rnf1.r	60304	SectShll9.1	60082	MATL24_160	60048	4.71E-04	0.9
pnlfrt1.l	60305	Sectshll75	60097	MATL24_210	60052	5.44E-04	0.75
pnlfrt1.r	60306	Sectshll75	60097	MATL24_210	60052	6.27E-04	0.75
shock.l	60307	Sectshll17.5	60096	MATL24_160	60048	0.001517	1.75
shock.r	60308	Sectshll17.5	60096	MATL24_160	60048	0.001546	1.75
pnlfrt2.l	60309	SectShll12.1	60084	MATL24_210	60052	0.001235	1.2
pnlfrt2.r	60310	SectShll12.1	60084	MATL24_210	60052	0.001294	1.2
plnmbrkt	60311	SectShll8.3	60081	MATL24_210	60052	1.50E-04	0.8
rnfpnldshext2	60312	SectShll8.3	60081	MATL24_210	60052	1.93E-04	0.8
temp	60313	SectShll7.2	60080	MATL24_600	60056	2.63E-04	0.7
frtflr	60401	SectShll085	60118	MATL24_160	60048	0.013015	0.85
bar1	60402	SectShll20.1	60088	MATL24_3404	60051	0.00262	2
tnl1	60403	SectShll18.1	60087	MATL24_340	60049	0.001311	1.8
tnl2	60404	SectShll12.1	60084	MATL24_250	60054	0.006463	1.2
dash	60405	SectShll95	60113	MATL24_160	60048	0.008026	0.95
cowlupr	60406	SectShll8.3	60081	MATL24_210	60052	0.001526	0.8
fflrlvrrnf	60407	SectShll15.3	60117	MATL24_160	60048	7.10E-04	1.5
pedal2	60408	SectShll30	60094	MATL24_160	60048	0.001364	3
wndshld.supt.upr	60409	Sectshll75	60097	MATL24_160	60048	0.002599	0.75
plnmltintjnt	60410	Sectshll75	60097	MATL24_160	60048	0.004045	0.75
rein_upr	60411	SectShll15.3	60117	MATL24_210	60052	9.29E-04	1.5

MTG1	60412	SectShll10.1	60083	MATL24_210	60052	4.34E-04	1
BRKT_Consol	60413	SectShll15.3	60117	MATL24_210	60052	6.89E-04	1.5
crush_brkt_lwr	60414	SectShll20.1	60088	MATL24_210	60052	0.002868	2
bar2.l	60501	SectShll12.1	60084	MATL24_160	60048	0.001367	1.2
bar2.r	60502	SectShll12.1	60084	MATL24_160	60048	0.001368	1.2
2barreinf	60503	SectShll17	60086	MATL24_340	60049	0.00249	1.7
22678921_256_1	60505	SectShll12.1	60084	MATL24_160	60048	2.43E-04	1.2
22678920_256_1	60506	SectShll12.1	60084	MATL24_160	60048	2.43E-04	1.2
22678921_255_1	60507	SectShll12.1	60084	MATL24_160	60048	1.85E-04	1.2
22678920_255_1	60508	SectShll12.1	60084	MATL24_160	60048	1.85E-04	1.2
seatrein.l	60509	SectShll12.1	60084	MATL24_160	60048	3.45E-04	1.2
seatrein.r	60510	SectShll12.1	60084	MATL24_160	60048	3.46E-04	1.2
tiebar3.l	60601	Sectshll75	60097	MATL24_180	60046	6.78E-04	0.75
tiebar3.r	60602	Sectshll75	60097	MATL24_180	60046	7.22E-04	0.75
tiebar4.l	60603	Sectshll75	60097	MATL24_180	60046	4.27E-05	0.75
tiebar4.r	60604	Sectshll75	60097	MATL24_180	60046	4.44E-05	0.75
lhfanmotor	60605	SectShll20.1	60088	MATL24_181	60047	5.60E-04	2
rhfanmotor	60606	SectShll20.1	60088	MATL24_181	60047	5.40E-04	2
tiebar	60607	SectShll9.1	60082	MATL24_210	60052	0.002278	0.9
tiebar2	60608	SectShll9.1	60082	MATL24_160	60048	0.001152	0.9
radsupport	60609	SectShll10.1	60083	MATL24_160	60048	0.001261	1
rad4	60610	SectShll10.1	60083	MATL24_160	60048	8.32E-06	1
Part_2	60611	SectShll10.1	60083	MATL9_2	60006	0.014989	1
rad2	60612	SectSld900	60121	MAT57rad&cond	60059	0.002656	0
rad1	60613	SectSld900	60121	MAT57rad&cond	60059	0.003782	0
fanshroud	60614	SectShll20.1	60088	MATL24_181	60047	0.007298	2
pt2	60702	SectShll10.1	60083	rigid	60014	0.001123	1
pt3	60703	SectShll10.1	60083	rigid	60014	0.006404	1
pt7	60704	SectShll10.1	60083	rigid	60014	0.001243	1
pt8	60705	SectShll20.1	60088	rigid	60014	0.005065	2
pt10	60706	SectShll10.1	60083	rigid	60014	9.92E-04	1
pt11	60707	SectShll225	60099	rigid	60014	0.001335	2.25
pt13	60708	SectShll10.1	60083	rigid	60014	1.07E-04	1
pt14	60709	SectShll10.1	60083	rigid	60014	0.001639	1
pt19	60710	SectShll10.1	60083	rigid	60014	4.08E-04	1
pt18	60711	SectShll40	60093	rigid	60014	0.007253	4
frtmnt1	60712	SectShll20.1	60088	MATL24_160	60048	1.04E-03	2
frtmnt2	60713	SectShll225	60099	MATL24_160	60048	3.84E-04	2.25
pt9	60714	SectShll100	60104	rigid	60014	0.005277	10
pt12	60715	SectShll80	60095	rigid	60014	0.007011	8
pt16	60716	SectShll40	60093	rigid	60014	0.003234	4
pt17	60717	SectShll30	60094	MATL24_160	60048	0.007696	3
expipefrt	60718	SectShll15.3	60117	MATL24_160	60048	0.003601	1.5
ep_7685	60719	SectShll10.1	60083	rigid	60014	2.83E-04	1
flywheel	60720	SectShll10.1	60083	rigid	60014	7.92E-04	1
ep_4776	60721	SectShll10.1	60083	rigid	60014	4.99E-04	1
ep_7498	60722	SectShll10.1	60083	rigid	60014	0.002605	1
ep_0939	60723	SectShll10.1	60083	rigid	60014	5.79E-04	1
ep_0017	60724	SectShll10.1	60083	rigid	60014	4.50E-04	1

ep_70842	60725	SectShll10.1	60083	rigid	60014	1.84E-04	1
eng_mnt_l_e	60726	SectShll80	60095	MATL24_160	60048	0.002636	8
top_bkt_l_e	60727	SectShll80	60095	MAT24_1111	60045	5.72E-04	8
eng_mnt_r_e	60728	SectShll80	60095	MATL24_160	60048	0.002631	8
top_bkt_r_e	60729	SectShll80	60095	MAT24_1111	60045	1.01E-03	8
eng_deformable	60730	SectShll80	60095	MATL24_160	60048	0.001725	8
62109a_e1	60731	SectShll37	60108	MATL24_160	60048	3.62E-04	3.7
62109a_e2	60732	SectShll37	60108	MATL24_160	60048	1.22E-04	3.7
62109a_e3	60733	SectShll37	60108	MATL24_160	60048	4.00E-04	3.7
62109b_e1	60734	SectShll10.1	60083	MATL24_160	60048	4.06E-04	1
rrmnt_bushing	60735	SectShll20.1	60088	MATL24_160	60048	5.79E-04	2
tire1.l	60801	SectShll20.1	60088	mat1.tirerubber	60007	0.00197	2
tire1.r	60802	SectShll20.1	60088	mat1.tirerubber	60007	0.00197	2
tire3.l	60803	SectShll3.3	60107	MATL24_160	60048	1.00E-03	0.3
tire2.r	60804	SectShll3.3	60107	MATL24_160	60048	1.00E-03	0.3
tir2.l	60805	SectShll7.2	60080	MATL24_160	60048	0.002042	0.7
tire3.r	60806	SectShll7.2	60080	MATL24_160	60048	0.002042	0.7
rim.l	60807	SectShll35	60106	MATL24_600	60056	0.008136	3.5
rim.r	60808	SectShll35	60106	MATL24_600	60056	0.008136	3.5
lwrcntrlarm.l	60809	SectShll30	60094	MATL24_160	60048	0.002294	3
lwrcntrlarm.r	60810	SectShll30	60094	MATL24_160	60048	0.002289	3
lcajnt_2.L1	60811	SectShll30	60094	rigid	60014	6.26E-05	3
lcajnt_2.R1	60812	SectShll30	60094	rigid	60014	6.33E-05	3
driveline	60813	SectShll70	60103	MATL24_340	60049	0.005373	7
lcajnt_2.L2	60815	SectShll30	60094	rigid	60014	2.76E-05	3
lcajnt_2.R2	60816	SectShll30	60094	rigid	60014	2.76E-05	3
fsuspstrut.l	60817	SectShll50	60092	MATL24_160	60048	0.005601	5
fsuspstrut.r	60818	SectShll50	60092	MATL24_160	60048	0.005601	5
crdlbltrnf	60819	SectShll275.1	60102	MATL24_160	60048	3.23E-04	2.75
strclnmend3	60820	SectShll50	60092	rigid	60014	3.64E-04	5
strngrack	60821	SectShll60	60101	MAT24_1111	60045	0.002617	6
strrackends	60822	SectShll60	60101	MATL24_160	60048	0.001165	6
stabbar	60823	SectShll40	60093	MATL24_160	60048	0.004576	4
btray1	60901	SectShll15.3	60117	MATL24_160	60048	0.003147	1.5
btray2	60902	SectShll10.1	60083	MATL24_160	60048	2.19E-04	1
battery1	60903	SectShll5.3	60105	MATL24_160	60048	8.66E-04	0.5
ECM	60904	SectShll10.1	60083	MATL24_160	60048	1.07E-03	1
battery_fill	60905	SectShll10.1	60083	MATL24_160	60048	0.001326	1
fcomptrnf2	60906	SectShll40	60093	MATL24_160	60048	0.002901	4
abs_brkt	60907	SectShll20.1	60088	MATL24_160	60048	4.33E-04	2
brkt_boost	60908	90060072	60042	90060009	60012	0.00385	3
edge	61001	SectShll2.1.1	60077	MAT24_3	60042	1.06E-03	1.35
inner	61002	SectShll3.2.1	60078	MAT24_3	60042	0.005147	0.7
outer	61003	SectShll4.1.1	60079	MAT24_3	60042	0.008252	0.7
MODPLT	61101	90060005	60010	90060020	60041	0.001613	1.5
CSUPT_forw	61102	90060006	60011	90060020	60041	5.32E-04	1.22
can	61103	90060008	60012	90060020	60041	6.77E-04	1.2
can1	61104	90060009	60013	90060020	60041	9.87E-05	1.2
can2	61105	90060010	60014	90060020	60041	1.09E-04	1.2

can.1	61106	90060011	60015	90060020	60041	9.05E-05	1.2
inflator	61107	90060012	60016	90060020	60041	0.001456	5.4
Brkt-1	61108	90060063	60039	90060020	60041	6.07E-04	3
gaspdel	61109	90060068	60040	90060020	60041	1.65E-04	2.5
stelpeice	61110	90060071	60041	90060020	60041	1.54E-04	3
SIPO_p	61111	90060014	60018	90060020	60041	6.06E-04	2
SIPO_d2	61112	90060015	60019	90060020	60041	6.11E-04	2
Steel_strip	61113	90060016	60020	90060020	60041	1.07E-04	1.5
Floor_Brkt2	61114	90060037	60022	90060020	60041	8.95E-04	2.5
Center_Stk_brkt	61115	90060038	60023	90060020	60041	3.09E-04	1.5
lower	61116	90060044	60026	90060013	60036	8.85E-04	2.43
upper	61117	90060045	60027	90060013	60036	8.69E-04	2.36
hvacbrkt_add	61118	90060046	60028	90060013	60036	2.49E-05	2.36
heatercvr	61119	90060047	60029	90060013	60036	3.21E-04	2.38
ai	61120	90060048	60030	90060013	60036	3.74E-04	2.1
ai_icebox	61121	90060049	60031	90060013	60036	1.51E-05	2.1
ai_actuator	61122	90060050	60032	90060013	60036	2.81E-05	2
lower_actuator	61123	90060051	60033	90060013	60036	2.86E-05	2
foamplate	61124	90060052	60034	90060020	60041	5.74E-05	1
filmvalve	61125	90060053	60035	90060013	60036	1.67E-04	2
arm1_srib	61126	90060054	60036	90060013	60036	8.90E-05	2
rib_4_hub	61127	90060055	60037	90060013	60036	1.42E-04	3.5
Lower_add1	61128	90060056	60038	90060013	60036	1.16E-05	2
foam	61129	90060125	60119	90060001	60001	1.48E-06	0
evapblock	61130	90060126	60120	90060003	60003	3.52E-05	0
IBEC	61131	90060013	60017	90060005	60004	3.04E-04	2
evap_lower_tube1	61132	90060041	60024	90060002	60002	8.68E-06	1
evap_upper_tube1	61133	90060041	60024	90060002	60002	1.38E-05	1
heat_upper_tube1	61134	90060041	60024	90060002	60002	4.22E-05	1
heat_lower_tube1	61135	90060041	60024	90060002	60002	2.58E-05	1
il	61136	90060042	60025	90060014	60037	1.89E-04	1
IP_sidepnl_E	61137	90060026	60021	90060015	60038	1.24E-04	2.5
sipo_fixed1	61138	90060015	60019	90060008	60011	1.39E-06	2
sipo_fixed2	61139	90060015	60019	90060008	60011	1.46E-06	2
sipo_fixed3	61140	90060015	60019	90060008	60011	1.53E-06	2
sipo_fixed4	61141	90060015	60019	90060008	60011	1.13E-06	2
sipo_fixed5	61142	90060015	60019	90060008	60011	1.85E-06	2
sipo_fixed6	61143	90060015	60019	90060008	60011	1.95E-06	2
sipo_fixed7	61144	90060015	60019	90060008	60011	1.83E-06	2
sipo_p_fixed7	61145	90060014	60018	90060008	60011	1.41E-06	2
sipo_p_fixed6	61146	90060014	60018	90060008	60011	1.59E-06	2
sipo_p_fixed5	61147	90060014	60018	90060008	60011	1.71E-06	2
sipo_p_fixed4	61148	90060014	60018	90060008	60011	1.13E-06	2
sipo_p_fixed3	61149	90060014	60018	90060008	60011	1.85E-06	2
sipo_p_fixed2	61150	90060014	60018	90060008	60011	1.95E-06	2
sipo_p_fixed12	61151	90060014	60018	90060008	60011	1.83E-06	2
modplate_rigid1	61152	90060005	60010	90060008	60011	1.55E-06	1.5
modplate_rigid2	61153	90060005	60010	90060008	60011	2.34E-06	1.5
modplate_rigid32	61154	90060005	60010	90060008	60011	1.45E-06	1.5

modplate_rigid4	61155	90060005	60010	90060008	60011	1.65E-06	1.5
modplate_rigid5	61156	90060005	60010	90060008	60011	1.58E-06	1.5
modplate_rigid6	61157	90060005	60010	90060008	60011	1.98E-06	1.5
modplate_rigid7	61158	90060005	60010	90060008	60011	9.84E-07	1.5
modplate_rigid8	61159	90060005	60010	90060008	60011	1.76E-06	1.5
e.pedal	61160	90060073	60043	90060011	60034	8.37E-04	8
e.pad	61164	90060074	60044	90060011	60034	1.20E-04	3.5
e.pin	61165	90060075	60045	90060011	60034	1.14E-04	2
pedalpivout	61167	90060072	60042	90060009	60012	8.58E-06	3
pedalpivinb	61168	90060072	60042	90060009	60012	8.58E-06	3
pedallink	61169	90060072	60042	90060009	60012	1.43E-06	3
pivot inb	61170	90060072	60042	90060009	60012	4.32E-06	3
pivot out	61171	90060072	60042	90060009	60012	1.10E-06	3
Part221130	61172	90060072	60042	90060009	60012	1.08E-06	3
Part221131	61173	90060072	60042	90060009	60012	1.39E-06	3
Part221132	61174	90060072	60042	90060009	60012	9.68E-07	3
Part221133	61175	90060072	60042	90060009	60012	9.79E-07	3
Part221134	61176	90060072	60042	90060009	60012	6.86E-07	3
Part221135	61177	90060072	60042	90060009	60012	1.30E-06	3
Part221136	61178	90060072	60042	90060009	60012	9.62E-07	3
dr_ealf	61179	90060077	60047	90060011	60034	2.25E-04	1.5
dr_eart	61180	90060077	60047	90060020	60041	2.25E-04	1.5
ps_eart	61181	90060076	60046	90060020	60041	1.64E-04	1.5
ps_eart.1	61182	90060076	60046	90060020	60041	1.64E-04	1.5
floor_attachment	61183	90060078	60048	90060020	60041	5.18E-04	2
tunlbkt_fixdeles	61184	90060078	60048	90060010	60013	1.18E-06	2
tunlbkt_fixdeles	61185	90060078	60048	90060010	60013	1.27E-06	2
tunlbkt_fixdeles	61186	90060078	60048	90060010	60013	2.33E-06	2
tunlbkt_fixdeles	61187	90060078	60048	90060010	60013	1.83E-06	2
tunlbkt_fixdeles	61188	90060078	60048	90060010	60013	4.47E-06	2
tunlbkt_fixdeles	61189	90060078	60048	90060010	60013	7.59E-06	2
tunlbkt_fixdeles	61190	90060078	60048	90060010	60013	2.76E-06	2
tunlbkt_fixdeles	61191	90060078	60048	90060010	60013	3.89E-06	2
gboxframe_base	61192	90060080	60049	90060016	60039	3.92E-04	2.5
vribs_gboxframe	61193	90060081	60050	90060016	60039	4.81E-06	1
hribs_gboxframe	61194	90060082	60051	90060016	60039	2.76E-05	1.2
Mag_6.5.1.1	61196	90060100	60052	90060012	60035	3.18E-04	6.5
Mag_3.0.1.1	61197	90060101	60053	90060012	60035	0.00345	3
Mag_4.0.1.1	61198	90060102	60054	90060012	60035	4.81E-04	4
Mag_ribs.1.1	61199	90060103	60055	90060012	60035	0.002748	3
Mag_1.5.1.1	61200	90060104	60056	90060012	60035	1.28E-04	1.5
Mag_5.0.1	61201	90060105	60057	90060012	60035	1.40E-04	5
Mag_2.5	61202	90060106	60058	90060012	60035	2.65E-04	2.5
inner.1	61203	90060107	60059	90060016	60039	3.58E-04	3
innergroorve	61204	90060111	60063	90060016	60039	8.37E-07	3.3
ribs.1	61205	90060112	60064	90060016	60039	1.36E-04	1.25
bin o	61206	90060108	60060	90060017	60040	2.74E-04	2.5
ribbin	61207	90060110	60062	90060017	60040	5.71E-07	1.7
bintongue	61208	90060109	60061	90060017	60040	4.40E-07	1.1

outer.1	61209	90060113	60065	90060016	60039	2.85E-04	2.5
hub	61210	90060115	60067	90060016	60039	1.76E-06	1
outerhrib	61211	90060114	60066	90060016	60039	7.18E-06	1.2
outervrib	61212	90060115	60067	90060016	60039	3.35E-07	1
hubrib	61213	90060116	60068	90060016	60039	1.93E-07	1.375
glvbx_frm_hinge_	61214	90060117	60069	90060016	60039	8.29E-06	3
knee bolster inn	61215	90060118	60070	90060016	60039	2.66E-04	2.5
inner rib h	61216	90060119	60071	90060016	60039	1.25E-04	1.875
small rib inner	61217	90060120	60072	90060016	60039	3.27E-06	2.6
knee bolster out	61218	90060121	60073	90060016	60039	4.25E-04	2.5
doghouse outer	61219	90060122	60074	90060016	60039	6.40E-06	1.4
outer rib	61220	90060123	60075	90060016	60039	4.29E-06	1.1
tipof bin	61221	90060124	60076	90060016	60039	5.01E-05	2.5
part.9	61301	SectShll20.1	60088	MAT9_704	60009	1.21E-04	2
part.10	61302	SectShll20.1	60088	MAT9_705	60010	5.67E-05	2
part.11	61303	SectShll5.3	60105	MAT20_706	60015	5.98E-05	0.5
part.14	61304	SectShll20.1	60088	MAT20_750	60016	0.001699	2
part.15	61305	SectShll10.1	60083	MAT20_751	60017	8.05E-05	1
part.16	61306	SectShll34	60115	MAT20_752	60018	1.83E-04	3.4
part.17	61307	SectShll25	60091	MAT20_753	60019	5.23E-04	2.5
part.18	61308	SectShll25	60091	MAT20_754	60020	6.50E-04	2.5
part.19	61309	SectShll20.1	60088	MAT20_755	60021	5.14E-04	2
part.20	61310	SectShll30	60094	MAT20_756	60022	4.70E-04	3
part.21	61311	SectShll34	60115	MAT20_757	60023	2.55E-04	3.4
part.22	61312	SectShll20.1	60088	MAT20_758	60024	5.61E-05	2
part.24	61313	SectShll20.1	60088	MAT20_760	60025	1.14E-04	2
part.25	61314	SectShll20.1	60088	MAT20_761	60026	8.86E-05	2
part.28	61315	SectShll20.1	60088	MAT20_764	60027	2.43E-05	2
part.29	61316	SectShll20.1	60088	MAT20_765	60028	2.32E-05	2
part.30	61317	SectShll40	60093	MAT20_766	60029	3.95E-06	4
part.31	61318	SectShll40	60093	MAT20_767	60030	3.95E-06	4
part.34	61319	SectShll40	60093	MAT24_771	60044	2.43E-05	4
part.40	61320	SectShll30	60094	MAT20_777	60031	3.28E-04	3
part.41	61321	SectShll30	60094	MAT20_778	60032	3.69E-04	3
strclnmend4	61323	SectShll50	60092	rigid	60014	2.10E-04	5
part.49	61324	SectShll15.3	60117	MAT20_20015	60033	9.89E-06	1.5
drinrpnl.l	61401	Sectshll75	60097	MATL24_160	60048	0.003637	0.75
drlwrhng.l	61402	SectShll50	60092	MATL24_160	60048	1.28E-04	5
drotrpnl.l	61403	Sectshll75	60097	MATL24_180	60046	0.004388	0.75
z-brkt.l	61404	SectShll10.1	60083	MATL24_160	60048	5.56E-05	1
upr_frame.l	61405	SectShll10.1	60083	MATL24_160	60048	0.001997	1
drbeam.l	61406	SectShll20.1	60088	MATL24_600	60056	0.001914	2
druprhng.l	61407	SectShll50	60092	MATL24_160	60048	1.30E-04	5
drinrpnl.r	61408	Sectshll75	60097	MATL24_160	60048	0.003636	0.75
drotrpnl.r	61409	Sectshll75	60097	MATL24_180	60046	0.004388	0.75
z-brkt.r	61410	SectShll10.1	60083	MATL24_160	60048	5.56E-05	1
upr_frame.r	61411	SectShll10.1	60083	MATL24_160	60048	0.001997	1
drbeam.r	61412	SectShll20.1	60088	MATL24_600	60056	0.001913	2
druphng.r	61413	SectShll50	60092	MATL24_160	60048	1.34E-04	5

drlwhng.r	61414	SectShll50	60092	MATL24_160	60048	1.26E-04	5
fdrbdhng	61415	SectShll50	60092	MATL24_210	60052	2.07E-04	5
fdrbdhng2	61416	SectShll20.1	60088	rigid	60014	1.96E-05	2
fdrbdhng3	61417	SectShll20.1	60088	rigid	60014	2.43E-05	2
fdrbdhng4	61418	SectShll50	60092	MATL24_210	60052	2.01E-04	5
fdrbdhng5	61419	SectShll20.1	60088	rigid	60014	2.07E-05	2
fdrbdhng6	61420	SectShll20.1	60088	rigid	60014	2.54E-05	2
fdrbdhng7	61421	SectShll50	60092	MATL24_210	60052	2.55E-04	5
fdrbdhng8	61422	SectShll20.1	60088	rigid	60014	2.01E-05	2
fdrbdhng9	61423	SectShll20.1	60088	rigid	60014	2.48E-05	2
fdrbdhng10	61424	SectShll50	60092	MATL24_210	60052	1.97E-04	5
fdrbdhng11	61425	SectShll20.1	60088	rigid	60014	2.07E-05	2
fdrbdhng12	61426	SectShll20.1	60088	rigid	60014	2.49E-05	2
drlsrwld.l	61427	SectShll18.1	60087	MATL24_160	60048	0.003567	1.8
drlsrwld.r	61428	SectShll18.1	60087	MATL24_160	60048	0.003567	1.8
rrdrinn.l	61429	Sectshll75	60097	MATL24_160	60048	0.00681	0.75
twdrrdrinr.l	61430	SectShll18.1	60087	MATL24_160	60048	0.005454	1.8
rrdrotr.l	61431	Sectshll75	60097	MATL24_160	60048	0.008021	0.75
rrdrfrm.l	61432	SectShll10.1	60083	MATL24_160	60048	0.003331	1
rrdrbm.l	61433	SectShll20.1	60088	MATL24_600	60056	0.002513	2
bathtub.l	61434	SectShll20.1	60088	MATL24_160	60048	2.59E-04	2
rrdrhng.l	61435	SectShll50	60092	MATL24_160	60048	1.06E-03	5
latchjt.l	61436	SectShll20.1	60088	MATL24_160	60048	2.28E-04	2
rrdrhng1.l	61437	SectShll50	60092	MATL24_160	60048	6.20E-04	5
roof	61501	Sectshll75	60097	MATL24_160	60048	0.010108	0.75
wshield	61502	SectShll48	60100	laminatedglass	60058	0.015411	4.8
rr_wndshld	61503	SectShll48	60100	laminatedglass	60058	0.011652	4.8
bdysdpnlotr.l	61601	Sectshll75	60097	MATL24_160	60048	0.014307	0.75
bdysdpnlotr.r	61602	Sectshll75	60097	MATL24_160	60048	0.014308	0.75
twldbsideinr.l	61603	SectShll21	60089	MATL24_160	60048	0.00905	2.1
twldbsideinr.r	61604	SectShll21	60089	MATL24_160	60048	0.009056	2.1
rkrx_l	61605	Sectshll13	60098	MATL24_340	60049	1.01E-03	1.3
rkrx_r	61606	Sectshll13	60098	MATL24_340	60049	1.01E-03	1.3
rkrinr.l	61607	sectshll16	60114	MATL24_3404	60051	0.003811	1.6
rkrinr.r	61608	sectshll16	60114	MATL24_3404	60051	0.003811	1.6
twldB-plr.l	61609	SectShll18.1	60087	MATL24_250	60054	0.003041	1.8
twldB-plr.r	61610	SectShll18.1	60087	MATL24_250	60054	0.003041	1.8
bdysdpnlinr.l	61611	SectShll10.1	60083	MATL24_160	60048	0.009621	1
bdysdpnlinr.r	61612	SectShll10.1	60083	MATL24_160	60048	0.009567	1
B_plr_rnf	61613	SectShll10.1	60083	MATL24_160	60048	6.01E-04	1
bplrrnf.l	61615	SectShll225	60099	MATL24_250	60054	0.003029	2.25
bplrrnf.r	61616	SectShll225	60099	MATL24_250	60054	0.003029	2.25
rfrailrnfl	61617	SectShll20.1	60088	MATL24_210	60052	0.002007	2
rfrailrnfr	61618	SectShll20.1	60088	MATL24_210	60052	0.002007	2
frt_hrn	61619	SectShll20.1	60088	MATL24_160	60048	7.90E-04	2
rfrailinr.r	61620	SectShll20.1	60088	MATL24_160	60048	7.85E-04	2
a_pilar_rnf_l	61621	SectShll10.1	60083	MATL24_160	60048	9.04E-04	1
a_pilar_rnf_r	61622	SectShll10.1	60083	MATL24_160	60048	9.05E-04	1
fbhplrrnf1.l	61623	SectShll10.1	60083	MATL24_210	60052	0.001632	1

fbhplrrnf1.r	61624	SectShll10.1	60083	MATL24_210	60052	0.001634	1
frthdr	61625	SectShll7.2	60080	MATL24_160	60048	9.30E-04	0.7
rfbow2	61626	SectShll9.1	60082	MATL24_340	60049	9.23E-04	0.9
rearflr	61627	SectShll8.3	60081	MATL24_160	60048	0.017539	0.8
bar3	61628	SectShll10.1	60083	MATL24_211	60053	0.002442	1
bar4ctr	61629	SectShll10.1	60083	MATL24_340	60049	0.001438	1
bar4lft	61630	SectShll15.3	60117	MATL24_160	60048	0.001168	1.5
rrrail.l	61631	SectShll15.3	60117	MATL24_251	60055	0.005535	1.5
rrrailrnf1.l	61632	SectShll10.1	60083	MATL24_160	60048	1.93E-04	1
rrailrnf2.l	61633	SectShll10.1	60083	MATL24_160	60048	2.10E-04	1
gusset.l	61634	SectShll15.3	60117	MATL24_160	60048	7.13E-04	1.5
gusset2.l	61635	SectShll15.3	60117	MATL24_160	60048	8.44E-04	1.5
gusset3.l	61636	SectShll15.3	60117	MATL24_160	60048	5.19E-04	1.5
gusset4.l	61637	SectShll15.3	60117	MATL24_160	60048	5.89E-04	1.5
whlhsinr.l	61638	SectShll10.1	60083	MATL24_160	60048	0.002906	1
4barrnf1.l	61639	SectShll20.1	60088	MATL24_160	60048	0.001399	2
4barrnf2.l	61640	SectShll25	60091	MATL24_160	60048	7.24E-04	2.5
backpanel	61641	SectShll8.3	60081	MATL24_160	60048	0.005311	0.8
bpnlrnf	61642	Sectshll75	60097	MATL24_160	60048	0.001933	0.75
rrhdr	61643	SectShll9.1	60082	MATL24_160	60048	0.001131	0.9
rrsuspshk.l	61644	SectShll225	60099	MATL24_160	60048	3.05E-04	2.25
rkrblkhds	61645	SectShll12.1	60084	MATL24_340	60049	7.54E-04	1.2
rdeck	61646	SectShll10.1	60083	MATL24_160	60048	0.005446	1
trnkgtrfrt	61647	SectShll10.1	60083	MATL24_160	60048	0.00209	1
rdeckbrkt1	61648	SectShll10.1	60083	MATL24_160	60048	9.01E-04	1
rdeckbrkt2	61649	SectShll10.1	60083	MATL24_160	60048	2.49E-04	1
trnkgtr.l	61650	SectShll9.1	60082	MATL24_160	60048	3.97E-04	0.9
rdeckbrkt3.l	61651	SectShll10.1	60083	MATL24_160	60048	8.76E-04	1
rdeckbrkt4.l	61652	SectShll10.1	60083	MATL24_160	60048	7.67E-04	1
trlrhtchbrkt	61653	SectShll10.1	60083	MATL24_160	60048	0.001306	1
rrailext.l	61654	SectShll15.3	60117	MATL24_160	60048	7.55E-04	1.5
bar4rt	61655	SectShll15.3	60117	MATL24_160	60048	0.001168	1.5
rrrail.r	61656	SectShll15.3	60117	MATL24_251	60055	0.005519	1.5
rrailrnf1.r	61657	SectShll10.1	60083	MATL24_160	60048	1.93E-04	1
rrailrnf2.r	61658	SectShll10.1	60083	MATL24_160	60048	2.10E-04	1
gusset.r	61659	SectShll15.3	60117	MATL24_160	60048	7.13E-04	1.5
gusset2.r	61660	SectShll15.3	60117	MATL24_160	60048	8.44E-04	1.5
gusset3.r	61661	SectShll15.3	60117	MATL24_160	60048	5.19E-04	1.5
gusset4.r	61662	SectShll15.3	60117	MATL24_160	60048	5.87E-04	1.5
whlhsinr.r	61663	SectShll10.1	60083	MATL24_160	60048	0.003046	1
4barrnf1.r	61664	SectShll20.1	60088	MATL24_160	60048	0.001459	2
4barrnf2.r	61665	SectShll25	60091	MATL24_160	60048	6.97E-04	2.5
rrsuspshk.r	61666	SectShll225	60099	MATL24_160	60048	3.05E-04	2.25
trnkgtr.r	61667	SectShll9.1	60082	MATL24_160	60048	4.00E-04	0.9
rdeckbrkt3.r	61668	SectShll10.1	60083	MATL24_160	60048	8.73E-04	1
rdeckbrkt4.r	61669	SectShll10.1	60083	MATL24_160	60048	7.63E-04	1
rrailext.r	61670	SectShll15.3	60117	MATL24_160	60048	7.48E-04	1.5
fbhpbulkhd.l	61671	SectShll20.1	60088	MATL24_340	60049	5.83E-04	2
rkrblkhds.1	61672	SectShll12.1	60084	MATL24_340	60049	2.83E-04	1.2

accl.r	61673	SectShll10.1	60083	rigid	60014	4.29E-05	1
accl.l	61674	SectShll10.1	60083	rigid	60014	4.56E-05	1
rr_hrn	61675	SectShll14.1	60085	MATL24_160	60048	9.12E-04	1.4
fbhp_brkt	61676	SectShll20.1	60088	MATL24_210	60052	1.84E-04	2
rkr_extn	61677	Sectshll75	60097	MATL24_600	60056	0.001526	0.75
muffler	61701	SectShll5.3	60105	MATL24_160	60048	0.00133	0.5
exhstpipe	61702	SectShll5.3	60105	MATL24_160	60048	0.00201	0.5
rtire.l	61801	SectShll10.1	60083	MATL24_160	60048	0.007576	1
rtire.r	61802	SectShll10.1	60083	MATL24_160	60048	0.007576	1
rearrim	61803	SectShll35	60106	MATL24_160	60048	0.015933	3.5
rbmpbmbrkt.l	61901	SectShll15.3	60117	MATL24_160	60048	4.35E-04	1.5
rbmpbmbrkt.r	61902	SectShll15.3	60117	MATL24_160	60048	4.35E-04	1.5
rbumpbeam	61903	SectShll10.1	60083	MATL24_160	60048	0.003708	1
part.42	62001	SectDisc779	60123	MATSpr1_779	60063	0	0
part.43	62002	SectDisc780	60124	MATDmp2_780	60064	0	0
part.44	62003	SectDisc781	60125	MATSpr4_781	60069	0	0
part.47	62004	SectDisc783	60126	MATDmp2_784	60065	0	0
part.12	62005	SectBeam707	60009	MAT24_707	60043	7.70E-04	0
bar1fsusp	62006	Sectbeam10500	60002	MATBEAM	60057	0.001903	0
bar2fsusp	62007	Sectbeam10501	60003	MATBEAM	60057	4.12E-05	0
bar3fsusp	62008	Sectbeam10500	60002	MATBEAM	60057	1.41E-04	0
BARDLINE	62009	Sectbeam10504	60004	MATBEAM	60057	7.06E-05	0
bar4fsusp	62010	Sectbeam10500	60002	MATBEAM	60057	9.48E-04	0
bar2dline	62011	Sectbeam10500	60002	MATBEAM	60057	0.001306	0
bar3dline	62012	Sectbeam10504	60004	MATBEAM	60057	1.16E-04	0
bar5dline	62013	Sectbeam10509	60005	MATBEAM	60057	8.50E-05	0
bar1rrsus	62014	Sectbeam10500	60002	MATBEAM	60057	0.007365	0
bar2rrsusp	62015	Sectbeam10516	60006	MATBEAM	60057	0.019679	0
bar3rrsusp	62016	Sectbeam10516	60006	MATBEAM	60057	0.0026	0
bar4rrsusp	62017	Sectbeam10516	60006	MATBEAM	60057	0.002841	0
bardummies	62018	Sectbeam10519	60007	MATBEAM	60057	0.003373	0
barseat	62019	Sectbeam10519	60007	MATBEAM	60057	3.34E-04	0
barradiator	62020	Sectbeam10522	60008	MATBEAM	60057	1.82E-04	0
bardriveline	62021	Sectbeam10504	60004	MATBEAM	60057	2.57E-04	0
bardriveline8	62022	Sectbeam10504	60004	MATBEAM	60057	7.05E-05	0
sprdrvline	62023	SectDisc1	60122	Matsprstr14	60066	0	0
sprengmnt3	62024	SectDisc1	60122	Matsprstr113	60067	0	0
sprdummy	62025	SectDisc1	60122	Matsprstr114	60068	0	0
spr2dummy	62026	SectDisc1	60122	Matsprstr116	60062	0	0
spr3dummy	62027	SectDisc1	60122	Matsprstr116	60062	0	0
ltmount_spring	62028	SectDisc20071.1	60127	MATSpr4_61112	60070	0	0
rt_mount_spring	62029	SectDisc20071.1	60127	MATSpr4_61113	60071	0	0
rr_cdl_atch_spri	62030	SectDisc20071.1	60127	MATSpr4_61116	60073	0	0
rr_cdl_atch_spri	62031	SectDisc20071.1	60127	MATSpr4_61115	60072	0	0
hinge_beam_65dia	62032	90060004	60001	90060006	60005	1.06E-04	0
pt6	60701	SectShll10.1	60083	rigid	60014	0.304199	1
Masses	62033	N/A	N/A	N/A	0	0.002085	N/A
ElemMass	62034	N/A	N/A	N/A	0	0.633762	N/A
ncap_driver_pass	62035	N/A	N/A	N/A	0	0.156	N/A

out_front_lh_doo	62047	N/A	N/A	N/A	0	1.42E-04	N/A
out_ip_masses_2	62050	N/A	N/A	N/A	0	0.001933	N/A
out_hood_masses_	62054	N/A	N/A	N/A	0	9.59E-05	N/A
out_roof_masses_	62056	N/A	N/A	N/A	0	8.76E-05	N/A
out_windshield_m	62058	N/A	N/A	N/A	0	1.92E-06	N/A
out_rear_lh_door	62060	N/A	N/A	N/A	0	1.96E-04	N/A
out_front_rh_doo	62064	N/A	N/A	N/A	0	1.53E-04	N/A
out_rear_rh_door	62066	N/A	N/A	N/A	0	1.90E-04	N/A
SpotWelds	62039	N/A	N/A	N/A	0	0	N/A
2T_Welds	62043	N/A	N/A	N/A	0	0	N/A
Rigids.5	62040	N/A	N/A	N/A	0	0	N/A
Joints	62068	N/A	N/A	N/A	0	0	N/A

Total Components	**495**
Model Mass	**1.778 tonnes**

- Model mass is from LS-DYNA3D d3hsp file.
- Part mass summary is from HYPERMESH.

Concept 1 Subsystem Design

Milestone 8

Lightweight Front End Structure Phase II

August 11, 2003



Auto/Steel Partnership

Abstract

This report documents the subsystem model for the *Concept 1* design that can simulate the NCAP performance of the full vehicle finite element model, in the first 40ms. The subsystem model is based on the *Preliminary Subsystem* model developed for the *Phase I Upgraded Powertrain* design . The subsystem will be employed to assess various rail and bumper concepts developed in Phase II of the Lightweight Front End Structure Project.

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1. Objectives

The goal of this study was to design a subsystem model for the *Concept 1* design that can simulate the NCAP performance of the full vehicle finite element model, in the first 40ms. The subsystem model is based on the *Preliminary Subsystem* model developed for the *Phase I Upgraded Powertrain* design. The subsystem predicts accurately the full vehicle response in the first 40 ms of the NCAP load case, and achieves a 24% reduction in the simulation time. The subsystem achieves the same crush pattern for rail and bumper, as in the full vehicle. The subsystem will be employed to assess various rail and bumper concepts developed in Phase II of the Lightweight Front End Structure Project.

2. Results Summary

It was concluded from the study that the following subsystem design (*Figure 1*) would predict accurately the full vehicle response in the first 40 ms of the NCAP load case (*Figure 3* through Figure 6, *Table 2* and *Table 3*), and also reduce the simulation time by 24%.

- **All parts forward of A-pillar**
  - Bumper
  - Rail Assembly
  - Shotgun & Fender
  - First Cross Member
  - Cradle Assembly
  - Engine, Battery and Radiator

- **A-pillar**
  - Rocker portion, to simulate tire hit
  - Upper A-pillar, for connecting shotgun, dash panel and IP cross member

- **Dash area**
  - Dash panel
  - IP cross member
  - Floor, up to B-pillar
  - Floor cross members

A rigid body with equivalent inertia properties represents the parts not included in the subsystem. Data collection points in the subsystem are identical to those in the full vehicle model.

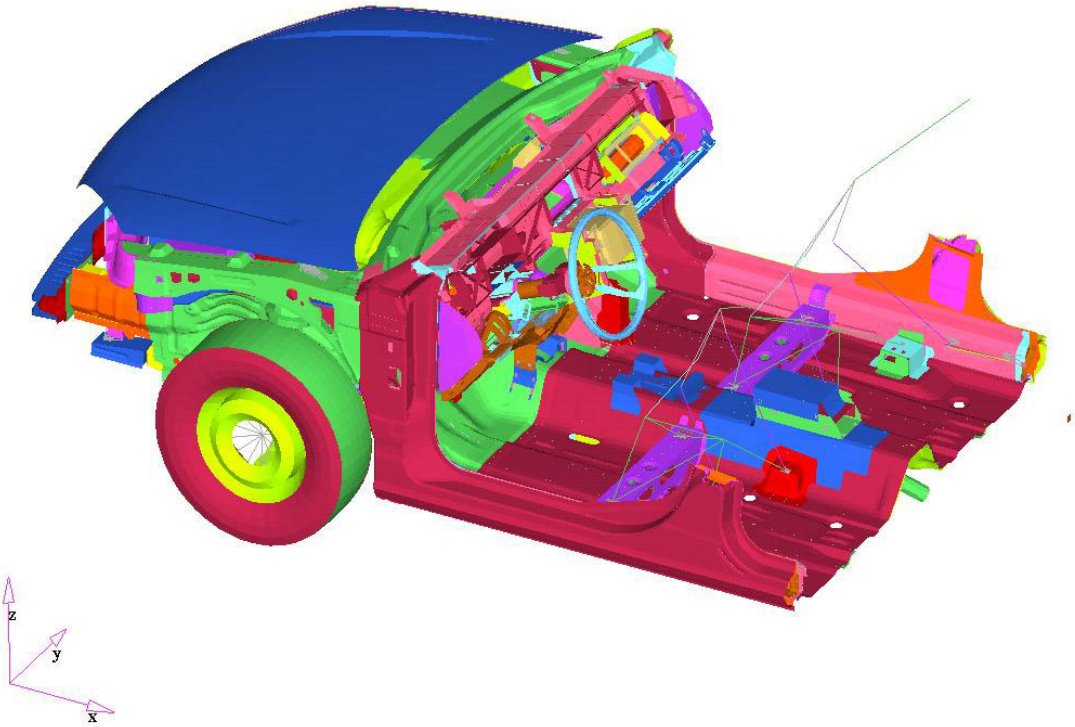


Figure 1: Subsystem of Concept 1 Design

3. Subsystem Development

The Preliminary Susbsystem Design (*Milestone 1*) served as the basis for developing the subsystem design for Concept 1 (*Milestone 10*). It corresponds to the **Level 2a** design that was determined as the **optimum subsystem**. It predicted accurately the full vehicle response in the first 40 ms of the NCAP load case.

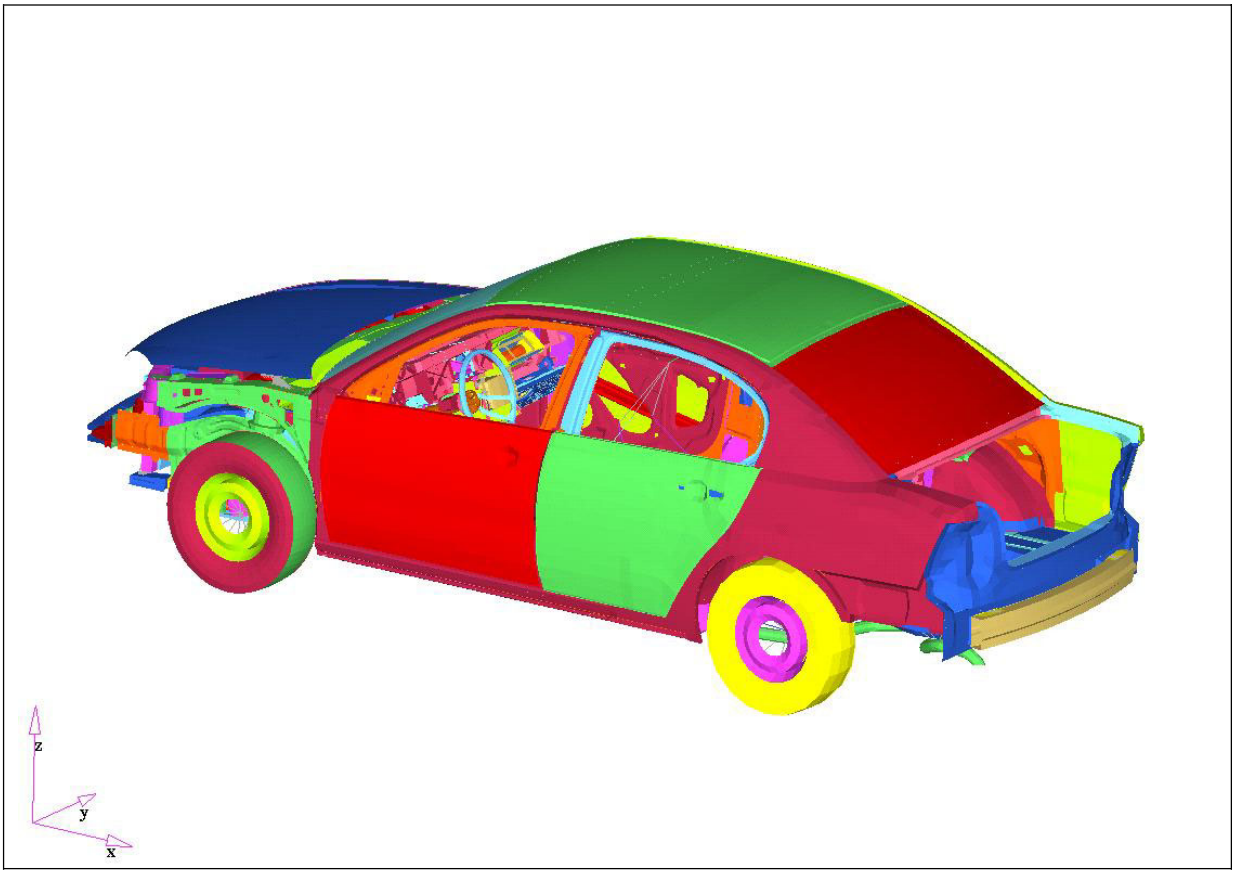


Figure 2: Full Vehicle Model of Concept 1 Design

Table 1: Model Summary

Level	Description	Model size	Relative Run Time
Baseline	Full Vehicle Model	Elements : 220092 Nodes : 211241	1.00
Subsystem	With Dash panel - Parts rearwards of A-pillar are removed.	Elements : 279461 Nodes : 270007	**0.76**

The subsystem captures the load path into the rocker, floor and hinge pillar quite accurately. The effects of engine and tire hit are simulated well, along with the distribution of load into the floor through the rail extension. The deformation of the bumper and rails are predicted very well by the subsystem.

There is an excellent correlation of vehicle crush between the full vehicle and subsystem models (*Table 3*). The B-pillar pulse prediction is quite accurate as well (*Table 2*, *Figure 3, Figure 4*).

The first peak is the most accurately predicted peak. There is a slight delay and under-prediction of the level of the first peak. The first peak represents the initial deformation of the bumper system.

The second peak is predicted slightly lower for the subsystem model.

The third peak level is predicted fairly accurately.

The maximum acceleration peak is also predicted reasonably well, both in magnitude and time. Thus, the subsystem yields reasonable predictions of the vehicle response after 40 ms.

The reduction in time is less for Concept 1 design (*Milestone 10*), as compared to the Upgraded Powertrain design (*Milestone 14*), as the mesh for parts rearwards of A-pillar is much coarser for the Concept 1 full vehicle model.

Table 2: Comparison of B-Pillar Peak Accelerations: Full Vehicle vs. Subsystem Level 2a

Design	Location	Model	B -Pillar Pulse (g)		
			First Peak	Second Peak	Third Peak
Concept 1	LH *(Figure 3)*	Full vehicle	10.92 g @ 3.3 ms	13.3 g @ 22.7 ms	20.08 g @ 20.29 ms
		Subsystem	9.9 g @ 4.6 ms	18.63 g @ 14.2 ms	20.64 g @ 19.6 ms
	RH *(Figure 4)*	Full vehicle	11.4g @ 3.8 ms	25.4 g @ 13.49 ms	17.98 g @ 20.3 ms
		Subsystem	*9.6 g @ 4.8 ms*	*20.36 @ 14.5 ms*	*21.6 g @ 18.8 ms*

Table 3: Comparison of Vehicle Crush: Full Vehicle vs. Subsystem Level 2a

Design	Model	Vehicle Crush (mm)
Concept 1	Full vehicle	636
	Subsystem	622

Note: Vehicle Crush measured at LH Acc Node at Rocker

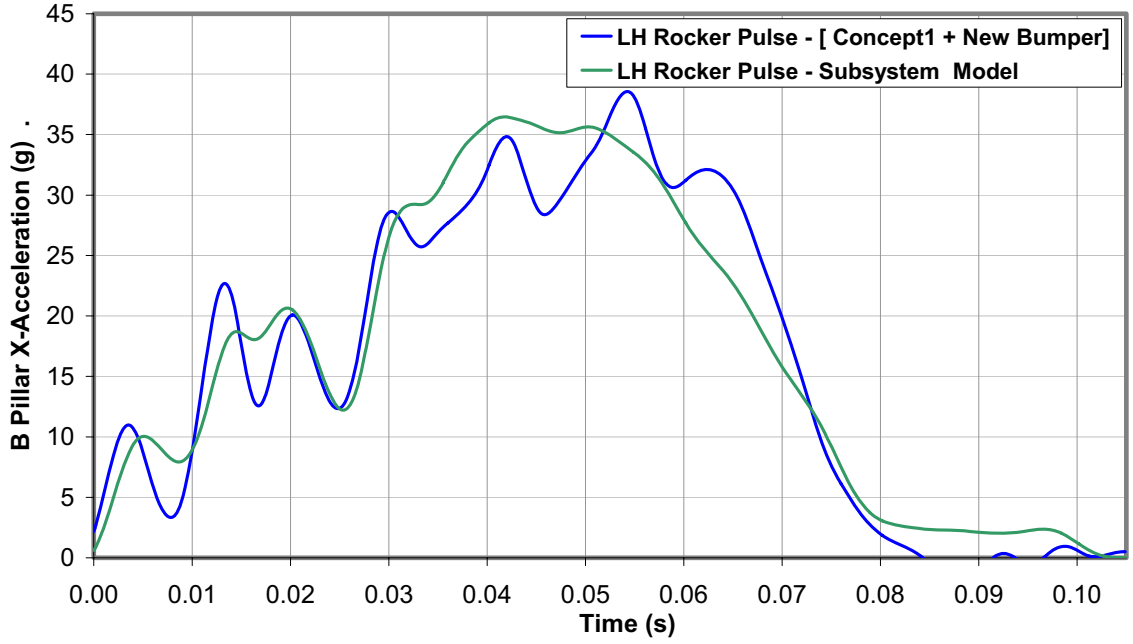


Figure 3: LH B-Pillar Pulse of Full Vehicle Model (Concept 1+ New bumper) and Subsystem

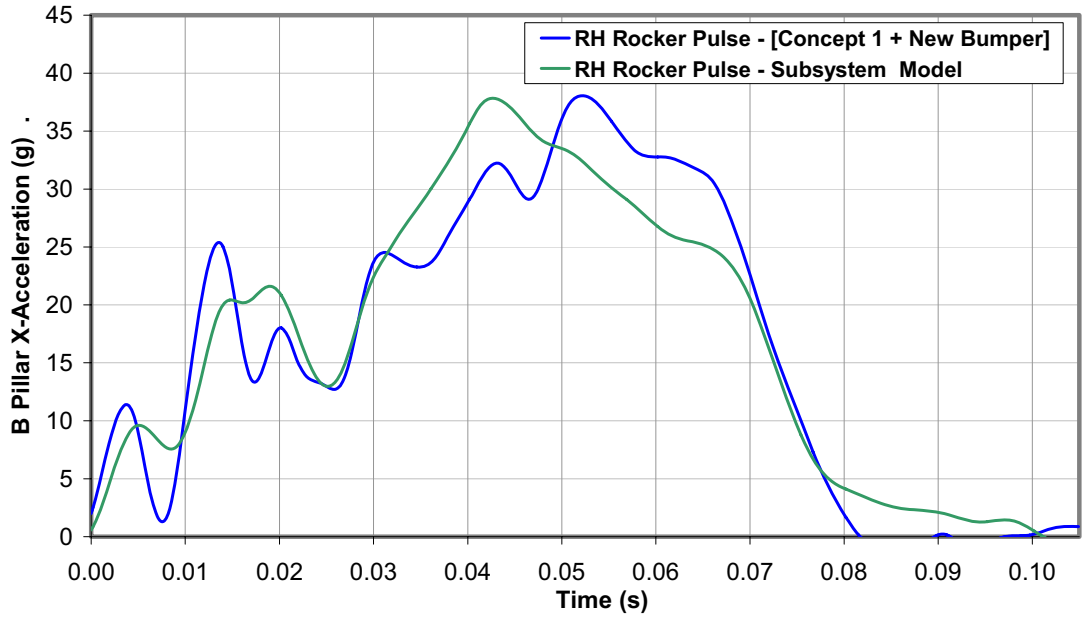


Figure 4: RH B-Pillar Pulse of Full Vehicle Model (Concept 1+ New bumper) and Subsystem

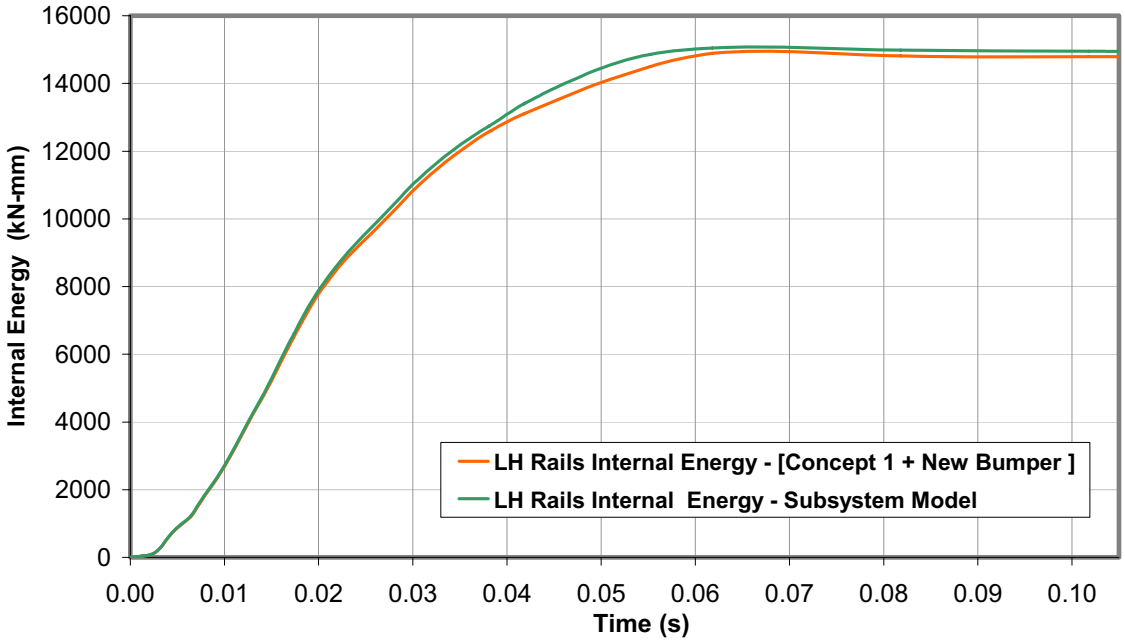


Figure 5: Internal Energy of LH Rails: Full Vehicle (Concept1+New Bumper) and Subsystem

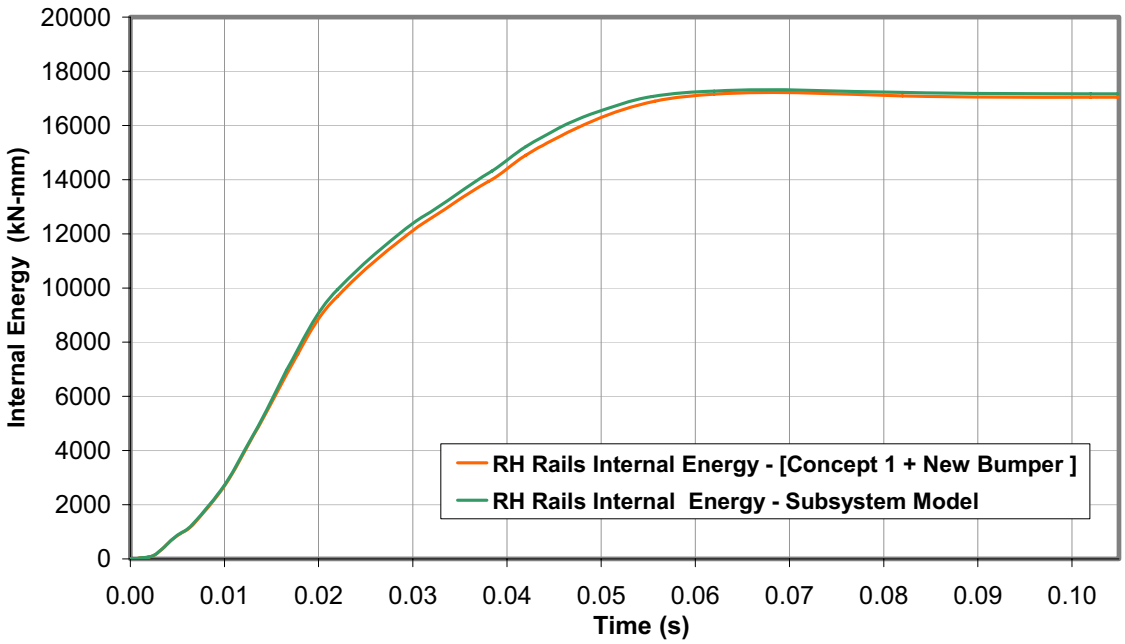


Figure 6: Internal Energy of RH Rails: Full Vehicle (Concept1 + New Bumper) and Subsystem

4. Conclusions

The subsystem model for *Concept 1* design (*Figure 1*) accurately predicts the full vehicle response in the first 40 ms of the NCAP load case, and also reduces the simulation time by 24%. The subsystem model can be used to assess bumper and rail designs in a shorter duration, especially for DOE studies.

5. Future Work

The subsystem design developed in this study will be employed to assess various rail and bumper concepts developed in Phase II of the Lightweight Front End Structure Project.

6. References

1) *ULSAB Model with Upgraded Powertrain, Milestone 14*, SPHINX, Phase I.

2) *Upgraded Powertrain: D.O.E. Parametric Study, Milestone 15*, SPHINX, Phase I.

3) *Library of Designs for KB: Upgraded Powertrain, Milestone 24*, SPHINX, Phase I.

4) *Preliminary Subsystem Design, Milestone 1*, SPHINX, Phase II.

5) *Concept 1: Preliminary Design, Milestone 10*, SPHINX, Phase II.

7. Appendix A: Animations

The following animation files for the subsystem development can be viewed at the Auto/Steel Partnership website, www.a-sp.org.

You will need a Hyperview Player in order to view these animations at the site. You can download this free software at www.altair.com.

1. Concept 1 Design: NCAP Full Vehicle
2. Concept 1 Design: NCAP Subsystem
3. Concept 1 Design: NCAP Full Vehicle Rails
4. Concept 1 Design: NCAP Subsystem Rails

Concept 1: Preliminary Design

Milestone 10

Revision 1

Lightweight Front End Structure Phase II

August 26, 2003

A/S P

Auto/Steel Partnership

Abstract

This report documents the preliminary design for Concept 1. The revised report includes dynamic IIHS intrusion plots. A final design for Concept 1 will be obtained, based on a DOE study. The final Concept 1 design will be compared to Concepts 2 and 3 that will be later developed in Phase II of the Lightweight Front End Structure Project.

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1. Objectives

The effort of this study was aimed at developing a preliminary design for Concept 1. Concept 1 has essentially the same rails as the existing donor vehicle rail design, except for modifications to holes and flanges. A new bumper design was also included in Concept 1. A final design for Concept 1 will be obtained, based on a DOE study. The final Concept 1 design will be compared to Concepts 2 and 3 that will be later developed in Phase II of the Lightweight Front End Structure Project.

2. Results Summary

The following modifications were made to the donor vehicle DOE FE models (*Milestone 7*).

- Two holes and a notch in the front rails were filled and the reinforcements in the areas were removed.
- Rail flange width was reduced by 5mm.
- The rails were made 2-piece tailor-welded.
- The existing donor vehicle bumper was replaced by a new bumper design.

The above modifications did not result in any significant change in vehicle response. There was a net mass reduction of 0.81kg.

The NCAP and IIHS results are summarized in *Table 1* and *Table 2*.

A positive value of steering column upward movement means that the steering column moves upwards and towards the occupant, and a positive value of steering column rearward movement means that the steering column moves rearwards and towards the occupant.

Table 1: NCAP Results

B Pillar Pulse	DOE Model	Concept 1 with New Bumper
LH	36.7 g @ 58.7 ms	38.6 @ 54.1 ms
RH	35.3 g @ 58.6 ms	38.1 @ 52.2 ms

Table 2: IIHS Results

Location	Intrusions @ 250ms (cm)	
	DOE Model	Concept 1 with New Bumper
Brake Pedal	11.2	12.1
Left Toepan	14.5	14.7
Center Toepan	14.4	15.1
Right Toepan	15.8	15.8
A-B Pillar Closure	11.8	12.8
Steering Column Upward Movement*	-1.8	-6.7
Steering Column Rearward Movement*	0.0	1.0

* Steering column movement does not stabilize at 250ms (*Figure 15*).

3. Model Modifications

The following holes and notches were modified (*Figure 1, Figure 2*).

Hole 1: A 120mm diameter hole on LH inner rail was filled and the corresponding reinforcement was removed. This hole is required only for European vehicles.

Hole 2: A 40mm x 40mm hole on LH/RH inner rails was reduced to 25mm x 40mm. This hole is required for tooling and its position can be changed, provided proper tool access is provided. However, the position was not changed in Concept 1.

Notch: A notch on the LH inner rails was filled up.

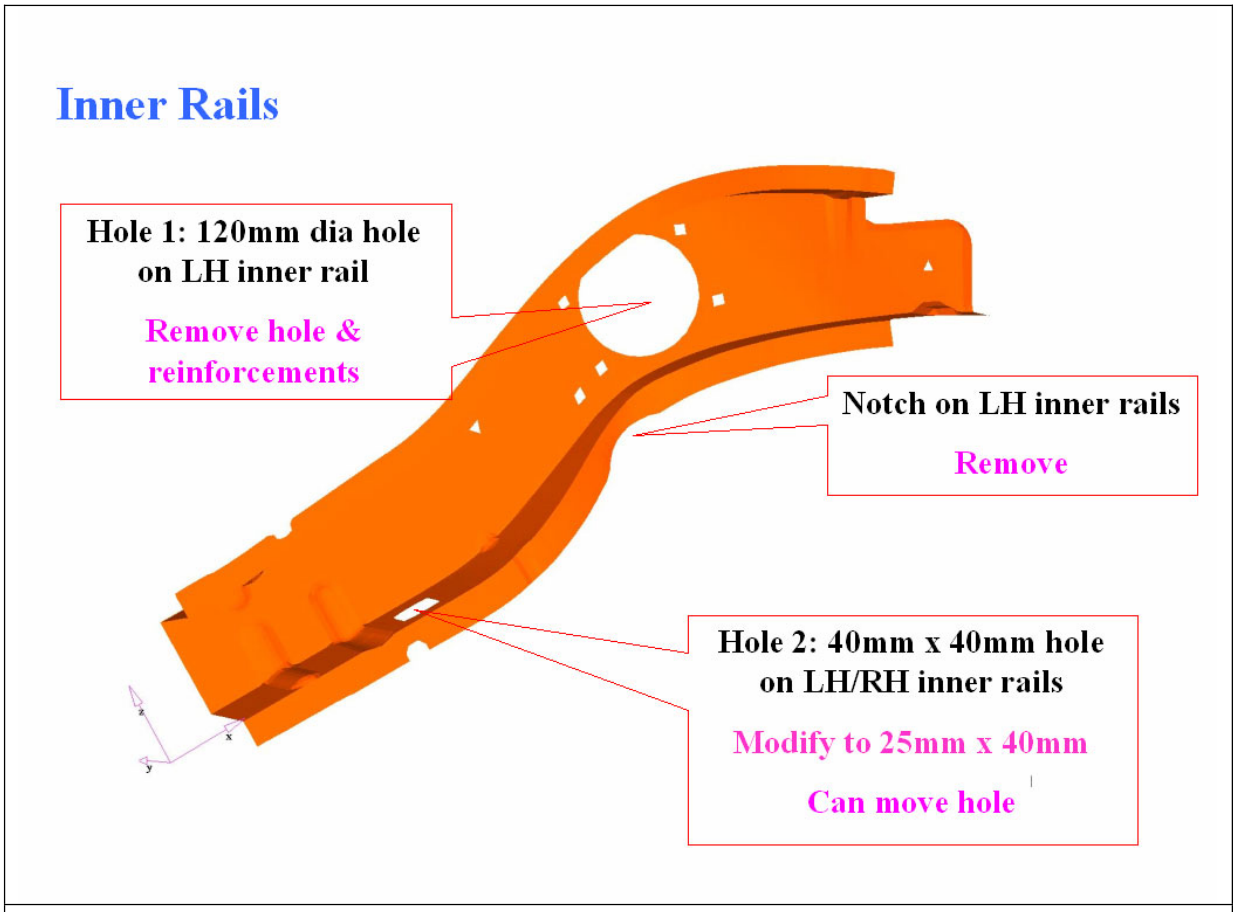


Figure 1: Holes and Notches on Inner Rails

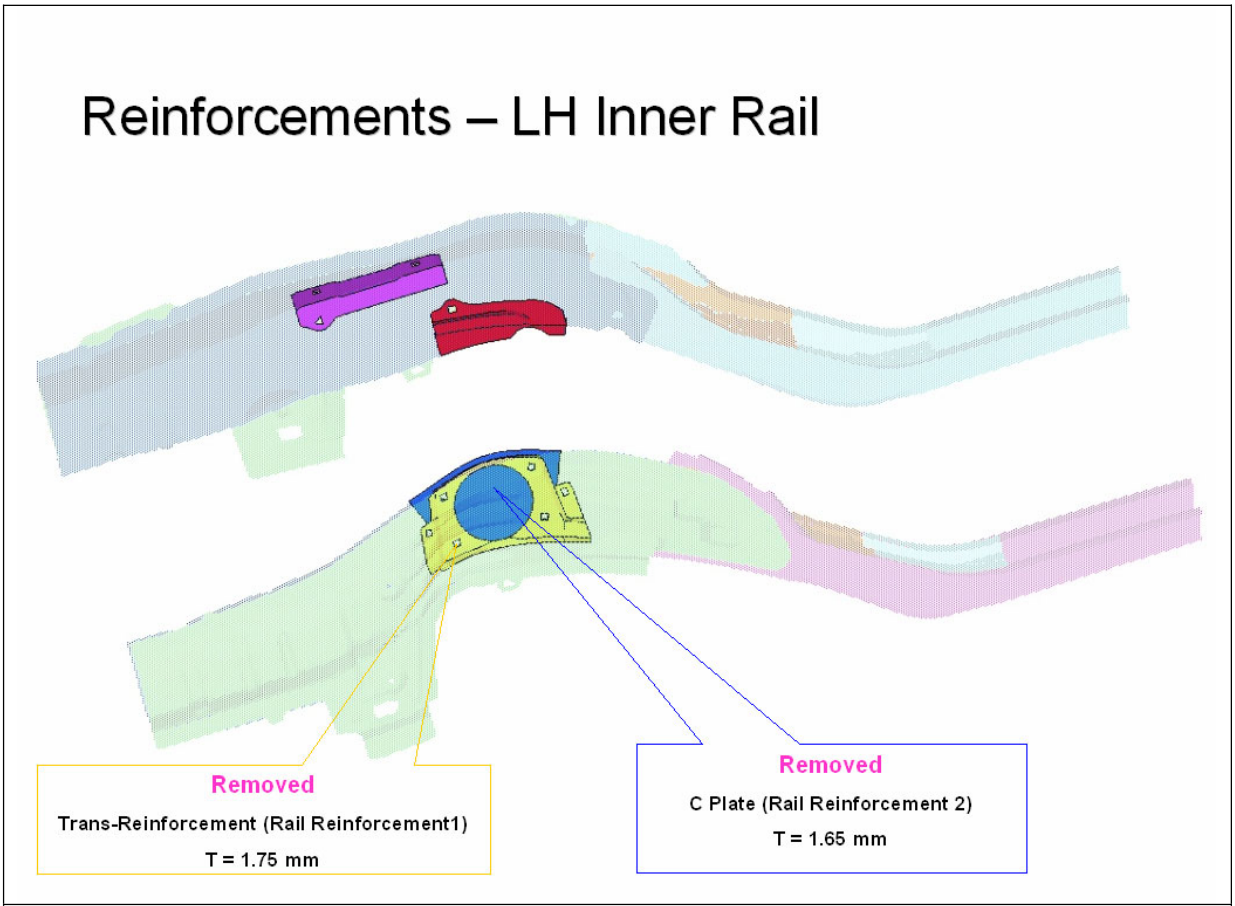


Figure 2: Reinforcements Removed

The flange width was reduced by 5mm (*Figure 3*). The flange width was reduced only for the front inner and outer rail pieces, and not for the rail extension parts. This was done primarily due to time restrictions. The purpose of the Concept 1 study is to merely to evaluate the performance of the existing rails. *The Concept1rails would not be a candidate for prototyping*. The total flange width is now 21 mm, which includes a 5mm radius and 16mm flat. This would make the flange width same as the ULSAB rails. The donor vehicle model has a flat of 21mm, resulting in a total flange width of 26mm.

Tailor-blanking was introduced in the rails. The rail is now considered to be 2-piece tailor-welded, with the weld line along A-A (*Figure 3*). The grades and gauges of the rail assembly will be varied in the DOE study.

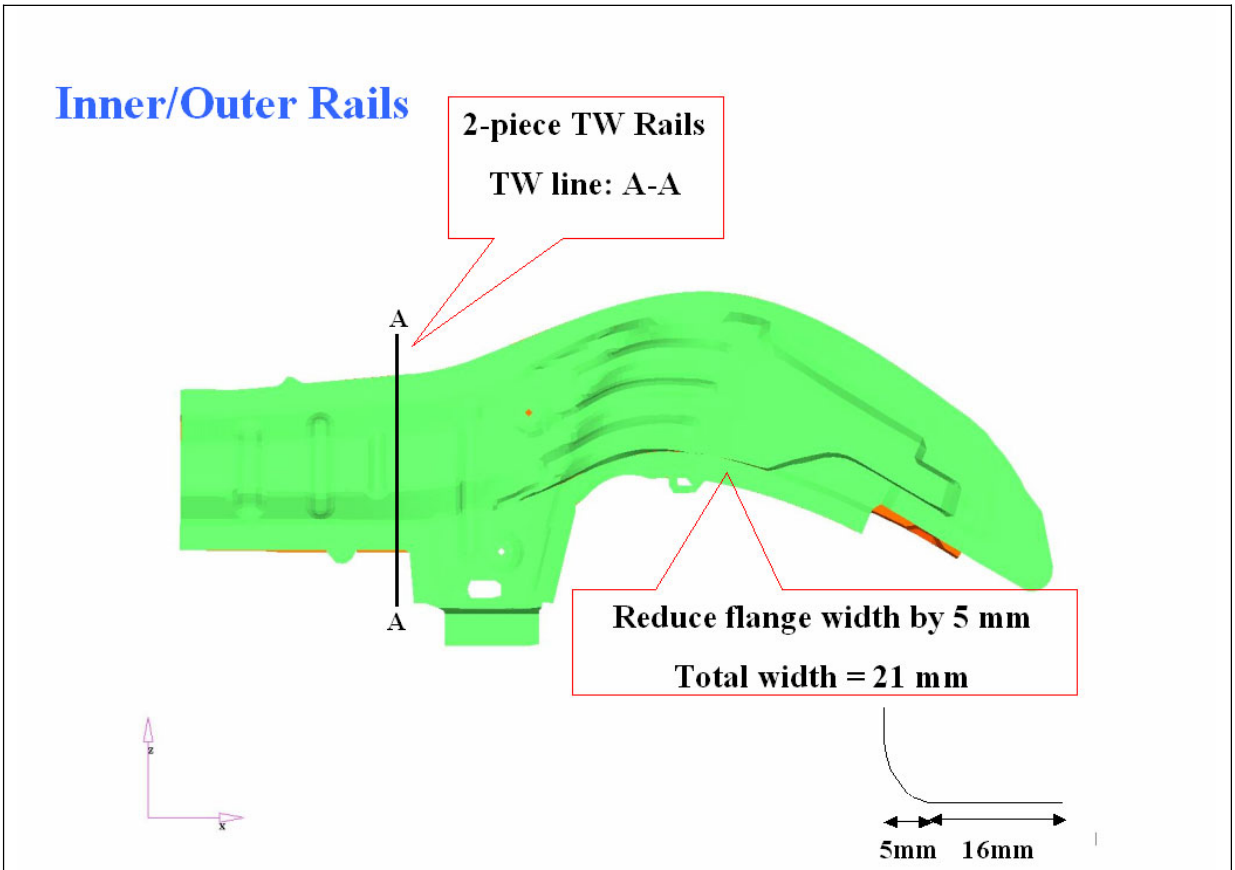


Figure 3: Rail Flanges and Tailor-Welding

The existing bumper was replaced by a new bumper design (*Figure 4, Figure 5*). The new bumper design is functionally quite similar to the Phase I Bumper 3 design. However, it has fewer manufacturing and welding concerns than the Bumper 3 design. The new bumper design is a 2-piece double-box stamped design using DP980 steel. The bumper has vertical flanges and beads on the front plate. The new bumper design has good energy absorption capability in high-speed impacts and results in a high initial peak in the NCAP B-pillar pulse. In addition, the bumper is more formable than the Phase I Bumper 3 design, and is easier to weld. *A design similar to the new bumper design has been prototyped using DF140T steel.*

A mass summary for rail and bumper parts is included in *Table 3*. The grades and gauges of parts are identical for DOE Model and Concept 1. The only difference is the bumper material. The DOE Model bumper has a material with yield 848 MPa and tensile strength 871 MPa. The Concept 1 bumper uses DP700/980 steel. A detailed part summary is included in *Appendix B: Summary of FE Model.*

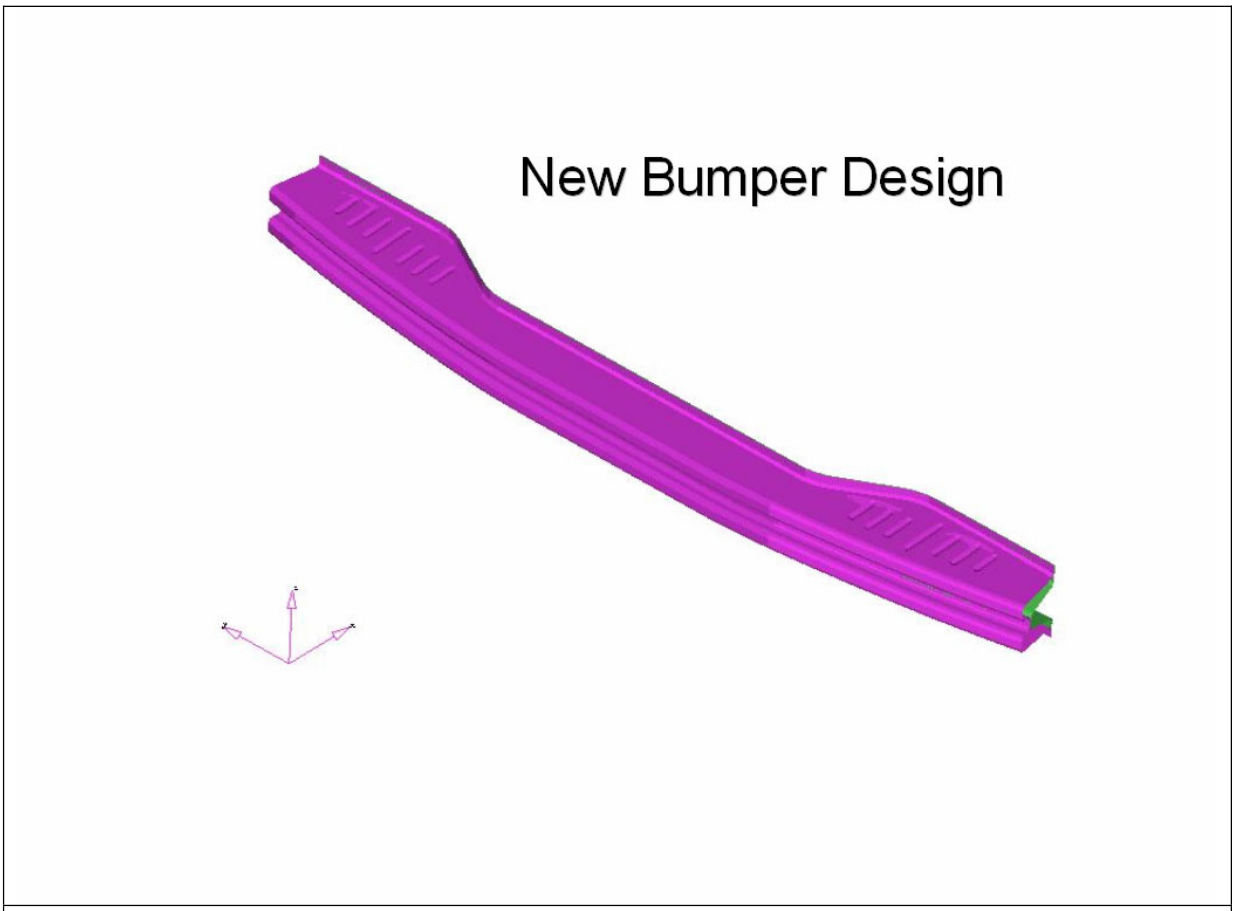


Figure 4: New Bumper Design

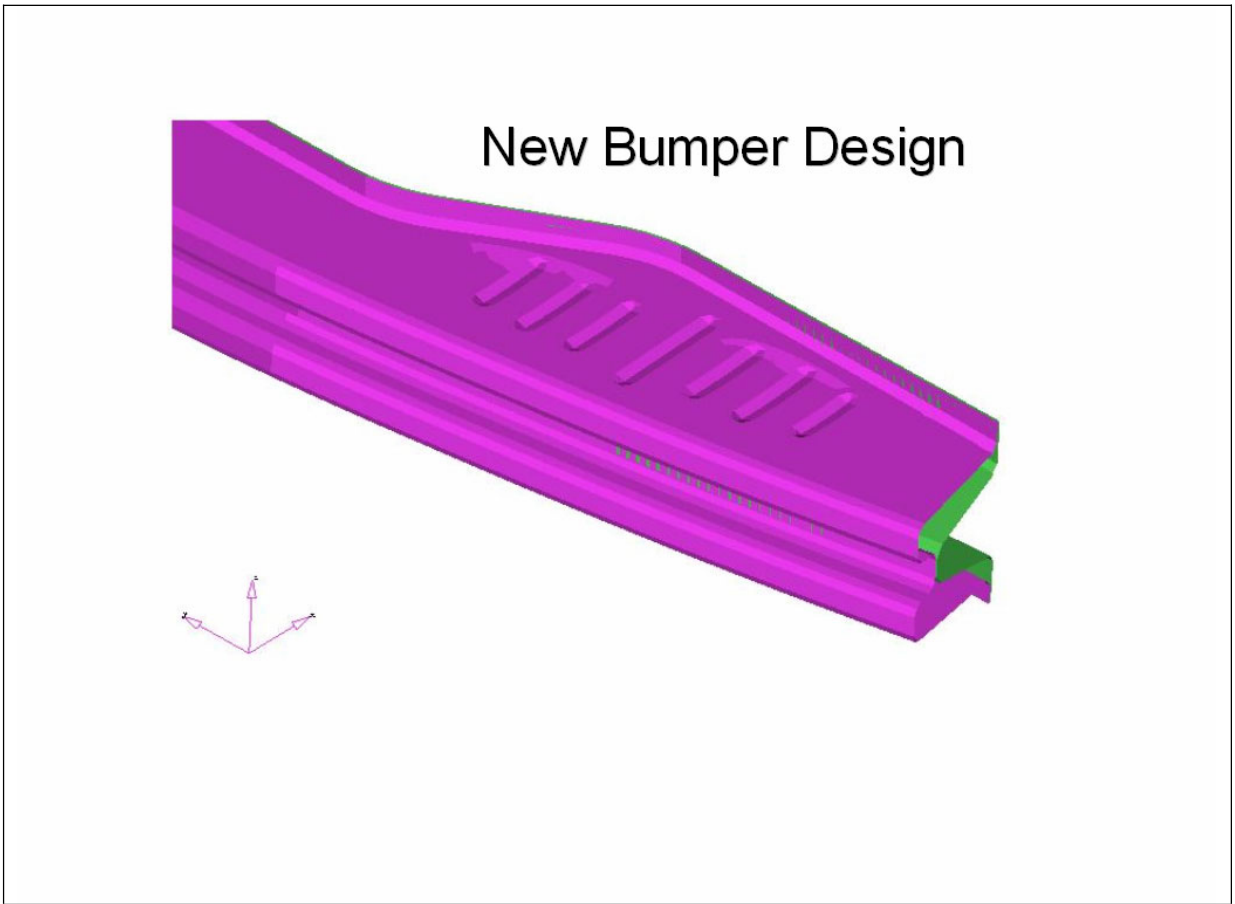


Figure 5: New Bumper Design – Close-up

Table 3: Mass Summary

Part	Mass (kg)	
	DOE Model	Concept 1 with New Bumper
LH Rail Inner	3.79	3.85
LH Rail Outer	2.78	2.66
LH C Plate	0.35	0.00
LH Trans Reinf	0.29	0.00
RH Rail Inner	3.65	3.55
RH Rail Outer	2.65	2.57
Bumper (without foam)	6.56	6.64
Total	20.08	19.27

4. FE Model - Output Location Summary

The nodes at which the desired NCAP and IIHS outputs were obtained are listed in *Table 4*.

The intrusions are measured at the nodes as specified in *Reference 3*.

The acceleration and intrusion node locations are shown in *Figure 6* and *Figure 7* below.

Table 4: Summary of Output Locations

Parameter	Location	Node Number
Accelerations	B-Pillar / Rocker - LH	5000001
	B-Pillar / Rocker - RH	5000002
Intrusions	Origin	6000000
	Plane Y-axis	6000001
	Plane Z-axis	6000002
	Steering Column	7000001
	Brake Pedal	7000002
	Toepan - Left	7000003
	Toepan - Center	7000004
	Toepan - Right	7000005
	Left Front Seat Bolt	7000006
	Right Front Seat Bolt	7000007
	Left Rear Seat Bolt	7000008
	Right Rear Seat Bolt	7000009
	AB Closure - A Pillar	7000010
	AB Closure - B Pillar	7000011

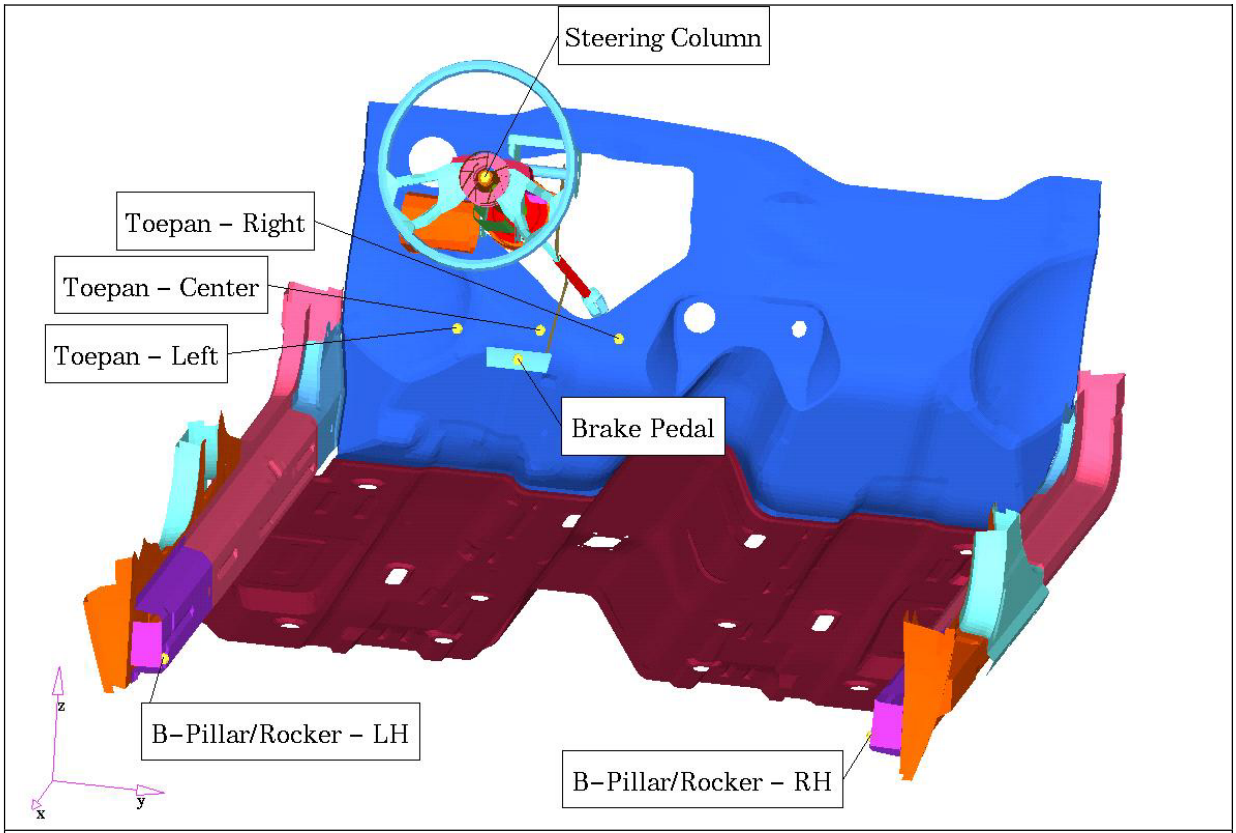


Figure 6: Output Locations for NCAP/IIHS



Figure 7: Output Locations for IIHS- AB Closure

5. NCAP Response

The figures below summarize the NCAP response of Concept 1.

Animation files are included in *Appendix A*.

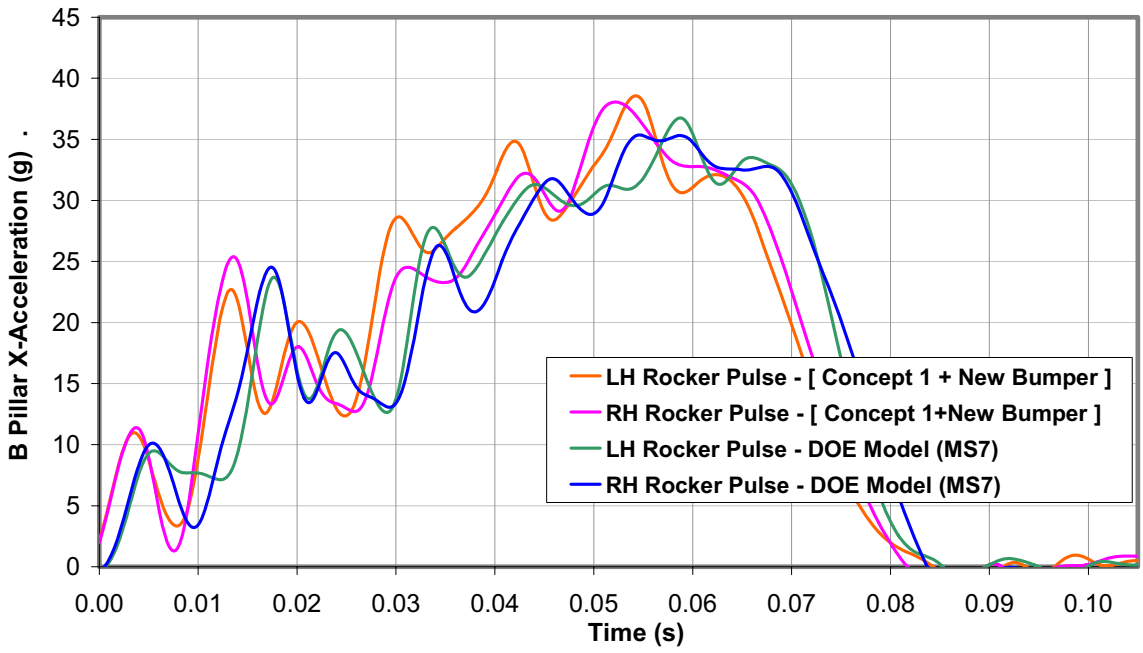


Figure 8: Comparison of B Pillar Pulse – Concept 1 with New Bumper Vs DOE Model

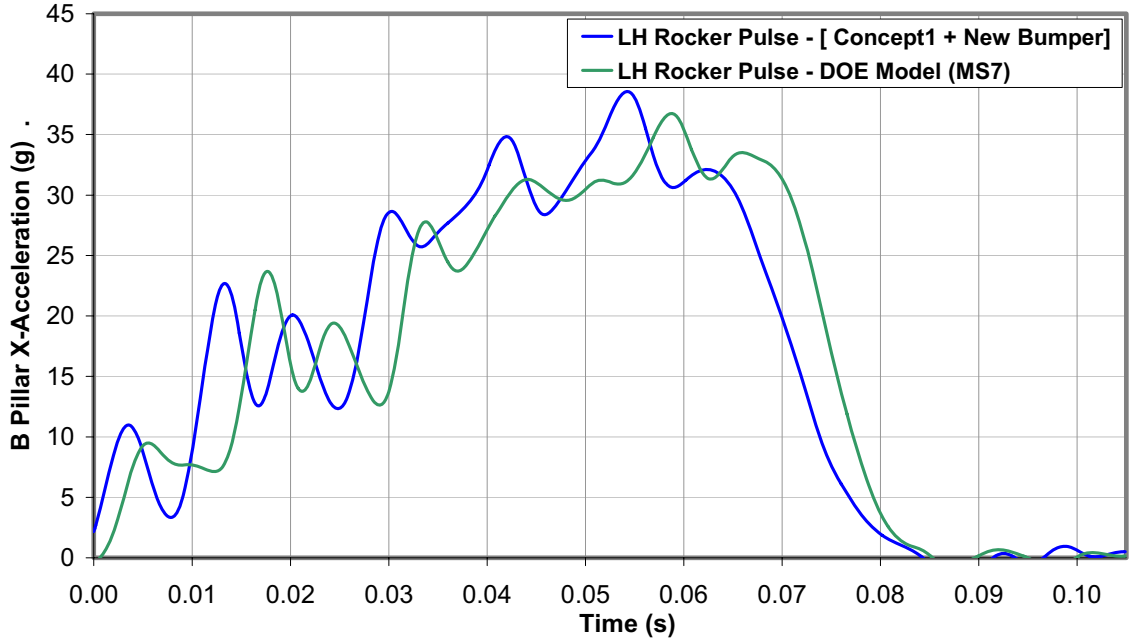


Figure 9: B Pillar Pulse – LH

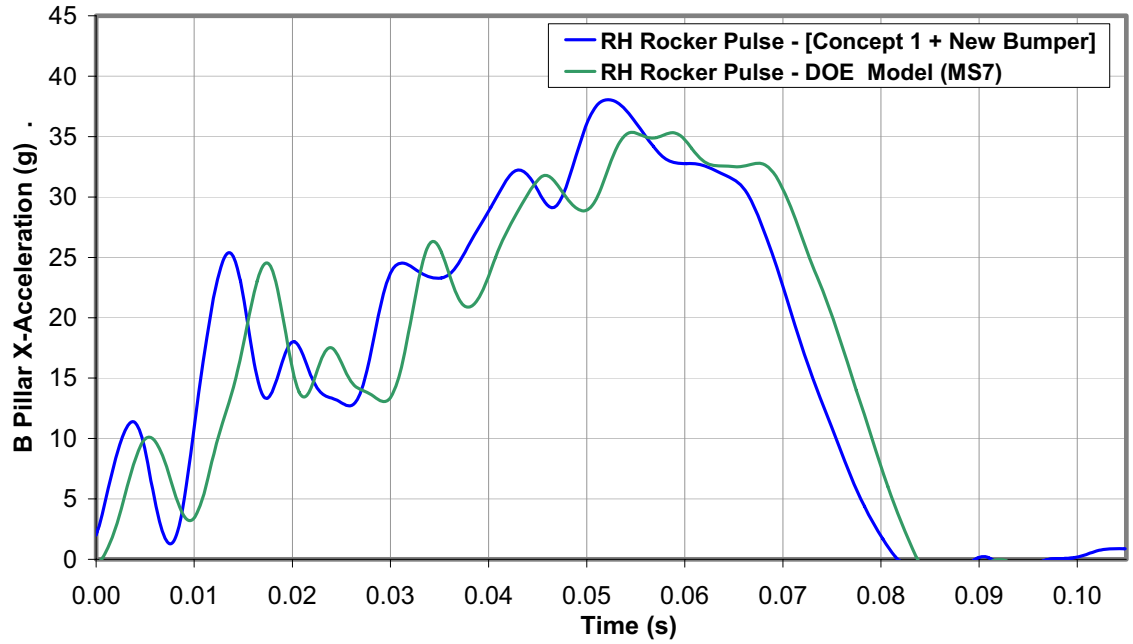


Figure 10: B Pillar Pulse – RH

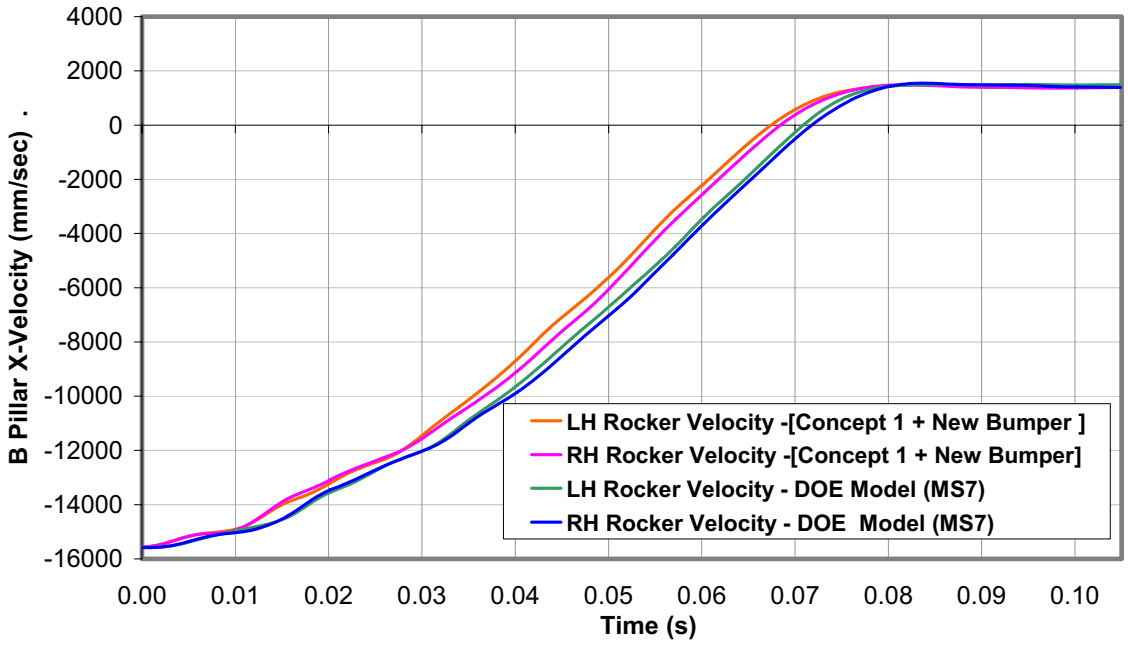


Figure 11: Comparison of B Pillar Velocity – Concept 1 with New Bumper Vs DOE Model

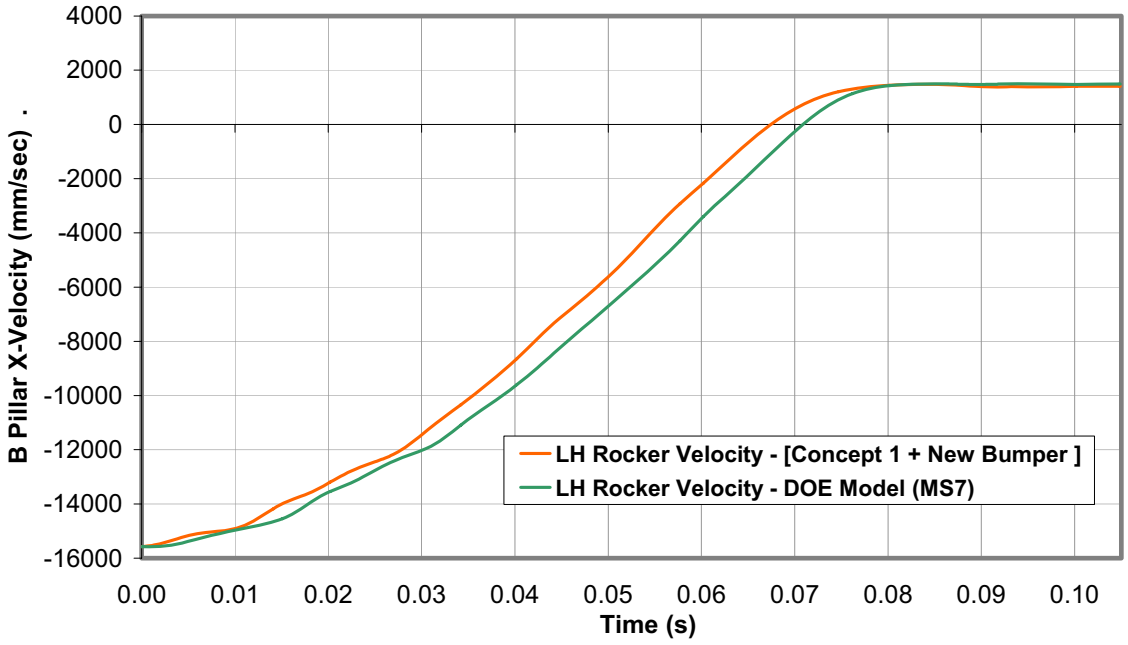


Figure 12: B Pillar Velocity - LH

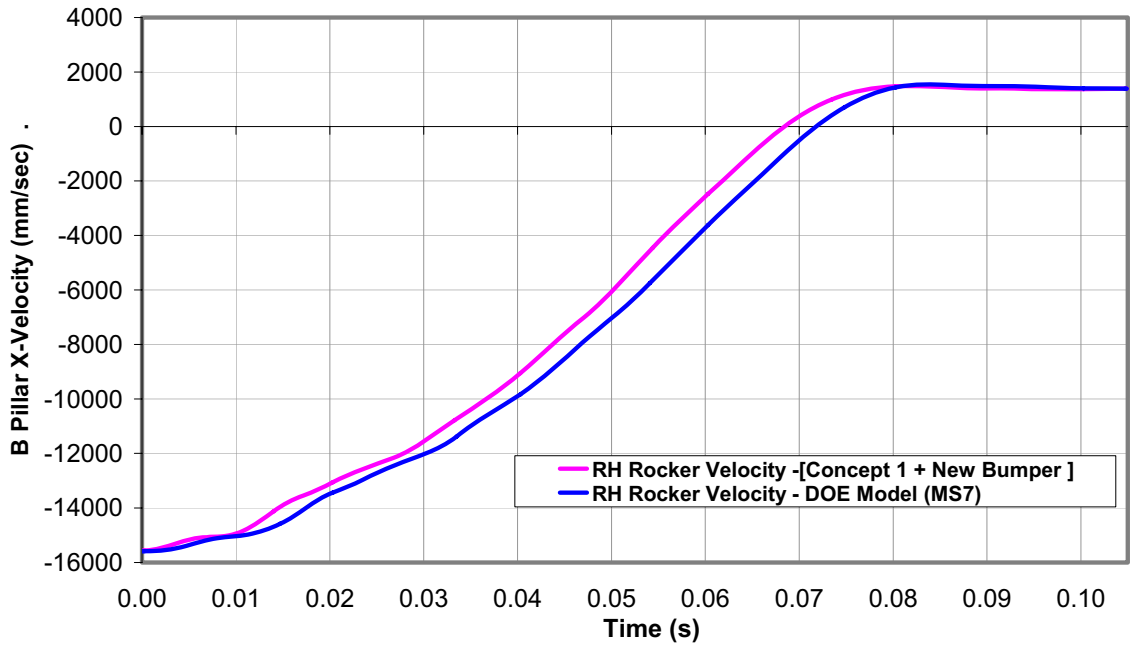


Figure 13: B-Pillar Velocity - RH

Table 5: NCAP Crash Events

Time (ms)	Crash Events
0-15	Bumper absorbs energy
15-20	Engine hits the radiator, Cradle Extension Buckles, Cradle engaged
20-30	Cradle and LH rail buckling started
35-40	LH front wheel hits the LH rail
40-45	Engine hits to dash
45-50	RH front wheel hits the RH rail
55-60	LH wheel hits the front rigid wall
60-70	RH wheel hits the front rigid wall, LH wheel hits the rocker
70-75	RH wheel hits the rocker

6. IIHS Response

IIHS intrusions are summarized in *Table 2*.

Animation files are included in *Appendix A*.

Toepan, brake pedal and A-B closure intrusions oscillate after 200ms about a mean value. Hence, the mean values should be used for comparison. However, the values reported in *Table 2* are at 250ms.

Steering column movement does not reach any equilibrium. The IIHS simulation would have to be carried out for a longer duration in order to report stable meaningful values. The steering column model may also be deficient, resulting in an unstable movement.

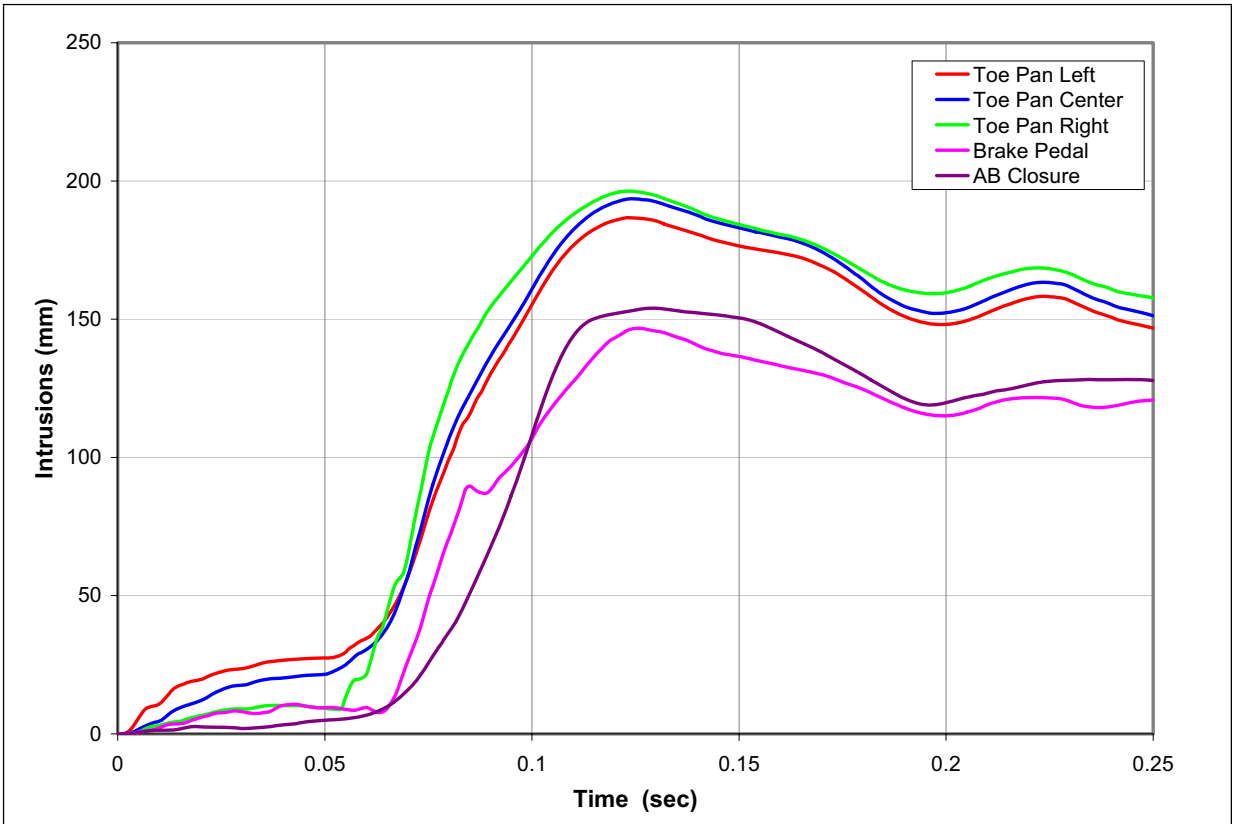


Figure 14: Toepan, Brake Pedal and A-B Closure Intrusions

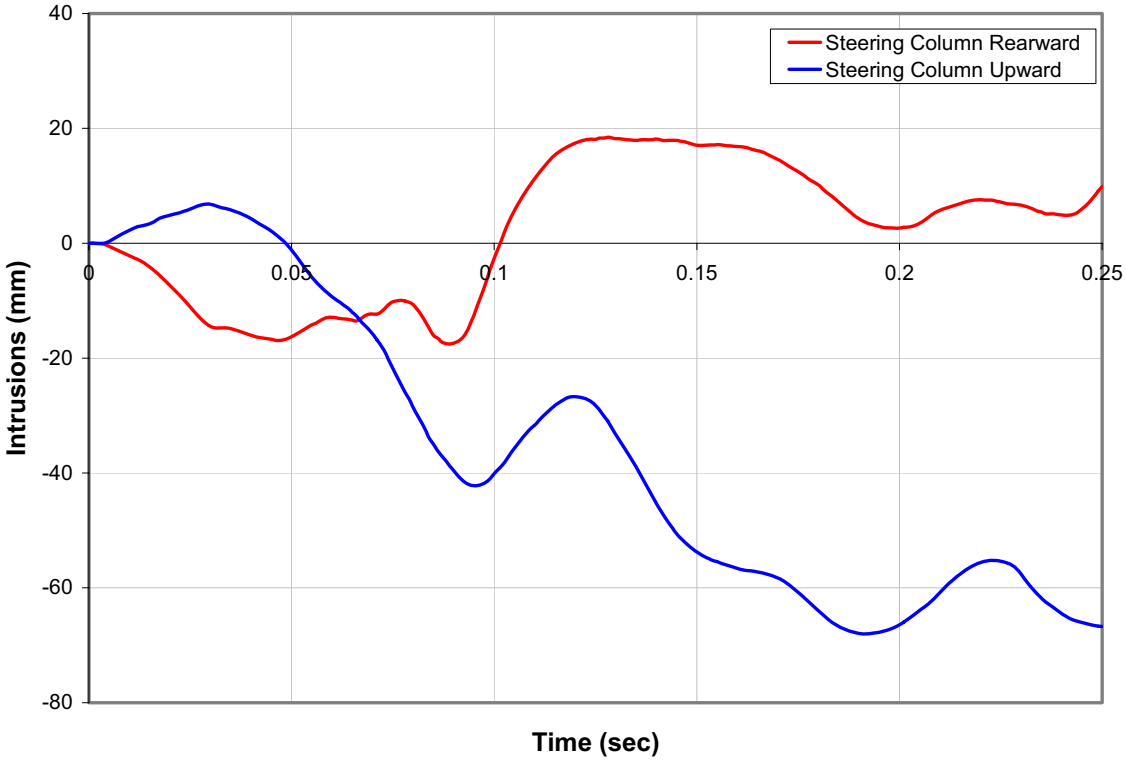


Figure 15: Steering Column Movement

7. Conclusions

The Concept 1 design was developed with essentially the same rails as the existing donor vehicle, except for modifications to holes and flanges. A new bumper design was also included in Concept 1. There was a net mass reduction of 0.81kg. The above modifications did not result in any significant change in vehicle response. This indicates that the donor vehicle rail architecture has to be modified in order to improve the high-speed crash performance. Some improvement in performance may be achieved by tuning the material grades and gauges for bumper and rails, based on a DOE study.

8. Future Work

A final design for Concept 1 will be obtained, based on a DOE study. The final Concept 1 design will be compared to Concepts 2 and 3 that will be later developed in Phase II of the Lightweight Front End Structure Project.

9. References

1) *Validated FE Models, Milestone 5*, SPHINX, Phase II.

2) *Enhanced FE Models, Milestone 6*, SPHINX, Phase II.

3) *IIHS Crashworthiness Evaluation Offset Barrier Crash Test Protocol (Version IX), October 2002.*

4) *DOE FE Models, Milestone 7*, SPHINX, Phase II.

5) *Third Bumper Design Report, Milestone 5*, SPHINX, Phase I.

10. Appendix A: Animations

The following animation files for the subsystem development can be viewed at the Auto/Steel Partnership website, www.a-sp.org.

You will need a Hyperview Player in order to view these animations at the site. You can download this free software at www.altair.com.

1. NCAP: Full Vehicle
2. NCAP: Front-End
3. IIHS: Full Vehicle
4. IIHS: Front-End

11. Appendix B: Summary of FE Model

Component Name	ID	Property Name	ID	Material Name	ID	MASS (ton)	Thickness (mm)
horsecollar_brkt	60001	SectShll18.1	60087	MATL24_340	60049	6.20E-04	1.8
l_bumper_plate	60003	SectShll20.1	60088	MATL24_340	60049	5.17E-04	2
r_bumper_plate	60004	SectShll20.1	60088	MATL24_340	60049	5.18E-04	2
bumpbeam	60005	SectShll12.1	60084	MATL24_848	60050	0.005409	1.2
bumpnull	60006	SectShll10.1	60083	null	60008	0.002833	1
ldfoam	60007	SectSld900	60121	foam2.8pcf	60060	1.91E-04	0
hdfoam	60008	SectSld900	60121	foam6.6pcf	60061	4.93E-04	0
railotr.l	60101	SectShll15.3	60117	MATL24_340	60049	0.002781	1.5
railotr.r	60102	SectShll15.3	60117	MATL24_340	60049	0.002653	1.5
railinr.l	60103	Sectshll16.5	60109	MATL24_250	60054	0.003794	1.65
railinr.r	60104	Sectshll16.5	60109	MATL24_250	60054	0.003652	1.65
railctr1.l	60105	SectShll20.1	60088	MATL24_210	60052	0.00383	2
railctr1.r	60106	SectShll20.1	60088	MATL24_210	60052	0.003998	2
railctr2.l	60107	SectShll12.1	60084	MATL24_340	60049	1.02E-03	1.2
railctr2.r	60108	SectShll12.1	60084	MATL24_340	60049	9.75E-04	1.2
ubrail.l	60109	SectShll95	60113	MATL24_340	60049	5.89E-04	0.95
ubrail.r	60110	SectShll95	60113	MATL24_340	60049	5.93E-04	0.95
ctrrailrnf1.l	60111	SectShll12.1	60084	MATL24_340	60049	4.45E-04	1.2
ctrrailrnf1.r	60112	SectShll12.1	60084	MATL24_340	60049	4.28E-04	1.2
ctrrailrnf3.l	60113	Sectshll14.5	60111	MATL24_340	60049	7.25E-04	1.45
ctrrailrnf3.r	60114	Sectshll14.5	60111	MATL24_340	60049	7.46E-04	1.45
ctrrailrnf2.l	60115	SectShll225	60099	MATL24_3404	60051	0.002819	2.25
ctrrailrnf2.r	60116	SectShll225	60099	MATL24_3404	60051	0.002855	2.25
trqbox1.l	60117	Sectshll14.5	60111	MATL24_210	60052	0.001434	1.45
trqbox1.r	60118	Sectshll14.5	60111	MATL24_210	60052	0.001625	1.45
trqbox2.l	60119	Sectshll14.5	60111	MATL24_160	60048	2.71E-04	1.45
trqbox2.r	60120	Sectshll14.5	60111	MATL24_160	60048	2.72E-04	1.45
trnsrnf	60121	Sectshll17.5	60096	MATL24_340	60049	2.91E-04	1.75
emntrnf	60122	Sectshll14.5	60111	MATL24_340	60049	2.40E-04	1.45
cplate	60123	Sectshll16.5	60109	MATL24_340	60049	3.54E-04	1.65
rlinrnf.r	60124	Sectshll17.5	60096	MATL24_210	60052	2.77E-04	1.75
crfmbrkt.l	60201	SectShll20.1	60088	MATL24_340	60049	5.34E-04	2
crfmbrkt.r	60202	SectShll20.1	60088	MATL24_340	60049	5.38E-04	2
crdlfbrkt	60203	SectShll30	60094	MATL24_600	60056	8.68E-04	3
crdl.l	60205	SectShll26	60116	MATL24_340	60049	0.006018	2.6
crdl.r	60206	SectShll26	60116	MATL24_340	60049	0.006321	2.6
rrcrdlbdattch.l	60207	SectShll35	60106	MATL24_160	60048	0.001148	3.5
rrcrdlbdattch.r	60208	SectShll35	60106	MATL24_160	60048	0.001147	3.5
trnfext.l	60209	SectShll20.1	60088	MATL24_250	60054	0.001243	2
trnfext.r	60210	SectShll20.1	60088	MATL24_250	60054	0.001222	2
rrcrdlmnt1.l	60211	SectShll25	60091	MATL24_210	60052	0.001237	2.5
rrcrdlmnt1.r	60212	SectShll25	60091	MATL24_210	60052	0.001394	2.5

rrcrdlmnt2.l	60213	SectShll19.1	60112	MATL24_210	60052	2.84E-04	1.9
rrcrdlmnt2.r	60214	SectShll19.1	60112	MATL24_210	60052	2.84E-04	1.9
frtcrdlmnt1.l	60215	Sectshll19.5	60110	MATL24_160	60048	8.12E-04	1.95
frtcrdlmnt1.r	60216	Sectshll19.5	60110	MATL24_160	60048	7.34E-04	1.95
frtcrdlmnt2.l	60217	Sectshll14.5	60111	MATL24_210	60052	1.37E-04	1.45
frtcrdlmnt2.r	60218	Sectshll14.5	60111	MATL24_210	60052	1.38E-04	1.45
frtcrdlmnt5	60219	SectShll15.3	60117	MATL24_160	60048	4.31E-04	1.5
frtcrdlmnt3.l	60221	SectShll25	60091	MATL24_340	60049	4.30E-04	2.5
frtcrdlmnt3.r	60222	SectShll25	60091	MATL24_340	60049	3.41E-04	2.5
bot_bkt_l_e	60223	SectShll30	60094	MATL24_340	60049	9.59E-04	3
bot_bkt_r_e	60224	SectShll30	60094	MATL24_340	60049	9.29E-04	3
cradbrkt	60225	SectShll30	60094	MATL24_340	60049	4.46E-04	3
cradbrkt2	60227	SectShll30	60094	MATL24_340	60049	3.58E-04	3
lcarnf.l	60229	SectShll30	60094	MATL24_340	60049	3.19E-04	3
lcarnf.r	60230	SectShll30	60094	MATL24_340	60049	3.41E-04	3
lcajnt_1.L1	60231	SectShll30	60094	rigid	60014	4.12E-05	3
lcajnt_1.R1	60232	SectShll30	60094	rigid	60014	4.12E-05	3
lcacyl.l	60235	SectShll50	60092	MATL24_160	60048	0.001295	5
lcacyl.r	60236	SectShll50	60092	MATL24_160	60048	0.001295	5
lcajnt_1.L2	60239	SectShll30	60094	rigid	60014	3.16E-05	3
lcajnt_1.R2	60240	SectShll30	60094	rigid	60014	3.16E-05	3
cradbrkt1	60241	SectShll10.1	60083	MATL24_180	60046	2.36E-04	1
crdlblt	60243	SectShll20.1	60088	MATL24_160	60048	2.41E-04	2
crdlrrxupr	60244	SectShll25	60091	MATL24_340	60049	0.002183	2.5
crdlrrxlwr	60245	SectShll23	60090	MATL24_340	60049	0.00129	2.3
urail_l	60301	SectShll8.3	60081	MATL24_160	60048	0.001457	0.8
urail_r	60302	SectShll8.3	60081	MATL24_160	60048	0.001456	0.8
urail_rnf2.l	60303	SectShll9.1	60082	MATL24_160	60048	4.72E-04	0.9
urail_rnf1.r	60304	SectShll9.1	60082	MATL24_160	60048	4.71E-04	0.9
pnlfrt1.l	60305	Sectshll75	60097	MATL24_210	60052	5.44E-04	0.75
pnlfrt1.r	60306	Sectshll75	60097	MATL24_210	60052	6.27E-04	0.75
shock.l	60307	Sectshll17.5	60096	MATL24_160	60048	0.001517	1.75
shock.r	60308	Sectshll17.5	60096	MATL24_160	60048	0.001546	1.75
pnlfrt2.l	60309	SectShll12.1	60084	MATL24_210	60052	0.001235	1.2
pnlfrt2.r	60310	SectShll12.1	60084	MATL24_210	60052	0.001294	1.2
plnmbrkt	60311	SectShll8.3	60081	MATL24_210	60052	1.50E-04	0.8
rnfpnldshext2	60312	SectShll8.3	60081	MATL24_210	60052	1.93E-04	0.8
temp	60313	SectShll7.2	60080	MATL24_600	60056	2.63E-04	0.7
frtflr	60401	SectShll085	60118	MATL24_160	60048	0.013015	0.85
bar1	60402	SectShll20.1	60088	MATL24_3404	60051	0.00262	2
tnl1	60403	SectShll18.1	60087	MATL24_340	60049	0.001311	1.8
tnl2	60404	SectShll12.1	60084	MATL24_250	60054	0.006463	1.2
dash	60405	SectShll95	60113	MATL24_160	60048	0.008026	0.95
cowlupr	60406	SectShll8.3	60081	MATL24_210	60052	0.001526	0.8
fflrlvrrnf	60407	SectShll15.3	60117	MATL24_160	60048	7.10E-04	1.5
pedal2	60408	SectShll30	60094	MATL24_160	60048	0.001364	3
wndshld.supt.upr	60409	Sectshll75	60097	MATL24_160	60048	0.002599	0.75
plnmltintjnt	60410	Sectshll75	60097	MATL24_160	60048	0.004045	0.75
rein_upr	60411	SectShll15.3	60117	MATL24_210	60052	9.29E-04	1.5

MTG1	60412	SectShll10.1	60083	MATL24_210	60052	4.34E-04	1
BRKT_Consol	60413	SectShll15.3	60117	MATL24_210	60052	6.89E-04	1.5
crush_brkt_lwr	60414	SectShll20.1	60088	MATL24_210	60052	0.002868	2
bar2.l	60501	SectShll12.1	60084	MATL24_160	60048	0.001367	1.2
bar2.r	60502	SectShll12.1	60084	MATL24_160	60048	0.001368	1.2
2barreinf	60503	SectShll17	60086	MATL24_340	60049	0.00249	1.7
22678921_256_1	60505	SectShll12.1	60084	MATL24_160	60048	2.43E-04	1.2
22678920_256_1	60506	SectShll12.1	60084	MATL24_160	60048	2.43E-04	1.2
22678921_255_1	60507	SectShll12.1	60084	MATL24_160	60048	1.85E-04	1.2
22678920_255_1	60508	SectShll12.1	60084	MATL24_160	60048	1.85E-04	1.2
seatrein.l	60509	SectShll12.1	60084	MATL24_160	60048	3.45E-04	1.2
seatrein.r	60510	SectShll12.1	60084	MATL24_160	60048	3.46E-04	1.2
tiebar3.l	60601	Sectshll75	60097	MATL24_180	60046	6.78E-04	0.75
tiebar3.r	60602	Sectshll75	60097	MATL24_180	60046	7.22E-04	0.75
tiebar4.l	60603	Sectshll75	60097	MATL24_180	60046	4.27E-05	0.75
tiebar4.r	60604	Sectshll75	60097	MATL24_180	60046	4.44E-05	0.75
lhfanmotor	60605	SectShll20.1	60088	MATL24_181	60047	5.60E-04	2
rhfanmotor	60606	SectShll20.1	60088	MATL24_181	60047	5.40E-04	2
tiebar	60607	SectShll9.1	60082	MATL24_210	60052	0.002278	0.9
tiebar2	60608	SectShll9.1	60082	MATL24_160	60048	0.001152	0.9
radsupport	60609	SectShll10.1	60083	MATL24_160	60048	0.001261	1
rad4	60610	SectShll10.1	60083	MATL24_160	60048	8.32E-06	1
Part_2	60611	SectShll10.1	60083	MATL9_2	60006	0.014989	1
rad2	60612	SectSld900	60121	MAT57rad&cond	60059	0.002656	0
rad1	60613	SectSld900	60121	MAT57rad&cond	60059	0.003782	0
fanshroud	60614	SectShll20.1	60088	MATL24_181	60047	0.007298	2
pt2	60702	SectShll10.1	60083	rigid	60014	0.001123	1
pt3	60703	SectShll10.1	60083	rigid	60014	0.006404	1
pt7	60704	SectShll10.1	60083	rigid	60014	0.001243	1
pt8	60705	SectShll20.1	60088	rigid	60014	0.005065	2
pt10	60706	SectShll10.1	60083	rigid	60014	9.92E-04	1
pt11	60707	SectShll225	60099	rigid	60014	0.001335	2.25
pt13	60708	SectShll10.1	60083	rigid	60014	1.07E-04	1
pt14	60709	SectShll10.1	60083	rigid	60014	0.001639	1
pt19	60710	SectShll10.1	60083	rigid	60014	4.08E-04	1
pt18	60711	SectShll40	60093	rigid	60014	0.007253	4
frtmnt1	60712	SectShll20.1	60088	MATL24_160	60048	1.04E-03	2
frtmnt2	60713	SectShll225	60099	MATL24_160	60048	3.84E-04	2.25
pt9	60714	SectShll100	60104	rigid	60014	0.005277	10
pt12	60715	SectShll80	60095	rigid	60014	0.007011	8
pt16	60716	SectShll40	60093	rigid	60014	0.003234	4
pt17	60717	SectShll30	60094	MATL24_160	60048	0.007696	3
expipefrt	60718	SectShll15.3	60117	MATL24_160	60048	0.003601	1.5
ep_7685	60719	SectShll10.1	60083	rigid	60014	2.83E-04	1
flywheel	60720	SectShll10.1	60083	rigid	60014	7.92E-04	1
ep_4776	60721	SectShll10.1	60083	rigid	60014	4.99E-04	1
ep_7498	60722	SectShll10.1	60083	rigid	60014	0.002605	1
ep_0939	60723	SectShll10.1	60083	rigid	60014	5.79E-04	1
ep_0017	60724	SectShll10.1	60083	rigid	60014	4.50E-04	1

ep_70842	60725	SectShll10.1	60083	rigid	60014	1.84E-04	1
eng_mnt_l_e	60726	SectShll80	60095	MATL24_160	60048	0.002636	8
top_bkt_l_e	60727	SectShll80	60095	MAT24_1111	60045	5.72E-04	8
eng_mnt_r_e	60728	SectShll80	60095	MATL24_160	60048	0.002631	8
top_bkt_r_e	60729	SectShll80	60095	MAT24_1111	60045	1.01E-03	8
eng_deformable	60730	SectShll80	60095	MATL24_160	60048	0.001725	8
62109a_e1	60731	SectShll37	60108	MATL24_160	60048	3.62E-04	3.7
62109a_e2	60732	SectShll37	60108	MATL24_160	60048	1.22E-04	3.7
62109a_e3	60733	SectShll37	60108	MATL24_160	60048	4.00E-04	3.7
62109b_e1	60734	SectShll10.1	60083	MATL24_160	60048	4.06E-04	1
rrmnt_bushing	60735	SectShll20.1	60088	MATL24_160	60048	5.79E-04	2
tire1.l	60801	SectShll20.1	60088	mat1.tirerubber	60007	0.00197	2
tire1.r	60802	SectShll20.1	60088	mat1.tirerubber	60007	0.00197	2
tire3.l	60803	SectShll3.3	60107	MATL24_160	60048	1.00E-03	0.3
tire2.r	60804	SectShll3.3	60107	MATL24_160	60048	1.00E-03	0.3
tir2.l	60805	SectShll7.2	60080	MATL24_160	60048	0.002042	0.7
tire3.r	60806	SectShll7.2	60080	MATL24_160	60048	0.002042	0.7
rim.l	60807	SectShll35	60106	MATL24_600	60056	0.008136	3.5
rim.r	60808	SectShll35	60106	MATL24_600	60056	0.008136	3.5
lwrcntrlarm.l	60809	SectShll30	60094	MATL24_160	60048	0.002294	3
lwrcntrlarm.r	60810	SectShll30	60094	MATL24_160	60048	0.002289	3
lcajnt_2.L1	60811	SectShll30	60094	rigid	60014	6.26E-05	3
lcajnt_2.R1	60812	SectShll30	60094	rigid	60014	6.33E-05	3
driveline	60813	SectShll70	60103	MATL24_340	60049	0.005373	7
lcajnt_2.L2	60815	SectShll30	60094	rigid	60014	2.76E-05	3
lcajnt_2.R2	60816	SectShll30	60094	rigid	60014	2.76E-05	3
fsuspstrut.l	60817	SectShll50	60092	MATL24_160	60048	0.005601	5
fsuspstrut.r	60818	SectShll50	60092	MATL24_160	60048	0.005601	5
crdlbltrnf	60819	SectShll275.1	60102	MATL24_160	60048	3.23E-04	2.75
strclnmend3	60820	SectShll50	60092	rigid	60014	3.64E-04	5
strngrack	60821	SectShll60	60101	MAT24_1111	60045	0.002617	6
strrackends	60822	SectShll60	60101	MATL24_160	60048	0.001165	6
stabbar	60823	SectShll40	60093	MATL24_160	60048	0.004576	4
btray1	60901	SectShll15.3	60117	MATL24_160	60048	0.003147	1.5
btray2	60902	SectShll10.1	60083	MATL24_160	60048	2.19E-04	1
battery1	60903	SectShll5.3	60105	MATL24_160	60048	8.66E-04	0.5
ECM	60904	SectShll10.1	60083	MATL24_160	60048	1.07E-03	1
battery_fill	60905	SectShll10.1	60083	MATL24_160	60048	0.001326	1
fcomptrnf2	60906	SectShll40	60093	MATL24_160	60048	0.002901	4
abs_brkt	60907	SectShll20.1	60088	MATL24_160	60048	4.33E-04	2
brkt_boost	60908	90060072	60042	90060009	60012	0.00385	3
edge	61001	SectShll2.1.1	60077	MAT24_3	60042	1.06E-03	1.35
inner	61002	SectShll3.2.1	60078	MAT24_3	60042	0.005147	0.7
outer	61003	SectShll4.1.1	60079	MAT24_3	60042	0.008252	0.7
MODPLT	61101	90060005	60010	90060020	60041	0.001613	1.5
CSUPT_forw	61102	90060006	60011	90060020	60041	5.32E-04	1.22
can	61103	90060008	60012	90060020	60041	6.77E-04	1.2
can1	61104	90060009	60013	90060020	60041	9.87E-05	1.2
can2	61105	90060010	60014	90060020	60041	1.09E-04	1.2

can.1	61106	90060011	60015	90060020	60041	9.05E-05	1.2
inflator	61107	90060012	60016	90060020	60041	0.001456	5.4
Brkt-1	61108	90060063	60039	90060020	60041	6.07E-04	3
gaspdel	61109	90060068	60040	90060020	60041	1.65E-04	2.5
stelpeice	61110	90060071	60041	90060020	60041	1.54E-04	3
SIPO_p	61111	90060014	60018	90060020	60041	6.06E-04	2
SIPO_d2	61112	90060015	60019	90060020	60041	6.11E-04	2
Steel_strip	61113	90060016	60020	90060020	60041	1.07E-04	1.5
Floor_Brkt2	61114	90060037	60022	90060020	60041	8.95E-04	2.5
Center_Stk_brkt	61115	90060038	60023	90060020	60041	3.09E-04	1.5
lower	61116	90060044	60026	90060013	60036	8.85E-04	2.43
upper	61117	90060045	60027	90060013	60036	8.69E-04	2.36
hvacbrkt_add	61118	90060046	60028	90060013	60036	2.49E-05	2.36
heatercvr	61119	90060047	60029	90060013	60036	3.21E-04	2.38
ai	61120	90060048	60030	90060013	60036	3.74E-04	2.1
ai_icebox	61121	90060049	60031	90060013	60036	1.51E-05	2.1
ai_actuator	61122	90060050	60032	90060013	60036	2.81E-05	2
lower_actuator	61123	90060051	60033	90060013	60036	2.86E-05	2
foamplate	61124	90060052	60034	90060020	60041	5.74E-05	1
filmvalve	61125	90060053	60035	90060013	60036	1.67E-04	2
arm1_srib	61126	90060054	60036	90060013	60036	8.90E-05	2
rib_4_hub	61127	90060055	60037	90060013	60036	1.42E-04	3.5
Lower_add1	61128	90060056	60038	90060013	60036	1.16E-05	2
foam	61129	90060125	60119	90060001	60001	1.48E-06	0
evapblock	61130	90060126	60120	90060003	60003	3.52E-05	0
IBEC	61131	90060013	60017	90060005	60004	3.04E-04	2
evap_lower_tube1	61132	90060041	60024	90060002	60002	8.68E-06	1
evap_upper_tube1	61133	90060041	60024	90060002	60002	1.38E-05	1
heat_upper_tube1	61134	90060041	60024	90060002	60002	4.22E-05	1
heat_lower_tube1	61135	90060041	60024	90060002	60002	2.58E-05	1
il	61136	90060042	60025	90060014	60037	1.89E-04	1
IP_sidepnl_E	61137	90060026	60021	90060015	60038	1.24E-04	2.5
sipo_fixed1	61138	90060015	60019	90060008	60011	1.39E-06	2
sipo_fixed2	61139	90060015	60019	90060008	60011	1.46E-06	2
sipo_fixed3	61140	90060015	60019	90060008	60011	1.53E-06	2
sipo_fixed4	61141	90060015	60019	90060008	60011	1.13E-06	2
sipo_fixed5	61142	90060015	60019	90060008	60011	1.85E-06	2
sipo_fixed6	61143	90060015	60019	90060008	60011	1.95E-06	2
sipo_fixed7	61144	90060015	60019	90060008	60011	1.83E-06	2
sipo_p_fixed7	61145	90060014	60018	90060008	60011	1.41E-06	2
sipo_p_fixed6	61146	90060014	60018	90060008	60011	1.59E-06	2
sipo_p_fixed5	61147	90060014	60018	90060008	60011	1.71E-06	2
sipo_p_fixed4	61148	90060014	60018	90060008	60011	1.13E-06	2
sipo_p_fixed3	61149	90060014	60018	90060008	60011	1.85E-06	2
sipo_p_fixed2	61150	90060014	60018	90060008	60011	1.95E-06	2
sipo_p_fixed12	61151	90060014	60018	90060008	60011	1.83E-06	2
modplate_rigid1	61152	90060005	60010	90060008	60011	1.55E-06	1.5
modplate_rigid2	61153	90060005	60010	90060008	60011	2.34E-06	1.5
modplate_rigid32	61154	90060005	60010	90060008	60011	1.45E-06	1.5

modplate_rigid4	61155	90060005	60010	90060008	60011	1.65E-06	1.5
modplate_rigid5	61156	90060005	60010	90060008	60011	1.58E-06	1.5
modplate_rigid6	61157	90060005	60010	90060008	60011	1.98E-06	1.5
modplate_rigid7	61158	90060005	60010	90060008	60011	9.84E-07	1.5
modplate_rigid8	61159	90060005	60010	90060008	60011	1.76E-06	1.5
e.pedal	61160	90060073	60043	90060011	60034	8.37E-04	8
e.pad	61164	90060074	60044	90060011	60034	1.20E-04	3.5
e.pin	61165	90060075	60045	90060011	60034	1.14E-04	2
pedalpivout	61167	90060072	60042	90060009	60012	8.58E-06	3
pedalpivinb	61168	90060072	60042	90060009	60012	8.58E-06	3
pedallink	61169	90060072	60042	90060009	60012	1.43E-06	3
pivot inb	61170	90060072	60042	90060009	60012	4.32E-06	3
pivot out	61171	90060072	60042	90060009	60012	1.10E-06	3
Part221130	61172	90060072	60042	90060009	60012	1.08E-06	3
Part221131	61173	90060072	60042	90060009	60012	1.39E-06	3
Part221132	61174	90060072	60042	90060009	60012	9.68E-07	3
Part221133	61175	90060072	60042	90060009	60012	9.79E-07	3
Part221134	61176	90060072	60042	90060009	60012	6.86E-07	3
Part221135	61177	90060072	60042	90060009	60012	1.30E-06	3
Part221136	61178	90060072	60042	90060009	60012	9.62E-07	3
dr_ealf	61179	90060077	60047	90060011	60034	2.25E-04	1.5
dr_eart	61180	90060077	60047	90060020	60041	2.25E-04	1.5
ps_eart	61181	90060076	60046	90060020	60041	1.64E-04	1.5
ps_eart.1	61182	90060076	60046	90060020	60041	1.64E-04	1.5
floor_attachment	61183	90060078	60048	90060020	60041	5.18E-04	2
tunlbkt_fixdeles	61184	90060078	60048	90060010	60013	1.18E-06	2
tunlbkt_fixdeles	61185	90060078	60048	90060010	60013	1.27E-06	2
tunlbkt_fixdeles	61186	90060078	60048	90060010	60013	2.33E-06	2
tunlbkt_fixdeles	61187	90060078	60048	90060010	60013	1.83E-06	2
tunlbkt_fixdeles	61188	90060078	60048	90060010	60013	4.47E-06	2
tunlbkt_fixdeles	61189	90060078	60048	90060010	60013	7.59E-06	2
tunlbkt_fixdeles	61190	90060078	60048	90060010	60013	2.76E-06	2
tunlbkt_fixdeles	61191	90060078	60048	90060010	60013	3.89E-06	2
gboxframe_base	61192	90060080	60049	90060016	60039	3.92E-04	2.5
vribs_gboxframe	61193	90060081	60050	90060016	60039	4.81E-06	1
hribs_gboxframe	61194	90060082	60051	90060016	60039	2.76E-05	1.2
Mag_6.5.1.1	61196	90060100	60052	90060012	60035	3.18E-04	6.5
Mag_3.0.1.1	61197	90060101	60053	90060012	60035	0.00345	3
Mag_4.0.1.1	61198	90060102	60054	90060012	60035	4.81E-04	4
Mag_ribs.1.1	61199	90060103	60055	90060012	60035	0.002748	3
Mag_1.5.1.1	61200	90060104	60056	90060012	60035	1.28E-04	1.5
Mag_5.0.1	61201	90060105	60057	90060012	60035	1.40E-04	5
Mag_2.5	61202	90060106	60058	90060012	60035	2.65E-04	2.5
inner.1	61203	90060107	60059	90060016	60039	3.58E-04	3
innergroorve	61204	90060111	60063	90060016	60039	8.37E-07	3.3
ribs.1	61205	90060112	60064	90060016	60039	1.36E-04	1.25
bin o	61206	90060108	60060	90060017	60040	2.74E-04	2.5
ribbin	61207	90060110	60062	90060017	60040	5.71E-07	1.7
bintongue	61208	90060109	60061	90060017	60040	4.40E-07	1.1

outer.1	61209	90060113	60065	90060016	60039	2.85E-04	2.5
hub	61210	90060115	60067	90060016	60039	1.76E-06	1
outerhrib	61211	90060114	60066	90060016	60039	7.18E-06	1.2
outervrib	61212	90060115	60067	90060016	60039	3.35E-07	1
hubrib	61213	90060116	60068	90060016	60039	1.93E-07	1.375
glvbx_frm_hinge_	61214	90060117	60069	90060016	60039	8.29E-06	3
knee bolster inn	61215	90060118	60070	90060016	60039	2.66E-04	2.5
inner rib h	61216	90060119	60071	90060016	60039	1.25E-04	1.875
small rib inner	61217	90060120	60072	90060016	60039	3.27E-06	2.6
knee bolster out	61218	90060121	60073	90060016	60039	4.25E-04	2.5
doghouse outer	61219	90060122	60074	90060016	60039	6.40E-06	1.4
outer rib	61220	90060123	60075	90060016	60039	4.29E-06	1.1
tipof bin	61221	90060124	60076	90060016	60039	5.01E-05	2.5
part.9	61301	SectShll20.1	60088	MAT9_704	60009	1.21E-04	2
part.10	61302	SectShll20.1	60088	MAT9_705	60010	5.67E-05	2
part.11	61303	SectShll5.3	60105	MAT20_706	60015	5.98E-05	0.5
part.14	61304	SectShll20.1	60088	MAT20_750	60016	0.001699	2
part.15	61305	SectShll10.1	60083	MAT20_751	60017	8.05E-05	1
part.16	61306	SectShll34	60115	MAT20_752	60018	1.83E-04	3.4
part.17	61307	SectShll25	60091	MAT20_753	60019	5.23E-04	2.5
part.18	61308	SectShll25	60091	MAT20_754	60020	6.50E-04	2.5
part.19	61309	SectShll20.1	60088	MAT20_755	60021	5.14E-04	2
part.20	61310	SectShll30	60094	MAT20_756	60022	4.70E-04	3
part.21	61311	SectShll34	60115	MAT20_757	60023	2.55E-04	3.4
part.22	61312	SectShll20.1	60088	MAT20_758	60024	5.61E-05	2
part.24	61313	SectShll20.1	60088	MAT20_760	60025	1.14E-04	2
part.25	61314	SectShll20.1	60088	MAT20_761	60026	8.86E-05	2
part.28	61315	SectShll20.1	60088	MAT20_764	60027	2.43E-05	2
part.29	61316	SectShll20.1	60088	MAT20_765	60028	2.32E-05	2
part.30	61317	SectShll40	60093	MAT20_766	60029	3.95E-06	4
part.31	61318	SectShll40	60093	MAT20_767	60030	3.95E-06	4
part.34	61319	SectShll40	60093	MAT24_771	60044	2.43E-05	4
part.40	61320	SectShll30	60094	MAT20_777	60031	3.28E-04	3
part.41	61321	SectShll30	60094	MAT20_778	60032	3.69E-04	3
strclnmend4	61323	SectShll50	60092	rigid	60014	2.10E-04	5
part.49	61324	SectShll15.3	60117	MAT20_20015	60033	9.89E-06	1.5
drinrpnl.l	61401	Sectshll75	60097	MATL24_160	60048	0.003637	0.75
drlwrhng.l	61402	SectShll50	60092	MATL24_160	60048	1.28E-04	5
drotrpnl.l	61403	Sectshll75	60097	MATL24_180	60046	0.004388	0.75
z-brkt.l	61404	SectShll10.1	60083	MATL24_160	60048	5.56E-05	1
upr_frame.l	61405	SectShll10.1	60083	MATL24_160	60048	0.001997	1
drbeam.l	61406	SectShll20.1	60088	MATL24_600	60056	0.001914	2
druprhng.l	61407	SectShll50	60092	MATL24_160	60048	1.30E-04	5
drinrpnl.r	61408	Sectshll75	60097	MATL24_160	60048	0.003636	0.75
drotrpnl.r	61409	Sectshll75	60097	MATL24_180	60046	0.004388	0.75
z-brkt.r	61410	SectShll10.1	60083	MATL24_160	60048	5.56E-05	1
upr_frame.r	61411	SectShll10.1	60083	MATL24_160	60048	0.001997	1
drbeam.r	61412	SectShll20.1	60088	MATL24_600	60056	0.001913	2
druphng.r	61413	SectShll50	60092	MATL24_160	60048	1.34E-04	5

drlwhng.r	61414	SectShll50	60092	MATL24_160	60048	1.26E-04	5
fdrbdhng	61415	SectShll50	60092	MATL24_210	60052	2.07E-04	5
fdrbdhng2	61416	SectShll20.1	60088	rigid	60014	1.96E-05	2
fdrbdhng3	61417	SectShll20.1	60088	rigid	60014	2.43E-05	2
fdrbdhng4	61418	SectShll50	60092	MATL24_210	60052	2.01E-04	5
fdrbdhng5	61419	SectShll20.1	60088	rigid	60014	2.07E-05	2
fdrbdhng6	61420	SectShll20.1	60088	rigid	60014	2.54E-05	2
fdrbdhng7	61421	SectShll50	60092	MATL24_210	60052	2.55E-04	5
fdrbdhng8	61422	SectShll20.1	60088	rigid	60014	2.01E-05	2
fdrbdhng9	61423	SectShll20.1	60088	rigid	60014	2.48E-05	2
fdrbdhng10	61424	SectShll50	60092	MATL24_210	60052	1.97E-04	5
fdrbdhng11	61425	SectShll20.1	60088	rigid	60014	2.07E-05	2
fdrbdhng12	61426	SectShll20.1	60088	rigid	60014	2.49E-05	2
drlsrwld.l	61427	SectShll18.1	60087	MATL24_160	60048	0.003567	1.8
drlsrwld.r	61428	SectShll18.1	60087	MATL24_160	60048	0.003567	1.8
rrdrinn.l	61429	Sectshll75	60097	MATL24_160	60048	0.00681	0.75
twdrrdrinr.l	61430	SectShll18.1	60087	MATL24_160	60048	0.005454	1.8
rrdrotr.l	61431	Sectshll75	60097	MATL24_160	60048	0.008021	0.75
rrdrfrm.l	61432	SectShll10.1	60083	MATL24_160	60048	0.003331	1
rrdrbm.l	61433	SectShll20.1	60088	MATL24_600	60056	0.002513	2
bathtub.l	61434	SectShll20.1	60088	MATL24_160	60048	2.59E-04	2
rrdrhng.l	61435	SectShll50	60092	MATL24_160	60048	1.06E-03	5
latchjt.l	61436	SectShll20.1	60088	MATL24_160	60048	2.28E-04	2
rrdrhng1.l	61437	SectShll50	60092	MATL24_160	60048	6.20E-04	5
roof	61501	Sectshll75	60097	MATL24_160	60048	0.010108	0.75
wshield	61502	SectShll48	60100	laminatedglass	60058	0.015411	4.8
rr_wndshld	61503	SectShll48	60100	laminatedglass	60058	0.011652	4.8
bdysdpnlotr.l	61601	Sectshll75	60097	MATL24_160	60048	0.014307	0.75
bdysdpnlotr.r	61602	Sectshll75	60097	MATL24_160	60048	0.014308	0.75
twldbsideinr.l	61603	SectShll21	60089	MATL24_160	60048	0.00905	2.1
twldbsideinr.r	61604	SectShll21	60089	MATL24_160	60048	0.009056	2.1
rkrx_l	61605	Sectshll13	60098	MATL24_340	60049	1.01E-03	1.3
rkrx_r	61606	Sectshll13	60098	MATL24_340	60049	1.01E-03	1.3
rkrinr.l	61607	sectshll16	60114	MATL24_3404	60051	0.003811	1.6
rkrinr.r	61608	sectshll16	60114	MATL24_3404	60051	0.003811	1.6
twldB-plr.l	61609	SectShll18.1	60087	MATL24_250	60054	0.003041	1.8
twldB-plr.r	61610	SectShll18.1	60087	MATL24_250	60054	0.003041	1.8
bdysdpnlinr.l	61611	SectShll10.1	60083	MATL24_160	60048	0.009621	1
bdysdpnlinr.r	61612	SectShll10.1	60083	MATL24_160	60048	0.009567	1
B_plr_rnf	61613	SectShll10.1	60083	MATL24_160	60048	6.01E-04	1
bplrrnf.l	61615	SectShll225	60099	MATL24_250	60054	0.003029	2.25
bplrrnf.r	61616	SectShll225	60099	MATL24_250	60054	0.003029	2.25
rfrailrnfl	61617	SectShll20.1	60088	MATL24_210	60052	0.002007	2
rfrailrnfr	61618	SectShll20.1	60088	MATL24_210	60052	0.002007	2
frt_hrn	61619	SectShll20.1	60088	MATL24_160	60048	7.90E-04	2
rfrailinr.r	61620	SectShll20.1	60088	MATL24_160	60048	7.85E-04	2
a_pilar_rnf_l	61621	SectShll10.1	60083	MATL24_160	60048	9.04E-04	1
a_pilar_rnf_r	61622	SectShll10.1	60083	MATL24_160	60048	9.05E-04	1
fbhplrrnf1.l	61623	SectShll10.1	60083	MATL24_210	60052	0.001632	1

fbhplrrnf1.r	61624	SectShll10.1	60083	MATL24_210	60052	0.001634	1
frthdr	61625	SectShll7.2	60080	MATL24_160	60048	9.30E-04	0.7
rfbow2	61626	SectShll9.1	60082	MATL24_340	60049	9.23E-04	0.9
rearflr	61627	SectShll8.3	60081	MATL24_160	60048	0.017539	0.8
bar3	61628	SectShll10.1	60083	MATL24_211	60053	0.002442	1
bar4ctr	61629	SectShll10.1	60083	MATL24_340	60049	0.001438	1
bar4lft	61630	SectShll15.3	60117	MATL24_160	60048	0.001168	1.5
rrrail.l	61631	SectShll15.3	60117	MATL24_251	60055	0.005535	1.5
rrrailrnf1.l	61632	SectShll10.1	60083	MATL24_160	60048	1.93E-04	1
rrailrnf2.l	61633	SectShll10.1	60083	MATL24_160	60048	2.10E-04	1
gusset.l	61634	SectShll15.3	60117	MATL24_160	60048	7.13E-04	1.5
gusset2.l	61635	SectShll15.3	60117	MATL24_160	60048	8.44E-04	1.5
gusset3.l	61636	SectShll15.3	60117	MATL24_160	60048	5.19E-04	1.5
gusset4.l	61637	SectShll15.3	60117	MATL24_160	60048	5.89E-04	1.5
whlhsinr.l	61638	SectShll10.1	60083	MATL24_160	60048	0.002906	1
4barrnf1.l	61639	SectShll20.1	60088	MATL24_160	60048	0.001399	2
4barrnf2.l	61640	SectShll25	60091	MATL24_160	60048	7.24E-04	2.5
backpanel	61641	SectShll8.3	60081	MATL24_160	60048	0.005311	0.8
bpnlrnf	61642	Sectshll75	60097	MATL24_160	60048	0.001933	0.75
rrhdr	61643	SectShll9.1	60082	MATL24_160	60048	0.001131	0.9
rrsuspshk.l	61644	SectShll225	60099	MATL24_160	60048	3.05E-04	2.25
rkrblkhds	61645	SectShll12.1	60084	MATL24_340	60049	7.54E-04	1.2
rdeck	61646	SectShll10.1	60083	MATL24_160	60048	0.005446	1
trnkgtrfrt	61647	SectShll10.1	60083	MATL24_160	60048	0.00209	1
rdeckbrkt1	61648	SectShll10.1	60083	MATL24_160	60048	9.01E-04	1
rdeckbrkt2	61649	SectShll10.1	60083	MATL24_160	60048	2.49E-04	1
trnkgtr.l	61650	SectShll9.1	60082	MATL24_160	60048	3.97E-04	0.9
rdeckbrkt3.l	61651	SectShll10.1	60083	MATL24_160	60048	8.76E-04	1
rdeckbrkt4.l	61652	SectShll10.1	60083	MATL24_160	60048	7.67E-04	1
trlrhtchbrkt	61653	SectShll10.1	60083	MATL24_160	60048	0.001306	1
rrailext.l	61654	SectShll15.3	60117	MATL24_160	60048	7.55E-04	1.5
bar4rt	61655	SectShll15.3	60117	MATL24_160	60048	0.001168	1.5
rrrail.r	61656	SectShll15.3	60117	MATL24_251	60055	0.005519	1.5
rrailrnf1.r	61657	SectShll10.1	60083	MATL24_160	60048	1.93E-04	1
rrailrnf2.r	61658	SectShll10.1	60083	MATL24_160	60048	2.10E-04	1
gusset.r	61659	SectShll15.3	60117	MATL24_160	60048	7.13E-04	1.5
gusset2.r	61660	SectShll15.3	60117	MATL24_160	60048	8.44E-04	1.5
gusset3.r	61661	SectShll15.3	60117	MATL24_160	60048	5.19E-04	1.5
gusset4.r	61662	SectShll15.3	60117	MATL24_160	60048	5.87E-04	1.5
whlhsinr.r	61663	SectShll10.1	60083	MATL24_160	60048	0.003046	1
4barrnf1.r	61664	SectShll20.1	60088	MATL24_160	60048	0.001459	2
4barrnf2.r	61665	SectShll25	60091	MATL24_160	60048	6.97E-04	2.5
rrsuspshk.r	61666	SectShll225	60099	MATL24_160	60048	3.05E-04	2.25
trnkgtr.r	61667	SectShll9.1	60082	MATL24_160	60048	4.00E-04	0.9
rdeckbrkt3.r	61668	SectShll10.1	60083	MATL24_160	60048	8.73E-04	1
rdeckbrkt4.r	61669	SectShll10.1	60083	MATL24_160	60048	7.63E-04	1
rrailext.r	61670	SectShll15.3	60117	MATL24_160	60048	7.48E-04	1.5
fbhpbulkhd.l	61671	SectShll20.1	60088	MATL24_340	60049	5.83E-04	2
rkrblkhds.1	61672	SectShll12.1	60084	MATL24_340	60049	2.83E-04	1.2

accl.r	61673	SectShll10.1	60083	rigid	60014	4.29E-05	1
accl.l	61674	SectShll10.1	60083	rigid	60014	4.56E-05	1
rr_hrn	61675	SectShll14.1	60085	MATL24_160	60048	9.12E-04	1.4
fbhp_brkt	61676	SectShll20.1	60088	MATL24_210	60052	1.84E-04	2
rkr_extn	61677	Sectshll75	60097	MATL24_600	60056	0.001526	0.75
muffler	61701	SectShll5.3	60105	MATL24_160	60048	0.00133	0.5
exhstpipe	61702	SectShll5.3	60105	MATL24_160	60048	0.00201	0.5
rtire.l	61801	SectShll10.1	60083	MATL24_160	60048	0.007576	1
rtire.r	61802	SectShll10.1	60083	MATL24_160	60048	0.007576	1
rearrim	61803	SectShll35	60106	MATL24_160	60048	0.015933	3.5
rbmpbmbrkt.l	61901	SectShll15.3	60117	MATL24_160	60048	4.35E-04	1.5
rbmpbmbrkt.r	61902	SectShll15.3	60117	MATL24_160	60048	4.35E-04	1.5
rbumpbeam	61903	SectShll10.1	60083	MATL24_160	60048	0.003708	1
part.42	62001	SectDisc779	60123	MATSpr1_779	60063	0	0
part.43	62002	SectDisc780	60124	MATDmp2_780	60064	0	0
part.44	62003	SectDisc781	60125	MATSpr4_781	60069	0	0
part.47	62004	SectDisc783	60126	MATDmp2_784	60065	0	0
part.12	62005	SectBeam707	60009	MAT24_707	60043	7.70E-04	0
bar1fsusp	62006	Sectbeam10500	60002	MATBEAM	60057	0.001903	0
bar2fsusp	62007	Sectbeam10501	60003	MATBEAM	60057	4.12E-05	0
bar3fsusp	62008	Sectbeam10500	60002	MATBEAM	60057	1.41E-04	0
BARDLINE	62009	Sectbeam10504	60004	MATBEAM	60057	7.06E-05	0
bar4fsusp	62010	Sectbeam10500	60002	MATBEAM	60057	9.48E-04	0
bar2dline	62011	Sectbeam10500	60002	MATBEAM	60057	0.001306	0
bar3dline	62012	Sectbeam10504	60004	MATBEAM	60057	1.16E-04	0
bar5dline	62013	Sectbeam10509	60005	MATBEAM	60057	8.50E-05	0
bar1rrsus	62014	Sectbeam10500	60002	MATBEAM	60057	0.007365	0
bar2rrsusp	62015	Sectbeam10516	60006	MATBEAM	60057	0.019679	0
bar3rrsusp	62016	Sectbeam10516	60006	MATBEAM	60057	0.0026	0
bar4rrsusp	62017	Sectbeam10516	60006	MATBEAM	60057	0.002841	0
bardummies	62018	Sectbeam10519	60007	MATBEAM	60057	0.003373	0
barseat	62019	Sectbeam10519	60007	MATBEAM	60057	3.34E-04	0
barradiator	62020	Sectbeam10522	60008	MATBEAM	60057	1.82E-04	0
bardriveline	62021	Sectbeam10504	60004	MATBEAM	60057	2.57E-04	0
bardriveline8	62022	Sectbeam10504	60004	MATBEAM	60057	7.05E-05	0
sprdrvline	62023	SectDisc1	60122	Matsprstr14	60066	0	0
sprengmnt3	62024	SectDisc1	60122	Matsprstr113	60067	0	0
sprdummy	62025	SectDisc1	60122	Matsprstr114	60068	0	0
spr2dummy	62026	SectDisc1	60122	Matsprstr116	60062	0	0
spr3dummy	62027	SectDisc1	60122	Matsprstr116	60062	0	0
ltmount_spring	62028	SectDisc20071.1	60127	MATSpr4_61112	60070	0	0
rt_mount_spring	62029	SectDisc20071.1	60127	MATSpr4_61113	60071	0	0
rr_cdl_atch_spri	62030	SectDisc20071.1	60127	MATSpr4_61116	60073	0	0
rr_cdl_atch_spri	62031	SectDisc20071.1	60127	MATSpr4_61115	60072	0	0
hinge_beam_65dia	62032	90060004	60001	90060006	60005	1.06E-04	0
pt6	60701	SectShll10.1	60083	rigid	60014	0.304199	1
Masses	62033	N/A	N/A	N/A	0	0.002085	N/A
ElemMass	62034	N/A	N/A	N/A	0	0.633762	N/A
ncap_driver_pass	62035	N/A	N/A	N/A	0	0.156	N/A

out_front_lh_doo	62047	N/A	N/A	N/A	0	1.42E-04	N/A
out_ip_masses_2	62050	N/A	N/A	N/A	0	0.001933	N/A
out_hood_masses_	62054	N/A	N/A	N/A	0	9.59E-05	N/A
out_roof_masses_	62056	N/A	N/A	N/A	0	8.76E-05	N/A
out_windshield_m	62058	N/A	N/A	N/A	0	1.92E-06	N/A
out_rear_lh_door	62060	N/A	N/A	N/A	0	1.96E-04	N/A
out_front_rh_doo	62064	N/A	N/A	N/A	0	1.53E-04	N/A
out_rear_rh_door	62066	N/A	N/A	N/A	0	1.90E-04	N/A
SpotWelds	62039	N/A	N/A	N/A	0	0	N/A
2T_Welds	62043	N/A	N/A	N/A	0	0	N/A
Rigids.5	62040	N/A	N/A	N/A	0	0	N/A
Joints	62068	N/A	N/A	N/A	0	0	N/A

Total Components	**495**
Model Mass	**1.778 tonnes**

- Model mass is from LS-DYNA3D d3hsp file.
- Part mass summary is from HYPERMESH.

Concept 1: DOE Study

Milestone 11

Lightweight Front End Structure Phase II

September 18, 2003

Auto/Steel Partnership

Abstract

This report documents the NCAP DOE study for *Concept 1*. A final design for Concept 1 will be obtained, based on this DOE study. The final Concept 1 design will be compared to Concepts 2 and 3 that will be later developed in Phase II of the Lightweight Front End Structure Project.

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1. Objectives

The effort of this study was aimed at undertaking an NCAP DOE study for *Concept 1*. Front rail and bumper grades and gauges were selected as design variables. Concept 1 has essentially the same rails as the existing donor vehicle rail design, except for modifications to holes and flanges. A new bumper design was also included in Concept 1. A final design for Concept 1 will be obtained, based on the DOE study. The final Concept 1 design will be compared to Concepts 2 and 3 that will be later developed in Phase II of the Lightweight Front End Structure Project.

2. Results Summary

The NCAP study was based on the following DOE model.

- Orthogonal L16 2-level study *(7)*.
- Front rail and bumper grades and gauges as design variables.
- B-pillar pulse, crush and mass responses.

The rankings of main effects and interactions are summarized in *Table 1*. These are for peak accelerations (LH) between 40-70ms.

The study showed that gauges had a more significant effect on the NCAP performance than grades.

Table 1: Rankings of Main Effects/Interactions

Rank	Main Effect or Interaction
1.	rail mid gauge
2.	rail ext gauge
3.	bumper gauge
4.	bumper gauge x rail mid gauge
5.	bumper gauge x bumper grade
6.	rail ext grade
7.	rail front gauge
8.	bumper gauge x rail front gauge
9.	bumper grade
10.	bumper grade x rail mid gauge

3. DOE Model

The DOE model selected for the NCAP study was the Orthogonal L16 Array (*7).* 8 main effects and 7 interactions can be determined from 16 experiments. The design variables and their levels are summarized in *Table 2* and *Figure 1.* The bumper front and back plates were clubbed together. Rail inner and outer pieces were clubbed together for the front and mid sections. All rail extension parts were also clubbed together.

Table 2: DOE Design Variables

S.No.	Design Variable	Level 1	Level 2
1	Bumper Gauge	1.0	1.4
2	Bumper Grade	DP800	DP980
3	Front Rail Section Gauge	70% of Baseline	Baseline
4	Front Rail Section Grade	DP600	DP800
5	Mid Rail Section Gauge	70% of Baseline	Baseline
6	Mid Rail Section Grade	DP600	DP800
7	Rail Extension Gauge	70% of Baseline	Baseline
8	Rail Extension Grade	DP600	DP800

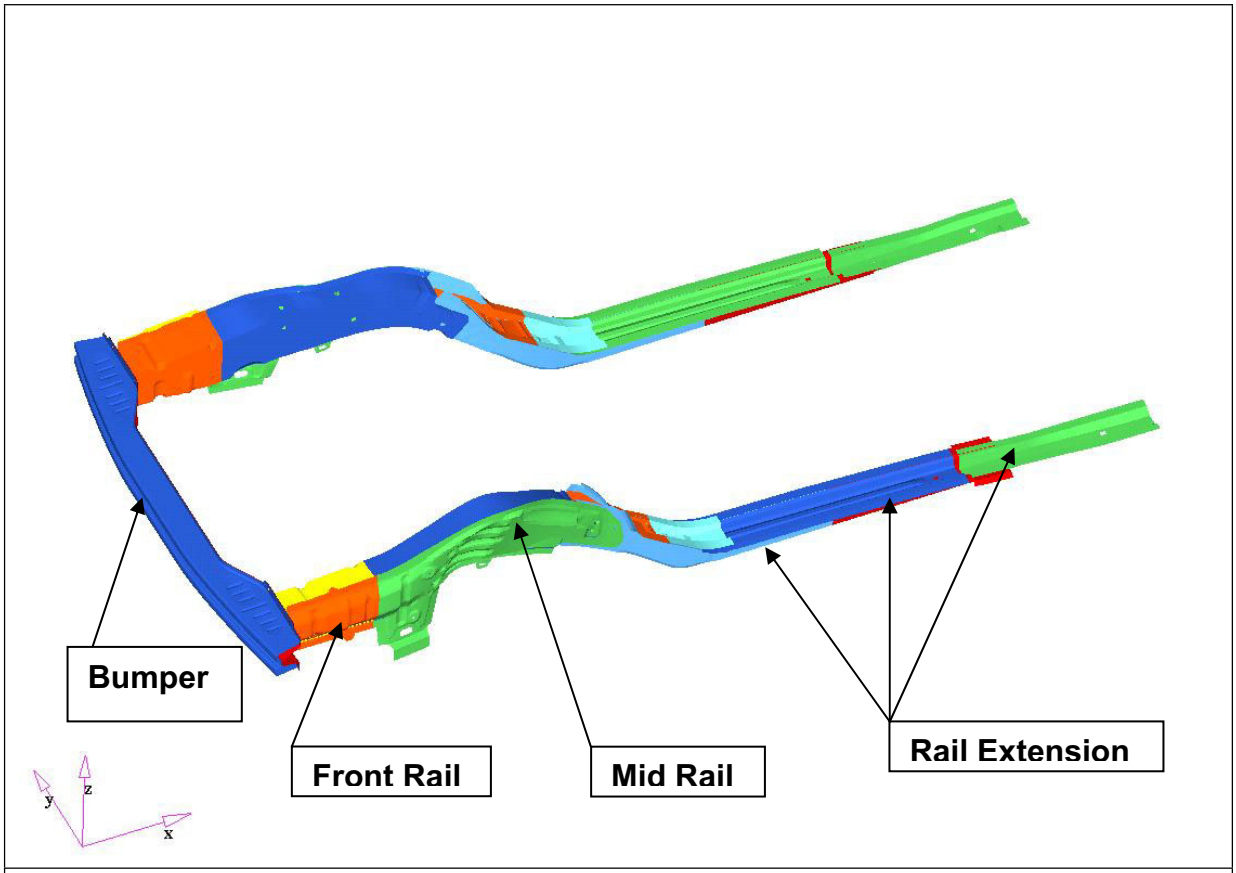


Figure 1: DOE Design Variables

4. FE Model - Output Location Summary

The nodes at which the desired NCAP and IIHS outputs were obtained are listed in *Table 3*.

The intrusions were measured at the nodes as specified in *Reference 3*.

The acceleration and intrusion node locations are shown in *Figure 2* and *Figure 3* below.

Table 3: Summary of Output Locations

Parameter	Location	Node Number
Accelerations	B-Pillar / Rocker - LH	5000001
	B-Pillar / Rocker - RH	5000002
Intrusions	Origin	6000000
	Plane Y-axis	6000001
	Plane Z-axis	6000002
	Steering Column	7000001
	Brake Pedal	7000002
	Toepan - Left	7000003
	Toepan - Center	7000004
	Toepan - Right	7000005
	Left Front Seat Bolt	7000006
	Right Front Seat Bolt	7000007
	Left Rear Seat Bolt	7000008
	Right Rear Seat Bolt	7000009
	AB Closure - A Pillar	7000010
	AB Closure - B Pillar	7000011

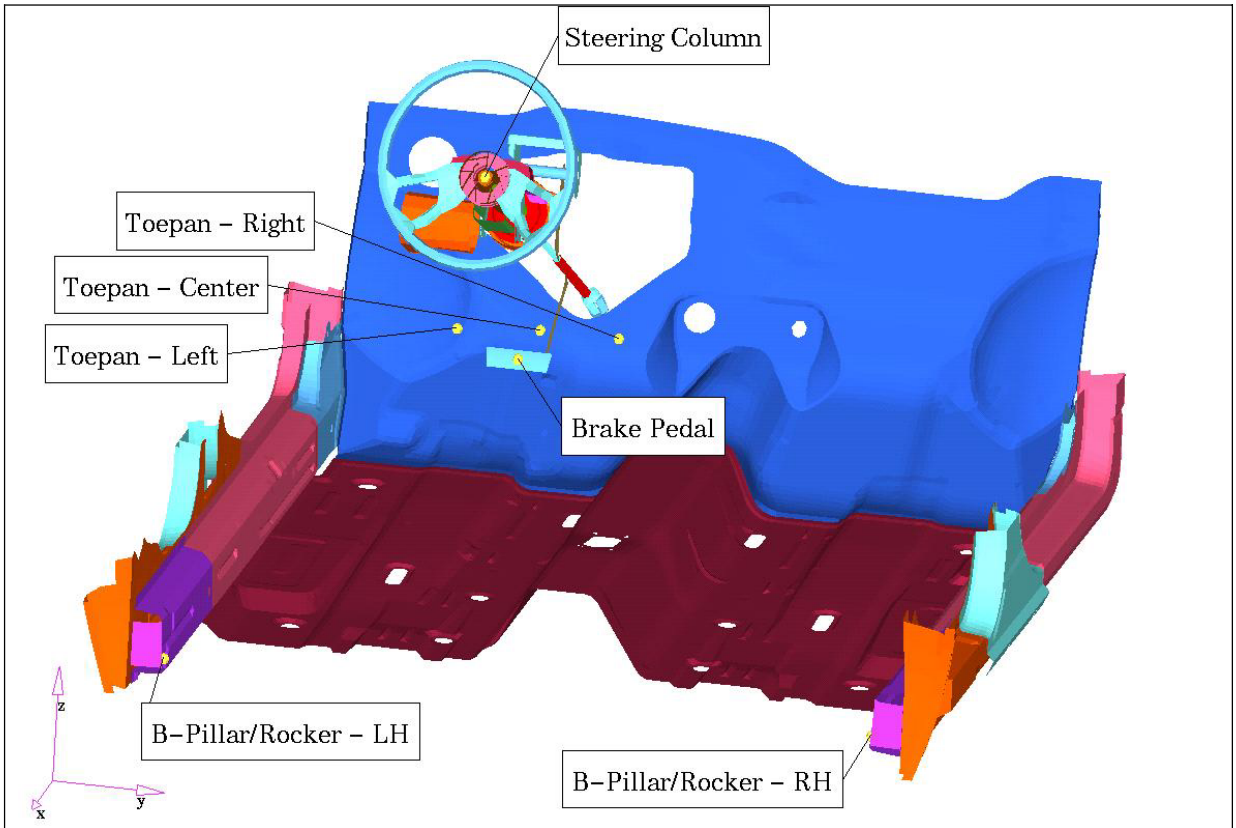


Figure 2: Output Locations for NCAP/IIHS



Figure 3: Output Locations for IIHS - AB Closure

5. NCAP DOE

Figure 4-6 show the normalized Sum of Squares *(7)* for crush, and LH B-pillar acceleration pulse.

The DOE study showed that gauges had a more significant effect on the NCAP performance than grades. Out of the top 9 factors that affect the acceleration between 40-70ms (*Figure 6*), 4 were gauges and only 2 were grades. Furthermore, the mid rail gauge was the dominant factor affecting the B-pillar pulse.

The initial peak was affected more by rail as compared to bumper (*Figure 5*). This scenario is quite different from the Phase I DOE studies *(8)* in which the bumper dictated the initial peak.

The dominant effect of gauges suggests that the design lacks geometric stability. Hence, the full potential of high strength materials is not realized as the rails do not crush well axially.

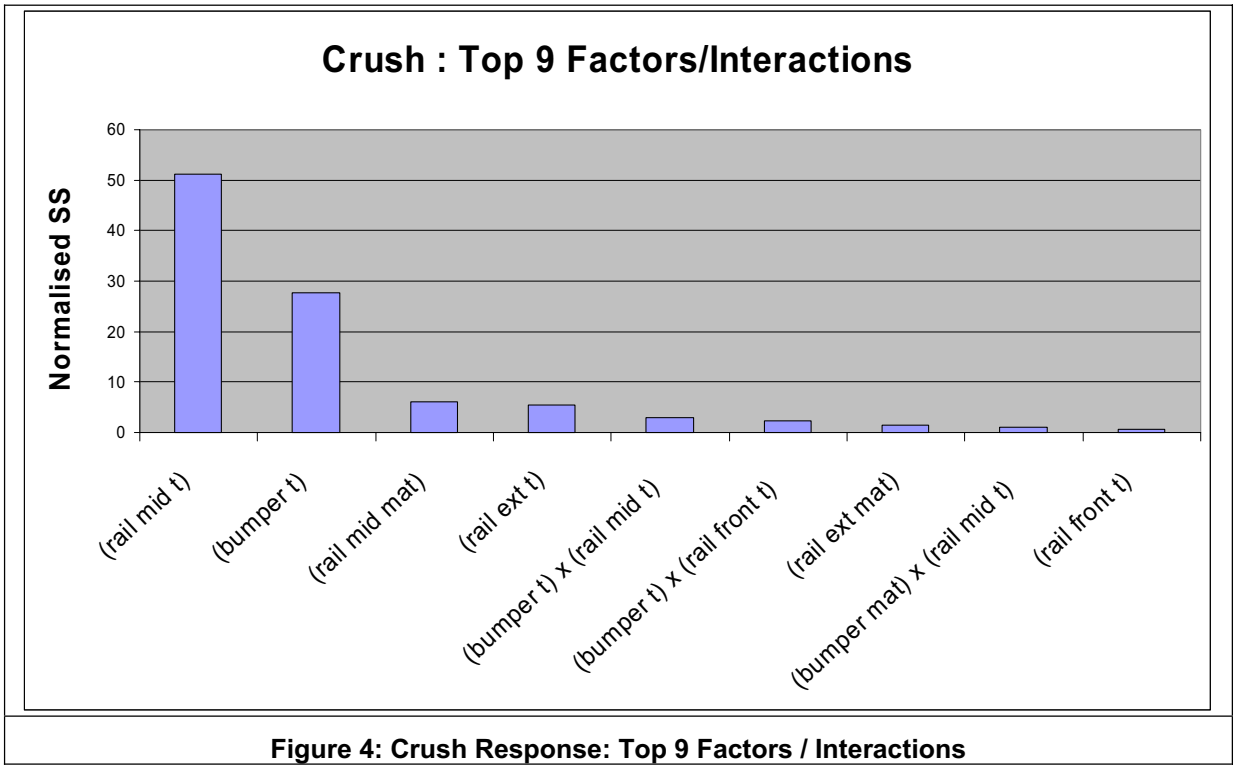


Figure 4: Crush Response: Top 9 Factors / Interactions

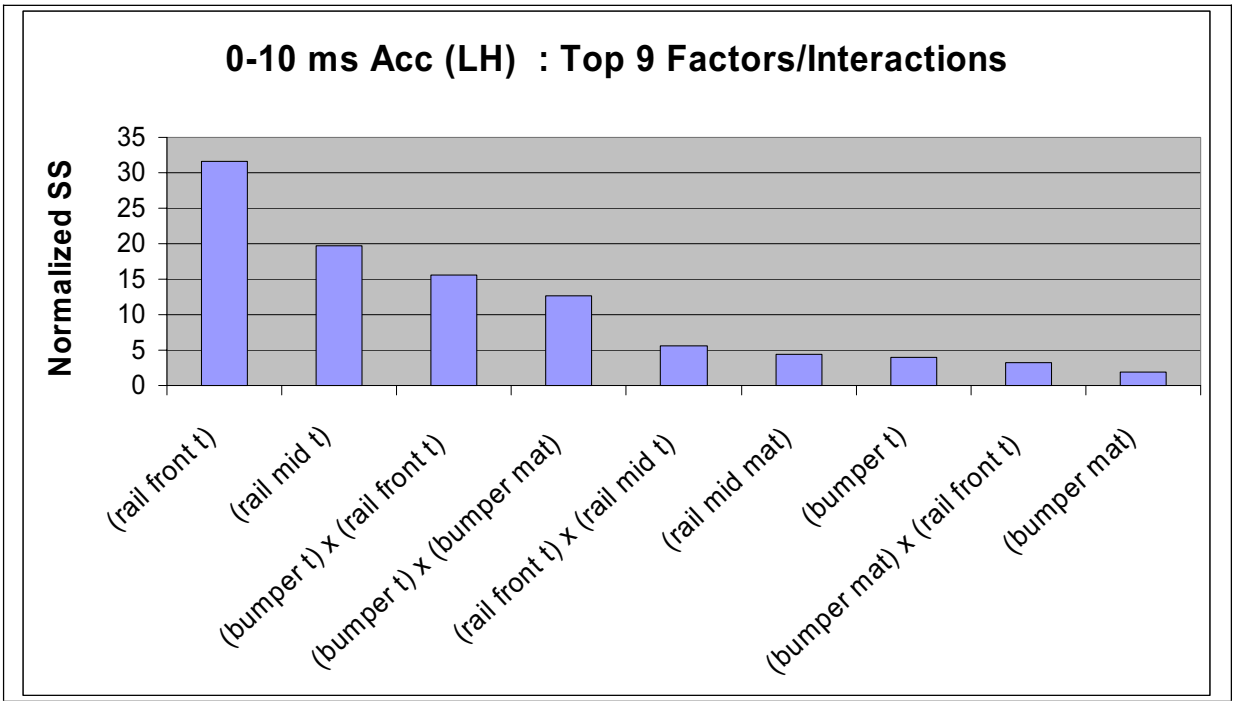


Figure 5: Peak Acceleration in 0-10ms: Top 9 Factors / Interactions

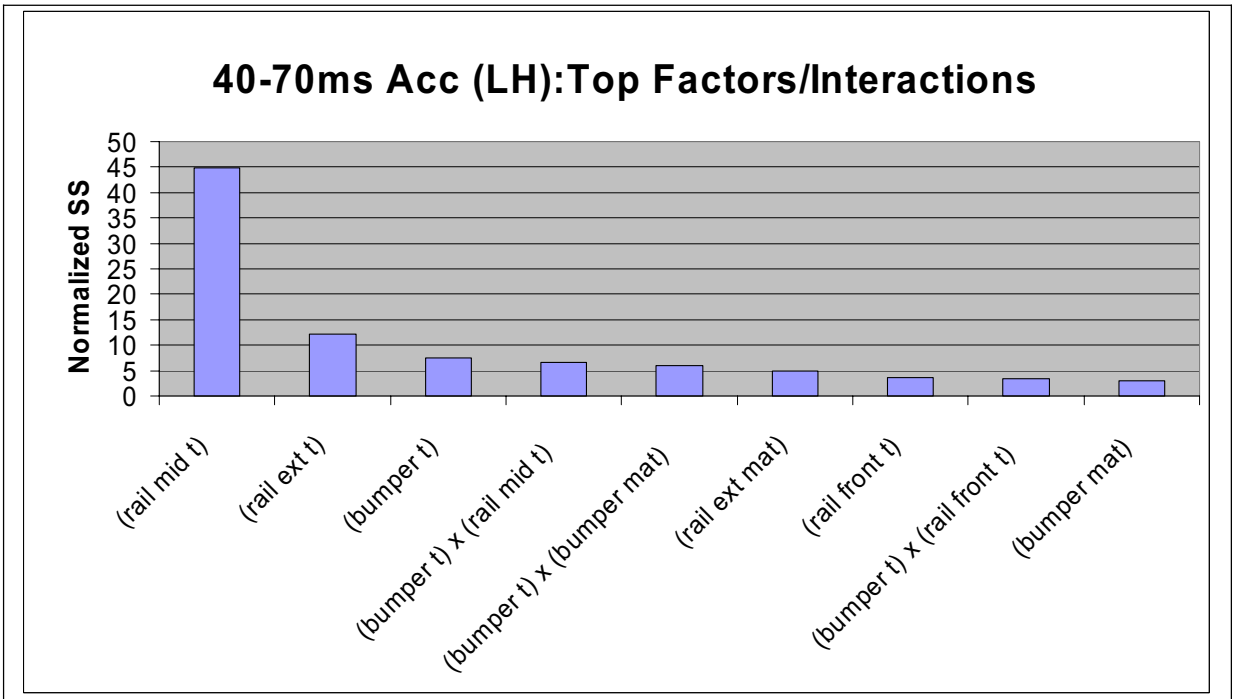


Figure 6: Peak Acceleration in 40-70ms: Top 9 Factors / Interactions

6. Conclusions

An NCAP DOE study was undertaken for *Concept 1*. Front rail and bumper grades and gauges were selected as design variables. The study showed that gauges had a more significant effect on the NCAP performance than grades. The dominant effect of gauges suggests that the design lacks geometric stability. Hence, the full potential of high strength materials is not realized as the rails do not crush well axially.

7. Future Work

A final design for Concept 1 will be obtained, based on the NCAP DOE study. The final Concept 1 design will be compared to Concepts 2 and 3 that will be later developed in Phase II of the Lightweight Front End Structure Project.

8. References

1) *Validated FE Models, Milestone 5*, SPHINX, Phase II.

2) *Enhanced FE Models, Milestone 6*, SPHINX, Phase II.

3) *IIHS Crashworthiness Evaluation Offset Barrier Crash Test Protocol Version IX), October 2002.*

4) *DOE FE Models, Milestone 7*, SPHINX, Phase II.

5) *Third Bumper Design Report, Milestone 5*, SPHINX, Phase I.

6) *Concept 1: Preliminary Design, Milestone 10*, SPHINX, Phase II.

7) *System of Experimental Design*, *Volumes 1 & 2*, Taguchi Genichi, 1987, Kraus International Publications.

8) *NCAP 35 mph Study, Milestone 11*, SPHINX, Phase I.

9) *Upgraded Powertrain DOE Study, Milestone 15*, SPHINX, Phase I.

9. Appendix A: Concept1 Baseline FE Model

Component Name	ID	Property Name	ID	Material Name	ID	MASS (tonne)	Thickness (mm)	# Elems
att_plate_mod_lh	60003	SectShll20.1.1	60150	DP700_980_phase_ll	60080	2.38E-04	2	444
att_plate_mod_rh	60004	SectShll20.1.1	60150	DP700_980_phase_	60080	2.42E-04	2	439
bumper_front	60005	bumper_front	60151	DP700_980_phase_	60080	0.003588	1.2	12420
bumper_back	60006	bumper_back	60152	DP700_980_phase_	60080	0.002573	1.2	7786
railotr.l	60101	SectShll15.3	60117	MATL24_340	60049	0.002072	1.5	5016
railotr.r	60102	SectShll15.3	60117	MATL24_340	60049	0.001948	1.5	5204
railinr.l	60103	Sectshll16.5	60109	MATL24_250	60054	0.002754	1.65	6328
railinr.r	60104	Sectshll16.5	60109	MATL24_250	60054	0.002393	1.65	5617
railctr1.l	60105	SectShll20.1	60088	MATL24_210	60052	0.00383	2	1502
railctr1.r	60106	SectShll20.1	60088	MATL24_210	60052	0.003998	2	1658
railctr2.l	60107	SectShll12.1	60084	MATL24_340	60049	1.02E-03	1.2	486
railctr2.r	60108	SectShll12.1	60084	MATL24_340	60049	9.75E-04	1.2	472
ubrail.l	60109	SectShll95	60113	MATL24_340	60049	5.89E-04	0.95	424
ubrail.r	60110	SectShll95	60113	MATL24_340	60049	5.93E-04	0.95	430
ctrrailrnf1.l	60111	SectShll12.1	60084	MATL24_340	60049	4.45E-04	1.2	337
ctrrailrnf1.r	60112	SectShll12.1	60084	MATL24_340	60049	4.28E-04	1.2	332
ctrrailrnf3.l	60113	Sectshll14.5	60111	MATL24_340	60049	7.25E-04	1.45	432
ctrrailrnf3.r	60114	Sectshll14.5	60111	MATL24_340	60049	7.46E-04	1.45	435
ctrrailrnf2.l	60115	SectShll225	60099	MATL24_3404	60051	0.002819	2.25	923
ctrrailrnf2.r	60116	SectShll225	60099	MATL24_3404	60051	0.002855	2.25	933
trqbox1.l	60117	Sectshll14.5	60111	MATL24_210	60052	0.001434	1.45	1022
trqbox1.r	60118	Sectshll14.5	60111	MATL24_210	60052	0.001625	1.45	855
trqbox2.l	60119	Sectshll14.5	60111	MATL24_160	60048	2.71E-04	1.45	241
trqbox2.r	60120	Sectshll14.5	60111	MATL24_160	60048	2.72E-04	1.45	241
trnsrnf	60121	Sectshll17.5	60096	MATL24_340	60049	0	1.75	0
emntrnf	60122	Sectshll14.5	60111	MATL24_340	60049	2.40E-04	1.45	177
cplate	60123	Sectshll16.5	60109	MATL24_340	60049	0	1.65	0
rlinrnf.r	60124	Sectshll17.5	60096	MATL24_210	60052	2.77E-04	1.75	171
crfmbrkt.l	60201	SectShll20.1	60088	MATL24_340	60049	5.34E-04	2	292
crfmbrkt.r	60202	SectShll20.1	60088	MATL24_340	60049	5.38E-04	2	292
crdlfbrkt	60203	SectShll30	60094	MATL24_600	60056	8.68E-04	3	585
crdl.l	60205	SectShll26	60116	MATL24_340	60049	0.006018	2.6	1885
crdl.r	60206	SectShll26	60116	MATL24_340	60049	0.006321	2.6	1950
rrcrdlbdattch.l	60207	SectShll35	60106	MATL24_160	60048	0.001148	3.5	241
rrcrdlbdattch.r	60208	SectShll35	60106	MATL24_160	60048	0.001147	3.5	933
trnfext.l	60209	SectShll20.1	60088	MATL24_250	60054	0.001243	2	500
trnfext.r	60210	SectShll20.1	60088	MATL24_250	60054	0.001222	2	469
rrcrdlmnt1.l	60211	SectShll25	60091	MATL24_210	60052	0.001237	2.5	484
rrcrdlmnt1.r	60212	SectShll25	60091	MATL24_210	60052	0.001394	2.5	455

rrcrdlmnt2.l	60213	SectShll19.1	60112	MATL24_210	60052	2.84E-04	1.9	200
rrcrdlmnt2.r	60214	SectShll19.1	60112	MATL24_210	60052	2.84E-04	1.9	200
frtcrdlmnt1.l	60215	Sectshll19.5	60110	MATL24_160	60048	8.12E-04	1.95	423
frtcrdlmnt1.r	60216	Sectshll19.5	60110	MATL24_160	60048	7.34E-04	1.95	380
frtcrdlmnt2.l	60217	Sectshll14.5	60111	MATL24_210	60052	1.37E-04	1.45	109
frtcrdlmnt2.r	60218	Sectshll14.5	60111	MATL24_210	60052	1.38E-04	1.45	114
frtcrdlmnt5	60219	SectShll15.3	60117	MATL24_160	60048	4.31E-04	1.5	168
frtcrdlmnt3.l	60221	SectShll25	60091	MATL24_340	60049	4.30E-04	2.5	146
frtcrdlmnt3.r	60222	SectShll25	60091	MATL24_340	60049	3.41E-04	2.5	117
bot_bkt_l_e	60223	SectShll30	60094	MATL24_340	60049	9.59E-04	3	221
bot_bkt_r_e	60224	SectShll30	60094	MATL24_340	60049	9.29E-04	3	217
cradbrkt	60225	SectShll30	60094	MATL24_340	60049	4.46E-04	3	109
cradbrkt2	60227	SectShll30	60094	MATL24_340	60049	3.58E-04	3	48
lcarnf.l	60229	SectShll30	60094	MATL24_340	60049	3.19E-04	3	83
lcarnf.r	60230	SectShll30	60094	MATL24_340	60049	3.41E-04	3	73
lcajnt_1.L1	60231	SectShll30	60094	rigid	60014	4.12E-05	3	8
lcajnt_1.R1	60232	SectShll30	60094	rigid	60014	4.12E-05	3	8
lcacyl.l	60235	SectShll50	60092	MATL24_160	60048	0.001295	5	180
lcacyl.r	60236	SectShll50	60092	MATL24_160	60048	0.001295	5	180
lcajnt_1.L2	60239	SectShll30	60094	rigid	60014	3.16E-05	3	8
lcajnt_1.R2	60240	SectShll30	60094	rigid	60014	3.16E-05	3	8
cradbrkt1	60241	SectShll10.1	60083	MATL24_180	60046	2.36E-04	1	177
crdlblt	60243	SectShll20.1	60088	MATL24_160	60048	2.41E-04	2	80
crdlrrxupr	60244	SectShll25	60091	MATL24_340	60049	0.002183	2.5	532
crdlrrxlwr	60245	SectShll23	60090	MATL24_340	60049	0.00129	2.3	351
urail_l	60301	SectShll8.3	60081	MATL24_160	60048	0.001457	0.8	1472
urail_r	60302	SectShll8.3	60081	MATL24_160	60048	0.001456	0.8	1470
urail_rnf2.l	60303	SectShll9.1	60082	MATL24_160	60048	4.72E-04	0.9	368
urail_rnf1.r	60304	SectShll9.1	60082	MATL24_160	60048	4.71E-04	0.9	368
pnlfrt1.l	60305	Sectshll75	60097	MATL24_210	60052	5.44E-04	0.75	663
pnlfrt1.r	60306	Sectshll75	60097	MATL24_210	60052	6.27E-04	0.75	567
shock.l	60307	Sectshll17.5	60096	MATL24_160	60048	0.001517	1.75	585
shock.r	60308	Sectshll17.5	60096	MATL24_160	60048	0.001546	1.75	614
pnlfrt2.l	60309	SectShll12.1	60084	MATL24_210	60052	0.001235	1.2	999
pnlfrt2.r	60310	SectShll12.1	60084	MATL24_210	60052	0.001294	1.2	765
plnmbrkt	60311	SectShll8.3	60081	MATL24_210	60052	1.50E-04	0.8	160
rnfpnldshext2	60312	SectShll8.3	60081	MATL24_210	60052	1.93E-04	0.8	222
temp	60313	SectShll7.2	60080	MATL24_600	60056	2.63E-04	0.7	272
frtflr	60401	SectShll085	60118	MATL24_160	60048	0.013015	0.85	10420
bar1	60402	SectShll20.1	60088	MATL24_3404	60051	0.00262	2	936
tnl1	60403	SectShll18.1	60087	MATL24_340	60049	0.001311	1.8	583
tnl2	60404	SectShll12.1	60084	MATL24_250	60054	0.006463	1.2	3950
dash	60405	SectShll95	60113	MATL24_160	60048	0.008026	0.95	5859
cowlupr	60406	SectShll8.3	60081	MATL24_210	60052	0.001526	0.8	1219
fflrlvrrnf	60407	SectShll15.3	60117	MATL24_160	60048	7.10E-04	1.5	315
pedal2	60408	SectShll30	60094	MATL24_160	60048	0.001364	3	502
wndshld.supt.upr	60409	Sectshll75	60097	MATL24_160	60048	0.002599	0.75	2388
plnmltintjnt	60410	Sectshll75	60097	MATL24_160	60048	0.004045	0.75	2904
rein_upr	60411	SectShll15.3	60117	MATL24_210	60052	9.29E-04	1.5	620

MTG1	60412	SectShll10.1	60083	MATL24_210	60052	4.34E-04	1	432
BRKT_Consol	60413	SectShll15.3	60117	MATL24_210	60052	6.89E-04	1.5	566
crush_brkt_lwr	60414	SectShll20.1	60088	MATL24_210	60052	0.002868	2	826
bar2.l	60501	SectShll12.1	60084	MATL24_160	60048	0.001367	1.2	797
bar2.r	60502	SectShll12.1	60084	MATL24_160	60048	0.001368	1.2	797
2barreinf	60503	SectShll17	60086	MATL24_340	60049	0.00249	1.7	922
22678921_256_1	60505	SectShll12.1	60084	MATL24_160	60048	2.43E-04	1.2	159
22678920_256_1	60506	SectShll12.1	60084	MATL24_160	60048	2.43E-04	1.2	159
22678921_255_1	60507	SectShll12.1	60084	MATL24_160	60048	1.85E-04	1.2	130
22678920_255_1	60508	SectShll12.1	60084	MATL24_160	60048	1.85E-04	1.2	130
seatrein.l	60509	SectShll12.1	60084	MATL24_160	60048	3.45E-04	1.2	227
seatrein.r	60510	SectShll12.1	60084	MATL24_160	60048	3.46E-04	1.2	227
tiebar3.l	60601	Sectshll75	60097	MATL24_180	60046	6.78E-04	0.75	698
tiebar3.r	60602	Sectshll75	60097	MATL24_180	60046	7.22E-04	0.75	779
tiebar4.l	60603	Sectshll75	60097	MATL24_180	60046	4.27E-05	0.75	120
tiebar4.r	60604	Sectshll75	60097	MATL24_180	60046	4.44E-05	0.75	148
lhfanmotor	60605	SectShll20.1	60088	MATL24_181	60047	5.60E-04	2	143
rhfanmotor	60606	SectShll20.1	60088	MATL24_181	60047	5.40E-04	2	133
tiebar	60607	SectShll9.1	60082	MATL24_210	60052	0.002278	0.9	1788
tiebar2	60608	SectShll9.1	60082	MATL24_160	60048	0.001152	0.9	984
radsupport	60609	SectShll10.1	60083	MATL24_160	60048	0.001261	1	321
rad4	60610	SectShll10.1	60083	MATL24_160	60048	8.32E-06	1	8
Part_2	60611	SectShll10.1	60083	MATL9_2	60006	0.014989	1	4716
rad2	60612	SectSld900	60121	MAT57rad&cond	60059	0.002656	0	527
rad1	60613	SectSld900	60121	MAT57rad&cond	60059	0.003782	0	627
fanshroud	60614	SectShll20.1	60088	MATL24_181	60047	0.007298	2	1531
Engine	60701		part inertia			0.304199		
pt2	60702	SectShll10.1	60083	rigid	60014	0.001123	1	681
pt3	60703	SectShll10.1	60083	rigid	60014	0.006404	1	4098
pt7	60704	SectShll10.1	60083	rigid	60014	0.001243	1	632
pt8	60705	SectShll20.1	60088	rigid	60014	0.005065	2	1108
pt10	60706	SectShll10.1	60083	rigid	60014	9.92E-04	1	463
pt11	60707	SectShll225	60099	rigid	60014	0.001335	2.25	284
pt13	60708	SectShll10.1	60083	rigid	60014	1.07E-04	1	56
pt14	60709	SectShll10.1	60083	rigid	60014	0.001639	1	475
pt19	60710	SectShll10.1	60083	rigid	60014	4.08E-04	1	788
pt18	60711	SectShll40	60093	rigid	60014	0.007253	4	985
frtmnt1	60712	SectShll20.1	60088	MATL24_160	60048	1.04E-03	2	335
frtmnt2	60713	SectShll225	60099	MATL24_160	60048	3.84E-04	2.25	151
pt9	60714	SectShll100	60104	rigid	60014	0.005277	10	215
pt12	60715	SectShll80	60095	rigid	60014	0.007011	8	714
pt16	60716	SectShll40	60093	rigid	60014	0.003234	4	2691
pt17	60717	SectShll30	60094	MATL24_160	60048	0.007696	3	1951
expipefrt	60718	SectShll15.3	60117	MATL24_160	60048	0.003601	1.5	1173
ep_7685	60719	SectShll10.1	60083	rigid	60014	2.83E-04	1	476
flywheel	60720	SectShll10.1	60083	rigid	60014	7.92E-04	1	288
ep_4776	60721	SectShll10.1	60083	rigid	60014	4.99E-04	1	353
ep_7498	60722	SectShll10.1	60083	rigid	60014	0.002605	1	895
ep_0939	60723	SectShll10.1	60083	rigid	60014	5.79E-04	1	293

ep_0017	60724	SectShll10.1	60083	rigid	60014	4.50E-04	1	242
ep_70842	60725	SectShll10.1	60083	rigid	60014	1.84E-04	1	76
eng_mnt_l_e	60726	SectShll80	60095	MATL24_160	60048	0.002636	8	187
top_bkt_l_e	60727	SectShll80	60095	MAT24_1111	60045	5.72E-04	8	151
eng_mnt_r_e	60728	SectShll80	60095	MATL24_160	60048	0.002631	8	187
top_bkt_r_e	60729	SectShll80	60095	MAT24_1111	60045	1.01E-03	8	308
eng_deformable	60730	SectShll80	60095	MATL24_160	60048	0.001725	8	133
62109a_e1	60731	SectShll37	60108	MATL24_160	60048	3.62E-04	3.7	155
62109a_e2	60732	SectShll37	60108	MATL24_160	60048	1.22E-04	3.7	36
62109a_e3	60733	SectShll37	60108	MATL24_160	60048	4.00E-04	3.7	170
62109b_e1	60734	SectShll10.1	60083	MATL24_160	60048	4.06E-04	1	692
rrmnt_bushing	60735	SectShll20.1	60088	MATL24_160	60048	5.79E-04	2	376
tire1.l	60801	SectShll20.1	60088	mat1.tirerubber	60007	0.00197	2	1320
tire1.r	60802	SectShll20.1	60088	mat1.tirerubber	60007	0.00197	2	1320
tire3.l	60803	SectShll3.3	60107	MATL24_160	60048	1.00E-03	0.3	540
tire2.r	60804	SectShll3.3	60107	MATL24_160	60048	1.00E-03	0.3	540
tir2.l	60805	SectShll7.2	60080	MATL24_160	60048	0.002042	0.7	360
tire3.r	60806	SectShll7.2	60080	MATL24_160	60048	0.002042	0.7	360
rim.l	60807	SectShll35	60106	MATL24_600	60056	0.008136	3.5	720
rim.r	60808	SectShll35	60106	MATL24_600	60056	0.008136	3.5	720
lwrcntrlarm.l	60809	SectShll30	60094	MATL24_160	60048	0.002294	3	465
lwrcntrlarm.r	60810	SectShll30	60094	MATL24_160	60048	0.002289	3	465
lcajnt_2.L1	60811	SectShll30	60094	rigid	60014	6.26E-05	3	21
lcajnt_2.R1	60812	SectShll30	60094	rigid	60014	6.33E-05	3	21
driveline	60813	SectShll70	60103	MATL24_340	60049	0.005373	7	496
lcajnt_2.L2	60815	SectShll30	60094	rigid	60014	2.76E-05	3	10
lcajnt_2.R2	60816	SectShll30	60094	rigid	60014	2.76E-05	3	10
fsuspstrut.l	60817	SectShll50	60092	MATL24_160	60048	0.005601	5	207
fsuspstrut.r	60818	SectShll50	60092	MATL24_160	60048	0.005601	5	207
crdlbltrnf	60819	SectShll275.1	60102	MATL24_160	60048	3.23E-04	2.75	74
strclnmend3	60820	SectShll50	60092	rigid	60014	3.64E-04	5	50
strngrack	60821	SectShll60	60101	MAT24_1111	60045	0.002617	6	446
strrackends	60822	SectShll60	60101	MATL24_160	60048	0.001165	6	122
stabbar	60823	SectShll40	60093	MATL24_160	60048	0.004576	4	576
btray1	60901	SectShll15.3	60117	MATL24_160	60048	0.003147	1.5	667
btray2	60902	SectShll10.1	60083	MATL24_160	60048	2.19E-04	1	230
battery1	60903	SectShll5.3	60105	MATL24_160	60048	8.66E-04	0.5	654
ECM	60904	SectShll10.1	60083	MATL24_160	60048	1.07E-03	1	322
battery_fill	60905	SectShll10.1	60083	MATL24_160	60048	0.001326	1	432
fcomptrnf2	60906	SectShll40	60093	MATL24_160	60048	0.002901	4	350
abs_brkt	60907	SectShll20.1	60088	MATL24_160	60048	4.33E-04	2	120
brkt_boost	60908	90060072	60042	90060009	60012	0.00385	3	912
edge	61001	SectShll2.1.1	60077	MAT24_3	60042	1.06E-03	1.35	146
inner	61002	SectShll3.2.1	60078	MAT24_3	60042	0.005147	0.7	1081
outer	61003	SectShll4.1.1	60079	MAT24_3	60042	0.008252	0.7	837
MODPLT	61101	90060005	60010	90060020	60041	0.001613	1.5	336
CSUPT_forw	61102	90060006	60011	90060020	60041	5.32E-04	1.22	1091
can	61103	90060008	60012	90060020	60041	6.77E-04	1.2	227
can1	61104	90060009	60013	90060020	60041	9.87E-05	1.2	63

can2	61105	90060010	60014	90060020	60041	1.09E-04	1.2	46
can.1	61106	90060011	60015	90060020	60041	9.05E-05	1.2	23
inflator	61107	90060012	60016	90060020	60041	0.001456	5.4	50
Brkt-1	61108	90060063	60039	90060020	60041	6.07E-04	3	1092
gaspdel	61109	90060068	60040	90060020	60041	1.65E-04	2.5	346
stelpeice	61110	90060071	60041	90060020	60041	1.54E-04	3	249
SIPO_p	61111	90060014	60018	90060020	60041	6.06E-04	2	66
SIPO_d2	61112	90060015	60019	90060020	60041	6.11E-04	2	72
Steel_strip	61113	90060016	60020	90060020	60041	1.07E-04	1.5	12
Floor_Brkt2	61114	90060037	60022	90060020	60041	8.95E-04	2.5	74
Center_Stk_brkt	61115	90060038	60023	90060020	60041	3.09E-04	1.5	53
lower	61116	90060044	60026	90060013	60036	8.85E-04	2.43	258
upper	61117	90060045	60027	90060013	60036	8.69E-04	2.36	410
hvacbrkt_add	61118	90060046	60028	90060013	60036	2.49E-05	2.36	28
heatercvr	61119	90060047	60029	90060013	60036	3.21E-04	2.38	62
ai	61120	90060048	60030	90060013	60036	3.74E-04	2.1	216
ai_icebox	61121	90060049	60031	90060013	60036	1.51E-05	2.1	48
ai_actuator	61122	90060050	60032	90060013	60036	2.81E-05	2	75
lower_actuator	61123	90060051	60033	90060013	60036	2.86E-05	2	116
foamplate	61124	90060052	60034	90060020	60041	5.74E-05	1	44
filmvalve	61125	90060053	60035	90060013	60036	1.67E-04	2	129
arm1_srib	61126	90060054	60036	90060013	60036	8.90E-05	2	222
rib_4_hub	61127	90060055	60037	90060013	60036	1.42E-04	3.5	100
Lower_add1	61128	90060056	60038	90060013	60036	1.16E-05	2	45
foam	61129	90060125	60119	90060001	60001	1.48E-06	0	136
evapblock	61130	90060126	60120	90060003	60003	3.52E-05	0	48
IBEC	61131	90060013	60017	90060005	60004	3.04E-04	2	115
evap_lower_tube1	61132	90060041	60024	90060002	60002	8.68E-06	1	10
evap_upper_tube1	61133	90060041	60024	90060002	60002	1.38E-05	1	10
heat_upper_tube1	61134	90060041	60024	90060002	60002	4.22E-05	1	36
heat_lower_tube1	61135	90060041	60024	90060002	60002	2.58E-05	1	20
il	61136	90060042	60025	90060014	60037	1.89E-04	1	159
IP_sidepnl_E	61137	90060026	60021	90060015	60038	1.24E-04	2.5	47
sipo_fixed1	61138	90060015	60019	90060008	60011	1.39E-06	2	1
sipo_fixed2	61139	90060015	60019	90060008	60011	1.46E-06	2	1
sipo_fixed3	61140	90060015	60019	90060008	60011	1.53E-06	2	1
sipo_fixed4	61141	90060015	60019	90060008	60011	1.13E-06	2	1
sipo_fixed5	61142	90060015	60019	90060008	60011	1.85E-06	2	1
sipo_fixed6	61143	90060015	60019	90060008	60011	1.95E-06	2	1
sipo_fixed7	61144	90060015	60019	90060008	60011	1.83E-06	2	1
sipo_p_fixed7	61145	90060014	60018	90060008	60011	1.41E-06	2	1
sipo_p_fixed6	61146	90060014	60018	90060008	60011	1.59E-06	2	1
sipo_p_fixed5	61147	90060014	60018	90060008	60011	1.71E-06	2	1
sipo_p_fixed4	61148	90060014	60018	90060008	60011	1.13E-06	2	1
sipo_p_fixed3	61149	90060014	60018	90060008	60011	1.85E-06	2	1
sipo_p_fixed2	61150	90060014	60018	90060008	60011	1.95E-06	2	1
sipo_p_fixed12	61151	90060014	60018	90060008	60011	1.83E-06	2	1
modplate_rigid1	61152	90060005	60010	90060008	60011	1.55E-06	1.5	1
modplate_rigid2	61153	90060005	60010	90060008	60011	2.34E-06	1.5	1

modplate_rigid32	61154	90060005	60010	90060008	60011	1.45E-06	1.5	1
modplate_rigid4	61155	90060005	60010	90060008	60011	1.65E-06	1.5	1
modplate_rigid5	61156	90060005	60010	90060008	60011	1.58E-06	1.5	1
modplate_rigid6	61157	90060005	60010	90060008	60011	1.98E-06	1.5	1
modplate_rigid7	61158	90060005	60010	90060008	60011	9.84E-07	1.5	1
modplate_rigid8	61159	90060005	60010	90060008	60011	1.76E-06	1.5	1
e.pedal	61160	90060073	60043	90060011	60034	8.37E-04	8	377
e.pad	61164	90060074	60044	90060011	60034	1.20E-04	3.5	120
e.pin	61165	90060075	60045	90060011	60034	1.14E-04	2	272
pedalpivout	61167	90060072	60042	90060009	60012	8.58E-06	3	16
pedalpivinb	61168	90060072	60042	90060009	60012	8.58E-06	3	16
pedallink	61169	90060072	60042	90060009	60012	1.43E-06	3	4
pivot inb	61170	90060072	60042	90060009	60012	4.32E-06	3	10
pivot out	61171	90060072	60042	90060009	60012	1.10E-06	3	8
Part221130	61172	90060072	60042	90060009	60012	1.08E-06	3	1
Part221131	61173	90060072	60042	90060009	60012	1.39E-06	3	1
Part221132	61174	90060072	60042	90060009	60012	9.68E-07	3	1
Part221133	61175	90060072	60042	90060009	60012	9.79E-07	3	1
Part221134	61176	90060072	60042	90060009	60012	6.86E-07	3	2
Part221135	61177	90060072	60042	90060009	60012	1.30E-06	3	2
Part221136	61178	90060072	60042	90060009	60012	9.62E-07	3	1
dr_ealf	61179	90060077	60047	90060011	60034	2.25E-04	1.5	103
dr_eart	61180	90060077	60047	90060020	60041	2.25E-04	1.5	87
ps_eart	61181	90060076	60046	90060020	60041	1.64E-04	1.5	85
ps_eart.1	61182	90060076	60046	90060020	60041	1.64E-04	1.5	92
floor_attachment	61183	90060078	60048	90060020	60041	5.18E-04	2	78
tunlbkt_fixdeles	61184	90060078	60048	90060010	60013	1.18E-06	2	1
tunlbkt_fixdeles	61185	90060078	60048	90060010	60013	1.27E-06	2	1
tunlbkt_fixdeles	61186	90060078	60048	90060010	60013	2.33E-06	2	1
tunlbkt_fixdeles	61187	90060078	60048	90060010	60013	1.83E-06	2	1
tunlbkt_fixdeles	61188	90060078	60048	90060010	60013	4.47E-06	2	1
tunlbkt_fixdeles	61189	90060078	60048	90060010	60013	7.59E-06	2	1
tunlbkt_fixdeles	61190	90060078	60048	90060010	60013	2.76E-06	2	1
tunlbkt_fixdeles	61191	90060078	60048	90060010	60013	3.89E-06	2	1
gboxframe_base	61192	90060080	60049	90060016	60039	3.92E-04	2.5	867
vribs_gboxframe	61193	90060081	60050	90060016	60039	4.81E-06	1	85
hribs_gboxframe	61194	90060082	60051	90060016	60039	2.76E-05	1.2	228
Mag_6.5.1.1	61196	90060100	60052	90060012	60035	3.18E-04	6.5	94
Mag_3.0.1.1	61197	90060101	60053	90060012	60035	0.00345	3	1465
Mag_4.0.1.1	61198	90060102	60054	90060012	60035	4.81E-04	4	151
Mag_ribs.1.1	61199	90060103	60055	90060012	60035	0.002748	3	1009
Mag_1.5.1.1	61200	90060104	60056	90060012	60035	1.28E-04	1.5	75
Mag_5.0.1	61201	90060105	60057	90060012	60035	1.40E-04	5	24
Mag_2.5	61202	90060106	60058	90060012	60035	2.65E-04	2.5	84
inner.1	61203	90060107	60059	90060016	60039	3.58E-04	3	613
innergroorve	61204	90060111	60063	90060016	60039	8.37E-07	3.3	10
ribs.1	61205	90060112	60064	90060016	60039	1.36E-04	1.25	720
bin o	61206	90060108	60060	90060017	60040	2.74E-04	2.5	117
ribbin	61207	90060110	60062	90060017	60040	5.71E-07	1.7	8

bintongue	61208	90060109	60061	90060017	60040	4.40E-07	1.1	6
outer.1	61209	90060113	60065	90060016	60039	2.85E-04	2.5	635
hub	61210	90060115	60067	90060016	60039	1.76E-06	1	124
outerhrib	61211	90060114	60066	90060016	60039	7.18E-06	1.2	46
outervrib	61212	90060115	60067	90060016	60039	3.35E-07	1	4
hubrib	61213	90060116	60068	90060016	60039	1.93E-07	1.375	24
glvbx_frm_hinge_	61214	90060117	60069	90060016	60039	8.29E-06	3	68
knee bolster inn	61215	90060118	60070	90060016	60039	2.66E-04	2.5	509
inner rib h	61216	90060119	60071	90060016	60039	1.25E-04	1.875	248
small rib inner	61217	90060120	60072	90060016	60039	3.27E-06	2.6	24
knee bolster out	61218	90060121	60073	90060016	60039	4.25E-04	2.5	532
doghouse outer	61219	90060122	60074	90060016	60039	6.40E-06	1.4	55
outer rib	61220	90060123	60075	90060016	60039	4.29E-06	1.1	39
tipof bin	61221	90060124	60076	90060016	60039	5.01E-05	2.5	54
part.9	61301	SectShll20.1	60088	MAT9_704	60009	1.21E-04	2	288
part.10	61302	SectShll20.1	60088	MAT9_705	60010	5.21E-05	2	147
part.11	61303	SectShll5.3	60105	MAT20_706	60015	5.98E-05	0.5	419
part.14	61304	SectShll20.1	60088	MAT20_750	60016	0.001699	2	515
part.15	61305	SectShll10.1	60083	MAT20_751	60017	8.05E-05	1	80
part.16	61306	SectShll34	60115	MAT20_752	60018	1.83E-04	3.4	136
part.17	61307	SectShll25	60091	MAT20_753	60019	5.23E-04	2.5	458
part.18	61308	SectShll25	60091	MAT20_754	60020	6.50E-04	2.5	493
part.19	61309	SectShll20.1	60088	MAT20_755	60021	5.14E-04	2	458
part.20	61310	SectShll30	60094	MAT20_756	60022	4.70E-04	3	96
part.21	61311	SectShll34	60115	MAT20_757	60023	2.55E-04	3.4	110
part.22	61312	SectShll20.1	60088	MAT20_758	60024	5.61E-05	2	52
part.24	61313	SectShll20.1	60088	MAT20_760	60025	1.14E-04	2	42
part.25	61314	SectShll20.1	60088	MAT20_761	60026	8.86E-05	2	58
part.28	61315	SectShll20.1	60088	MAT20_764	60027	2.43E-05	2	22
part.29	61316	SectShll20.1	60088	MAT20_765	60028	2.32E-05	2	21
part.30	61317	SectShll40	60093	MAT20_766	60029	3.95E-06	4	1
part.31	61318	SectShll40	60093	MAT20_767	60030	3.95E-06	4	1
part.34	61319	SectShll40	60093	MAT24_771	60044	2.43E-05	4	72
part.40	61320	SectShll30	60094	MAT20_777	60031	3.28E-04	3	204
part.41	61321	SectShll30	60094	MAT20_778	60032	3.69E-04	3	118
strclnmend4	61323	SectShll50	60092	rigid	60014	2.10E-04	5	28
part.49	61324	SectShll15.3	60117	MAT20_20015	60033	9.89E-06	1.5	8
drinrpnl.l	61401	Sectshll75	60097	MATL24_160	60048	0.003637	0.75	1077
drlwrhng.l	61402	SectShll50	60092	MATL24_160	60048	1.28E-04	5	14
drotrpnl.l	61403	Sectshll75	60097	MATL24_180	60046	0.004388	0.75	439
z-brkt.l	61404	SectShll10.1	60083	MATL24_160	60048	5.56E-05	1	50
upr_frame.l	61405	SectShll10.1	60083	MATL24_160	60048	0.001997	1	726
drbeam.l	61406	SectShll20.1	60088	MATL24_600	60056	0.001914	2	386
druprhng.l	61407	SectShll50	60092	MATL24_160	60048	1.30E-04	5	14
drinrpnl.r	61408	Sectshll75	60097	MATL24_160	60048	0.003636	0.75	1109
drotrpnl.r	61409	Sectshll75	60097	MATL24_180	60046	0.004388	0.75	439
z-brkt.r	61410	SectShll10.1	60083	MATL24_160	60048	5.56E-05	1	50
upr_frame.r	61411	SectShll10.1	60083	MATL24_160	60048	0.001997	1	726
drbeam.r	61412	SectShll20.1	60088	MATL24_600	60056	0.001913	2	386

druphng.r	61413	SectShll50	60092	MATL24_160	60048	1.34E-04	5	14
drlwhng.r	61414	SectShll50	60092	MATL24_160	60048	1.26E-04	5	14
fdrbdhng	61415	SectShll50	60092	MATL24_210	60052	2.07E-04	5	23
fdrbdhng2	61416	SectShll20.1	60088	rigid	60014	1.96E-05	2	8
fdrbdhng3	61417	SectShll20.1	60088	rigid	60014	2.43E-05	2	12
fdrbdhng4	61418	SectShll50	60092	MATL24_210	60052	2.01E-04	5	22
fdrbdhng5	61419	SectShll20.1	60088	rigid	60014	2.07E-05	2	8
fdrbdhng6	61420	SectShll20.1	60088	rigid	60014	2.54E-05	2	12
fdrbdhng7	61421	SectShll50	60092	MATL24_210	60052	2.55E-04	5	38
fdrbdhng8	61422	SectShll20.1	60088	rigid	60014	2.01E-05	2	8
fdrbdhng9	61423	SectShll20.1	60088	rigid	60014	2.48E-05	2	12
fdrbdhng10	61424	SectShll50	60092	MATL24_210	60052	1.97E-04	5	22
fdrbdhng11	61425	SectShll20.1	60088	rigid	60014	2.07E-05	2	8
fdrbdhng12	61426	SectShll20.1	60088	rigid	60014	2.49E-05	2	12
drlsrwld.l	61427	SectShll18.1	60087	MATL24_160	60048	0.003567	1.8	561
drlsrwld.r	61428	SectShll18.1	60087	MATL24_160	60048	0.003567	1.8	570
rrdrinn.l	61429	Sectshll75	60097	MATL24_160	60048	0.006811	0.75	2598
twdrrdrinr.l	61430	SectShll18.1	60087	MATL24_160	60048	0.005454	1.8	1238
rrdrotr.l	61431	Sectshll75	60097	MATL24_160	60048	0.008021	0.75	1014
rrdrfrm.l	61432	SectShll10.1	60083	MATL24_160	60048	0.003331	1	1266
rrdrbm.l	61433	SectShll20.1	60088	MATL24_600	60056	0.002513	2	666
bathtub.l	61434	SectShll20.1	60088	MATL24_160	60048	2.59E-04	2	94
rrdrhng.l	61435	SectShll50	60092	MATL24_160	60048	1.06E-03	5	396
latchjt.l	61436	SectShll20.1	60088	MATL24_160	60048	2.28E-04	2	306
rrdrhng1.l	61437	SectShll50	60092	MATL24_160	60048	6.20E-04	5	404
roof	61501	Sectshll75	60097	MATL24_160	60048	0.010108	0.75	1190
wshield	61502	SectShll48	60100	laminatedglass	60058	0.015411	4.8	700
rr_wndshld	61503	SectShll48	60100	laminatedglass	60058	0.011652	4.8	130
bdysdpnlotr.l	61601	Sectshll75	60097	MATL24_160	60048	0.014307	0.75	7706
bdysdpnlotr.r	61602	Sectshll75	60097	MATL24_160	60048	0.014308	0.75	7697
twldbsideinr.l	61603	SectShll21	60089	MATL24_160	60048	0.00905	2.1	3336
twldbsideinr.r	61604	SectShll21	60089	MATL24_160	60048	0.009056	2.1	3336
rkrx_l	61605	Sectshll13	60098	MATL24_340	60049	1.01E-03	1.3	552
rkrx_r	61606	Sectshll13	60098	MATL24_340	60049	1.01E-03	1.3	569
rkrinr.l	61607	sectshll16	60114	MATL24_3404	60051	0.003811	1.6	1603
rkrinr.r	61608	sectshll16	60114	MATL24_3404	60051	0.003811	1.6	1593
twldB-plr.l	61609	SectShll18.1	60087	MATL24_250	60054	0.003041	1.8	1144
twldB-plr.r	61610	SectShll18.1	60087	MATL24_250	60054	0.003041	1.8	1144
bdysdpnlinr.l	61611	SectShll10.1	60083	MATL24_160	60048	0.009621	1	3477
bdysdpnlinr.r	61612	SectShll10.1	60083	MATL24_160	60048	0.009567	1	3528
B_plr_rnf	61613	SectShll10.1	60083	MATL24_160	60048	6.01E-04	1	350
bplrrnf.l	61615	SectShll225	60099	MATL24_250	60054	0.003029	2.25	1004
bplrrnf.r	61616	SectShll225	60099	MATL24_250	60054	0.003029	2.25	1004
rfrailrnfl	61617	SectShll20.1	60088	MATL24_210	60052	0.002007	2	847
rfrailrnfr	61618	SectShll20.1	60088	MATL24_210	60052	0.002007	2	847
frt_hrn	61619	SectShll20.1	60088	MATL24_160	60048	7.90E-04	2	287
rfrailinr.r	61620	SectShll20.1	60088	MATL24_160	60048	7.85E-04	2	283
a_pilar_rnf_l	61621	SectShll10.1	60083	MATL24_160	60048	9.04E-04	1	667
a_pilar_rnf_r	61622	SectShll10.1	60083	MATL24_160	60048	9.05E-04	1	667

fbhplrrnf1.l	61623	SectShll10.1	60083	MATL24_210	60052	0.001632	1	1066
fbhplrrnf1.r	61624	SectShll10.1	60083	MATL24_210	60052	0.001634	1	1074
frthdr	61625	SectShll7.2	60080	MATL24_160	60048	9.30E-04	0.7	818
rfbow2	61626	SectShll9.1	60082	MATL24_340	60049	9.23E-04	0.9	884
rearflr	61627	SectShll8.3	60081	MATL24_160	60048	0.017539	0.8	4637
bar3	61628	SectShll10.1	60083	MATL24_211	60053	0.002442	1	1356
bar4ctr	61629	SectShll10.1	60083	MATL24_340	60049	0.001438	1	106
bar4lft	61630	SectShll15.3	60117	MATL24_160	60048	0.001168	1.5	62
rrrail.l	61631	SectShll15.3	60117	MATL24_251	60055	0.005535	1.5	776
rrrailrnf1.l	61632	SectShll10.1	60083	MATL24_160	60048	1.93E-04	1	21
rrailrnf2.l	61633	SectShll10.1	60083	MATL24_160	60048	2.10E-04	1	33
gusset.l	61634	SectShll15.3	60117	MATL24_160	60048	7.13E-04	1.5	224
gusset2.l	61635	SectShll15.3	60117	MATL24_160	60048	8.44E-04	1.5	235
gusset3.l	61636	SectShll15.3	60117	MATL24_160	60048	5.19E-04	1.5	202
gusset4.l	61637	SectShll15.3	60117	MATL24_160	60048	5.89E-04	1.5	216
whlhsinr.l	61638	SectShll10.1	60083	MATL24_160	60048	0.002906	1	269
4barrnf1.l	61639	SectShll20.1	60088	MATL24_160	60048	0.001399	2	67
4barrnf2.l	61640	SectShll25	60091	MATL24_160	60048	7.24E-04	2.5	36
backpanel	61641	SectShll8.3	60081	MATL24_160	60048	0.005311	0.8	616
bpnlrnf	61642	Sectshll75	60097	MATL24_160	60048	0.001933	0.75	222
rrhdr	61643	SectShll9.1	60082	MATL24_160	60048	0.001131	0.9	176
rrsuspshk.l	61644	SectShll225	60099	MATL24_160	60048	3.05E-04	2.25	9
rkrblkhds	61645	SectShll12.1	60084	MATL24_340	60049	7.54E-04	1.2	726
rdeck	61646	SectShll10.1	60083	MATL24_160	60048	0.005446	1	496
trnkgtrfrt	61647	SectShll10.1	60083	MATL24_160	60048	0.00209	1	224
rdeckbrkt1	61648	SectShll10.1	60083	MATL24_160	60048	9.01E-04	1	93
rdeckbrkt2	61649	SectShll10.1	60083	MATL24_160	60048	2.49E-04	1	30
trnkgtr.l	61650	SectShll9.1	60082	MATL24_160	60048	3.97E-04	0.9	79
rdeckbrkt3.l	61651	SectShll10.1	60083	MATL24_160	60048	8.76E-04	1	104
rdeckbrkt4.l	61652	SectShll10.1	60083	MATL24_160	60048	7.67E-04	1	113
trlrhtchbrkt	61653	SectShll10.1	60083	MATL24_160	60048	0.001306	1	152
rrailext.l	61654	SectShll15.3	60117	MATL24_160	60048	7.55E-04	1.5	74
bar4rt	61655	SectShll15.3	60117	MATL24_160	60048	0.001168	1.5	62
rrrail.r	61656	SectShll15.3	60117	MATL24_251	60055	0.005519	1.5	776
rrailrnf1.r	61657	SectShll10.1	60083	MATL24_160	60048	1.93E-04	1	21
rrailrnf2.r	61658	SectShll10.1	60083	MATL24_160	60048	2.10E-04	1	33
gusset.r	61659	SectShll15.3	60117	MATL24_160	60048	7.13E-04	1.5	224
gusset2.r	61660	SectShll15.3	60117	MATL24_160	60048	8.44E-04	1.5	235
gusset3.r	61661	SectShll15.3	60117	MATL24_160	60048	5.19E-04	1.5	202
gusset4.r	61662	SectShll15.3	60117	MATL24_160	60048	5.87E-04	1.5	216
whlhsinr.r	61663	SectShll10.1	60083	MATL24_160	60048	0.003046	1	288
4barrnf1.r	61664	SectShll20.1	60088	MATL24_160	60048	0.001459	2	71
4barrnf2.r	61665	SectShll25	60091	MATL24_160	60048	6.97E-04	2.5	35
rrsuspshk.r	61666	SectShll225	60099	MATL24_160	60048	3.05E-04	2.25	9
trnkgtr.r	61667	SectShll9.1	60082	MATL24_160	60048	4.00E-04	0.9	79
rdeckbrkt3.r	61668	SectShll10.1	60083	MATL24_160	60048	8.73E-04	1	101
rdeckbrkt4.r	61669	SectShll10.1	60083	MATL24_160	60048	7.63E-04	1	110
rrailext.r	61670	SectShll15.3	60117	MATL24_160	60048	7.48E-04	1.5	74
fbhpbulkhd.l	61671	SectShll20.1	60088	MATL24_340	60049	5.83E-04	2	268

rkrblkhds.1	61672	SectShll12.1	60084	MATL24_340	60049	2.83E-04	1.2	320
accl.r	61673	SectShll10.1	60083	rigid	60014	4.29E-05	1	4
accl.l	61674	SectShll10.1	60083	rigid	60014	4.56E-05	1	4
rr_hrn	61675	SectShll14.1	60085	MATL24_160	60048	9.12E-04	1.4	121
fbhp_brkt	61676	SectShll20.1	60088	MATL24_210	60052	1.84E-04	2	193
rkr_extn	61677	Sectshll75	60097	MATL24_600	60056	0.001526	0.75	1078
muffler	61701	SectShll5.3	60105	MATL24_160	60048	0.00133	0.5	1641
exhstpipe	61702	SectShll5.3	60105	MATL24_160	60048	0.00201	0.5	2044
rtire.l	61801	SectShll10.1	60083	MATL24_160	60048	0.007576	1	240
rtire.r	61802	SectShll10.1	60083	MATL24_160	60048	0.007576	1	240
rearrim	61803	SectShll35	60106	MATL24_160	60048	0.015933	3.5	240
rbmpbmbrkt.l	61901	SectShll15.3	60117	MATL24_160	60048	4.35E-04	1.5	32
rbmpbmbrkt.r	61902	SectShll15.3	60117	MATL24_160	60048	4.35E-04	1.5	32
rbumpbeam	61903	SectShll10.1	60083	MATL24_160	60048	0.003708	1	300
part.42	62001	SectDisc779	60123	MATSpr1_779	60063	0	0	1
part.43	62002	SectDisc780	60124	MATDmp2_780	60064	0	0	1
part.44	62003	SectDisc781	60125	MATSpr4_781	60069	0	0	1
part.47	62004	SectDisc783	60126	MATDmp2_784	60065	0	0	1
part.12	62005	SectBeam707	60009	MAT24_707	60043	7.70E-04	0	76
bar1fsusp	62006	Sectbeam10500	60002	MATBEAM	60057	0.001903	0	12
bar2fsusp	62007	Sectbeam10501	60003	MATBEAM	60057	4.12E-05	0	2
bar3fsusp	62008	Sectbeam10500	60002	MATBEAM	60057	1.41E-04	0	2
BARDLINE	62009	Sectbeam10504	60004	MATBEAM	60057	7.06E-05	0	1
bar4fsusp	62010	Sectbeam10500	60002	MATBEAM	60057	9.48E-04	0	2
bar2dline	62011	Sectbeam10500	60002	MATBEAM	60057	0.001306	0	1
bar3dline	62012	Sectbeam10504	60004	MATBEAM	60057	1.16E-04	0	2
bar5dline	62013	Sectbeam10509	60005	MATBEAM	60057	8.50E-05	0	2
bar1rrsus	62014	Sectbeam10500	60002	MATBEAM	60057	0.007365	0	48
bar2rrsusp	62015	Sectbeam10516	60006	MATBEAM	60057	0.019679	0	56
bar3rrsusp	62016	Sectbeam10516	60006	MATBEAM	60057	0.0026	0	8
bar4rrsusp	62017	Sectbeam10516	60006	MATBEAM	60057	0.002841	0	10
bardummies	62018	Sectbeam10519	60007	MATBEAM	60057	0.003373	0	14
barseat	62019	Sectbeam10519	60007	MATBEAM	60057	3.34E-04	0	4
barradiator	62020	Sectbeam10522	60008	MATBEAM	60057	1.82E-04	0	8
bardriveline	62021	Sectbeam10504	60004	MATBEAM	60057	2.57E-04	0	4
bardriveline8	62022	Sectbeam10504	60004	MATBEAM	60057	7.05E-05	0	1
sprdrvline	62023	SectDisc1	60122	Matsprstr14	60066	0	0	2
sprengmnt3	62024	SectDisc1	60122	Matsprstr113	60067	0	0	2
sprdummy	62025	SectDisc1	60122	Matsprstr114	60068	0	0	4
spr2dummy	62026	SectDisc1	60122	Matsprstr116	60062	0	0	2
spr3dummy	62027	SectDisc1	60122	Matsprstr116	60062	0	0	2
ltmount_spring	62028	SectDisc20071.1	60127	MATSpr4_61112	60070	0	0	1
rt_mount_spring	62029	SectDisc20071.1	60127	MATSpr4_61113	60071	0	0	1
rr_cdl_atch_spri	62030	SectDisc20071.1	60127	MATSpr4_61116	60073	0	0	1
rr_cdl_atch_spri	62031	SectDisc20071.1	60127	MATSpr4_61115	60072	0	0	1
hinge_beam_65dia	62032	90060004	60001	90060006	60005	1.06E-04	0	10
Masses	62033	N/A	N/A		0	0.002085	N/A	7
ElemMass	62034	N/A	N/A		0	0.633762	N/A	631
ncap_driver_pass	62035	N/A	N/A		0	0.156	N/A	8

SpotWelds	62039	N/A	N/A		0	0	N/A	327
Rigids.5	62040	N/A	N/A		0	0	N/A	1357
Joints	62042	N/A	N/A		0	0	N/A	25
2T_Welds	62043	N/A	N/A	2T_Welds	60075	0	N/A	3504
out_front_lh_doo	62047	N/A	N/A		0	1.42E-04	N/A	361
out_ip_masses_2	62050	N/A	N/A		0	0.001933	N/A	277
out_hood_masses_	62054	N/A	N/A		0	9.59E-05	N/A	323
out_roof_masses_	62056	N/A	N/A		0	8.76E-05	N/A	157
out_windshield_m	62058	N/A	N/A		0	1.92E-06	N/A	105
out_rear_lh_door	62060	N/A	N/A		0	1.96E-04	N/A	385
out_front_rh_doo	62064	N/A	N/A		0	1.53E-04	N/A	358
out_rear_rh_door	62066	N/A	N/A		0	1.90E-04	N/A	371
railotr_frt.l	62071	SectShll15.3	60117	MATL24_340	60049	5.97E-04	1.5	1374
railinr_frt.l	62072	Sectshll16.5	60109	MATL24_250	60054	1.10E-03	1.65	2597
railotr_frt.r	62073	SectShll15.3	60117	MATL24_340	60049	6.24E-04	1.5	1429
railinr_frt.r	62074	Sectshll16.5	60109	MATL24_250	60054	0.001155	1.65	2720
bumper_att_bolt_	62084	bumper_att_bolt_	60147	bumper_att_bolt_	60078	1.46E-05	0	8
att_plate_rail_s	62085	N/A	N/A		0	0	N/A	147
bumper_welds_new	62086	N/A	N/A		0	0	N/A	74
bumper_bolt_rgd	62087	N/A	N/A		0	0	N/A	16

Total Components	**500**
Model Mass	**1.77336 tonnes**

- Model mass is from LS-DYNA3D d3hsp file.
- Part mass summary is from HYPERMESH.

Concept 1: Final Design

Milestone 12

Lightweight Front End Structure Phase II

October 1, 2003

Auto/Steel Partnership

Abstract

This report documents the final design for *Concept 1* derived from an *NCAP DOE study*. The final *Concept 1* design will be compared to Concepts 2 and 3 that will be later developed in Phase II of the Lightweight Front End Structure Project.

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1. Objectives

The effort of this study was aimed at developing a final design for *Concept 1*. *Concept 1* has essentially the same rails as the existing donor vehicle rail design, except for modifications to holes and flanges. A new bumper design was also included in *Concept 1*. The final design for *Concept 1* was derived from an *NCAP DOE study*. The final Concept 1 design will be compared to Concepts 2 and 3 that will be later developed in Phase II of the Lightweight Front End Structure Project.

2. Results Summary

Regression analysis of the response surfaces obtained from the *NCAP DOE study of Concept 1* resulted in a design with 11kg (28%) mass reduction and NCAP performance at par with that of the *Baseline*. However, the IIHS performance of the design was inferior to the *Baseline*.

The NCAP and IIHS results are summarized in *Table 1* and *Table 2*.

A positive value of steering column upward movement means that the steering column moves upwards and towards the occupant, and a positive value of steering column rearward movement means that the steering column moves rearwards and towards the occupant.

Table 1: NCAP Results

B Pillar Pulse	Baseline Design	Concept 1 Preliminary Design	Concept 1 Final Design
LH	36.7 g @ 58.7 ms	38.6 @ 54.1 ms	38.4@55.3 ms
RH	35.3 g @ 58.6 ms	38.1 @ 52.2 ms	35.0@49.4 ms

Table 2: IIHS Results

Location	Intrusions @ 250ms (cm)		
	Baseline Design	Concept 1 Preliminary Design	Concept 1 Final Design
Brake Pedal	11.2	12.1	10.4
Left Toepan	14.5	14.7	14.5
Center Toepan	14.4	15.1	16.0
Right Toepan	15.8	15.8	16.7
A-B Pillar Closure	11.8	12.8	13.6
Steering Column Upward Movement*	-1.8	-6.7	-6.0
Steering Column Rearward Movement*	0.0	1.0	1.2

* Steering column movement does not stabilize at 250ms (*Figure 9*).

3. Design Summary

The *Final Design* was derived from an *NCAP DOE study of Concept 1.* The design variables are described in *Figure 1.*

The grades and gauges of all parts were identical for *Baseline* and *Concept 1 Preliminary Design*. A detailed part summary for Baseline model is included in *Appendix B.* The only difference between the two designs is the bumper material. The *Baseline* bumper has a material with yield 848MPa and tensile strength 871MPa. The *Concept 1* bumper uses DP700/980 steel.

The *Final Design* uses DP700/980 for bumper and DP365/600 for rails. All bumper and rail gauges are 30% lower than those in the *Preliminary Design.*

A summary of relevant designs is included in ***Table 3-5****.*

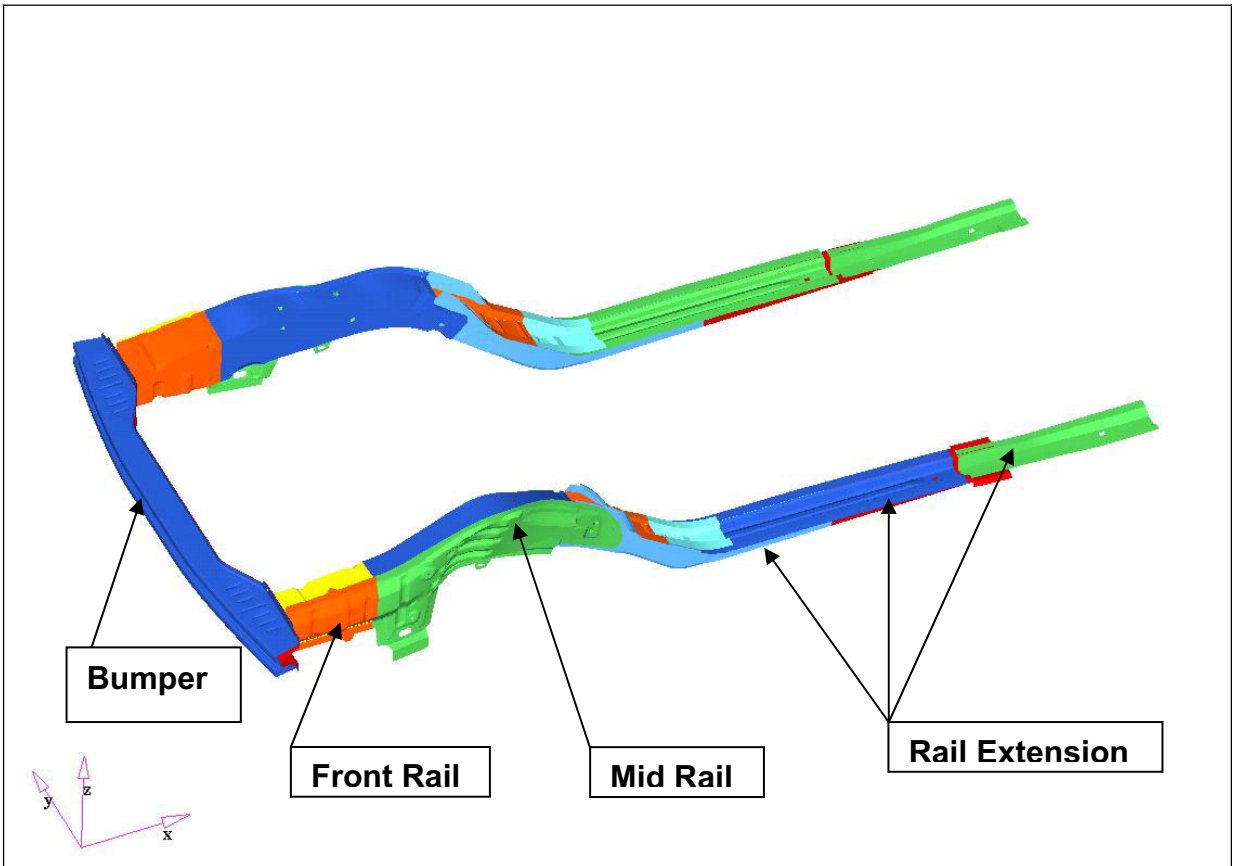


Figure 1: Concept 1 DOE Design Variables

Table 3: Mass Summary

Part	Mass (kg)		
	Baseline Design	Concept 1 Preliminary Design	Concept 1 Final Design
LH Rail Inner	3.79	3.85	2.80
LH Rail Outer	2.78	2.66	1.78
LH Reinf	0.64	0.00	0.00
LH Rail Extension	9.43	9.43	6.66
RH Rail Inner	3.65	3.55	2.58
RH Rail Outer	2.65	2.57	1.72
RH Rail Extension	9.59	9.59	6.72
Bumper (without foam)	6.56	6.64	5.61
Total	39.10	38.29	27.87 *

* 28% mass reduction with respect to *Baseline*

Table 4: Gauge Summary

Part	Gauge (mm)		
	Baseline Design	Concept 1 Preliminary Design	Concept 1 Final Design
Rail Front Inner	1.5	1.5	1.0
Rail Front Outer	1.65	1.65	1.2
Rail Mid Inner	1.5	1.5	1.0
Rail Mid Outer	1.65	1.65	1.2
Rail Extension railctr1	2.0	2.0	1.4
Rail Extension railctr2	1.2	1.2	0.8
Rail Extension ubrail	0.95	0.95	0.7
Rail Extension ctrrailrnf1	1.2	1.2	0.8
Rail Extension ctrrailrnf2	1.45	1.45	1.0
Rail Extension ctrrailrnf3	2.25	2.25	1.6
Bumper Beam	1.2	1.2	1.0

Table 5: Grade Summary

Part	Grade Yield/Ultimate (MPa)		
	Baseline Design	Concept 1 Preliminary Design	Concept 1 Final Design
Rail Front Inner	358/865	358/865	365/600
Rail Front Outer	314/847	314/847	365/600
Rail Mid Inner	358/865	358/865	365/600
Rail Mid Outer	314/847	314/847	365/600
Rail Extension railctr1	314/847	314/847	365/600
Rail Extension railctr2	358/865	358/865	365/600
Rail Extension ubrail	358/865	358/865	365/600
Rail Extension ctrrailrnf1	358/865	358/865	365/600
Rail Extension ctrrailrnf2	358/865	358/865	365/600
Rail Extension ctrrailrnf3	386/993	386/993	365/600
Bumper Beam	848/971	848/971	579/980
	Ultimate strength is extrapolated	*Ultimate strength is extrapolated*	*Rails are DP600 Bumper is DP980*

4. FE Model - Output Location Summary

The nodes at which the desired NCAP and IIHS outputs were obtained are listed in *Table 6*.

The intrusions are measured at the nodes as specified in *Reference 3*.

The acceleration and intrusion node locations are shown in *Figure 2* and *Figure 3* below.

Table 6: Summary of Output Locations

Parameter	Location	Node Number
Accelerations	B-Pillar / Rocker - LH	5000001
	B-Pillar / Rocker - RH	5000002
Intrusions	Origin	6000000
	Plane Y-axis	6000001
	Plane Z-axis	6000002
	Steering Column	7000001
	Brake Pedal	7000002
	Toepan - Left	7000003
	Toepan - Center	7000004
	Toepan - Right	7000005
	Left Front Seat Bolt	7000006
	Right Front Seat Bolt	7000007
	Left Rear Seat Bolt	7000008
	Right Rear Seat Bolt	7000009
	AB Closure - A Pillar	7000010
	AB Closure - B Pillar	7000011

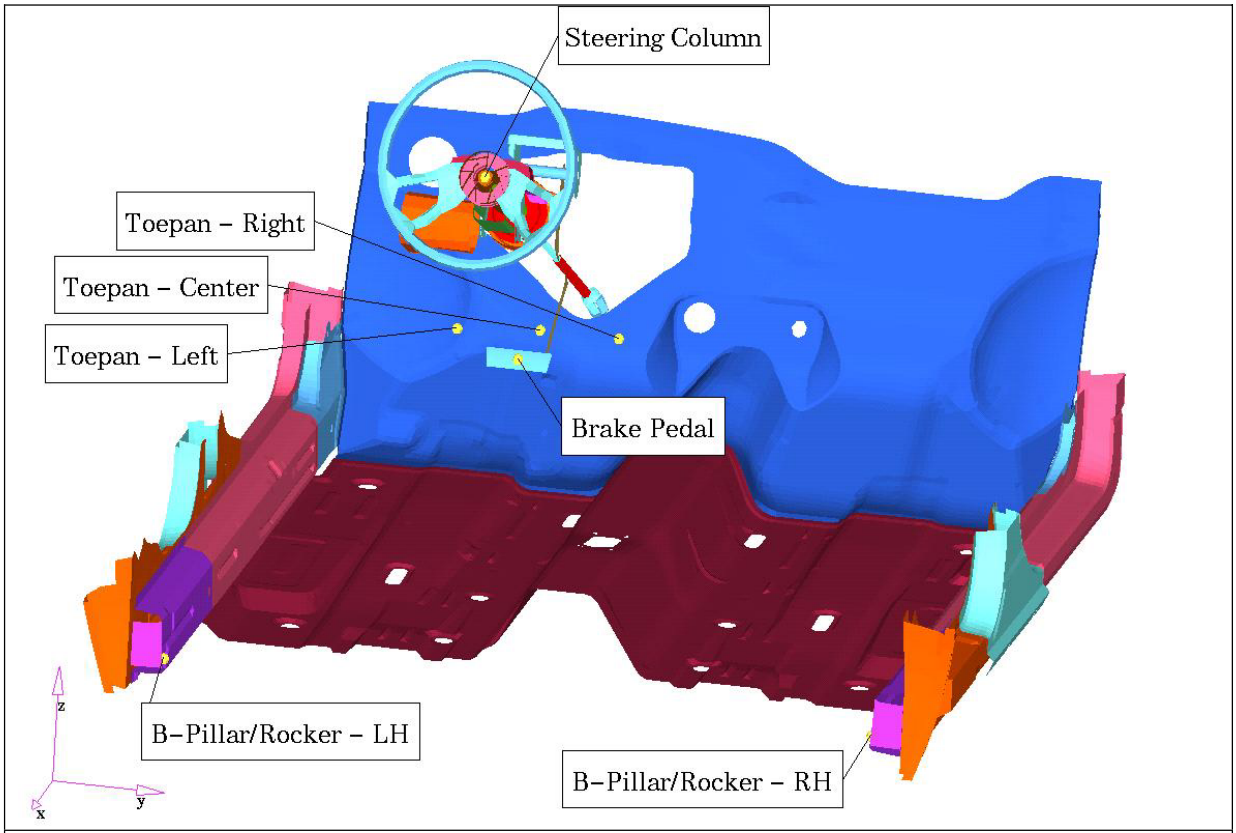


Figure 2: Output Locations for NCAP/IIHS



Figure 3: Output Locations for IIHS- AB Closure

5. *NCAP* Response

The figures below summarize the NCAP response of *Concept 1*.

Animation files are included in *Appendix A*.

The NCAP response of the *Preliminary Design* is the stiffest, followed by the *Final Design* and the *Baseline*. This is evident by a higher gradient of the velocity profile for the *Preliminary Design (Figure 6, Figure 7)* and the highest acceleration peak for the *Preliminary Design (Figure 4, Figure 5).*

The initial acceleration peak is also the highest for *Preliminary Design.* However, the *Final Design* has a lower initial peak than the *Baseline (Figure 4, Figure 5)*.

Overall, the NCAP performance of the *Final Design* can be considered to be at par with that of the *Baseline*.

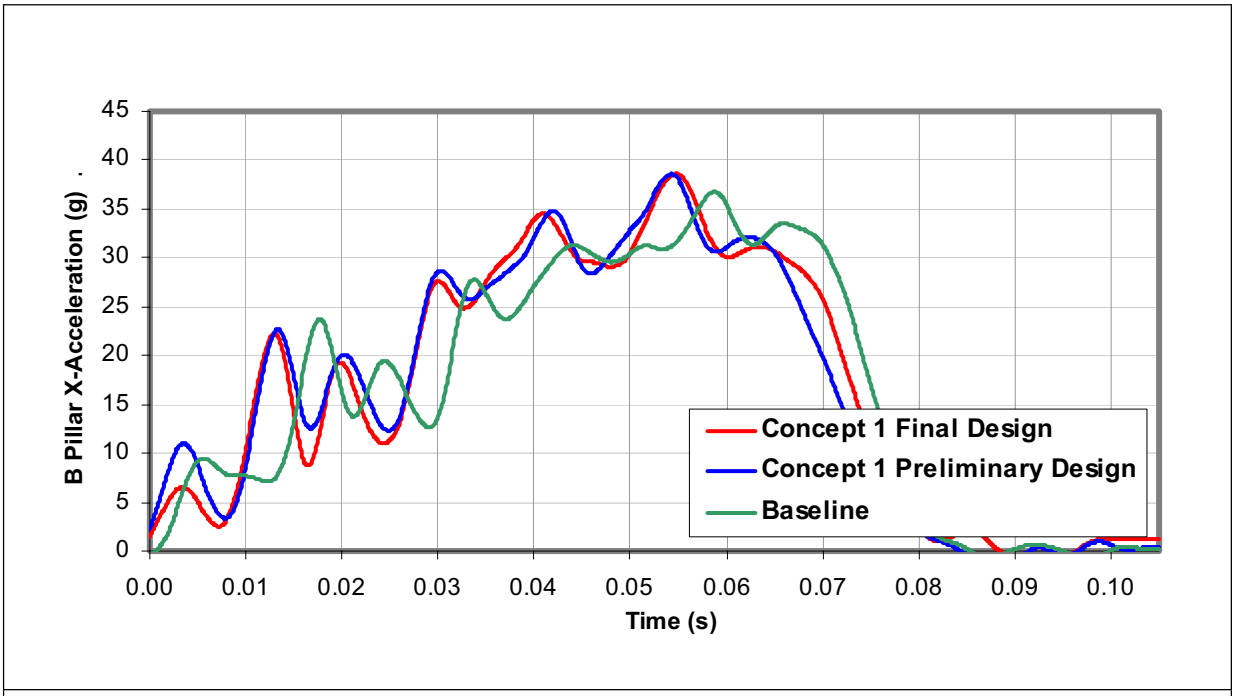


Figure 4: B Pillar Pulse – LH

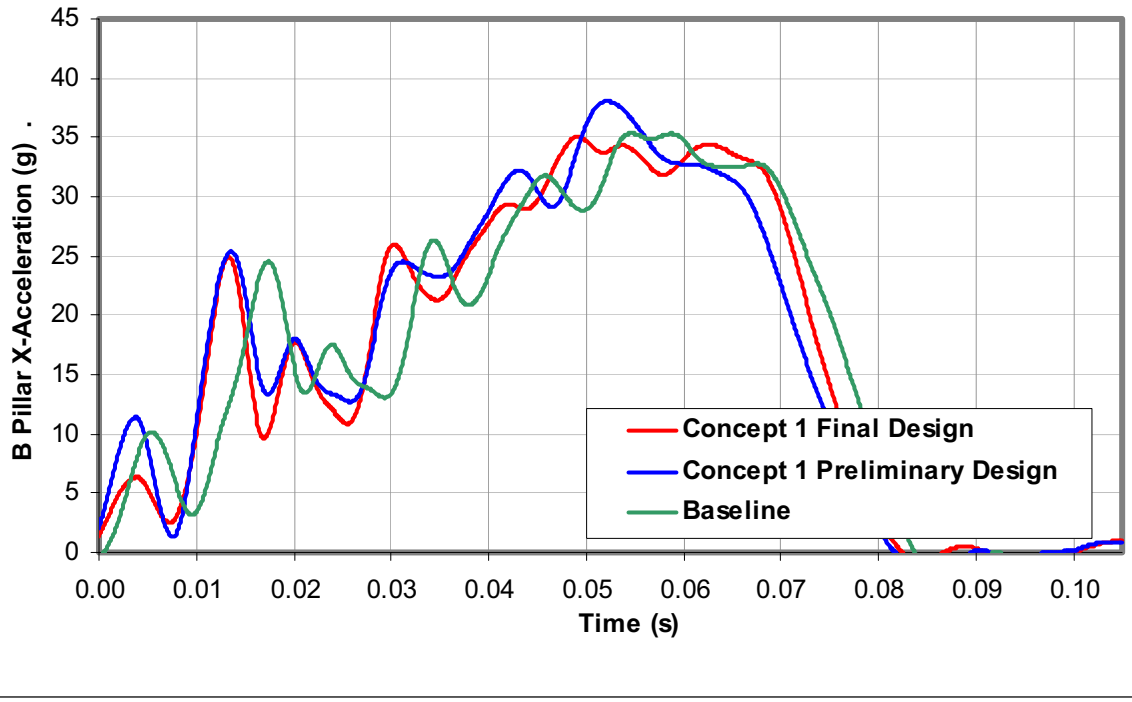


Figure 5: B Pillar Pulse – RH

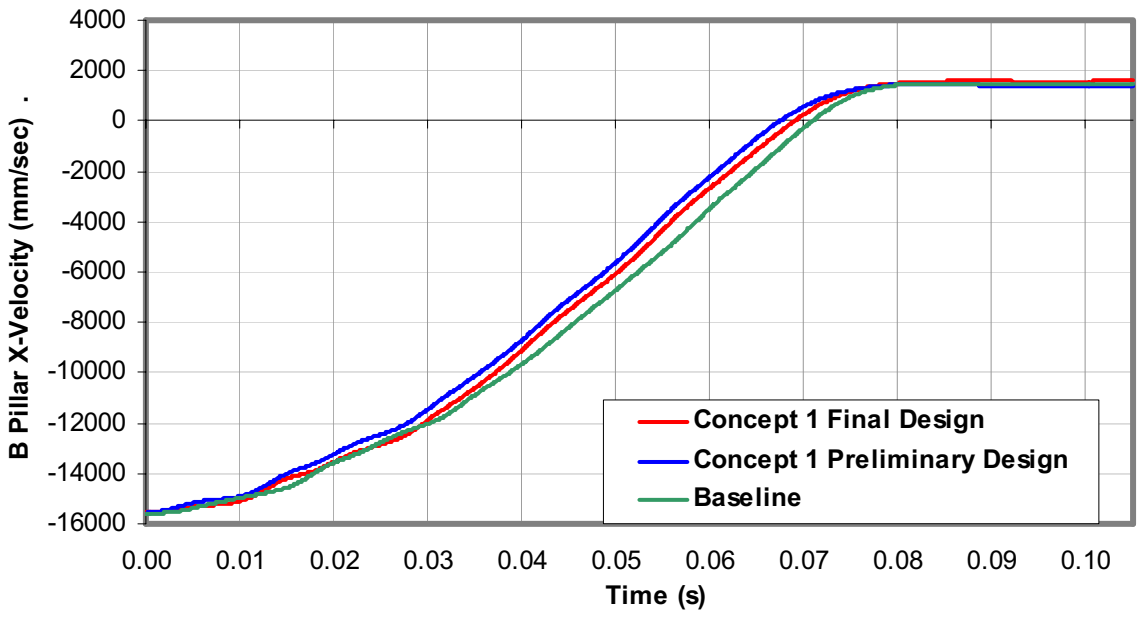


Figure 6: B Pillar Velocity - LH

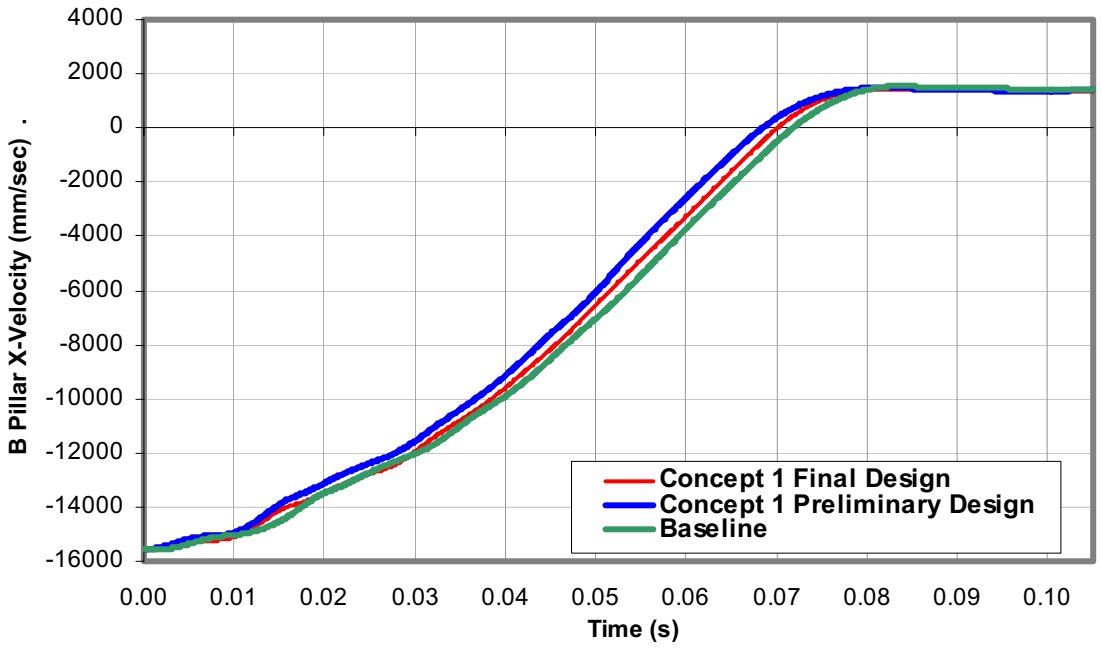


Figure 7: B-Pillar Velocity - RH

Table 7: NCAP Crash Events

Time (ms)	Crash Events
0-15	Bumper absorbs energy
15-20	Engine hits the radiator, Cradle Extension Buckles, Cradle engaged
20-30	Cradle and LH rail buckling started
35-40	LH front wheel hits the LH rail
40-45	Engine hits to dash
45-50	RH front wheel hits the RH rail
55-60	LH wheel hits the front rigid wall
60-70	RH wheel hits the front rigid wall, LH wheel hits the rocker
70-75	RH wheel hits the rocker

6. *IIHS* Response

IIHS intrusions are summarized in *Table 2*.

Animation files are included in *Appendix A*.

The intrusions are the highest for the *Final Design*, followed by the *Preliminary Design* and the *Baseline* (*Table 2*). The intrusions can be reduced by increasing the gauges appropriately, albeit, with a mass penalty.

Toepan, brake pedal and A-B closure intrusions oscillate after 200ms about a mean value. Hence, the mean values should be used for comparison. However, the values reported in *Table 2* are at 250ms.

Steering column movement does not reach any equilibrium. The IIHS simulation would have to be carried out for a longer duration in order to report stable meaningful values. The steering column model may also be deficient, resulting in an unstable movement.

The brake pedal oscillates about a pivot joint. Hence, brake pedal intrusions can vary randomly and should not be used for design comparisons.

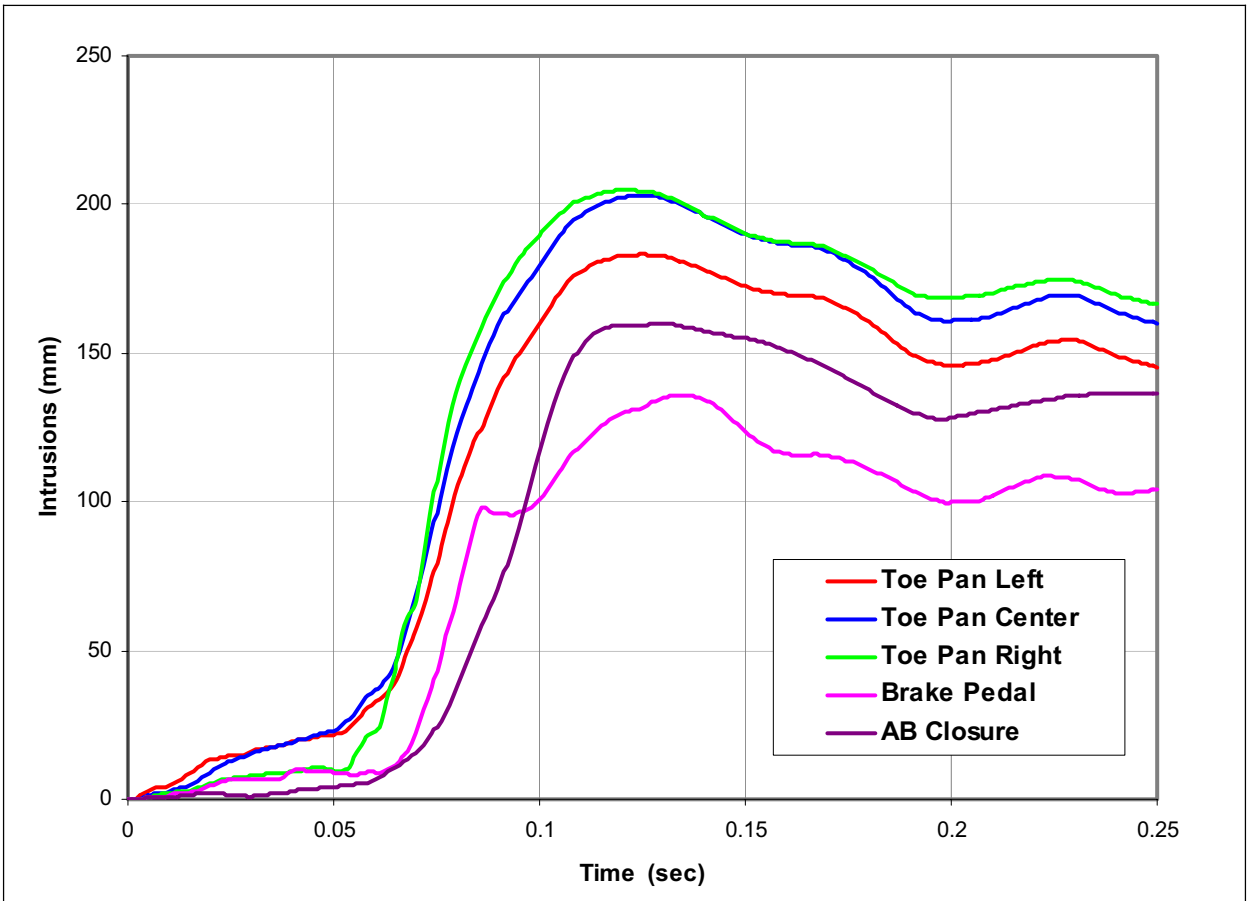


Figure 8: Toepan, Brake Pedal and A-B Closure Intrusions

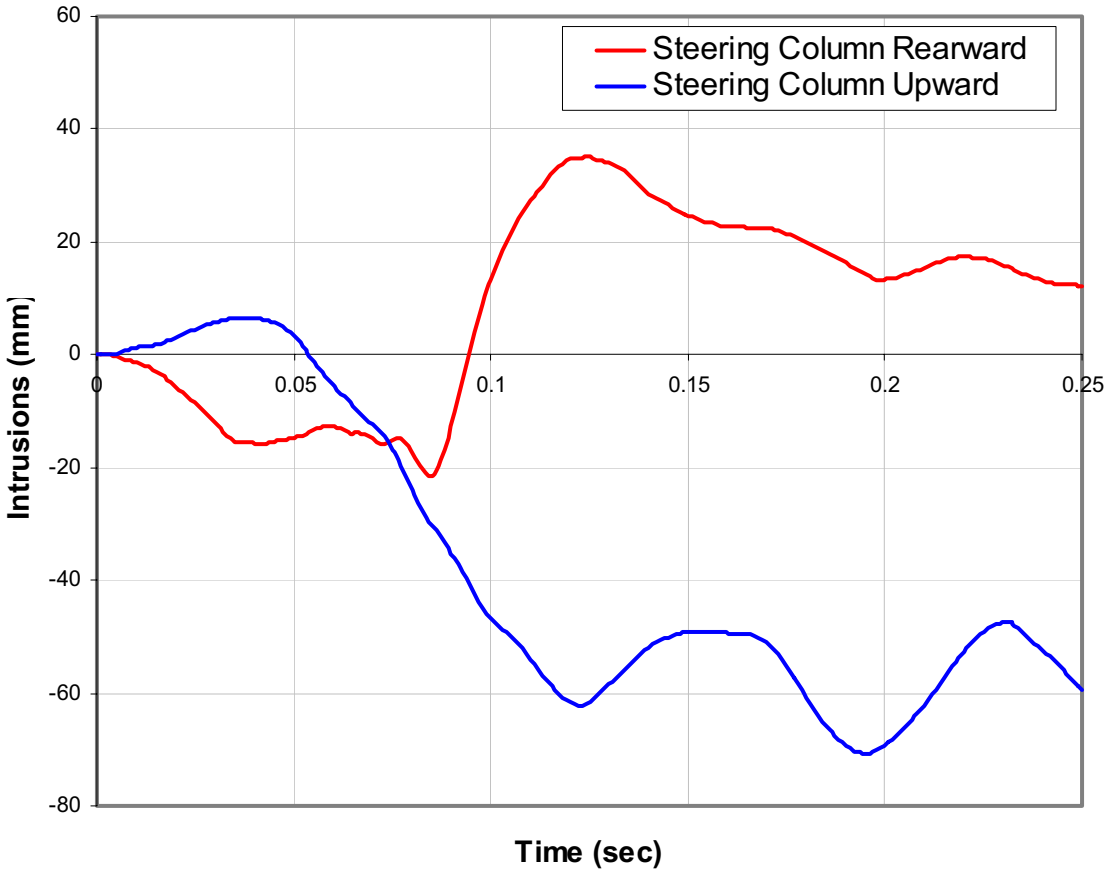


Figure 9: Steering Column Movement

7. Conclusions

A *Final Design* for *Concept 1* was derived based on an *NCAP DOE study.* The *Final Design* achieved 11kg (28%) mass reduction and NCAP performance at par with the *Baseline*. However, the IIHS performance of the design was inferior to that of the *Baseline*. Undertaking an IIHS DOE study will supplement the current NCAP DOE study and optimize the design for both NCAP and IIHS load cases.

8. Future Work

The *Concept 1 Final Design* will be compared to Concepts 2 and 3 that will be later developed in Phase II of the Lightweight Front End Structure Project.

9. References

1) *Validated FE Models, Milestone 5*, SPHINX, Phase II.

2) *Enhanced FE Models, Milestone 6*, SPHINX, Phase II.

3) *IIHS Crashworthiness Evaluation Offset Barrier Crash Test Protocol (Version IX), October 2002.*

4) *DOE FE Models, Milestone 7*, SPHINX, Phase II.

5) *Third Bumper Design Report, Milestone 5*, SPHINX, Phase I.

6) Concept 1 Preliminary Design, Milestone 10, SPHINX, Phase II.

7) Concept 1 DOE Study, Milestone 11, SPHINX, Phase II.

10. Appendix A: Animations

The following animation files for the subsystem development can be viewed at the Auto/Steel Partnership website, www.a-sp.org.

You will need a Hyperview Player in order to view these animations at the site. You can download this free software at www.altair.com.

1. NCAP: Baseline
2. NCAP: Concept 1 Preliminary Design
3. NCAP: Concept 1 Final Design
4. IIHS: Baseline
5. IIHS: Concept 1 Preliminary Design
6. IIHS: Concept 1 Final Design

11. Appendix B: Summary of *Baseline FE Model*

Component Name	ID	Property Name	ID	Material Name	ID	MASS (ton)	Thickness (mm)
horsecollar_brkt	60001	SectShll18.1	60087	MATL24_340	60049	6.20E-04	1.8
l_bumper_plate	60003	SectShll20.1	60088	MATL24_340	60049	5.17E-04	2
r_bumper_plate	60004	SectShll20.1	60088	MATL24_340	60049	5.18E-04	2
bumpbeam	60005	SectShll12.1	60084	MATL24_848	60050	0.005409	1.2
bumpnull	60006	SectShll10.1	60083	null	60008	0.002833	1
ldfoam	60007	SectSld900	60121	foam2.8pcf	60060	1.91E-04	0
hdfoam	60008	SectSld900	60121	foam6.6pcf	60061	4.93E-04	0
railotr.l	60101	SectShll15.3	60117	MATL24_340	60049	0.002781	1.5
railotr.r	60102	SectShll15.3	60117	MATL24_340	60049	0.002653	1.5
railinr.l	60103	Sectshll16.5	60109	MATL24_250	60054	0.003794	1.65
railinr.r	60104	Sectshll16.5	60109	MATL24_250	60054	0.003652	1.65
railctr1.l	60105	SectShll20.1	60088	MATL24_210	60052	0.00383	2
railctr1.r	60106	SectShll20.1	60088	MATL24_210	60052	0.003998	2
railctr2.l	60107	SectShll12.1	60084	MATL24_340	60049	1.02E-03	1.2
railctr2.r	60108	SectShll12.1	60084	MATL24_340	60049	9.75E-04	1.2
ubrail.l	60109	SectShll95	60113	MATL24_340	60049	5.89E-04	0.95
ubrail.r	60110	SectShll95	60113	MATL24_340	60049	5.93E-04	0.95
ctrrailrnf1.l	60111	SectShll12.1	60084	MATL24_340	60049	4.45E-04	1.2
ctrrailrnf1.r	60112	SectShll12.1	60084	MATL24_340	60049	4.28E-04	1.2
ctrrailrnf3.l	60113	Sectshll14.5	60111	MATL24_340	60049	7.25E-04	1.45
ctrrailrnf3.r	60114	Sectshll14.5	60111	MATL24_340	60049	7.46E-04	1.45
ctrrailrnf2.l	60115	SectShll225	60099	MATL24_3404	60051	0.002819	2.25
ctrrailrnf2.r	60116	SectShll225	60099	MATL24_3404	60051	0.002855	2.25
trqbox1.l	60117	Sectshll14.5	60111	MATL24_210	60052	0.001434	1.45
trqbox1.r	60118	Sectshll14.5	60111	MATL24_210	60052	0.001625	1.45
trqbox2.l	60119	Sectshll14.5	60111	MATL24_160	60048	2.71E-04	1.45
trqbox2.r	60120	Sectshll14.5	60111	MATL24_160	60048	2.72E-04	1.45
trnsrnf	60121	Sectshll17.5	60096	MATL24_340	60049	2.91E-04	1.75
emntrnf	60122	Sectshll14.5	60111	MATL24_340	60049	2.40E-04	1.45
cplate	60123	Sectshll16.5	60109	MATL24_340	60049	3.54E-04	1.65
rlinrnf.r	60124	Sectshll17.5	60096	MATL24_210	60052	2.77E-04	1.75
crfmbrkt.l	60201	SectShll20.1	60088	MATL24_340	60049	5.34E-04	2
crfmbrkt.r	60202	SectShll20.1	60088	MATL24_340	60049	5.38E-04	2
crdlfbrkt	60203	SectShll30	60094	MATL24_600	60056	8.68E-04	3
crdl.l	60205	SectShll26	60116	MATL24_340	60049	0.006018	2.6
crdl.r	60206	SectShll26	60116	MATL24_340	60049	0.006321	2.6
rrcrdlbdattch.l	60207	SectShll35	60106	MATL24_160	60048	0.001148	3.5
rrcrdlbdattch.r	60208	SectShll35	60106	MATL24_160	60048	0.001147	3.5
trnfext.l	60209	SectShll20.1	60088	MATL24_250	60054	0.001243	2
trnfext.r	60210	SectShll20.1	60088	MATL24_250	60054	0.001222	2
rrcrdlmnt1.l	60211	SectShll25	60091	MATL24_210	60052	0.001237	2.5
rrcrdlmnt1.r	60212	SectShll25	60091	MATL24_210	60052	0.001394	2.5
rrcrdlmnt2.l	60213	SectShll19.1	60112	MATL24_210	60052	2.84E-04	1.9

Component Name	ID	Property Name	ID	Material Name	ID	MASS (ton)	Thickness (mm)
rrcrdlmnt2.r	60214	SectShll19.1	60112	MATL24_210	60052	2.84E-04	1.9
frtcrdlmnt1.l	60215	Sectshll19.5	60110	MATL24_160	60048	8.12E-04	1.95
frtcrdlmnt1.r	60216	Sectshll19.5	60110	MATL24_160	60048	7.34E-04	1.95
frtcrdlmnt2.l	60217	Sectshll14.5	60111	MATL24_210	60052	1.37E-04	1.45
frtcrdlmnt2.r	60218	Sectshll14.5	60111	MATL24_210	60052	1.38E-04	1.45
frtcrdlmnt5	60219	SectShll15.3	60117	MATL24_160	60048	4.31E-04	1.5
frtcrdlmnt3.l	60221	SectShll25	60091	MATL24_340	60049	4.30E-04	2.5
frtcrdlmnt3.r	60222	SectShll25	60091	MATL24_340	60049	3.41E-04	2.5
bot_bkt_l_e	60223	SectShll30	60094	MATL24_340	60049	9.59E-04	3
bot_bkt_r_e	60224	SectShll30	60094	MATL24_340	60049	9.29E-04	3
cradbrkt	60225	SectShll30	60094	MATL24_340	60049	4.46E-04	3
cradbrkt2	60227	SectShll30	60094	MATL24_340	60049	3.58E-04	3
lcarnf.l	60229	SectShll30	60094	MATL24_340	60049	3.19E-04	3
lcarnf.r	60230	SectShll30	60094	MATL24_340	60049	3.41E-04	3
lcajnt_1.L1	60231	SectShll30	60094	rigid	60014	4.12E-05	3
lcajnt_1.R1	60232	SectShll30	60094	rigid	60014	4.12E-05	3
lcacyl.l	60235	SectShll50	60092	MATL24_160	60048	0.001295	5
lcacyl.r	60236	SectShll50	60092	MATL24_160	60048	0.001295	5
lcajnt_1.L2	60239	SectShll30	60094	rigid	60014	3.16E-05	3
lcajnt_1.R2	60240	SectShll30	60094	rigid	60014	3.16E-05	3
cradbrkt1	60241	SectShll10.1	60083	MATL24_180	60046	2.36E-04	1
crdlblt	60243	SectShll20.1	60088	MATL24_160	60048	2.41E-04	2
crdlrrxupr	60244	SectShll25	60091	MATL24_340	60049	0.002183	2.5
crdlrrxlwr	60245	SectShll23	60090	MATL24_340	60049	0.00129	2.3
urail_l	60301	SectShll8.3	60081	MATL24_160	60048	0.001457	0.8
urail_r	60302	SectShll8.3	60081	MATL24_160	60048	0.001456	0.8
urail_rnf2.l	60303	SectShll9.1	60082	MATL24_160	60048	4.72E-04	0.9
urail_rnf1.r	60304	SectShll9.1	60082	MATL24_160	60048	4.71E-04	0.9
pnlfrt1.l	60305	Sectshll75	60097	MATL24_210	60052	5.44E-04	0.75
pnlfrt1.r	60306	Sectshll75	60097	MATL24_210	60052	6.27E-04	0.75
shock.l	60307	Sectshll17.5	60096	MATL24_160	60048	0.001517	1.75
shock.r	60308	Sectshll17.5	60096	MATL24_160	60048	0.001546	1.75
pnlfrt2.l	60309	SectShll12.1	60084	MATL24_210	60052	0.001235	1.2
pnlfrt2.r	60310	SectShll12.1	60084	MATL24_210	60052	0.001294	1.2
plnmbrkt	60311	SectShll8.3	60081	MATL24_210	60052	1.50E-04	0.8
rnfpnldshext2	60312	SectShll8.3	60081	MATL24_210	60052	1.93E-04	0.8
temp	60313	SectShll7.2	60080	MATL24_600	60056	2.63E-04	0.7
frtflr	60401	SectShll085	60118	MATL24_160	60048	0.013015	0.85
bar1	60402	SectShll20.1	60088	MATL24_3404	60051	0.00262	2
tnl1	60403	SectShll18.1	60087	MATL24_340	60049	0.001311	1.8
tnl2	60404	SectShll12.1	60084	MATL24_250	60054	0.006463	1.2
dash	60405	SectShll95	60113	MATL24_160	60048	0.008026	0.95
cowlupr	60406	SectShll8.3	60081	MATL24_210	60052	0.001526	0.8
fflrlvrrnf	60407	SectShll15.3	60117	MATL24_160	60048	7.10E-04	1.5
pedal2	60408	SectShll30	60094	MATL24_160	60048	0.001364	3
wndshld.supt.upr	60409	Sectshll75	60097	MATL24_160	60048	0.002599	0.75
plnmltintjnt	60410	Sectshll75	60097	MATL24_160	60048	0.004045	0.75

Component Name	ID	Property Name	ID	Material Name	ID	MASS (ton)	Thickness (mm)
rein_upr	60411	SectShll15.3	60117	MATL24_210	60052	9.29E-04	1.5
MTG1	60412	SectShll10.1	60083	MATL24_210	60052	4.34E-04	1
BRKT_Consol	60413	SectShll15.3	60117	MATL24_210	60052	6.89E-04	1.5
crush_brkt_lwr	60414	SectShll20.1	60088	MATL24_210	60052	0.002868	2
bar2.l	60501	SectShll12.1	60084	MATL24_160	60048	0.001367	1.2
bar2.r	60502	SectShll12.1	60084	MATL24_160	60048	0.001368	1.2
2barreinf	60503	SectShll17	60086	MATL24_340	60049	0.00249	1.7
22678921_256_1	60505	SectShll12.1	60084	MATL24_160	60048	2.43E-04	1.2
22678920_256_1	60506	SectShll12.1	60084	MATL24_160	60048	2.43E-04	1.2
22678921_255_1	60507	SectShll12.1	60084	MATL24_160	60048	1.85E-04	1.2
22678920_255_1	60508	SectShll12.1	60084	MATL24_160	60048	1.85E-04	1.2
seatrein.l	60509	SectShll12.1	60084	MATL24_160	60048	3.45E-04	1.2
seatrein.r	60510	SectShll12.1	60084	MATL24_160	60048	3.46E-04	1.2
tiebar3.l	60601	Sectshll75	60097	MATL24_180	60046	6.78E-04	0.75
tiebar3.r	60602	Sectshll75	60097	MATL24_180	60046	7.22E-04	0.75
tiebar4.l	60603	Sectshll75	60097	MATL24_180	60046	4.27E-05	0.75
tiebar4.r	60604	Sectshll75	60097	MATL24_180	60046	4.44E-05	0.75
lhfanmotor	60605	SectShll20.1	60088	MATL24_181	60047	5.60E-04	2
rhfanmotor	60606	SectShll20.1	60088	MATL24_181	60047	5.40E-04	2
tiebar	60607	SectShll9.1	60082	MATL24_210	60052	0.002278	0.9
tiebar2	60608	SectShll9.1	60082	MATL24_160	60048	0.001152	0.9
radsupport	60609	SectShll10.1	60083	MATL24_160	60048	0.001261	1
rad4	60610	SectShll10.1	60083	MATL24_160	60048	8.32E-06	1
Part_2	60611	SectShll10.1	60083	MATL9_2	60006	0.014989	1
rad2	60612	SectSld900	60121	MAT57rad&cond	60059	0.002656	0
rad1	60613	SectSld900	60121	MAT57rad&cond	60059	0.003782	0
fanshroud	60614	SectShll20.1	60088	MATL24_181	60047	0.007298	2
pt2	60702	SectShll10.1	60083	rigid	60014	0.001123	1
pt3	60703	SectShll10.1	60083	rigid	60014	0.006404	1
pt7	60704	SectShll10.1	60083	rigid	60014	0.001243	1
pt8	60705	SectShll20.1	60088	rigid	60014	0.005065	2
pt10	60706	SectShll10.1	60083	rigid	60014	9.92E-04	1
pt11	60707	SectShll225	60099	rigid	60014	0.001335	2.25
pt13	60708	SectShll10.1	60083	rigid	60014	1.07E-04	1
pt14	60709	SectShll10.1	60083	rigid	60014	0.001639	1
pt19	60710	SectShll10.1	60083	rigid	60014	4.08E-04	1
pt18	60711	SectShll40	60093	rigid	60014	0.007253	4
frtmnt1	60712	SectShll20.1	60088	MATL24_160	60048	1.04E-03	2
frtmnt2	60713	SectShll225	60099	MATL24_160	60048	3.84E-04	2.25
pt9	60714	SectShll100	60104	rigid	60014	0.005277	10
pt12	60715	SectShll80	60095	rigid	60014	0.007011	8
pt16	60716	SectShll40	60093	rigid	60014	0.003234	4
pt17	60717	SectShll30	60094	MATL24_160	60048	0.007696	3
expipefrt	60718	SectShll15.3	60117	MATL24_160	60048	0.003601	1.5
ep_7685	60719	SectShll10.1	60083	rigid	60014	2.83E-04	1
flywheel	60720	SectShll10.1	60083	rigid	60014	7.92E-04	1
ep_4776	60721	SectShll10.1	60083	rigid	60014	4.99E-04	1

Component Name	ID	Property Name	ID	Material Name	ID	MASS (ton)	Thickness (mm)
ep_7498	60722	SectShll10.1	60083	rigid	60014	0.002605	1
ep_0939	60723	SectShll10.1	60083	rigid	60014	5.79E-04	1
ep_0017	60724	SectShll10.1	60083	rigid	60014	4.50E-04	1
ep_70842	60725	SectShll10.1	60083	rigid	60014	1.84E-04	1
eng_mnt_l_e	60726	SectShll80	60095	MATL24_160	60048	0.002636	8
top_bkt_l_e	60727	SectShll80	60095	MAT24_1111	60045	5.72E-04	8
eng_mnt_r_e	60728	SectShll80	60095	MATL24_160	60048	0.002631	8
top_bkt_r_e	60729	SectShll80	60095	MAT24_1111	60045	1.01E-03	8
eng_deformable	60730	SectShll80	60095	MATL24_160	60048	0.001725	8
62109a_e1	60731	SectShll37	60108	MATL24_160	60048	3.62E-04	3.7
62109a_e2	60732	SectShll37	60108	MATL24_160	60048	1.22E-04	3.7
62109a_e3	60733	SectShll37	60108	MATL24_160	60048	4.00E-04	3.7
62109b_e1	60734	SectShll10.1	60083	MATL24_160	60048	4.06E-04	1
rrmnt_bushing	60735	SectShll20.1	60088	MATL24_160	60048	5.79E-04	2
tire1.l	60801	SectShll20.1	60088	mat1.tirerubber	60007	0.00197	2
tire1.r	60802	SectShll20.1	60088	mat1.tirerubber	60007	0.00197	2
tire3.l	60803	SectShll3.3	60107	MATL24_160	60048	1.00E-03	0.3
tire2.r	60804	SectShll3.3	60107	MATL24_160	60048	1.00E-03	0.3
tir2.l	60805	SectShll7.2	60080	MATL24_160	60048	0.002042	0.7
tire3.r	60806	SectShll7.2	60080	MATL24_160	60048	0.002042	0.7
rim.l	60807	SectShll35	60106	MATL24_600	60056	0.008136	3.5
rim.r	60808	SectShll35	60106	MATL24_600	60056	0.008136	3.5
lwrcntrlarm.l	60809	SectShll30	60094	MATL24_160	60048	0.002294	3
lwrcntrlarm.r	60810	SectShll30	60094	MATL24_160	60048	0.002289	3
lcajnt_2.L1	60811	SectShll30	60094	rigid	60014	6.26E-05	3
lcajnt_2.R1	60812	SectShll30	60094	rigid	60014	6.33E-05	3
driveline	60813	SectShll70	60103	MATL24_340	60049	0.005373	7
lcajnt_2.L2	60815	SectShll30	60094	rigid	60014	2.76E-05	3
lcajnt_2.R2	60816	SectShll30	60094	rigid	60014	2.76E-05	3
fsuspstrut.l	60817	SectShll50	60092	MATL24_160	60048	0.005601	5
fsuspstrut.r	60818	SectShll50	60092	MATL24_160	60048	0.005601	5
crdlbltrnf	60819	SectShll275.1	60102	MATL24_160	60048	3.23E-04	2.75
strclnmend3	60820	SectShll50	60092	rigid	60014	3.64E-04	5
strngrack	60821	SectShll60	60101	MAT24_1111	60045	0.002617	6
strrackends	60822	SectShll60	60101	MATL24_160	60048	0.001165	6
stabbar	60823	SectShll40	60093	MATL24_160	60048	0.004576	4
btray1	60901	SectShll15.3	60117	MATL24_160	60048	0.003147	1.5
btray2	60902	SectShll10.1	60083	MATL24_160	60048	2.19E-04	1
battery1	60903	SectShll5.3	60105	MATL24_160	60048	8.66E-04	0.5
ECM	60904	SectShll10.1	60083	MATL24_160	60048	1.07E-03	1
battery_fill	60905	SectShll10.1	60083	MATL24_160	60048	0.001326	1
fcomptrnf2	60906	SectShll40	60093	MATL24_160	60048	0.002901	4
abs_brkt	60907	SectShll20.1	60088	MATL24_160	60048	4.33E-04	2
brkt_boost	60908	90060072	60042	90060009	60012	0.00385	3
edge	61001	SectShll2.1.1	60077	MAT24_3	60042	1.06E-03	1.35
inner	61002	SectShll3.2.1	60078	MAT24_3	60042	0.005147	0.7
outer	61003	SectShll4.1.1	60079	MAT24_3	60042	0.008252	0.7

Component Name	ID	Property Name	ID	Material Name	ID	MASS (ton)	Thickness (mm)
MODPLT	61101	90060005	60010	90060020	60041	0.001613	1.5
CSUPT_forw	61102	90060006	60011	90060020	60041	5.32E-04	1.22
can	61103	90060008	60012	90060020	60041	6.77E-04	1.2
can1	61104	90060009	60013	90060020	60041	9.87E-05	1.2
can2	61105	90060010	60014	90060020	60041	1.09E-04	1.2
can.1	61106	90060011	60015	90060020	60041	9.05E-05	1.2
inflator	61107	90060012	60016	90060020	60041	0.001456	5.4
Brkt-1	61108	90060063	60039	90060020	60041	6.07E-04	3
gaspdel	61109	90060068	60040	90060020	60041	1.65E-04	2.5
stelpeice	61110	90060071	60041	90060020	60041	1.54E-04	3
SIPO_p	61111	90060014	60018	90060020	60041	6.06E-04	2
SIPO_d2	61112	90060015	60019	90060020	60041	6.11E-04	2
Steel_strip	61113	90060016	60020	90060020	60041	1.07E-04	1.5
Floor_Brkt2	61114	90060037	60022	90060020	60041	8.95E-04	2.5
Center_Stk_brkt	61115	90060038	60023	90060020	60041	3.09E-04	1.5
lower	61116	90060044	60026	90060013	60036	8.85E-04	2.43
upper	61117	90060045	60027	90060013	60036	8.69E-04	2.36
hvacbrkt_add	61118	90060046	60028	90060013	60036	2.49E-05	2.36
heatercvr	61119	90060047	60029	90060013	60036	3.21E-04	2.38
ai	61120	90060048	60030	90060013	60036	3.74E-04	2.1
ai_icebox	61121	90060049	60031	90060013	60036	1.51E-05	2.1
ai_actuator	61122	90060050	60032	90060013	60036	2.81E-05	2
lower_actuator	61123	90060051	60033	90060013	60036	2.86E-05	2
foamplate	61124	90060052	60034	90060020	60041	5.74E-05	1
filmvalve	61125	90060053	60035	90060013	60036	1.67E-04	2
arm1_srib	61126	90060054	60036	90060013	60036	8.90E-05	2
rib_4_hub	61127	90060055	60037	90060013	60036	1.42E-04	3.5
Lower_add1	61128	90060056	60038	90060013	60036	1.16E-05	2
foam	61129	90060125	60119	90060001	60001	1.48E-06	0
evapblock	61130	90060126	60120	90060003	60003	3.52E-05	0
IBEC	61131	90060013	60017	90060005	60004	3.04E-04	2
evap_lower_tube1	61132	90060041	60024	90060002	60002	8.68E-06	1
evap_upper_tube1	61133	90060041	60024	90060002	60002	1.38E-05	1
heat_upper_tube1	61134	90060041	60024	90060002	60002	4.22E-05	1
heat_lower_tube1	61135	90060041	60024	90060002	60002	2.58E-05	1
il	61136	90060042	60025	90060014	60037	1.89E-04	1
IP_sidepnl_E	61137	90060026	60021	90060015	60038	1.24E-04	2.5
sipo_fixed1	61138	90060015	60019	90060008	60011	1.39E-06	2
sipo_fixed2	61139	90060015	60019	90060008	60011	1.46E-06	2
sipo_fixed3	61140	90060015	60019	90060008	60011	1.53E-06	2
sipo_fixed4	61141	90060015	60019	90060008	60011	1.13E-06	2
sipo_fixed5	61142	90060015	60019	90060008	60011	1.85E-06	2
sipo_fixed6	61143	90060015	60019	90060008	60011	1.95E-06	2
sipo_fixed7	61144	90060015	60019	90060008	60011	1.83E-06	2
sipo_p_fixed7	61145	90060014	60018	90060008	60011	1.41E-06	2
sipo_p_fixed6	61146	90060014	60018	90060008	60011	1.59E-06	2
sipo_p_fixed5	61147	90060014	60018	90060008	60011	1.71E-06	2

Component Name	ID	Property Name	ID	Material Name	ID	MASS (ton)	Thickness (mm)
sipo_p_fixed4	61148	90060014	60018	90060008	60011	1.13E-06	2
sipo_p_fixed3	61149	90060014	60018	90060008	60011	1.85E-06	2
sipo_p_fixed2	61150	90060014	60018	90060008	60011	1.95E-06	2
sipo_p_fixed12	61151	90060014	60018	90060008	60011	1.83E-06	2
modplate_rigid1	61152	90060005	60010	90060008	60011	1.55E-06	1.5
modplate_rigid2	61153	90060005	60010	90060008	60011	2.34E-06	1.5
modplate_rigid32	61154	90060005	60010	90060008	60011	1.45E-06	1.5
modplate_rigid4	61155	90060005	60010	90060008	60011	1.65E-06	1.5
modplate_rigid5	61156	90060005	60010	90060008	60011	1.58E-06	1.5
modplate_rigid6	61157	90060005	60010	90060008	60011	1.98E-06	1.5
modplate_rigid7	61158	90060005	60010	90060008	60011	9.84E-07	1.5
modplate_rigid8	61159	90060005	60010	90060008	60011	1.76E-06	1.5
e.pedal	61160	90060073	60043	90060011	60034	8.37E-04	8
e.pad	61164	90060074	60044	90060011	60034	1.20E-04	3.5
e.pin	61165	90060075	60045	90060011	60034	1.14E-04	2
pedalpivout	61167	90060072	60042	90060009	60012	8.58E-06	3
pedalpivinb	61168	90060072	60042	90060009	60012	8.58E-06	3
pedallink	61169	90060072	60042	90060009	60012	1.43E-06	3
pivot inb	61170	90060072	60042	90060009	60012	4.32E-06	3
pivot out	61171	90060072	60042	90060009	60012	1.10E-06	3
Part221130	61172	90060072	60042	90060009	60012	1.08E-06	3
Part221131	61173	90060072	60042	90060009	60012	1.39E-06	3
Part221132	61174	90060072	60042	90060009	60012	9.68E-07	3
Part221133	61175	90060072	60042	90060009	60012	9.79E-07	3
Part221134	61176	90060072	60042	90060009	60012	6.86E-07	3
Part221135	61177	90060072	60042	90060009	60012	1.30E-06	3
Part221136	61178	90060072	60042	90060009	60012	9.62E-07	3
dr_ealf	61179	90060077	60047	90060011	60034	2.25E-04	1.5
dr_eart	61180	90060077	60047	90060020	60041	2.25E-04	1.5
ps_eart	61181	90060076	60046	90060020	60041	1.64E-04	1.5
ps_eart.1	61182	90060076	60046	90060020	60041	1.64E-04	1.5
floor_attachment	61183	90060078	60048	90060020	60041	5.18E-04	2
tunlbkt_fixdeles	61184	90060078	60048	90060010	60013	1.18E-06	2
tunlbkt_fixdeles	61185	90060078	60048	90060010	60013	1.27E-06	2
tunlbkt_fixdeles	61186	90060078	60048	90060010	60013	2.33E-06	2
tunlbkt_fixdeles	61187	90060078	60048	90060010	60013	1.83E-06	2
tunlbkt_fixdeles	61188	90060078	60048	90060010	60013	4.47E-06	2
tunlbkt_fixdeles	61189	90060078	60048	90060010	60013	7.59E-06	2
tunlbkt_fixdeles	61190	90060078	60048	90060010	60013	2.76E-06	2
tunlbkt_fixdeles	61191	90060078	60048	90060010	60013	3.89E-06	2
gboxframe_base	61192	90060080	60049	90060016	60039	3.92E-04	2.5
vribs_gboxframe	61193	90060081	60050	90060016	60039	4.81E-06	1
hribs_gboxframe	61194	90060082	60051	90060016	60039	2.76E-05	1.2
Mag_6.5.1.1	61196	90060100	60052	90060012	60035	3.18E-04	6.5
Mag_3.0.1.1	61197	90060101	60053	90060012	60035	0.00345	3
Mag_4.0.1.1	61198	90060102	60054	90060012	60035	4.81E-04	4
Mag_ribs.1.1	61199	90060103	60055	90060012	60035	0.002748	3

Component Name	ID	Property Name	ID	Material Name	ID	MASS (ton)	Thickness (mm)
Mag_1.5.1.1	61200	90060104	60056	90060012	60035	1.28E-04	1.5
Mag_5.0.1	61201	90060105	60057	90060012	60035	1.40E-04	5
Mag_2.5	61202	90060106	60058	90060012	60035	2.65E-04	2.5
inner.1	61203	90060107	60059	90060016	60039	3.58E-04	3
innergroorve	61204	90060111	60063	90060016	60039	8.37E-07	3.3
ribs.1	61205	90060112	60064	90060016	60039	1.36E-04	1.25
bin o	61206	90060108	60060	90060017	60040	2.74E-04	2.5
ribbin	61207	90060110	60062	90060017	60040	5.71E-07	1.7
bintongue	61208	90060109	60061	90060017	60040	4.40E-07	1.1
outer.1	61209	90060113	60065	90060016	60039	2.85E-04	2.5
hub	61210	90060115	60067	90060016	60039	1.76E-06	1
outerhrib	61211	90060114	60066	90060016	60039	7.18E-06	1.2
outervrib	61212	90060115	60067	90060016	60039	3.35E-07	1
hubrib	61213	90060116	60068	90060016	60039	1.93E-07	1.375
glvbx_frm_hinge_	61214	90060117	60069	90060016	60039	8.29E-06	3
knee bolster inn	61215	90060118	60070	90060016	60039	2.66E-04	2.5
inner rib h	61216	90060119	60071	90060016	60039	1.25E-04	1.875
small rib inner	61217	90060120	60072	90060016	60039	3.27E-06	2.6
knee bolster out	61218	90060121	60073	90060016	60039	4.25E-04	2.5
doghouse outer	61219	90060122	60074	90060016	60039	6.40E-06	1.4
outer rib	61220	90060123	60075	90060016	60039	4.29E-06	1.1
tipof bin	61221	90060124	60076	90060016	60039	5.01E-05	2.5
part.9	61301	SectShll20.1	60088	MAT9_704	60009	1.21E-04	2
part.10	61302	SectShll20.1	60088	MAT9_705	60010	5.67E-05	2
part.11	61303	SectShll5.3	60105	MAT20_706	60015	5.98E-05	0.5
part.14	61304	SectShll20.1	60088	MAT20_750	60016	0.001699	2
part.15	61305	SectShll10.1	60083	MAT20_751	60017	8.05E-05	1
part.16	61306	SectShll34	60115	MAT20_752	60018	1.83E-04	3.4
part.17	61307	SectShll25	60091	MAT20_753	60019	5.23E-04	2.5
part.18	61308	SectShll25	60091	MAT20_754	60020	6.50E-04	2.5
part.19	61309	SectShll20.1	60088	MAT20_755	60021	5.14E-04	2
part.20	61310	SectShll30	60094	MAT20_756	60022	4.70E-04	3
part.21	61311	SectShll34	60115	MAT20_757	60023	2.55E-04	3.4
part.22	61312	SectShll20.1	60088	MAT20_758	60024	5.61E-05	2
part.24	61313	SectShll20.1	60088	MAT20_760	60025	1.14E-04	2
part.25	61314	SectShll20.1	60088	MAT20_761	60026	8.86E-05	2
part.28	61315	SectShll20.1	60088	MAT20_764	60027	2.43E-05	2
part.29	61316	SectShll20.1	60088	MAT20_765	60028	2.32E-05	2
part.30	61317	SectShll40	60093	MAT20_766	60029	3.95E-06	4
part.31	61318	SectShll40	60093	MAT20_767	60030	3.95E-06	4
part.34	61319	SectShll40	60093	MAT24_771	60044	2.43E-05	4
part.40	61320	SectShll30	60094	MAT20_777	60031	3.28E-04	3
part.41	61321	SectShll30	60094	MAT20_778	60032	3.69E-04	3
strclnmend4	61323	SectShll50	60092	rigid	60014	2.10E-04	5
part.49	61324	SectShll15.3	60117	MAT20_20015	60033	9.89E-06	1.5
drinrpnl.l	61401	Sectshll75	60097	MATL24_160	60048	0.003637	0.75
drlwrhng.l	61402	SectShll50	60092	MATL24_160	60048	1.28E-04	5

Component Name	ID	Property Name	ID	Material Name	ID	MASS (ton)	Thickness (mm)
drotrpnl.l	61403	Sectshll75	60097	MATL24_180	60046	0.004388	0.75
z-brkt.l	61404	SectShll10.1	60083	MATL24_160	60048	5.56E-05	1
upr_frame.l	61405	SectShll10.1	60083	MATL24_160	60048	0.001997	1
drbeam.l	61406	SectShll20.1	60088	MATL24_600	60056	0.001914	2
druprhng.l	61407	SectShll50	60092	MATL24_160	60048	1.30E-04	5
drinrpnl.r	61408	Sectshll75	60097	MATL24_160	60048	0.003636	0.75
drotrpnl.r	61409	Sectshll75	60097	MATL24_180	60046	0.004388	0.75
z-brkt.r	61410	SectShll10.1	60083	MATL24_160	60048	5.56E-05	1
upr_frame.r	61411	SectShll10.1	60083	MATL24_160	60048	0.001997	1
drbeam.r	61412	SectShll20.1	60088	MATL24_600	60056	0.001913	2
druphng.r	61413	SectShll50	60092	MATL24_160	60048	1.34E-04	5
drlwhng.r	61414	SectShll50	60092	MATL24_160	60048	1.26E-04	5
fdrbdhng	61415	SectShll50	60092	MATL24_210	60052	2.07E-04	5
fdrbdhng2	61416	SectShll20.1	60088	rigid	60014	1.96E-05	2
fdrbdhng3	61417	SectShll20.1	60088	rigid	60014	2.43E-05	2
fdrbdhng4	61418	SectShll50	60092	MATL24_210	60052	2.01E-04	5
fdrbdhng5	61419	SectShll20.1	60088	rigid	60014	2.07E-05	2
fdrbdhng6	61420	SectShll20.1	60088	rigid	60014	2.54E-05	2
fdrbdhng7	61421	SectShll50	60092	MATL24_210	60052	2.55E-04	5
fdrbdhng8	61422	SectShll20.1	60088	rigid	60014	2.01E-05	2
fdrbdhng9	61423	SectShll20.1	60088	rigid	60014	2.48E-05	2
fdrbdhng10	61424	SectShll50	60092	MATL24_210	60052	1.97E-04	5
fdrbdhng11	61425	SectShll20.1	60088	rigid	60014	2.07E-05	2
fdrbdhng12	61426	SectShll20.1	60088	rigid	60014	2.49E-05	2
drlsrwld.l	61427	SectShll18.1	60087	MATL24_160	60048	0.003567	1.8
drlsrwld.r	61428	SectShll18.1	60087	MATL24_160	60048	0.003567	1.8
rrdrinn.l	61429	Sectshll75	60097	MATL24_160	60048	0.00681	0.75
twdrrdrinr.l	61430	SectShll18.1	60087	MATL24_160	60048	0.005454	1.8
rrdrotr.l	61431	Sectshll75	60097	MATL24_160	60048	0.008021	0.75
rrdrfrm.l	61432	SectShll10.1	60083	MATL24_160	60048	0.003331	1
rrdrbm.l	61433	SectShll20.1	60088	MATL24_600	60056	0.002513	2
bathtub.l	61434	SectShll20.1	60088	MATL24_160	60048	2.59E-04	2
rrdrhng.l	61435	SectShll50	60092	MATL24_160	60048	1.06E-03	5
latchjt.l	61436	SectShll20.1	60088	MATL24_160	60048	2.28E-04	2
rrdrhng1.l	61437	SectShll50	60092	MATL24_160	60048	6.20E-04	5
roof	61501	Sectshll75	60097	MATL24_160	60048	0.010108	0.75
wshield	61502	SectShll48	60100	laminatedglass	60058	0.015411	4.8
rr_wndshld	61503	SectShll48	60100	laminatedglass	60058	0.011652	4.8
bdysdpnlotr.l	61601	Sectshll75	60097	MATL24_160	60048	0.014307	0.75
bdysdpnlotr.r	61602	Sectshll75	60097	MATL24_160	60048	0.014308	0.75
twldbsideinr.l	61603	SectShll21	60089	MATL24_160	60048	0.00905	2.1
twldbsideinr.r	61604	SectShll21	60089	MATL24_160	60048	0.009056	2.1
rkrx_l	61605	Sectshll13	60098	MATL24_340	60049	1.01E-03	1.3
rkrx_r	61606	Sectshll13	60098	MATL24_340	60049	1.01E-03	1.3
rkrinr.l	61607	sectshll16	60114	MATL24_3404	60051	0.003811	1.6
rkrinr.r	61608	sectshll16	60114	MATL24_3404	60051	0.003811	1.6
twldB-plr.l	61609	SectShll18.1	60087	MATL24_250	60054	0.003041	1.8

Component Name	ID	Property Name	ID	Material Name	ID	MASS (ton)	Thickness (mm)
twldB-plr.r	61610	SectShll18.1	60087	MATL24_250	60054	0.003041	1.8
bdysdpnlinr.l	61611	SectShll10.1	60083	MATL24_160	60048	0.009621	1
bdysdpnlinr.r	61612	SectShll10.1	60083	MATL24_160	60048	0.009567	1
B_plr_rnf	61613	SectShll10.1	60083	MATL24_160	60048	6.01E-04	1
bplrrnf.l	61615	SectShll225	60099	MATL24_250	60054	0.003029	2.25
bplrrnf.r	61616	SectShll225	60099	MATL24_250	60054	0.003029	2.25
rfrailrnfl	61617	SectShll20.1	60088	MATL24_210	60052	0.002007	2
rfrailrnfr	61618	SectShll20.1	60088	MATL24_210	60052	0.002007	2
frt_hrn	61619	SectShll20.1	60088	MATL24_160	60048	7.90E-04	2
rfrailinr.r	61620	SectShll20.1	60088	MATL24_160	60048	7.85E-04	2
a_pilar_rnf_l	61621	SectShll10.1	60083	MATL24_160	60048	9.04E-04	1
a_pilar_rnf_r	61622	SectShll10.1	60083	MATL24_160	60048	9.05E-04	1
fbhplrrnf1.l	61623	SectShll10.1	60083	MATL24_210	60052	0.001632	1
fbhplrrnf1.r	61624	SectShll10.1	60083	MATL24_210	60052	0.001634	1
frthdr	61625	SectShll7.2	60080	MATL24_160	60048	9.30E-04	0.7
rfbow2	61626	SectShll9.1	60082	MATL24_340	60049	9.23E-04	0.9
rearflr	61627	SectShll8.3	60081	MATL24_160	60048	0.017539	0.8
bar3	61628	SectShll10.1	60083	MATL24_211	60053	0.002442	1
bar4ctr	61629	SectShll10.1	60083	MATL24_340	60049	0.001438	1
bar4lft	61630	SectShll15.3	60117	MATL24_160	60048	0.001168	1.5
rrrail.l	61631	SectShll15.3	60117	MATL24_251	60055	0.005535	1.5
rrrailrnf1.l	61632	SectShll10.1	60083	MATL24_160	60048	1.93E-04	1
rrailrnf2.l	61633	SectShll10.1	60083	MATL24_160	60048	2.10E-04	1
gusset.l	61634	SectShll15.3	60117	MATL24_160	60048	7.13E-04	1.5
gusset2.l	61635	SectShll15.3	60117	MATL24_160	60048	8.44E-04	1.5
gusset3.l	61636	SectShll15.3	60117	MATL24_160	60048	5.19E-04	1.5
gusset4.l	61637	SectShll15.3	60117	MATL24_160	60048	5.89E-04	1.5
whlhsinr.l	61638	SectShll10.1	60083	MATL24_160	60048	0.002906	1
4barrnf1.l	61639	SectShll20.1	60088	MATL24_160	60048	0.001399	2
4barrnf2.l	61640	SectShll25	60091	MATL24_160	60048	7.24E-04	2.5
backpanel	61641	SectShll8.3	60081	MATL24_160	60048	0.005311	0.8
bpnlrnf	61642	Sectshll75	60097	MATL24_160	60048	0.001933	0.75
rrhdr	61643	SectShll9.1	60082	MATL24_160	60048	0.001131	0.9
rrsuspshk.l	61644	SectShll225	60099	MATL24_160	60048	3.05E-04	2.25
rkrblkhds	61645	SectShll12.1	60084	MATL24_340	60049	7.54E-04	1.2
rdeck	61646	SectShll10.1	60083	MATL24_160	60048	0.005446	1
trnkgtrfrt	61647	SectShll10.1	60083	MATL24_160	60048	0.00209	1
rdeckbrkt1	61648	SectShll10.1	60083	MATL24_160	60048	9.01E-04	1
rdeckbrkt2	61649	SectShll10.1	60083	MATL24_160	60048	2.49E-04	1
trnkgtr.l	61650	SectShll9.1	60082	MATL24_160	60048	3.97E-04	0.9
rdeckbrkt3.l	61651	SectShll10.1	60083	MATL24_160	60048	8.76E-04	1
rdeckbrkt4.l	61652	SectShll10.1	60083	MATL24_160	60048	7.67E-04	1
trlrhtchbrkt	61653	SectShll10.1	60083	MATL24_160	60048	0.001306	1
rrailext.l	61654	SectShll15.3	60117	MATL24_160	60048	7.55E-04	1.5
bar4rt	61655	SectShll15.3	60117	MATL24_160	60048	0.001168	1.5
rrrail.r	61656	SectShll15.3	60117	MATL24_251	60055	0.005519	1.5
rrailrnf1.r	61657	SectShll10.1	60083	MATL24_160	60048	1.93E-04	1

Component Name	ID	Property Name	ID	Material Name	ID	MASS (ton)	Thickness (mm)
rrailrnf2.r	61658	SectShll10.1	60083	MATL24_160	60048	2.10E-04	1
gusset.r	61659	SectShll15.3	60117	MATL24_160	60048	7.13E-04	1.5
gusset2.r	61660	SectShll15.3	60117	MATL24_160	60048	8.44E-04	1.5
gusset3.r	61661	SectShll15.3	60117	MATL24_160	60048	5.19E-04	1.5
gusset4.r	61662	SectShll15.3	60117	MATL24_160	60048	5.87E-04	1.5
whlhsinr.r	61663	SectShll10.1	60083	MATL24_160	60048	0.003046	1
4barrnf1.r	61664	SectShll20.1	60088	MATL24_160	60048	0.001459	2
4barrnf2.r	61665	SectShll25	60091	MATL24_160	60048	6.97E-04	2.5
rrsuspshk.r	61666	SectShll225	60099	MATL24_160	60048	3.05E-04	2.25
trnkgtr.r	61667	SectShll9.1	60082	MATL24_160	60048	4.00E-04	0.9
rdeckbrkt3.r	61668	SectShll10.1	60083	MATL24_160	60048	8.73E-04	1
rdeckbrkt4.r	61669	SectShll10.1	60083	MATL24_160	60048	7.63E-04	1
rrailext.r	61670	SectShll15.3	60117	MATL24_160	60048	7.48E-04	1.5
fbhpbulkhd.l	61671	SectShll20.1	60088	MATL24_340	60049	5.83E-04	2
rkrblkhds.1	61672	SectShll12.1	60084	MATL24_340	60049	2.83E-04	1.2
accl.r	61673	SectShll10.1	60083	rigid	60014	4.29E-05	1
accl.l	61674	SectShll10.1	60083	rigid	60014	4.56E-05	1
rr_hrn	61675	SectShll14.1	60085	MATL24_160	60048	9.12E-04	1.4
fbhp_brkt	61676	SectShll20.1	60088	MATL24_210	60052	1.84E-04	2
rkr_extn	61677	Sectshll75	60097	MATL24_600	60056	0.001526	0.75
muffler	61701	SectShll5.3	60105	MATL24_160	60048	0.00133	0.5
exhstpipe	61702	SectShll5.3	60105	MATL24_160	60048	0.00201	0.5
rtire.l	61801	SectShll10.1	60083	MATL24_160	60048	0.007576	1
rtire.r	61802	SectShll10.1	60083	MATL24_160	60048	0.007576	1
rearrim	61803	SectShll35	60106	MATL24_160	60048	0.015933	3.5
rbmpbmbrkt.l	61901	SectShll15.3	60117	MATL24_160	60048	4.35E-04	1.5
rbmpbmbrkt.r	61902	SectShll15.3	60117	MATL24_160	60048	4.35E-04	1.5
rbumpbeam	61903	SectShll10.1	60083	MATL24_160	60048	0.003708	1
part.42	62001	SectDisc779	60123	MATSpr1_779	60063	0	0
part.43	62002	SectDisc780	60124	MATDmp2_780	60064	0	0
part.44	62003	SectDisc781	60125	MATSpr4_781	60069	0	0
part.47	62004	SectDisc783	60126	MATDmp2_784	60065	0	0
part.12	62005	SectBeam707	60009	MAT24_707	60043	7.70E-04	0
bar1fsusp	62006	Sectbeam10500	60002	MATBEAM	60057	0.001903	0
bar2fsusp	62007	Sectbeam10501	60003	MATBEAM	60057	4.12E-05	0
bar3fsusp	62008	Sectbeam10500	60002	MATBEAM	60057	1.41E-04	0
BARDLINE	62009	Sectbeam10504	60004	MATBEAM	60057	7.06E-05	0
bar4fsusp	62010	Sectbeam10500	60002	MATBEAM	60057	9.48E-04	0
bar2dline	62011	Sectbeam10500	60002	MATBEAM	60057	0.001306	0
bar3dline	62012	Sectbeam10504	60004	MATBEAM	60057	1.16E-04	0
bar5dline	62013	Sectbeam10509	60005	MATBEAM	60057	8.50E-05	0
bar1rrsus	62014	Sectbeam10500	60002	MATBEAM	60057	0.007365	0
bar2rrsusp	62015	Sectbeam10516	60006	MATBEAM	60057	0.019679	0
bar3rrsusp	62016	Sectbeam10516	60006	MATBEAM	60057	0.0026	0
bar4rrsusp	62017	Sectbeam10516	60006	MATBEAM	60057	0.002841	0
bardummies	62018	Sectbeam10519	60007	MATBEAM	60057	0.003373	0
barseat	62019	Sectbeam10519	60007	MATBEAM	60057	3.34E-04	0

Component Name	ID	Property Name	ID	Material Name	ID	MASS (ton)	Thickness (mm)
barradiator	62020	Sectbeam10522	60008	MATBEAM	60057	1.82E-04	0
bardriveline	62021	Sectbeam10504	60004	MATBEAM	60057	2.57E-04	0
bardriveline8	62022	Sectbeam10504	60004	MATBEAM	60057	7.05E-05	0
sprdrvline	62023	SectDisc1	60122	Matsprstr14	60066	0	0
sprengmnt3	62024	SectDisc1	60122	Matsprstr113	60067	0	0
sprdummy	62025	SectDisc1	60122	Matsprstr114	60068	0	0
spr2dummy	62026	SectDisc1	60122	Matsprstr116	60062	0	0
spr3dummy	62027	SectDisc1	60122	Matsprstr116	60062	0	0
ltmount_spring	62028	SectDisc20071.1	60127	MATSpr4_61112	60070	0	0
rt_mount_spring	62029	SectDisc20071.1	60127	MATSpr4_61113	60071	0	0
rr_cdl_atch_spri	62030	SectDisc20071.1	60127	MATSpr4_61116	60073	0	0
rr_cdl_atch_spri	62031	SectDisc20071.1	60127	MATSpr4_61115	60072	0	0
hinge_beam_65dia	62032	90060004	60001	90060006	60005	1.06E-04	0
pt6	60701	SectShll10.1	60083	rigid	60014	0.304199	1
Masses	62033	N/A	N/A	N/A	0	0.002085	N/A
ElemMass	62034	N/A	N/A	N/A	0	0.633762	N/A
ncap_driver_pass	62035	N/A	N/A	N/A	0	0.156	N/A
out_front_lh_doo	62047	N/A	N/A	N/A	0	1.42E-04	N/A
out_ip_masses_2	62050	N/A	N/A	N/A	0	0.001933	N/A
out_hood_masses_	62054	N/A	N/A	N/A	0	9.59E-05	N/A
out_roof_masses_	62056	N/A	N/A	N/A	0	8.76E-05	N/A
out_windshield_m	62058	N/A	N/A	N/A	0	1.92E-06	N/A
out_rear_lh_door	62060	N/A	N/A	N/A	0	1.96E-04	N/A
out_front_rh_doo	62064	N/A	N/A	N/A	0	1.53E-04	N/A
out_rear_rh_door	62066	N/A	N/A	N/A	0	1.90E-04	N/A
SpotWelds	62039	N/A	N/A	N/A	0	0	N/A
2T_Welds	62043	N/A	N/A	N/A	0	0	N/A
Rigids.5	62040	N/A	N/A	N/A	0	0	N/A
Joints	62068	N/A	N/A	N/A	0	0	N/A

Total Components	**495**
Model Mass	**1.778 tonnes**

- Model mass is from LS-DYNA3D d3hsp file.
- Part mass summary is from HYPERMESH.

Concept 2: Preliminary Design

Milestone 13

Lightweight Front End Structure Phase II

February 2, 2004

Auto/Steel Partnership

Abstract

This report documents the preliminary design for *Concept 2* that has a new stamped rail design and a stamped bumper design. The final *Concept 2* design will be compared to Concepts 1 and 3 developed in Phase II of the Lightweight Front End Structure Project.

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1. Objectives

The effort of this study was aimed at developing a preliminary design for *Concept 1*, which has a new stamped rail design and a stamped bumper design. The final *Concept 2* design will be compared to Concepts 1 and 3 developed in Phase II of the Lightweight Front End Structure Project.

2. Results Summary

The *Concept 2* design has the following features.

- Octagonal 3-piece tailor-welded rail inner and outer pieces with symmetric flanges and tapered front section.
- Three-piece rail tailor-welded extension design with a reinforcement.
- Front suspension panel extended to act as reinforcement to rail inner.
- Symmetric LH/RH rail assemblies.
- Two-piece double box bumper design with energy absorbing features.

The Concept 2 design achieves a mass reduction of **4.95kg** (**12.6%**) compared to the *Baseline* design. The NCAP performance is superior to that of the baseline design. The IIHS performance is similar to that of the baseline design.

The NCAP and IIHS results are summarized in *Table 1* and *Table 2*.

Table 1: NCAP Results

	Peak Acceleration	
B Pillar Pulse	Baseline	Concept 2
LH	36.7 g @ 58.7 ms	31.5 g @ 53.2 ms
RH	35.3 g @ 58.6 ms	29.3 g @ 48.0 ms

Table 2: IIHS Results

Location	Peak Intrusions (cm)	
	Baseline	Concept 2
Left Toepan	18.2	18.1
Center Toepan	18.4	19.9
Right Toepan	19.4	19.5
A-B Pillar Closure	14.4	14.9

3. Concept 2 Design

The rail design is a 3-part stamped design with symmetric LH and RH rail assemblies. The inner and outer rails are 3-piece octagonal tailor-welded sections with symmetric flanges. The front section of the rails is tapered. The rail extension is 3-piece tailor-welded and has a reinforcement. The front suspension panel (skirt) is extended to act as a reinforcement to inner rail.

The rail and bumper gauges were obtained through a mini-DOE study.

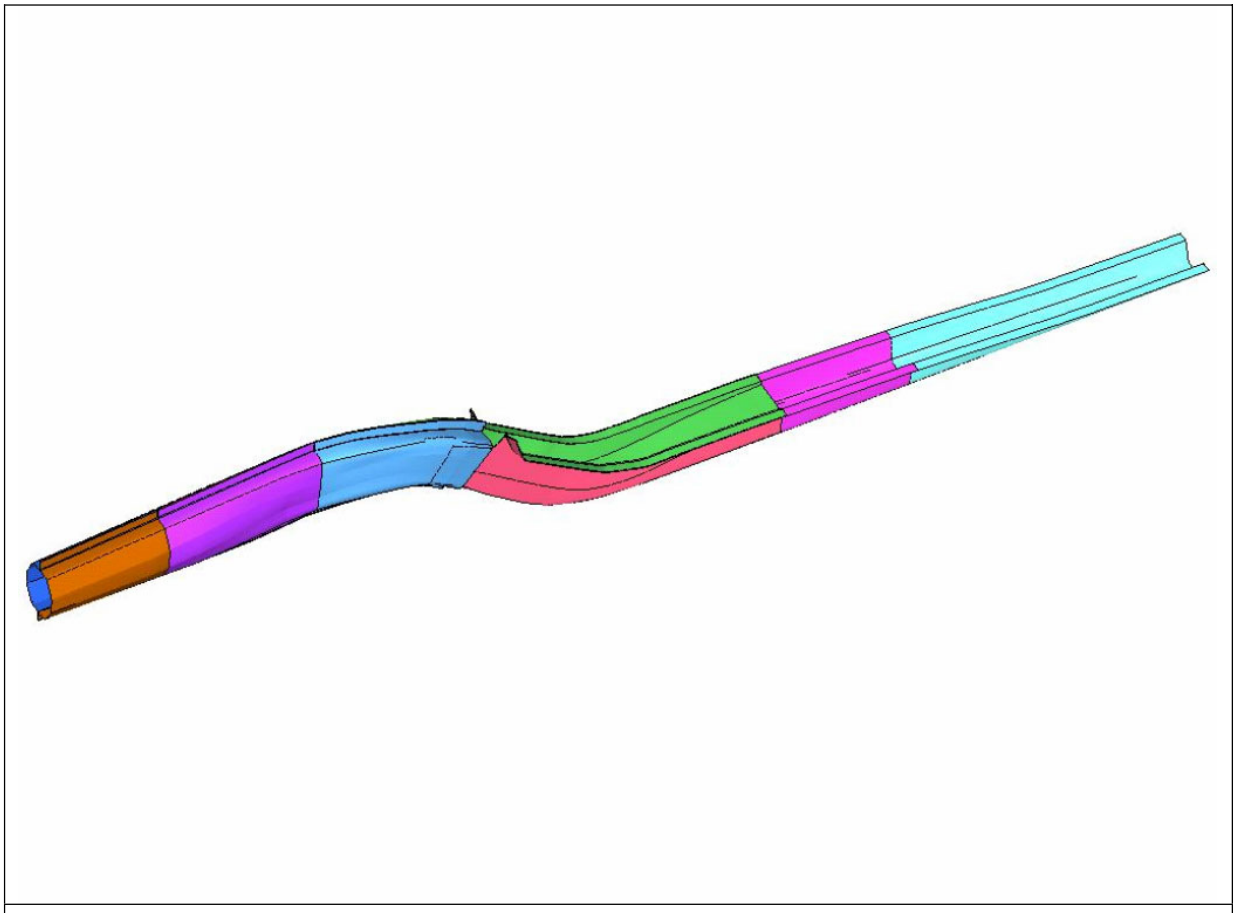


Figure 1: LH Rail Assembly

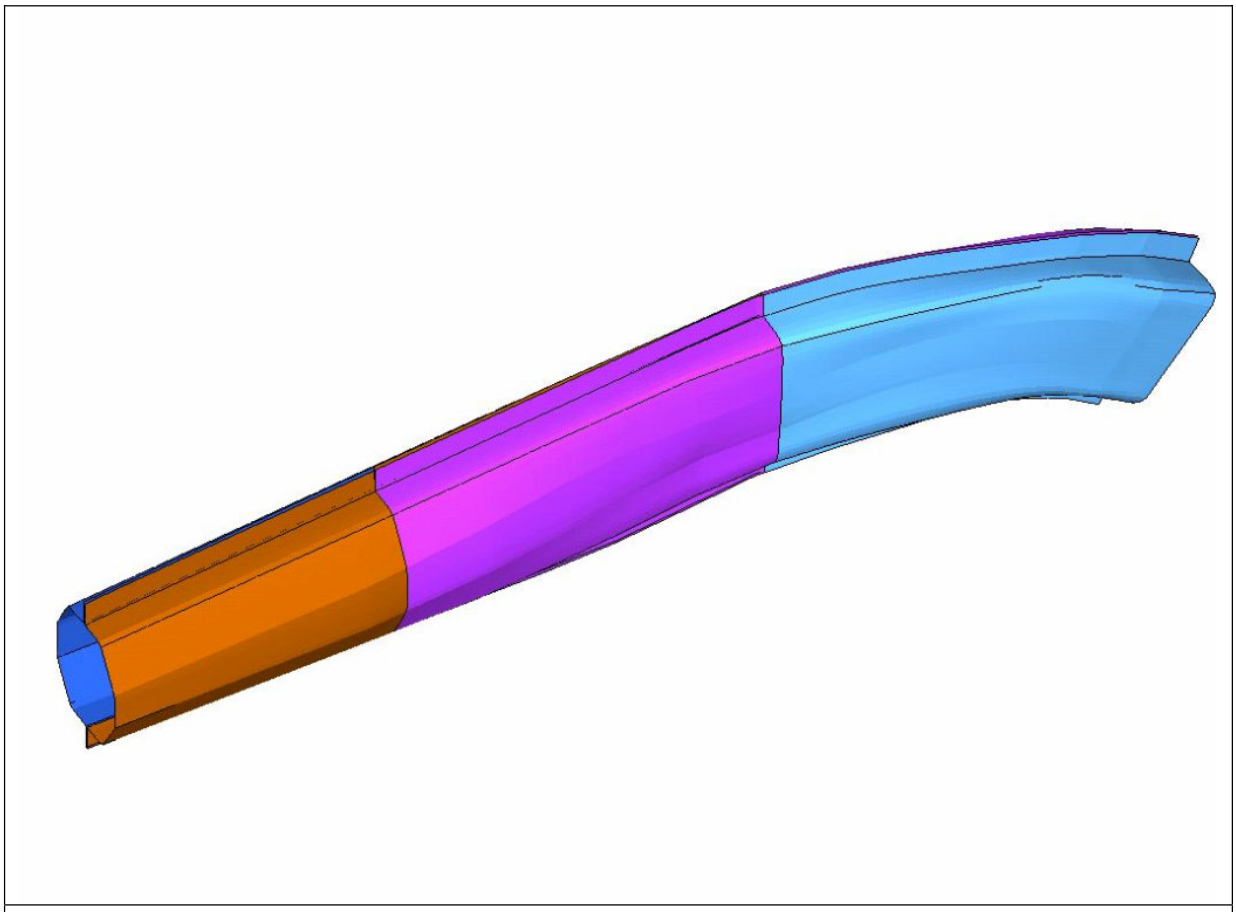


Figure 2: LH Inner & Outer Rails

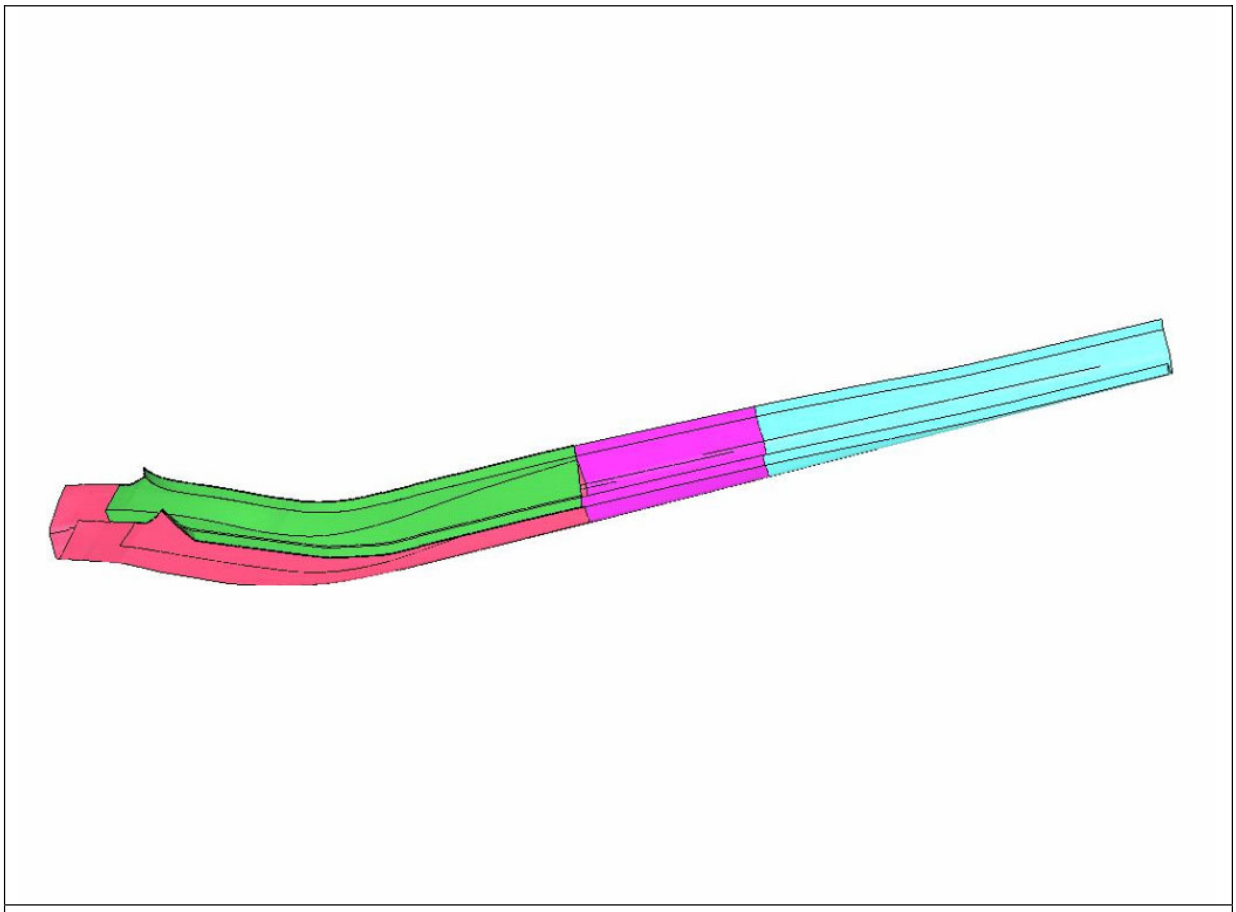


Figure 3: LH Rail Extension

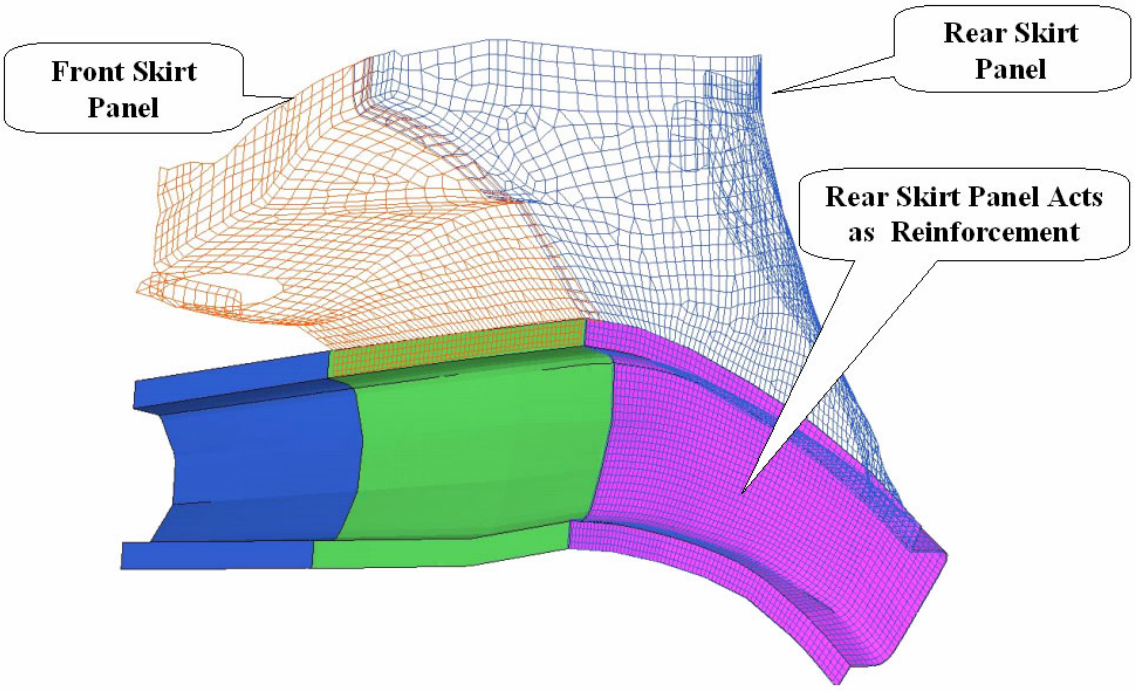


Figure 4: LH Skirt Reinforcement

The flange width was reduced by 5mm, as compared to the *Baseline*. The total flange width is now 21 mm, which includes a 5mm radius and 16mm flat. This would make the flange width same as the ULSAB rails. The donor vehicle model has a flat of 21mm, resulting in a total flange width of 26mm. Refer to *Concept1* milestone report for details on rail flanges.

The baseline bumper was replaced by a new bumper design (*Figure 5, Figure 6*). The new bumper design is functionally quite similar to the Phase I *Bumper 3* design. However, it has fewer manufacturing and welding concerns than the Bumper 3 design. The new bumper design is a 2-piece double-box stamped design using DP980 steel. The bumper has vertical flanges and beads on the front and back plates. The new bumper design has good energy absorption capability in high-speed impacts and results in a high initial peak in the NCAP B-pillar pulse. In addition, the bumper is more formable than the Phase I Bumper 3 design, and is easier to weld. *A design similar to the new bumper design has been prototyped using DF140T steel.*

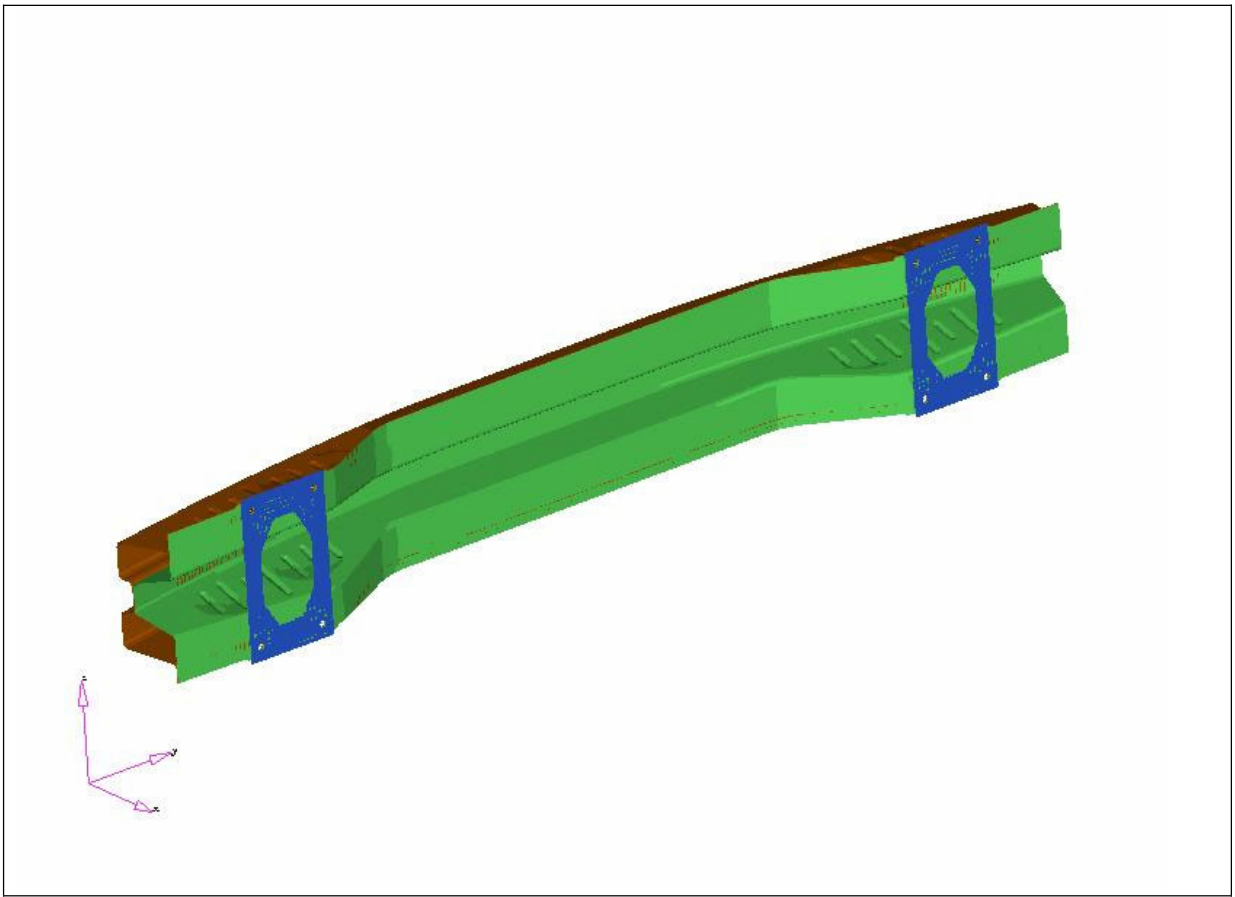


Figure 5: New Bumper Design

The bumper plates are attached to the front rails through an attachment plate. The plate is bolted to the bumper beam through four bolts. The plate has a hole of the same shape as the rail front section, but of a smaller size. The plate is MIG welded to the front rails. The bumper centerline matches that of the rail. This ensures a proper load transfer from the bumper to the rails.

The bumper design passes the low-speed bumper requirements (7).

A mass summary for rail and bumper parts is included in *Table 3*.

A grade/gauge summary for rail and bumper parts is included in *Table 4*.

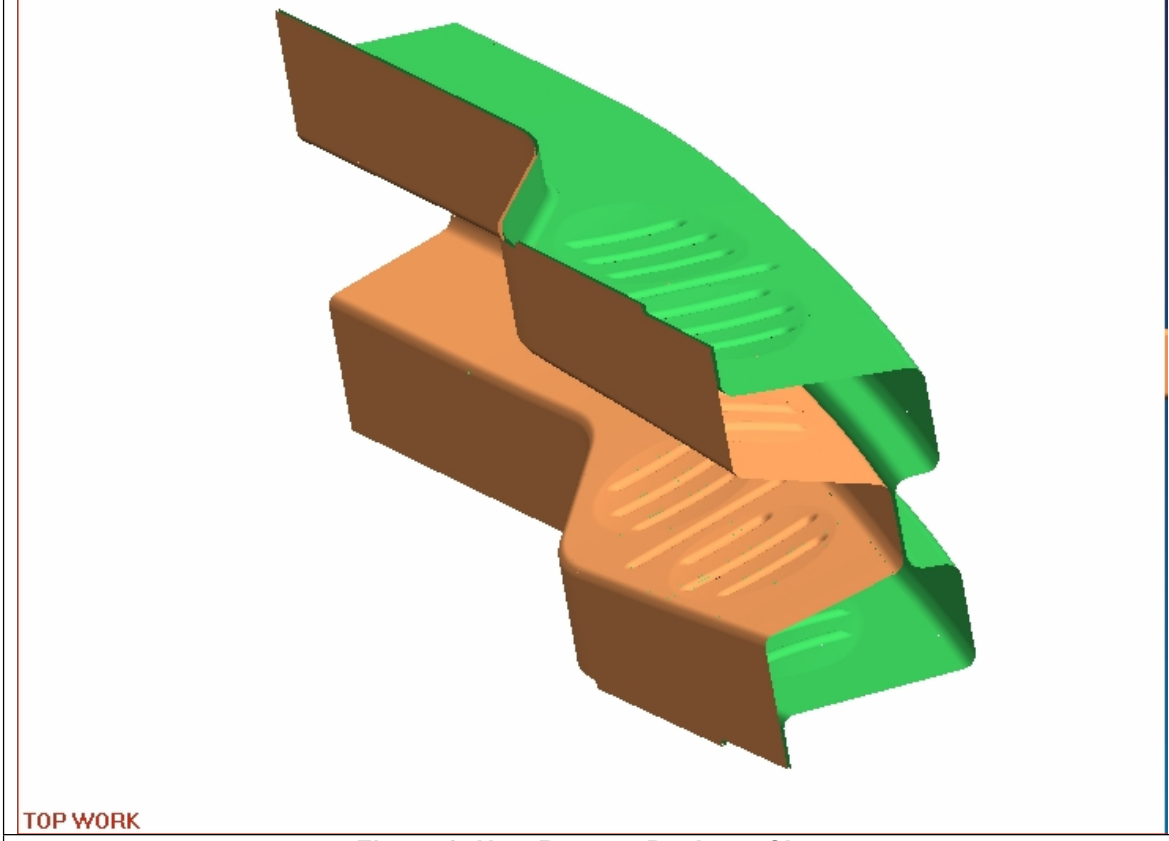


Figure 6: New Bumper Design – Close-up

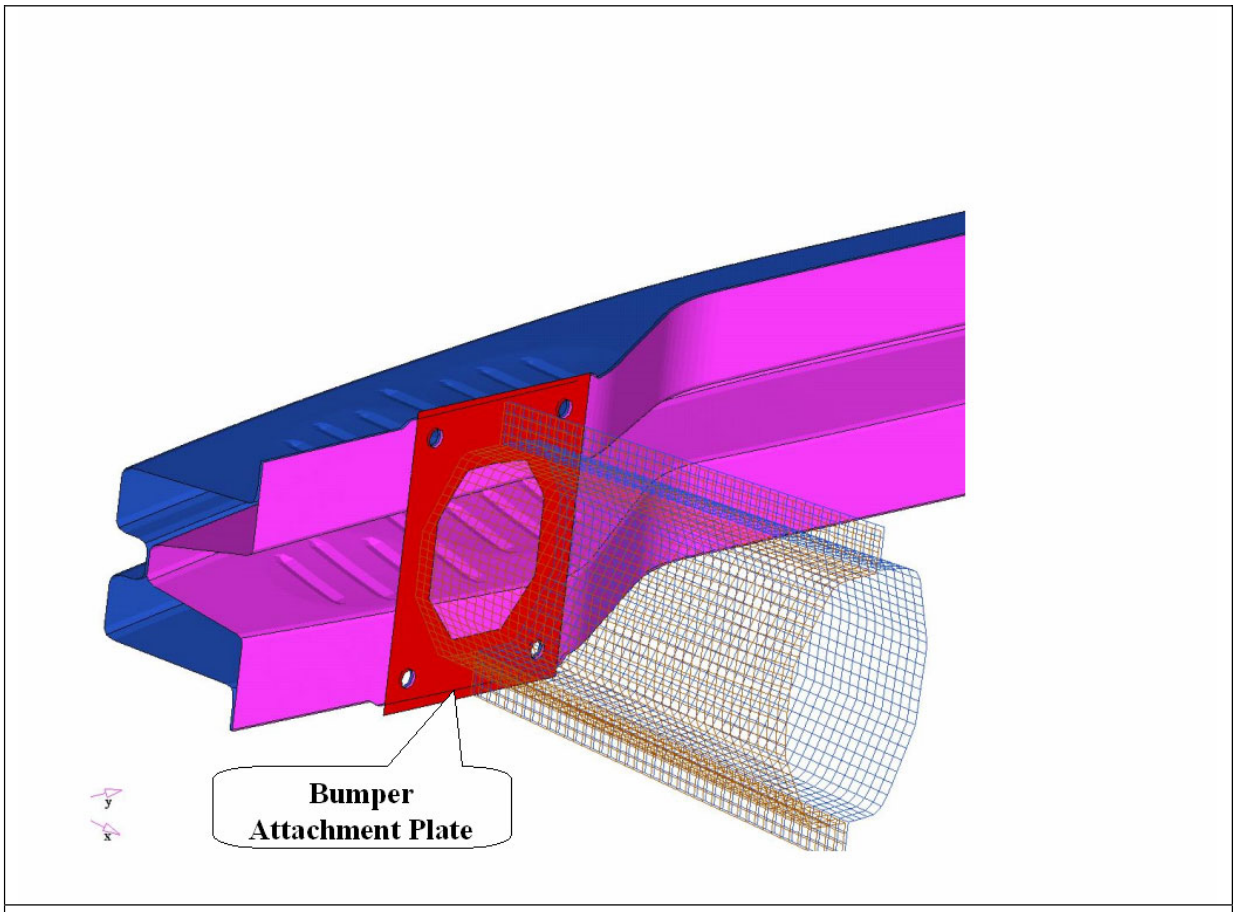


Figure 7: Bumper Attachment

Table 3: Mass Summary

Part	Mass (kg)	
	Baseline Design	Concept 2 Preliminary Design
LH Rail Assembly	16.52	13.96
RH Rail Assembly	16.15	13.96
Bumper (without foam)	6.56	5.98
Total	39.23	34.28*

* 12.6% mass reduction with respect to *Baseline*

Table 4: Grade and Gauge Summary

Part	Concept 2 Preliminary Design	
	Grade	Gauge (mm)
Rail Front Inner	DP 450/800	1.0
Rail Front Outer	DP 450/800	1.0
Rail Mid Inner	DP 450/800	1.6
Rail Mid Outer	DP 450/800	1.6
Rail Rear Inner	DP 450/800	2.0
Rail Rear Outer	DP 450/800	2.0
Rail Extension Front	DP 450/800	2.0
Rail Extension Mid	DP 450/800	1.6
Rail Extension Rear	DP 450/800	1.3
Rail Extension Reinforcement	DP 450/800	2.0
Skirt Reinforcement	DP 450/800	1.2
Bumper Beam	DP 700/980	1.0

4. FE Model - Output Location Summary

The nodes at which the desired NCAP and IIHS outputs were obtained are listed in *Table 5*.

The intrusions are measured at the nodes as specified in *Reference 3*.

The acceleration and intrusion node locations are shown in *Figure 8* and *Figure 9* below.

Table 5: Summary of Output Locations

Parameter	Location	Node Number
Accelerations	B-Pillar / Rocker - LH	5000001
	B-Pillar / Rocker - RH	5000002
Intrusions	Origin	6000000
	Plane Y-axis	6000001
	Plane Z-axis	6000002
	Steering Column	7000001
	Brake Pedal	7000002
	Toepan - Left	7000003
	Toepan - Center	7000004
	Toepan - Right	7000005
	Left Front Seat Bolt	7000006
	Right Front Seat Bolt	7000007
	Left Rear Seat Bolt	7000008
	Right Rear Seat Bolt	7000009
	AB Closure - A Pillar	7000010
	AB Closure - B Pillar	7000011

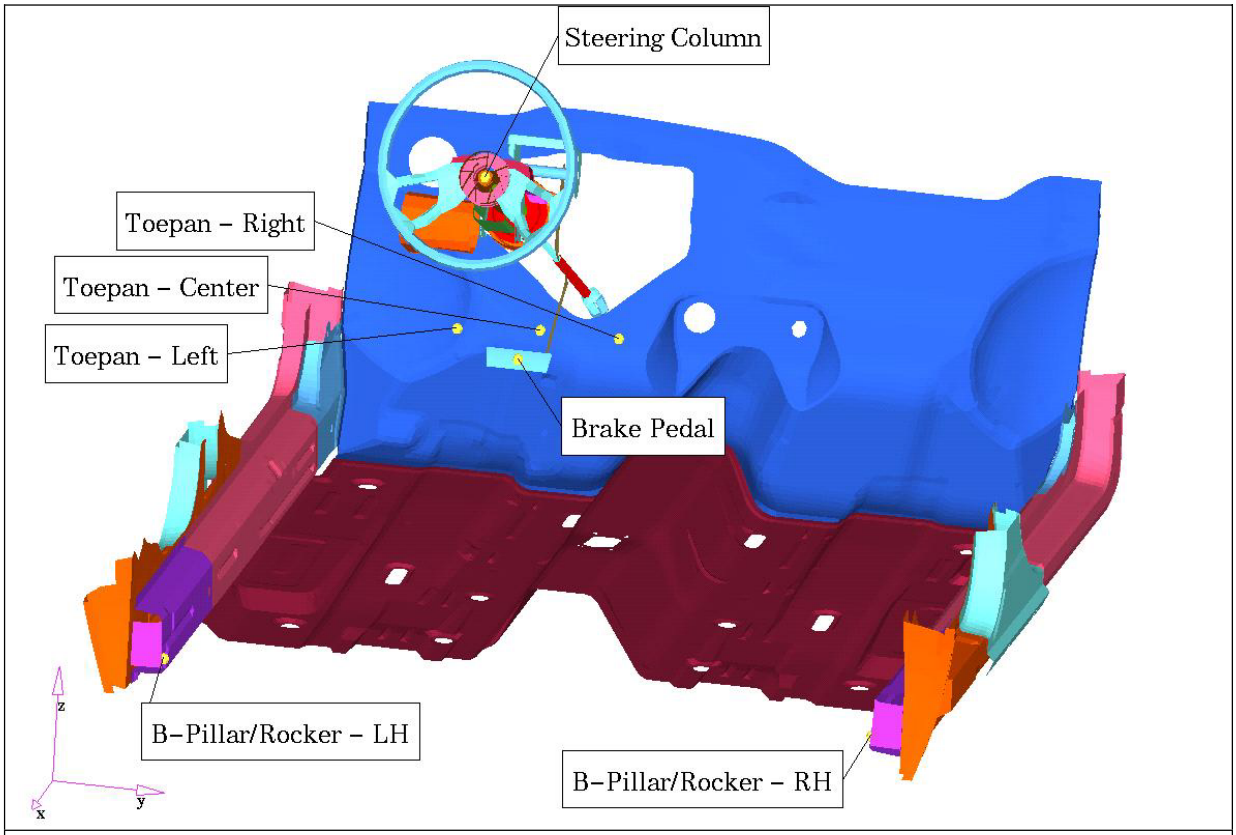


Figure 8: Output Locations for NCAP/IIHS



Figure 9: Output Locations for IIHS- AB Closure

5. NCAP Response

The figures below summarize the NCAP response of Concept 1.

Animation files are included in *Appendix A*.

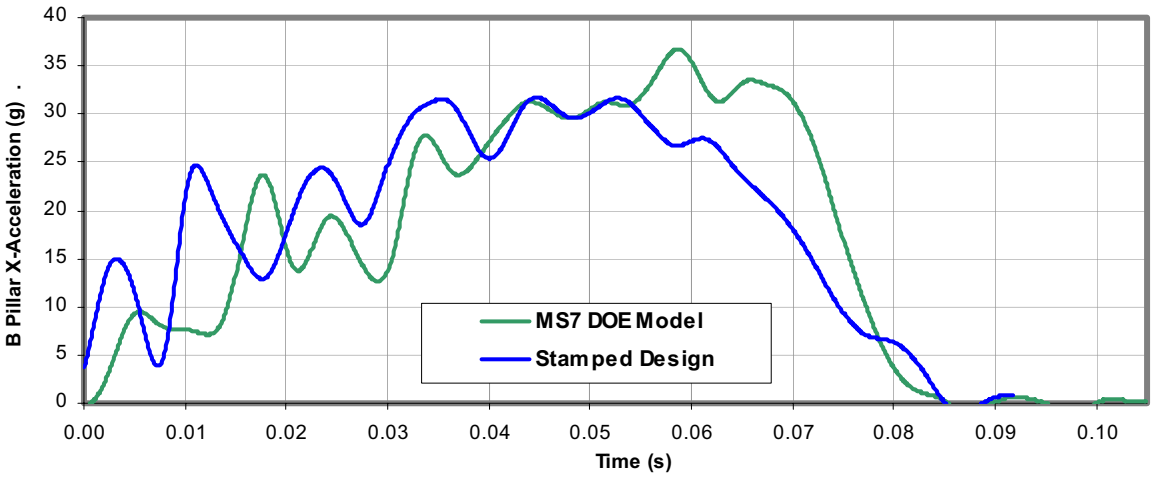


Figure 10: LH B-Pillar Pulse – Concept 2 with Baseline (MS7 DOE Model)

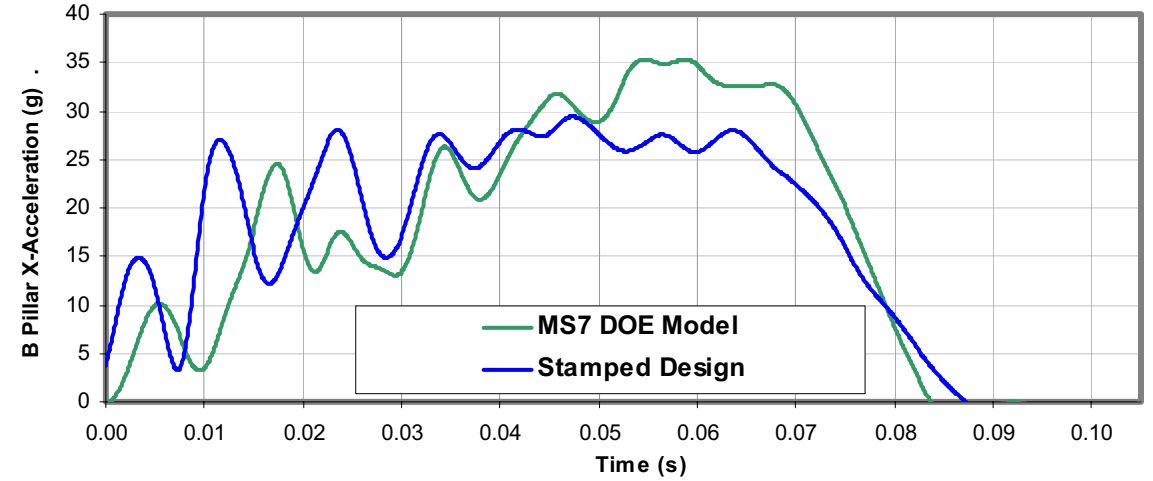


Figure 11: RH B-Pillar Pulse – Concept 2 with Baseline (MS7 DOE Model)

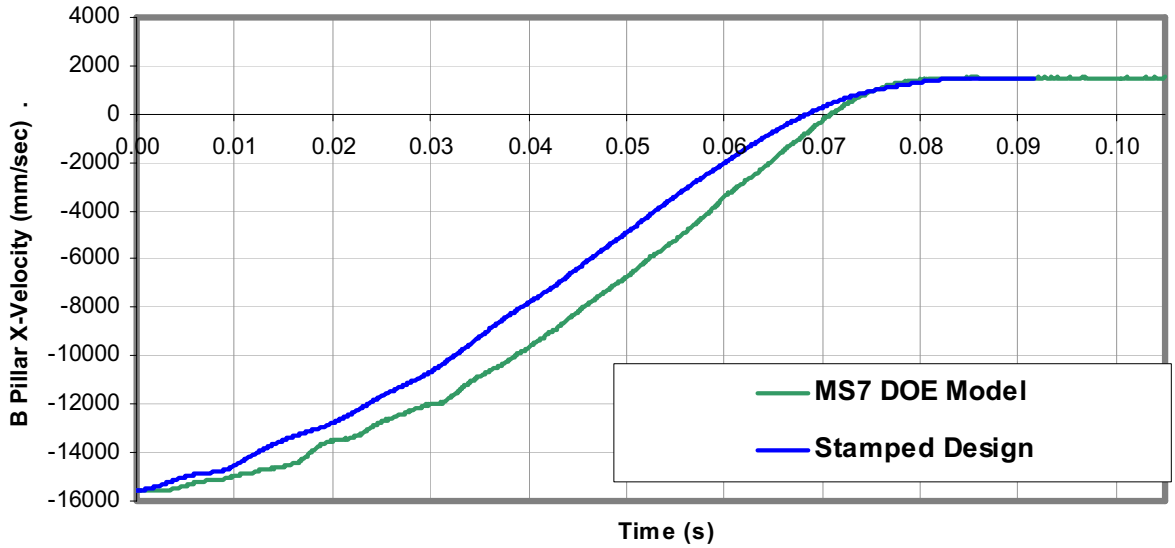


Figure 12: LH B-Pillar Velocity – Concept 2 with Baseline (MS7 DOE Model)

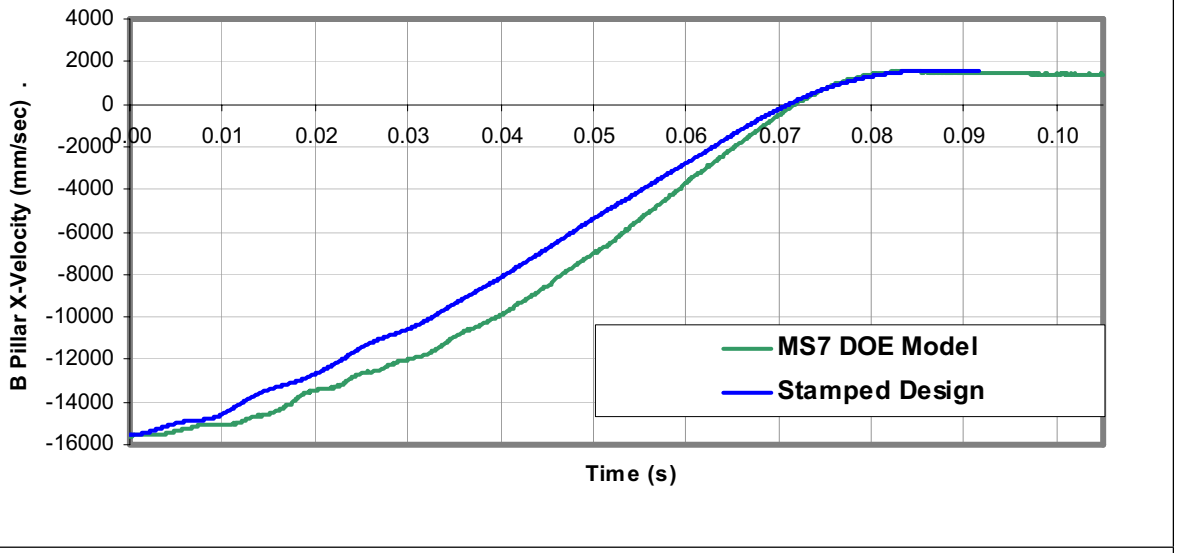


Figure 13: RH B-Pillar Velocity – Concept 2 with Baseline (MS7 DOE Model)

Table 6: NCAP Crash Events

Time (ms)	Crash Events
0-15	Bumper absorbs energy
15-20	Engine hits the radiator, Cradle Extension Buckles, Cradle engaged
20-30	Cradle and LH rail buckling started
35-40	LH front wheel hits the LH rail
40-45	Engine hits to dash
45-50	RH front wheel hits the RH rail
55-60	LH wheel hits the front rigid wall
60-70	RH wheel hits the front rigid wall, LH wheel hits the rocker
70-75	RH wheel hits the rocker

6. IIHS Response

IIHS intrusions are summarized in *Table 2*.

Animation files are included in *Appendix A*.

Toepan, brake pedal and A-B closure intrusions oscillate after 200ms about a mean value. Hence, the peak intrusion values are used for comparison (*Table 2*).

Steering column movement does not reach any equilibrium. The IIHS simulation would have to be carried out for a longer duration in order to report stable meaningful values. The steering column model may also be deficient, resulting in an unstable movement. Hence, steering column movement should not be used for design comparisons.

The brake pedal oscillates about a pivot joint. Hence, brake pedal intrusions can vary randomly and should not be used for design comparisons.

7. Conclusions

The Concept 2 design achieves a mass reduction of **4.95kg** (**12.6%**) compared to the *Baseline* design. The NCAP performance is superior to that of the baseline design. The IIHS performance is similar to that of the baseline design.

8. Future Work

The skirt reinforcement will be replaced by a separate reinforcement on the inner rail, as it is easier to manufacture and assemble. Beads will also be added to the inner and outer rails to increase local stiffness. Some modification in the rail is required to provide more clearance with the stabilizer bar.

The final Concept 2 design will be compared to Concepts 1 and 3 developed in Phase II of the Lightweight Front End Structure Project.

9. References

1) *Validated FE Models, Milestone 5*, SPHINX, Phase II.

2) *Enhanced FE Models, Milestone 6*, SPHINX, Phase II.

3) *IIHS Crashworthiness Evaluation Offset Barrier Crash Test Protocol (Version IX), October 2002.*

4) *DOE FE Models, Milestone 7*, SPHINX, Phase II.

5) *Third Bumper Design Report, Milestone 5*, SPHINX, Phase I.

6) *Concept 1: Preliminary Design, Milestone 10*, SPHINX, Phase II.

7) *FMVSS Part 581 Bumper Standard*.

10. Appendix A: Animations

The following animation files for the subsystem development can be viewed at the Auto/Steel Partnership website, www.a-sp.org.

You will need a Hyperview Player in order to view these animations at the site. You can download this free software at www.altair.com.

1. **Baseline NCAP: Full Vehicle**
2. **Baseline NCAP: Front-End**
3. **Baseline IIHS: Full Vehicle**
4. **Baseline IIHS: Front-End**
5. **Concept 2 NCAP: Full Vehicle**
6. **Concept 2 NCAP: Front-End**
7. **Concept 2 IIHS: Full Vehicle**
8. **Concept 2 IIHS: Front-End**

11. Appendix B: Summary of FE Model

Total Components	
Model Mass	1.778 tonnes

- Model mass is from LS-DYNA3D d3hsp file.

Concept 2: DOE Study

Milestone 14

Lightweight Front End Structure Phase II

February 2, 2004

A/S P

Auto/Steel Partnership

Abstract

This report documents the DOE study for *Concept 2* that has a new stamped rail design and a stamped bumper design. The final *Concept 2* design will be compared to *Concepts 1* and *3* developed in Phase II of the Lightweight Front End Structure Project.

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1. Objectives

The effort of this study was aimed at conducting a DOE study to arrive at a preliminary design for *Concept 2*, which has a new stamped rail design and a stamped bumper design. The final *Concept 2* design will be compared to *Concepts 1* and *3* developed in Phase II of the Lightweight Front End Structure Project.

2. DOE Model

The *Concept 2* DOE study incorporates the following features.

- IIHS load case up to 60 ms.
- 2-level L16 Orthogonal Array.
- Bumper and rail gauges as design parameters.
- 8 factors and 7 interactions.
- Section centroidal displacements as responses.

The aim of the study was to arrive at a stable rail design. Section centroidal displacements were taken as a measure of stability.

DOE parameters and their levels are summarized in *Table 1*.

Table 1: DOE Model

	Part	Level 1 Gauge	Level 2 Gauge
1	Bumper	1.0	1.3
2	Rail Front Inner/Outer	1.0	1.3
3	Rail Mid Inner	1.2	1.6
4	Rail Mid Outer	1.2	1.6
5	Rail Rear Inner	1.5	2.0
6	Rail Rear Outer	1.5	2.0
7	Rail Extension Reinf.	1.5	2.0
8	Rail Extension	1.5/1.2/1.0	2.0/1.6/1.3

3. DOE Responses

Centroidal y and z displacements at sections 35, 45 and 53 were obtained from the DOE study. Section 53 is critical fro buckling and was monitored, in order to predict rail buckling. Section 53 y-displacements are plotted in *Figure 1* for all the 16 DOE runs. The vehicle rotates only after 60 ms. Thus, the displacements before 60 ms are valid without applying a rotation correction.

Displacements of *Baseline* model are also plotted for reference. It can be seen that the Baseline model has a more stable response, as the centroidal displacement is much lower.

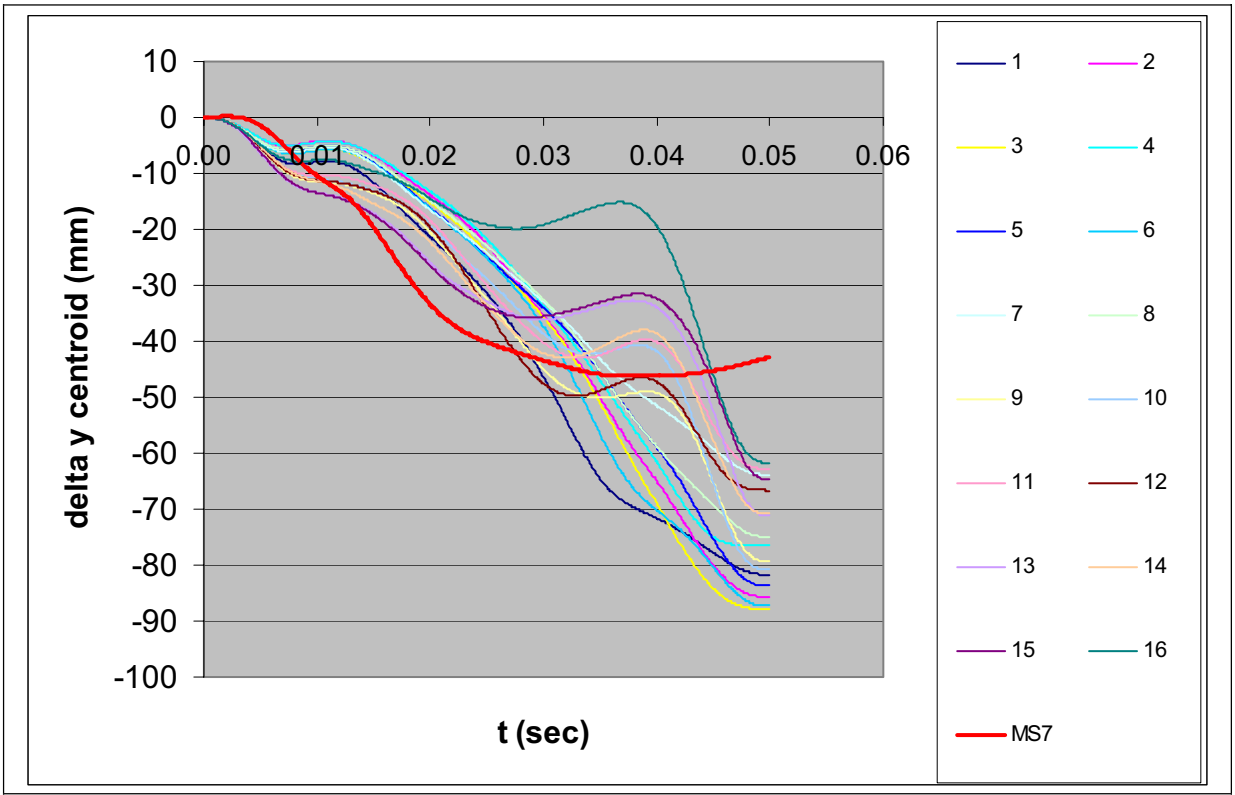


Figure 1: Section 53 Centroidal Y-Displacements

4. Conclusions

An IIHS DOE study of *Concept 2* design was conducted, in order to arrive at a stable rail design.

5. Future Work

The *Concept 2* design will be improved so as to stabilize the rail buckling. The results of the DOE study will help arrive at such a design. The final *Concept 2* design will be compared to *Concepts 1* and *3* developed in Phase II of the Lightweight Front End Structure Project.

6. References

1) *Validated FE Models, Milestone 5*, SPHINX, Phase II.

2) *Enhanced FE Models, Milestone 6*, SPHINX, Phase II.

3) *IIHS Crashworthiness Evaluation Offset Barrier Crash Test Protocol (Version IX), October 2002.*

4) *DOE FE Models, Milestone 7*, SPHINX, Phase II.

5) *Concept 2: Preliminary Design, Milestone 10*, SPHINX, Phase II.

Concept 2: Final Design

Milestone 15

Lightweight Front End Structure Phase II

February 6, 2004

Auto/Steel Partnership

Abstract

This report documents the final design for *Concept 2* that has a new stamped rail design and a stamped bumper design. The *Concept 2* design will serve as the baseline for the DOE study and optimization that would result in the final design for prototyping the bumper and rail assemblies in Phase II of the Lightweight Front End Structure Project.

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1. Objectives

The effort of this study was aimed at developing the final design for *Concept 2* that has a new stamped rail design and a stamped bumper design. The *Concept 2* design will serve as the baseline for the DOE study and optimization that would result in the final design for prototyping the bumper and rail assemblies in Phase II of the Lightweight Front End Structure Project.

2. Results Summary

The *Concept 2* design has the following features.

- Octagonal 3-piece tailor-welded rail inner and outer pieces with symmetric flanges and tapered front section.
- Two-piece rail tailor-welded extension design with a reinforcement.
- Rail inner reinforcement.
- Symmetric LH/RH rail assemblies.
- Two-piece double box bumper design with energy absorbing features.

The Concept 2 design achieves a mass reduction of **4.77kg** (**12.2%**) compared to the *Baseline* design. The NCAP performance is superior to that of the baseline design. The IIHS performance is similar to that of the baseline design.

The NCAP and IIHS results are summarized in *Table 1* and *Table 2*.

Table 1: NCAP Results

	Peak Acceleration	
B Pillar Pulse	**Baseline**	**Concept 2**
LH	**36.7 g @ 58.7 ms**	**32.4 g @ 51.7 ms**
RH	**35.3 g @ 58.6 ms**	**30.3 g @ 50.6 ms**

Table 2: IIHS Results

Location	Peak Intrusions (cm)	
	Baseline	**Concept 2**
Left Toepan	**18.2**	**18.3**
Center Toepan	**18.4**	**22.0**
Right Toepan	**19.4**	**19.4**
A-B Pillar Closure	**14.4**	**14.7**

3. Concept 2 Design

The rail design is a 3-part stamped design with symmetric LH and RH rail assemblies. The inner and outer rails are 3-piece octagonal tailor-welded sections with symmetric flanges. The front section of the rails is tapered. The rail extension is 2-piece tailor-welded and has a reinforcement.

The final rail design is a modification of the *Preliminary Design* developed earlier. The key differences are a separate reinforcement for the inner rail and addition of beads to the inner and outer rails. A separate reinforcement is easier to tool than the skirt reinforcement employed in the preliminary design. The second tailor-weld line location in the rail inner/outer pieces is now skewed. Beads were added so as to increase the local stability of the rail and achieve better crash performance.

The rail extension was also modified so as to increase the clearance with the lower control arm to 10mm. In addition, the RH skirt was modified to account for the missing damper attachment bracket.

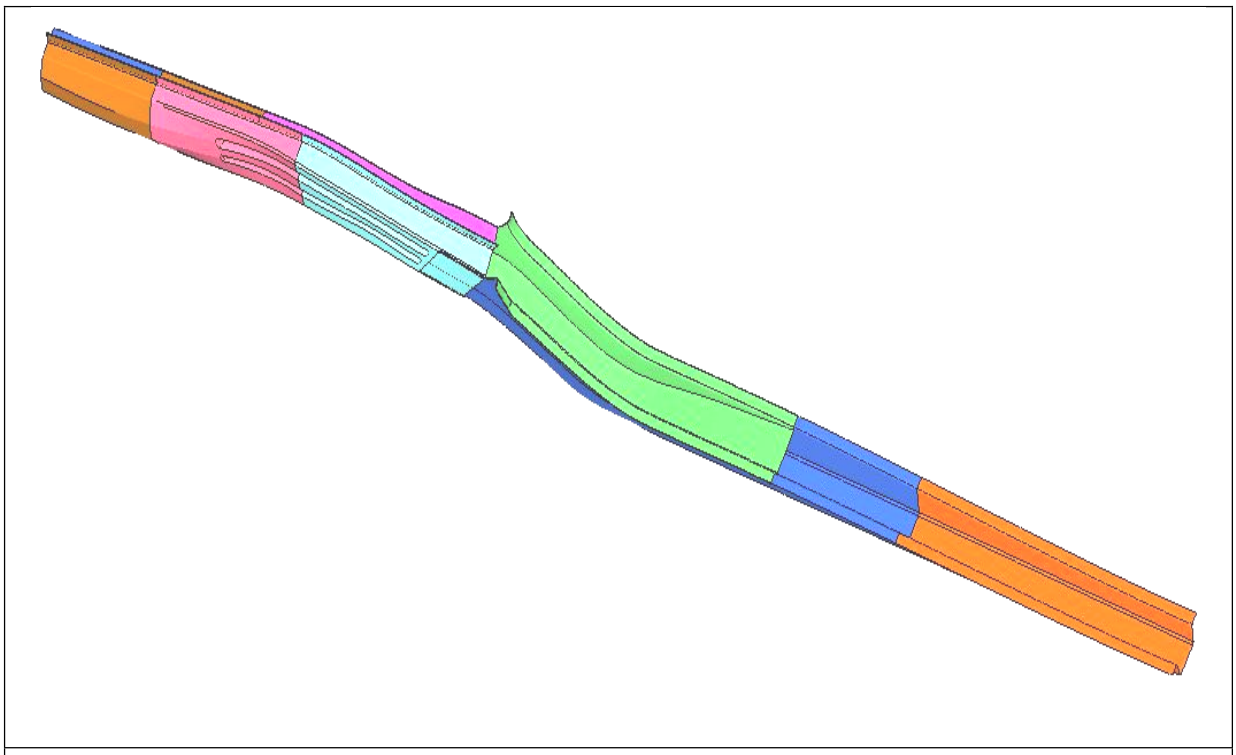


Figure 1: LH Rail Assembly

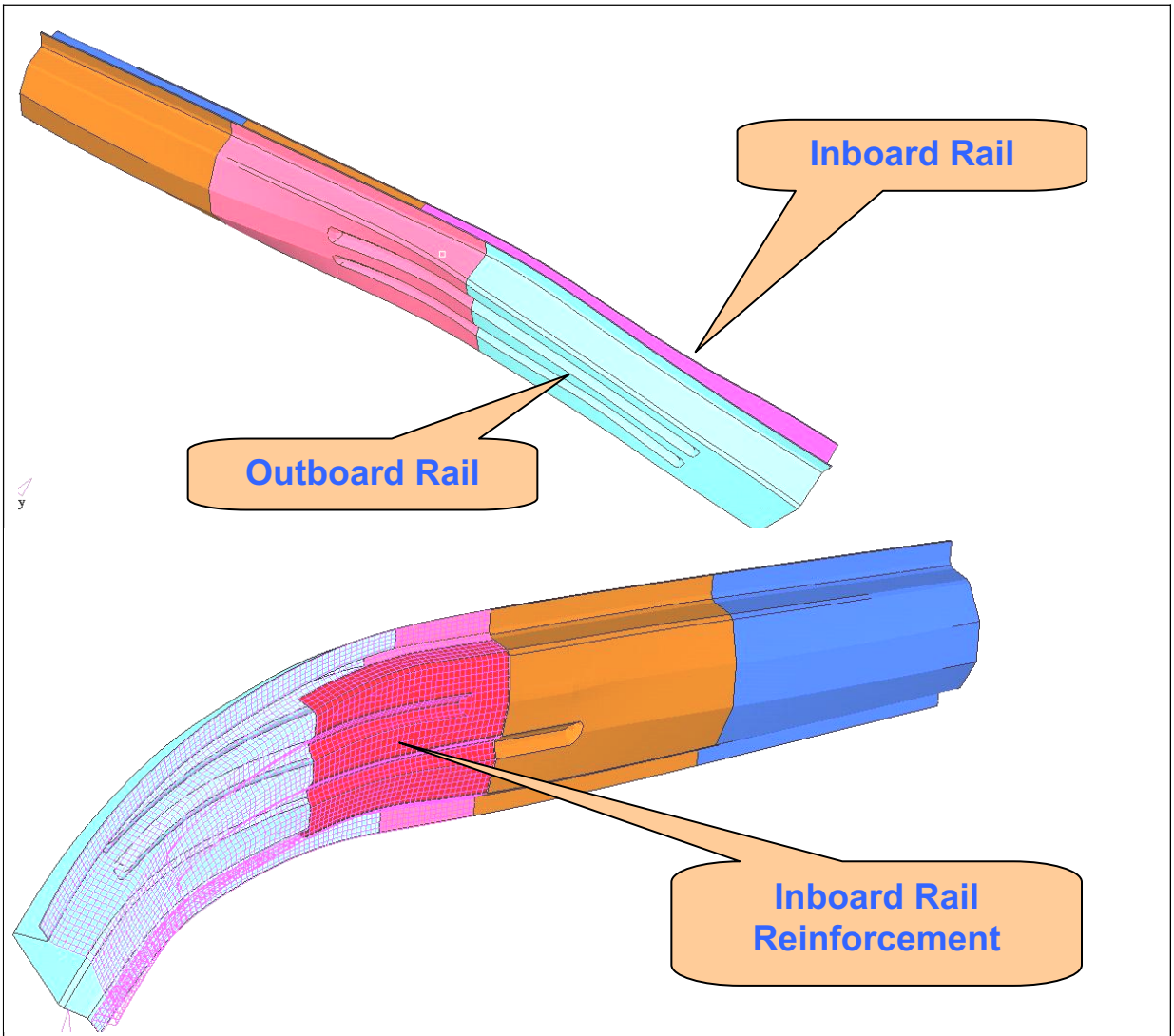


Figure 2: LH Inner & Outer Rails

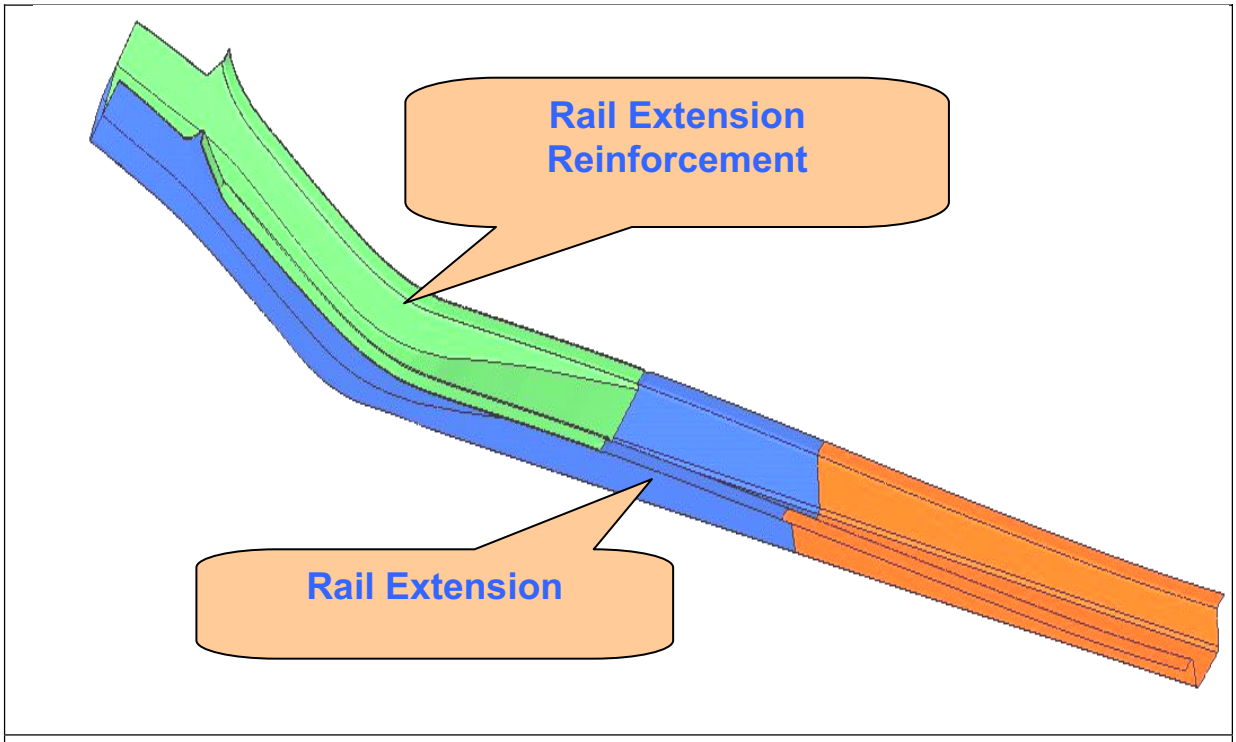


Figure 3: LH Rail Extension

The flange width was reduced by 5mm, as compared to the *Baseline*. The total flange width is now 21 mm, which includes a 5mm radius and 16mm flat. This would make the flange width same as the ULSAB rails. The donor vehicle model has a flat of 21mm, resulting in a total flange width of 26mm. Refer to *Concept1* milestone report for details on rail flanges.

The baseline bumper was replaced by a new bumper design (*Figure 4, Figure 5*). The new bumper design is functionally quite similar to the Phase I *Bumper 3* design. However, it has fewer manufacturing and welding concerns than the Bumper 3 design. The new bumper design is a 2-piece double-box stamped design using DP980 steel. The bumper has vertical flanges and beads on the front and back plates. The new bumper design has good energy absorption capability in high-speed impacts and results in a high initial peak in the NCAP B-pillar pulse. In addition, the bumper is more formable than the Phase I Bumper 3 design, and is easier to weld. *A design similar to the new bumper design has been prototyped using DF140T steel.*

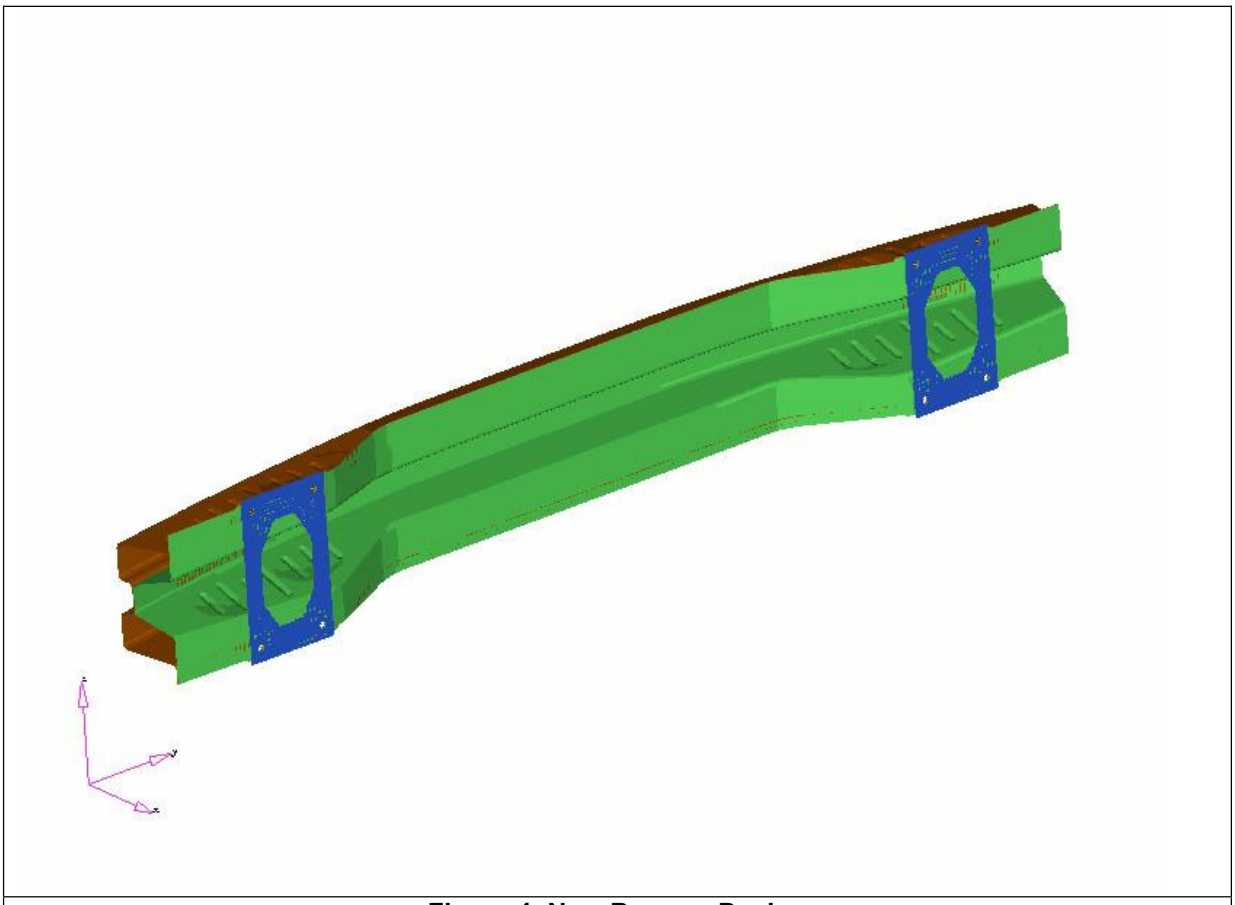


Figure 4: New Bumper Design

The bumper plates are attached to the front rails through an attachment plate. The plate is bolted to the bumper beam through four bolts. The plate has a hole of the same shape as the rail front section, but of a smaller size. The plate is MIG welded to the front rails. The bumper centerline matches that of the rail. This ensures a proper load transfer from the bumper to the rails.

The bumper design passes the low-speed bumper requirements (7).

A mass summary for rail and bumper parts is included in *Table 3*.

A grade/gauge summary for rail and bumper parts is included in *Table 4*.

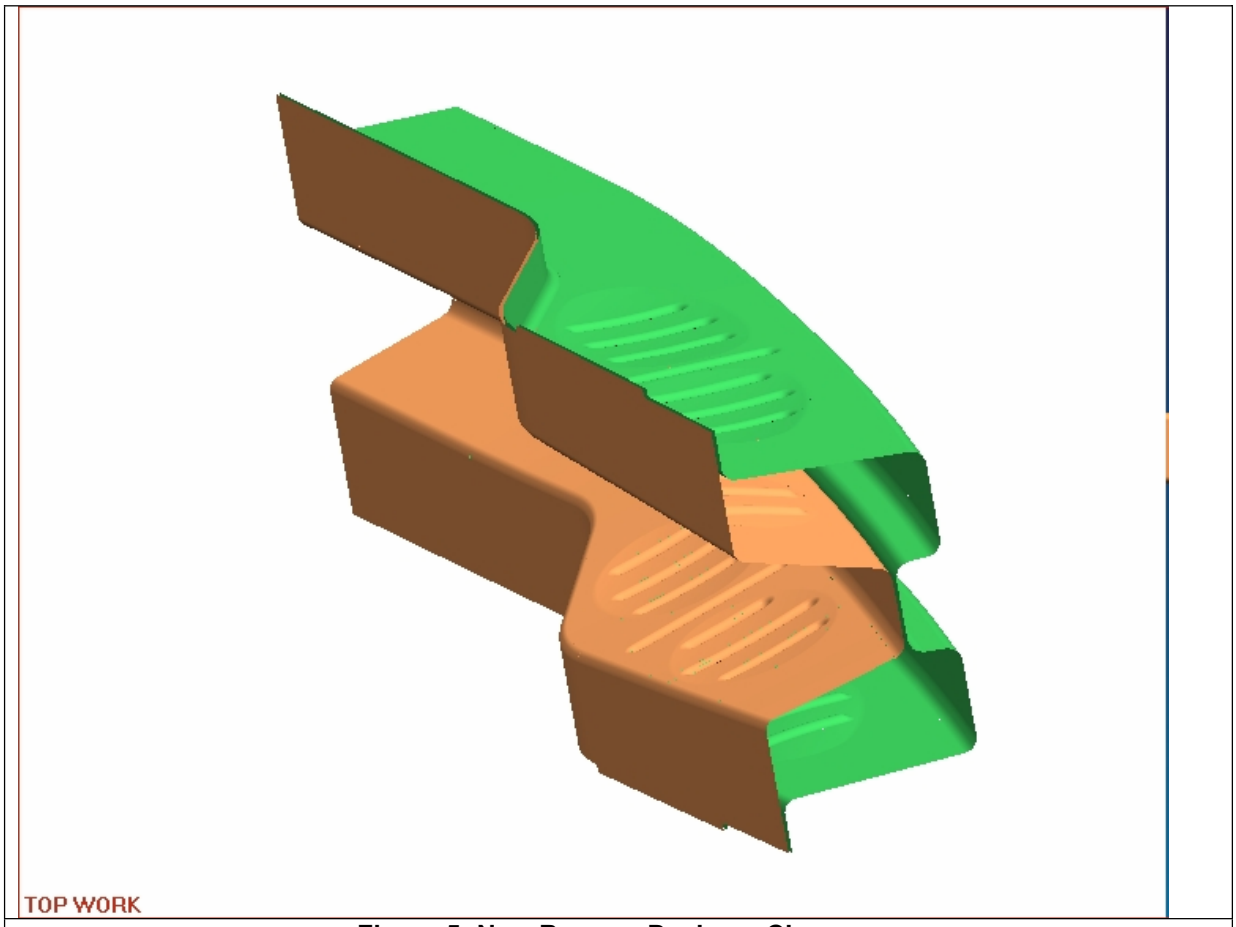


Figure 5: New Bumper Design – Close-up

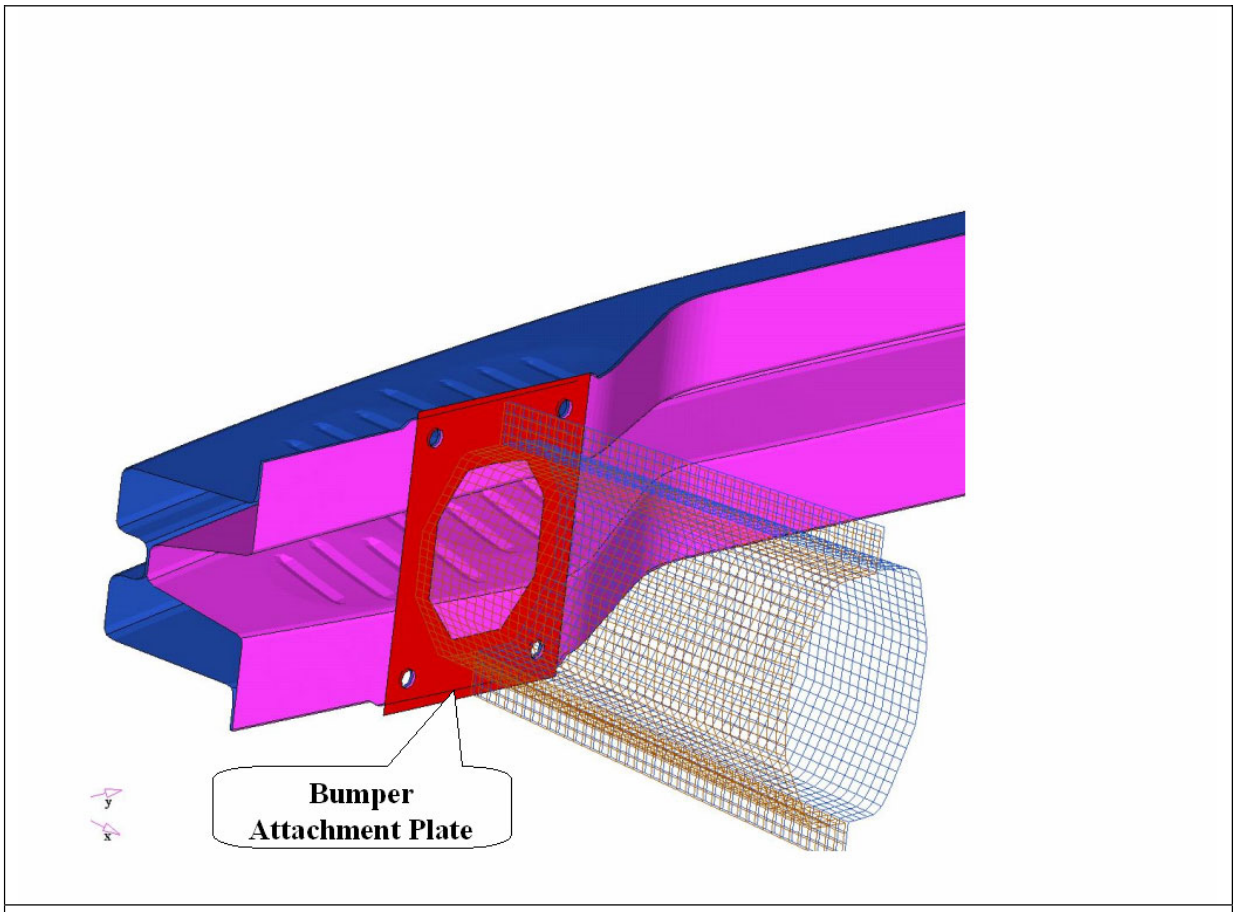


Figure 6: Bumper Attachment

Table 3: Mass Summary

Part	Mass (kg)	
	Baseline Design	Concept 2 Preliminary Design
LH Rail Assembly	16.52	14.25
RH Rail Assembly	16.15	14.25
Bumper (without foam)	6.56	5.96
Total	39.23	34.46*

* 12.2% mass reduction with respect to *Baseline*

Table 4: Grade and Gauge Summary

Part	Concept 2 Preliminary Design	
	Grade	Gauge (mm)
Rail Front Inner	DP 450/800	1.0
Rail Front Outer	DP 450/800	1.0
Rail Mid Inner	DP 450/800	1.4
Rail Mid Outer	DP 450/800	1.4
Rail Rear Inner	DP 450/800	2.0
Rail Rear Outer	DP 450/800	2.0
Rail Extension Front	DP 450/800	2.0
Rail Extension Rear	DP 450/800	1.3
Rail Extension Reinforcement	DP 450/800	2.0
Rail Inner Reinforcement	DP 450/800	2.0
Bumper Beam	DP 700/980	1.0

4. FE Model - Output Location Summary

The nodes at which the desired NCAP and IIHS outputs were obtained are listed in *Table 5*.

The intrusions are measured at the nodes as specified in *Reference 3*.

The acceleration and intrusion node locations are shown in *Figure 7* and *Figure 8* below.

Table 5: Summary of Output Locations

Parameter	Location	Node Number
Accelerations	B-Pillar / Rocker - LH	5000001
	B-Pillar / Rocker - RH	5000002
Intrusions	Origin	6000000
	Plane Y-axis	6000001
	Plane Z-axis	6000002
	Steering Column	7000001
	Brake Pedal	7000002
	Toepan - Left	7000003
	Toepan - Center	7000004
	Toepan - Right	7000005
	Left Front Seat Bolt	7000006
	Right Front Seat Bolt	7000007
	Left Rear Seat Bolt	7000008
	Right Rear Seat Bolt	7000009
	AB Closure - A Pillar	7000010
	AB Closure - B Pillar	7000011

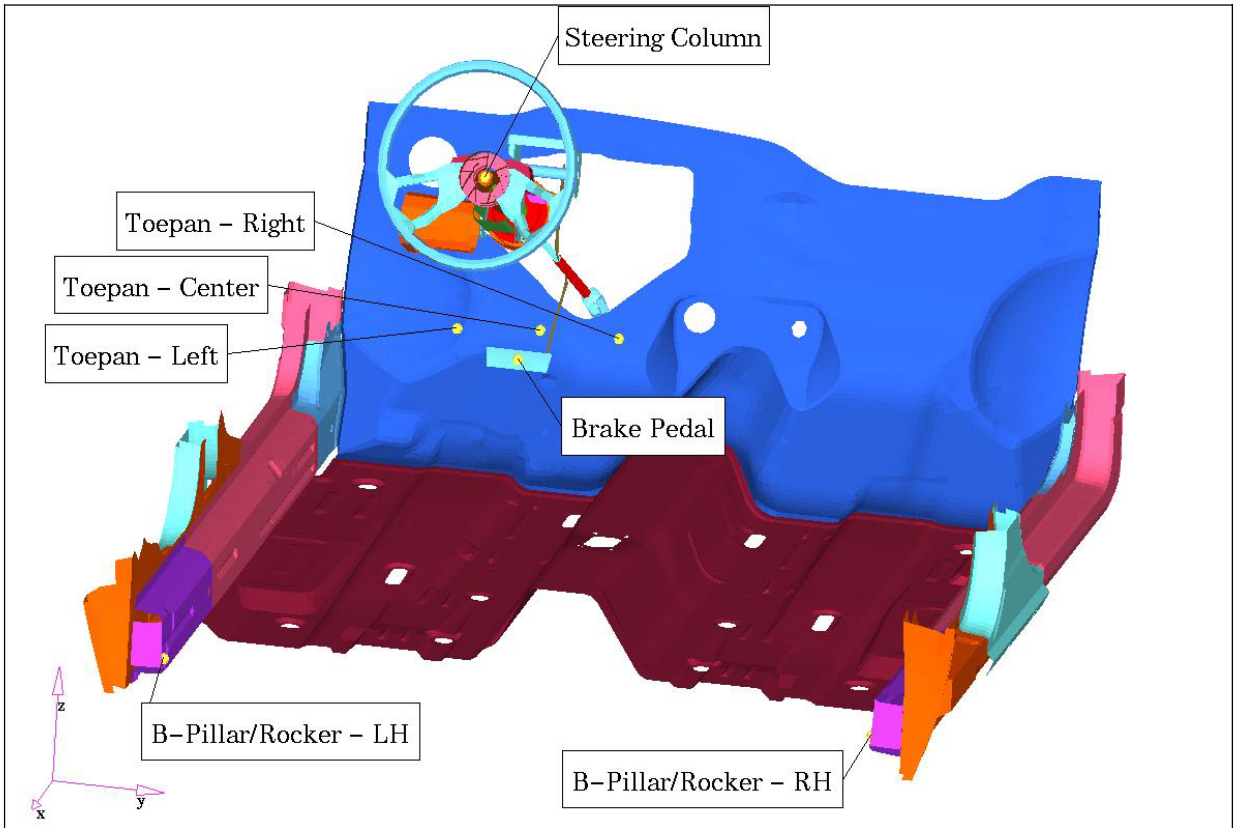


Figure 7: Output Locations for NCAP/IIHS



Figure 8: Output Locations for IIHS- AB Closure

5. NCAP Response

The figures below summarize the NCAP response of Concept 1.

Animation files are included in *Appendix A*.

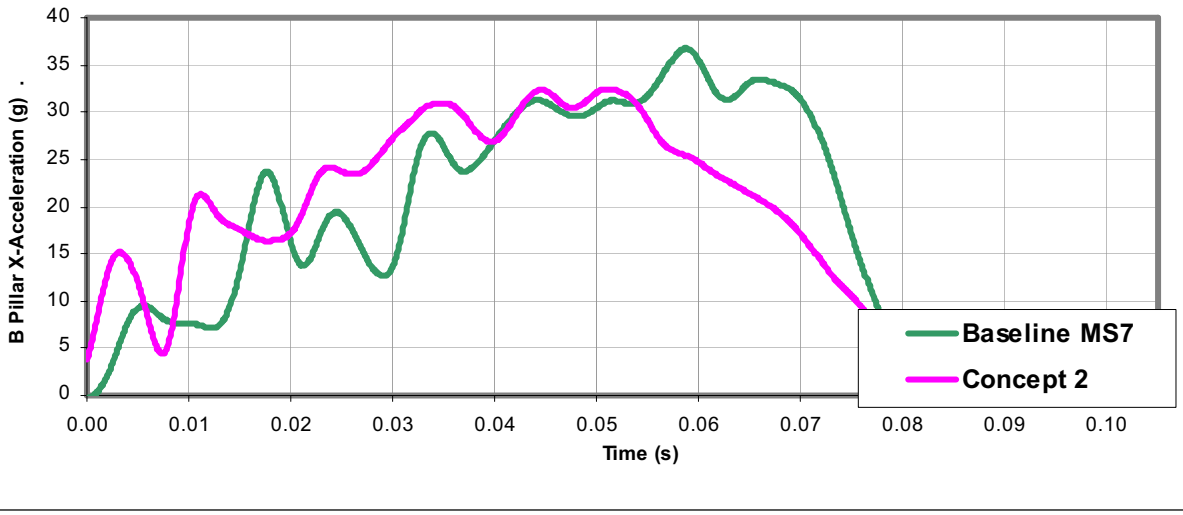


Figure 9: LH B-Pillar Pulse – Concept 2 with Baseline (MS7 DOE Model)

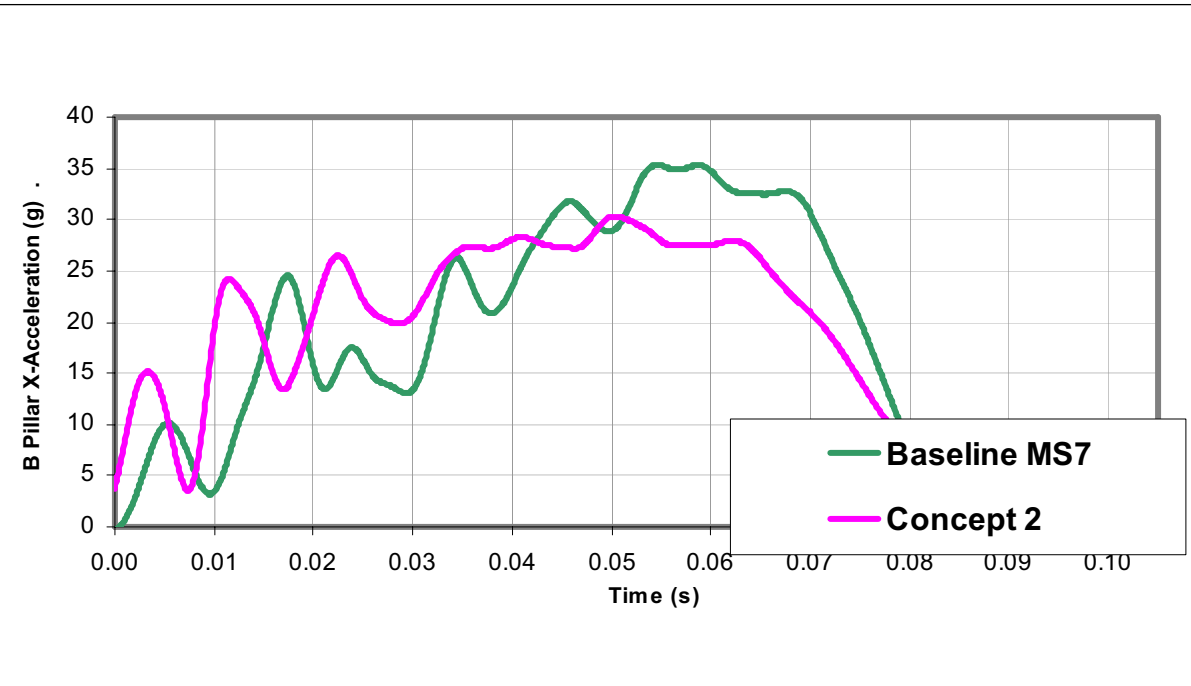


Figure 10: RH B-Pillar Pulse – Concept 2 with Baseline (MS7 DOE Model)

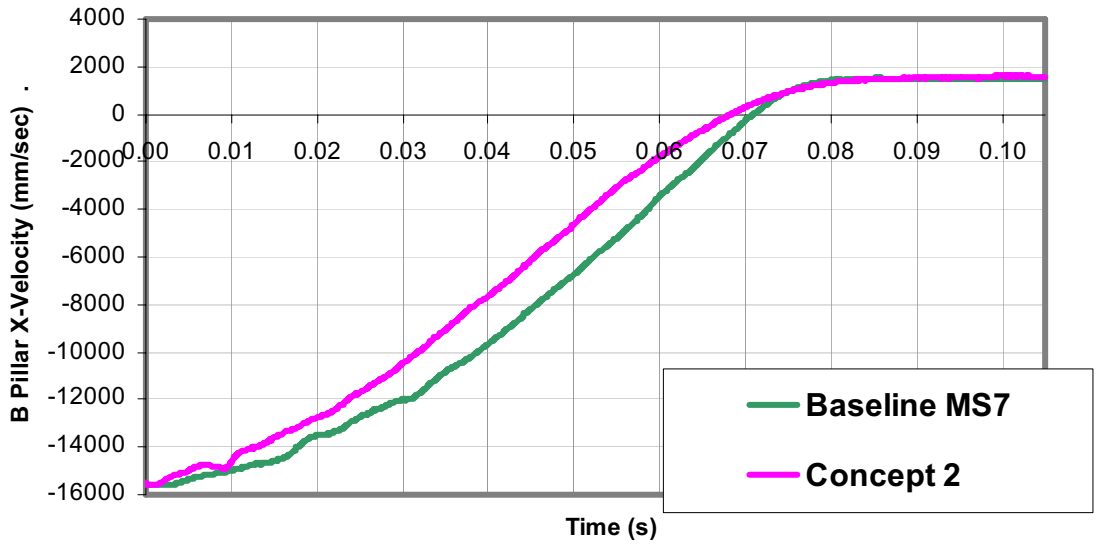


Figure 11: LH B-Pillar Velocity – Concept 2 with Baseline (MS7 DOE Model)

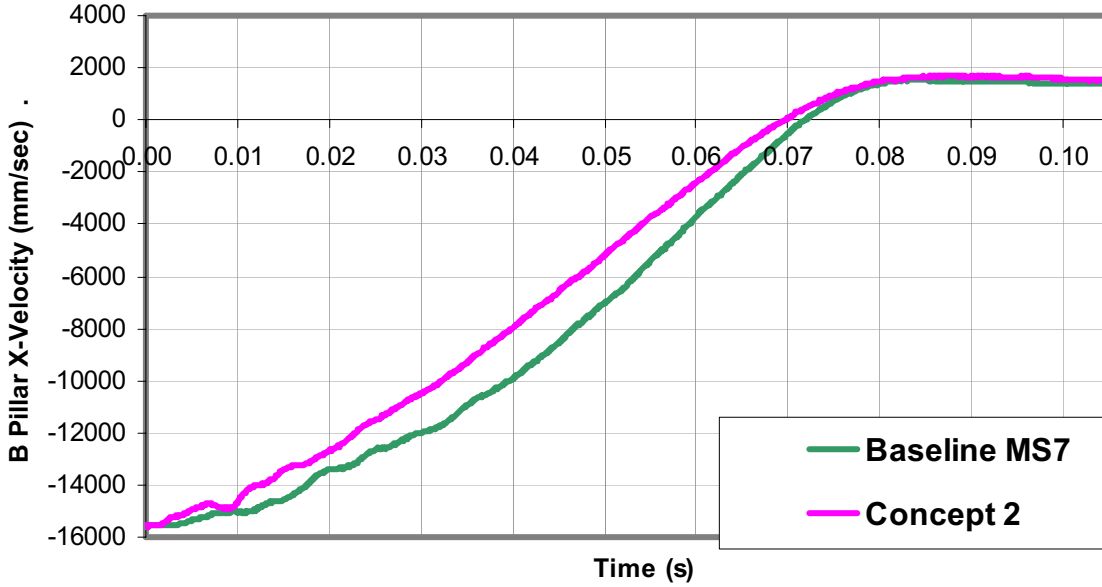


Figure 12: RH B-Pillar Velocity – Concept 2 with Baseline (MS7 DOE Model)

Table 6: NCAP Crash Events

Time (ms)	Crash Events
0-15	Bumper absorbs energy
15-20	Engine hits the radiator, Cradle Extension Buckles, Cradle engaged
20-30	Cradle and LH rail buckling started
35-40	LH front wheel hits the LH rail
40-45	Engine hits to dash
45-50	RH front wheel hits the RH rail
55-60	LH wheel hits the front rigid wall
60-70	RH wheel hits the front rigid wall, LH wheel hits the rocker
70-75	RH wheel hits the rocker

6. IIHS Response

IIHS intrusions are summarized in *Table 2*.

Animation files are included in *Appendix A*.

Toepan, brake pedal and A-B closure intrusions oscillate after 200ms about a mean value. Hence, the peak intrusion values are used for comparison (*Table 2*).

Steering column movement does not reach any equilibrium. The IIHS simulation would have to be carried out for a longer duration in order to report stable meaningful values. The steering column model may also be deficient, resulting in an unstable movement. Hence, steering column movement should not be used for design comparisons.

The brake pedal oscillates about a pivot joint. Hence, brake pedal intrusions can vary randomly and should not be used for design comparisons.

7. Conclusions

The *Concept 2* design achieves a mass reduction of **4.77kg** (**12.2%**) compared to the *Baseline* design. The NCAP performance is superior to that of the baseline design. The IIHS performance is similar to that of the baseline design.

8. Future Work

The *Concept 2* design will serve as the baseline for the DOE study and optimization that would result in the final design for prototyping the bumper and rail assemblies in Phase II of the Lightweight Front End Structure Project.

9. References

1) *Validated FE Models, Milestone 5*, SPHINX, Phase II.

2) *Enhanced FE Models, Milestone 6*, SPHINX, Phase II.

3) *IIHS Crashworthiness Evaluation Offset Barrier Crash Test Protocol (Version IX), October 2002.*

4) *DOE FE Models, Milestone 7*, SPHINX, Phase II.

5) *Third Bumper Design Report, Milestone 5*, SPHINX, Phase I.

6) *Concept 1: Preliminary Design, Milestone 10*, SPHINX, Phase II.

7) *FMVSS Part 581 Bumper Standard*.

8) *Concept 2: Preliminary Design, Milestone 13*, SPHINX, Phase II.

10. Appendix A: Animations

The following animation files for the subsystem development can be viewed at the Auto/Steel Partnership website, www.a-sp.org.

You will need a Hyperview Player in order to view these animations at the site. You can download this free software at www.altair.com.

1. **Baseline NCAP: Full Vehicle**
2. **Baseline NCAP: Front-End**
3. **Baseline IIHS: Full Vehicle**
4. **Baseline IIHS: Front-End**
5. **Concept 2 NCAP: Full Vehicle**
6. **Concept 2 NCAP: Front-End**
7. **Concept 2 IIHS: Full Vehicle**
8. **Concept 2 IIHS: Front-End**

11. Appendix B: Summary of FE Model

Total Components	
Model Mass	1.778 tonnes

- Model mass is from LS-DYNA3D d3hsp file.

lcarnf.r	60230	SectShll30	60094	MATL24_340	60049	3.41E-04	3
lcajnt_1.L1	60231	SectShll30	60094	rigid	60014	4.12E-05	3
lcajnt_1.R1	60232	SectShll30	60094	rigid	60014	4.12E-05	3
lcacyl.l	60235	SectShll50	60092	MATL24_160	60048	0.001295	5
lcacyl.r	60236	SectShll50	60092	MATL24_160	60048	0.001295	5
lcajnt_1.L2	60239	SectShll30	60094	rigid	60014	3.16E-05	3
lcajnt_1.R2	60240	SectShll30	60094	rigid	60014	3.16E-05	3
cradbrkt1	60241	SectShll10.1	60083	MATL24_180	60046	2.36E-04	1
crdlblt	60243	SectShll20.1	60088	MATL24_160	60048	2.41E-04	2
crdlrrxupr	60244	SectShll25	60091	MATL24_340	60049	0.002183	2.5
crdlrrxlwr	60245	SectShll23	60090	MATL24_340	60049	0.00129	2.3
crdmtfrt_otb.l	60246	crd_frt_mt_otr	60161	MATL24_160	60048	6.02E-04	1.95
crdmtfrt_otb.r	60247	crd_frt_mt_otr	60161	MATL24_160	60048	6.02E-04	1.95
urail_l	60301	SectShll8.3	60081	MATL24_160	60048	0.001457	0.8
urail_r	60302	SectShll8.3	60081	MATL24_160	60048	0.001456	0.8
urail_rnf2.l	60303	SectShll9.1	60082	MATL24_160	60048	4.72E-04	0.9
urail_rnf1.r	60304	SectShll9.1	60082	MATL24_160	60048	4.71E-04	0.9
pnlfrt1.l	60305	Sectshll75	60097	MATL24_210	60052	8.60E-04	0.75
pnlfrt1.r	60306	Sectshll75	60097	MATL24_210	60052	8.60E-04	0.75
shock.l	60307	Sectshll17.5	60096	MATL24_160	60048	0.001517	1.75
shock.r	60308	Sectshll17.5	60096	MATL24_160	60048	0.001546	1.75
pnlfrt2.l	60309	SectShll12.1	60084	MATL24_210	60052	0.001561	1.2
pnlfrt2.r	60310	SectShll12.1	60084	MATL24_210	60052	0.001561	1.2
plnmbrkt	60311	SectShll8.3	60081	MATL24_210	60052	1.50E-04	0.8
rnfpnldshext2	60312	SectShll8.3	60081	MATL24_210	60052	1.93E-04	0.8
temp	60313	SectShll7.2	60080	MATL24_600	60056	2.63E-04	0.7
frtflr	60401	SectShll085	60118	MATL24_160	60048	0.013015	0.85
bar1	60402	SectShll20.1	60088	MATL24_3404	60051	0.00262	2
tnl1	60403	SectShll18.1	60087	MATL24_340	60049	0.001311	1.8
tnl2	60404	SectShll12.1	60084	MATL24_250	60054	0.006463	1.2
dash	60405	SectShll95	60113	MATL24_160	60048	0.008026	0.95
cowlupr	60406	SectShll8.3	60081	MATL24_210	60052	0.001526	0.8
fflrlvrrnf	60407	SectShll15.3	60117	MATL24_160	60048	7.10E-04	1.5
pedal2	60408	SectShll30	60094	MATL24_160	60048	0.001364	3
wndshld.supt.upr	60409	Sectshll75	60097	MATL24_160	60048	0.002599	0.75
plnmltintjnt	60410	Sectshll75	60097	MATL24_160	60048	0.004045	0.75
rein_upr	60411	SectShll15.3	60117	MATL24_210	60052	9.29E-04	1.5
MTG1	60412	SectShll10.1	60083	MATL24_210	60052	4.34E-04	1
BRKT_Consol	60413	SectShll15.3	60117	MATL24_210	60052	6.89E-04	1.5
crush_brkt_lwr	60414	SectShll20.1	60088	MATL24_210	60052	0.002868	2
bar2.l	60501	SectShll12.1	60084	MATL24_160	60048	0.001367	1.2
bar2.r	60502	SectShll12.1	60084	MATL24_160	60048	0.001368	1.2
2barreinf	60503	SectShll17	60086	MATL24_340	60049	0.00249	1.7
22678921_256_1	60505	SectShll12.1	60084	MATL24_160	60048	2.43E-04	1.2
22678920_256_1	60506	SectShll12.1	60084	MATL24_160	60048	2.43E-04	1.2
22678921_255_1	60507	SectShll12.1	60084	MATL24_160	60048	1.85E-04	1.2
22678920_255_1	60508	SectShll12.1	60084	MATL24_160	60048	1.85E-04	1.2
seatrein.l	60509	SectShll12.1	60084	MATL24_160	60048	3.45E-04	1.2
seatrein.r	60510	SectShll12.1	60084	MATL24_160	60048	3.46E-04	1.2

tiebar3.l	60601	Sectshll75	60097	MATL24_180	60046	6.78E-04	0.75
tiebar3.r	60602	Sectshll75	60097	MATL24_180	60046	7.20E-04	0.75
tiebar4.l	60603	Sectshll75	60097	MATL24_180	60046	3.84E-05	0.75
tiebar4.r	60604	Sectshll75	60097	MATL24_180	60046	3.84E-05	0.75
lhfanmotor	60605	SectShll20.1	60088	MATL24_181	60047	5.60E-04	2
rhfanmotor	60606	SectShll20.1	60088	MATL24_181	60047	5.40E-04	2
tiebar	60607	SectShll9.1	60082	MATL24_210	60052	0.002278	0.9
tiebar2	60608	SectShll9.1	60082	MATL24_160	60048	0.001163	0.9
radsupport	60609	SectShll10.1	60083	MATL24_160	60048	0.001261	1
rad4	60610	SectShll10.1	60083	MATL24_160	60048	8.32E-06	1
Part_2	60611	SectShll10.1	60083	MATL9_2	60006	0.014989	1
rad2	60612	SectSld900	60121	MAT57rad&cond	60059	0.002656	0
rad1	60613	SectSld900	60121	MAT57rad&cond	60059	0.003782	0
fanshroud	60614	SectShll20.1	60088	MATL24_181	60047	0.007298	2
egine_main_block	60701	SectShll10.1	60083	rigid	60014	0.3042	1
pt2	60702	SectShll10.1	60083	rigid	60014	0.001123	1
pt3	60703	SectShll10.1	60083	rigid	60014	0.006404	1
pt7	60704	SectShll10.1	60083	rigid	60014	0.001243	1
pt8	60705	SectShll20.1	60088	rigid	60014	0.005065	2
pt10	60706	SectShll10.1	60083	rigid	60014	9.92E-04	1
pt11	60707	SectShll225	60099	rigid	60014	0.001335	2.25
pt13	60708	SectShll10.1	60083	rigid	60014	1.07E-04	1
pt14	60709	SectShll10.1	60083	rigid	60014	0.001639	1
pt19	60710	SectShll10.1	60083	rigid	60014	4.08E-04	1
pt18	60711	SectShll40	60093	rigid	60014	0.007253	4
frtmnt1	60712	SectShll20.1	60088	MATL24_160	60048	1.04E-03	2
frtmnt2	60713	SectShll225	60099	MATL24_160	60048	3.84E-04	2.25
pt9	60714	SectShll100	60104	rigid	60014	0.005277	10
pt12	60715	SectShll80	60095	rigid	60014	0.007011	8
pt16	60716	SectShll40	60093	rigid	60014	0.003234	4
pt17	60717	SectShll30	60094	MATL24_160	60048	0.007696	3
expipefrt	60718	SectShll15.3	60117	MATL24_160	60048	0.003601	1.5
ep_7685	60719	SectShll10.1	60083	rigid	60014	2.83E-04	1
flywheel	60720	SectShll10.1	60083	rigid	60014	7.92E-04	1
ep_4776	60721	SectShll10.1	60083	rigid	60014	4.99E-04	1
ep_7498	60722	SectShll10.1	60083	rigid	60014	0.002605	1
ep_0939	60723	SectShll10.1	60083	rigid	60014	5.79E-04	1
ep_0017	60724	SectShll10.1	60083	rigid	60014	4.50E-04	1
ep_70842	60725	SectShll10.1	60083	rigid	60014	1.84E-04	1
eng_mnt_l_e	60726	SectShll80	60095	MATL24_160	60048	0.002636	8
top_bkt_l_e	60727	SectShll80	60095	MAT24_1111	60045	5.72E-04	8
eng_mnt_r_e	60728	SectShll80	60095	MATL24_160	60048	0.002631	8
top_bkt_r_e	60729	SectShll80	60095	MAT24_1111	60045	1.01E-03	8
eng_deformable	60730	SectShll80	60095	MATL24_160	60048	0.001725	8
62109a_e1	60731	SectShll37	60108	MATL24_160	60048	3.62E-04	3.7
62109a_e2	60732	SectShll37	60108	MATL24_160	60048	1.22E-04	3.7
62109a_e3	60733	SectShll37	60108	MATL24_160	60048	4.00E-04	3.7
62109b_e1	60734	SectShll10.1	60083	MATL24_160	60048	4.06E-04	1
rrmnt_bushing	60735	SectShll20.1	60088	MATL24_160	60048	5.79E-04	2

tire1.l	60801	SectShll20.1	60088	mat1.tirerubber	60007	0.00197	2
tire1.r	60802	SectShll20.1	60088	mat1.tirerubber	60007	0.00197	2
tire3.l	60803	SectShll3.3	60107	MATL24_160	60048	1.00E-03	0.3
tire2.r	60804	SectShll3.3	60107	MATL24_160	60048	1.00E-03	0.3
tir2.l	60805	SectShll7.2	60080	MATL24_160	60048	0.002042	0.7
tire3.r	60806	SectShll7.2	60080	MATL24_160	60048	0.002042	0.7
rim.l	60807	SectShll35	60106	MATL24_600	60056	0.008136	3.5
rim.r	60808	SectShll35	60106	MATL24_600	60056	0.008136	3.5
lwrcntrlarm.l	60809	SectShll30	60094	MATL24_160	60048	0.002294	3
lwrcntrlarm.r	60810	SectShll30	60094	MATL24_160	60048	0.002289	3
lcajnt_2.L1	60811	SectShll30	60094	rigid	60014	6.26E-05	3
lcajnt_2.R1	60812	SectShll30	60094	rigid	60014	6.33E-05	3
driveline	60813	SectShll70	60103	MATL24_340	60049	0.005373	7
lcajnt_2.L2	60815	SectShll30	60094	rigid	60014	2.76E-05	3
lcajnt_2.R2	60816	SectShll30	60094	rigid	60014	2.76E-05	3
fsuspstrut.l	60817	SectShll50	60092	MATL24_160	60048	0.005601	5
fsuspstrut.r	60818	SectShll50	60092	MATL24_160	60048	0.005601	5
crdlbltrnf	60819	SectShll275.1	60102	MATL24_160	60048	3.23E-04	2.75
strclnmend3	60820	SectShll50	60092	rigid	60014	3.64E-04	5
strngrack	60821	SectShll60	60101	MAT24_1111	60045	0.002617	6
strrackends	60822	SectShll60	60101	MATL24_160	60048	0.001165	6
stabbar	60823	SectShll40	60093	MATL24_160	60048	0.004576	4
btray1	60901	SectShll15.3	60117	MATL24_160	60048	0.003147	1.5
btray2	60902	SectShll10.1	60083	MATL24_160	60048	2.14E-04	1
battery1	60903	SectShll5.3	60105	MATL24_160	60048	8.66E-04	0.5
ECM	60904	SectShll10.1	60083	MATL24_160	60048	1.07E-03	1
battery_fill	60905	SectShll10.1	60083	MATL24_160	60048	0.001326	1
fcomptrnf2	60906	SectShll40	60093	MATL24_160	60048	0.002901	4
abs_brkt	60907	SectShll20.1	60088	MATL24_160	60048	4.33E-04	2
brkt_boost	60908	90060072	60042	90060009	60012	0.00385	3
edge	61001	SectShll2.1.1	60077	MAT24_3	60042	1.06E-03	1.35
inner	61002	SectShll3.2.1	60078	MAT24_3	60042	0.005147	0.7
outer	61003	SectShll4.1.1	60079	MAT24_3	60042	0.008252	0.7
MODPLT	61101	90060005	60010	90060020	60041	0.001613	1.5
CSUPT_forw	61102	90060006	60011	90060020	60041	5.32E-04	1.22
can	61103	90060008	60012	90060020	60041	6.77E-04	1.2
can1	61104	90060009	60013	90060020	60041	9.87E-05	1.2
can2	61105	90060010	60014	90060020	60041	1.09E-04	1.2
can.1	61106	90060011	60015	90060020	60041	9.05E-05	1.2
inflator	61107	90060012	60016	90060020	60041	0.001456	5.4
Brkt-1	61108	90060063	60039	90060020	60041	6.07E-04	3
gaspdel	61109	90060068	60040	90060020	60041	1.65E-04	2.5
stelpeice	61110	90060071	60041	90060020	60041	1.54E-04	3
SIPO_p	61111	90060014	60018	90060020	60041	6.06E-04	2
SIPO_d2	61112	90060015	60019	90060020	60041	6.11E-04	2
Steel_strip	61113	90060016	60020	90060020	60041	1.07E-04	1.5
Floor_Brkt2	61114	90060037	60022	90060020	60041	8.95E-04	2.5
Center_Stk_brkt	61115	90060038	60023	90060020	60041	3.09E-04	1.5
lower	61116	90060044	60026	90060013	60036	8.85E-04	2.43

upper	61117	90060045	60027	90060013	60036	8.69E-04	2.36
hvacbrkt_add	61118	90060046	60028	90060013	60036	2.49E-05	2.36
heatercvr	61119	90060047	60029	90060013	60036	3.21E-04	2.38
ai	61120	90060048	60030	90060013	60036	3.74E-04	2.1
ai_icebox	61121	90060049	60031	90060013	60036	1.51E-05	2.1
ai_actuator	61122	90060050	60032	90060013	60036	2.81E-05	2
lower_actuator	61123	90060051	60033	90060013	60036	2.86E-05	2
foamplate	61124	90060052	60034	90060020	60041	5.74E-05	1
filmvalve	61125	90060053	60035	90060013	60036	1.67E-04	2
arm1_srib	61126	90060054	60036	90060013	60036	8.90E-05	2
rib_4_hub	61127	90060055	60037	90060013	60036	1.42E-04	3.5
Lower_add1	61128	90060056	60038	90060013	60036	1.16E-05	2
foam	61129	90060125	60119	90060001	60001	1.48E-06	0
evapblock	61130	90060126	60120	90060003	60003	3.52E-05	0
IBEC	61131	90060013	60017	90060005	60004	3.04E-04	2
evap_lower_tube1	61132	90060041	60024	90060002	60002	8.68E-06	1
evap_upper_tube1	61133	90060041	60024	90060002	60002	1.38E-05	1
heat_upper_tube1	61134	90060041	60024	90060002	60002	4.22E-05	1
heat_lower_tube1	61135	90060041	60024	90060002	60002	2.58E-05	1
il	61136	90060042	60025	90060014	60037	1.89E-04	1
IP_sidepnl_E	61137	90060026	60021	90060015	60038	1.24E-04	2.5
sipo_fixed1	61138	90060015	60019	90060008	60011	1.39E-06	2
sipo_fixed2	61139	90060015	60019	90060008	60011	1.46E-06	2
sipo_fixed3	61140	90060015	60019	90060008	60011	1.53E-06	2
sipo_fixed4	61141	90060015	60019	90060008	60011	1.13E-06	2
sipo_fixed5	61142	90060015	60019	90060008	60011	1.85E-06	2
sipo_fixed6	61143	90060015	60019	90060008	60011	1.95E-06	2
sipo_fixed7	61144	90060015	60019	90060008	60011	1.83E-06	2
sipo_p_fixed7	61145	90060014	60018	90060008	60011	1.41E-06	2
sipo_p_fixed6	61146	90060014	60018	90060008	60011	1.59E-06	2
sipo_p_fixed5	61147	90060014	60018	90060008	60011	1.71E-06	2
sipo_p_fixed4	61148	90060014	60018	90060008	60011	1.13E-06	2
sipo_p_fixed3	61149	90060014	60018	90060008	60011	1.85E-06	2
sipo_p_fixed2	61150	90060014	60018	90060008	60011	1.95E-06	2
sipo_p_fixed12	61151	90060014	60018	90060008	60011	1.83E-06	2
modplate_rigid1	61152	90060005	60010	90060008	60011	1.55E-06	1.5
modplate_rigid2	61153	90060005	60010	90060008	60011	2.34E-06	1.5
modplate_rigid32	61154	90060005	60010	90060008	60011	1.45E-06	1.5
modplate_rigid4	61155	90060005	60010	90060008	60011	1.65E-06	1.5
modplate_rigid5	61156	90060005	60010	90060008	60011	1.58E-06	1.5
modplate_rigid6	61157	90060005	60010	90060008	60011	1.98E-06	1.5
modplate_rigid7	61158	90060005	60010	90060008	60011	9.84E-07	1.5
modplate_rigid8	61159	90060005	60010	90060008	60011	1.76E-06	1.5
e.pedal	61160	90060073	60043	90060011	60034	8.37E-04	8
e.pad	61164	90060074	60044	90060011	60034	1.20E-04	3.5
e.pin	61165	90060075	60045	90060011	60034	1.14E-04	2
pedalpivout	61167	90060072	60042	90060009	60012	8.58E-06	3
pedalpivinb	61168	90060072	60042	90060009	60012	8.58E-06	3
pedallink	61169	90060072	60042	90060009	60012	1.43E-06	3

pivot inb	61170	90060072	60042	90060009	60012	4.32E-06	3
pivot out	61171	90060072	60042	90060009	60012	1.10E-06	3
Part221130	61172	90060072	60042	90060009	60012	1.08E-06	3
Part221131	61173	90060072	60042	90060009	60012	1.39E-06	3
Part221132	61174	90060072	60042	90060009	60012	9.68E-07	3
Part221133	61175	90060072	60042	90060009	60012	9.79E-07	3
Part221134	61176	90060072	60042	90060009	60012	6.86E-07	3
Part221135	61177	90060072	60042	90060009	60012	1.30E-06	3
Part221136	61178	90060072	60042	90060009	60012	9.62E-07	3
dr_ealf	61179	90060077	60047	90060011	60034	2.25E-04	1.5
dr_eart	61180	90060077	60047	90060020	60041	2.25E-04	1.5
ps_eart	61181	90060076	60046	90060020	60041	1.64E-04	1.5
ps_eart.1	61182	90060076	60046	90060020	60041	1.64E-04	1.5
floor_attachment	61183	90060078	60048	90060020	60041	5.18E-04	2
tunlbkt_fixdeles	61184	90060078	60048	90060010	60013	1.18E-06	2
tunlbkt_fixdeles	61185	90060078	60048	90060010	60013	1.27E-06	2
tunlbkt_fixdeles	61186	90060078	60048	90060010	60013	2.33E-06	2
tunlbkt_fixdeles	61187	90060078	60048	90060010	60013	1.83E-06	2
tunlbkt_fixdeles	61188	90060078	60048	90060010	60013	4.47E-06	2
tunlbkt_fixdeles	61189	90060078	60048	90060010	60013	7.59E-06	2
tunlbkt_fixdeles	61190	90060078	60048	90060010	60013	2.76E-06	2
tunlbkt_fixdeles	61191	90060078	60048	90060010	60013	3.89E-06	2
gboxframe_base	61192	90060080	60049	90060016	60039	3.92E-04	2.5
vribs_gboxframe	61193	90060081	60050	90060016	60039	4.81E-06	1
hribs_gboxframe	61194	90060082	60051	90060016	60039	2.76E-05	1.2
Mag_6.5.1.1	61196	90060100	60052	90060012	60035	3.18E-04	6.5
Mag_3.0.1.1	61197	90060101	60053	90060012	60035	0.00345	3
Mag_4.0.1.1	61198	90060102	60054	90060012	60035	4.81E-04	4
Mag_ribs.1.1	61199	90060103	60055	90060012	60035	0.002748	3
Mag_1.5.1.1	61200	90060104	60056	90060012	60035	1.28E-04	1.5
Mag_5.0.1	61201	90060105	60057	90060012	60035	1.40E-04	5
Mag_2.5	61202	90060106	60058	90060012	60035	2.65E-04	2.5
inner.1	61203	90060107	60059	90060016	60039	3.58E-04	3
innergroorve	61204	90060111	60063	90060016	60039	8.37E-07	3.3
ribs.1	61205	90060112	60064	90060016	60039	1.36E-04	1.25
bin o	61206	90060108	60060	90060017	60040	2.74E-04	2.5
ribbin	61207	90060110	60062	90060017	60040	5.71E-07	1.7
bintongue	61208	90060109	60061	90060017	60040	4.40E-07	1.1
outer.1	61209	90060113	60065	90060016	60039	2.85E-04	2.5
hub	61210	90060115	60067	90060016	60039	1.76E-06	1
outerhrib	61211	90060114	60066	90060016	60039	7.18E-06	1.2
outervrib	61212	90060115	60067	90060016	60039	3.35E-07	1
hubrib	61213	90060116	60068	90060016	60039	1.93E-07	1.375
glvbx_frm_hinge_	61214	90060117	60069	90060016	60039	8.29E-06	3
knee bolster inn	61215	90060118	60070	90060016	60039	2.66E-04	2.5
inner rib h	61216	90060119	60071	90060016	60039	1.25E-04	1.875
small rib inner	61217	90060120	60072	90060016	60039	3.27E-06	2.6
knee bolster out	61218	90060121	60073	90060016	60039	4.25E-04	2.5
doghouse outer	61219	90060122	60074	90060016	60039	6.40E-06	1.4

outer rib	61220	90060123	60075	90060016	60039	4.29E-06	1.1
tipof bin	61221	90060124	60076	90060016	60039	5.01E-05	2.5
part.9	61301	SectShll20.1	60088	MAT9_704	60009	1.21E-04	2
part.10	61302	SectShll20.1	60088	MAT9_705	60010	5.21E-05	2
part.11	61303	SectShll5.3	60105	MAT20_706	60015	5.98E-05	0.5
part.14	61304	SectShll20.1	60088	MAT20_750	60016	0.001699	2
part.15	61305	SectShll10.1	60083	MAT20_751	60017	8.05E-05	1
part.16	61306	SectShll34	60115	MAT20_752	60018	1.83E-04	3.4
part.17	61307	SectShll25	60091	MAT20_753	60019	5.23E-04	2.5
part.18	61308	SectShll25	60091	MAT20_754	60020	6.50E-04	2.5
part.19	61309	SectShll20.1	60088	MAT20_755	60021	5.14E-04	2
part.20	61310	SectShll30	60094	MAT20_756	60022	4.70E-04	3
part.21	61311	SectShll34	60115	MAT20_757	60023	2.55E-04	3.4
part.22	61312	SectShll20.1	60088	MAT20_758	60024	5.61E-05	2
part.24	61313	SectShll20.1	60088	MAT20_760	60025	1.14E-04	2
part.25	61314	SectShll20.1	60088	MAT20_761	60026	8.86E-05	2
part.28	61315	SectShll20.1	60088	MAT20_764	60027	2.43E-05	2
part.29	61316	SectShll20.1	60088	MAT20_765	60028	2.32E-05	2
part.30	61317	SectShll40	60093	MAT20_766	60029	3.95E-06	4
part.31	61318	SectShll40	60093	MAT20_767	60030	3.95E-06	4
part.34	61319	SectShll40	60093	MAT24_771	60044	2.43E-05	4
part.40	61320	SectShll30	60094	MAT20_777	60031	3.28E-04	3
part.41	61321	SectShll30	60094	MAT20_778	60032	3.69E-04	3
strclnmend4	61323	SectShll50	60092	rigid	60014	2.10E-04	5
part.49	61324	SectShll15.3	60117	MAT20_20015	60033	9.89E-06	1.5
drinrpnl.l	61401	Sectshll75	60097	MATL24_160	60048	0.003637	0.75
drlwrhng.l	61402	SectShll50	60092	MATL24_160	60048	1.28E-04	5
drotrpnl.l	61403	Sectshll75	60097	MATL24_180	60046	0.004388	0.75
z-brkt.l	61404	SectShll10.1	60083	MATL24_160	60048	5.56E-05	1
upr_frame.l	61405	SectShll10.1	60083	MATL24_160	60048	0.001997	1
drbeam.l	61406	SectShll20.1	60088	MATL24_600	60056	0.001914	2
druprhng.l	61407	SectShll50	60092	MATL24_160	60048	1.30E-04	5
drinrpnl.r	61408	Sectshll75	60097	MATL24_160	60048	0.003636	0.75
drotrpnl.r	61409	Sectshll75	60097	MATL24_180	60046	0.004388	0.75
z-brkt.r	61410	SectShll10.1	60083	MATL24_160	60048	5.56E-05	1
upr_frame.r	61411	SectShll10.1	60083	MATL24_160	60048	0.001997	1
drbeam.r	61412	SectShll20.1	60088	MATL24_600	60056	0.001913	2
druphng.r	61413	SectShll50	60092	MATL24_160	60048	1.34E-04	5
drlwhng.r	61414	SectShll50	60092	MATL24_160	60048	1.26E-04	5
fdrbdhng	61415	SectShll50	60092	MATL24_210	60052	2.07E-04	5
fdrbdhng2	61416	SectShll20.1	60088	rigid	60014	1.96E-05	2
fdrbdhng3	61417	SectShll20.1	60088	rigid	60014	2.43E-05	2
fdrbdhng4	61418	SectShll50	60092	MATL24_210	60052	2.01E-04	5
fdrbdhng5	61419	SectShll20.1	60088	rigid	60014	2.07E-05	2
fdrbdhng6	61420	SectShll20.1	60088	rigid	60014	2.54E-05	2
fdrbdhng7	61421	SectShll50	60092	MATL24_210	60052	2.55E-04	5
fdrbdhng8	61422	SectShll20.1	60088	rigid	60014	2.01E-05	2
fdrbdhng9	61423	SectShll20.1	60088	rigid	60014	2.48E-05	2
fdrbdhng10	61424	SectShll50	60092	MATL24_210	60052	1.97E-04	5

fdrbdhng11	61425	SectShll20.1	60088	rigid	60014	2.07E-05	2
fdrbdhng12	61426	SectShll20.1	60088	rigid	60014	2.49E-05	2
drlsrwld.l	61427	SectShll18.1	60087	MATL24_160	60048	0.003567	1.8
drlsrwld.r	61428	SectShll18.1	60087	MATL24_160	60048	0.003567	1.8
rrdrinn.l	61429	Sectshll75	60097	MATL24_160	60048	0.006811	0.75
twdrrdrinr.l	61430	SectShll18.1	60087	MATL24_160	60048	0.005454	1.8
rrdrotr.l	61431	Sectshll75	60097	MATL24_160	60048	0.008021	0.75
rrdrfrm.l	61432	SectShll10.1	60083	MATL24_160	60048	0.003331	1
rrdrbm.l	61433	SectShll20.1	60088	MATL24_600	60056	0.002513	2
bathtub.l	61434	SectShll20.1	60088	MATL24_160	60048	2.59E-04	2
rrdrhng.l	61435	SectShll50	60092	MATL24_160	60048	1.06E-03	5
latchjt.l	61436	SectShll20.1	60088	MATL24_160	60048	2.28E-04	2
rrdrhng1.l	61437	SectShll50	60092	MATL24_160	60048	6.20E-04	5
roof	61501	Sectshll75	60097	MATL24_160	60048	0.010108	0.75
wshield	61502	SectShll48	60100	laminatedglass	60058	0.015411	4.8
rr_wndshld	61503	SectShll48	60100	laminatedglass	60058	0.011652	4.8
bdysdpnlotr.l	61601	Sectshll75	60097	MATL24_160	60048	0.014307	0.75
bdysdpnlotr.r	61602	Sectshll75	60097	MATL24_160	60048	0.014308	0.75
twldbsideinr.l	61603	SectShll21	60089	MATL24_160	60048	0.00905	2.1
twldbsideinr.r	61604	SectShll21	60089	MATL24_160	60048	0.009056	2.1
rkrx_l	61605	Sectshll13	60098	MATL24_340	60049	1.01E-03	1.3
rkrx_r	61606	Sectshll13	60098	MATL24_340	60049	1.01E-03	1.3
rkrinr.l	61607	sectshll16	60114	MATL24_3404	60051	0.003811	1.6
rkrinr.r	61608	sectshll16	60114	MATL24_3404	60051	0.003811	1.6
twldB-plr.l	61609	SectShll18.1	60087	MATL24_250	60054	0.003041	1.8
twldB-plr.r	61610	SectShll18.1	60087	MATL24_250	60054	0.003041	1.8
bdysdpnlinr.l	61611	SectShll10.1	60083	MATL24_160	60048	0.009621	1
bdysdpnlinr.r	61612	SectShll10.1	60083	MATL24_160	60048	0.009567	1
B_plr_rnf	61613	SectShll10.1	60083	MATL24_160	60048	6.01E-04	1
bplrrnf.l	61615	SectShll225	60099	MATL24_250	60054	0.003029	2.25
bplrrnf.r	61616	SectShll225	60099	MATL24_250	60054	0.003029	2.25
rfrailrnfl	61617	SectShll20.1	60088	MATL24_210	60052	0.002007	2
rfrailrnfr	61618	SectShll20.1	60088	MATL24_210	60052	0.002007	2
frt_hrn	61619	SectShll20.1	60088	MATL24_160	60048	7.90E-04	2
rfrailinr.r	61620	SectShll20.1	60088	MATL24_160	60048	7.85E-04	2
a_pilar_rnf_l	61621	SectShll10.1	60083	MATL24_160	60048	9.04E-04	1
a_pilar_rnf_r	61622	SectShll10.1	60083	MATL24_160	60048	9.05E-04	1
fbhplrrnf1.l	61623	SectShll10.1	60083	MATL24_210	60052	0.001632	1
fbhplrrnf1.r	61624	SectShll10.1	60083	MATL24_210	60052	0.001634	1
frthdr	61625	SectShll7.2	60080	MATL24_160	60048	9.30E-04	0.7
rfbow2	61626	SectShll9.1	60082	MATL24_340	60049	9.23E-04	0.9
rearflr	61627	SectShll8.3	60081	MATL24_160	60048	0.017539	0.8
bar3	61628	SectShll10.1	60083	MATL24_211	60053	0.002442	1
bar4ctr	61629	SectShll10.1	60083	MATL24_340	60049	0.001438	1
bar4lft	61630	SectShll15.3	60117	MATL24_160	60048	0.001168	1.5
rrrail.l	61631	SectShll15.3	60117	MATL24_251	60055	0.005535	1.5
rrrailrnf1.l	61632	SectShll10.1	60083	MATL24_160	60048	1.93E-04	1
rrailrnf2.l	61633	SectShll10.1	60083	MATL24_160	60048	2.10E-04	1
gusset.l	61634	SectShll15.3	60117	MATL24_160	60048	7.13E-04	1.5

gusset2.l	61635	SectShll15.3	60117	MATL24_160	60048	8.44E-04	1.5
gusset3.l	61636	SectShll15.3	60117	MATL24_160	60048	5.19E-04	1.5
gusset4.l	61637	SectShll15.3	60117	MATL24_160	60048	5.89E-04	1.5
whlhsinr.l	61638	SectShll10.1	60083	MATL24_160	60048	0.002906	1
4barrnf1.l	61639	SectShll20.1	60088	MATL24_160	60048	0.001399	2
4barrnf2.l	61640	SectShll25	60091	MATL24_160	60048	7.24E-04	2.5
backpanel	61641	SectShll8.3	60081	MATL24_160	60048	0.005311	0.8
bpnlrnf	61642	Sectshll75	60097	MATL24_160	60048	0.001933	0.75
rrhdr	61643	SectShll9.1	60082	MATL24_160	60048	0.001131	0.9
rrsuspshk.l	61644	SectShll225	60099	MATL24_160	60048	3.05E-04	2.25
rkrblkhds	61645	SectShll12.1	60084	MATL24_340	60049	7.54E-04	1.2
rdeck	61646	SectShll10.1	60083	MATL24_160	60048	0.005446	1
trnkgtrfrt	61647	SectShll10.1	60083	MATL24_160	60048	0.00209	1
rdeckbrkt1	61648	SectShll10.1	60083	MATL24_160	60048	9.01E-04	1
rdeckbrkt2	61649	SectShll10.1	60083	MATL24_160	60048	2.49E-04	1
trnkgtr.l	61650	SectShll9.1	60082	MATL24_160	60048	3.97E-04	0.9
rdeckbrkt3.l	61651	SectShll10.1	60083	MATL24_160	60048	8.76E-04	1
rdeckbrkt4.l	61652	SectShll10.1	60083	MATL24_160	60048	7.67E-04	1
trlrhtchbrkt	61653	SectShll10.1	60083	MATL24_160	60048	0.001306	1
rrailext.l	61654	SectShll15.3	60117	MATL24_160	60048	7.55E-04	1.5
bar4rt	61655	SectShll15.3	60117	MATL24_160	60048	0.001168	1.5
rrrail.r	61656	SectShll15.3	60117	MATL24_251	60055	0.005519	1.5
rrailrnf1.r	61657	SectShll10.1	60083	MATL24_160	60048	1.93E-04	1
rrailrnf2.r	61658	SectShll10.1	60083	MATL24_160	60048	2.10E-04	1
gusset.r	61659	SectShll15.3	60117	MATL24_160	60048	7.13E-04	1.5
gusset2.r	61660	SectShll15.3	60117	MATL24_160	60048	8.44E-04	1.5
gusset3.r	61661	SectShll15.3	60117	MATL24_160	60048	5.19E-04	1.5
gusset4.r	61662	SectShll15.3	60117	MATL24_160	60048	5.87E-04	1.5
whlhsinr.r	61663	SectShll10.1	60083	MATL24_160	60048	0.003046	1
4barrnf1.r	61664	SectShll20.1	60088	MATL24_160	60048	0.001459	2
4barrnf2.r	61665	SectShll25	60091	MATL24_160	60048	6.97E-04	2.5
rrsuspshk.r	61666	SectShll225	60099	MATL24_160	60048	3.05E-04	2.25
trnkgtr.r	61667	SectShll9.1	60082	MATL24_160	60048	4.00E-04	0.9
rdeckbrkt3.r	61668	SectShll10.1	60083	MATL24_160	60048	8.73E-04	1
rdeckbrkt4.r	61669	SectShll10.1	60083	MATL24_160	60048	7.63E-04	1
rrailext.r	61670	SectShll15.3	60117	MATL24_160	60048	7.48E-04	1.5
fbhpbulkhd.l	61671	SectShll20.1	60088	MATL24_340	60049	5.83E-04	2
rkrblkhds.1	61672	SectShll12.1	60084	MATL24_340	60049	2.83E-04	1.2
accl.r	61673	SectShll10.1	60083	rigid	60014	4.29E-05	1
accl.l	61674	SectShll10.1	60083	rigid	60014	4.56E-05	1
rr_hrn	61675	SectShll14.1	60085	MATL24_160	60048	9.12E-04	1.4
fbhp_brkt	61676	SectShll20.1	60088	MATL24_210	60052	1.84E-04	2
rkr_extn	61677	Sectshll75	60097	MATL24_600	60056	0.001526	0.75
muffler	61701	SectShll5.3	60105	MATL24_160	60048	0.00133	0.5
exhstpipe	61702	SectShll5.3	60105	MATL24_160	60048	0.00201	0.5
rtire.l	61801	SectShll10.1	60083	MATL24_160	60048	0.007576	1
rtire.r	61802	SectShll10.1	60083	MATL24_160	60048	0.007576	1
rearrim	61803	SectShll35	60106	MATL24_160	60048	0.015933	3.5
rbmpbmbrkt.l	61901	SectShll15.3	60117	MATL24_160	60048	4.35E-04	1.5

rbmpbmbrkt.r	61902	SectShll15.3	60117	MATL24_160	60048	4.35E-04	1.5
rbumpbeam	61903	SectShll10.1	60083	MATL24_160	60048	0.003708	1
part.42	62001	SectDisc779	60123	MATSpr1_779	60063	0	0
part.43	62002	SectDisc780	60124	MATDmp2_780	60064	0	0
part.44	62003	SectDisc781	60125	MATSpr4_781	60069	0	0
part.47	62004	SectDisc783	60126	MATDmp2_784	60065	0	0
part.12	62005	SectBeam707	60009	MAT24_707	60043	7.70E-04	0
bar1fsusp	62006	Sectbeam10500	60002	MATBEAM	60057	0.001903	0
bar2fsusp	62007	Sectbeam10501	60003	MATBEAM	60057	4.12E-05	0
bar3fsusp	62008	Sectbeam10500	60002	MATBEAM	60057	1.41E-04	0
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bar3dline	62012	Sectbeam10504	60004	MATBEAM	60057	1.16E-04	0
bar5dline	62013	Sectbeam10509	60005	MATBEAM	60057	8.50E-05	0
bar1rrsus	62014	Sectbeam10500	60002	MATBEAM	60057	0.007365	0
bar2rrsusp	62015	Sectbeam10516	60006	MATBEAM	60057	0.019679	0
bar3rrsusp	62016	Sectbeam10516	60006	MATBEAM	60057	0.0026	0
bar4rrsusp	62017	Sectbeam10516	60006	MATBEAM	60057	0.002841	0
bardummies	62018	Sectbeam10519	60007	MATBEAM	60057	0.003373	0
barseat	62019	Sectbeam10519	60007	MATBEAM	60057	3.34E-04	0
barradiator	62020	Sectbeam10522	60008	MATBEAM	60057	1.82E-04	0
bardriveline	62021	Sectbeam10504	60004	MATBEAM	60057	2.57E-04	0
bardriveline8	62022	Sectbeam10504	60004	MATBEAM	60057	7.05E-05	0
sprdrvline	62023	SectDisc1	60122	Matsprstr14	60066	0	0
sprengmnt3	62024	SectDisc1	60122	Matsprstr113	60067	0	0
sprdummy	62025	SectDisc1	60122	Matsprstr114	60068	0	0
spr2dummy	62026	SectDisc1	60122	Matsprstr116	60062	0	0
spr3dummy	62027	SectDisc1	60122	Matsprstr116	60062	0	0
ltmount_spring	62028	SectDisc20071.1	60127	MATSpr4_61112	60070	0	0
rt_mount_spring	62029	SectDisc20071.1	60127	MATSpr4_61113	60071	0	0
rr_cdl_atch_spri	62030	SectDisc20071.1	60127	MATSpr4_61116	60073	0	0
rr_cdl_atch_spri	62031	SectDisc20071.1	60127	MATSpr4_61115	60072	0	0
hinge_beam_65dia	62032	90060004	60001	90060006	60005	1.06E-04	0
Masses	62033	N/A	N/A		0	0.002085	N/A
ElemMass	62034	N/A	N/A		0	0.633762	N/A
ncap_driver_pass	62035	N/A	N/A		0	0.156	N/A
SpotWelds	62039	N/A	N/A		0	0	N/A
Rigids.5	62040	N/A	N/A		0	0	N/A
Joints	62042	N/A	N/A		0	0	N/A
2T_Welds	62043	N/A	N/A	2T_Welds	60075	0	N/A
out_front_lh_doo	62047	N/A	N/A		0	1.42E-04	N/A
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out_hood_masses_	62054	N/A	N/A		0	9.59E-05	N/A
out_roof_masses_	62056	N/A	N/A		0	8.76E-05	N/A
out_windshield_m	62058	N/A	N/A		0	1.92E-06	N/A
out_rear_lh_door	62060	N/A	N/A		0	1.96E-04	N/A
new_weld	124214	N/A	N/A		0	0	N/A
out_front_rh_doo	62064	N/A	N/A		0	1.53E-04	N/A

out_rear_rh_door	62066	N/A	N/A		0	1.90E-04	N/A
new_rgds	124215	N/A	N/A		0	0	N/A
rgd_should_not_b	124216	N/A	N/A	MAT20_751	60017	0	N/A
wleds_should_not	124217	N/A	N/A	MAT20_751	60017	0	N/A

Total Components	**488**
Model Mass	**1.763 tonnes**

- Model mass is from LS-DYNA3D d3hsp file.
- Part mass summary is from HYPERMESH.

12. Appendix C: Attached Parts

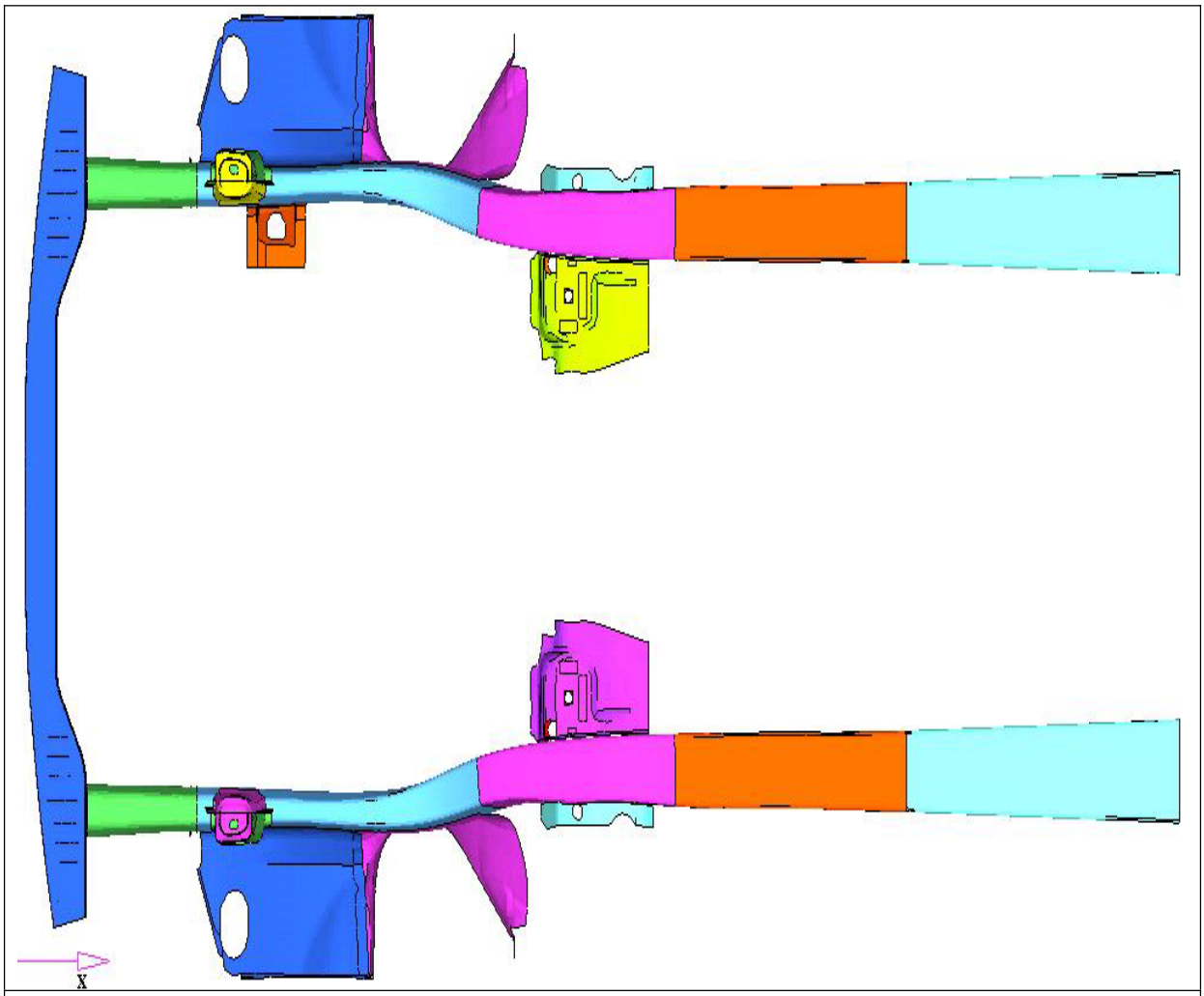


Figure 21: Attached Parts – Top View

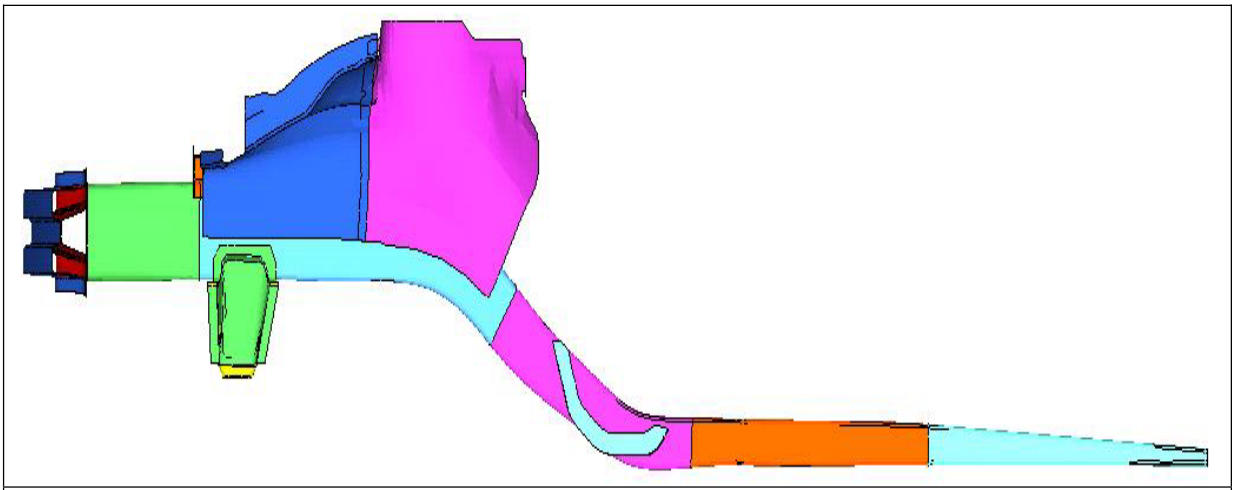


Figure 22: Attached Parts – Side View

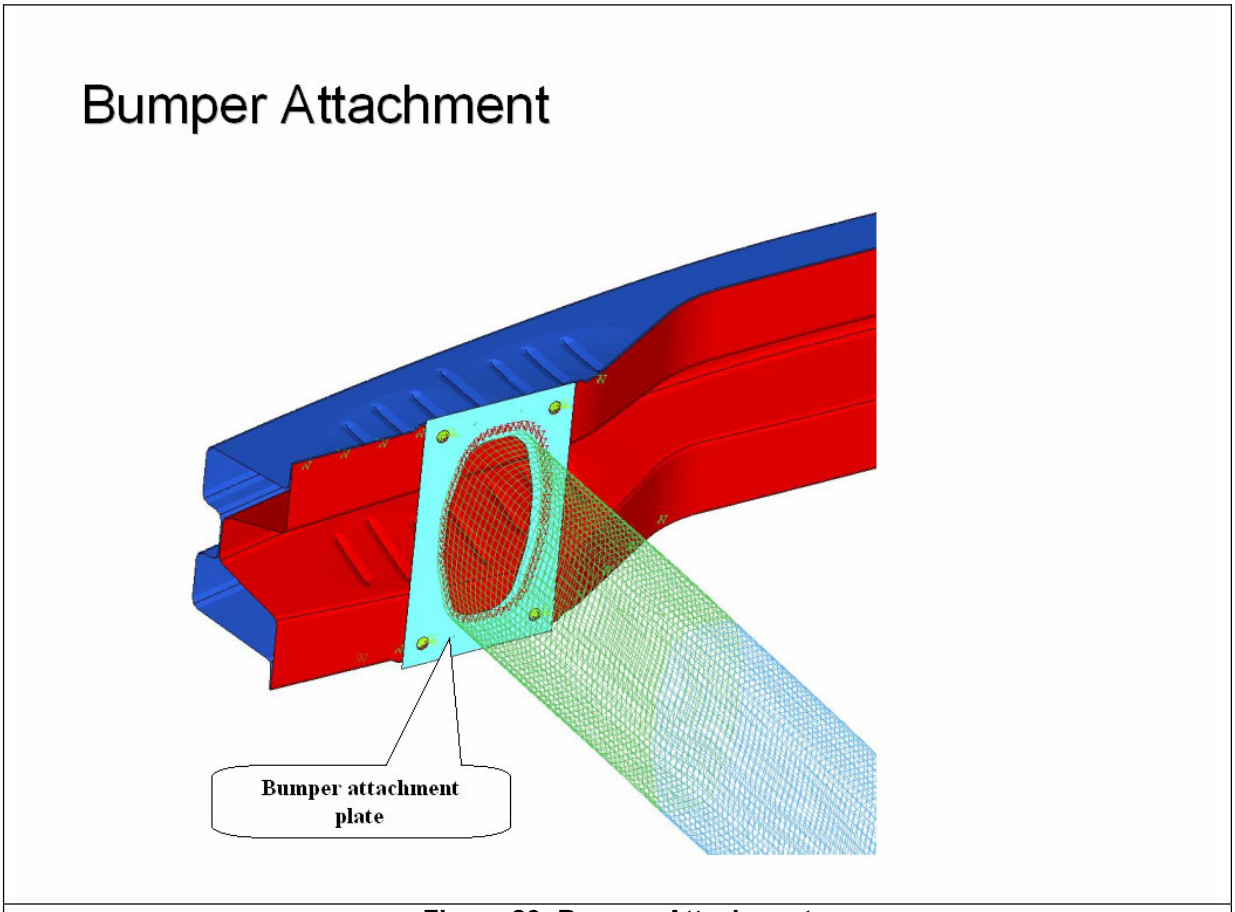


Figure 23: Bumper Attachment

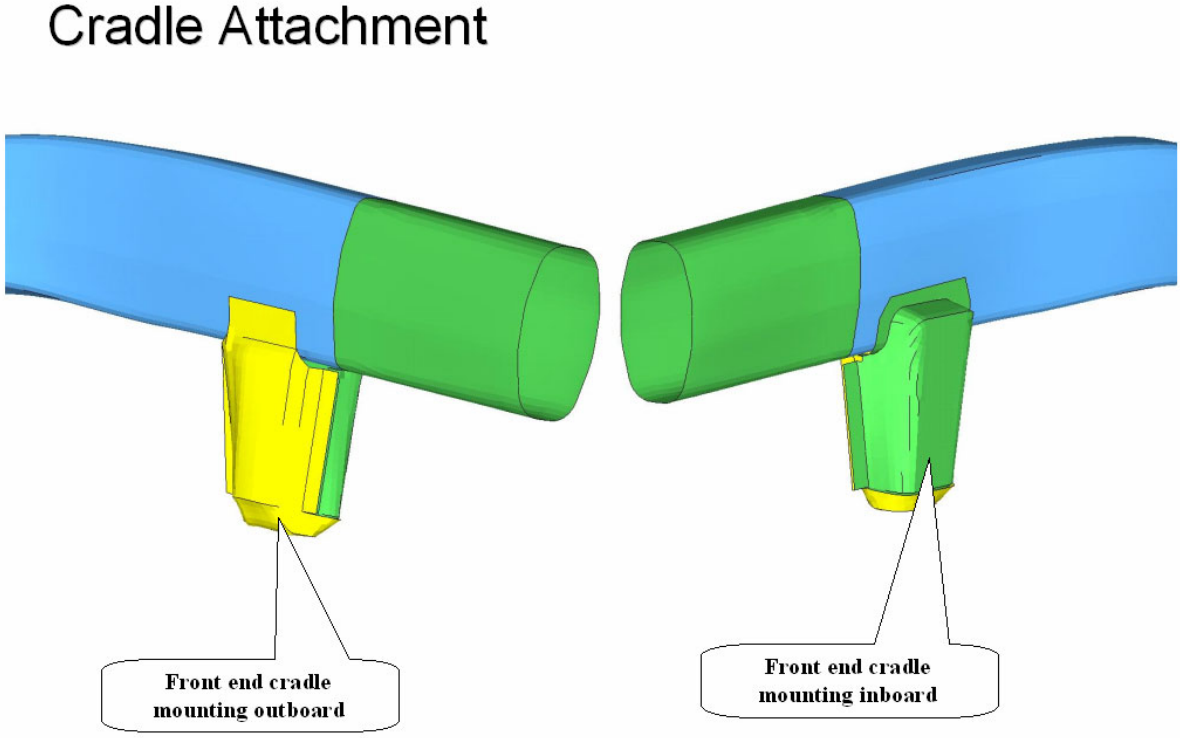


Figure 24: Front Cradle Mount

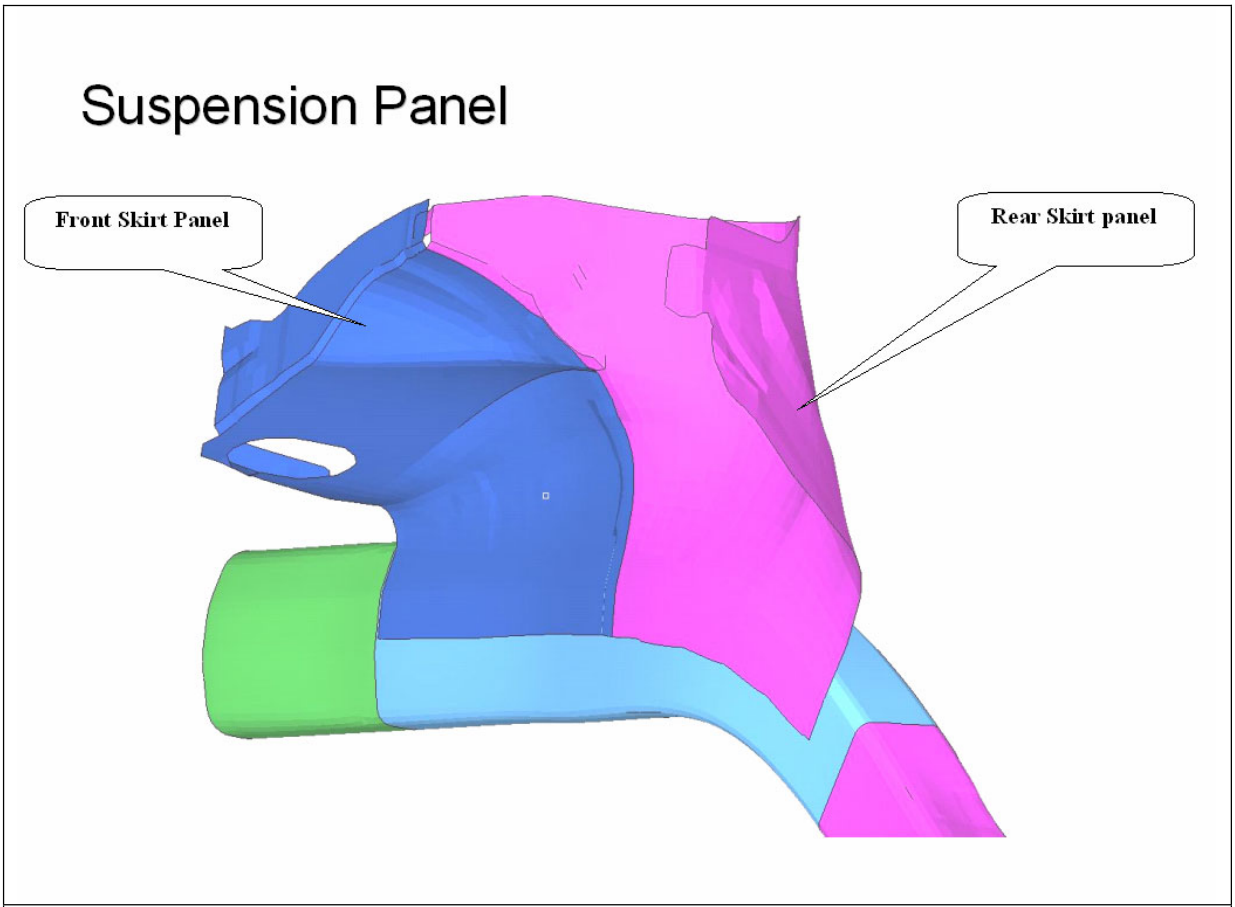


Figure 25: Suspension Panel

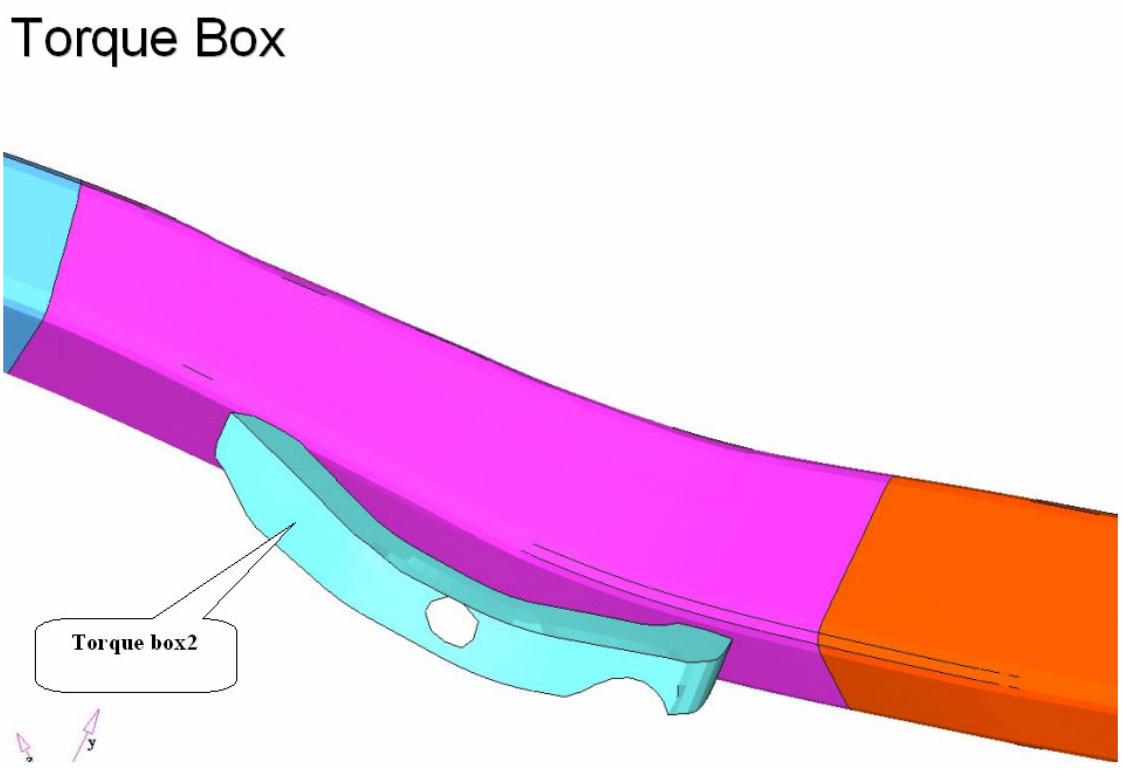


Figure 26: Torque Box

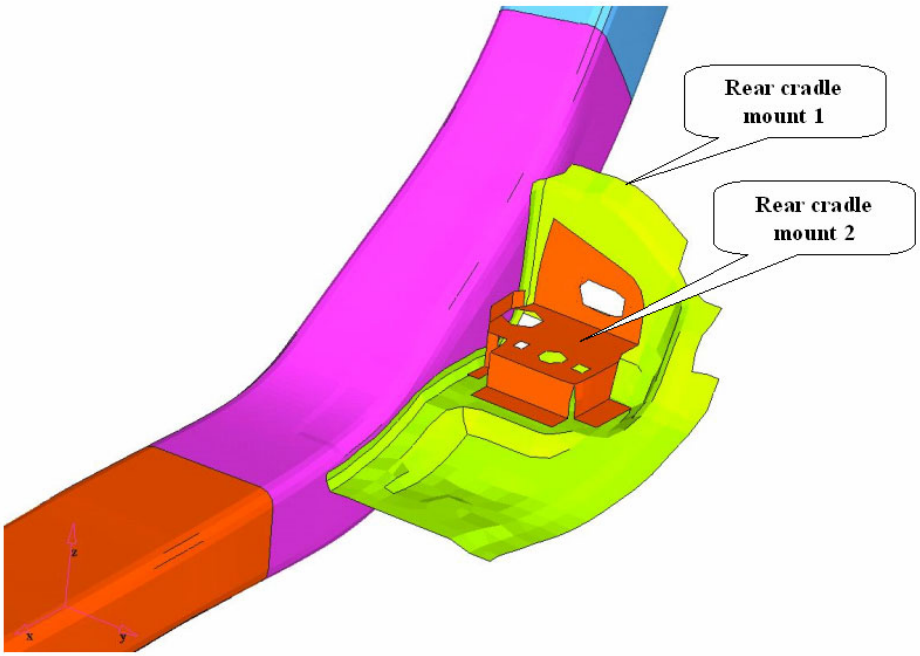


Figure 27: Rear Cradle Mount

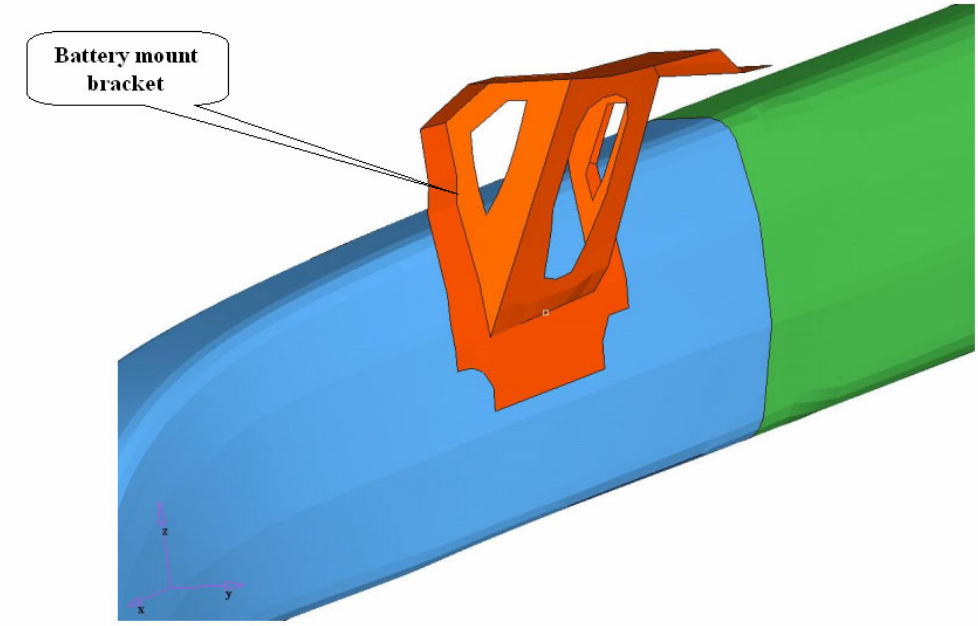


Figure 28: Battery

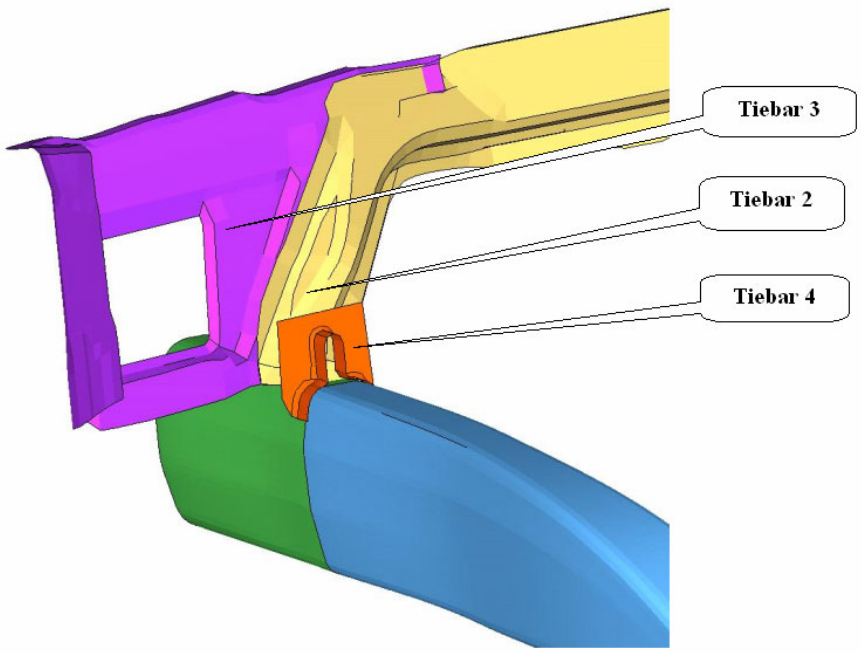


Figure 29: Tie Bar

Concept 3: Preliminary Design

Milestone 16

Lightweight Front End Structure Phase II

September 10, 2003

Auto/Steel Partnership

Abstract

This report documents the preliminary design for Concept 3 that has a new hydroformed rail design and a stamped bumper design. A final design for Concept 3 will be obtained, based on a DOE study. The final Concept 3 design will be compared to Concepts 1 and 2 developed in Phase II of the Lightweight Front End Structure Project.

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1. Objectives

The effort of this study was aimed at developing a preliminary design for Concept 3. Concept 3 has a new hydroformed rail design and a stamped bumper design. A final design for Concept 3 will be obtained, based on a DOE study. The final Concept 3 design will be compared to Concepts 1 and 2 developed in Phase II of the Lightweight Front End Structure Project.

2. Results Summary

The Concept 3 design has the following salient features.

- Symmetric LH/RH rail assemblies.
- One-piece tailor-welded rail design.
- Octagonal front sections and rectangular rear sections.
- Two-piece double box bumper design with energy absorbing features.

The Concept 3 design achieves a mass reduction of **12.1kg (31%)** compared to the *Baseline* design. The *NCAP performance* is essentially the same as that of the baseline design. The *IIHS performance* is similar to that of the baseline design, except for A-B closure, which is higher than baseline.

The NCAP and IIHS results are summarized in *Table 1* and *Table 2*.

A positive value of steering column upward movement means that the steering column moves upwards and towards the occupant, and a positive value of steering column rearward movement means that the steering column moves rearwards and towards the occupant.

Table 1: NCAP Results

B Pillar Pulse	Baseline	Concept 3
LH	36.7g @ 58.7ms	33.9g @ 43.9ms
RH	35.3g @ 58.6ms	35.9g @ 62.0 ms

Table 2: IIHS Results

Location	Intrusions @ 250ms (cm)	
	Baseline	Concept 3
Brake Pedal**	11.2	5.2
Left Toepan	14.5	14.6
Center Toepan	14.4	17.2
Right Toepan	15.8	15.6
A-B Pillar Closure	11.8	15.9
Steering Column Upward Movement*	-1.8	-4.5
Steering Column Rearward Movement*	0.0	7.2

* Steering column movement does not stabilize at 250ms (*Figure 20*).
** *Brake pedal intrusions are unreliable*.

3. Concept 3 Design

The rail design (*Figure 1* through *Figure 3*) is a one-piece tailor-welded hydroformed design with symmetric LH and RH rail assemblies. The front portion of the rail has an octagonal section and the rear portion of the rail has a rectangular section (*Figure 4*). The cross-section transitions from octagonal to rectangular. Octagonal sections are highly efficient in absorbing energy in dynamic crush. Therefore, the rail sections are octagonal in the crush zone and the section centroids have been aligned so as to create an axial load path. Elsewhere, the rail sections are limited by design space and have been chosen so as to maximize the section modulus and to achieve a smooth surface. The perimeter variation (*Figure 5*) has been kept below 8% (8), 9) and the minimum radius is 10mm. Flat surfaces of minimum 10mm width have been provided for welding attached parts.

The cross-sections were optimized so as to achieve maximum section modulus subject to packaging and perimeter restrictions. The optimization problem was setup as.

Maximize: Iyy

Subject: Izz > min Izz
Perimeter change < 8%
Packaging constraints

The optimized sections were adjusted in order to obtain a smooth design surface.

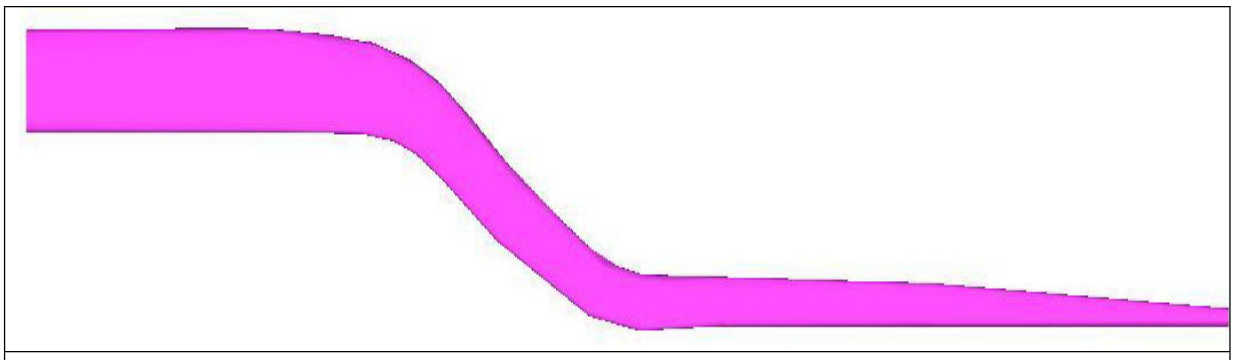


Figure 1: LH Rail - Side View

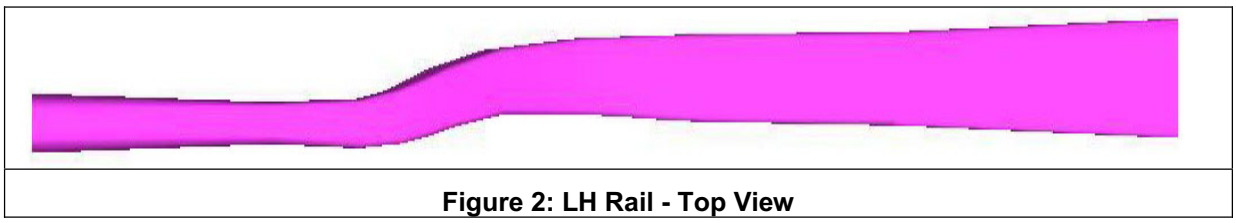


Figure 2: LH Rail - Top View

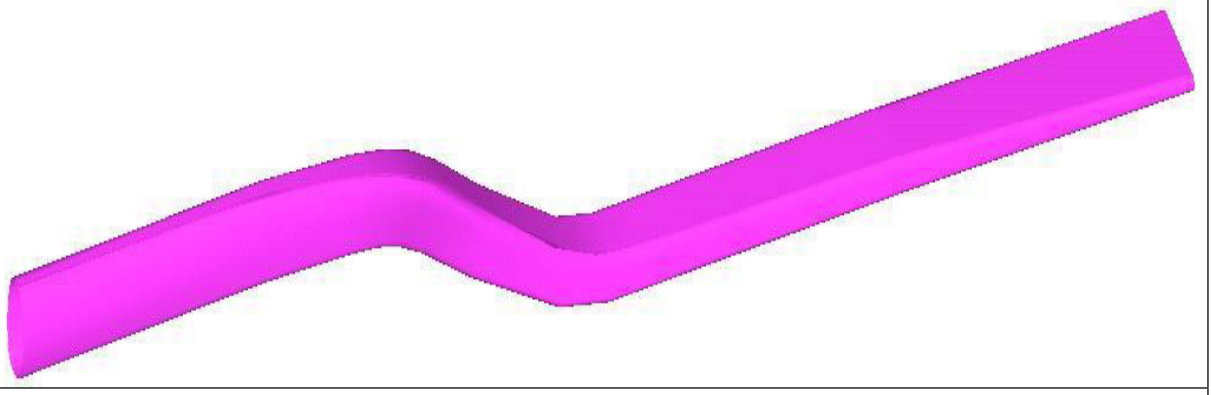


Figure 3: LH Rail - Isometric View

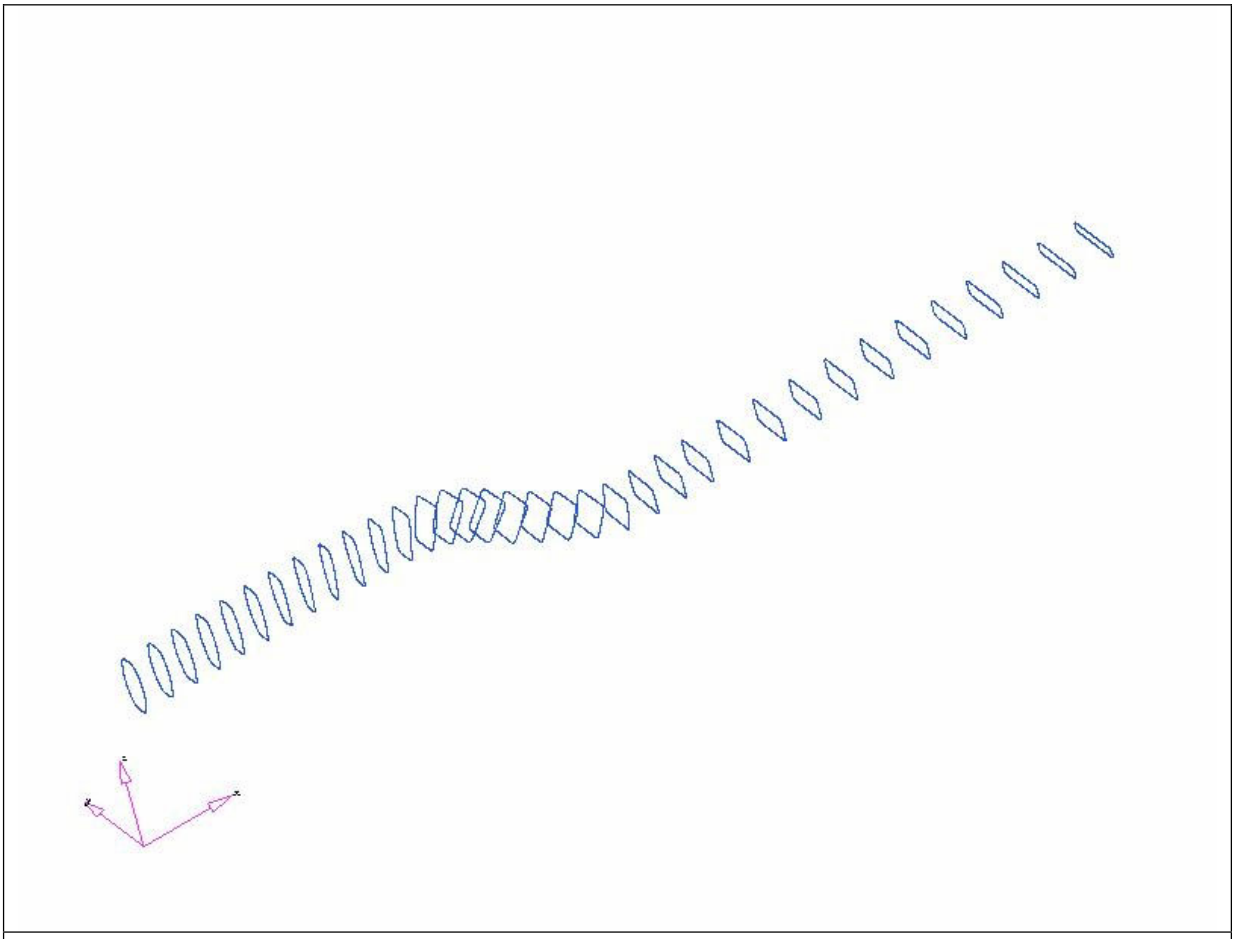


Figure 4: LH Rail Sections

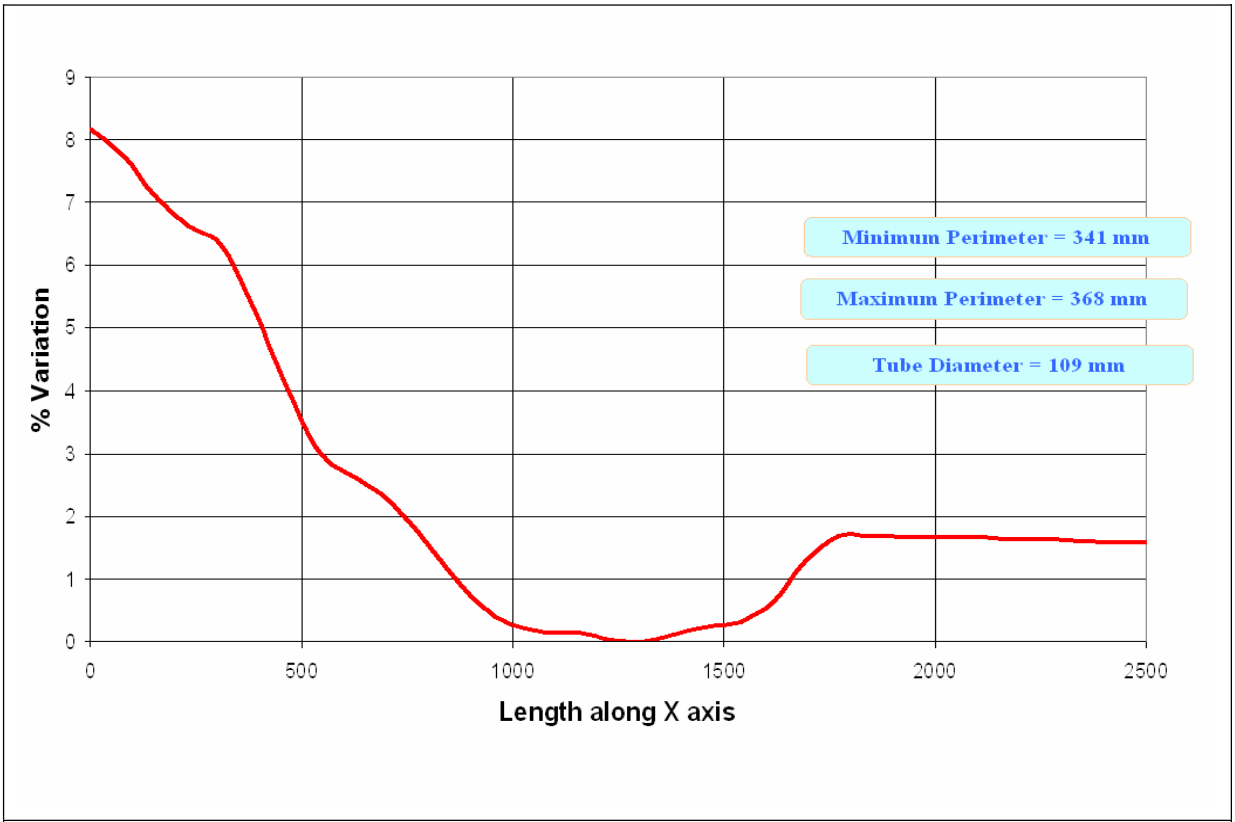


Figure 5: Perimeter Variation

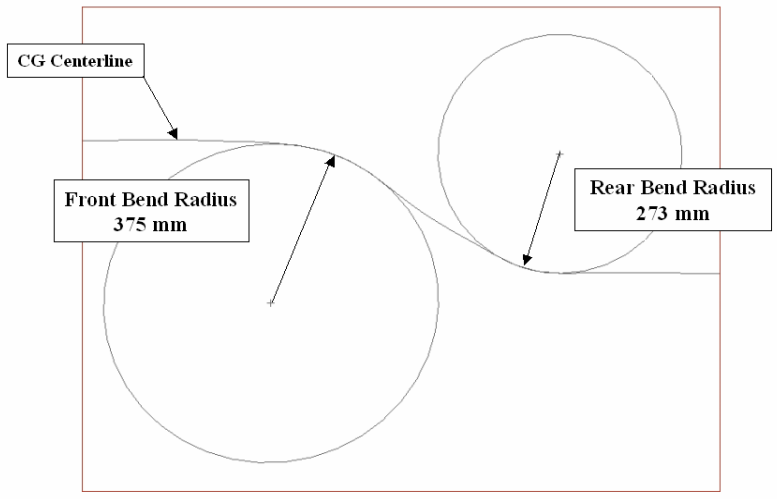


Figure 6: Bend Radius

The rail centerline has curvatures in both top and side views. The bend radii are indicated in *Figure 6*. The centerline has been adjusted so as to limit the number of bends to two.

Tailor-blanking was introduced in the rails. The rail is now considered to be 5-piece tailor-welded, with the weld lines indicated in *Figure 7*. The grades and gauges of the rail assembly will be varied in the DOE study. The feasibility of tailor-welded hydroformed rails has to be explored.

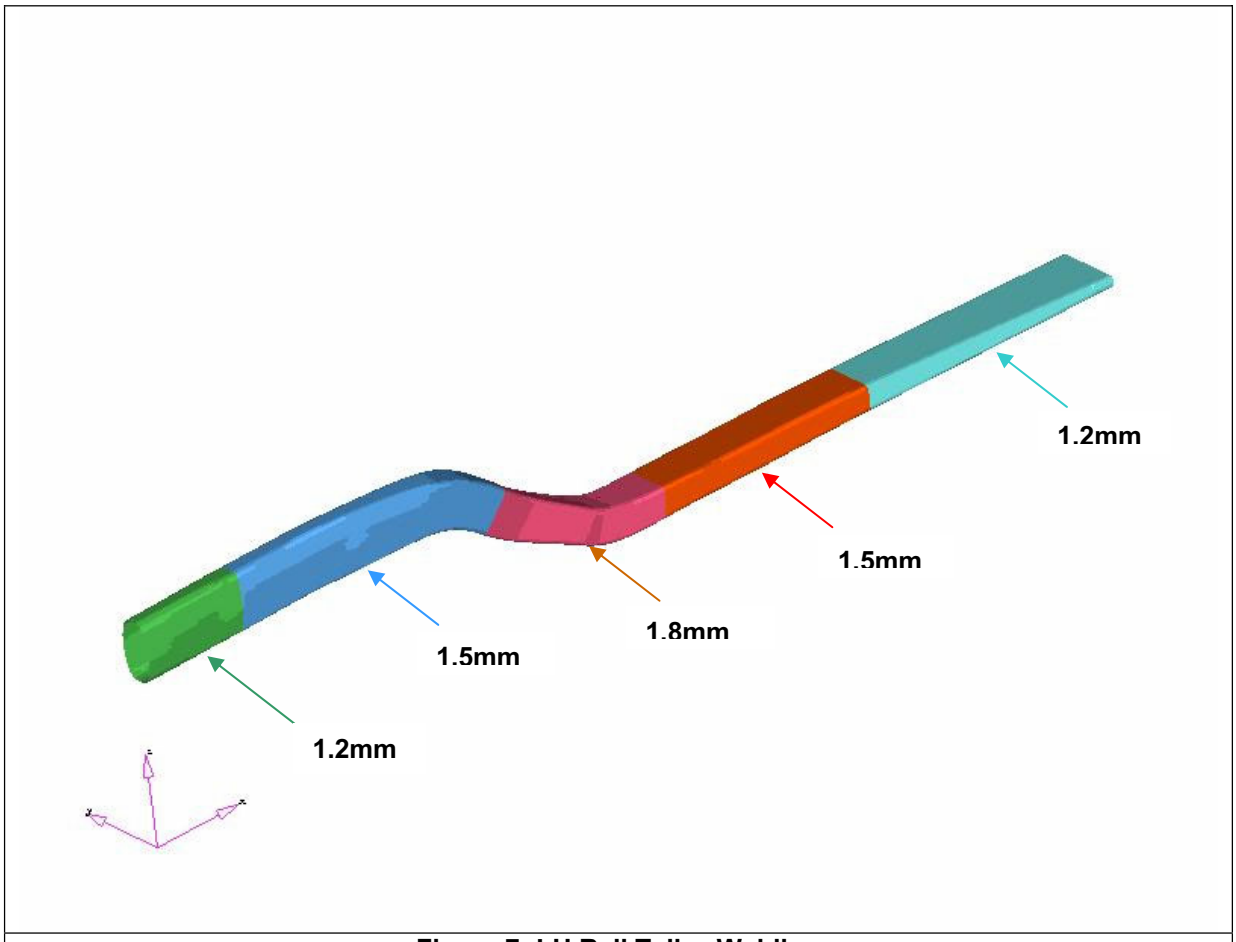


Figure 7: LH Rail Tailor-Welding

The baseline bumper was replaced by a new bumper design (*Figure 8, Figure 9*). The new bumper design is functionally quite similar to the Phase I Bumper 3 design. However, it has fewer manufacturing and welding concerns than the Bumper 3 design. The new bumper design is a 2-piece double-box stamped design using DP980 steel. The bumper has vertical flanges and beads on the front and back plates. The new bumper design has good energy absorption capability in high-speed impacts and results in a high initial peak in the NCAP B-pillar pulse. In addition, the bumper is more formable than the Phase I Bumper 3 design, and is easier to weld. *A design similar to the new bumper design has been prototyped using DF140T steel.*

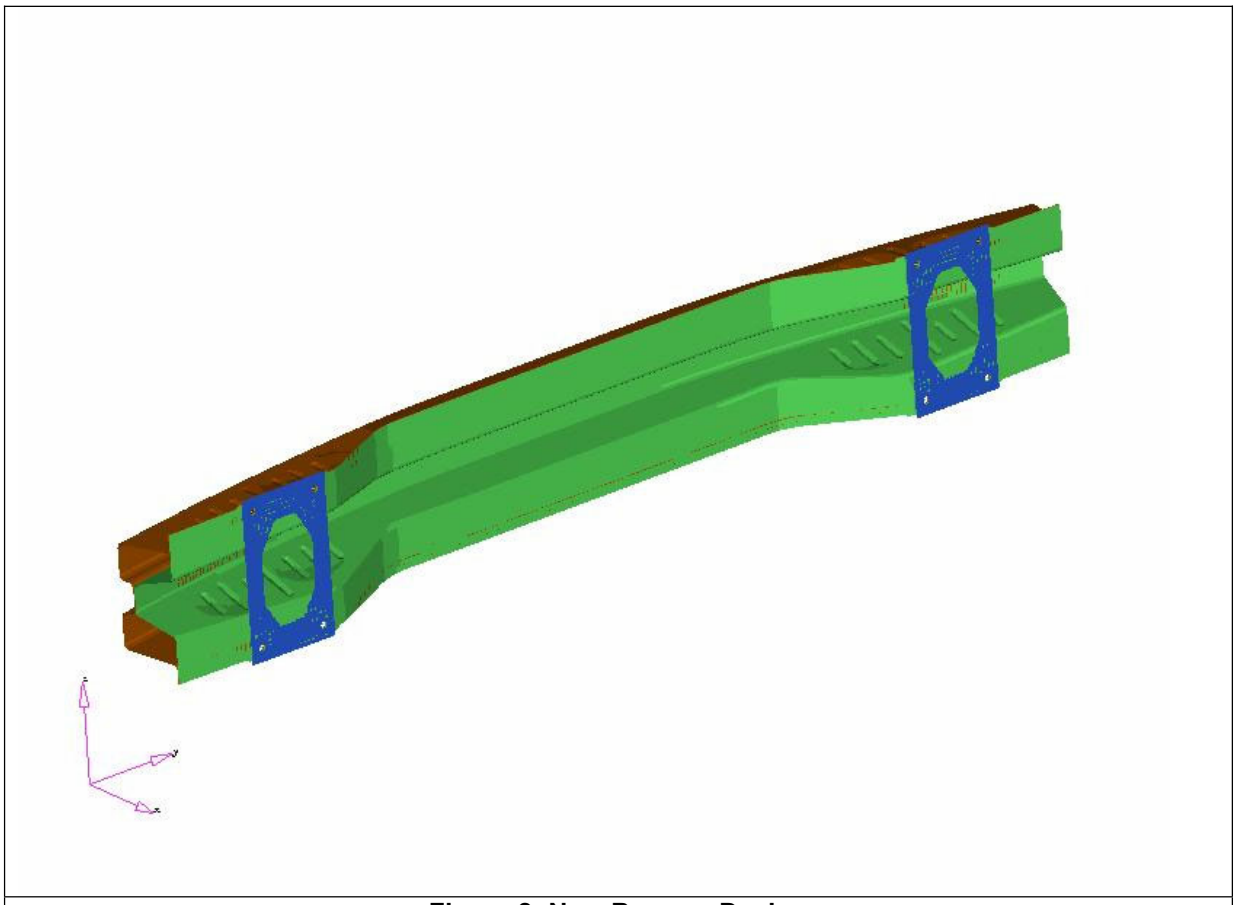


Figure 8: New Bumper Design

The bumper plates are attached to the front rails through an attachment plate (*Figure 23*). The plate is bolted to the bumper beam through four bolts (5/16” or 3/4”). The plate has a hole of the same shape as the rail front section, but of a smaller size. The plate is MIG welded to the front rails. The bumper centerline matches that of the rail (*Figure 22*). This ensures a proper load transfer from the bumper to the rails.

The bumper design passes the low-speed bumper requirements (7).

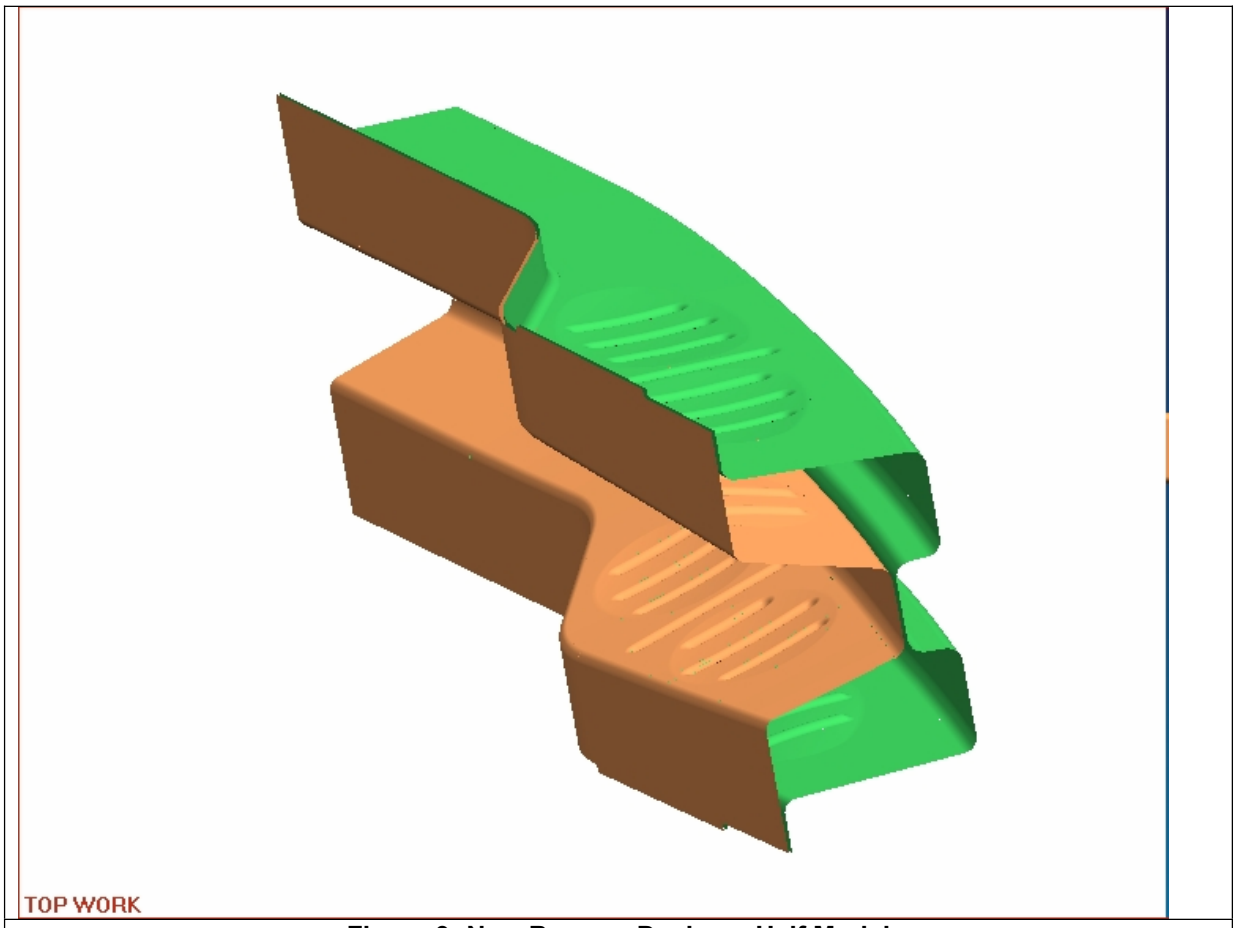


Figure 9: New Bumper Design – Half Model

A mass summary for rail and bumper parts is included in *Table 3*. A detailed part summary is included in *Appendix B: Summary of FE Model.*

Table 3: Mass Summary

Part	Mass (kg)	
	Baseline	Concept 2
LH Rail Assembly	16.5	10.3
RH Rail Assembly	16.2	10.3
Bumper Assembly (without foam)	6.6	6.6
Total	39.3	27.2
Mass Reduction	-	12.1

4. FE Model - Output Location Summary

The nodes at which the desired NCAP and IIHS outputs were obtained are listed in *Table 4*.

The intrusions are measured at the nodes as specified in *Reference 3*.

The acceleration and intrusion node locations are shown in *Figure 10* and *Figure 11* below.

Table 4: Summary of Output Locations

Parameter	Location	Node Number
Accelerations	B-Pillar / Rocker - LH	5000001
	B-Pillar / Rocker - RH	5000002
Intrusions	Origin	6000000
	Plane Y-axis	6000001
	Plane Z-axis	6000002
	Steering Column	7000001
	Brake Pedal	7000002
	Toepan - Left	7000003
	Toepan - Center	7000004
	Toepan - Right	7000005
	Left Front Seat Bolt	7000006
	Right Front Seat Bolt	7000007
	Left Rear Seat Bolt	7000008
	Right Rear Seat Bolt	7000009
	AB Closure - A Pillar	7000010
	AB Closure - B Pillar	7000011

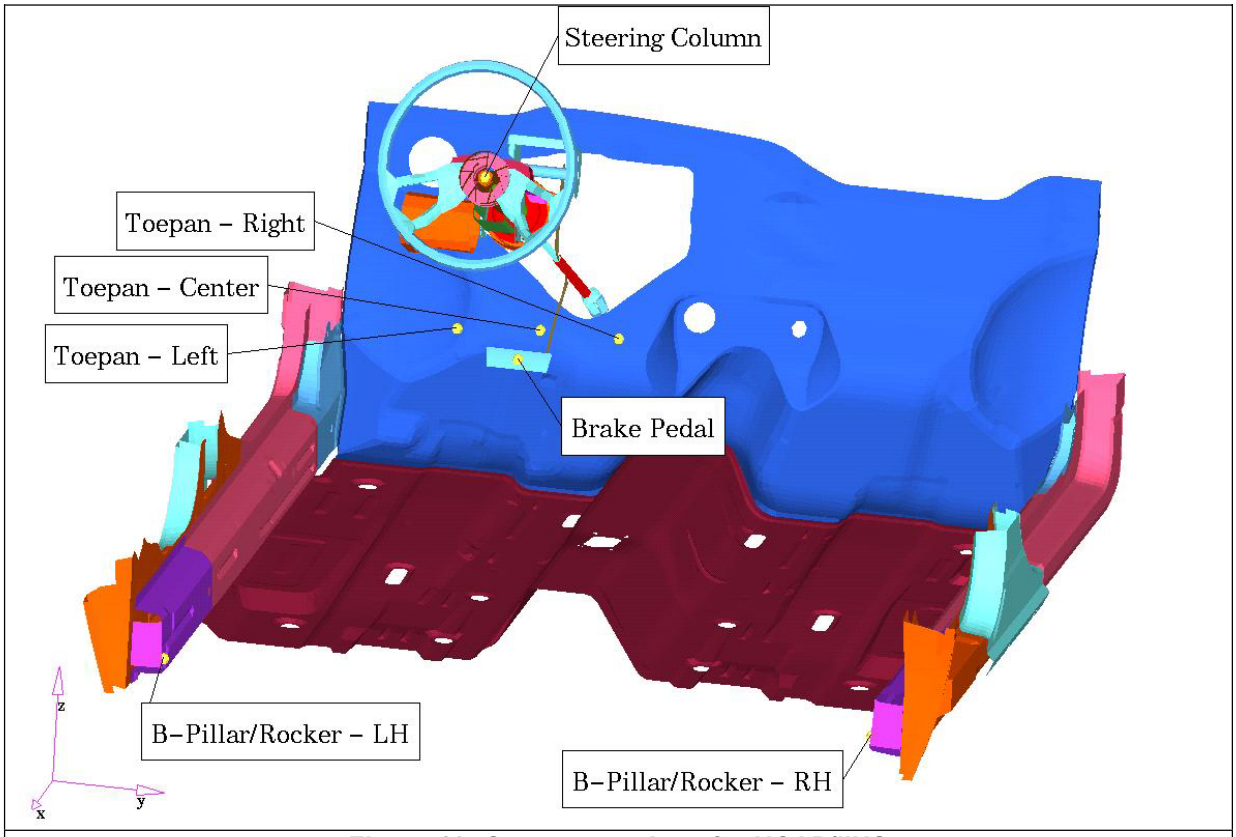


Figure 10: Output Locations for NCAP/IIHS



Figure 11: Output Locations for IIHS- AB Closure

5. NCAP Response

Figure 12 depict the NCAP response of Concept 3. Animation files are included in *Appendix A*.

The hydroformed design has a higher initial peak as compared to the baseline design (*Figure 12, Figure 13*). The velocity profiles have higher slope for the hydroformed design (*Figure 14, Figure 15*). This indicates a stiffer bumper and front rails. The maximum acceleration of the hydroformed design is less than that of the baseline design.

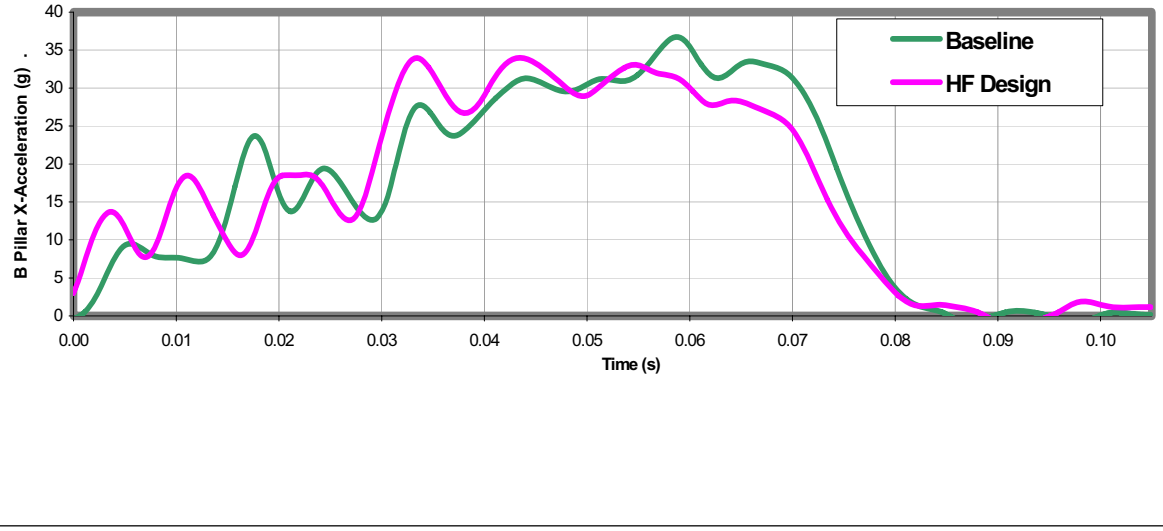


Figure 12: B Pillar Pulse – LH

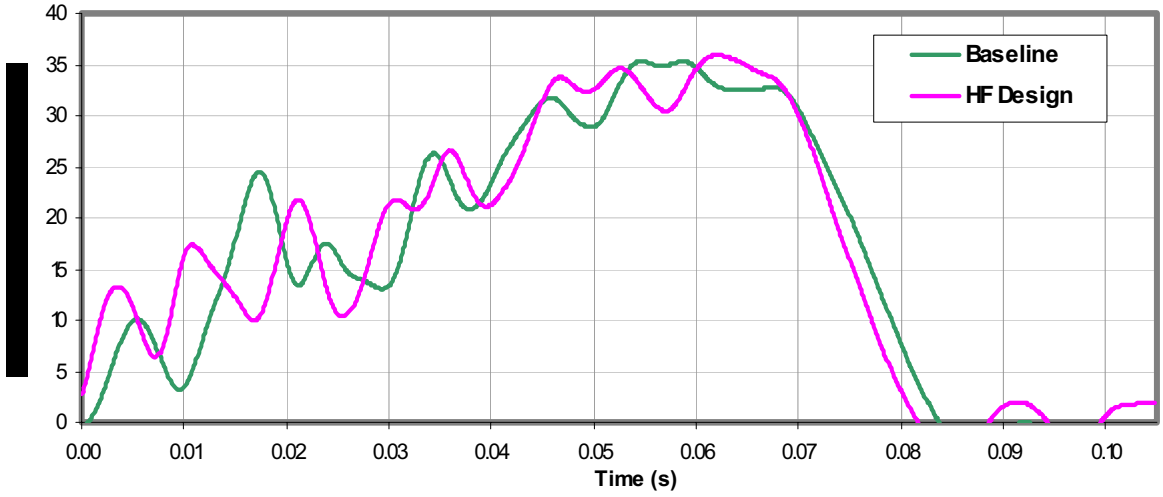


Figure 13: B Pillar Pulse – RH

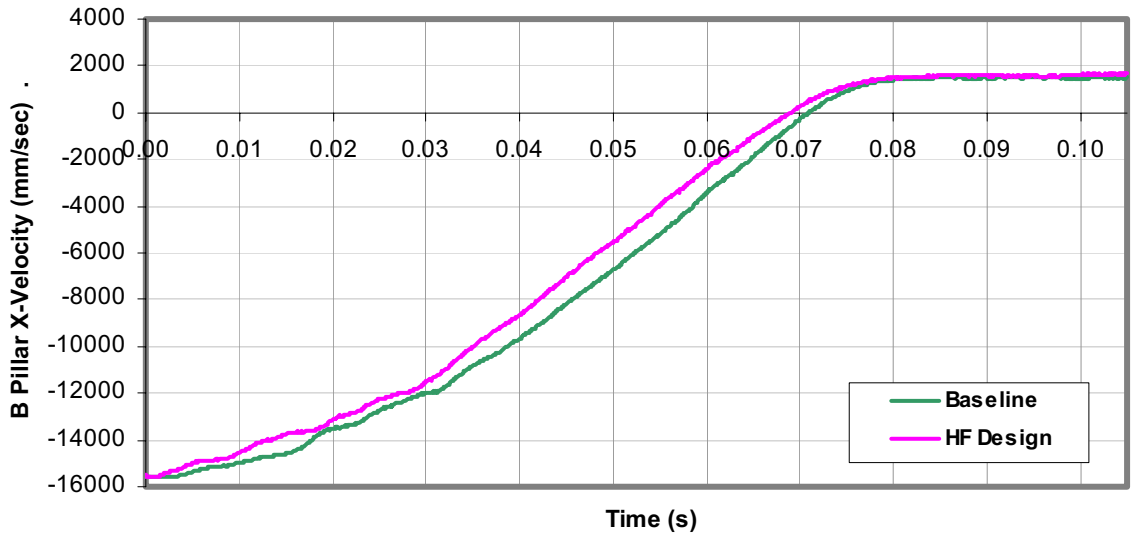


Figure 14: B Pillar Velocity - LH

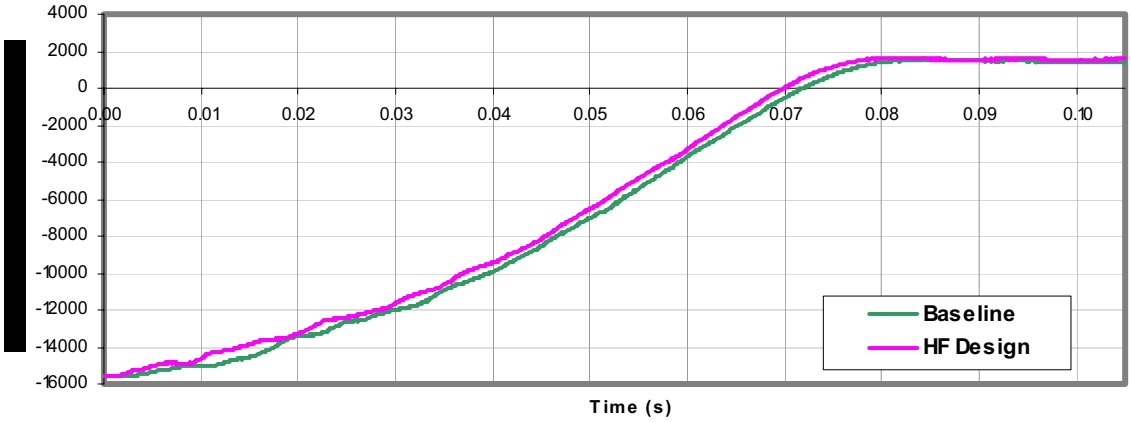


Figure 15: B-Pillar Velocity - RH

The hydroformed rails crush better than the baseline stamped rails (*Appendix A)*. However, there is still scope for improving crush by reducing buckling at critical cross-sections. Thus, the NCAP performance of the hydroformed design is better than that of the baseline design. *Table 5* summarizes the sequence of crash events in the baseline design.

Table 5: Baseline NCAP Crash Events

Time (ms)	Crash Events
0-15	Bumper absorbs energy
15-20	Engine hits the radiator, Cradle Extension Buckles, Cradle engaged
20-30	Cradle and LH rail buckling started
35-40	LH front wheel hits the LH rail
40-45	Engine hits to dash
45-50	RH front wheel hits the RH rail
55-60	LH wheel hits the front rigid wall
60-70	RH wheel hits the front rigid wall, LH wheel hits the rocker
70-75	RH wheel hits the rocker

6. IIHS Response

IIHS intrusions are summarized in *Table 2* and *Figure 16*. Animation files are included in *Appendix A*.

Toepan, brake pedal and A-B closure intrusions oscillate after 200ms about a mean value. Hence, the mean values should be used for comparison. However, the values reported in *Table 2* are at 250ms.

The brake pedal intrusions are unreliable as there is a pivot joint in the pedal attachment that results in random motion of the brake pedal.

Steering column movement does not reach any equilibrium. The IIHS simulation would have to be carried out for a longer duration in order to report stable meaningful values. The steering column model may also be deficient, resulting in an unstable movement.

Thus, only the toepan intrusions and A-B closure (*Figure 17* through *Figure 20*) have been used to compare the hydroformed design to the baseline design.

The toepan intrusions for the hydroformed design are similar to that of the baseline. The A-B closure is higher for the hydroformed design. This is also evident by the greater deformation seen in the cage area. However, the current hydroformed design has not yet been optimized for IIHS performance.

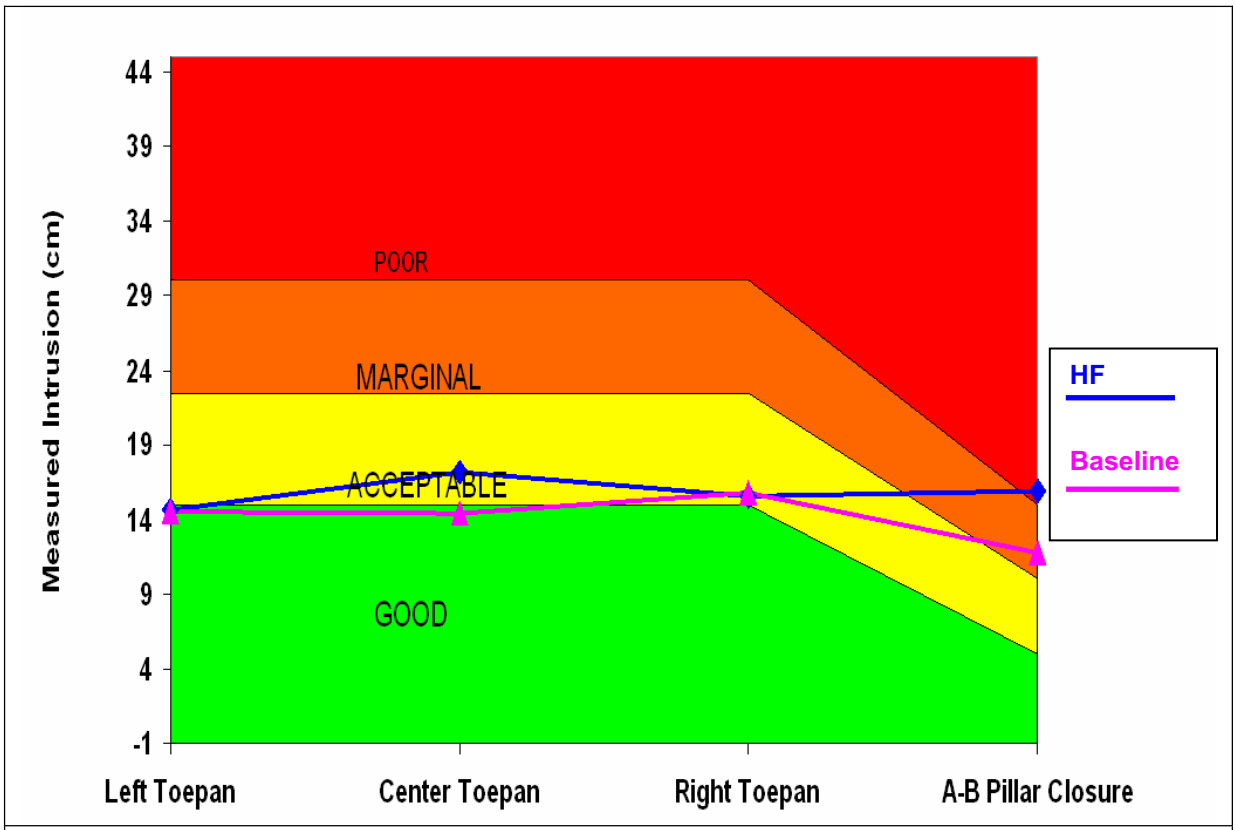


Figure 16: IIHS Intrusions

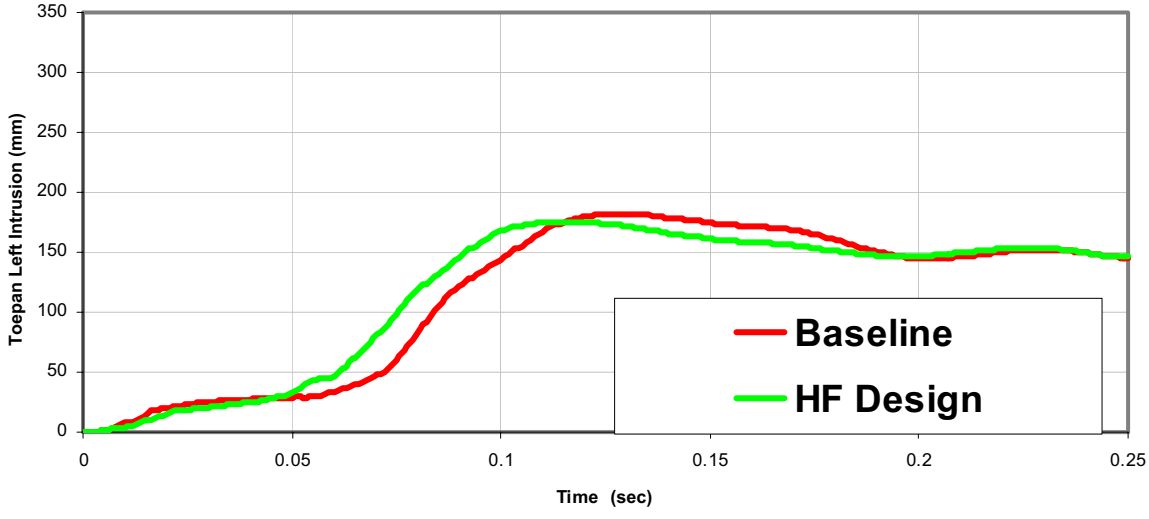


Figure 17: Left Toepan Intrusions

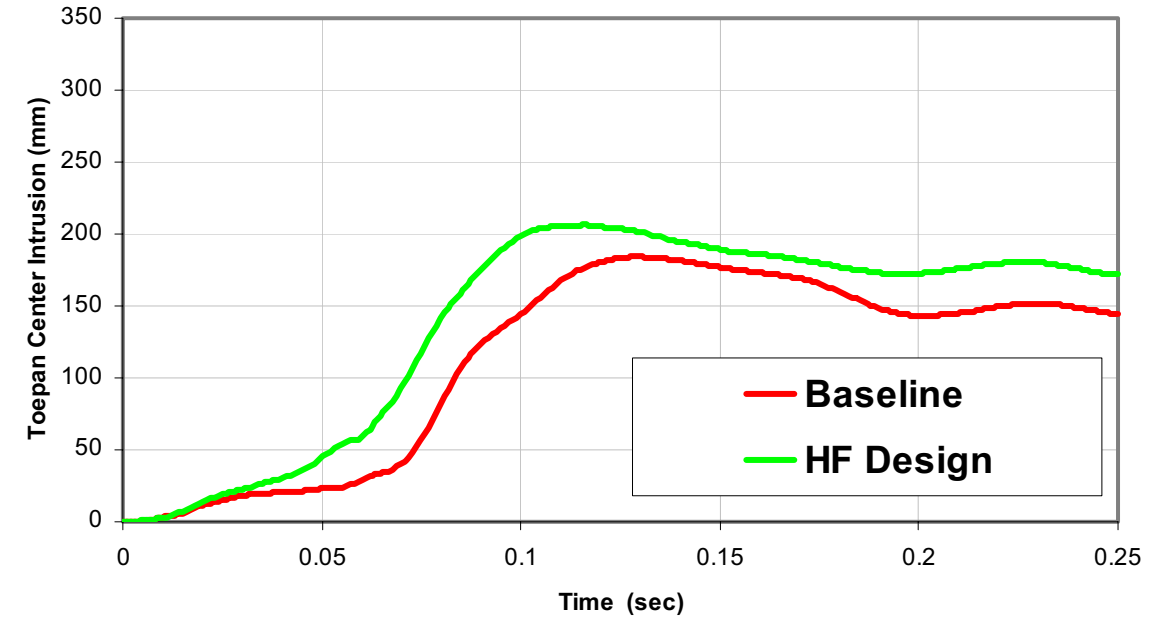


Figure 18: Center Toepan Intrusions

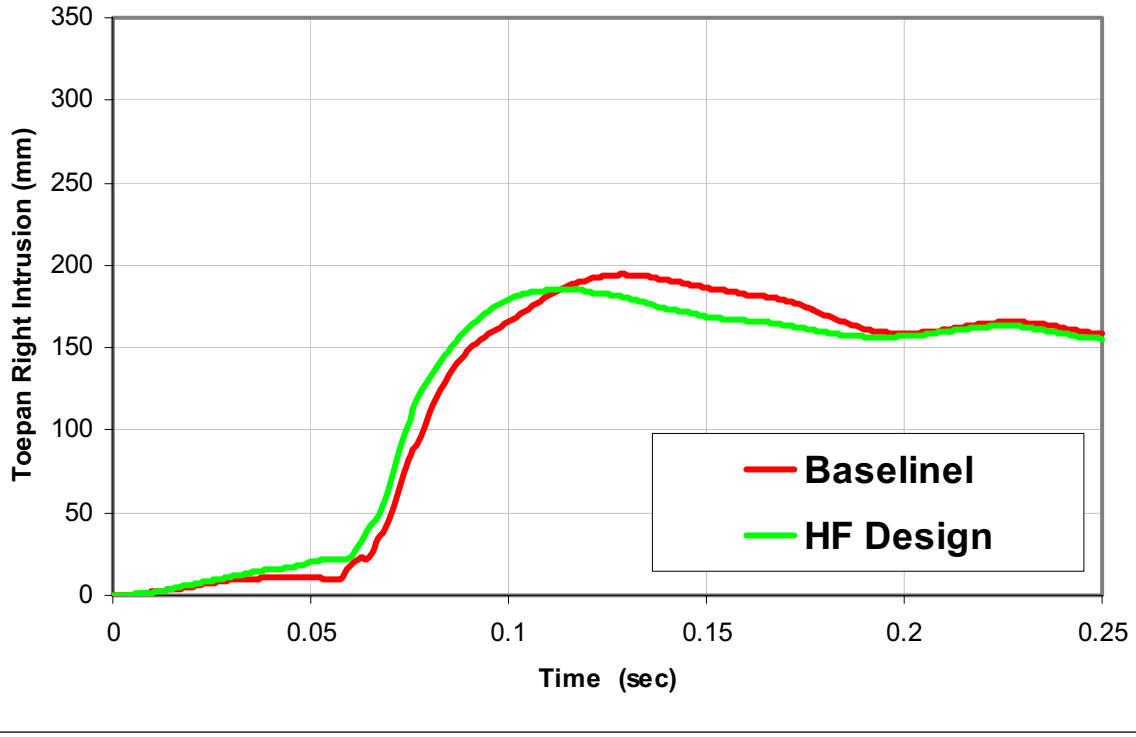


Figure 19: Right Toepan Intrusions

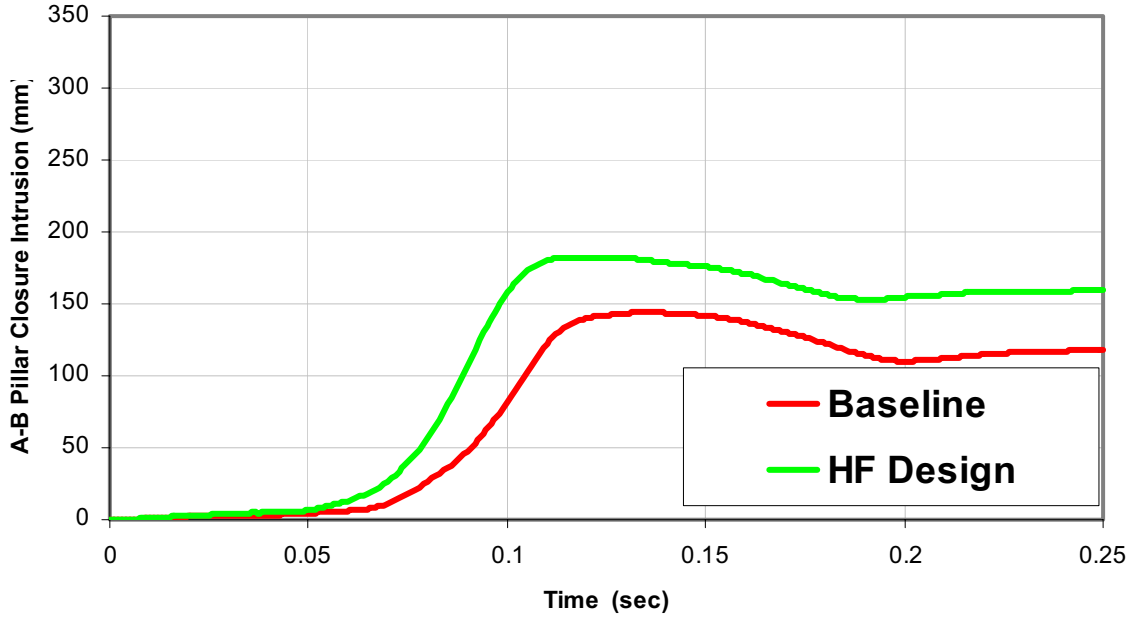


Figure 20: A-B Closure

7. Conclusions

The Concept 3 with a new hydroformed rail design and a stamped bumper design has been developed. The Concept 3 design achieves a mass reduction of **12.1kg (31%)** compared to the *Baseline* design. The *NCAP performance* is essentially the same as that of the baseline design. The *IIHS performance* is similar to that of the baseline design, except for A-B closure, which is higher than baseline. **I**mprovement in performance may be achieved by tuning the material grades and gauges for bumper and rails, based on a DOE study.

8. Future Work

A final design for Concept 3 will be obtained, based on a DOE study. The final Concept 3 design will be compared to Concepts 1 and 2 developed in Phase II of the Lightweight Front End Structure Project.

9. References

1) *Validated FE Models, Milestone 5*, SPHINX, Phase II.

2) *Enhanced FE Models, Milestone 6*, SPHINX, Phase II.

3) *IIHS Crashworthiness Evaluation Offset Barrier Crash Test Protocol (Version IX), October 2002.*

4) *DOE FE Models, Milestone 7*, SPHINX, Phase II.

5) *Third Bumper Design Report, Milestone 5*, SPHINX, Phase I.

6) *Concept 1: Preliminary Design, Milestone 10*, SPHINX, Phase II.

7) *FMVSS Part 581 Bumper Standard*.

8) *Automotive Steel Design Manual*, AISI, Revision 6 April 2000.

9) *Metal Forming Handbook*, Schuler.

10. Appendix A: Animations

The following animation files for the subsystem development can be viewed at the Auto/Steel Partnership website, www.a-sp.org.

You will need a Hyperview Player in order to view these animations at the site. You can download this free software at www.altair.com.

1. NCAP: Concept 3
2. IIHS: Concept 3
3. NCAP: Baseline
4. IIHS: Baseline

11. Appendix B: Summary of FE Model

Component Name	ID	Property Name	ID	Material Name	ID	MASS (ton)	Thickness (mm)
att_plate_mod_lh	60003	SectShll20.1.1	60150	DP700_980_phase_	60080	2.19E-04	2
att_plate_mod_rh	60004	SectShll20.1.1	60150	DP700_980_phase_	60080	2.19E-04	2
bumper_front	60005	bumper_front	60151	DP700_980_phase_	60080	0.003506	1
bumper_back	60006	bumper_back	60152	DP700_980_phase_	60080	0.002671	1
bumper_att_bolt_	60007	bumper_att_bolt_	60147	bumper_att_bolt_	60078	1.46E-05	0
hf_rail_lh_A	60101	rail_frt_out	60154	DP450_800_phase_	60079	8.73E-04	1.2
hf_rail_rh_A	60102	rail_frt_out	60154	DP450_800_phase_	60079	8.73E-04	1.2
hf_rail_lh_B	60105	rail_rr_otr	60156	DP450_800_phase_	60079	0.002916	1.5
hf_rail_rh_B	60106	rail_rr_otr	60156	DP450_800_phase_	60079	0.002916	1.5
hf_rail_lh_C	60109	rail_ext_frt	60158	DP450_800_phase_	60079	0.002276	1.8
hf_rail_rh_C	60110	rail_ext_frt	60158	DP450_800_phase_	60079	0.002276	1.8
hf_rail_lh_D	60111	rail_ext_mid	60159	DP450_800_phase_	60079	0.002171	1.5
hf_rail_rh_D	60112	rail_ext_mid	60159	DP450_800_phase_	60079	0.002171	1.5
hf_rail_lh_E	60113	rail_ext_rr	60160	DP450_800_phase_	60079	0.002048	1.2
hf_rail_rh_E	60114	rail_ext_rr	60160	DP450_800_phase_	60079	0.002048	1.2
trqbox1.l	60117	Sectshll14.5	60111	MATL24_210	60052	0.001434	1.45
trqbox1.r	60118	Sectshll14.5	60111	MATL24_210	60052	0.001625	1.45
trqbox2.l	60119	Sectshll14.5	60111	MATL24_160	60048	2.35E-04	1.45
trqbox2.r	60120	Sectshll14.5	60111	MATL24_160	60048	2.35E-04	1.45
crfmbrkt.l	60201	SectShll20.1	60088	MATL24_340	60049	5.34E-04	2
crfmbrkt.r	60202	SectShll20.1	60088	MATL24_340	60049	5.38E-04	2
crdlfbrkt	60203	SectShll30	60094	MATL24_600	60056	8.68E-04	3
crdl.l	60205	SectShll26	60116	MATL24_340	60049	0.006018	2.6
crdl.r	60206	SectShll26	60116	MATL24_340	60049	0.006321	2.6
rrcrdlbdattch.l	60207	SectShll35	60106	MATL24_160	60048	0.001148	3.5
rrcrdlbdattch.r	60208	SectShll35	60106	MATL24_160	60048	0.001147	3.5
trnfext.l	60209	SectShll20.1	60088	MATL24_250	60054	0.001243	2
trnfext.r	60210	SectShll20.1	60088	MATL24_250	60054	0.001222	2
rrcrdlmnt1.l	60211	SectShll25	60091	MATL24_210	60052	0.001136	2.5
rrcrdlmnt1.r	60212	SectShll25	60091	MATL24_210	60052	0.001136	2.5
rrcrdlmnt2.l	60213	SectShll19.1	60112	MATL24_210	60052	2.37E-04	1.9
rrcrdlmnt2.r	60214	SectShll19.1	60112	MATL24_210	60052	2.37E-04	1.9
frtcrdlmnt1.l	60215	Sectshll19.5	60110	MATL24_160	60048	4.66E-04	1.95
frtcrdlmnt1.r	60216	Sectshll19.5	60110	MATL24_160	60048	4.66E-04	1.95
frtcrdlmnt2.l	60217	Sectshll14.5	60111	MATL24_210	60052	1.02E-04	1.45
frtcrdlmnt2.r	60218	Sectshll14.5	60111	MATL24_210	60052	1.02E-04	1.45
frtcrdlmnt5	60219	SectShll15.3	60117	MATL24_160	60048	4.31E-04	1.5
frtcrdlmnt3.l	60221	SectShll25	60091	MATL24_340	60049	4.30E-04	2.5
frtcrdlmnt3.r	60222	SectShll25	60091	MATL24_340	60049	3.41E-04	2.5
bot_bkt_l_e	60223	SectShll30	60094	MATL24_340	60049	9.59E-04	3
bot_bkt_r_e	60224	SectShll30	60094	MATL24_340	60049	9.29E-04	3
cradbrkt	60225	SectShll30	60094	MATL24_340	60049	4.46E-04	3
cradbrkt2	60227	SectShll30	60094	MATL24_340	60049	3.58E-04	3
lcarnf.l	60229	SectShll30	60094	MATL24_340	60049	3.19E-04	3

lcarnf.r	60230	SectShll30	60094	MATL24_340	60049	3.41E-04	3
lcajnt_1.L1	60231	SectShll30	60094	rigid	60014	4.12E-05	3
lcajnt_1.R1	60232	SectShll30	60094	rigid	60014	4.12E-05	3
lcacyl.l	60235	SectShll50	60092	MATL24_160	60048	0.001295	5
lcacyl.r	60236	SectShll50	60092	MATL24_160	60048	0.001295	5
lcajnt_1.L2	60239	SectShll30	60094	rigid	60014	3.16E-05	3
lcajnt_1.R2	60240	SectShll30	60094	rigid	60014	3.16E-05	3
cradbrkt1	60241	SectShll10.1	60083	MATL24_180	60046	2.36E-04	1
crdlblt	60243	SectShll20.1	60088	MATL24_160	60048	2.41E-04	2
crdlrrxupr	60244	SectShll25	60091	MATL24_340	60049	0.002183	2.5
crdlrrxlwr	60245	SectShll23	60090	MATL24_340	60049	0.00129	2.3
crdmtfrt_otb.l	60246	crd_frt_mt_otr	60161	MATL24_160	60048	6.02E-04	1.95
crdmtfrt_otb.r	60247	crd_frt_mt_otr	60161	MATL24_160	60048	6.02E-04	1.95
urail_l	60301	SectShll8.3	60081	MATL24_160	60048	0.001457	0.8
urail_r	60302	SectShll8.3	60081	MATL24_160	60048	0.001456	0.8
urail_rnf2.l	60303	SectShll9.1	60082	MATL24_160	60048	4.72E-04	0.9
urail_rnf1.r	60304	SectShll9.1	60082	MATL24_160	60048	4.71E-04	0.9
pnlfrt1.l	60305	Sectshll75	60097	MATL24_210	60052	8.60E-04	0.75
pnlfrt1.r	60306	Sectshll75	60097	MATL24_210	60052	8.60E-04	0.75
shock.l	60307	Sectshll17.5	60096	MATL24_160	60048	0.001517	1.75
shock.r	60308	Sectshll17.5	60096	MATL24_160	60048	0.001546	1.75
pnlfrt2.l	60309	SectShll12.1	60084	MATL24_210	60052	0.001561	1.2
pnlfrt2.r	60310	SectShll12.1	60084	MATL24_210	60052	0.001561	1.2
plnmbrkt	60311	SectShll8.3	60081	MATL24_210	60052	1.50E-04	0.8
rnfpnldshext2	60312	SectShll8.3	60081	MATL24_210	60052	1.93E-04	0.8
temp	60313	SectShll7.2	60080	MATL24_600	60056	2.63E-04	0.7
frtflr	60401	SectShll085	60118	MATL24_160	60048	0.013015	0.85
bar1	60402	SectShll20.1	60088	MATL24_3404	60051	0.00262	2
tnl1	60403	SectShll18.1	60087	MATL24_340	60049	0.001311	1.8
tnl2	60404	SectShll12.1	60084	MATL24_250	60054	0.006463	1.2
dash	60405	SectShll95	60113	MATL24_160	60048	0.008026	0.95
cowlupr	60406	SectShll8.3	60081	MATL24_210	60052	0.001526	0.8
fflrlvrrnf	60407	SectShll15.3	60117	MATL24_160	60048	7.10E-04	1.5
pedal2	60408	SectShll30	60094	MATL24_160	60048	0.001364	3
wndshld.supt.upr	60409	Sectshll75	60097	MATL24_160	60048	0.002599	0.75
plnmltintjnt	60410	Sectshll75	60097	MATL24_160	60048	0.004045	0.75
rein_upr	60411	SectShll15.3	60117	MATL24_210	60052	9.29E-04	1.5
MTG1	60412	SectShll10.1	60083	MATL24_210	60052	4.34E-04	1
BRKT_Consol	60413	SectShll15.3	60117	MATL24_210	60052	6.89E-04	1.5
crush_brkt_lwr	60414	SectShll20.1	60088	MATL24_210	60052	0.002868	2
bar2.l	60501	SectShll12.1	60084	MATL24_160	60048	0.001367	1.2
bar2.r	60502	SectShll12.1	60084	MATL24_160	60048	0.001368	1.2
2barreinf	60503	SectShll17	60086	MATL24_340	60049	0.00249	1.7
22678921_256_1	60505	SectShll12.1	60084	MATL24_160	60048	2.43E-04	1.2
22678920_256_1	60506	SectShll12.1	60084	MATL24_160	60048	2.43E-04	1.2
22678921_255_1	60507	SectShll12.1	60084	MATL24_160	60048	1.85E-04	1.2
22678920_255_1	60508	SectShll12.1	60084	MATL24_160	60048	1.85E-04	1.2
seatrein.l	60509	SectShll12.1	60084	MATL24_160	60048	3.45E-04	1.2
seatrein.r	60510	SectShll12.1	60084	MATL24_160	60048	3.46E-04	1.2

tiebar3.l	60601	Sectshll75	60097	MATL24_180	60046	6.78E-04	0.75
tiebar3.r	60602	Sectshll75	60097	MATL24_180	60046	7.20E-04	0.75
tiebar4.l	60603	Sectshll75	60097	MATL24_180	60046	3.84E-05	0.75
tiebar4.r	60604	Sectshll75	60097	MATL24_180	60046	3.84E-05	0.75
lhfanmotor	60605	SectShll20.1	60088	MATL24_181	60047	5.60E-04	2
rhfanmotor	60606	SectShll20.1	60088	MATL24_181	60047	5.40E-04	2
tiebar	60607	SectShll9.1	60082	MATL24_210	60052	0.002278	0.9
tiebar2	60608	SectShll9.1	60082	MATL24_160	60048	0.001163	0.9
radsupport	60609	SectShll10.1	60083	MATL24_160	60048	0.001261	1
rad4	60610	SectShll10.1	60083	MATL24_160	60048	8.32E-06	1
Part_2	60611	SectShll10.1	60083	MATL9_2	60006	0.014989	1
rad2	60612	SectSld900	60121	MAT57rad&cond	60059	0.002656	0
rad1	60613	SectSld900	60121	MAT57rad&cond	60059	0.003782	0
fanshroud	60614	SectShll20.1	60088	MATL24_181	60047	0.007298	2
egine_main_block	60701	SectShll10.1	60083	rigid	60014	0.3042	1
pt2	60702	SectShll10.1	60083	rigid	60014	0.001123	1
pt3	60703	SectShll10.1	60083	rigid	60014	0.006404	1
pt7	60704	SectShll10.1	60083	rigid	60014	0.001243	1
pt8	60705	SectShll20.1	60088	rigid	60014	0.005065	2
pt10	60706	SectShll10.1	60083	rigid	60014	9.92E-04	1
pt11	60707	SectShll225	60099	rigid	60014	0.001335	2.25
pt13	60708	SectShll10.1	60083	rigid	60014	1.07E-04	1
pt14	60709	SectShll10.1	60083	rigid	60014	0.001639	1
pt19	60710	SectShll10.1	60083	rigid	60014	4.08E-04	1
pt18	60711	SectShll40	60093	rigid	60014	0.007253	4
frtmnt1	60712	SectShll20.1	60088	MATL24_160	60048	1.04E-03	2
frtmnt2	60713	SectShll225	60099	MATL24_160	60048	3.84E-04	2.25
pt9	60714	SectShll100	60104	rigid	60014	0.005277	10
pt12	60715	SectShll80	60095	rigid	60014	0.007011	8
pt16	60716	SectShll40	60093	rigid	60014	0.003234	4
pt17	60717	SectShll30	60094	MATL24_160	60048	0.007696	3
expipefrt	60718	SectShll15.3	60117	MATL24_160	60048	0.003601	1.5
ep_7685	60719	SectShll10.1	60083	rigid	60014	2.83E-04	1
flywheel	60720	SectShll10.1	60083	rigid	60014	7.92E-04	1
ep_4776	60721	SectShll10.1	60083	rigid	60014	4.99E-04	1
ep_7498	60722	SectShll10.1	60083	rigid	60014	0.002605	1
ep_0939	60723	SectShll10.1	60083	rigid	60014	5.79E-04	1
ep_0017	60724	SectShll10.1	60083	rigid	60014	4.50E-04	1
ep_70842	60725	SectShll10.1	60083	rigid	60014	1.84E-04	1
eng_mnt_l_e	60726	SectShll80	60095	MATL24_160	60048	0.002636	8
top_bkt_l_e	60727	SectShll80	60095	MAT24_1111	60045	5.72E-04	8
eng_mnt_r_e	60728	SectShll80	60095	MATL24_160	60048	0.002631	8
top_bkt_r_e	60729	SectShll80	60095	MAT24_1111	60045	1.01E-03	8
eng_deformable	60730	SectShll80	60095	MATL24_160	60048	0.001725	8
62109a_e1	60731	SectShll37	60108	MATL24_160	60048	3.62E-04	3.7
62109a_e2	60732	SectShll37	60108	MATL24_160	60048	1.22E-04	3.7
62109a_e3	60733	SectShll37	60108	MATL24_160	60048	4.00E-04	3.7
62109b_e1	60734	SectShll10.1	60083	MATL24_160	60048	4.06E-04	1
rrmnt_bushing	60735	SectShll20.1	60088	MATL24_160	60048	5.79E-04	2

tire1.l	60801	SectShll20.1	60088	mat1.tirerubber	60007	0.00197	2
tire1.r	60802	SectShll20.1	60088	mat1.tirerubber	60007	0.00197	2
tire3.l	60803	SectShll3.3	60107	MATL24_160	60048	1.00E-03	0.3
tire2.r	60804	SectShll3.3	60107	MATL24_160	60048	1.00E-03	0.3
tir2.l	60805	SectShll7.2	60080	MATL24_160	60048	0.002042	0.7
tire3.r	60806	SectShll7.2	60080	MATL24_160	60048	0.002042	0.7
rim.l	60807	SectShll35	60106	MATL24_600	60056	0.008136	3.5
rim.r	60808	SectShll35	60106	MATL24_600	60056	0.008136	3.5
lwrcntrlarm.l	60809	SectShll30	60094	MATL24_160	60048	0.002294	3
lwrcntrlarm.r	60810	SectShll30	60094	MATL24_160	60048	0.002289	3
lcajnt_2.L1	60811	SectShll30	60094	rigid	60014	6.26E-05	3
lcajnt_2.R1	60812	SectShll30	60094	rigid	60014	6.33E-05	3
driveline	60813	SectShll70	60103	MATL24_340	60049	0.005373	7
lcajnt_2.L2	60815	SectShll30	60094	rigid	60014	2.76E-05	3
lcajnt_2.R2	60816	SectShll30	60094	rigid	60014	2.76E-05	3
fsuspstrut.l	60817	SectShll50	60092	MATL24_160	60048	0.005601	5
fsuspstrut.r	60818	SectShll50	60092	MATL24_160	60048	0.005601	5
crdlbltrnf	60819	SectShll275.1	60102	MATL24_160	60048	3.23E-04	2.75
strclnmend3	60820	SectShll50	60092	rigid	60014	3.64E-04	5
strngrack	60821	SectShll60	60101	MAT24_1111	60045	0.002617	6
strrackends	60822	SectShll60	60101	MATL24_160	60048	0.001165	6
stabbar	60823	SectShll40	60093	MATL24_160	60048	0.004576	4
btray1	60901	SectShll15.3	60117	MATL24_160	60048	0.003147	1.5
btray2	60902	SectShll10.1	60083	MATL24_160	60048	2.14E-04	1
battery1	60903	SectShll5.3	60105	MATL24_160	60048	8.66E-04	0.5
ECM	60904	SectShll10.1	60083	MATL24_160	60048	1.07E-03	1
battery_fill	60905	SectShll10.1	60083	MATL24_160	60048	0.001326	1
fcomptrnf2	60906	SectShll40	60093	MATL24_160	60048	0.002901	4
abs_brkt	60907	SectShll20.1	60088	MATL24_160	60048	4.33E-04	2
brkt_boost	60908	90060072	60042	90060009	60012	0.00385	3
edge	61001	SectShll2.1.1	60077	MAT24_3	60042	1.06E-03	1.35
inner	61002	SectShll3.2.1	60078	MAT24_3	60042	0.005147	0.7
outer	61003	SectShll4.1.1	60079	MAT24_3	60042	0.008252	0.7
MODPLT	61101	90060005	60010	90060020	60041	0.001613	1.5
CSUPT_forw	61102	90060006	60011	90060020	60041	5.32E-04	1.22
can	61103	90060008	60012	90060020	60041	6.77E-04	1.2
can1	61104	90060009	60013	90060020	60041	9.87E-05	1.2
can2	61105	90060010	60014	90060020	60041	1.09E-04	1.2
can.1	61106	90060011	60015	90060020	60041	9.05E-05	1.2
inflator	61107	90060012	60016	90060020	60041	0.001456	5.4
Brkt-1	61108	90060063	60039	90060020	60041	6.07E-04	3
gaspdel	61109	90060068	60040	90060020	60041	1.65E-04	2.5
stelpeice	61110	90060071	60041	90060020	60041	1.54E-04	3
SIPO_p	61111	90060014	60018	90060020	60041	6.06E-04	2
SIPO_d2	61112	90060015	60019	90060020	60041	6.11E-04	2
Steel_strip	61113	90060016	60020	90060020	60041	1.07E-04	1.5
Floor_Brkt2	61114	90060037	60022	90060020	60041	8.95E-04	2.5
Center_Stk_brkt	61115	90060038	60023	90060020	60041	3.09E-04	1.5
lower	61116	90060044	60026	90060013	60036	8.85E-04	2.43

upper	61117	90060045	60027	90060013	60036	8.69E-04	2.36
hvacbrkt_add	61118	90060046	60028	90060013	60036	2.49E-05	2.36
heatercvr	61119	90060047	60029	90060013	60036	3.21E-04	2.38
ai	61120	90060048	60030	90060013	60036	3.74E-04	2.1
ai_icebox	61121	90060049	60031	90060013	60036	1.51E-05	2.1
ai_actuator	61122	90060050	60032	90060013	60036	2.81E-05	2
lower_actuator	61123	90060051	60033	90060013	60036	2.86E-05	2
foamplate	61124	90060052	60034	90060020	60041	5.74E-05	1
filmvalve	61125	90060053	60035	90060013	60036	1.67E-04	2
arm1_srib	61126	90060054	60036	90060013	60036	8.90E-05	2
rib_4_hub	61127	90060055	60037	90060013	60036	1.42E-04	3.5
Lower_add1	61128	90060056	60038	90060013	60036	1.16E-05	2
foam	61129	90060125	60119	90060001	60001	1.48E-06	0
evapblock	61130	90060126	60120	90060003	60003	3.52E-05	0
IBEC	61131	90060013	60017	90060005	60004	3.04E-04	2
evap_lower_tube1	61132	90060041	60024	90060002	60002	8.68E-06	1
evap_upper_tube1	61133	90060041	60024	90060002	60002	1.38E-05	1
heat_upper_tube1	61134	90060041	60024	90060002	60002	4.22E-05	1
heat_lower_tube1	61135	90060041	60024	90060002	60002	2.58E-05	1
il	61136	90060042	60025	90060014	60037	1.89E-04	1
IP_sidepnl_E	61137	90060026	60021	90060015	60038	1.24E-04	2.5
sipo_fixed1	61138	90060015	60019	90060008	60011	1.39E-06	2
sipo_fixed2	61139	90060015	60019	90060008	60011	1.46E-06	2
sipo_fixed3	61140	90060015	60019	90060008	60011	1.53E-06	2
sipo_fixed4	61141	90060015	60019	90060008	60011	1.13E-06	2
sipo_fixed5	61142	90060015	60019	90060008	60011	1.85E-06	2
sipo_fixed6	61143	90060015	60019	90060008	60011	1.95E-06	2
sipo_fixed7	61144	90060015	60019	90060008	60011	1.83E-06	2
sipo_p_fixed7	61145	90060014	60018	90060008	60011	1.41E-06	2
sipo_p_fixed6	61146	90060014	60018	90060008	60011	1.59E-06	2
sipo_p_fixed5	61147	90060014	60018	90060008	60011	1.71E-06	2
sipo_p_fixed4	61148	90060014	60018	90060008	60011	1.13E-06	2
sipo_p_fixed3	61149	90060014	60018	90060008	60011	1.85E-06	2
sipo_p_fixed2	61150	90060014	60018	90060008	60011	1.95E-06	2
sipo_p_fixed12	61151	90060014	60018	90060008	60011	1.83E-06	2
modplate_rigid1	61152	90060005	60010	90060008	60011	1.55E-06	1.5
modplate_rigid2	61153	90060005	60010	90060008	60011	2.34E-06	1.5
modplate_rigid32	61154	90060005	60010	90060008	60011	1.45E-06	1.5
modplate_rigid4	61155	90060005	60010	90060008	60011	1.65E-06	1.5
modplate_rigid5	61156	90060005	60010	90060008	60011	1.58E-06	1.5
modplate_rigid6	61157	90060005	60010	90060008	60011	1.98E-06	1.5
modplate_rigid7	61158	90060005	60010	90060008	60011	9.84E-07	1.5
modplate_rigid8	61159	90060005	60010	90060008	60011	1.76E-06	1.5
e.pedal	61160	90060073	60043	90060011	60034	8.37E-04	8
e.pad	61164	90060074	60044	90060011	60034	1.20E-04	3.5
e.pin	61165	90060075	60045	90060011	60034	1.14E-04	2
pedalpivout	61167	90060072	60042	90060009	60012	8.58E-06	3
pedalpivinb	61168	90060072	60042	90060009	60012	8.58E-06	3
pedallink	61169	90060072	60042	90060009	60012	1.43E-06	3

pivot inb	61170	90060072	60042	90060009	60012	4.32E-06	3
pivot out	61171	90060072	60042	90060009	60012	1.10E-06	3
Part221130	61172	90060072	60042	90060009	60012	1.08E-06	3
Part221131	61173	90060072	60042	90060009	60012	1.39E-06	3
Part221132	61174	90060072	60042	90060009	60012	9.68E-07	3
Part221133	61175	90060072	60042	90060009	60012	9.79E-07	3
Part221134	61176	90060072	60042	90060009	60012	6.86E-07	3
Part221135	61177	90060072	60042	90060009	60012	1.30E-06	3
Part221136	61178	90060072	60042	90060009	60012	9.62E-07	3
dr_ealf	61179	90060077	60047	90060011	60034	2.25E-04	1.5
dr_eart	61180	90060077	60047	90060020	60041	2.25E-04	1.5
ps_eart	61181	90060076	60046	90060020	60041	1.64E-04	1.5
ps_eart.1	61182	90060076	60046	90060020	60041	1.64E-04	1.5
floor_attachment	61183	90060078	60048	90060020	60041	5.18E-04	2
tunlbkt_fixdeles	61184	90060078	60048	90060010	60013	1.18E-06	2
tunlbkt_fixdeles	61185	90060078	60048	90060010	60013	1.27E-06	2
tunlbkt_fixdeles	61186	90060078	60048	90060010	60013	2.33E-06	2
tunlbkt_fixdeles	61187	90060078	60048	90060010	60013	1.83E-06	2
tunlbkt_fixdeles	61188	90060078	60048	90060010	60013	4.47E-06	2
tunlbkt_fixdeles	61189	90060078	60048	90060010	60013	7.59E-06	2
tunlbkt_fixdeles	61190	90060078	60048	90060010	60013	2.76E-06	2
tunlbkt_fixdeles	61191	90060078	60048	90060010	60013	3.89E-06	2
gboxframe_base	61192	90060080	60049	90060016	60039	3.92E-04	2.5
vribs_gboxframe	61193	90060081	60050	90060016	60039	4.81E-06	1
hribs_gboxframe	61194	90060082	60051	90060016	60039	2.76E-05	1.2
Mag_6.5.1.1	61196	90060100	60052	90060012	60035	3.18E-04	6.5
Mag_3.0.1.1	61197	90060101	60053	90060012	60035	0.00345	3
Mag_4.0.1.1	61198	90060102	60054	90060012	60035	4.81E-04	4
Mag_ribs.1.1	61199	90060103	60055	90060012	60035	0.002748	3
Mag_1.5.1.1	61200	90060104	60056	90060012	60035	1.28E-04	1.5
Mag_5.0.1	61201	90060105	60057	90060012	60035	1.40E-04	5
Mag_2.5	61202	90060106	60058	90060012	60035	2.65E-04	2.5
inner.1	61203	90060107	60059	90060016	60039	3.58E-04	3
innergroorve	61204	90060111	60063	90060016	60039	8.37E-07	3.3
ribs.1	61205	90060112	60064	90060016	60039	1.36E-04	1.25
bin o	61206	90060108	60060	90060017	60040	2.74E-04	2.5
ribbin	61207	90060110	60062	90060017	60040	5.71E-07	1.7
bintongue	61208	90060109	60061	90060017	60040	4.40E-07	1.1
outer.1	61209	90060113	60065	90060016	60039	2.85E-04	2.5
hub	61210	90060115	60067	90060016	60039	1.76E-06	1
outerhrib	61211	90060114	60066	90060016	60039	7.18E-06	1.2
outervrib	61212	90060115	60067	90060016	60039	3.35E-07	1
hubrib	61213	90060116	60068	90060016	60039	1.93E-07	1.375
glvbx_frm_hinge_	61214	90060117	60069	90060016	60039	8.29E-06	3
knee bolster inn	61215	90060118	60070	90060016	60039	2.66E-04	2.5
inner rib h	61216	90060119	60071	90060016	60039	1.25E-04	1.875
small rib inner	61217	90060120	60072	90060016	60039	3.27E-06	2.6
knee bolster out	61218	90060121	60073	90060016	60039	4.25E-04	2.5
doghouse outer	61219	90060122	60074	90060016	60039	6.40E-06	1.4

outer rib	61220	90060123	60075	90060016	60039	4.29E-06	1.1
tipof bin	61221	90060124	60076	90060016	60039	5.01E-05	2.5
part.9	61301	SectShll20.1	60088	MAT9_704	60009	1.21E-04	2
part.10	61302	SectShll20.1	60088	MAT9_705	60010	5.21E-05	2
part.11	61303	SectShll5.3	60105	MAT20_706	60015	5.98E-05	0.5
part.14	61304	SectShll20.1	60088	MAT20_750	60016	0.001699	2
part.15	61305	SectShll10.1	60083	MAT20_751	60017	8.05E-05	1
part.16	61306	SectShll34	60115	MAT20_752	60018	1.83E-04	3.4
part.17	61307	SectShll25	60091	MAT20_753	60019	5.23E-04	2.5
part.18	61308	SectShll25	60091	MAT20_754	60020	6.50E-04	2.5
part.19	61309	SectShll20.1	60088	MAT20_755	60021	5.14E-04	2
part.20	61310	SectShll30	60094	MAT20_756	60022	4.70E-04	3
part.21	61311	SectShll34	60115	MAT20_757	60023	2.55E-04	3.4
part.22	61312	SectShll20.1	60088	MAT20_758	60024	5.61E-05	2
part.24	61313	SectShll20.1	60088	MAT20_760	60025	1.14E-04	2
part.25	61314	SectShll20.1	60088	MAT20_761	60026	8.86E-05	2
part.28	61315	SectShll20.1	60088	MAT20_764	60027	2.43E-05	2
part.29	61316	SectShll20.1	60088	MAT20_765	60028	2.32E-05	2
part.30	61317	SectShll40	60093	MAT20_766	60029	3.95E-06	4
part.31	61318	SectShll40	60093	MAT20_767	60030	3.95E-06	4
part.34	61319	SectShll40	60093	MAT24_771	60044	2.43E-05	4
part.40	61320	SectShll30	60094	MAT20_777	60031	3.28E-04	3
part.41	61321	SectShll30	60094	MAT20_778	60032	3.69E-04	3
strclnmend4	61323	SectShll50	60092	rigid	60014	2.10E-04	5
part.49	61324	SectShll15.3	60117	MAT20_20015	60033	9.89E-06	1.5
drinrpnl.l	61401	Sectshll75	60097	MATL24_160	60048	0.003637	0.75
drlwrhng.l	61402	SectShll50	60092	MATL24_160	60048	1.28E-04	5
drotrpnl.l	61403	Sectshll75	60097	MATL24_180	60046	0.004388	0.75
z-brkt.l	61404	SectShll10.1	60083	MATL24_160	60048	5.56E-05	1
upr_frame.l	61405	SectShll10.1	60083	MATL24_160	60048	0.001997	1
drbeam.l	61406	SectShll20.1	60088	MATL24_600	60056	0.001914	2
druprhng.l	61407	SectShll50	60092	MATL24_160	60048	1.30E-04	5
drinrpnl.r	61408	Sectshll75	60097	MATL24_160	60048	0.003636	0.75
drotrpnl.r	61409	Sectshll75	60097	MATL24_180	60046	0.004388	0.75
z-brkt.r	61410	SectShll10.1	60083	MATL24_160	60048	5.56E-05	1
upr_frame.r	61411	SectShll10.1	60083	MATL24_160	60048	0.001997	1
drbeam.r	61412	SectShll20.1	60088	MATL24_600	60056	0.001913	2
druphng.r	61413	SectShll50	60092	MATL24_160	60048	1.34E-04	5
drlwhng.r	61414	SectShll50	60092	MATL24_160	60048	1.26E-04	5
fdrbdhng	61415	SectShll50	60092	MATL24_210	60052	2.07E-04	5
fdrbdhng2	61416	SectShll20.1	60088	rigid	60014	1.96E-05	2
fdrbdhng3	61417	SectShll20.1	60088	rigid	60014	2.43E-05	2
fdrbdhng4	61418	SectShll50	60092	MATL24_210	60052	2.01E-04	5
fdrbdhng5	61419	SectShll20.1	60088	rigid	60014	2.07E-05	2
fdrbdhng6	61420	SectShll20.1	60088	rigid	60014	2.54E-05	2
fdrbdhng7	61421	SectShll50	60092	MATL24_210	60052	2.55E-04	5
fdrbdhng8	61422	SectShll20.1	60088	rigid	60014	2.01E-05	2
fdrbdhng9	61423	SectShll20.1	60088	rigid	60014	2.48E-05	2
fdrbdhng10	61424	SectShll50	60092	MATL24_210	60052	1.97E-04	5

fdrbdhng11	61425	SectShll20.1	60088	rigid	60014	2.07E-05	2
fdrbdhng12	61426	SectShll20.1	60088	rigid	60014	2.49E-05	2
drlsrwld.l	61427	SectShll18.1	60087	MATL24_160	60048	0.003567	1.8
drlsrwld.r	61428	SectShll18.1	60087	MATL24_160	60048	0.003567	1.8
rrdrinn.l	61429	Sectshll75	60097	MATL24_160	60048	0.006811	0.75
twdrrdrinr.l	61430	SectShll18.1	60087	MATL24_160	60048	0.005454	1.8
rrdrotr.l	61431	Sectshll75	60097	MATL24_160	60048	0.008021	0.75
rrdrfrm.l	61432	SectShll10.1	60083	MATL24_160	60048	0.003331	1
rrdrbm.l	61433	SectShll20.1	60088	MATL24_600	60056	0.002513	2
bathtub.l	61434	SectShll20.1	60088	MATL24_160	60048	2.59E-04	2
rrdrhng.l	61435	SectShll50	60092	MATL24_160	60048	1.06E-03	5
latchjt.l	61436	SectShll20.1	60088	MATL24_160	60048	2.28E-04	2
rrdrhng1.l	61437	SectShll50	60092	MATL24_160	60048	6.20E-04	5
roof	61501	Sectshll75	60097	MATL24_160	60048	0.010108	0.75
wshield	61502	SectShll48	60100	laminatedglass	60058	0.015411	4.8
rr_wndshld	61503	SectShll48	60100	laminatedglass	60058	0.011652	4.8
bdysdpnlotr.l	61601	Sectshll75	60097	MATL24_160	60048	0.014307	0.75
bdysdpnlotr.r	61602	Sectshll75	60097	MATL24_160	60048	0.014308	0.75
twldbsideinr.l	61603	SectShll21	60089	MATL24_160	60048	0.00905	2.1
twldbsideinr.r	61604	SectShll21	60089	MATL24_160	60048	0.009056	2.1
rkrx_l	61605	Sectshll13	60098	MATL24_340	60049	1.01E-03	1.3
rkrx_r	61606	Sectshll13	60098	MATL24_340	60049	1.01E-03	1.3
rkrinr.l	61607	sectshll16	60114	MATL24_3404	60051	0.003811	1.6
rkrinr.r	61608	sectshll16	60114	MATL24_3404	60051	0.003811	1.6
twldB-plr.l	61609	SectShll18.1	60087	MATL24_250	60054	0.003041	1.8
twldB-plr.r	61610	SectShll18.1	60087	MATL24_250	60054	0.003041	1.8
bdysdpnlinr.l	61611	SectShll10.1	60083	MATL24_160	60048	0.009621	1
bdysdpnlinr.r	61612	SectShll10.1	60083	MATL24_160	60048	0.009567	1
B_plr_rnf	61613	SectShll10.1	60083	MATL24_160	60048	6.01E-04	1
bplrrnf.l	61615	SectShll225	60099	MATL24_250	60054	0.003029	2.25
bplrrnf.r	61616	SectShll225	60099	MATL24_250	60054	0.003029	2.25
rfrailrnfl	61617	SectShll20.1	60088	MATL24_210	60052	0.002007	2
rfrailrnfr	61618	SectShll20.1	60088	MATL24_210	60052	0.002007	2
frt_hrn	61619	SectShll20.1	60088	MATL24_160	60048	7.90E-04	2
rfrailinr.r	61620	SectShll20.1	60088	MATL24_160	60048	7.85E-04	2
a_pilar_rnf_l	61621	SectShll10.1	60083	MATL24_160	60048	9.04E-04	1
a_pilar_rnf_r	61622	SectShll10.1	60083	MATL24_160	60048	9.05E-04	1
fbhplrrnf1.l	61623	SectShll10.1	60083	MATL24_210	60052	0.001632	1
fbhplrrnf1.r	61624	SectShll10.1	60083	MATL24_210	60052	0.001634	1
frthdr	61625	SectShll7.2	60080	MATL24_160	60048	9.30E-04	0.7
rfbow2	61626	SectShll9.1	60082	MATL24_340	60049	9.23E-04	0.9
rearflr	61627	SectShll8.3	60081	MATL24_160	60048	0.017539	0.8
bar3	61628	SectShll10.1	60083	MATL24_211	60053	0.002442	1
bar4ctr	61629	SectShll10.1	60083	MATL24_340	60049	0.001438	1
bar4lft	61630	SectShll15.3	60117	MATL24_160	60048	0.001168	1.5
rrrail.l	61631	SectShll15.3	60117	MATL24_251	60055	0.005535	1.5
rrrailrnf1.l	61632	SectShll10.1	60083	MATL24_160	60048	1.93E-04	1
rrailrnf2.l	61633	SectShll10.1	60083	MATL24_160	60048	2.10E-04	1
gusset.l	61634	SectShll15.3	60117	MATL24_160	60048	7.13E-04	1.5

gusset2.l	61635	SectShll15.3	60117	MATL24_160	60048	8.44E-04	1.5
gusset3.l	61636	SectShll15.3	60117	MATL24_160	60048	5.19E-04	1.5
gusset4.l	61637	SectShll15.3	60117	MATL24_160	60048	5.89E-04	1.5
whlhsinr.l	61638	SectShll10.1	60083	MATL24_160	60048	0.002906	1
4barrnf1.l	61639	SectShll20.1	60088	MATL24_160	60048	0.001399	2
4barrnf2.l	61640	SectShll25	60091	MATL24_160	60048	7.24E-04	2.5
backpanel	61641	SectShll8.3	60081	MATL24_160	60048	0.005311	0.8
bpnlrnf	61642	Sectshll75	60097	MATL24_160	60048	0.001933	0.75
rrhdr	61643	SectShll9.1	60082	MATL24_160	60048	0.001131	0.9
rrsuspshk.l	61644	SectShll225	60099	MATL24_160	60048	3.05E-04	2.25
rkrblkhds	61645	SectShll12.1	60084	MATL24_340	60049	7.54E-04	1.2
rdeck	61646	SectShll10.1	60083	MATL24_160	60048	0.005446	1
trnkgtrfrt	61647	SectShll10.1	60083	MATL24_160	60048	0.00209	1
rdeckbrkt1	61648	SectShll10.1	60083	MATL24_160	60048	9.01E-04	1
rdeckbrkt2	61649	SectShll10.1	60083	MATL24_160	60048	2.49E-04	1
trnkgtr.l	61650	SectShll9.1	60082	MATL24_160	60048	3.97E-04	0.9
rdeckbrkt3.l	61651	SectShll10.1	60083	MATL24_160	60048	8.76E-04	1
rdeckbrkt4.l	61652	SectShll10.1	60083	MATL24_160	60048	7.67E-04	1
trlrhtchbrkt	61653	SectShll10.1	60083	MATL24_160	60048	0.001306	1
rrailext.l	61654	SectShll15.3	60117	MATL24_160	60048	7.55E-04	1.5
bar4rt	61655	SectShll15.3	60117	MATL24_160	60048	0.001168	1.5
rrrail.r	61656	SectShll15.3	60117	MATL24_251	60055	0.005519	1.5
rrailrnf1.r	61657	SectShll10.1	60083	MATL24_160	60048	1.93E-04	1
rrailrnf2.r	61658	SectShll10.1	60083	MATL24_160	60048	2.10E-04	1
gusset.r	61659	SectShll15.3	60117	MATL24_160	60048	7.13E-04	1.5
gusset2.r	61660	SectShll15.3	60117	MATL24_160	60048	8.44E-04	1.5
gusset3.r	61661	SectShll15.3	60117	MATL24_160	60048	5.19E-04	1.5
gusset4.r	61662	SectShll15.3	60117	MATL24_160	60048	5.87E-04	1.5
whlhsinr.r	61663	SectShll10.1	60083	MATL24_160	60048	0.003046	1
4barrnf1.r	61664	SectShll20.1	60088	MATL24_160	60048	0.001459	2
4barrnf2.r	61665	SectShll25	60091	MATL24_160	60048	6.97E-04	2.5
rrsuspshk.r	61666	SectShll225	60099	MATL24_160	60048	3.05E-04	2.25
trnkgtr.r	61667	SectShll9.1	60082	MATL24_160	60048	4.00E-04	0.9
rdeckbrkt3.r	61668	SectShll10.1	60083	MATL24_160	60048	8.73E-04	1
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rrailext.r	61670	SectShll15.3	60117	MATL24_160	60048	7.48E-04	1.5
fbhpbulkhd.l	61671	SectShll20.1	60088	MATL24_340	60049	5.83E-04	2
rkrblkhds.1	61672	SectShll12.1	60084	MATL24_340	60049	2.83E-04	1.2
accl.r	61673	SectShll10.1	60083	rigid	60014	4.29E-05	1
accl.l	61674	SectShll10.1	60083	rigid	60014	4.56E-05	1
rr_hrn	61675	SectShll14.1	60085	MATL24_160	60048	9.12E-04	1.4
fbhp_brkt	61676	SectShll20.1	60088	MATL24_210	60052	1.84E-04	2
rkr_extn	61677	Sectshll75	60097	MATL24_600	60056	0.001526	0.75
muffler	61701	SectShll5.3	60105	MATL24_160	60048	0.00133	0.5
exhstpipe	61702	SectShll5.3	60105	MATL24_160	60048	0.00201	0.5
rtire.l	61801	SectShll10.1	60083	MATL24_160	60048	0.007576	1
rtire.r	61802	SectShll10.1	60083	MATL24_160	60048	0.007576	1
rearrim	61803	SectShll35	60106	MATL24_160	60048	0.015933	3.5
rbmpbmbrkt.l	61901	SectShll15.3	60117	MATL24_160	60048	4.35E-04	1.5

rbmpbmbrkt.r	61902	SectShll15.3	60117	MATL24_160	60048	4.35E-04	1.5
rbumpbeam	61903	SectShll10.1	60083	MATL24_160	60048	0.003708	1
part.42	62001	SectDisc779	60123	MATSpr1_779	60063	0	0
part.43	62002	SectDisc780	60124	MATDmp2_780	60064	0	0
part.44	62003	SectDisc781	60125	MATSpr4_781	60069	0	0
part.47	62004	SectDisc783	60126	MATDmp2_784	60065	0	0
part.12	62005	SectBeam707	60009	MAT24_707	60043	7.70E-04	0
bar1fsusp	62006	Sectbeam10500	60002	MATBEAM	60057	0.001903	0
bar2fsusp	62007	Sectbeam10501	60003	MATBEAM	60057	4.12E-05	0
bar3fsusp	62008	Sectbeam10500	60002	MATBEAM	60057	1.41E-04	0
BARDLINE	62009	Sectbeam10504	60004	MATBEAM	60057	7.06E-05	0
bar4fsusp	62010	Sectbeam10500	60002	MATBEAM	60057	9.48E-04	0
bar2dline	62011	Sectbeam10500	60002	MATBEAM	60057	0.001306	0
bar3dline	62012	Sectbeam10504	60004	MATBEAM	60057	1.16E-04	0
bar5dline	62013	Sectbeam10509	60005	MATBEAM	60057	8.50E-05	0
bar1rrsus	62014	Sectbeam10500	60002	MATBEAM	60057	0.007365	0
bar2rrsusp	62015	Sectbeam10516	60006	MATBEAM	60057	0.019679	0
bar3rrsusp	62016	Sectbeam10516	60006	MATBEAM	60057	0.0026	0
bar4rrsusp	62017	Sectbeam10516	60006	MATBEAM	60057	0.002841	0
bardummies	62018	Sectbeam10519	60007	MATBEAM	60057	0.003373	0
barseat	62019	Sectbeam10519	60007	MATBEAM	60057	3.34E-04	0
barradiator	62020	Sectbeam10522	60008	MATBEAM	60057	1.82E-04	0
bardriveline	62021	Sectbeam10504	60004	MATBEAM	60057	2.57E-04	0
bardriveline8	62022	Sectbeam10504	60004	MATBEAM	60057	7.05E-05	0
sprdrvline	62023	SectDisc1	60122	Matsprstr14	60066	0	0
sprengmnt3	62024	SectDisc1	60122	Matsprstr113	60067	0	0
sprdummy	62025	SectDisc1	60122	Matsprstr114	60068	0	0
spr2dummy	62026	SectDisc1	60122	Matsprstr116	60062	0	0
spr3dummy	62027	SectDisc1	60122	Matsprstr116	60062	0	0
ltmount_spring	62028	SectDisc20071.1	60127	MATSpr4_61112	60070	0	0
rt_mount_spring	62029	SectDisc20071.1	60127	MATSpr4_61113	60071	0	0
rr_cdl_atch_spri	62030	SectDisc20071.1	60127	MATSpr4_61116	60073	0	0
rr_cdl_atch_spri	62031	SectDisc20071.1	60127	MATSpr4_61115	60072	0	0
hinge_beam_65dia	62032	90060004	60001	90060006	60005	1.06E-04	0
Masses	62033	N/A	N/A		0	0.002085	N/A
ElemMass	62034	N/A	N/A		0	0.633762	N/A
ncap_driver_pass	62035	N/A	N/A		0	0.156	N/A
SpotWelds	62039	N/A	N/A		0	0	N/A
Rigids.5	62040	N/A	N/A		0	0	N/A
Joints	62042	N/A	N/A		0	0	N/A
2T_Welds	62043	N/A	N/A	2T_Welds	60075	0	N/A
out_front_lh_doo	62047	N/A	N/A		0	1.42E-04	N/A
out_ip_masses_2	62050	N/A	N/A		0	0.001933	N/A
out_hood_masses_	62054	N/A	N/A		0	9.59E-05	N/A
out_roof_masses_	62056	N/A	N/A		0	8.76E-05	N/A
out_windshield_m	62058	N/A	N/A		0	1.92E-06	N/A
out_rear_lh_door	62060	N/A	N/A		0	1.96E-04	N/A
new_weld	124214	N/A	N/A		0	0	N/A
out_front_rh_doo	62064	N/A	N/A		0	1.53E-04	N/A

out_rear_rh_door	62066	N/A	N/A		0	1.90E-04	N/A
new_rgds	124215	N/A	N/A		0	0	N/A
rgd_should_not_b	124216	N/A	N/A	MAT20_751	60017	0	N/A
wleds_should_not	124217	N/A	N/A	MAT20_751	60017	0	N/A

Total Components	**488**
Model Mass	**1.763 tonnes**

- Model mass is from LS-DYNA3D d3hsp file.
- Part mass summary is from HYPERMESH.

12. Appendix C: Attached Parts

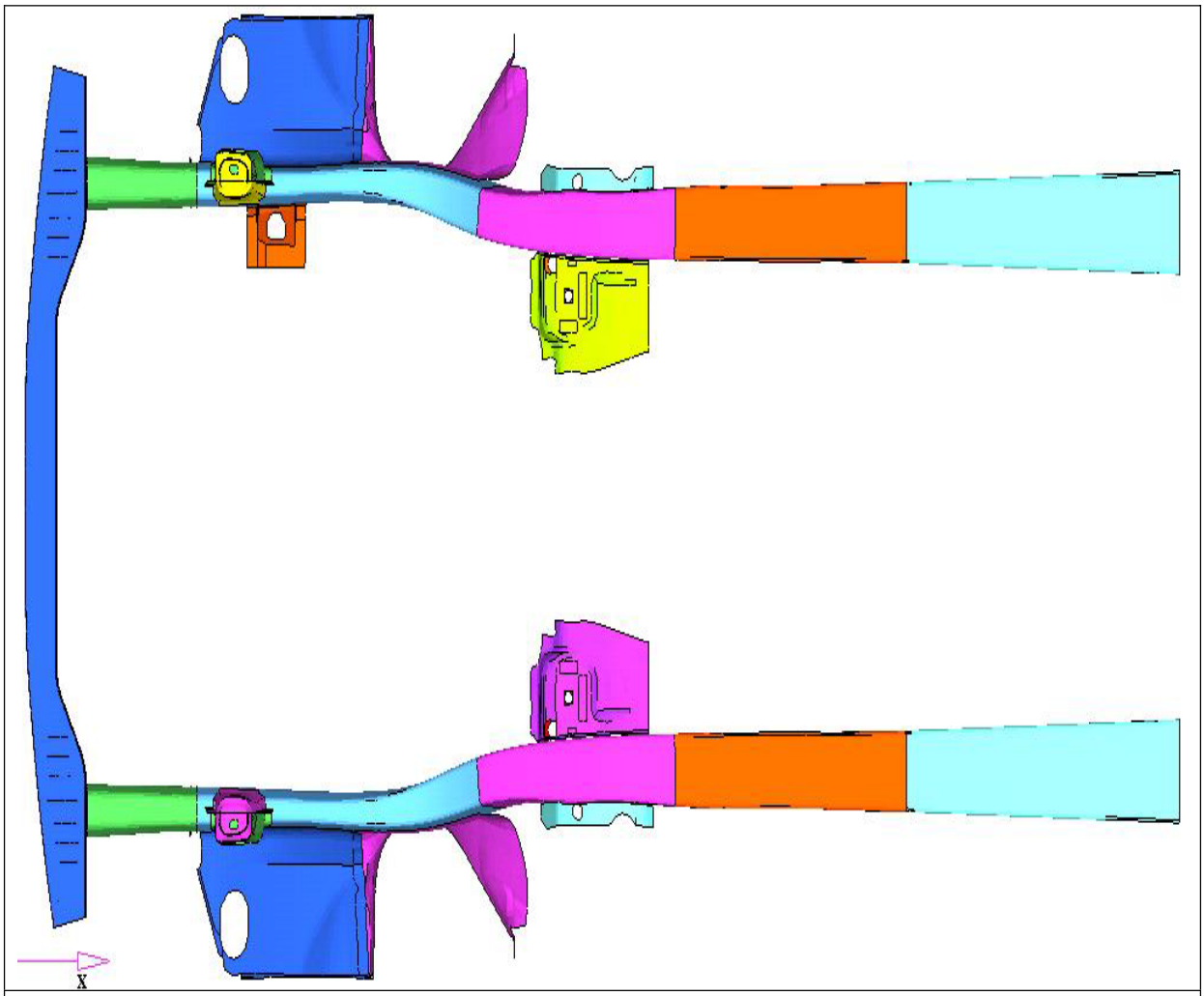


Figure 21: Attached Parts – Top View

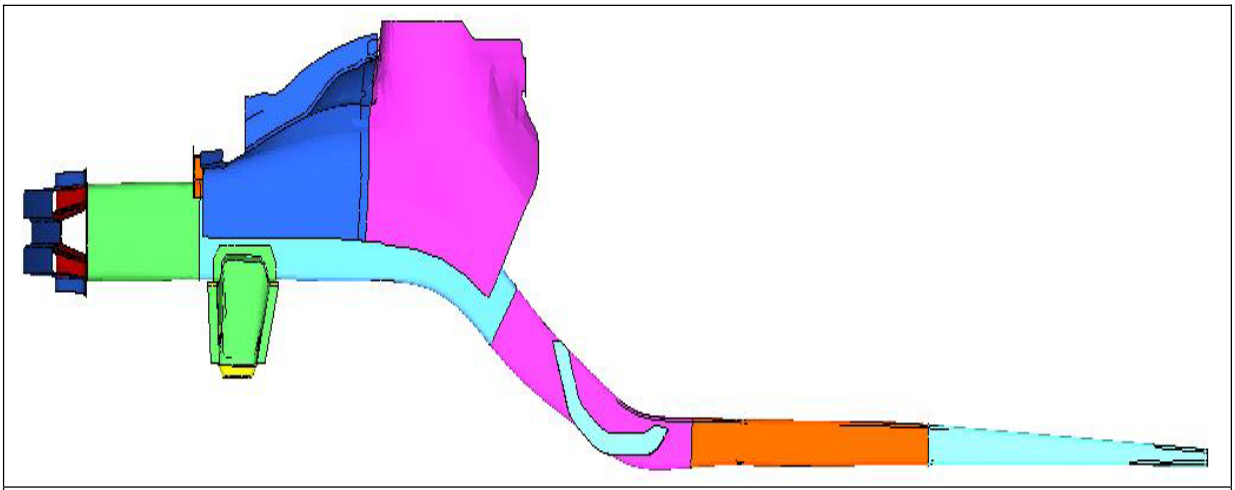


Figure 22: Attached Parts – Side View

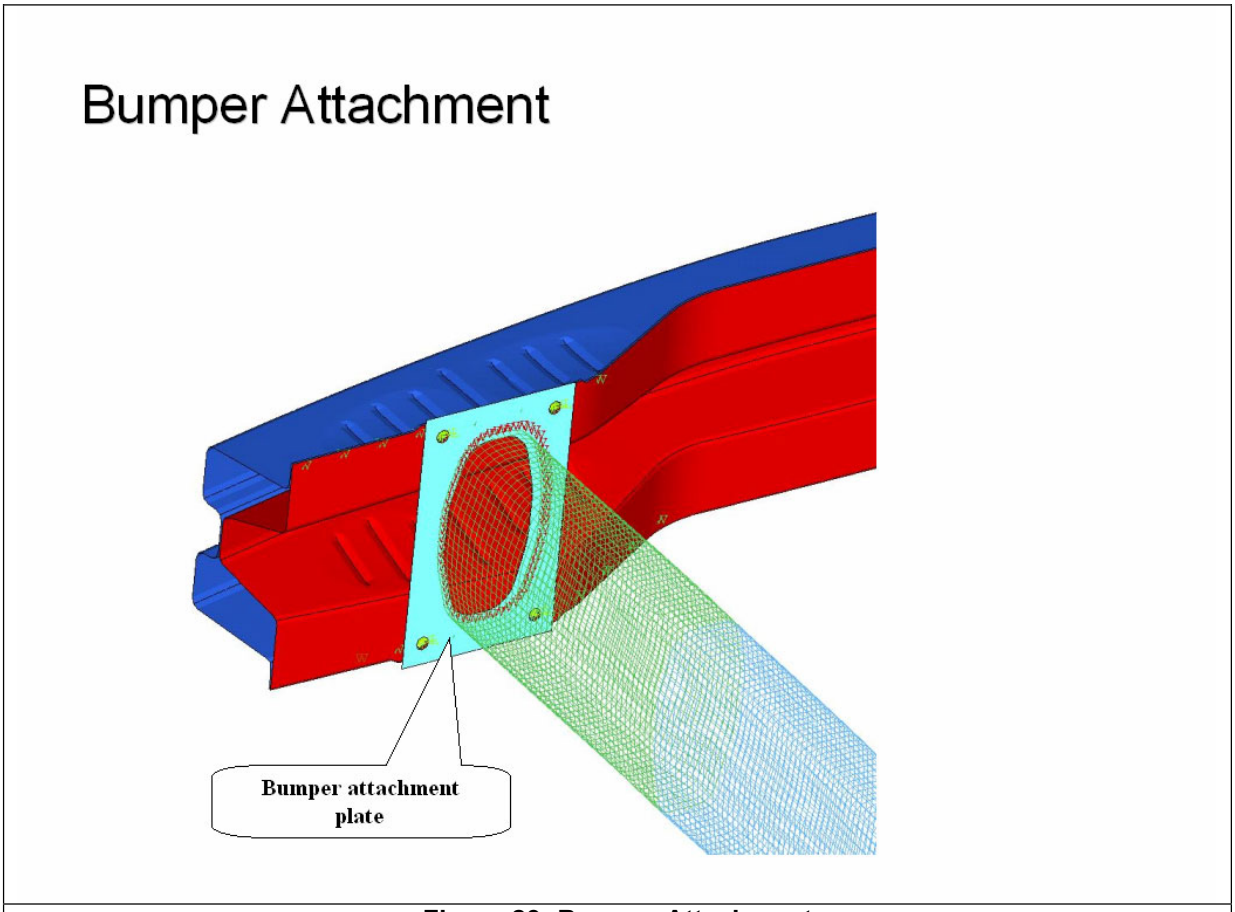


Figure 23: Bumper Attachment

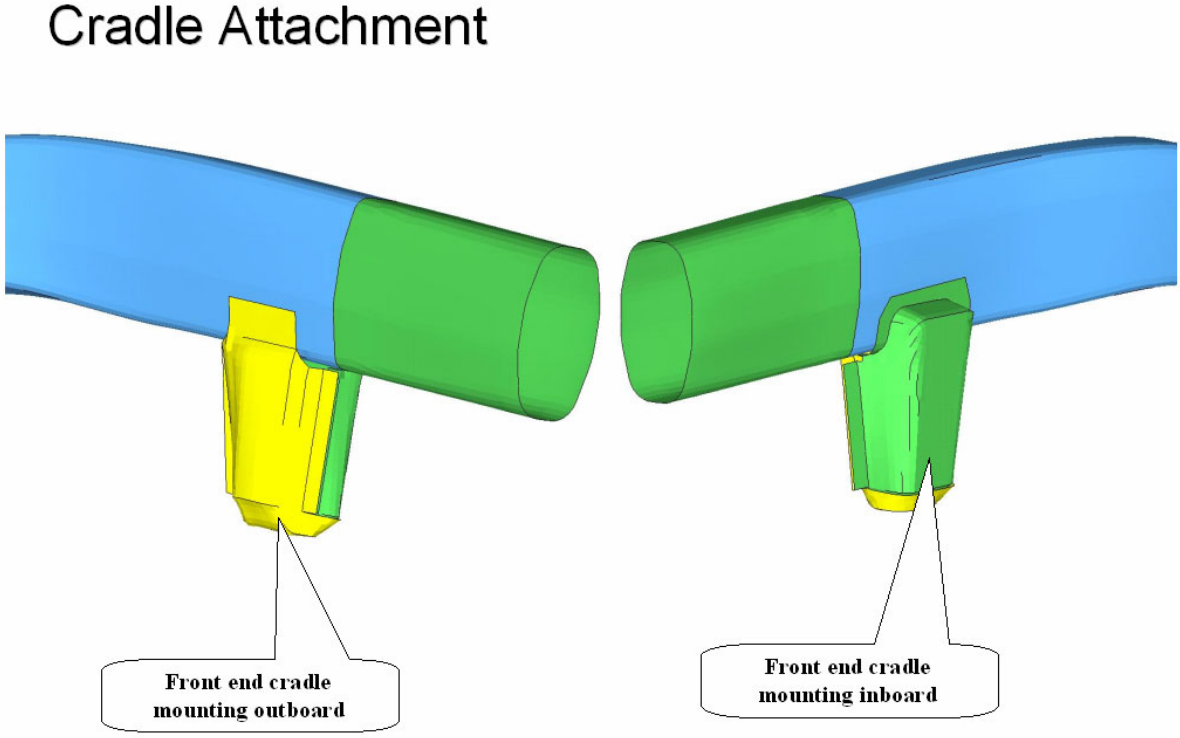


Figure 24: Front Cradle Mount

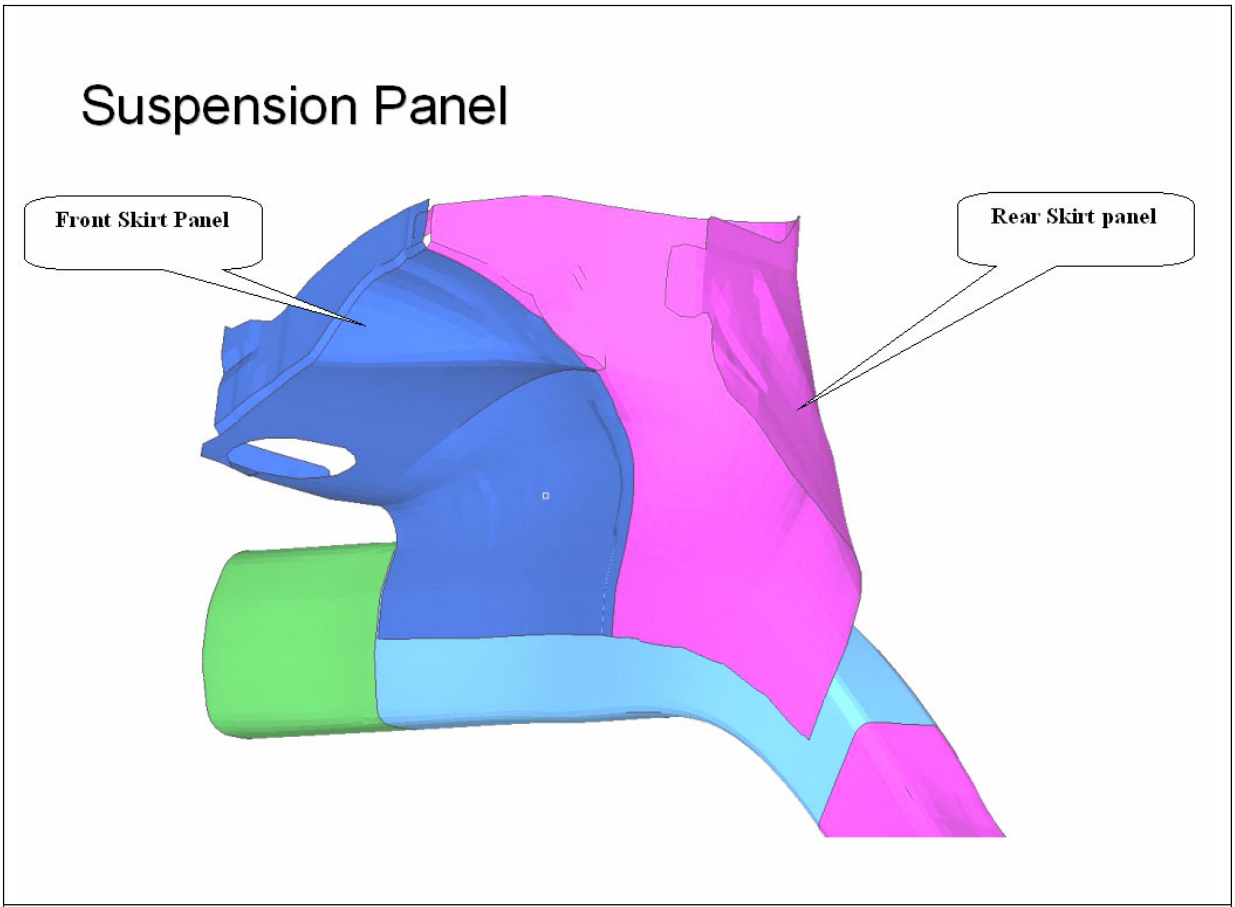


Figure 25: Suspension Panel

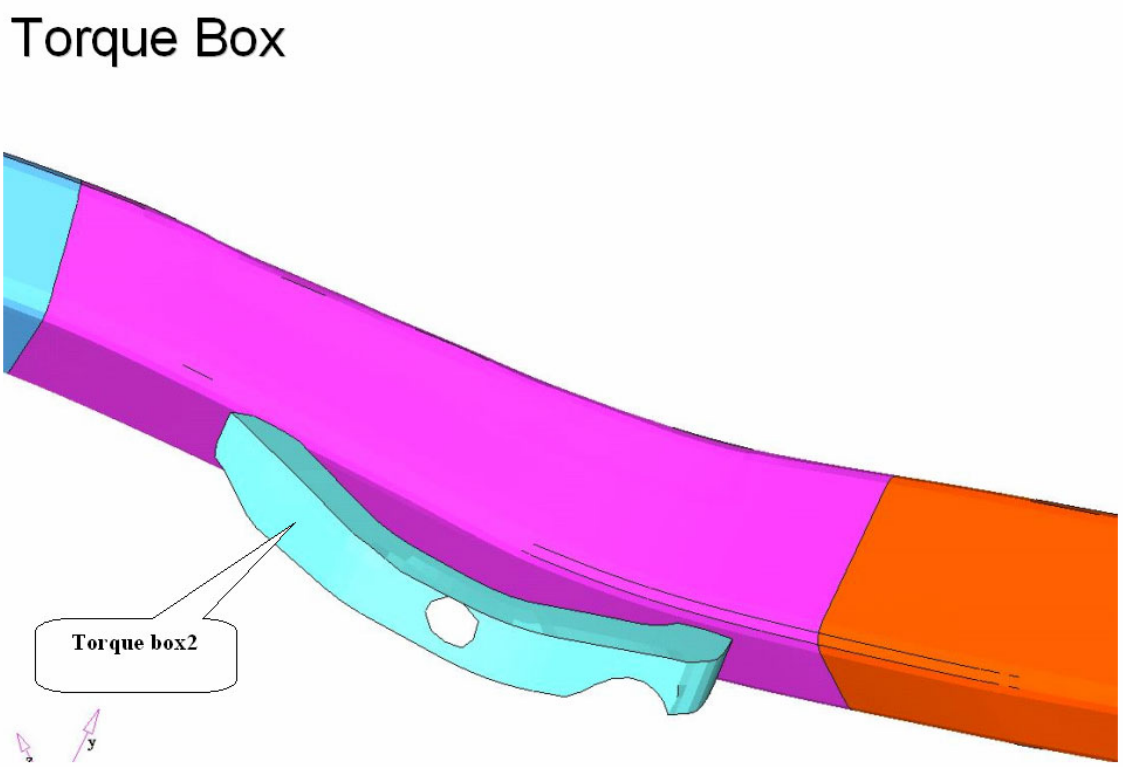


Figure 26: Torque Box

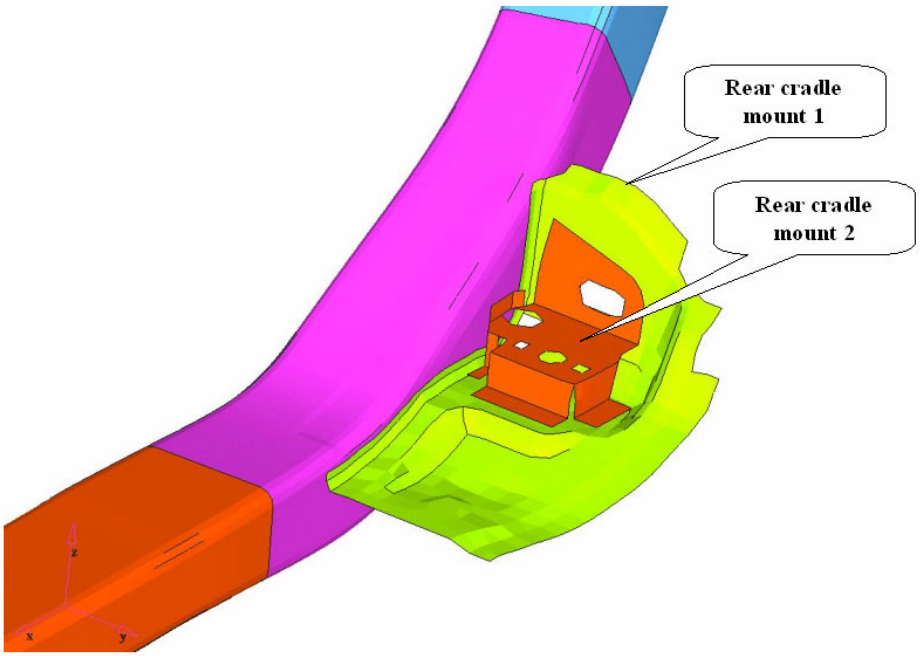


Figure 27: Rear Cradle Mount

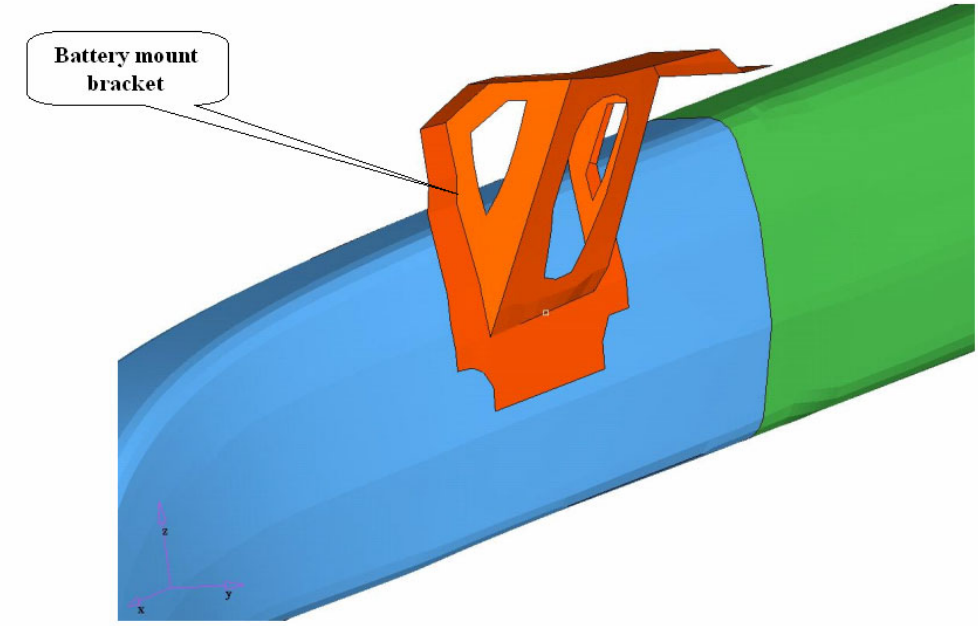


Figure 28: Battery

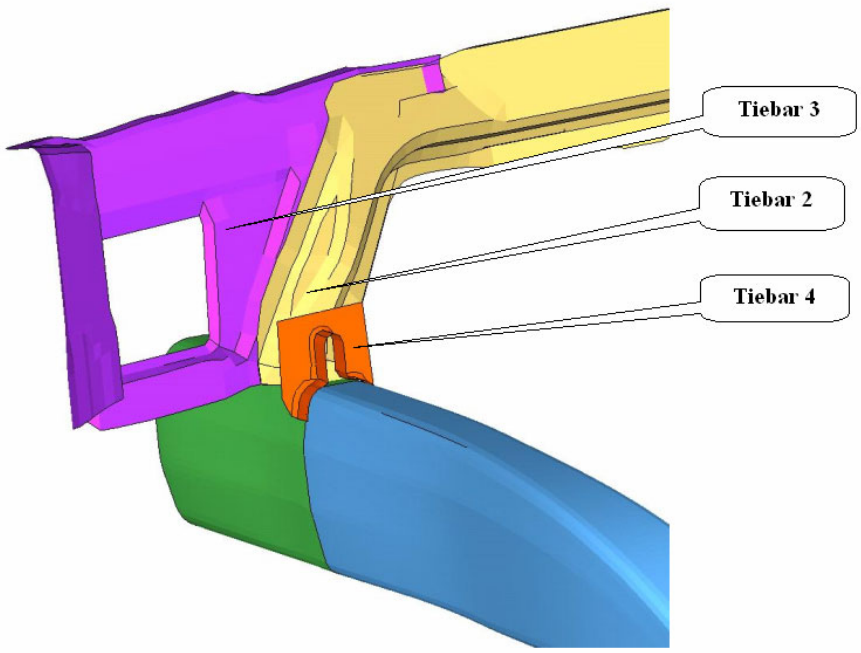


Figure 29: Tie Bar

Concept 3: DOE Study

Milestone 17

Lightweight Front End Structure Phase II

September 22, 2004



Auto/Steel Partnership

Abstract

This report documents the NCAP DOE study for *Concept 3*, which has the hydroformed rail design and a new bumper design. A final design for *Concept 3* will be obtained, based on this DOE study. The final *Concept 3* design will be compared to *Concepts 1* and *2* developed in Phase II of the Lightweight Front End Structure Project.

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1. Objectives

The effort of this study was aimed at undertaking an NCAP DOE study for *Concept 3*. Front rail and bumper grades and gauges were selected as design variables. *Concept 3* has the hydroformed rail design and a new bumper design. A final design for *Concept 3* will be obtained, based on the NCAP DOE study. The final *Concept 3* design will be compared to *Concepts 1* and *2* developed in Phase II of the Lightweight Front End Structure Project.

An IIHS DOE Study was not undertaken for the *Concept 3* design.

2. Results Summary

The NCAP study was based on the following DOE model.

- Orthogonal L16 2-level study *(7)*.
- Front rail and bumper grades and gauges as design variables (*Table 2*).
- B-pillar pulse, crush and mass responses.

The rankings of main effects and interactions are summarized in *Table 1*. These rankings are for peak accelerations (LH) between 40-70ms.

The 40-70ms accelerations (*Figure 6*) were affected significantly by all the gauges; with the exception of rail E. Rail materials affected the accelerations to a lesser extent.

Table 1: Rankings of Main Effects/Interactions

Rank	Main Effect or Interaction
1.	rail D t
2.	rail A t x rail D t
3.	bumper t
4.	rail A t x rail B t
5.	rail C t x rail D t
6.	rail E t
7.	rail A/B/C mat
8.	bumper t x rail A t
9.	rail B t
10.	rail B t x rail D t

3. DOE Model

The DOE model selected for the NCAP study was the Orthogonal L16 Array (*7).* 8 main effects and 7 interactions can be determined from 16 experiments. The design variables and their levels are summarized in *Table 2* and *Figure 1.* Grades of rail sections A, B and C were clubbed together. Grades of rail sections D and E were also clubbed together. Bumper grade was not included as a design variable and was fixed at DP980 material. The rail tailor-weld lines correspond to those in the *Concept 2* Stamped Design.

Table 2: DOE Design Variables

S.No.	Design Variable	Level 1	Level 2
1	Bumper Gauge	1.0	1.3
2	Rail Section A Gauge	1.0	1.3
3	Rail Section B Gauge	1.2	1.6
4	Rail Section C Gauge	1.4	1.8
5	Rail Section D Gauge	1.5	2.0
6	Rail Section E Gauge	1.2	1.6
7	Rail Section A/B/C Grade	DP600	DP800
8	Rail Section D/E Grade	DP600	DP800

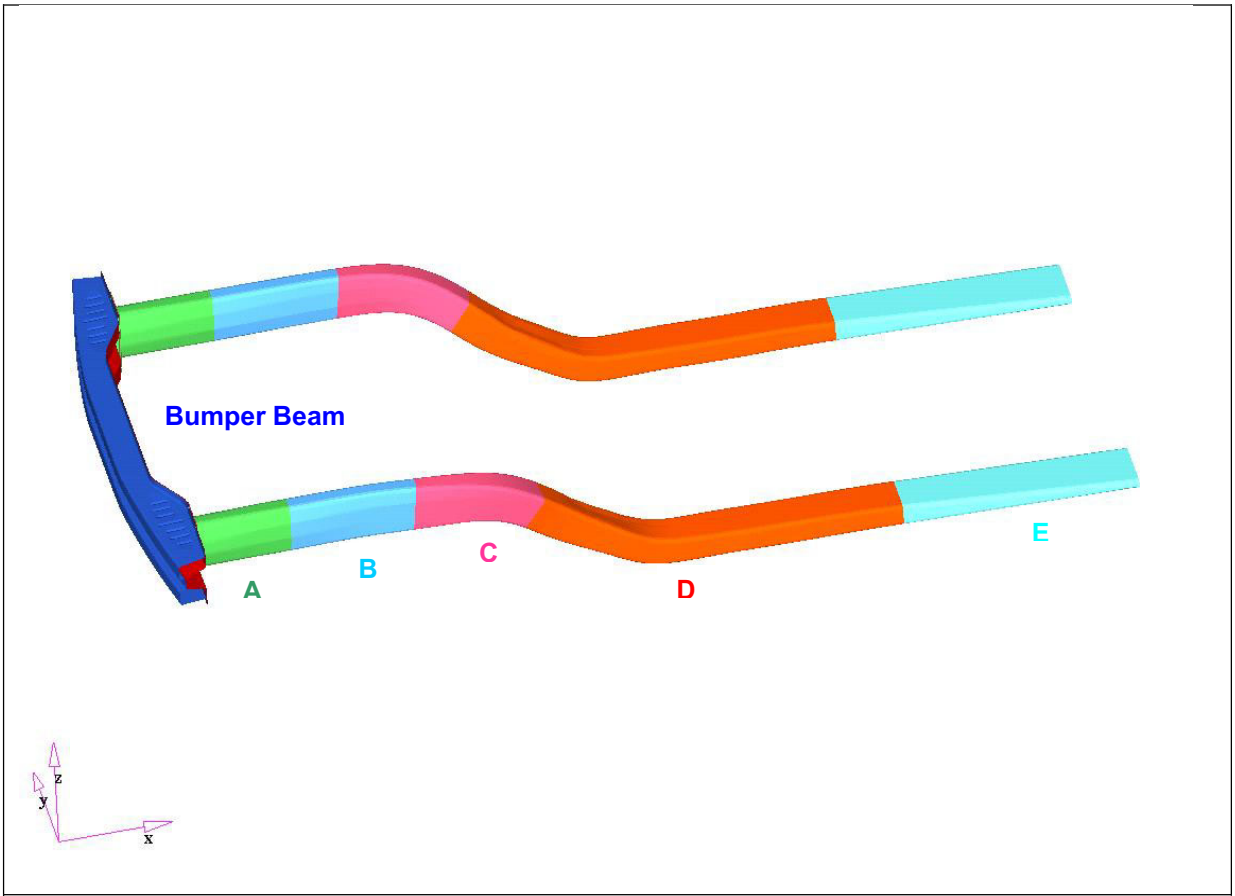


Figure 1: DOE Design Variables: Rail and Bumper Assembly

4. FE Model - Output Location Summary

The nodes at which the desired NCAP and IIHS outputs were obtained are listed in *Table 3*.

The intrusions were measured at the nodes as specified in *Reference 3*.

The acceleration and intrusion node locations are shown in *Figure 2* and *Figure 3* below.

Table 3: Summary of Output Locations

Load Case	Location	Node Number
NCAP	B-Pillar / Rocker - LH	5000001
	B-Pillar / Rocker - RH	5000002
	Crush	5000003
IIHS	Origin	6000000
	Plane Y-axis	6000001
	Plane Z-axis	6000002
	Steering Column	7000001
	Brake Pedal	7000002
	Toepan - Left	7000003
	Toepan - Center	7000004
	Toepan - Right	7000005
	Left Front Seat Bolt	7000006
	Right Front Seat Bolt	7000007
	Left Rear Seat Bolt	7000008
	Right Rear Seat Bolt	7000009
	AB Closure - A Pillar	7000010
	AB Closure - B Pillar	7000011

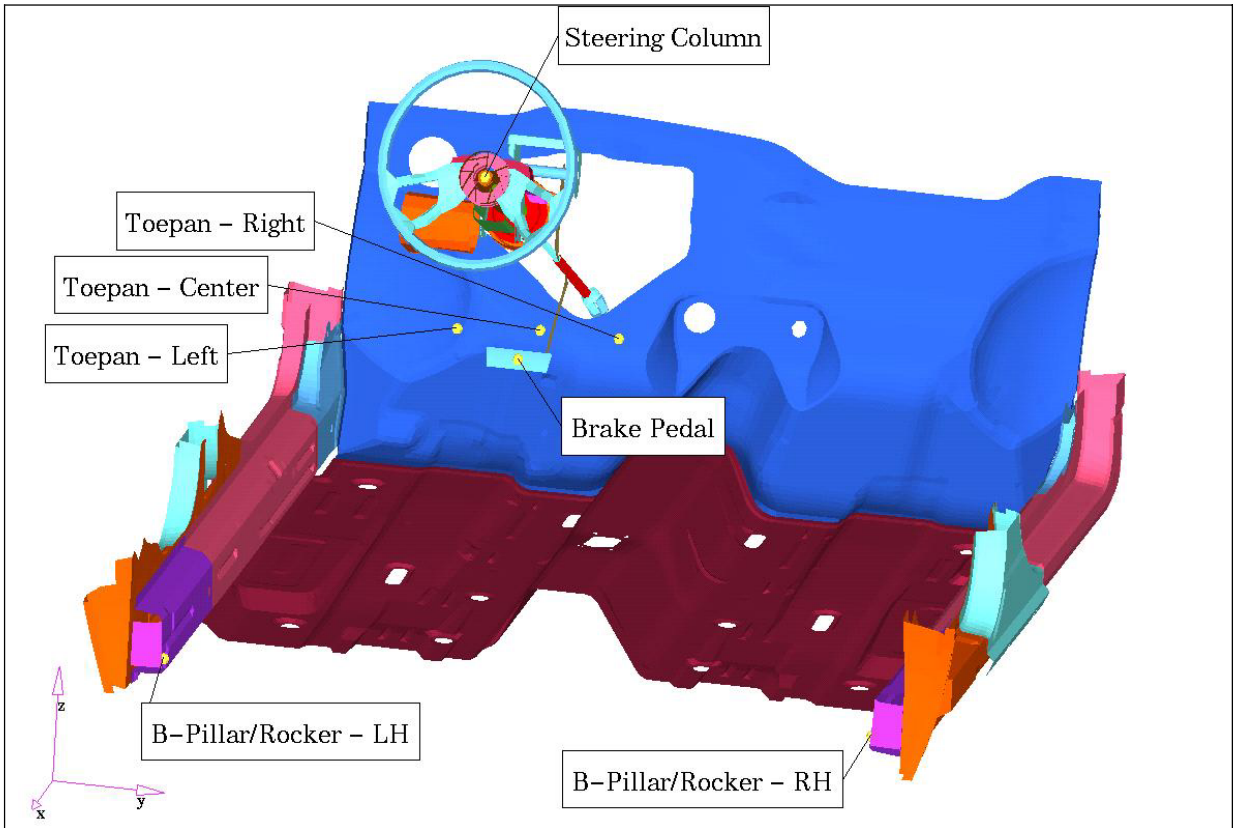


Figure 2: Output Locations for NCAP/IIHS



Figure 3: Output Locations for IIHS - AB Closure

5. NCAP DOE

Figure 4-Figure 6 show the normalized Sequential Sum of Squares *(7)* for crush, and LH B-pillar acceleration pulse.

The peak crush (*Figure 4*) and the initial acceleration peak (*Figure 5*) were affected the most by bumper gauge and rail material. This behavior is quite consistent with the Phase I DOE studies *(8)* in which the bumper dictated the initial peak.

The 40-70ms accelerations (*Figure 6*) were affected significantly by all gauges; with the exception of rail E. Rail material affected the accelerations to a lesser extent.

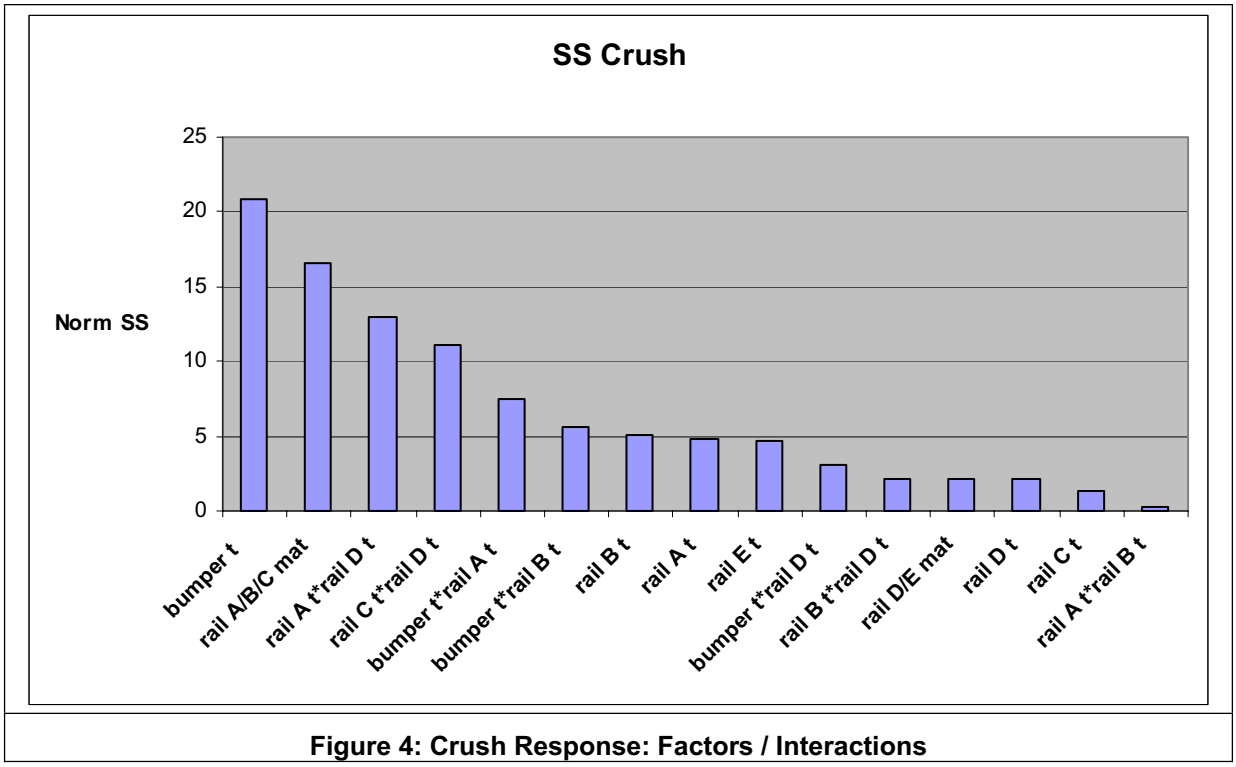


Figure 4: Crush Response: Factors / Interactions

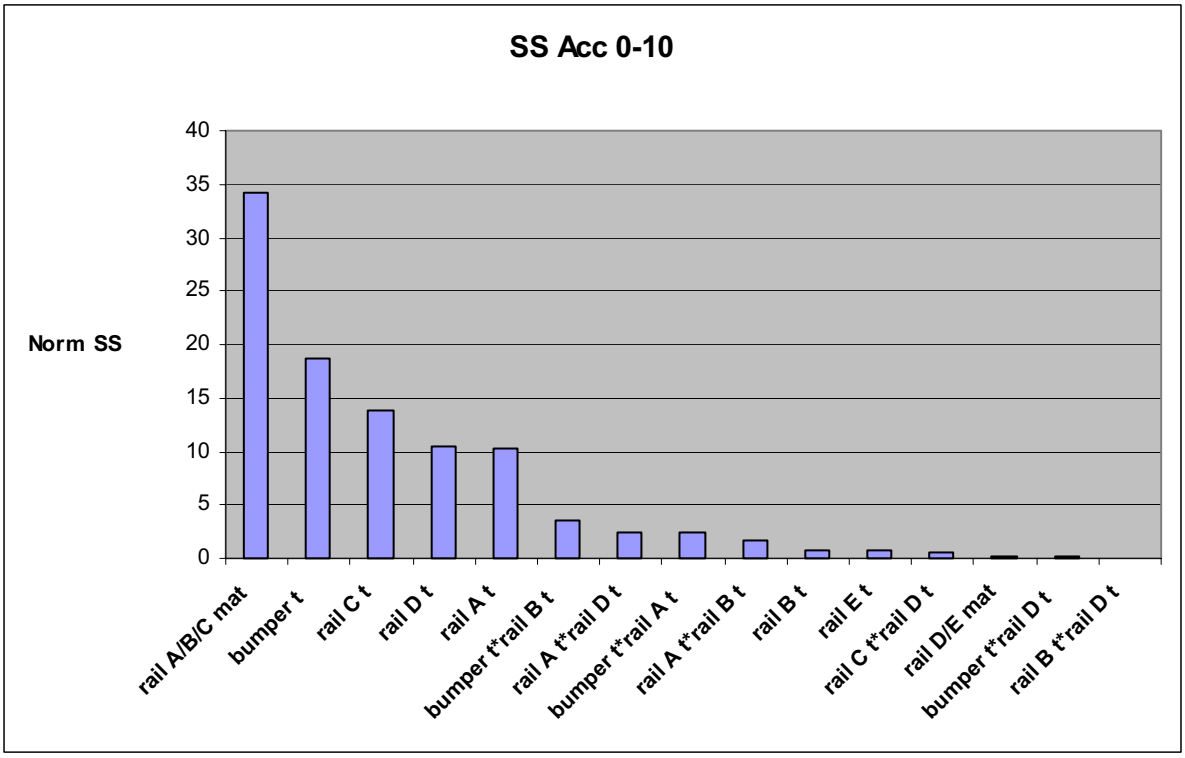


Figure 5: Peak Acceleration in 0-10ms: Factors / Interactions

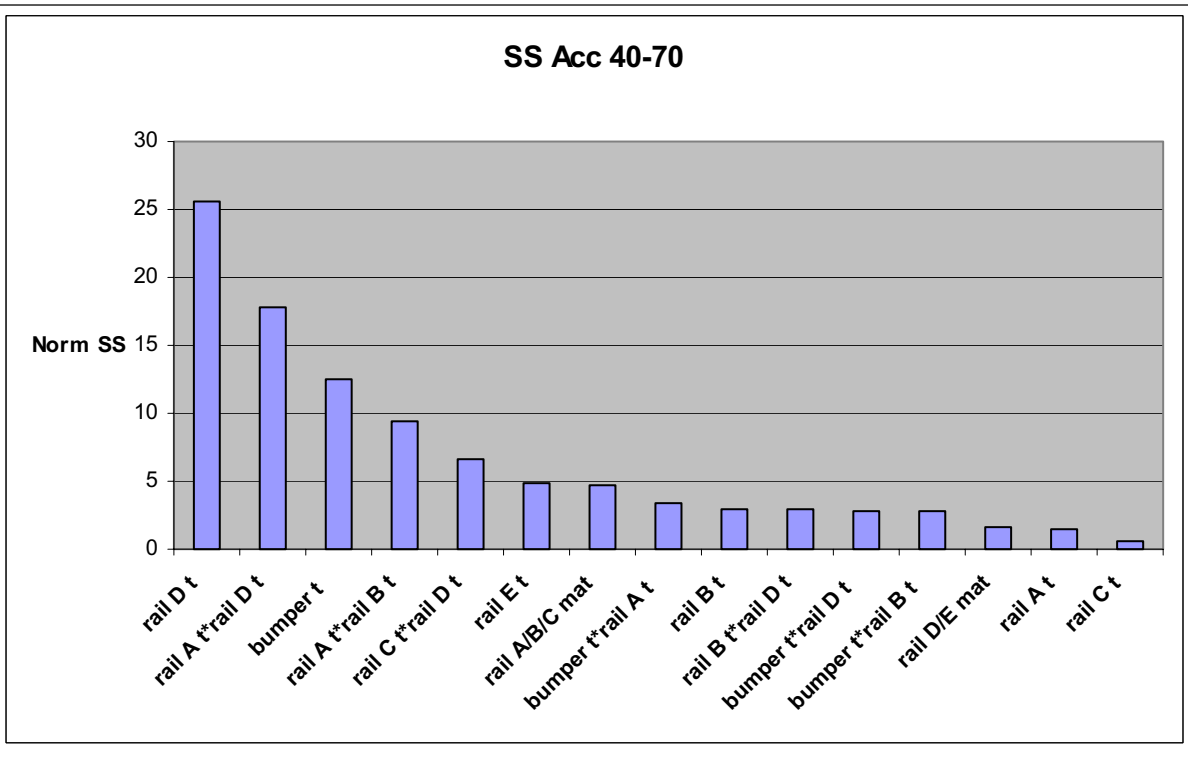


Figure 6: Peak Acceleration in 40-70ms: Factors / Interactions

6. Conclusions

An NCAP DOE study was undertaken for *Concept 3*. Front rail and bumper grades and gauges were selected as design variables. The 40-70ms accelerations (*Figure 6*) were affected significantly by all gauges; with the exception of rail E. Rail materials affected the accelerations to a lesser extent.

7. Future Work

A final design for *Concept 3* will be obtained, based on the NCAP DOE study. The final *Concept 3* design will be compared to *Concepts 1* and *2* developed in Phase II of the Lightweight Front End Structure Project.

8. References

1) *Validated FE Models, Milestone 5*, SPHINX, Phase II.

2) *Enhanced FE Models, Milestone 6*, SPHINX, Phase II.

3) *IIHS Crashworthiness Evaluation Offset Barrier Crash Test Protocol Version IX), October 2002.*

4) *DOE FE Models, Milestone 7*, SPHINX, Phase II.

5) *Third Bumper Design Report, Milestone 5*, SPHINX, Phase I.

6) *Concept 3: Preliminary Design, Milestone 16*, SPHINX, Phase II.

7) *System of Experimental Design*, *Volumes 1 & 2*, Taguchi Genichi, 1987, Kraus International Publications.

8) *NCAP 35 mph Study, Milestone 11*, SPHINX, Phase I.

9) *Upgraded Powertrain DOE Study, Milestone 15*, SPHINX, Phase I.

9. Appendix A: Concept 3 FE Model

Total Components	**489**
Model Mass	**1.763 tonnes**

- Model mass is from LS-DYNA3D d3hsp file.

Concept 3: Final Design

Milestone 18

Lightweight Front End Structure Phase II

October 6, 2004

A/S P

Auto/Steel Partnership

Abstract

This report documents the final design for Concept 3 that has a new hydroformed rail design and a stamped bumper design. The final Concept 3 design will be compared to Concepts 1 and 2 developed in Phase II of the Lightweight Front End Structure Project.

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1. Objectives

The effort of this study was aimed at developing a final design for Concept 3. Concept 3 has a new hydroformed rail design and a stamped bumper design. A final design for Concept 3 was obtained, based on an NCAP DOE study only – no IIHS DOE study was undertaken. The final Concept 3 design will be compared to Concepts 1 and 2 developed in Phase II of the Lightweight Front End Structure Project.

2. Results Summary

An attempt was made to predict the IIHS performance from NCAP peak crush. However, no design prediction satisfied all IIHS targets. The best solution obtained was the *Initial Concept Design*.

The Concept 3 design has the following salient features.

- Symmetric LH/RH rail assemblies.
- One-piece tailor-welded rail design.
- Octagonal front sections and rectangular rear sections.
- Two-piece double box bumper design with energy absorbing features.

The Concept 3 design achieves a mass reduction of **12.1kg (31%)** compared to the *Baseline* design. The *NCAP performance* is essentially the same as that of the baseline design. The *IIHS performance* is mixed – the left and right toepan intrusions are lower that in the baseline design. However, the center toepan intrusion and A-B closure are higher than in baseline design.

The NCAP and IIHS results are summarized in *Table 1* and *Table 2*.

Table 1: NCAP Results

B Pillar Pulse	Baseline	Concept 3
LH	36.7g @ 58.7ms	33.9g @ 43.9ms
RH	35.3g @ 58.6ms	35.9g @ 62.0 ms

Table 2: IIHS Results

Location	Peak Intrusions (cm)	
	Baseline	Concept 3
Left Toepan	18.2	17.6
Center Toepan	18.4	20.6
Right Toepan	19.4	18.5
A-B Pillar Closure	14.4	18.2

3. Concept 3 Design

The rail design (*Figure 1* through *Figure 3*) is a one-piece tailor-welded hydroformed design with symmetric LH and RH rail assemblies. The front portion of the rail has an octagonal section and the rear portion of the rail has a rectangular section (*Figure 4*). The cross-section transitions from octagonal to rectangular. Octagonal sections are highly efficient in absorbing energy in dynamic crush. Therefore, the rail sections are octagonal in the crush zone and the section centroids have been aligned so as to create an axial load path. Elsewhere, the rail sections are limited by design space and have been chosen so as to maximize the section modulus and to achieve a smooth surface. The perimeter variation (*Figure 5*) has been kept below 8% (8), 9) and the minimum radius is 10mm. Flat surfaces of minimum 10mm width have been provided for welding attached parts.

The cross-sections were optimized so as to achieve maximum section modulus subject to packaging and perimeter restrictions. The optimization problem was setup as.

Maximize: Iyy

Subject: Izz > min Izz
Perimeter change < 8%
Packaging constraints

The optimized sections were adjusted in order to obtain a smooth design surface.

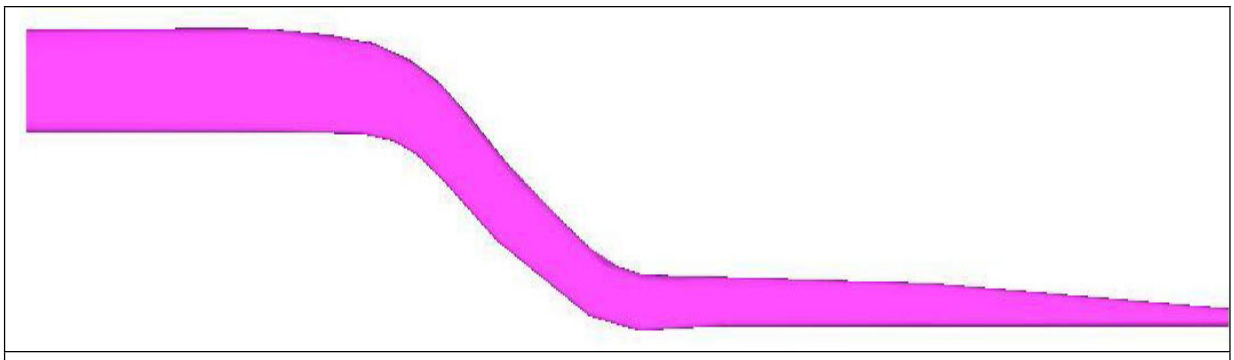


Figure 1: LH Rail - Side View

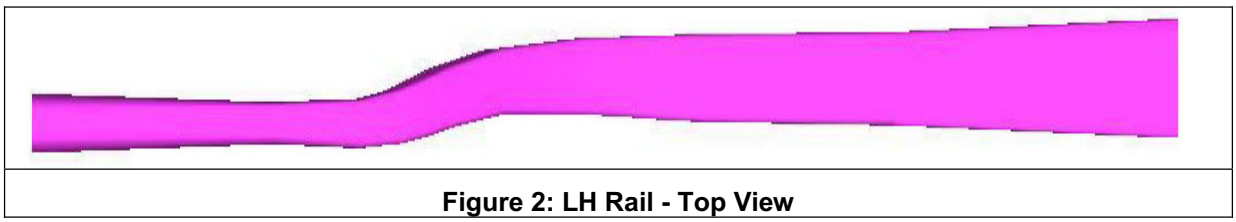


Figure 2: LH Rail - Top View

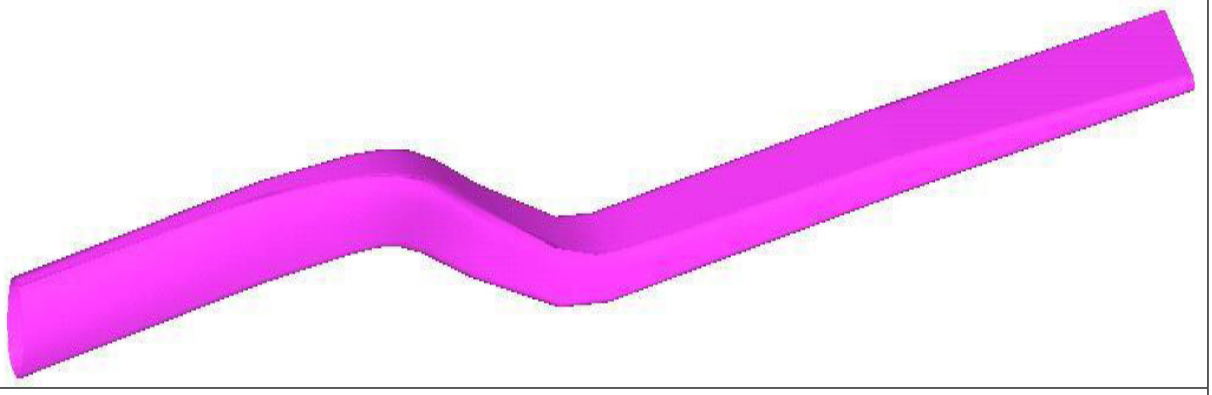


Figure 3: LH Rail - Isometric View

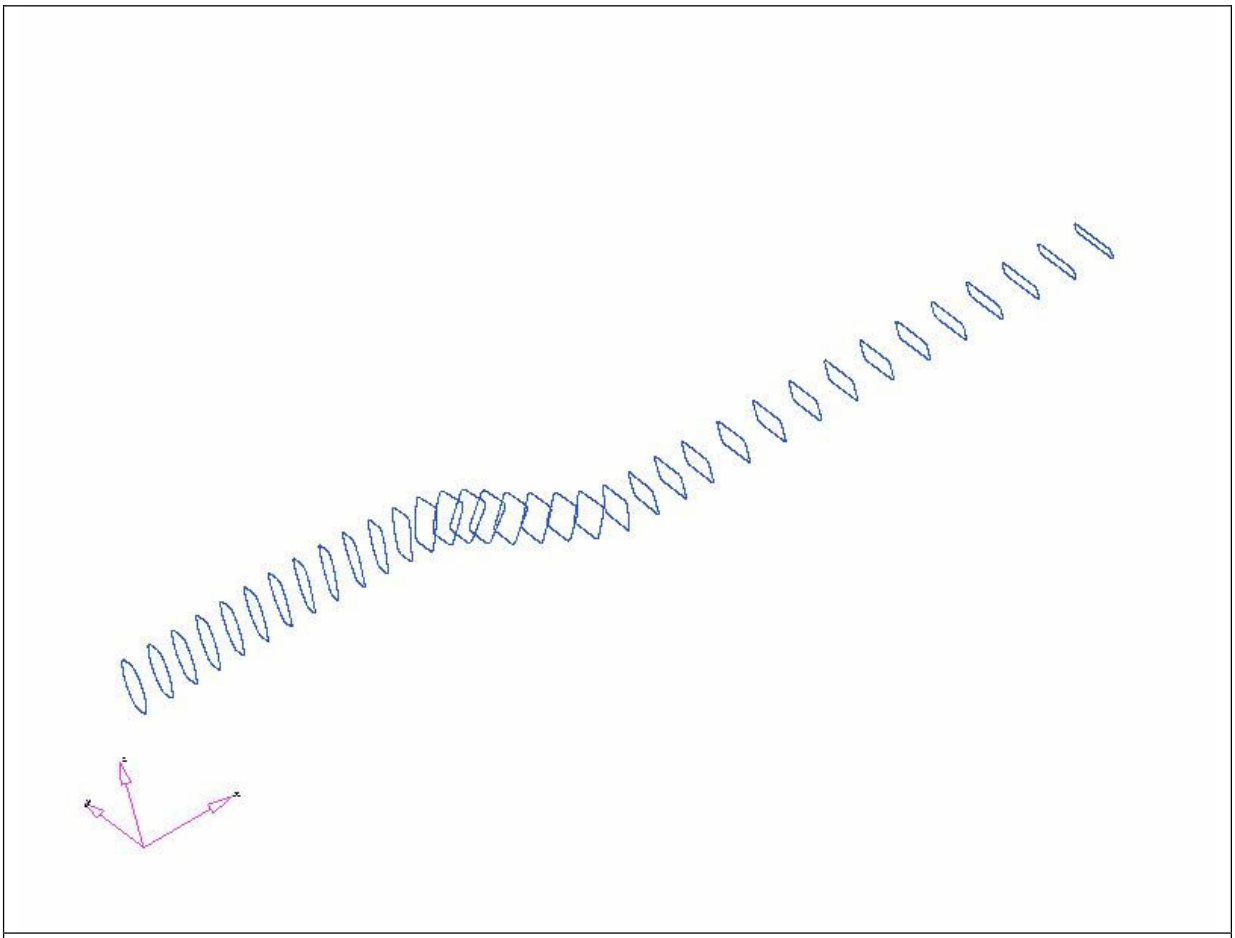


Figure 4: LH Rail Sections

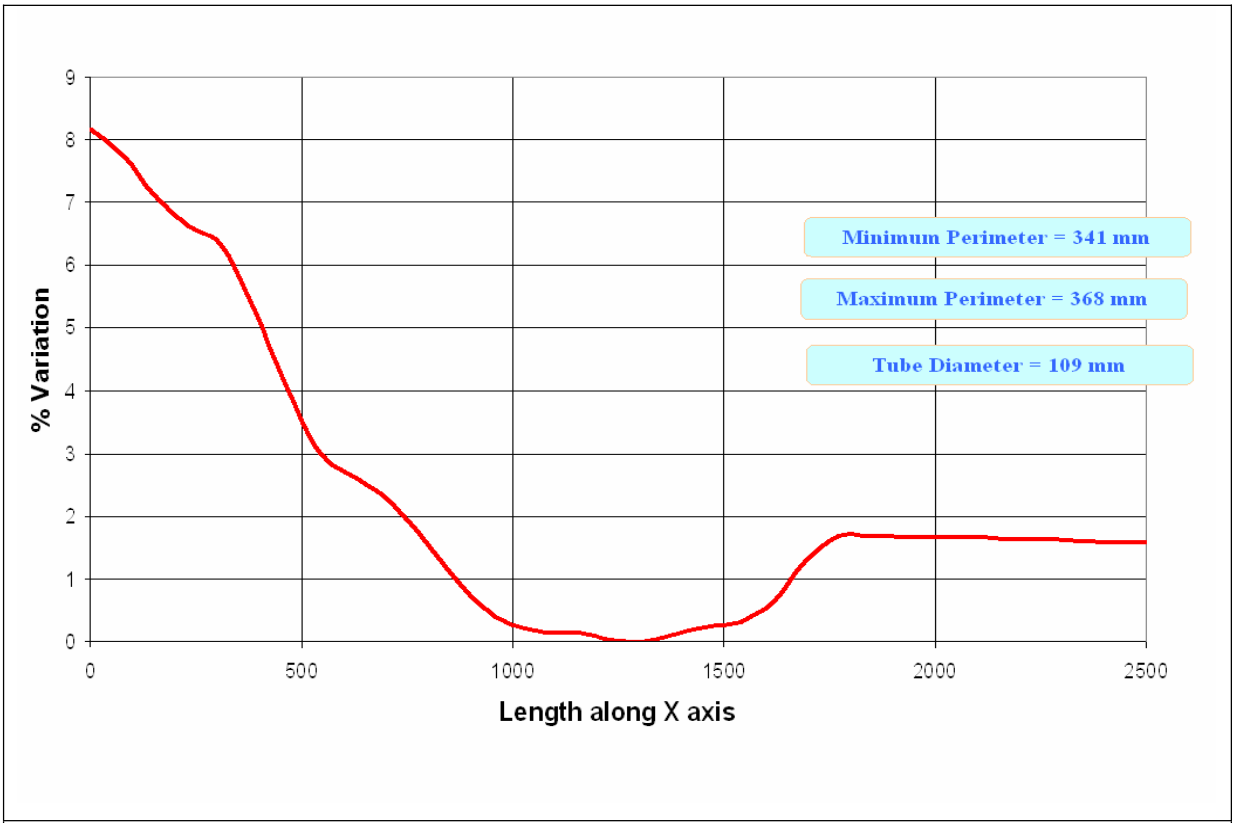


Figure 5: Perimeter Variation

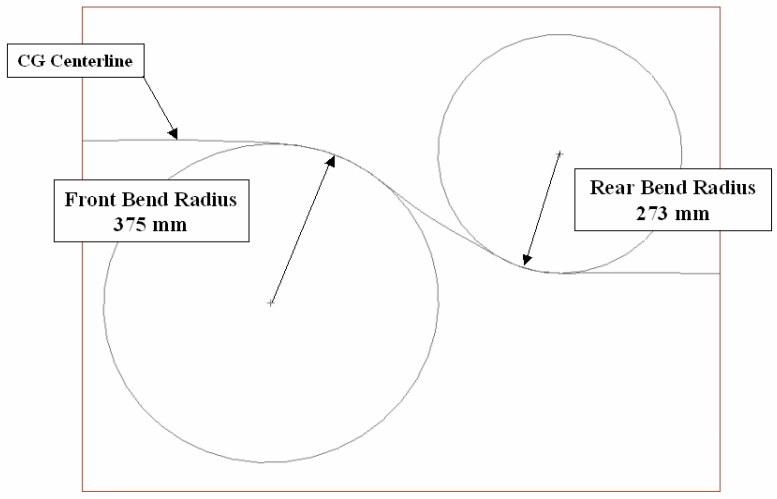


Figure 6: Bend Radius

The rail centerline has curvatures in both top and side views. The bend radii are indicated in *Figure 6*. The centerline has been adjusted so as to limit the number of bends to two.

Tailor-blanking was introduced in the rails. The rail is now considered to be 5-piece tailor-welded, with the weld lines indicated in *Figure 7*. The grades and gauges of the rail assembly will be varied in the DOE study. The feasibility of tailor-welded hydroformed rails has to be explored.

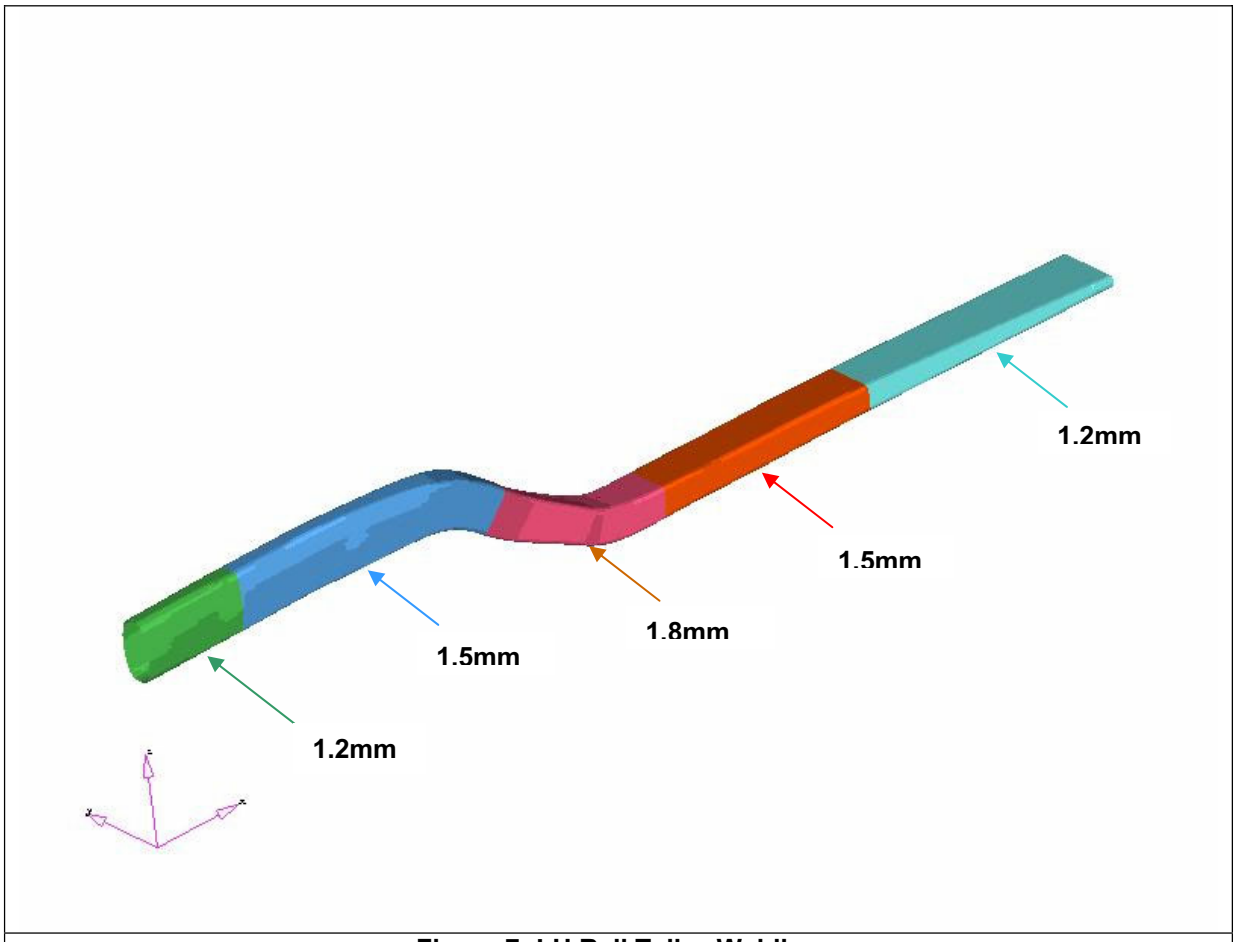


Figure 7: LH Rail Tailor-Welding

The baseline bumper was replaced by a new bumper design (*Figure 8, Figure 9*). The new bumper design is functionally quite similar to the Phase I Bumper 3 design. However, it has fewer manufacturing and welding concerns than the Bumper 3 design. The new bumper design is a 2-piece double-box stamped design using DP980 steel. The bumper has vertical flanges and beads on the front and back plates. The new bumper design has good energy absorption capability in high-speed impacts and results in a high initial peak in the NCAP B-pillar pulse. In addition, the bumper is more formable than the Phase I Bumper 3 design, and is easier to weld. *A design similar to the new bumper design has been prototyped using DF140T steel.*

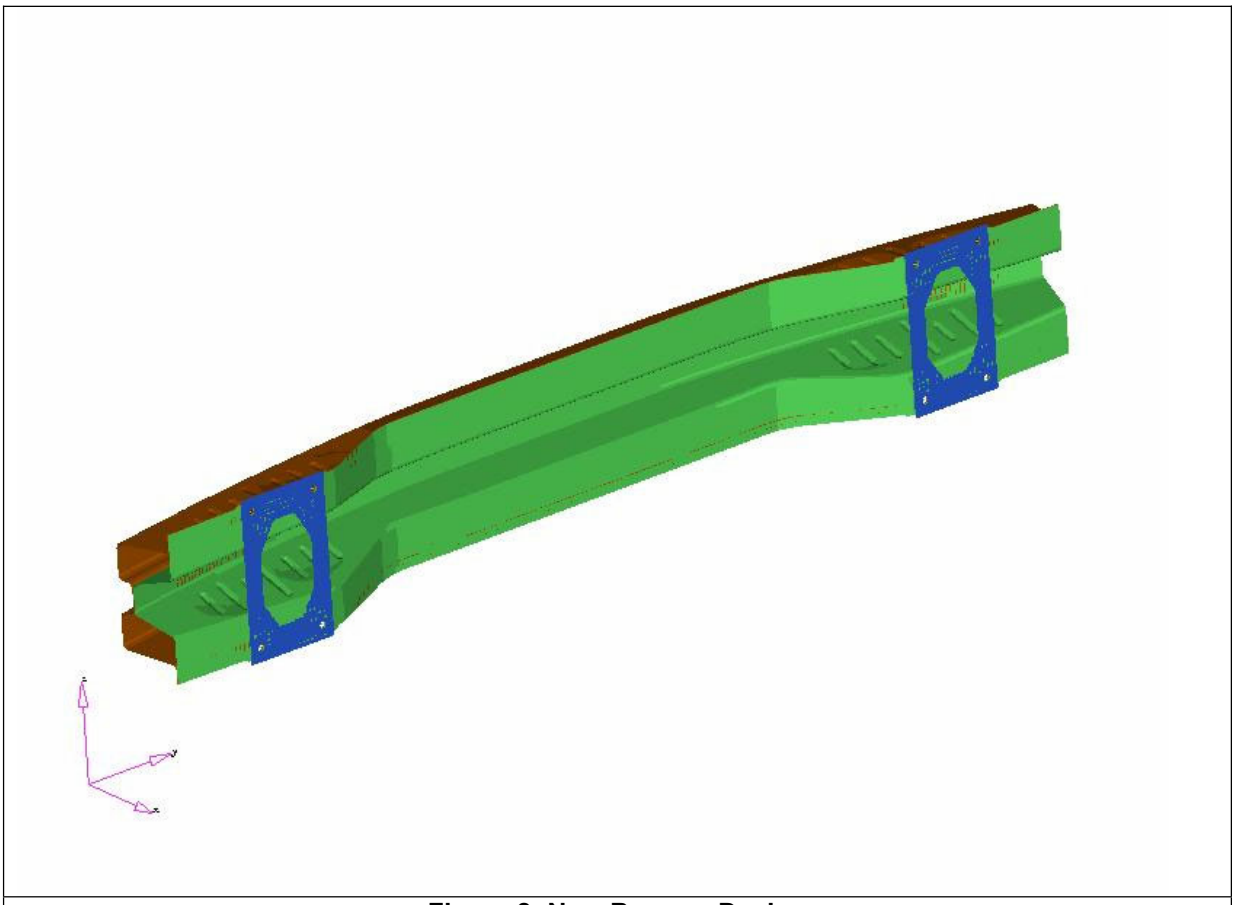


Figure 8: New Bumper Design

The bumper plates are attached to the front rails through an attachment plate (*Figure 23*). The plate is bolted to the bumper beam through four bolts (5/16” or 3/4”). The plate has a hole of the same shape as the rail front section, but of a smaller size. The plate is MIG welded to the front rails. The bumper centerline matches that of the rail (*Figure 22*). This ensures a proper load transfer from the bumper to the rails.

The bumper design passes the low-speed bumper requirements (7).

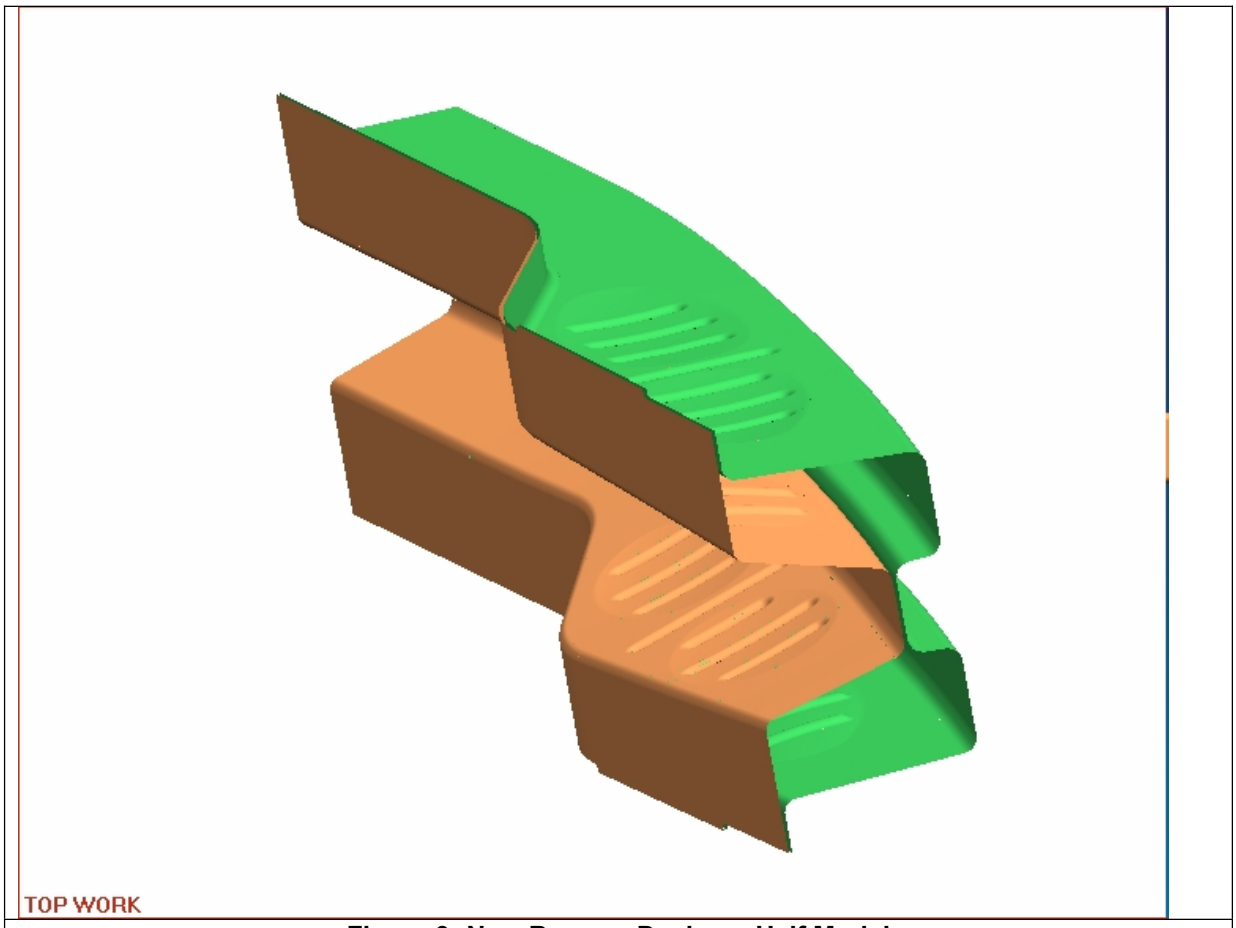


Figure 9: New Bumper Design – Half Model

A mass summary for rail and bumper parts is included in *Table 3*. A detailed part summary is included in *Appendix B: Summary of FE Model.*

Table 3: Mass Summary

Part	Mass (kg)	
	Baseline	Concept 2
LH Rail Assembly	16.5	10.3
RH Rail Assembly	16.2	10.3
Bumper Assembly (without foam)	6.6	6.6
Total	39.3	27.2
Mass Reduction	-	12.1

4. FE Model - Output Location Summary

The nodes at which the desired NCAP and IIHS outputs were obtained are listed in *Table 4*.

The intrusions are measured at the nodes as specified in *Reference 3*.

The acceleration and intrusion node locations are shown in *Figure 10* and *Figure 11* below.

Table 4: Summary of Output Locations

Parameter	Location	Node Number
Accelerations	B-Pillar / Rocker - LH	5000001
	B-Pillar / Rocker - RH	5000002
Intrusions	Origin	6000000
	Plane Y-axis	6000001
	Plane Z-axis	6000002
	Steering Column	7000001
	Brake Pedal	7000002
	Toepan - Left	7000003
	Toepan - Center	7000004
	Toepan - Right	7000005
	Left Front Seat Bolt	7000006
	Right Front Seat Bolt	7000007
	Left Rear Seat Bolt	7000008
	Right Rear Seat Bolt	7000009
	AB Closure - A Pillar	7000010
	AB Closure - B Pillar	7000011

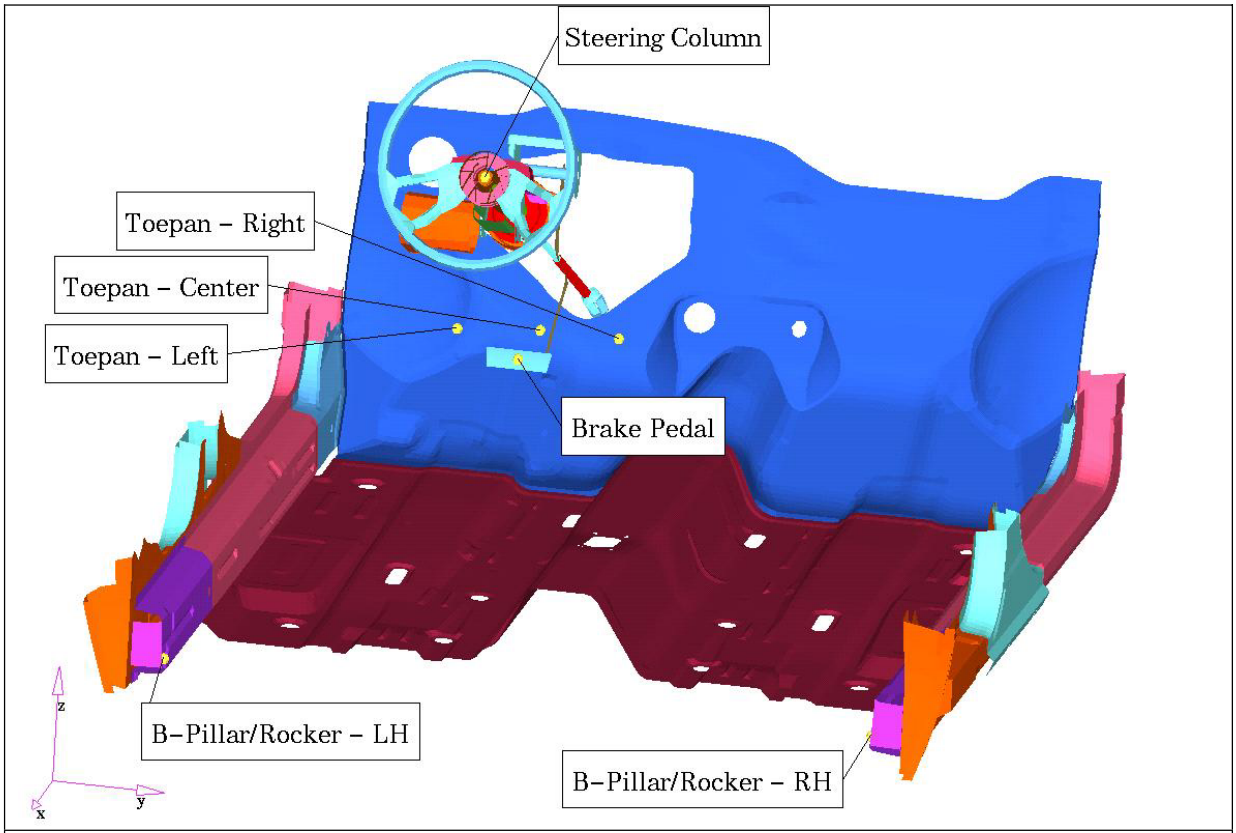


Figure 10: Output Locations for NCAP/IIHS



Figure 11: Output Locations for IIHS- AB Closure

5. NCAP Response

Figure 12 depicts the NCAP response of Concept 3. Animation files are included in *Appendix A*.

The hydroformed design has a higher initial peak as compared to the baseline design (*Figure 12, Figure 13*). The velocity profiles have higher slope for the hydroformed design (*Figure 14, Figure 15*). This indicates a stiffer bumper and front rails. The maximum acceleration of the hydroformed design is less than that of the baseline design.

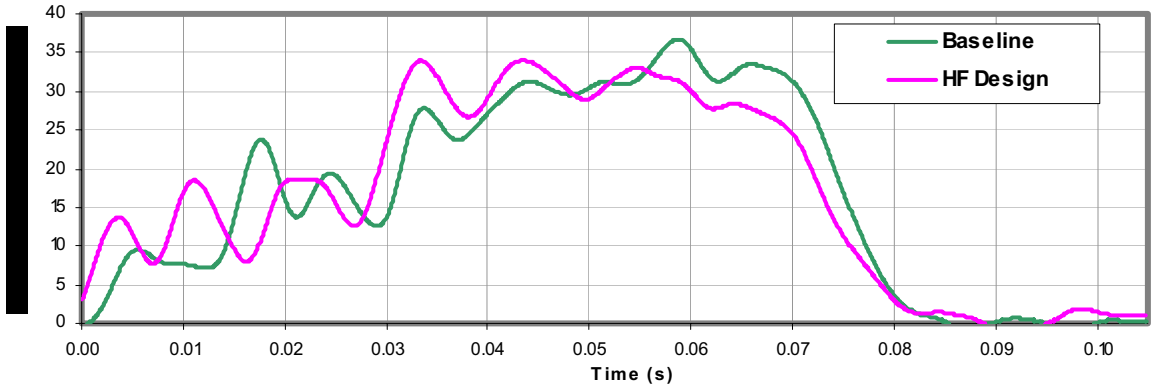


Figure 12: B Pillar Pulse – LH

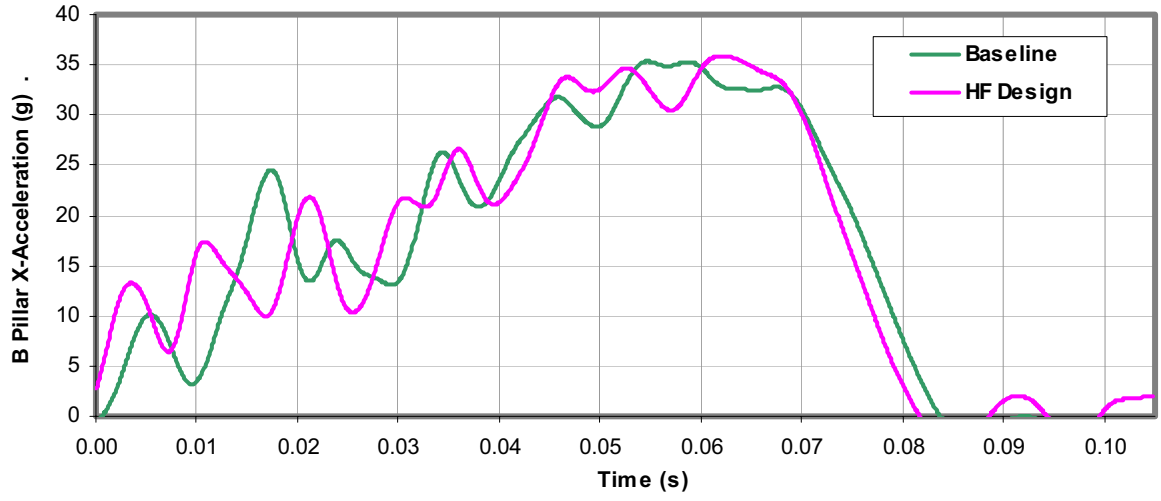


Figure 13: B Pillar Pulse – RH

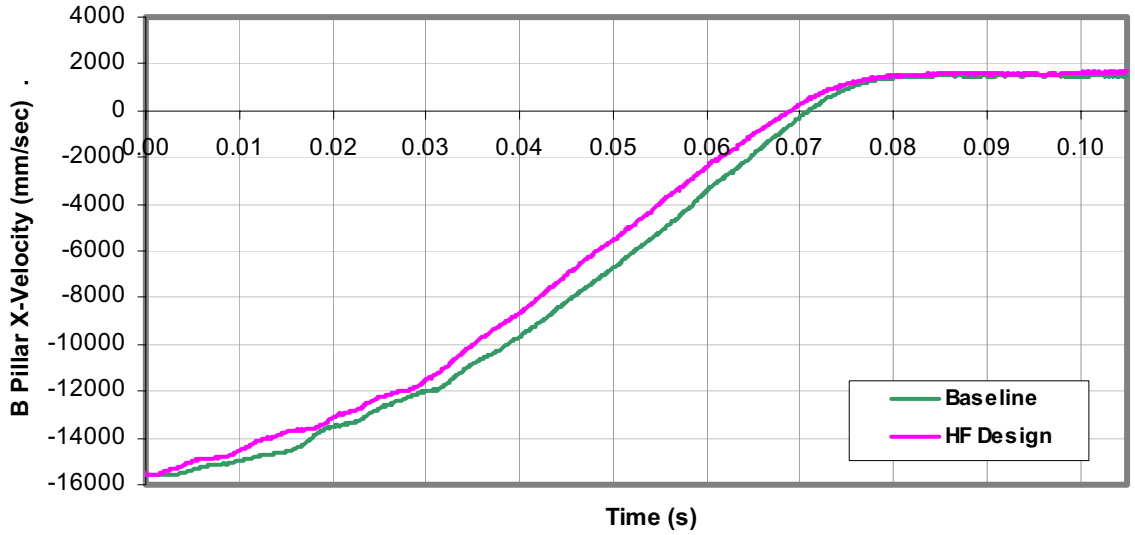


Figure 14: B Pillar Velocity - LH

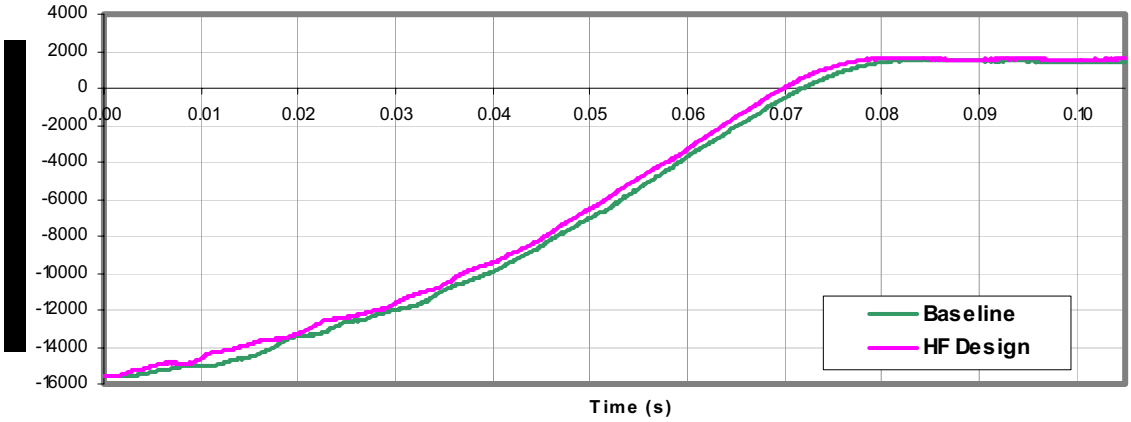


Figure 15: B-Pillar Velocity - RH

The hydroformed rails crush better than the baseline stamped rails (*Appendix A)*. However, there is still scope for improving crush by reducing buckling at critical cross-sections. Thus, the NCAP performance of the hydroformed design is better than that of the baseline design. *Table 5* summarizes the sequence of crash events in the baseline design.

Table 5: Baseline NCAP Crash Events

Time (ms)	Crash Events
0-15	Bumper absorbs energy
15-20	Engine hits the radiator, Cradle Extension Buckles, Cradle engaged
20-30	Cradle and LH rail buckling started
35-40	LH front wheel hits the LH rail
40-45	Engine hits to dash
45-50	RH front wheel hits the RH rail
55-60	LH wheel hits the front rigid wall
60-70	RH wheel hits the front rigid wall, LH wheel hits the rocker
70-75	RH wheel hits the rocker

6. IIHS Response

IIHS intrusions are summarized in *Table 2* and *Figure 16*. Animation files are included in *Appendix A*.

Toepan, brake pedal and A-B closure intrusions oscillate after 200ms about a mean value. Hence, the mean values should be used for comparison. However, the values reported in *Table 2* are at 250ms.

The brake pedal intrusions are unreliable as there is a pivot joint in the pedal attachment that results in random motion of the brake pedal.

Steering column movement does not reach any equilibrium. The IIHS simulation would have to be carried out for a longer duration in order to report stable meaningful values. The steering column model may also be deficient, resulting in an unstable movement.

Thus, only the toepan intrusions and A-B closure (*Figure 17* through *Figure 20*) have been used to compare the hydroformed design to the baseline design.

The toepan intrusions for the hydroformed design are similar to that of the baseline. The A-B closure is higher for the hydroformed design. This is also evident by the greater deformation seen in the cage area. However, the current hydroformed design has not yet been optimized for IIHS performance.

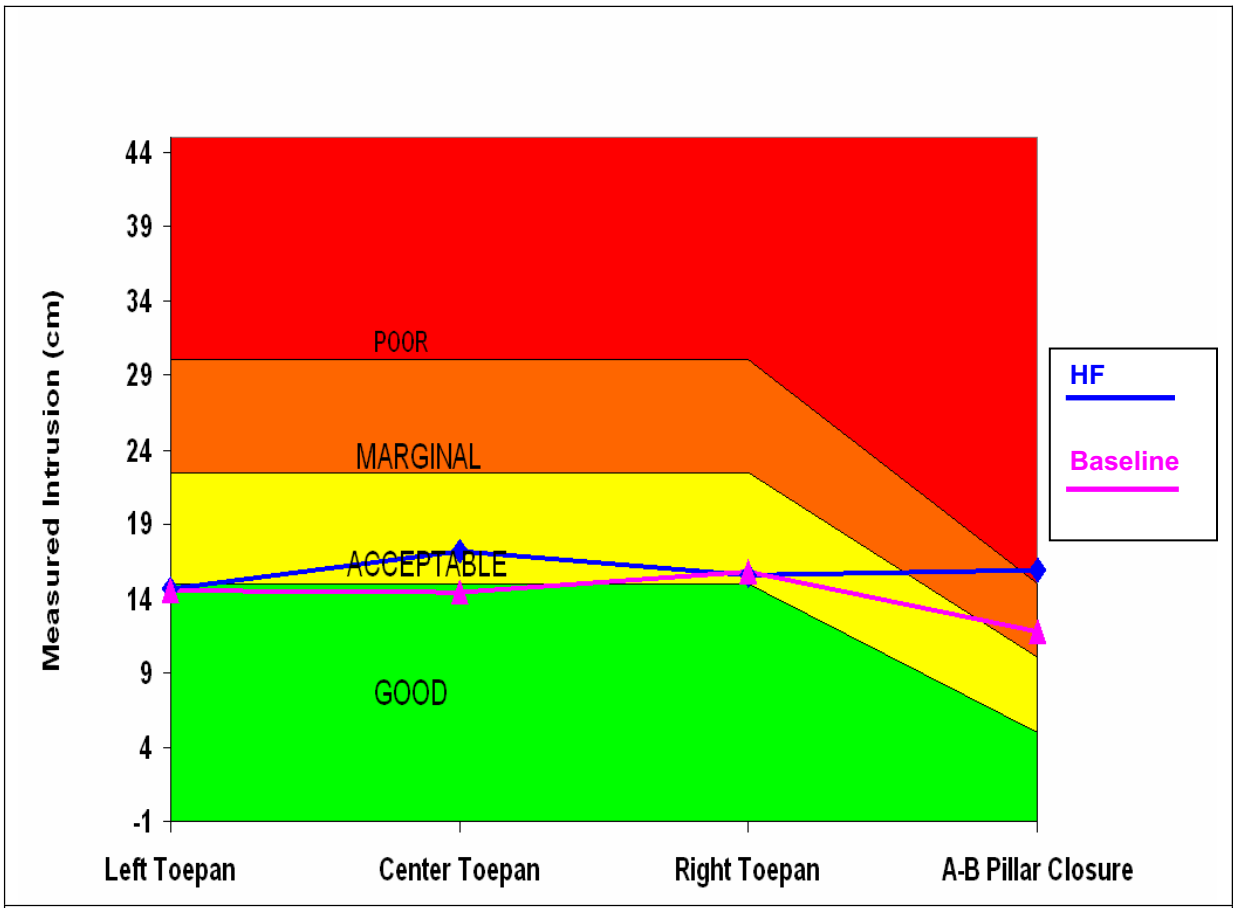


Figure 16: IIHS Intrusions

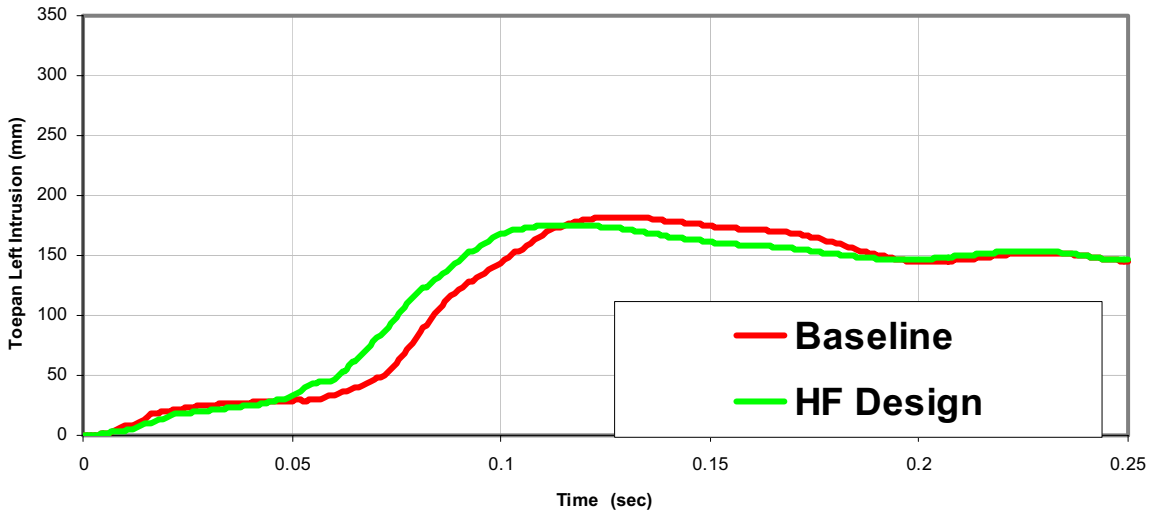


Figure 17: Left Toepan Intrusions

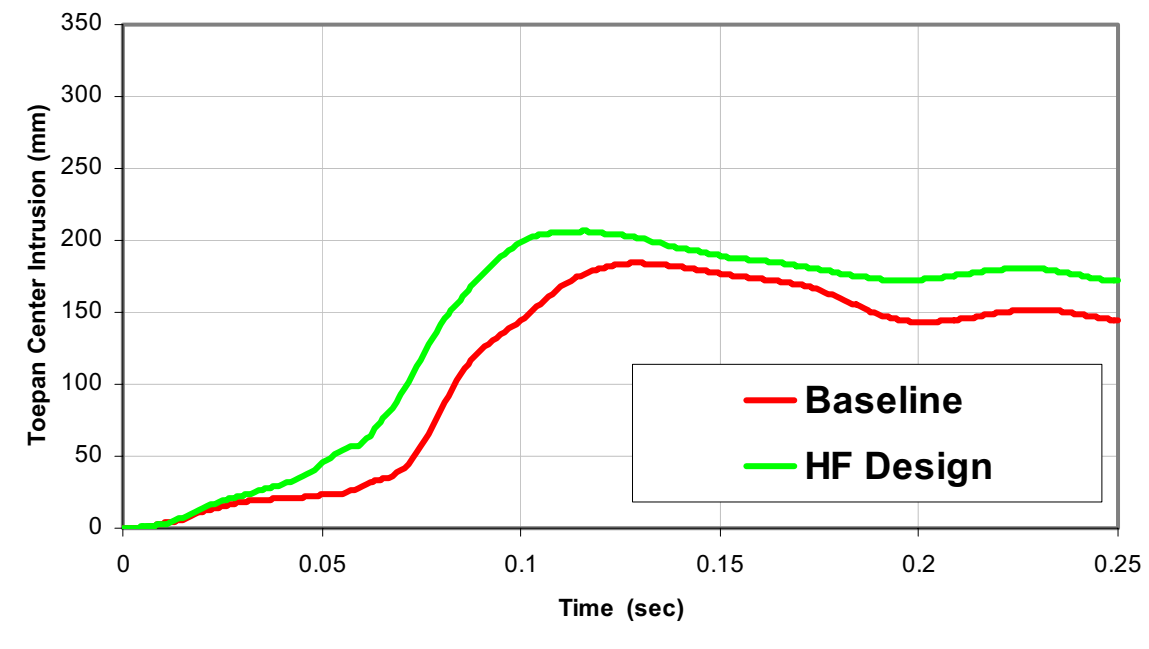


Figure 18: Center Toepan Intrusions

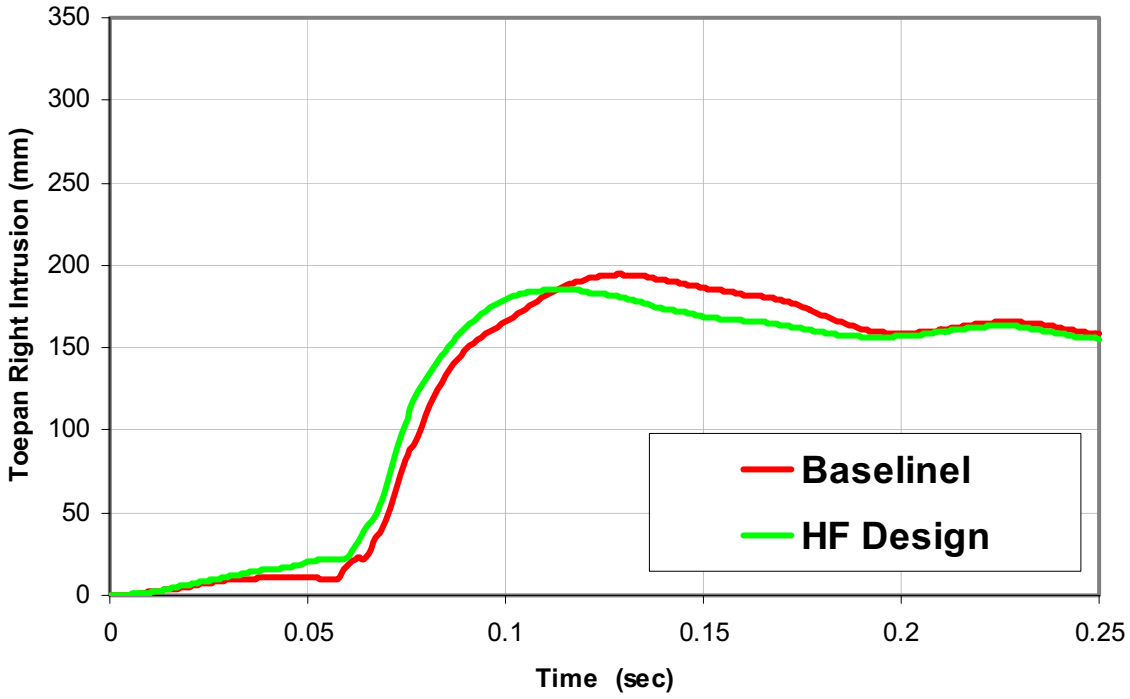


Figure 19: Right Toepan Intrusions

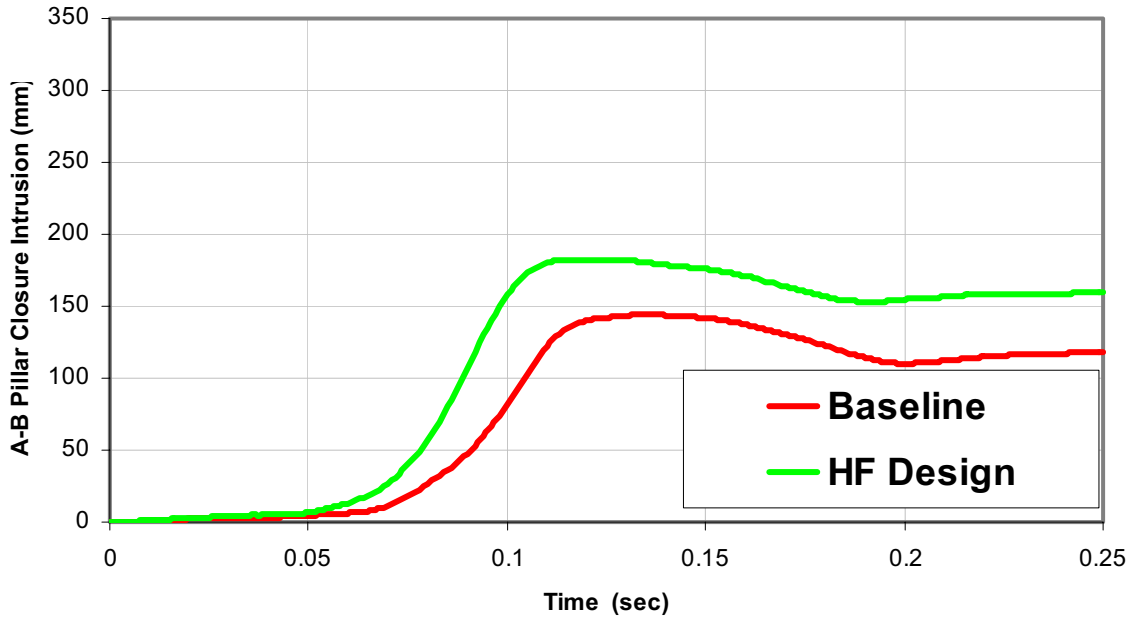


Figure 20: A-B Closure

7. Conclusions

The Concept 3 with a new hydroformed rail design and a stamped bumper design has been developed. The Concept 3 design achieves a mass reduction of **12.1kg (31%)** compared to the *Baseline* design. The *NCAP performance* is essentially the same as that of the baseline design. The *IIHS performance* is mixed – the left and right toepan intrusions are lower that in the baseline design. However, the center toepan intrusion and A-B closure are higher than in baseline design.

8. Future Work

The final Concept 3 design will be compared to Concepts 1 and 2 developed in Phase II of the Lightweight Front End Structure Project. An IIHS DOE study for Concept 3 is required in order to meet all IIHS targets.

9. References

1) *Validated FE Models, Milestone 5*, SPHINX, Phase II.

2) *Enhanced FE Models, Milestone 6*, SPHINX, Phase II.

3) *IIHS Crashworthiness Evaluation Offset Barrier Crash Test Protocol (Version IX), October 2002.*

4) *DOE FE Models, Milestone 7*, SPHINX, Phase II.

5) *Third Bumper Design Report, Milestone 5*, SPHINX, Phase I.

6) *Concept 1: Preliminary Design, Milestone 10*, SPHINX, Phase II.

7) *FMVSS Part 581 Bumper Standard*.

8) *Automotive Steel Design Manual*, AISI, Revision 6 April 2000.

9) *Metal Forming Handbook*, Schuler.

10) *Concept 2: Preliminary Design, Milestone 13*, SPHINX, Phase II.

11) *Concept 3: Preliminary Design, Milestone 16*, SPHINX, Phase II.

12) *Concept 1: Final Design, Milestone 12*, SPHINX, Phase II.

13) *Concept 2: Final Design, Milestone 15*, SPHINX, Phase II.

10. Appendix A: Animations

The following animation files for the subsystem development can be viewed at the Auto/Steel Partnership website, www.a-sp.org.

You will need a Hyperview Player in order to view these animations at the site. You can download this free software at www.altair.com.

1. NCAP: Concept 3
2. IIHS: Concept 3
3. NCAP: Baseline
4. IIHS: Baseline

11. Appendix B: Summary of FE Model

Component Name	ID	Property Name	ID	Material Name	ID	MASS (ton)	Thickness (mm)
att_plate_mod_lh	60003	SectShll20.1.1	60150	DP700_980_phase_	60080	2.19E-04	2
att_plate_mod_rh	60004	SectShll20.1.1	60150	DP700_980_phase_	60080	2.19E-04	2
bumper_front	60005	bumper_front	60151	DP700_980_phase_	60080	0.003506	1
bumper_back	60006	bumper_back	60152	DP700_980_phase_	60080	0.002671	1
bumper_att_bolt_	60007	bumper_att_bolt_	60147	bumper_att_bolt_	60078	1.46E-05	0
hf_rail_lh_A	60101	rail_frt_out	60154	DP450_800_phase_	60079	8.73E-04	1.2
hf_rail_rh_A	60102	rail_frt_out	60154	DP450_800_phase_	60079	8.73E-04	1.2
hf_rail_lh_B	60105	rail_rr_otr	60156	DP450_800_phase_	60079	0.002916	1.5
hf_rail_rh_B	60106	rail_rr_otr	60156	DP450_800_phase_	60079	0.002916	1.5
hf_rail_lh_C	60109	rail_ext_frt	60158	DP450_800_phase_	60079	0.002276	1.8
hf_rail_rh_C	60110	rail_ext_frt	60158	DP450_800_phase_	60079	0.002276	1.8
hf_rail_lh_D	60111	rail_ext_mid	60159	DP450_800_phase_	60079	0.002171	1.5
hf_rail_rh_D	60112	rail_ext_mid	60159	DP450_800_phase_	60079	0.002171	1.5
hf_rail_lh_E	60113	rail_ext_rr	60160	DP450_800_phase_	60079	0.002048	1.2
hf_rail_rh_E	60114	rail_ext_rr	60160	DP450_800_phase_	60079	0.002048	1.2
trqbox1.l	60117	Sectshll14.5	60111	MATL24_210	60052	0.001434	1.45
trqbox1.r	60118	Sectshll14.5	60111	MATL24_210	60052	0.001625	1.45
trqbox2.l	60119	Sectshll14.5	60111	MATL24_160	60048	2.35E-04	1.45
trqbox2.r	60120	Sectshll14.5	60111	MATL24_160	60048	2.35E-04	1.45
crfmbrkt.l	60201	SectShll20.1	60088	MATL24_340	60049	5.34E-04	2
crfmbrkt.r	60202	SectShll20.1	60088	MATL24_340	60049	5.38E-04	2
crdlfbrkt	60203	SectShll30	60094	MATL24_600	60056	8.68E-04	3
crdl.l	60205	SectShll26	60116	MATL24_340	60049	0.006018	2.6
crdl.r	60206	SectShll26	60116	MATL24_340	60049	0.006321	2.6
rrcrdlbdattch.l	60207	SectShll35	60106	MATL24_160	60048	0.001148	3.5
rrcrdlbdattch.r	60208	SectShll35	60106	MATL24_160	60048	0.001147	3.5
trnfext.l	60209	SectShll20.1	60088	MATL24_250	60054	0.001243	2
trnfext.r	60210	SectShll20.1	60088	MATL24_250	60054	0.001222	2
rrcrdlmnt1.l	60211	SectShll25	60091	MATL24_210	60052	0.001136	2.5
rrcrdlmnt1.r	60212	SectShll25	60091	MATL24_210	60052	0.001136	2.5
rrcrdlmnt2.l	60213	SectShll19.1	60112	MATL24_210	60052	2.37E-04	1.9
rrcrdlmnt2.r	60214	SectShll19.1	60112	MATL24_210	60052	2.37E-04	1.9
frtcrdlmnt1.l	60215	Sectshll19.5	60110	MATL24_160	60048	4.66E-04	1.95
frtcrdlmnt1.r	60216	Sectshll19.5	60110	MATL24_160	60048	4.66E-04	1.95
frtcrdlmnt2.l	60217	Sectshll14.5	60111	MATL24_210	60052	1.02E-04	1.45
frtcrdlmnt2.r	60218	Sectshll14.5	60111	MATL24_210	60052	1.02E-04	1.45
frtcrdlmnt5	60219	SectShll15.3	60117	MATL24_160	60048	4.31E-04	1.5
frtcrdlmnt3.l	60221	SectShll25	60091	MATL24_340	60049	4.30E-04	2.5
frtcrdlmnt3.r	60222	SectShll25	60091	MATL24_340	60049	3.41E-04	2.5
bot_bkt_l_e	60223	SectShll30	60094	MATL24_340	60049	9.59E-04	3
bot_bkt_r_e	60224	SectShll30	60094	MATL24_340	60049	9.29E-04	3
cradbrkt	60225	SectShll30	60094	MATL24_340	60049	4.46E-04	3
cradbrkt2	60227	SectShll30	60094	MATL24_340	60049	3.58E-04	3
lcarnf.l	60229	SectShll30	60094	MATL24_340	60049	3.19E-04	3
lcarnf.r	60230	SectShll30	60094	MATL24_340	60049	3.41E-04	3

lcajnt_1.L1	60231	SectShll30	60094	rigid	60014	4.12E-05	3
lcajnt_1.R1	60232	SectShll30	60094	rigid	60014	4.12E-05	3
lcacyl.l	60235	SectShll50	60092	MATL24_160	60048	0.001295	5
lcacyl.r	60236	SectShll50	60092	MATL24_160	60048	0.001295	5
lcajnt_1.L2	60239	SectShll30	60094	rigid	60014	3.16E-05	3
lcajnt_1.R2	60240	SectShll30	60094	rigid	60014	3.16E-05	3
cradbrkt1	60241	SectShll10.1	60083	MATL24_180	60046	2.36E-04	1
crdlblt	60243	SectShll20.1	60088	MATL24_160	60048	2.41E-04	2
crdlrrxupr	60244	SectShll25	60091	MATL24_340	60049	0.002183	2.5
crdlrrxlwr	60245	SectShll23	60090	MATL24_340	60049	0.00129	2.3
crdmtfrt_otb.l	60246	crd_frt_mt_otr	60161	MATL24_160	60048	6.02E-04	1.95
crdmtfrt_otb.r	60247	crd_frt_mt_otr	60161	MATL24_160	60048	6.02E-04	1.95
urail_l	60301	SectShll8.3	60081	MATL24_160	60048	0.001457	0.8
urail_r	60302	SectShll8.3	60081	MATL24_160	60048	0.001456	0.8
urail_rnf2.l	60303	SectShll9.1	60082	MATL24_160	60048	4.72E-04	0.9
urail_rnf1.r	60304	SectShll9.1	60082	MATL24_160	60048	4.71E-04	0.9
pnlfrt1.l	60305	Sectshll75	60097	MATL24_210	60052	8.60E-04	0.75
pnlfrt1.r	60306	Sectshll75	60097	MATL24_210	60052	8.60E-04	0.75
shock.l	60307	Sectshll17.5	60096	MATL24_160	60048	0.001517	1.75
shock.r	60308	Sectshll17.5	60096	MATL24_160	60048	0.001546	1.75
pnlfrt2.l	60309	SectShll12.1	60084	MATL24_210	60052	0.001561	1.2
pnlfrt2.r	60310	SectShll12.1	60084	MATL24_210	60052	0.001561	1.2
plnmbrkt	60311	SectShll8.3	60081	MATL24_210	60052	1.50E-04	0.8
rnfpnldshext2	60312	SectShll8.3	60081	MATL24_210	60052	1.93E-04	0.8
temp	60313	SectShll7.2	60080	MATL24_600	60056	2.63E-04	0.7
frtflr	60401	SectShll085	60118	MATL24_160	60048	0.013015	0.85
bar1	60402	SectShll20.1	60088	MATL24_3404	60051	0.00262	2
tnl1	60403	SectShll18.1	60087	MATL24_340	60049	0.001311	1.8
tnl2	60404	SectShll12.1	60084	MATL24_250	60054	0.006463	1.2
dash	60405	SectShll95	60113	MATL24_160	60048	0.008026	0.95
cowlupr	60406	SectShll8.3	60081	MATL24_210	60052	0.001526	0.8
fflrlvrrnf	60407	SectShll15.3	60117	MATL24_160	60048	7.10E-04	1.5
pedal2	60408	SectShll30	60094	MATL24_160	60048	0.001364	3
wndshld.supt.upr	60409	Sectshll75	60097	MATL24_160	60048	0.002599	0.75
plnmltintjnt	60410	Sectshll75	60097	MATL24_160	60048	0.004045	0.75
rein_upr	60411	SectShll15.3	60117	MATL24_210	60052	9.29E-04	1.5
MTG1	60412	SectShll10.1	60083	MATL24_210	60052	4.34E-04	1
BRKT_Consol	60413	SectShll15.3	60117	MATL24_210	60052	6.89E-04	1.5
crush_brkt_lwr	60414	SectShll20.1	60088	MATL24_210	60052	0.002868	2
bar2.l	60501	SectShll12.1	60084	MATL24_160	60048	0.001367	1.2
bar2.r	60502	SectShll12.1	60084	MATL24_160	60048	0.001368	1.2
2barreinf	60503	SectShll17	60086	MATL24_340	60049	0.00249	1.7
22678921_256_1	60505	SectShll12.1	60084	MATL24_160	60048	2.43E-04	1.2
22678920_256_1	60506	SectShll12.1	60084	MATL24_160	60048	2.43E-04	1.2
22678921_255_1	60507	SectShll12.1	60084	MATL24_160	60048	1.85E-04	1.2
22678920_255_1	60508	SectShll12.1	60084	MATL24_160	60048	1.85E-04	1.2
seatrein.l	60509	SectShll12.1	60084	MATL24_160	60048	3.45E-04	1.2
seatrein.r	60510	SectShll12.1	60084	MATL24_160	60048	3.46E-04	1.2
tiebar3.l	60601	Sectshll75	60097	MATL24_180	60046	6.78E-04	0.75
tiebar3.r	60602	Sectshll75	60097	MATL24_180	60046	7.20E-04	0.75

tiebar4.l	60603	Sectshll75	60097	MATL24_180	60046	3.84E-05	0.75
tiebar4.r	60604	Sectshll75	60097	MATL24_180	60046	3.84E-05	0.75
lhfanmotor	60605	SectShll20.1	60088	MATL24_181	60047	5.60E-04	2
rhfanmotor	60606	SectShll20.1	60088	MATL24_181	60047	5.40E-04	2
tiebar	60607	SectShll9.1	60082	MATL24_210	60052	0.002278	0.9
tiebar2	60608	SectShll9.1	60082	MATL24_160	60048	0.001163	0.9
radsupport	60609	SectShll10.1	60083	MATL24_160	60048	0.001261	1
rad4	60610	SectShll10.1	60083	MATL24_160	60048	8.32E-06	1
Part_2	60611	SectShll10.1	60083	MATL9_2	60006	0.014989	1
rad2	60612	SectSld900	60121	MAT57rad&cond	60059	0.002656	0
rad1	60613	SectSld900	60121	MAT57rad&cond	60059	0.003782	0
fanshroud	60614	SectShll20.1	60088	MATL24_181	60047	0.007298	2
egine_main_block	60701	SectShll10.1	60083	rigid	60014	0.3042	1
pt2	60702	SectShll10.1	60083	rigid	60014	0.001123	1
pt3	60703	SectShll10.1	60083	rigid	60014	0.006404	1
pt7	60704	SectShll10.1	60083	rigid	60014	0.001243	1
pt8	60705	SectShll20.1	60088	rigid	60014	0.005065	2
pt10	60706	SectShll10.1	60083	rigid	60014	9.92E-04	1
pt11	60707	SectShll225	60099	rigid	60014	0.001335	2.25
pt13	60708	SectShll10.1	60083	rigid	60014	1.07E-04	1
pt14	60709	SectShll10.1	60083	rigid	60014	0.001639	1
pt19	60710	SectShll10.1	60083	rigid	60014	4.08E-04	1
pt18	60711	SectShll40	60093	rigid	60014	0.007253	4
frtmnt1	60712	SectShll20.1	60088	MATL24_160	60048	1.04E-03	2
frtmnt2	60713	SectShll225	60099	MATL24_160	60048	3.84E-04	2.25
pt9	60714	SectShll100	60104	rigid	60014	0.005277	10
pt12	60715	SectShll80	60095	rigid	60014	0.007011	8
pt16	60716	SectShll40	60093	rigid	60014	0.003234	4
pt17	60717	SectShll30	60094	MATL24_160	60048	0.007696	3
expipefrt	60718	SectShll15.3	60117	MATL24_160	60048	0.003601	1.5
ep_7685	60719	SectShll10.1	60083	rigid	60014	2.83E-04	1
flywheel	60720	SectShll10.1	60083	rigid	60014	7.92E-04	1
ep_4776	60721	SectShll10.1	60083	rigid	60014	4.99E-04	1
ep_7498	60722	SectShll10.1	60083	rigid	60014	0.002605	1
ep_0939	60723	SectShll10.1	60083	rigid	60014	5.79E-04	1
ep_0017	60724	SectShll10.1	60083	rigid	60014	4.50E-04	1
ep_70842	60725	SectShll10.1	60083	rigid	60014	1.84E-04	1
eng_mnt_l_e	60726	SectShll80	60095	MATL24_160	60048	0.002636	8
top_bkt_l_e	60727	SectShll80	60095	MAT24_1111	60045	5.72E-04	8
eng_mnt_r_e	60728	SectShll80	60095	MATL24_160	60048	0.002631	8
top_bkt_r_e	60729	SectShll80	60095	MAT24_1111	60045	1.01E-03	8
eng_deformable	60730	SectShll80	60095	MATL24_160	60048	0.001725	8
62109a_e1	60731	SectShll37	60108	MATL24_160	60048	3.62E-04	3.7
62109a_e2	60732	SectShll37	60108	MATL24_160	60048	1.22E-04	3.7
62109a_e3	60733	SectShll37	60108	MATL24_160	60048	4.00E-04	3.7
62109b_e1	60734	SectShll10.1	60083	MATL24_160	60048	4.06E-04	1
rrmnt_bushing	60735	SectShll20.1	60088	MATL24_160	60048	5.79E-04	2
tire1.l	60801	SectShll20.1	60088	mat1.tirerubber	60007	0.00197	2
tire1.r	60802	SectShll20.1	60088	mat1.tirerubber	60007	0.00197	2
tire3.l	60803	SectShll3.3	60107	MATL24_160	60048	1.00E-03	0.3

tire2.r	60804	SectShll3.3	60107	MATL24_160	60048	1.00E-03	0.3
tir2.l	60805	SectShll7.2	60080	MATL24_160	60048	0.002042	0.7
tire3.r	60806	SectShll7.2	60080	MATL24_160	60048	0.002042	0.7
rim.l	60807	SectShll35	60106	MATL24_600	60056	0.008136	3.5
rim.r	60808	SectShll35	60106	MATL24_600	60056	0.008136	3.5
lwrcntrlarm.l	60809	SectShll30	60094	MATL24_160	60048	0.002294	3
lwrcntrlarm.r	60810	SectShll30	60094	MATL24_160	60048	0.002289	3
lcajnt_2.L1	60811	SectShll30	60094	rigid	60014	6.26E-05	3
lcajnt_2.R1	60812	SectShll30	60094	rigid	60014	6.33E-05	3
driveline	60813	SectShll70	60103	MATL24_340	60049	0.005373	7
lcajnt_2.L2	60815	SectShll30	60094	rigid	60014	2.76E-05	3
lcajnt_2.R2	60816	SectShll30	60094	rigid	60014	2.76E-05	3
fsuspstrut.l	60817	SectShll50	60092	MATL24_160	60048	0.005601	5
fsuspstrut.r	60818	SectShll50	60092	MATL24_160	60048	0.005601	5
crdlbltrnf	60819	SectShll275.1	60102	MATL24_160	60048	3.23E-04	2.75
strclnmend3	60820	SectShll50	60092	rigid	60014	3.64E-04	5
strngrack	60821	SectShll60	60101	MAT24_1111	60045	0.002617	6
strrackends	60822	SectShll60	60101	MATL24_160	60048	0.001165	6
stabbar	60823	SectShll40	60093	MATL24_160	60048	0.004576	4
btray1	60901	SectShll15.3	60117	MATL24_160	60048	0.003147	1.5
btray2	60902	SectShll10.1	60083	MATL24_160	60048	2.14E-04	1
battery1	60903	SectShll5.3	60105	MATL24_160	60048	8.66E-04	0.5
ECM	60904	SectShll10.1	60083	MATL24_160	60048	1.07E-03	1
battery_fill	60905	SectShll10.1	60083	MATL24_160	60048	0.001326	1
fcomptrnf2	60906	SectShll40	60093	MATL24_160	60048	0.002901	4
abs_brkt	60907	SectShll20.1	60088	MATL24_160	60048	4.33E-04	2
brkt_boost	60908	90060072	60042	90060009	60012	0.00385	3
edge	61001	SectShll2.1.1	60077	MAT24_3	60042	1.06E-03	1.35
inner	61002	SectShll3.2.1	60078	MAT24_3	60042	0.005147	0.7
outer	61003	SectShll4.1.1	60079	MAT24_3	60042	0.008252	0.7
MODPLT	61101	90060005	60010	90060020	60041	0.001613	1.5
CSUPT_forw	61102	90060006	60011	90060020	60041	5.32E-04	1.22
can	61103	90060008	60012	90060020	60041	6.77E-04	1.2
can1	61104	90060009	60013	90060020	60041	9.87E-05	1.2
can2	61105	90060010	60014	90060020	60041	1.09E-04	1.2
can.1	61106	90060011	60015	90060020	60041	9.05E-05	1.2
inflator	61107	90060012	60016	90060020	60041	0.001456	5.4
Brkt-1	61108	90060063	60039	90060020	60041	6.07E-04	3
gaspdel	61109	90060068	60040	90060020	60041	1.65E-04	2.5
stelpeice	61110	90060071	60041	90060020	60041	1.54E-04	3
SIPO_p	61111	90060014	60018	90060020	60041	6.06E-04	2
SIPO_d2	61112	90060015	60019	90060020	60041	6.11E-04	2
Steel_strip	61113	90060016	60020	90060020	60041	1.07E-04	1.5
Floor_Brkt2	61114	90060037	60022	90060020	60041	8.95E-04	2.5
Center_Stk_brkt	61115	90060038	60023	90060020	60041	3.09E-04	1.5
lower	61116	90060044	60026	90060013	60036	8.85E-04	2.43
upper	61117	90060045	60027	90060013	60036	8.69E-04	2.36
hvacbrkt_add	61118	90060046	60028	90060013	60036	2.49E-05	2.36
heatercvr	61119	90060047	60029	90060013	60036	3.21E-04	2.38
ai	61120	90060048	60030	90060013	60036	3.74E-04	2.1

ai_icebox	61121	90060049	60031	90060013	60036	1.51E-05	2.1
ai_actuator	61122	90060050	60032	90060013	60036	2.81E-05	2
lower_actuator	61123	90060051	60033	90060013	60036	2.86E-05	2
foamplate	61124	90060052	60034	90060020	60041	5.74E-05	1
filmvalve	61125	90060053	60035	90060013	60036	1.67E-04	2
arm1_srib	61126	90060054	60036	90060013	60036	8.90E-05	2
rib_4_hub	61127	90060055	60037	90060013	60036	1.42E-04	3.5
Lower_add1	61128	90060056	60038	90060013	60036	1.16E-05	2
foam	61129	90060125	60119	90060001	60001	1.48E-06	0
evapblock	61130	90060126	60120	90060003	60003	3.52E-05	0
IBEC	61131	90060013	60017	90060005	60004	3.04E-04	2
evap_lower_tube1	61132	90060041	60024	90060002	60002	8.68E-06	1
evap_upper_tube1	61133	90060041	60024	90060002	60002	1.38E-05	1
heat_upper_tube1	61134	90060041	60024	90060002	60002	4.22E-05	1
heat_lower_tube1	61135	90060041	60024	90060002	60002	2.58E-05	1
il	61136	90060042	60025	90060014	60037	1.89E-04	1
IP_sidepnl_E	61137	90060026	60021	90060015	60038	1.24E-04	2.5
sipo_fixed1	61138	90060015	60019	90060008	60011	1.39E-06	2
sipo_fixed2	61139	90060015	60019	90060008	60011	1.46E-06	2
sipo_fixed3	61140	90060015	60019	90060008	60011	1.53E-06	2
sipo_fixed4	61141	90060015	60019	90060008	60011	1.13E-06	2
sipo_fixed5	61142	90060015	60019	90060008	60011	1.85E-06	2
sipo_fixed6	61143	90060015	60019	90060008	60011	1.95E-06	2
sipo_fixed7	61144	90060015	60019	90060008	60011	1.83E-06	2
sipo_p_fixed7	61145	90060014	60018	90060008	60011	1.41E-06	2
sipo_p_fixed6	61146	90060014	60018	90060008	60011	1.59E-06	2
sipo_p_fixed5	61147	90060014	60018	90060008	60011	1.71E-06	2
sipo_p_fixed4	61148	90060014	60018	90060008	60011	1.13E-06	2
sipo_p_fixed3	61149	90060014	60018	90060008	60011	1.85E-06	2
sipo_p_fixed2	61150	90060014	60018	90060008	60011	1.95E-06	2
sipo_p_fixed12	61151	90060014	60018	90060008	60011	1.83E-06	2
modplate_rigid1	61152	90060005	60010	90060008	60011	1.55E-06	1.5
modplate_rigid2	61153	90060005	60010	90060008	60011	2.34E-06	1.5
modplate_rigid32	61154	90060005	60010	90060008	60011	1.45E-06	1.5
modplate_rigid4	61155	90060005	60010	90060008	60011	1.65E-06	1.5
modplate_rigid5	61156	90060005	60010	90060008	60011	1.58E-06	1.5
modplate_rigid6	61157	90060005	60010	90060008	60011	1.98E-06	1.5
modplate_rigid7	61158	90060005	60010	90060008	60011	9.84E-07	1.5
modplate_rigid8	61159	90060005	60010	90060008	60011	1.76E-06	1.5
e.pedal	61160	90060073	60043	90060011	60034	8.37E-04	8
e.pad	61164	90060074	60044	90060011	60034	1.20E-04	3.5
e.pin	61165	90060075	60045	90060011	60034	1.14E-04	2
pedalpivout	61167	90060072	60042	90060009	60012	8.58E-06	3
pedalpivinb	61168	90060072	60042	90060009	60012	8.58E-06	3
pedallink	61169	90060072	60042	90060009	60012	1.43E-06	3
pivot inb	61170	90060072	60042	90060009	60012	4.32E-06	3
pivot out	61171	90060072	60042	90060009	60012	1.10E-06	3
Part221130	61172	90060072	60042	90060009	60012	1.08E-06	3
Part221131	61173	90060072	60042	90060009	60012	1.39E-06	3
Part221132	61174	90060072	60042	90060009	60012	9.68E-07	3

Part221133	61175	90060072	60042	90060009	60012	9.79E-07	3
Part221134	61176	90060072	60042	90060009	60012	6.86E-07	3
Part221135	61177	90060072	60042	90060009	60012	1.30E-06	3
Part221136	61178	90060072	60042	90060009	60012	9.62E-07	3
dr_ealf	61179	90060077	60047	90060011	60034	2.25E-04	1.5
dr_eart	61180	90060077	60047	90060020	60041	2.25E-04	1.5
ps_eart	61181	90060076	60046	90060020	60041	1.64E-04	1.5
ps_eart.1	61182	90060076	60046	90060020	60041	1.64E-04	1.5
floor_attachment	61183	90060078	60048	90060020	60041	5.18E-04	2
tunlbkt_fixdeles	61184	90060078	60048	90060010	60013	1.18E-06	2
tunlbkt_fixdeles	61185	90060078	60048	90060010	60013	1.27E-06	2
tunlbkt_fixdeles	61186	90060078	60048	90060010	60013	2.33E-06	2
tunlbkt_fixdeles	61187	90060078	60048	90060010	60013	1.83E-06	2
tunlbkt_fixdeles	61188	90060078	60048	90060010	60013	4.47E-06	2
tunlbkt_fixdeles	61189	90060078	60048	90060010	60013	7.59E-06	2
tunlbkt_fixdeles	61190	90060078	60048	90060010	60013	2.76E-06	2
tunlbkt_fixdeles	61191	90060078	60048	90060010	60013	3.89E-06	2
gboxframe_base	61192	90060080	60049	90060016	60039	3.92E-04	2.5
vribs_gboxframe	61193	90060081	60050	90060016	60039	4.81E-06	1
hribs_gboxframe	61194	90060082	60051	90060016	60039	2.76E-05	1.2
Mag_6.5.1.1	61196	90060100	60052	90060012	60035	3.18E-04	6.5
Mag_3.0.1.1	61197	90060101	60053	90060012	60035	0.00345	3
Mag_4.0.1.1	61198	90060102	60054	90060012	60035	4.81E-04	4
Mag_ribs.1.1	61199	90060103	60055	90060012	60035	0.002748	3
Mag_1.5.1.1	61200	90060104	60056	90060012	60035	1.28E-04	1.5
Mag_5.0.1	61201	90060105	60057	90060012	60035	1.40E-04	5
Mag_2.5	61202	90060106	60058	90060012	60035	2.65E-04	2.5
inner.1	61203	90060107	60059	90060016	60039	3.58E-04	3
innergroorve	61204	90060111	60063	90060016	60039	8.37E-07	3.3
ribs.1	61205	90060112	60064	90060016	60039	1.36E-04	1.25
bin o	61206	90060108	60060	90060017	60040	2.74E-04	2.5
ribbin	61207	90060110	60062	90060017	60040	5.71E-07	1.7
bintongue	61208	90060109	60061	90060017	60040	4.40E-07	1.1
outer.1	61209	90060113	60065	90060016	60039	2.85E-04	2.5
hub	61210	90060115	60067	90060016	60039	1.76E-06	1
outerhrib	61211	90060114	60066	90060016	60039	7.18E-06	1.2
outervrib	61212	90060115	60067	90060016	60039	3.35E-07	1
hubrib	61213	90060116	60068	90060016	60039	1.93E-07	1.375
glvbx_frm_hinge_	61214	90060117	60069	90060016	60039	8.29E-06	3
knee bolster inn	61215	90060118	60070	90060016	60039	2.66E-04	2.5
inner rib h	61216	90060119	60071	90060016	60039	1.25E-04	1.875
small rib inner	61217	90060120	60072	90060016	60039	3.27E-06	2.6
knee bolster out	61218	90060121	60073	90060016	60039	4.25E-04	2.5
doghouse outer	61219	90060122	60074	90060016	60039	6.40E-06	1.4
outer rib	61220	90060123	60075	90060016	60039	4.29E-06	1.1
tipof bin	61221	90060124	60076	90060016	60039	5.01E-05	2.5
part.9	61301	SectShll20.1	60088	MAT9_704	60009	1.21E-04	2
part.10	61302	SectShll20.1	60088	MAT9_705	60010	5.21E-05	2
part.11	61303	SectShll5.3	60105	MAT20_706	60015	5.98E-05	0.5
part.14	61304	SectShll20.1	60088	MAT20_750	60016	0.001699	2

part.15	61305	SectShll10.1	60083	MAT20_751	60017	8.05E-05	1
part.16	61306	SectShll34	60115	MAT20_752	60018	1.83E-04	3.4
part.17	61307	SectShll25	60091	MAT20_753	60019	5.23E-04	2.5
part.18	61308	SectShll25	60091	MAT20_754	60020	6.50E-04	2.5
part.19	61309	SectShll20.1	60088	MAT20_755	60021	5.14E-04	2
part.20	61310	SectShll30	60094	MAT20_756	60022	4.70E-04	3
part.21	61311	SectShll34	60115	MAT20_757	60023	2.55E-04	3.4
part.22	61312	SectShll20.1	60088	MAT20_758	60024	5.61E-05	2
part.24	61313	SectShll20.1	60088	MAT20_760	60025	1.14E-04	2
part.25	61314	SectShll20.1	60088	MAT20_761	60026	8.86E-05	2
part.28	61315	SectShll20.1	60088	MAT20_764	60027	2.43E-05	2
part.29	61316	SectShll20.1	60088	MAT20_765	60028	2.32E-05	2
part.30	61317	SectShll40	60093	MAT20_766	60029	3.95E-06	4
part.31	61318	SectShll40	60093	MAT20_767	60030	3.95E-06	4
part.34	61319	SectShll40	60093	MAT24_771	60044	2.43E-05	4
part.40	61320	SectShll30	60094	MAT20_777	60031	3.28E-04	3
part.41	61321	SectShll30	60094	MAT20_778	60032	3.69E-04	3
strclnmend4	61323	SectShll50	60092	rigid	60014	2.10E-04	5
part.49	61324	SectShll15.3	60117	MAT20_20015	60033	9.89E-06	1.5
drinrpnl.l	61401	Sectshll75	60097	MATL24_160	60048	0.003637	0.75
drlwrhng.l	61402	SectShll50	60092	MATL24_160	60048	1.28E-04	5
drotrpnl.l	61403	Sectshll75	60097	MATL24_180	60046	0.004388	0.75
z-brkt.l	61404	SectShll10.1	60083	MATL24_160	60048	5.56E-05	1
upr_frame.l	61405	SectShll10.1	60083	MATL24_160	60048	0.001997	1
drbeam.l	61406	SectShll20.1	60088	MATL24_600	60056	0.001914	2
druprhng.l	61407	SectShll50	60092	MATL24_160	60048	1.30E-04	5
drinrpnl.r	61408	Sectshll75	60097	MATL24_160	60048	0.003636	0.75
drotrpnl.r	61409	Sectshll75	60097	MATL24_180	60046	0.004388	0.75
z-brkt.r	61410	SectShll10.1	60083	MATL24_160	60048	5.56E-05	1
upr_frame.r	61411	SectShll10.1	60083	MATL24_160	60048	0.001997	1
drbeam.r	61412	SectShll20.1	60088	MATL24_600	60056	0.001913	2
druphng.r	61413	SectShll50	60092	MATL24_160	60048	1.34E-04	5
drlwhng.r	61414	SectShll50	60092	MATL24_160	60048	1.26E-04	5
fdrbdhng	61415	SectShll50	60092	MATL24_210	60052	2.07E-04	5
fdrbdhng2	61416	SectShll20.1	60088	rigid	60014	1.96E-05	2
fdrbdhng3	61417	SectShll20.1	60088	rigid	60014	2.43E-05	2
fdrbdhng4	61418	SectShll50	60092	MATL24_210	60052	2.01E-04	5
fdrbdhng5	61419	SectShll20.1	60088	rigid	60014	2.07E-05	2
fdrbdhng6	61420	SectShll20.1	60088	rigid	60014	2.54E-05	2
fdrbdhng7	61421	SectShll50	60092	MATL24_210	60052	2.55E-04	5
fdrbdhng8	61422	SectShll20.1	60088	rigid	60014	2.01E-05	2
fdrbdhng9	61423	SectShll20.1	60088	rigid	60014	2.48E-05	2
fdrbdhng10	61424	SectShll50	60092	MATL24_210	60052	1.97E-04	5
fdrbdhng11	61425	SectShll20.1	60088	rigid	60014	2.07E-05	2
fdrbdhng12	61426	SectShll20.1	60088	rigid	60014	2.49E-05	2
drlsrwld.l	61427	SectShll18.1	60087	MATL24_160	60048	0.003567	1.8
drlsrwld.r	61428	SectShll18.1	60087	MATL24_160	60048	0.003567	1.8
rrdrinn.l	61429	Sectshll75	60097	MATL24_160	60048	0.006811	0.75
twdrrdrinr.l	61430	SectShll18.1	60087	MATL24_160	60048	0.005454	1.8
rrdrotr.l	61431	Sectshll75	60097	MATL24_160	60048	0.008021	0.75

rrdrfrm.l	61432	SectShll10.1	60083	MATL24_160	60048	0.003331	1
rrdrbm.l	61433	SectShll20.1	60088	MATL24_600	60056	0.002513	2
bathtub.l	61434	SectShll20.1	60088	MATL24_160	60048	2.59E-04	2
rrdrhng.l	61435	SectShll50	60092	MATL24_160	60048	1.06E-03	5
latchjt.l	61436	SectShll20.1	60088	MATL24_160	60048	2.28E-04	2
rrdrhng1.l	61437	SectShll50	60092	MATL24_160	60048	6.20E-04	5
roof	61501	Sectshll75	60097	MATL24_160	60048	0.010108	0.75
wshield	61502	SectShll48	60100	laminatedglass	60058	0.015411	4.8
rr_wndshld	61503	SectShll48	60100	laminatedglass	60058	0.011652	4.8
bdysdpnlotr.l	61601	Sectshll75	60097	MATL24_160	60048	0.014307	0.75
bdysdpnlotr.r	61602	Sectshll75	60097	MATL24_160	60048	0.014308	0.75
twldbsideinr.l	61603	SectShll21	60089	MATL24_160	60048	0.00905	2.1
twldbsideinr.r	61604	SectShll21	60089	MATL24_160	60048	0.009056	2.1
rkrx_l	61605	Sectshll13	60098	MATL24_340	60049	1.01E-03	1.3
rkrx_r	61606	Sectshll13	60098	MATL24_340	60049	1.01E-03	1.3
rkrinr.l	61607	sectshll16	60114	MATL24_3404	60051	0.003811	1.6
rkrinr.r	61608	sectshll16	60114	MATL24_3404	60051	0.003811	1.6
twldB-plr.l	61609	SectShll18.1	60087	MATL24_250	60054	0.003041	1.8
twldB-plr.r	61610	SectShll18.1	60087	MATL24_250	60054	0.003041	1.8
bdysdpnlinr.l	61611	SectShll10.1	60083	MATL24_160	60048	0.009621	1
bdysdpnlinr.r	61612	SectShll10.1	60083	MATL24_160	60048	0.009567	1
B_plr_rnf	61613	SectShll10.1	60083	MATL24_160	60048	6.01E-04	1
bplrrnf.l	61615	SectShll225	60099	MATL24_250	60054	0.003029	2.25
bplrrnf.r	61616	SectShll225	60099	MATL24_250	60054	0.003029	2.25
rfrailrnfl	61617	SectShll20.1	60088	MATL24_210	60052	0.002007	2
rfrailrnfr	61618	SectShll20.1	60088	MATL24_210	60052	0.002007	2
frt_hrn	61619	SectShll20.1	60088	MATL24_160	60048	7.90E-04	2
rfrailinr.r	61620	SectShll20.1	60088	MATL24_160	60048	7.85E-04	2
a_pilar_rnf_l	61621	SectShll10.1	60083	MATL24_160	60048	9.04E-04	1
a_pilar_rnf_r	61622	SectShll10.1	60083	MATL24_160	60048	9.05E-04	1
fbhplrrnf1.l	61623	SectShll10.1	60083	MATL24_210	60052	0.001632	1
fbhplrrnf1.r	61624	SectShll10.1	60083	MATL24_210	60052	0.001634	1
frthdr	61625	SectShll7.2	60080	MATL24_160	60048	9.30E-04	0.7
rfbow2	61626	SectShll9.1	60082	MATL24_340	60049	9.23E-04	0.9
rearflr	61627	SectShll8.3	60081	MATL24_160	60048	0.017539	0.8
bar3	61628	SectShll10.1	60083	MATL24_211	60053	0.002442	1
bar4ctr	61629	SectShll10.1	60083	MATL24_340	60049	0.001438	1
bar4lft	61630	SectShll15.3	60117	MATL24_160	60048	0.001168	1.5
rrrail.l	61631	SectShll15.3	60117	MATL24_251	60055	0.005535	1.5
rrrailrnf1.l	61632	SectShll10.1	60083	MATL24_160	60048	1.93E-04	1
rrailrnf2.l	61633	SectShll10.1	60083	MATL24_160	60048	2.10E-04	1
gusset.l	61634	SectShll15.3	60117	MATL24_160	60048	7.13E-04	1.5
gusset2.l	61635	SectShll15.3	60117	MATL24_160	60048	8.44E-04	1.5
gusset3.l	61636	SectShll15.3	60117	MATL24_160	60048	5.19E-04	1.5
gusset4.l	61637	SectShll15.3	60117	MATL24_160	60048	5.89E-04	1.5
whlhsinr.l	61638	SectShll10.1	60083	MATL24_160	60048	0.002906	1
4barrnf1.l	61639	SectShll20.1	60088	MATL24_160	60048	0.001399	2
4barrnf2.l	61640	SectShll25	60091	MATL24_160	60048	7.24E-04	2.5
backpanel	61641	SectShll8.3	60081	MATL24_160	60048	0.005311	0.8
bpnlrnf	61642	Sectshll75	60097	MATL24_160	60048	0.001933	0.75

rrhdr	61643	SectShll9.1	60082	MATL24_160	60048	0.001131	0.9
rrsuspshk.l	61644	SectShll225	60099	MATL24_160	60048	3.05E-04	2.25
rkrblkhds	61645	SectShll12.1	60084	MATL24_340	60049	7.54E-04	1.2
rdeck	61646	SectShll10.1	60083	MATL24_160	60048	0.005446	1
trnkgtrfrt	61647	SectShll10.1	60083	MATL24_160	60048	0.00209	1
rdeckbrkt1	61648	SectShll10.1	60083	MATL24_160	60048	9.01E-04	1
rdeckbrkt2	61649	SectShll10.1	60083	MATL24_160	60048	2.49E-04	1
trnkgtr.l	61650	SectShll9.1	60082	MATL24_160	60048	3.97E-04	0.9
rdeckbrkt3.l	61651	SectShll10.1	60083	MATL24_160	60048	8.76E-04	1
rdeckbrkt4.l	61652	SectShll10.1	60083	MATL24_160	60048	7.67E-04	1
trlrhtchbrkt	61653	SectShll10.1	60083	MATL24_160	60048	0.001306	1
rrailext.l	61654	SectShll15.3	60117	MATL24_160	60048	7.55E-04	1.5
bar4rt	61655	SectShll15.3	60117	MATL24_160	60048	0.001168	1.5
rrrail.r	61656	SectShll15.3	60117	MATL24_251	60055	0.005519	1.5
rrailrnf1.r	61657	SectShll10.1	60083	MATL24_160	60048	1.93E-04	1
rrailrnf2.r	61658	SectShll10.1	60083	MATL24_160	60048	2.10E-04	1
gusset.r	61659	SectShll15.3	60117	MATL24_160	60048	7.13E-04	1.5
gusset2.r	61660	SectShll15.3	60117	MATL24_160	60048	8.44E-04	1.5
gusset3.r	61661	SectShll15.3	60117	MATL24_160	60048	5.19E-04	1.5
gusset4.r	61662	SectShll15.3	60117	MATL24_160	60048	5.87E-04	1.5
whlhsinr.r	61663	SectShll10.1	60083	MATL24_160	60048	0.003046	1
4barrnf1.r	61664	SectShll20.1	60088	MATL24_160	60048	0.001459	2
4barrnf2.r	61665	SectShll25	60091	MATL24_160	60048	6.97E-04	2.5
rrsuspshk.r	61666	SectShll225	60099	MATL24_160	60048	3.05E-04	2.25
trnkgtr.r	61667	SectShll9.1	60082	MATL24_160	60048	4.00E-04	0.9
rdeckbrkt3.r	61668	SectShll10.1	60083	MATL24_160	60048	8.73E-04	1
rdeckbrkt4.r	61669	SectShll10.1	60083	MATL24_160	60048	7.63E-04	1
rrailext.r	61670	SectShll15.3	60117	MATL24_160	60048	7.48E-04	1.5
fbhpbulkhd.l	61671	SectShll20.1	60088	MATL24_340	60049	5.83E-04	2
rkrblkhds.1	61672	SectShll12.1	60084	MATL24_340	60049	2.83E-04	1.2
accl.r	61673	SectShll10.1	60083	rigid	60014	4.29E-05	1
accl.l	61674	SectShll10.1	60083	rigid	60014	4.56E-05	1
rr_hrn	61675	SectShll14.1	60085	MATL24_160	60048	9.12E-04	1.4
fbhp_brkt	61676	SectShll20.1	60088	MATL24_210	60052	1.84E-04	2
rkr_extn	61677	Sectshll75	60097	MATL24_600	60056	0.001526	0.75
muffler	61701	SectShll5.3	60105	MATL24_160	60048	0.00133	0.5
exhstpipe	61702	SectShll5.3	60105	MATL24_160	60048	0.00201	0.5
rtire.l	61801	SectShll10.1	60083	MATL24_160	60048	0.007576	1
rtire.r	61802	SectShll10.1	60083	MATL24_160	60048	0.007576	1
rearrim	61803	SectShll35	60106	MATL24_160	60048	0.015933	3.5
rbmpbmbrkt.l	61901	SectShll15.3	60117	MATL24_160	60048	4.35E-04	1.5
rbmpbmbrkt.r	61902	SectShll15.3	60117	MATL24_160	60048	4.35E-04	1.5
rbumpbeam	61903	SectShll10.1	60083	MATL24_160	60048	0.003708	1
part.42	62001	SectDisc779	60123	MATSpr1_779	60063	0	0
part.43	62002	SectDisc780	60124	MATDmp2_780	60064	0	0
part.44	62003	SectDisc781	60125	MATSpr4_781	60069	0	0
part.47	62004	SectDisc783	60126	MATDmp2_784	60065	0	0
part.12	62005	SectBeam707	60009	MAT24_707	60043	7.70E-04	0
bar1fsusp	62006	Sectbeam10500	60002	MATBEAM	60057	0.001903	0
bar2fsusp	62007	Sectbeam10501	60003	MATBEAM	60057	4.12E-05	0

bar3fsusp	62008	Sectbeam10500	60002	MATBEAM	60057	1.41E-04	0
BARDLINE	62009	Sectbeam10504	60004	MATBEAM	60057	7.06E-05	0
bar4fsusp	62010	Sectbeam10500	60002	MATBEAM	60057	9.48E-04	0
bar2dline	62011	Sectbeam10500	60002	MATBEAM	60057	0.001306	0
bar3dline	62012	Sectbeam10504	60004	MATBEAM	60057	1.16E-04	0
bar5dline	62013	Sectbeam10509	60005	MATBEAM	60057	8.50E-05	0
bar1rrsus	62014	Sectbeam10500	60002	MATBEAM	60057	0.007365	0
bar2rrsusp	62015	Sectbeam10516	60006	MATBEAM	60057	0.019679	0
bar3rrsusp	62016	Sectbeam10516	60006	MATBEAM	60057	0.0026	0
bar4rrsusp	62017	Sectbeam10516	60006	MATBEAM	60057	0.002841	0
bardummies	62018	Sectbeam10519	60007	MATBEAM	60057	0.003373	0
barseat	62019	Sectbeam10519	60007	MATBEAM	60057	3.34E-04	0
barradiator	62020	Sectbeam10522	60008	MATBEAM	60057	1.82E-04	0
bardriveline	62021	Sectbeam10504	60004	MATBEAM	60057	2.57E-04	0
bardriveline8	62022	Sectbeam10504	60004	MATBEAM	60057	7.05E-05	0
sprdrvline	62023	SectDisc1	60122	Matsprstr14	60066	0	0
sprengmnt3	62024	SectDisc1	60122	Matsprstr113	60067	0	0
sprdummy	62025	SectDisc1	60122	Matsprstr114	60068	0	0
spr2dummy	62026	SectDisc1	60122	Matsprstr116	60062	0	0
spr3dummy	62027	SectDisc1	60122	Matsprstr116	60062	0	0
ltmount_spring	62028	SectDisc20071.1	60127	MATSpr4_61112	60070	0	0
rt_mount_spring	62029	SectDisc20071.1	60127	MATSpr4_61113	60071	0	0
rr_cdl_atch_spri	62030	SectDisc20071.1	60127	MATSpr4_61116	60073	0	0
rr_cdl_atch_spri	62031	SectDisc20071.1	60127	MATSpr4_61115	60072	0	0
hinge_beam_65dia	62032	90060004	60001	90060006	60005	1.06E-04	0
Masses	62033	N/A	N/A		0	0.002085	N/A
ElemMass	62034	N/A	N/A		0	0.633762	N/A
ncap_driver_pass	62035	N/A	N/A		0	0.156	N/A
SpotWelds	62039	N/A	N/A		0	0	N/A
Rigids.5	62040	N/A	N/A		0	0	N/A
Joints	62042	N/A	N/A		0	0	N/A
2T_Welds	62043	N/A	N/A	2T_Welds	60075	0	N/A
out_front_lh_doo	62047	N/A	N/A		0	1.42E-04	N/A
out_ip_masses_2	62050	N/A	N/A		0	0.001933	N/A
out_hood_masses_	62054	N/A	N/A		0	9.59E-05	N/A
out_roof_masses_	62056	N/A	N/A		0	8.76E-05	N/A
out_windshield_m	62058	N/A	N/A		0	1.92E-06	N/A
out_rear_lh_door	62060	N/A	N/A		0	1.96E-04	N/A
new_weld	124214	N/A	N/A		0	0	N/A
out_front_rh_doo	62064	N/A	N/A		0	1.53E-04	N/A
out_rear_rh_door	62066	N/A	N/A		0	1.90E-04	N/A
new_rgds	124215	N/A	N/A		0	0	N/A
rgd_should_not_b	124216	N/A	N/A	MAT20_751	60017	0	N/A
wleds_should_not	124217	N/A	N/A	MAT20_751	60017	0	N/A

Total Components	**488**
Model Mass	**1.763 tonnes**

- Model mass is from LS-DYNA3D d3hsp file.
- Part mass summary is from HYPERMESH.

12. Appendix C: Attached Parts

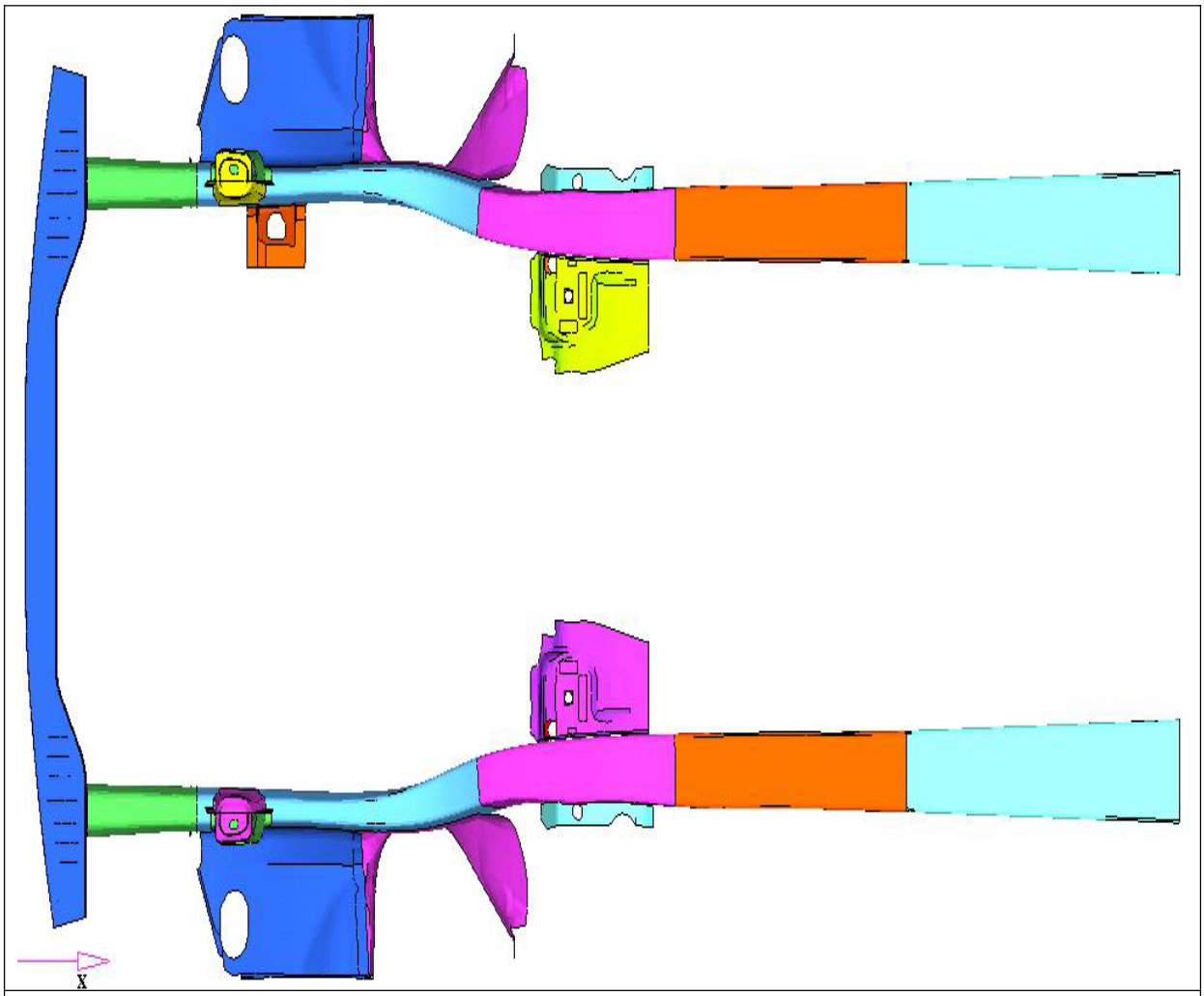


Figure 21: Attached Parts – Top View

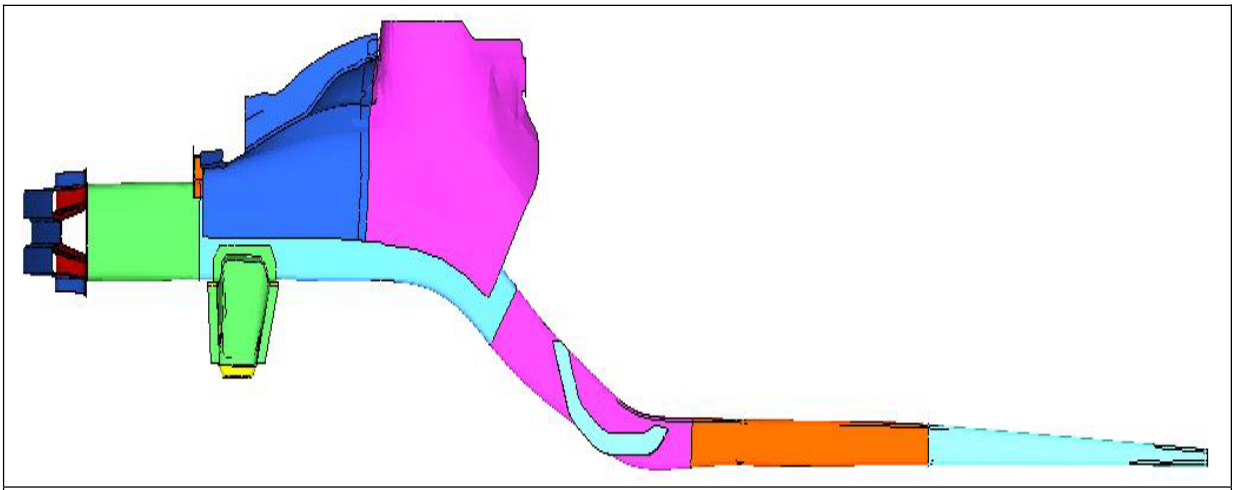


Figure 22: Attached Parts – Side View

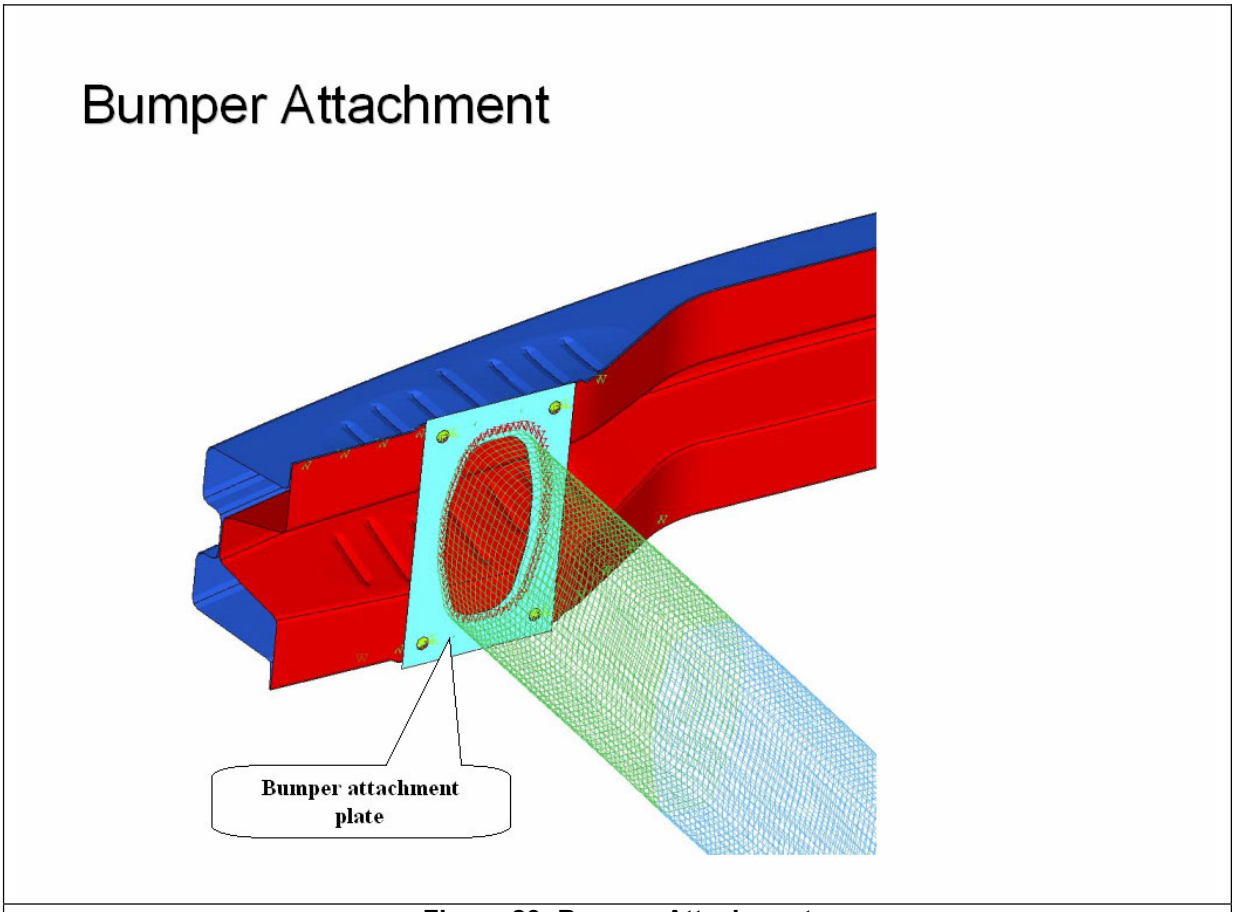


Figure 23: Bumper Attachment

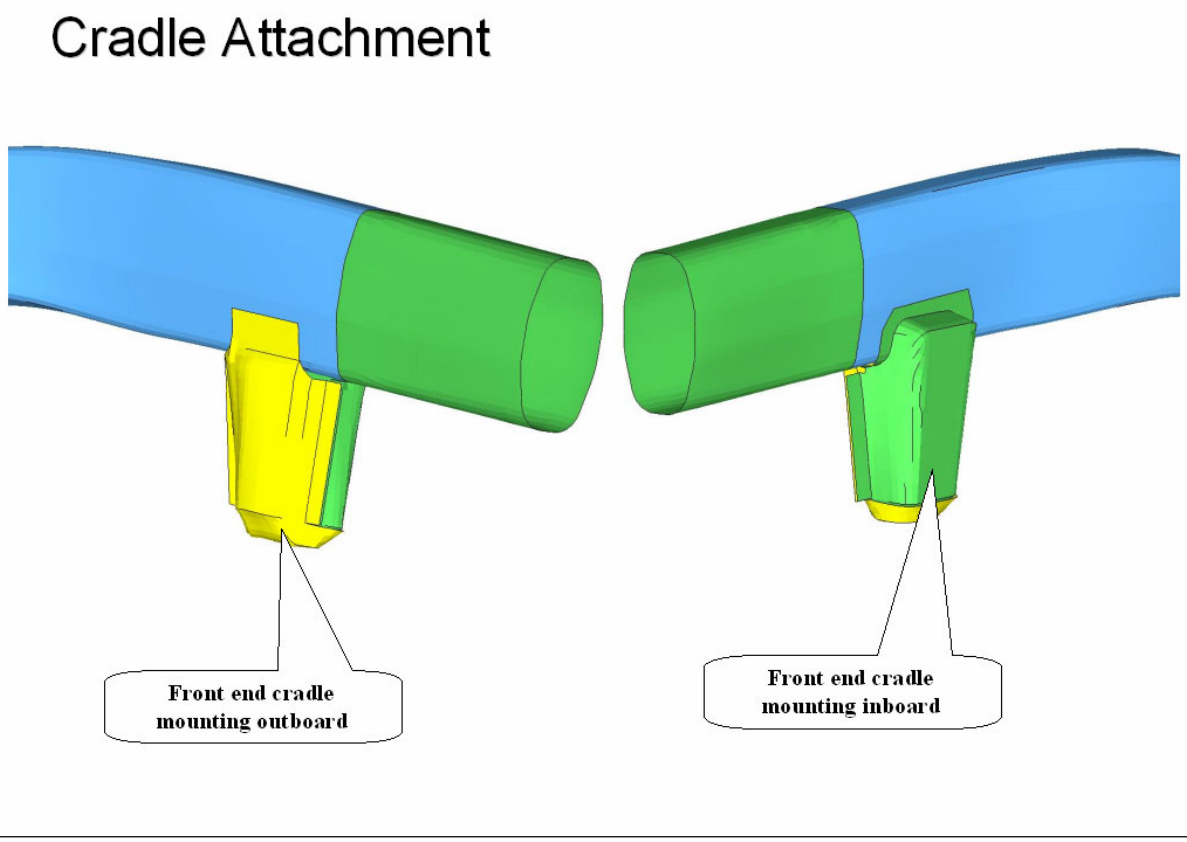


Figure 24: Front Cradle Mount

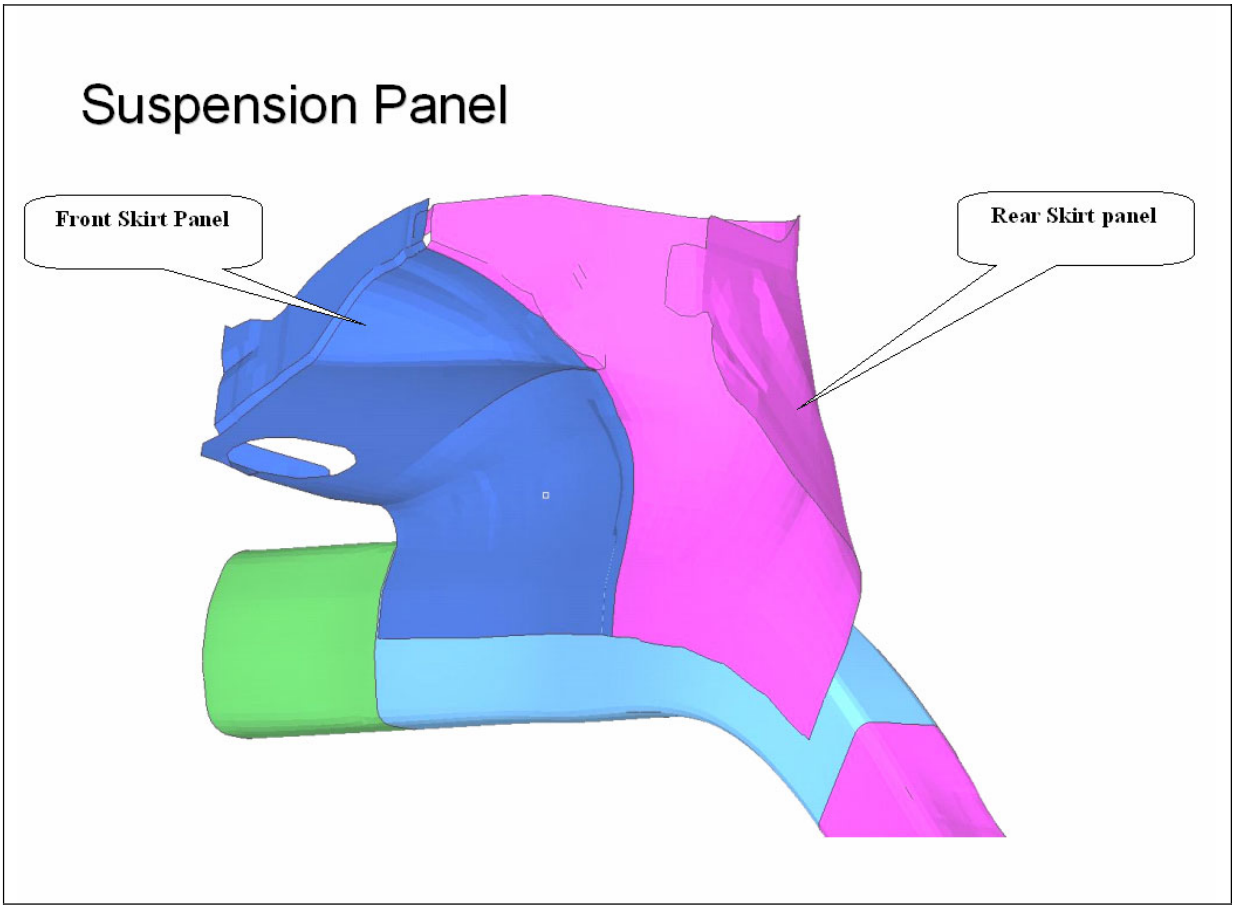


Figure 25: Suspension Panel

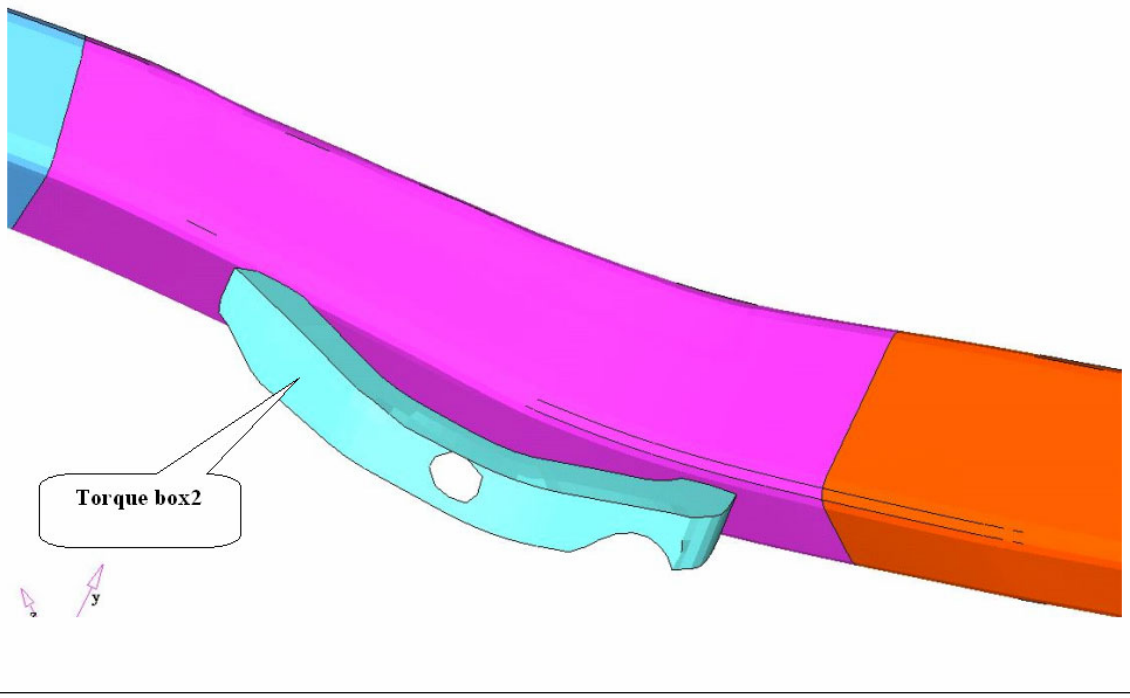


Figure 26: Torque Box

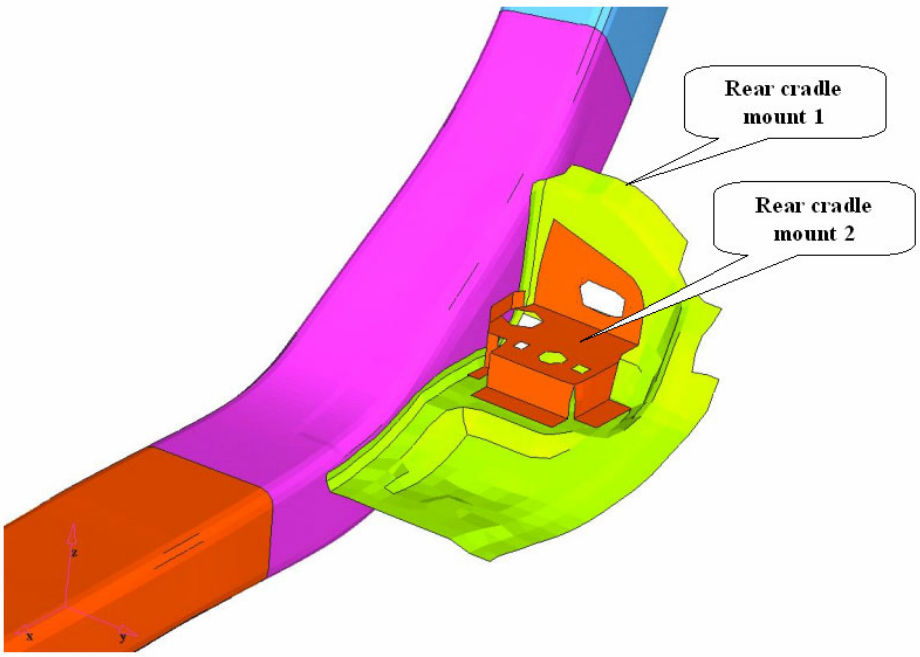


Figure 27: Rear Cradle Mount

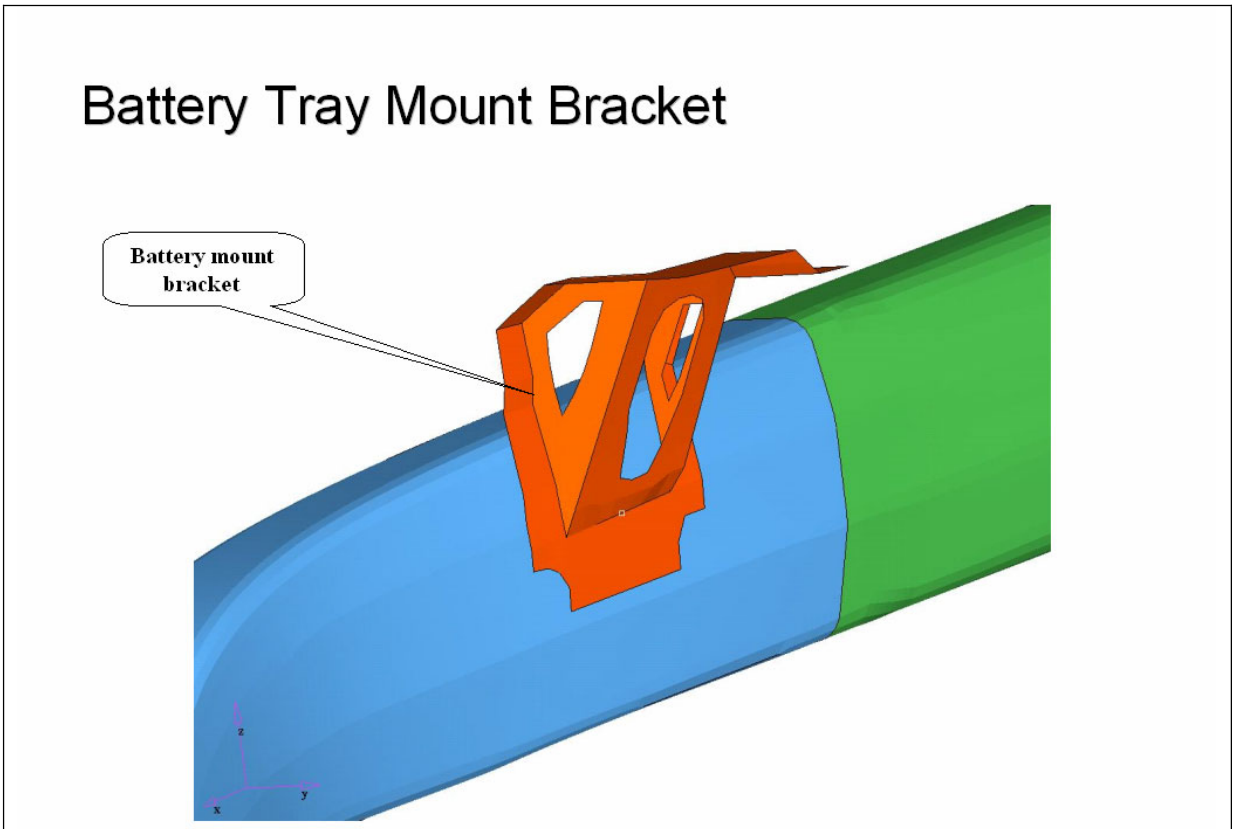


Figure 28: Battery

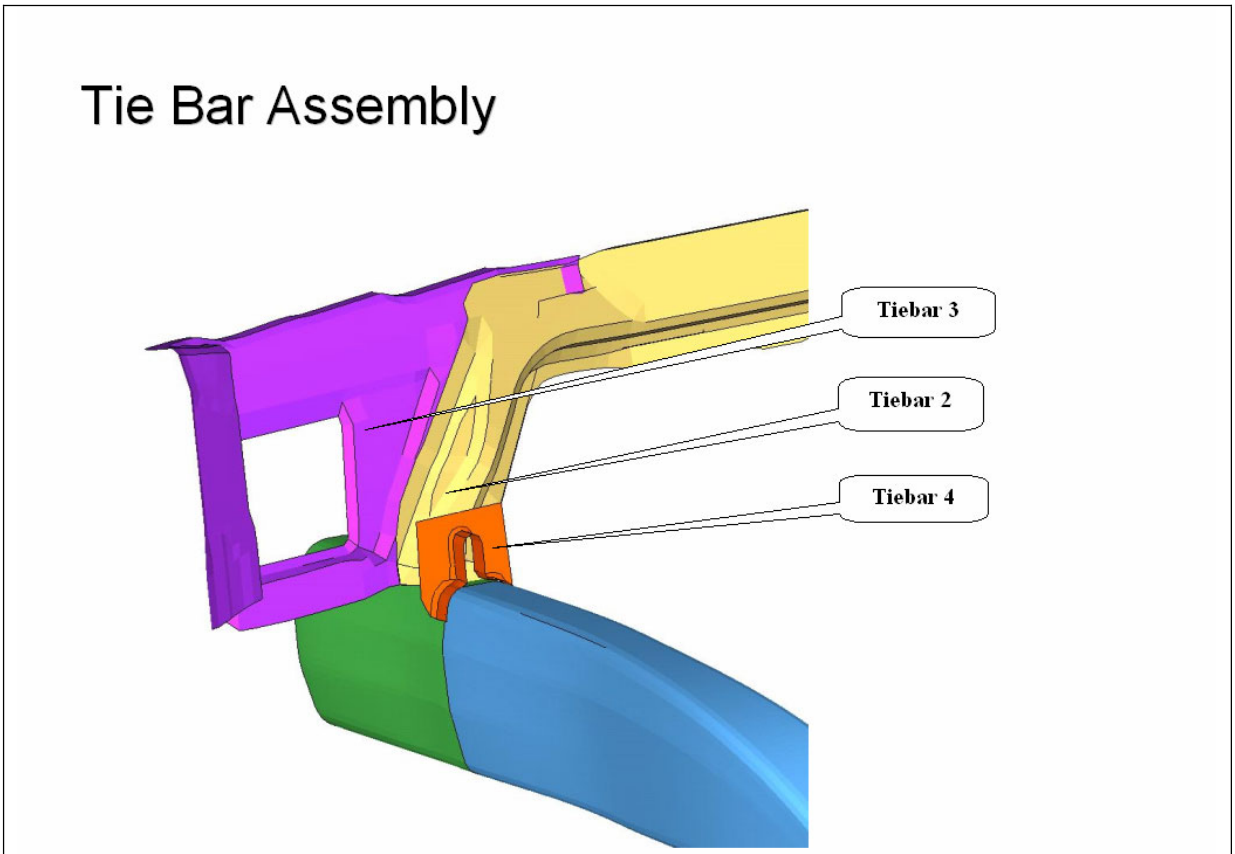


Figure 29: Tie Bar

Bumper Formability

Milestone 19

Lightweight Front End Structure Phase II

March 11, 2004

Auto/Steel Partnership

Abstract

This report documents the formability analyses of the stamped bumper design developed in Phase II of the Lightweight Front End Structure Project. This bumper design will be prototyped and assembled into the donor vehicle along with the *new stamped rail assembly*.

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1. Objectives

The effort of this study was aimed at conducting the formability analyses of the stamped bumper design developed in Phase II of the Lightweight Front End Structure Project. This bumper design will be prototyped and assembled into the donor vehicle along with the *new stamped rail assembly*.

2. Results Summary

The bumper design has the following features.

- 2-piece double-box stamped design using DP980 steel.
- Vertical flanges and beads on the inner and outer pieces.
- Bumper beam is bolted to the front rails through an attachment plate.
- Good high-speed crash performance (*9)*.
- Satisfies low-speed criterion.
- Good manufacturability and weldability.

The bumper grade/gauge are summarized in *Table 1.* Please note that the final optimized bumper beam gauge is 1.0mm. However, a gauge of 1.2mm was used in the formability analyses included in this report.

Table 1: Grade and Gauge Summary

Part	Bumper Design	
	Grade	Gauge (mm)
Bumper Beam – Inner and Outer	**DP 700/980**	**1.2**
Bumper Plate	**DP 700/980**	**2.0**

3. Bumper Design

The baseline bumper was replaced by a new bumper design (*Figure 1, Figure 2*). The new bumper design is functionally quite similar to the Phase I *Bumper 3* design. However, it has fewer manufacturing and welding concerns than the Bumper 3 design. The new bumper design is a 2-piece double-box stamped design using DP980 steel. The bumper has vertical flanges and beads on the inner and outer pieces. The new bumper design has good energy absorption capability in high-speed impacts and results in a high initial peak in the NCAP B-pillar pulse. In addition, the bumper is more formable than the Phase I Bumper 3 design, and is easier to weld. *A design similar to the new bumper design has been prototyped using DF140T steel.*

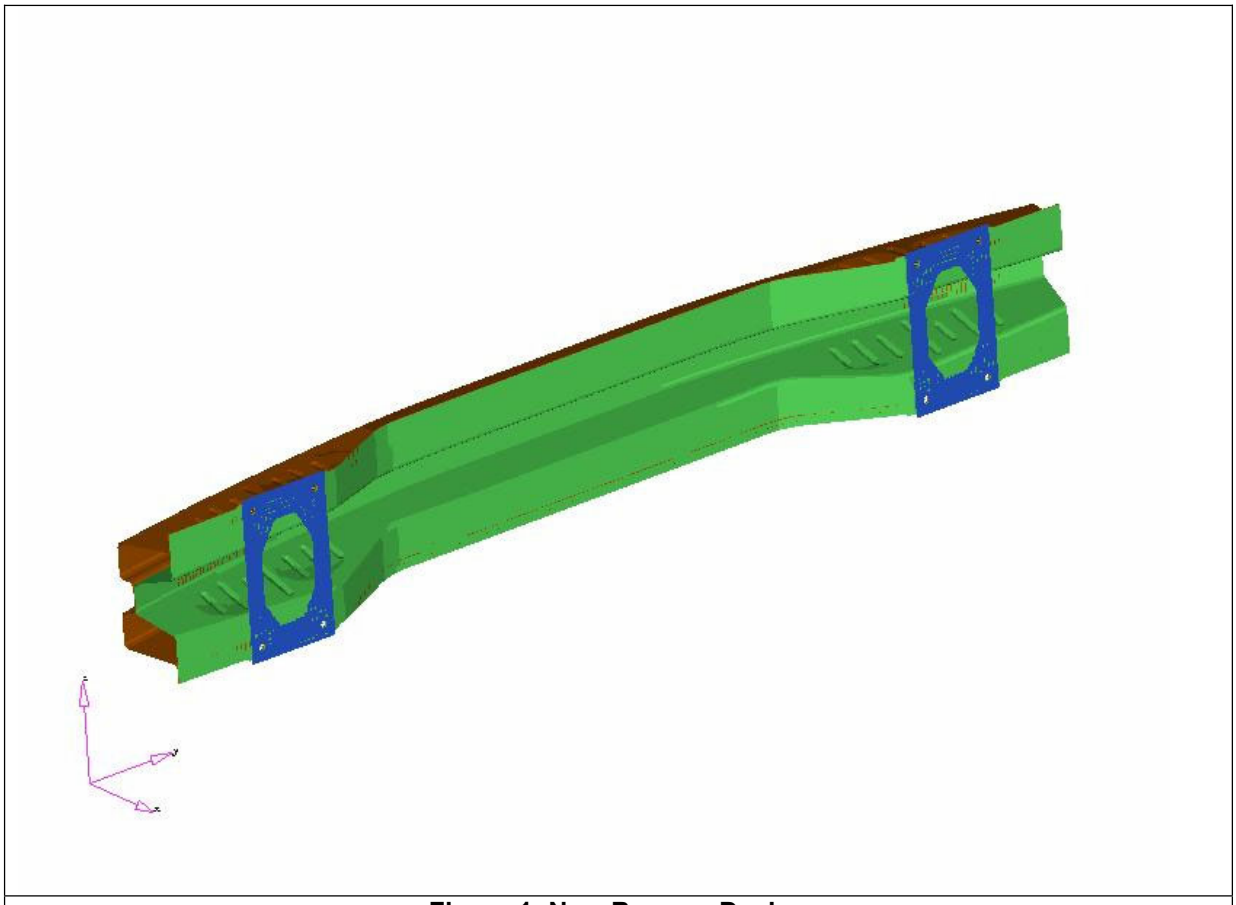


Figure 1: New Bumper Design

The bumper beam is attached to the front rails through an attachment plate. The plate is bolted to the bumper beam through four bolts. The plate has a hole of the same shape as the rail front section, but of a smaller size. The plate is MIG welded to the front rails. The bumper centerline matches that of the rail. This ensures a proper load transfer from the bumper to the rails.

The bumper design passes the low-speed bumper requirements (7).

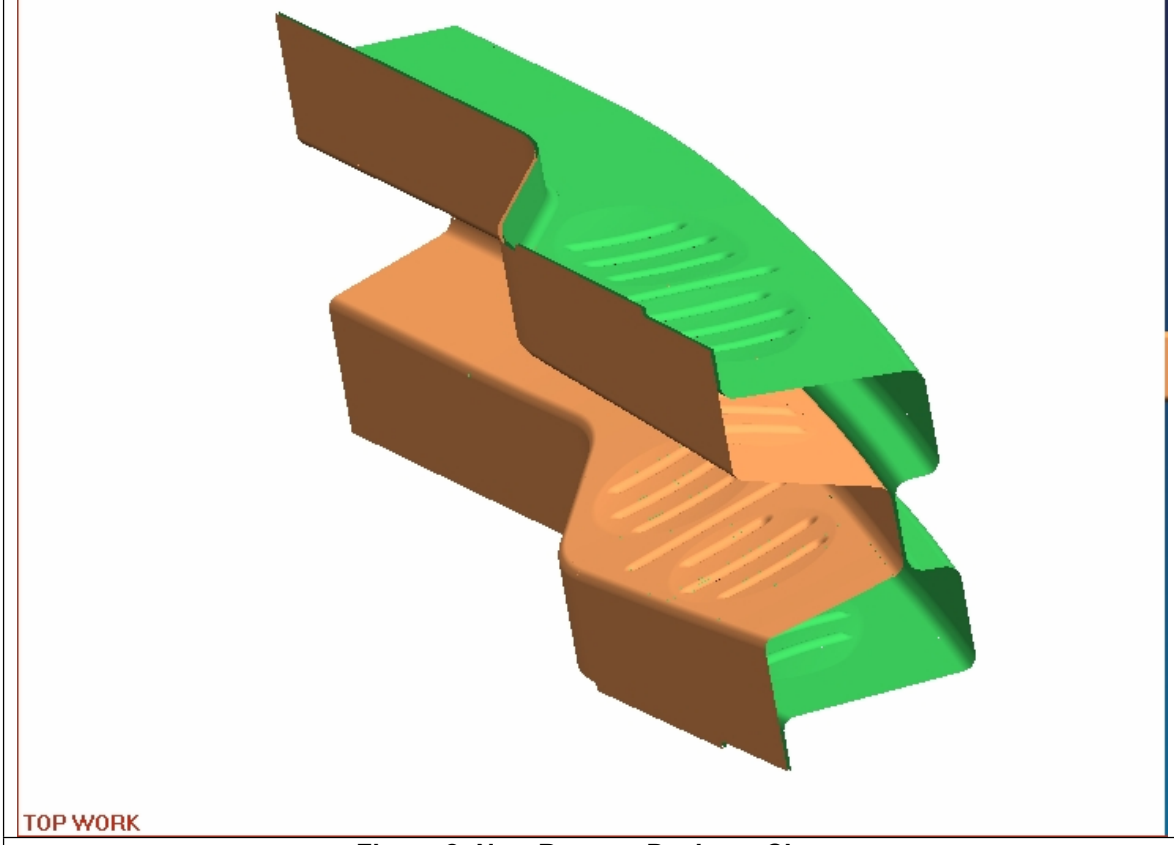


Figure 2: New Bumper Design – Close-up

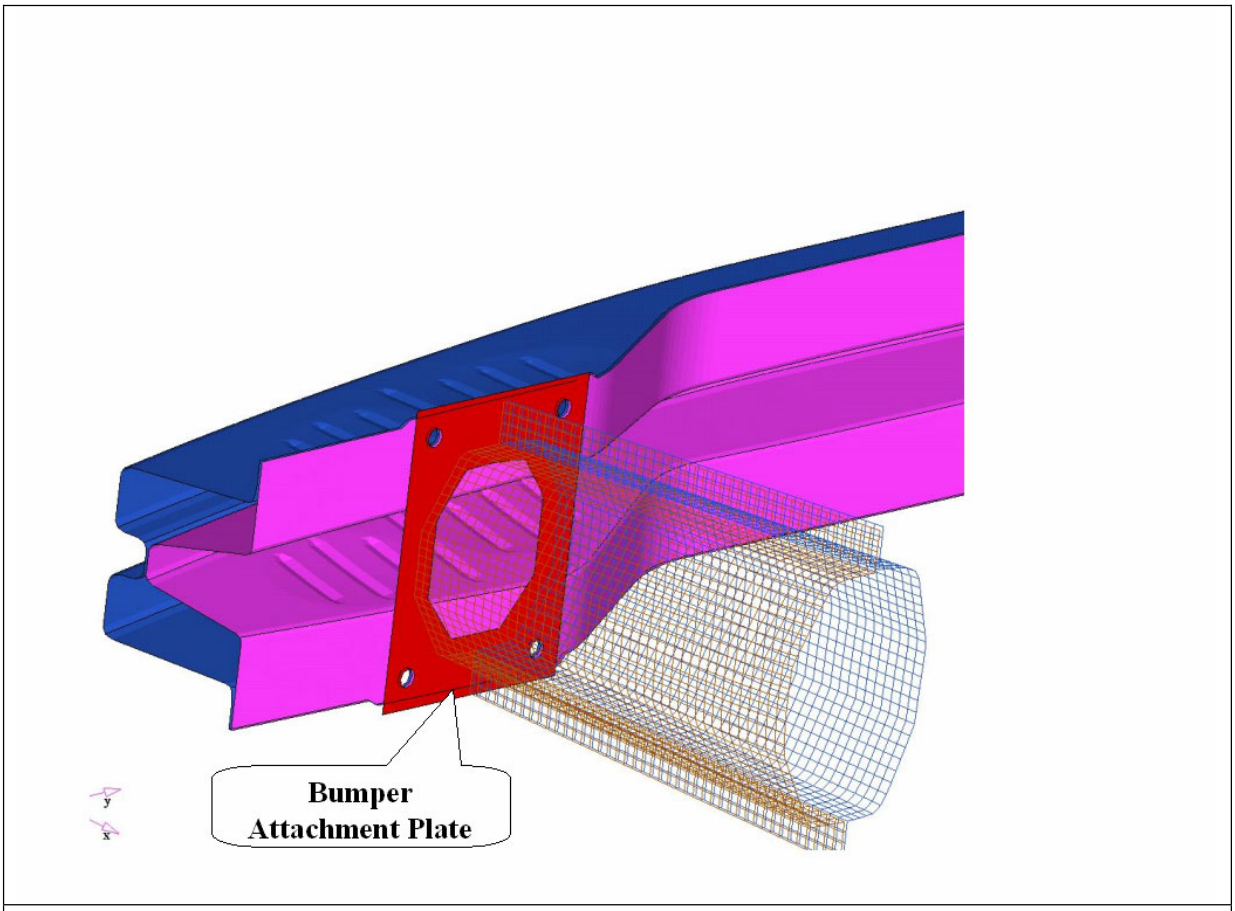


Figure 3: Bumper Attachment

4. Bumper Formability Results

The forming processes for bumper parts are summarized in *Table 2*. The results of the formability analyses are shown in *Figure 4-Figure 7*. Both inner and outer bumper pieces have thinning below the target 11% thinning. Hence, the bumper beam is essentially *formable*.

Material properties for DP980 are summarized in *Appendix 1: Material Properties.*

Table 2: Part Processes

PART NAME	PROCESSES
OUTER BUMPER	DRAW DIE FLANGE RESTRIKE FINAL FORM LASER TRIM WELD FIXTURE
INNER BUMPER	DRAW DIE FLANGE RESTRIKE FINAL FORM LASER TRIM WELD FIXTURE
BUMPER ATTACHMENT PLATE	TURRET PRESS

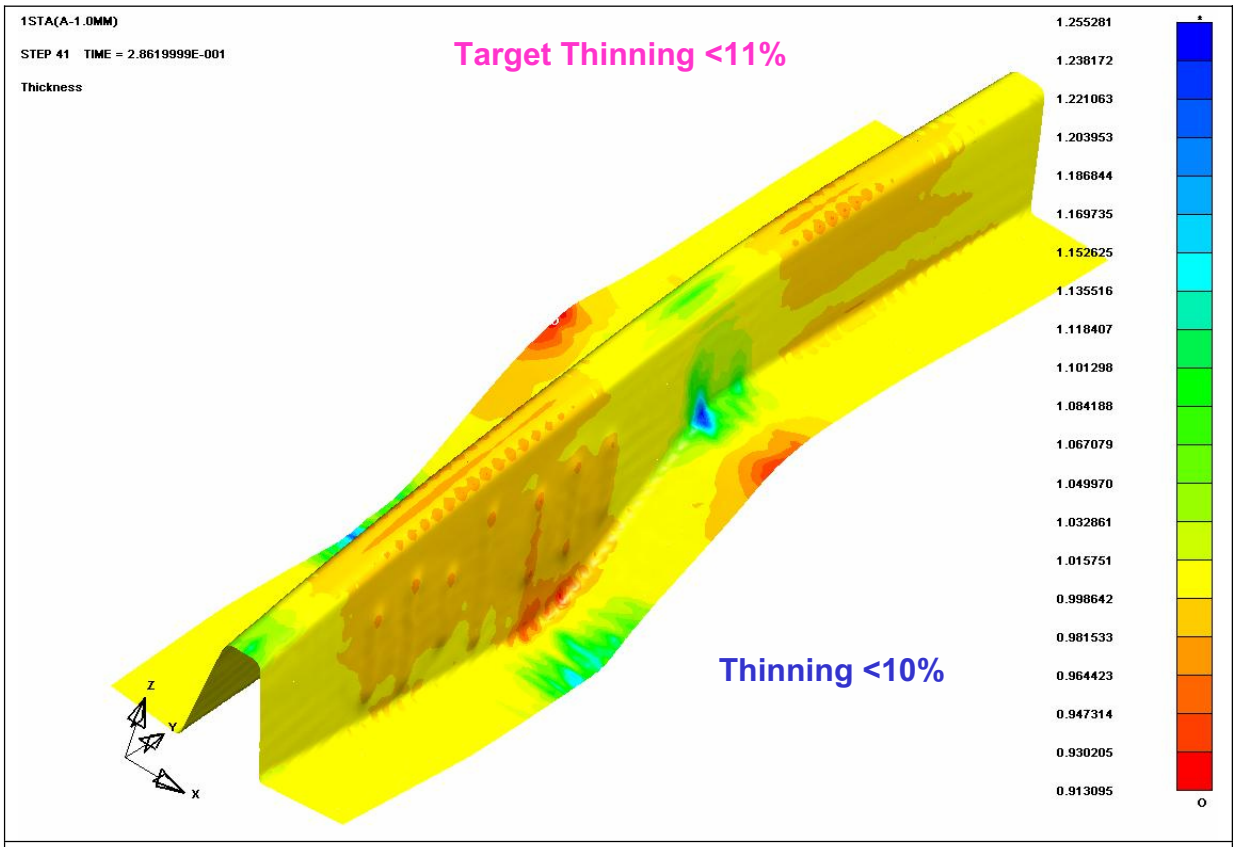


Figure 4: Bumper Inner - Thinning

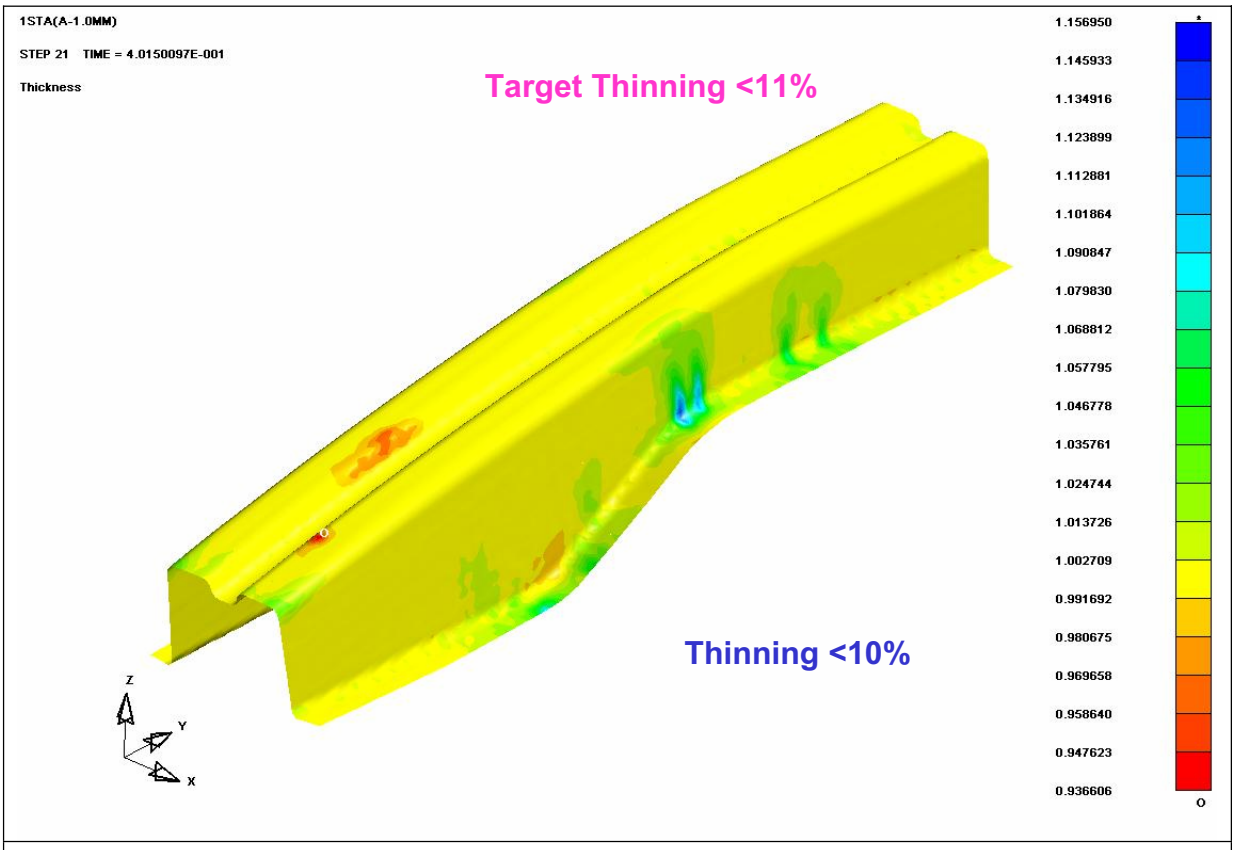


Figure 5: Bumper Outer - Thinning

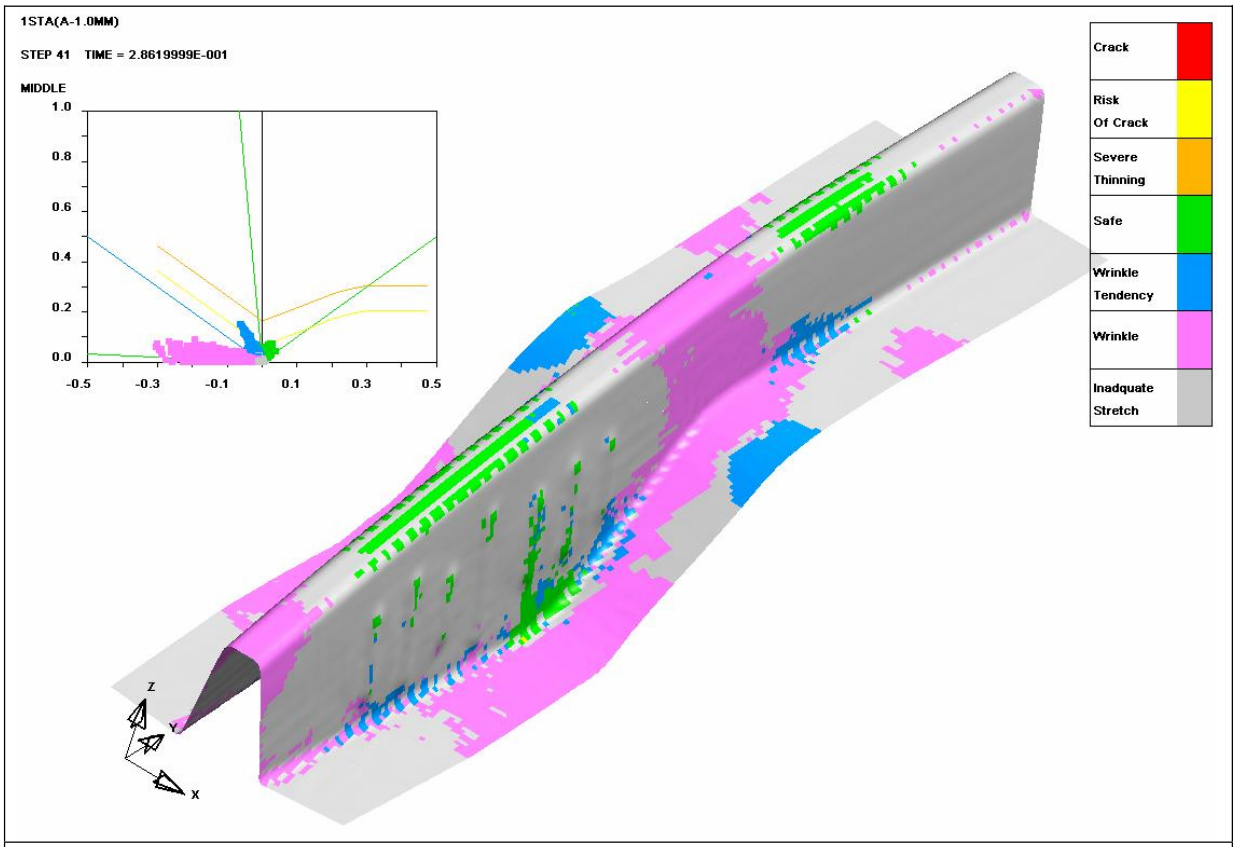


Figure 6: Bumper Inner - FLD Curve

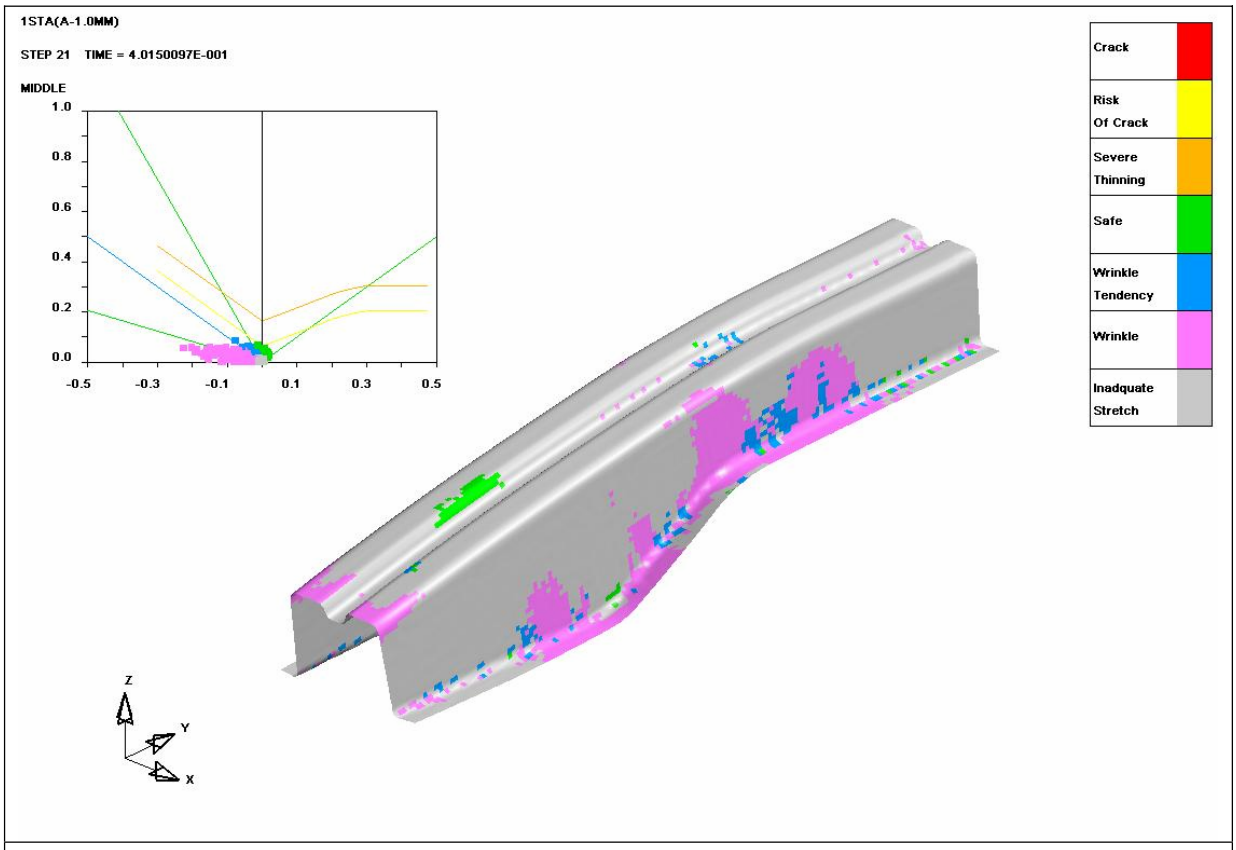


Figure 7: Bumper Outer - FLD Curve

5. Conclusions

The new bumper design satisfies all performance criteria and exhibits good formability and weldability. The final optimized gauge of the bumper beam was determined to be 1.0mm. Formability analyses of the 1.2mm bumper beam suggest that the 1.0mm beam should not present any manufacturing problems.

6. Future Work

The new bumper design will be prototyped and assembled into the donor vehicle along with the *new stamped rail assembly* developed in this Phase II of the Lightweight Front End Structure Project.

7. References

1) *Validated FE Models, Milestone 5*, SPHINX, Phase II.

2) *Enhanced FE Models, Milestone 6*, SPHINX, Phase II.

3) *IIHS Crashworthiness Evaluation Offset Barrier Crash Test Protocol (Version IX), October 2002.*

4) *DOE FE Models, Milestone 7*, SPHINX, Phase II.

5) *Third Bumper Design Report, Milestone 5*, SPHINX, Phase I.

6) *Concept 1: Preliminary Design, Milestone 10*, SPHINX, Phase II.

7) *FMVSS Part 581 Bumper Standard*.

8) *Concept 2: Preliminary Design, Milestone 13*, SPHINX, Phase II.

9) *Concept 2: Final Design, Milestone 15*, SPHINX, Phase II.

8. Appendix 1: Material Properties

Table 3: Formability Properties

	Yield Strength	Tensile Strength	Uniform Elongation	Total Elongation	N	N	K	r
	0.2% Offset				0.1 Fit	4 - 6% Fit		
	(MPa)	(MPa)	(%)	(%)			(MPa)	
DP980	721.3	1008.30	-	11.5	0.070	-	1308.3	-

Note:
DP980 properties are for 1.43mm gauge.
A/SP recommends using 0.1 fit n-value for formability analyses.

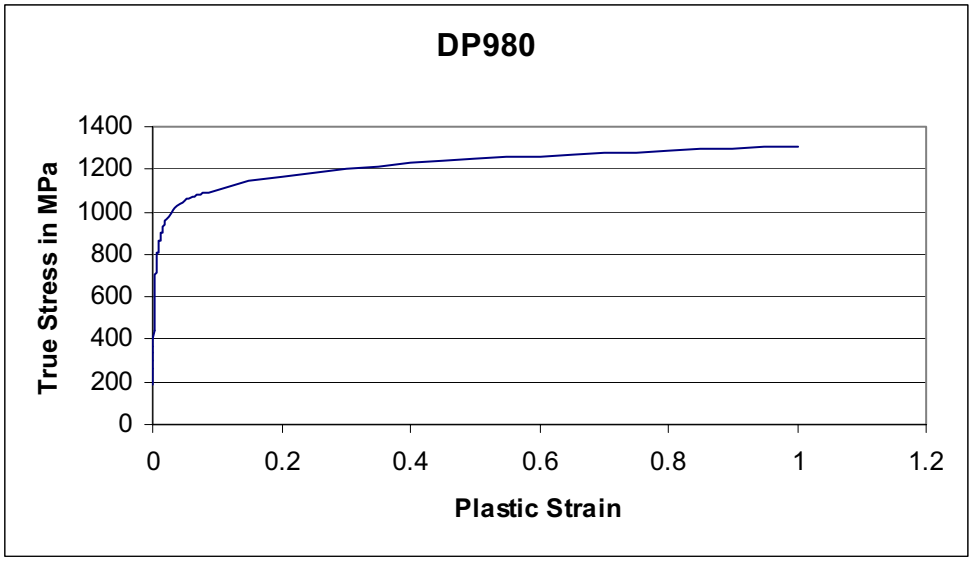


Figure 8: DP980 Formability Properties

Note:
The stress-strain curves are extrapolated for DP980 (by A/SP)

NCAP DOE Response Surface

Milestone 20

Lightweight Front End Structure Phase II

March 18, 2004



Auto/Steel Partnership

Abstract

This report documents the NCAP DOE study for the final *Concept 2* design that has a new stamped rail design and a new stamped bumper design. The response surface obtained from the NCAP DOE study will be utilized for the computer-aided optimization of the *Concept 2* design. The final optimized design will be prototyped in the Phase II of the Lightweight Front End Structure Project.

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1. Objectives

The effort of this study was aimed at conducting an NCAP DOE study for the final *Concept 2* design that has a new stamped rail design and a new stamped bumper design. The response surface obtained from the NCAP DOE study will be utilized for the computer-aided optimization of the *Concept 2* design. The final optimized design will be prototyped in the Phase II of the Lightweight Front End Structure Project.

2. DOE Model

The NCAP DOE study incorporates the following features.

- NCAP load case up to 100 ms.
- 2-level L32 Orthogonal Array.
- Bumper and rail grades/gauges as design parameters.
- 16 factors and 16 interactions.
- NCAP B-pillar accelerations as responses.

DOE parameters and their levels are summarized in *Table 1* and *Figure 1-Figure 4*.

Table 1: DOE Model

	Part	Level 1 Gauge (mm)	Level 2 Gauge (mm)
1	Bumper	1.0	1.3
2	Rail Front Inner/Outer	1.0	1.3
3	Rail Mid Inner/Outer	1.2	1.6
4	Rail Rear Inner	1.4	2.0
5	Rail Rear Outer	1.4	2.0
6	Rail Reinforcement	1.4	2.0
7	Rail Extension Front	1.4	2.0
8	Rail Extension Rear	1.2	1.6
9	Rail Extension Reinf	1.4	2.0
	Part	**Level 1 Grade**	**Level 2 Grade**
10	Bumper	DP800	DP980
11	Rail Front Inner/Outer	DP600	DP800
12	Rail Mid Inner/Outer	DP600	DP800
13	Rail Rear Inner/Outer	DP600	DP800
14	Rail Reinforcement	DP600	DP800
15	Rail Extension Front/Rear	DP600	DP800
16	Rail Extension Reinf	DP600	DP800

- Level 1 gauges correspond to 30% mass reduction compared to the *Donor Vehicle*.
- Level 2 gauges are 130% of Level 1 gauges.

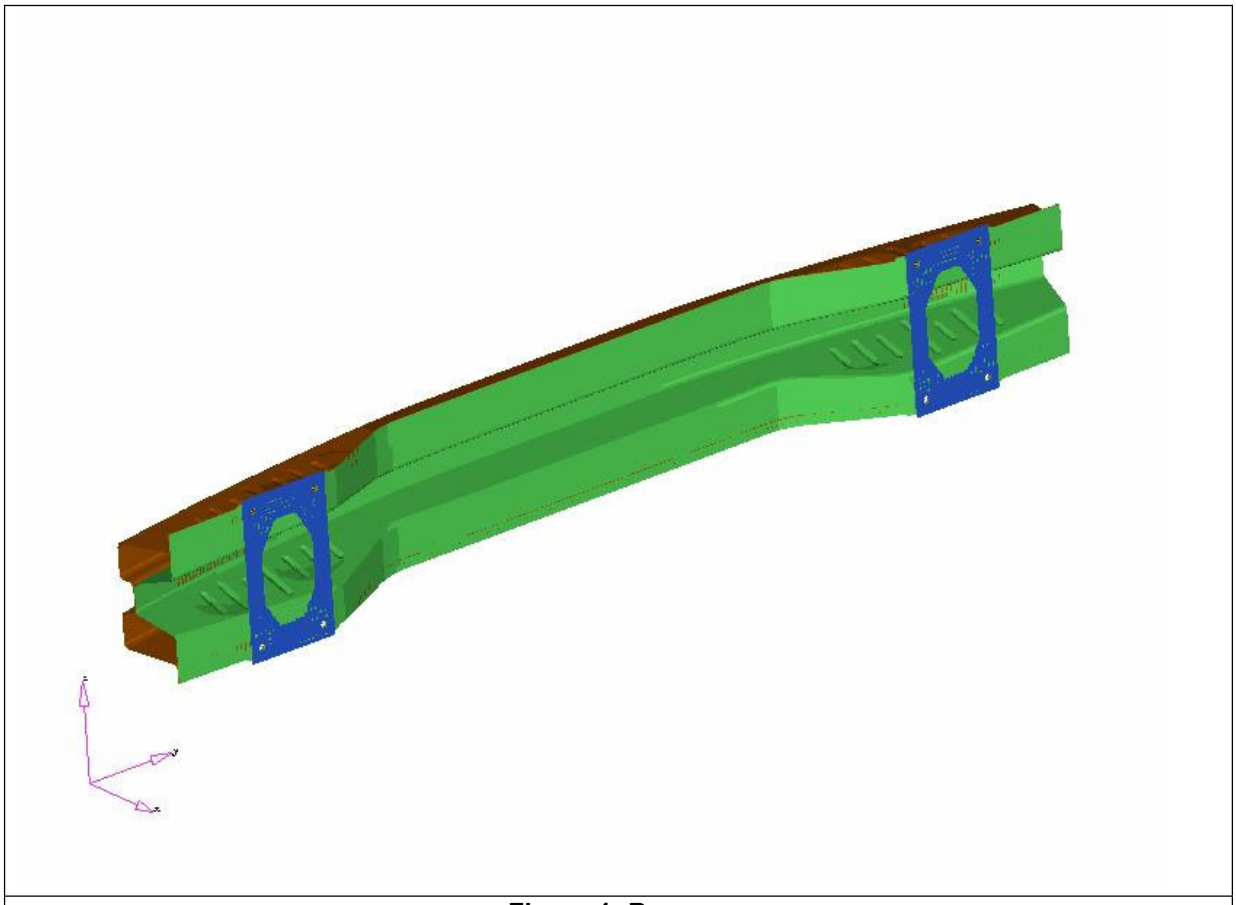


Figure 1: Bumper

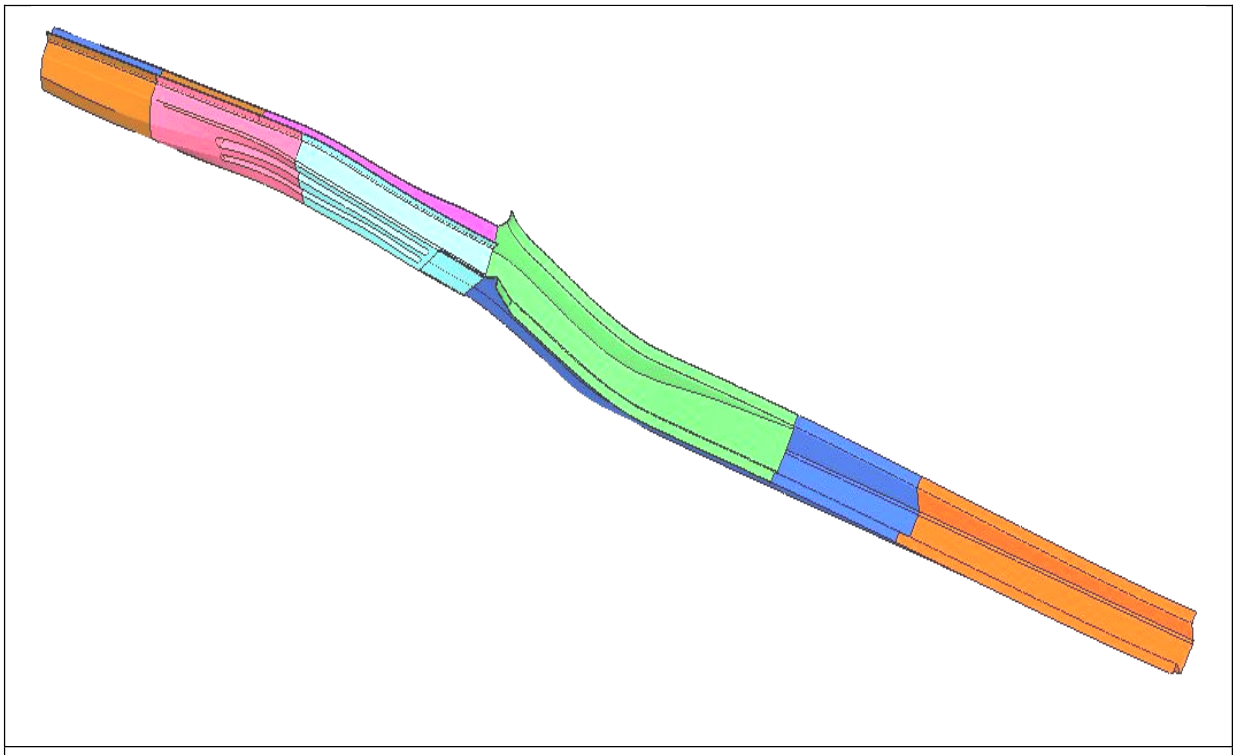


Figure 2: LH Rail Assembly

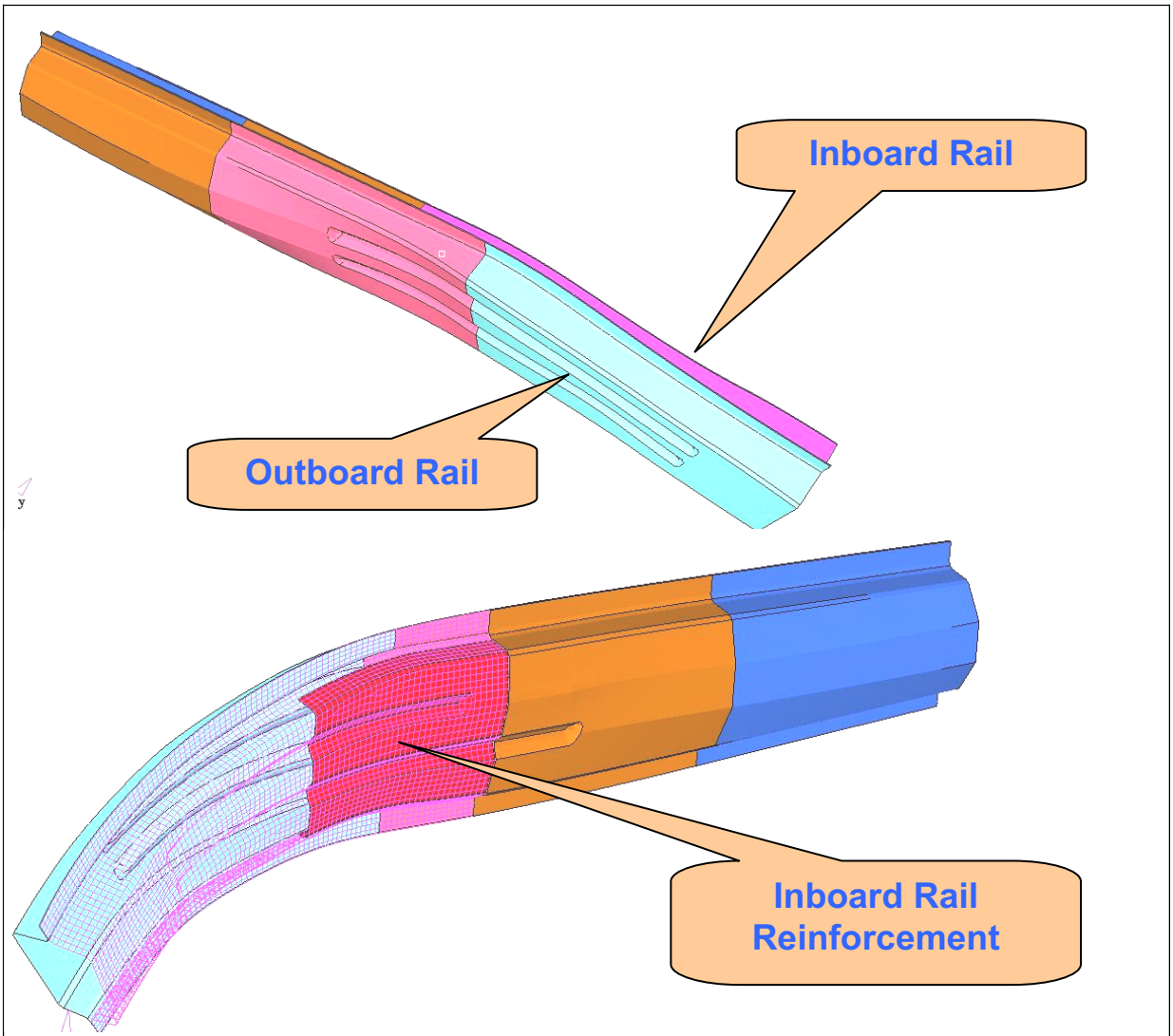


Figure 3: LH Inner & Outer Rails

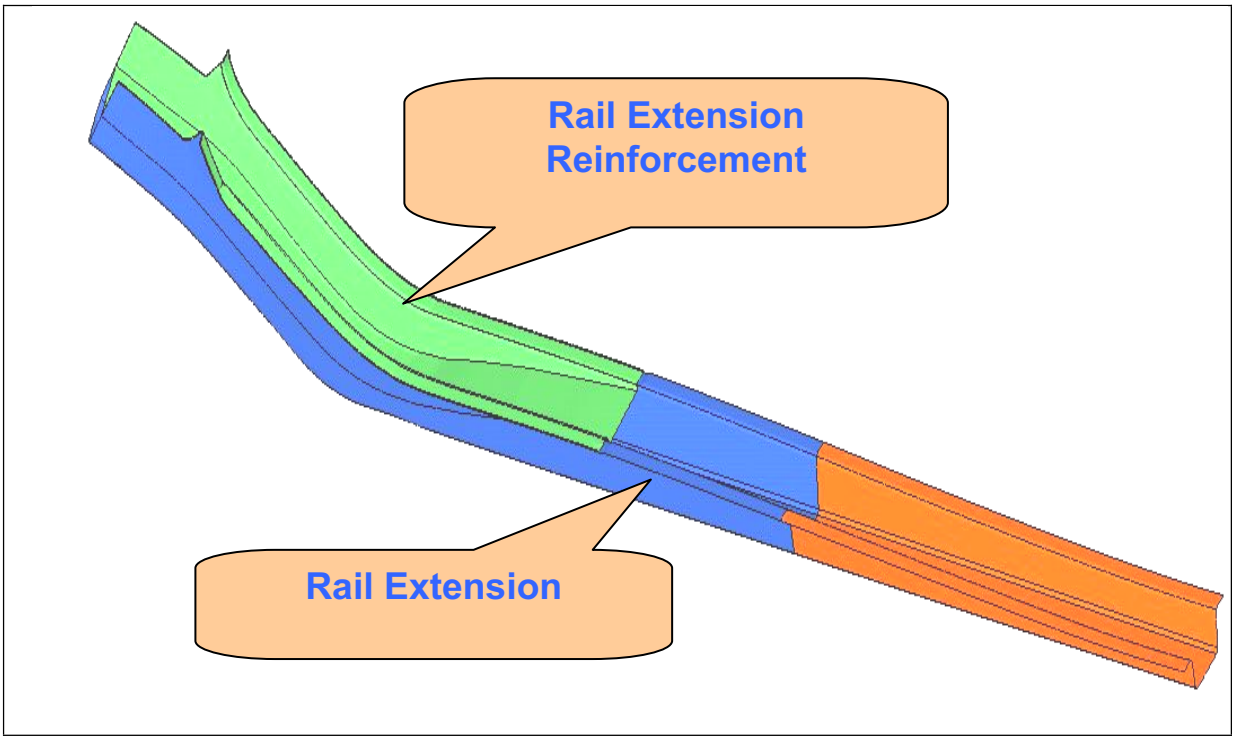


Figure 4: LH Rail Extension

3. NCAP Response Surface

Linear regression was employed to obtain response surfaces for the LH and RH B-pillar accelerations.

The B-pillar pulse was broken down into 10ms intervals. Response surfaces were obtained for the minimum and maximum peaks in each interval, as well as the times of the peaks.

The NCAP response surfaces will serve as inputs for the computer-aided optimization of the design.

4. FE Model - Output Location Summary

The nodes at which the desired NCAP and IIHS outputs were obtained are listed in *Table 2*.

The intrusions are measured at the nodes as specified in *Reference 3*.

The acceleration and intrusion node locations are shown in *Figure 5* and *Figure 6* below.

Table 2: Summary of Output Locations

Parameter	Location	Node Number
Accelerations	B-Pillar / Rocker - LH	5000001
	B-Pillar / Rocker - RH	5000002
Intrusions	Origin	6000000
	Plane Y-axis	6000001
	Plane Z-axis	6000002
	Steering Column	7000001
	Brake Pedal	7000002
	Toepan - Left	7000003
	Toepan - Center	7000004
	Toepan - Right	7000005
	Left Front Seat Bolt	7000006
	Right Front Seat Bolt	7000007
	Left Rear Seat Bolt	7000008
	Right Rear Seat Bolt	7000009
	AB Closure - A Pillar	7000010
	AB Closure - B Pillar	7000011

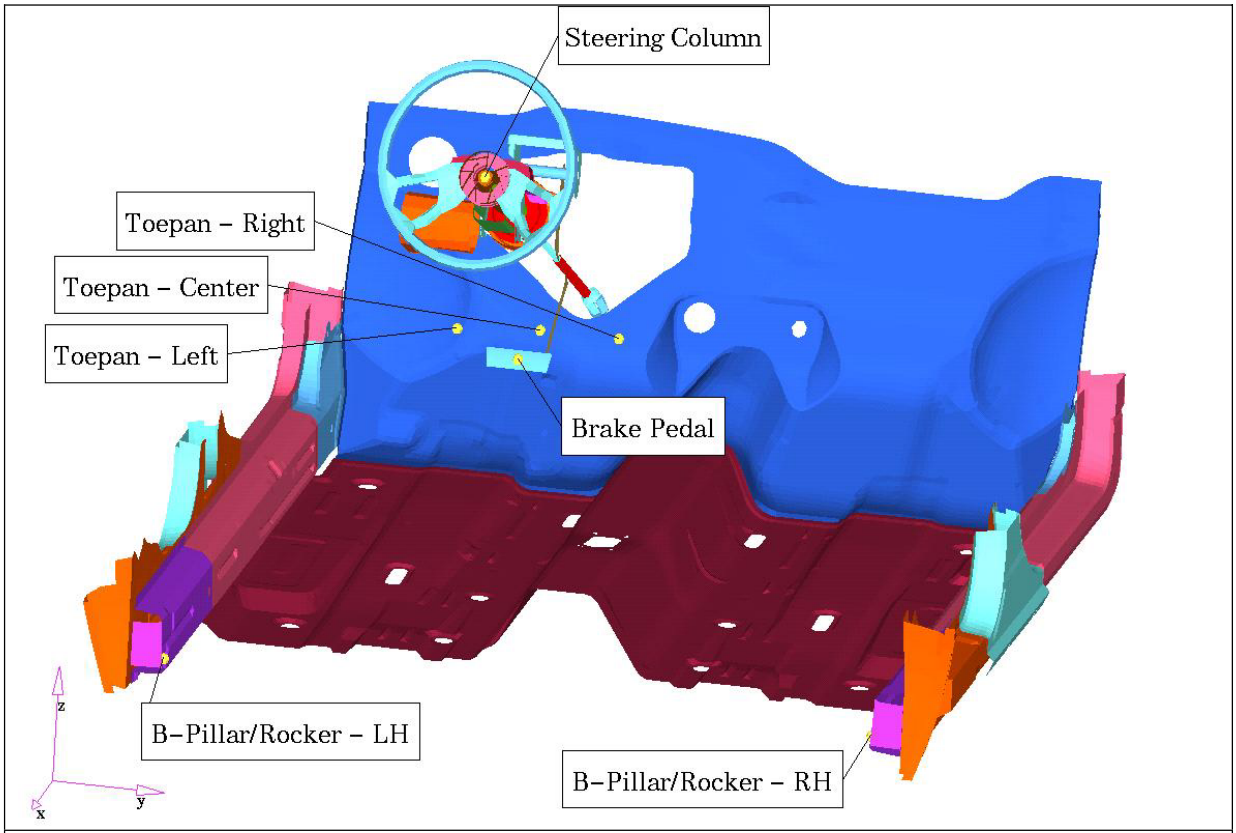


Figure 5: Output Locations for NCAP/IIHS



Figure 6: Output Locations for IIHS - AB Closure

5. Conclusions

An NCAP DOE study of the *Concept 2* design was conducted and response surfaces were derived for the computer-aided optimization of the design.

6. Future Work

Computer-aided optimization of the rail/bumper designs will be performed using the IIHS, NCAP, static and dynamic stiffness response surfaces. The final optimized design will be prototyped in the Phase II of the Lightweight Front End Structure Project.

7. References

1) *Validated FE Models, Milestone 5*, SPHINX, Phase II.

2) *Enhanced FE Models, Milestone 6*, SPHINX, Phase II.

3) *IIHS Crashworthiness Evaluation Offset Barrier Crash Test Protocol (Version IX), October 2002.*

4) *DOE FE Models, Milestone 7*, SPHINX, Phase II.

5) *Concept 2: Final Design, Milestone 15*, SPHINX, Phase II.

IIHS DOE Response Surface

Milestone 21

Lightweight Front End Structure Phase II

March 18, 2004



Auto/Steel Partnership

Abstract

This report documents the IIHS DOE study for the final *Concept 2* design that has a new stamped rail design and a new stamped bumper design. The response surface obtained from the IIHS DOE study will be utilized for the computer-aided optimization of the *Concept 2* design. The final optimized design will be prototyped in the Phase II of the Lightweight Front End Structure Project.

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List of Tables

Table 1: DOE Model 5
Table 2: Summary of Output Locations 10

1. Objectives

The effort of this study was aimed at conducting an IIHS DOE study for the final *Concept 2* design that has a new stamped rail design and a new stamped bumper design. The response surface obtained from the IIHS DOE study will be utilized for the computer-aided optimization of the *Concept 2* design. The final optimized design will be prototyped in the Phase II of the Lightweight Front End Structure Project.

2. DOE Model

The IIHS DOE study incorporates the following features.

- IIHS load case up to 150 ms.
- 2-level L32 Orthogonal Array.
- Bumper and rail grades/gauges as design parameters.
- 16 factors and 16 interactions.
- IIHS intrusions as responses.

DOE parameters and their levels are summarized in *Table 1* and *Figure 1-Figure 4*.

Table 1: DOE Model

	Part	Level 1 Gauge (mm)	Level 2 Gauge (mm)
1	Bumper	1.0	1.3
2	Rail Front Inner/Outer	1.0	1.3
3	Rail Mid Inner/Outer	1.2	1.6
4	Rail Rear Inner	1.4	2.0
5	Rail Rear Outer	1.4	2.0
6	Rail Reinforcement	1.4	2.0
7	Rail Extension Front	1.4	2.0
8	Rail Extension Rear	1.2	1.6
9	Rail Extension Reinf	1.4	2.0
	Part	**Level 1 Grade**	**Level 2 Grade**
10	Bumper	DP800	DP980
11	Rail Front Inner/Outer	DP600	DP800
12	Rail Mid Inner/Outer	DP600	DP800
13	Rail Rear Inner/Outer	DP600	DP800
14	Rail Reinforcement	DP600	DP800
15	Rail Extension Front/Rear	DP600	DP800
16	Rail Extension Reinf	DP600	DP800

- Level 1 gauges correspond to 30% mass reduction compared to the *Donor Vehicle*.
- Level 2 gauges are 130% of Level 1 gauges.

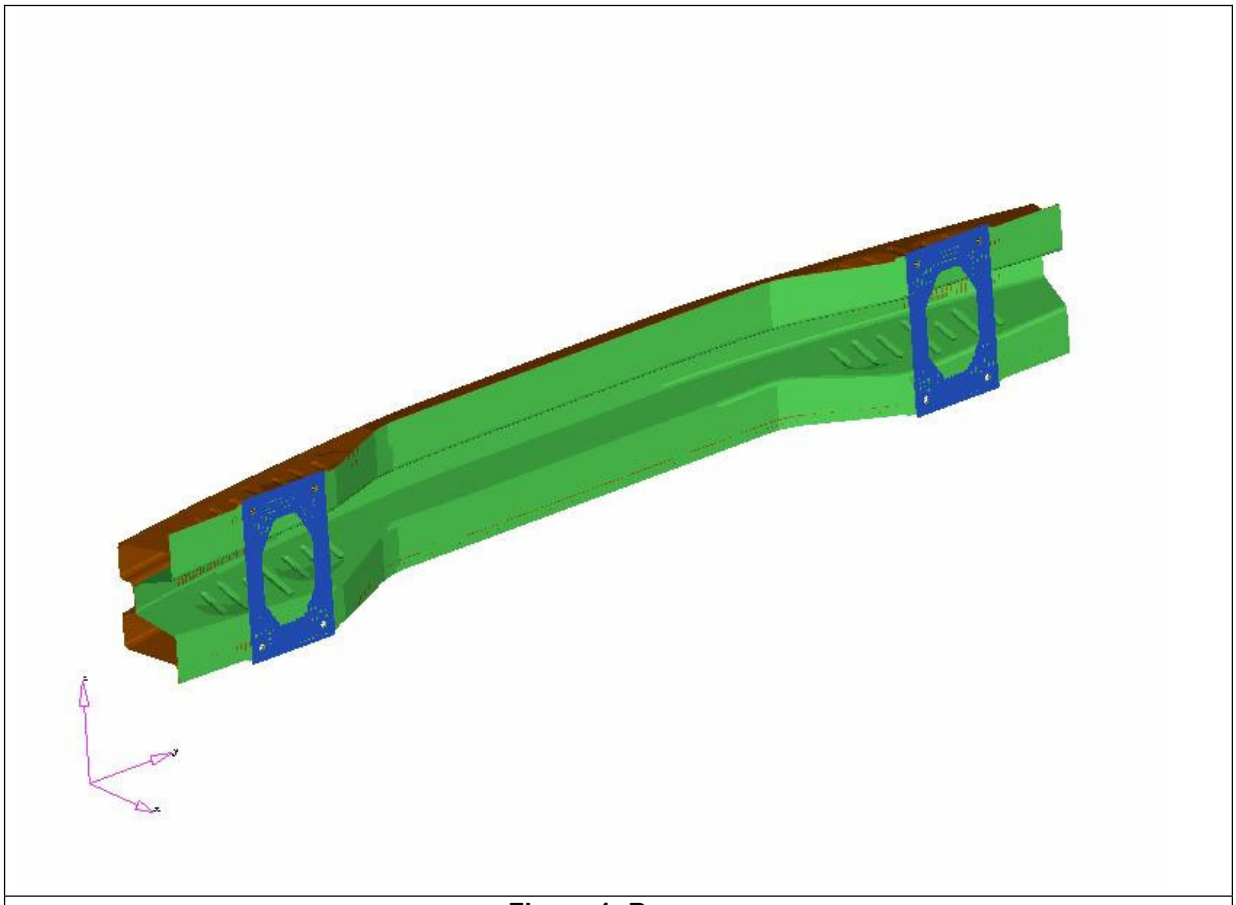


Figure 1: Bumper

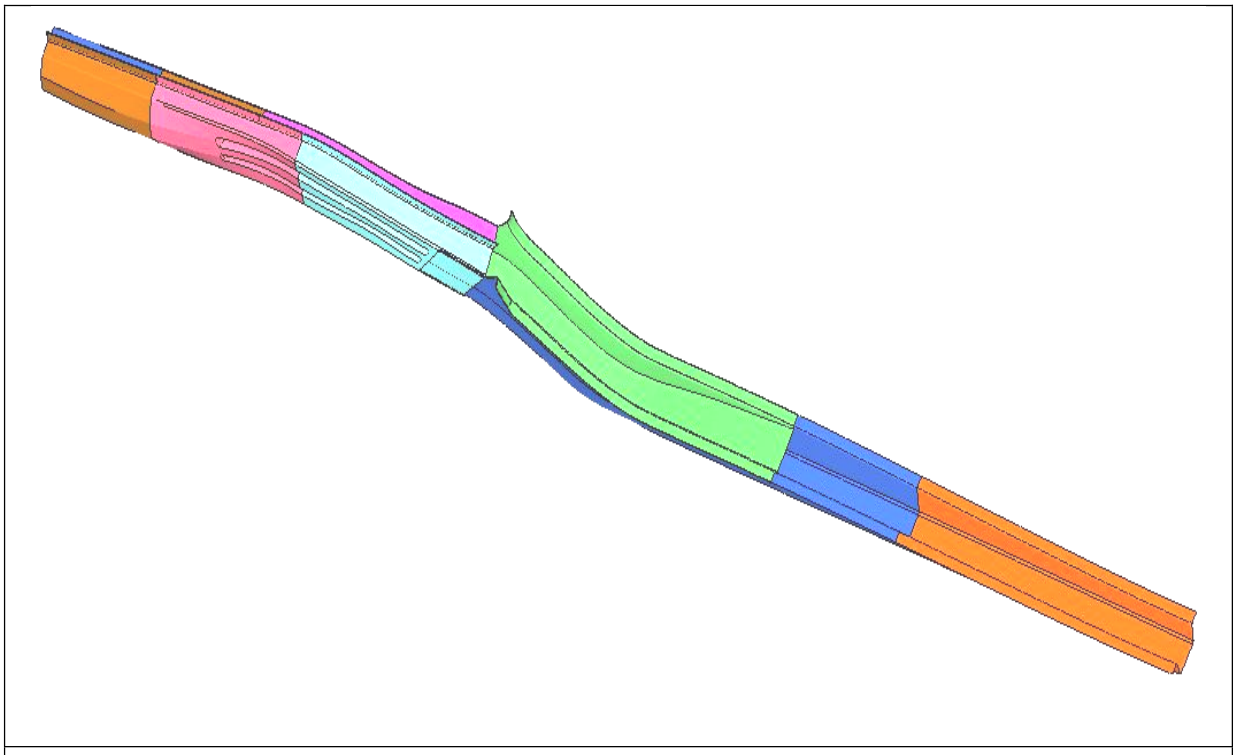


Figure 2: LH Rail Assembly

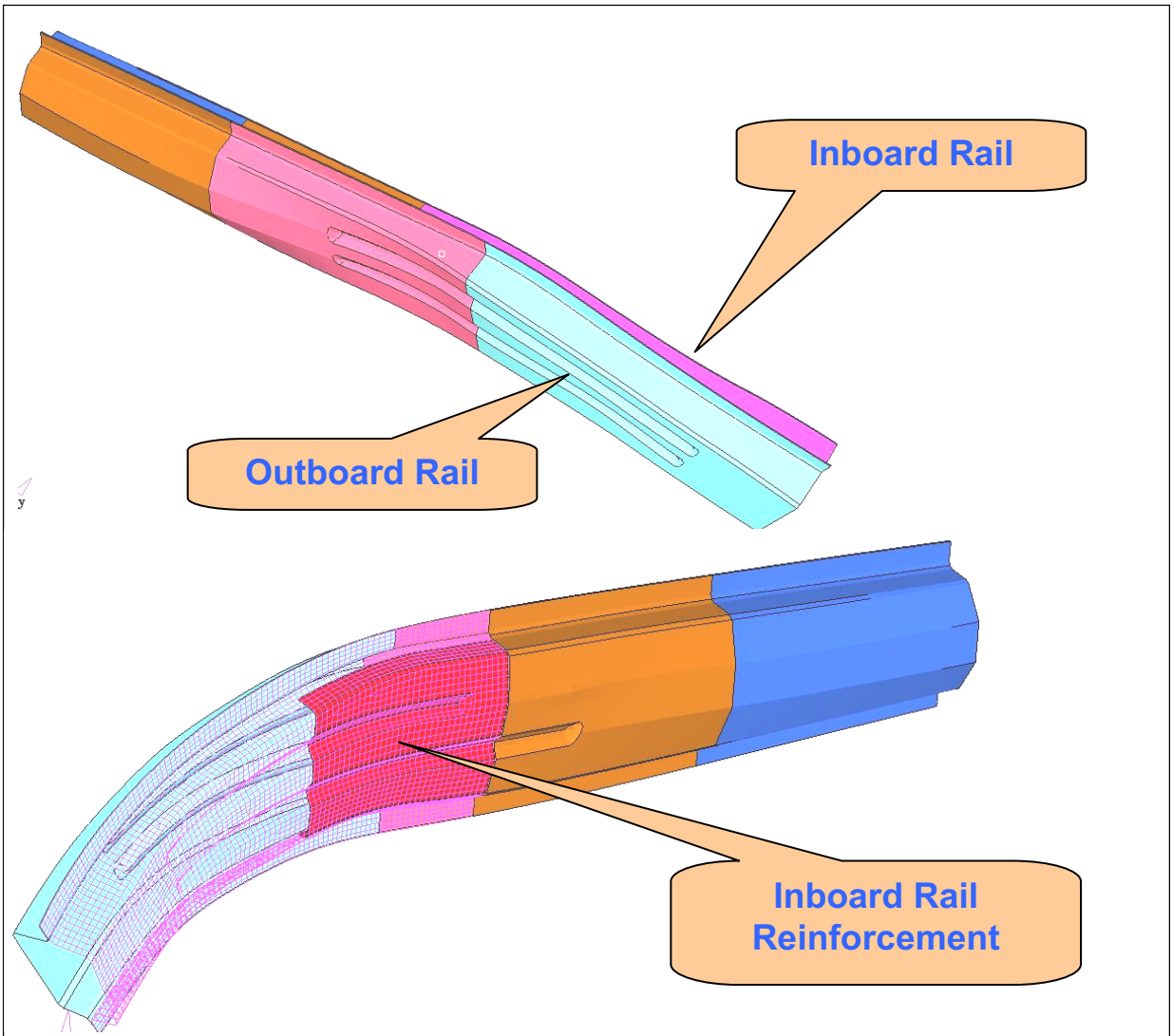


Figure 3: LH Inner & Outer Rails

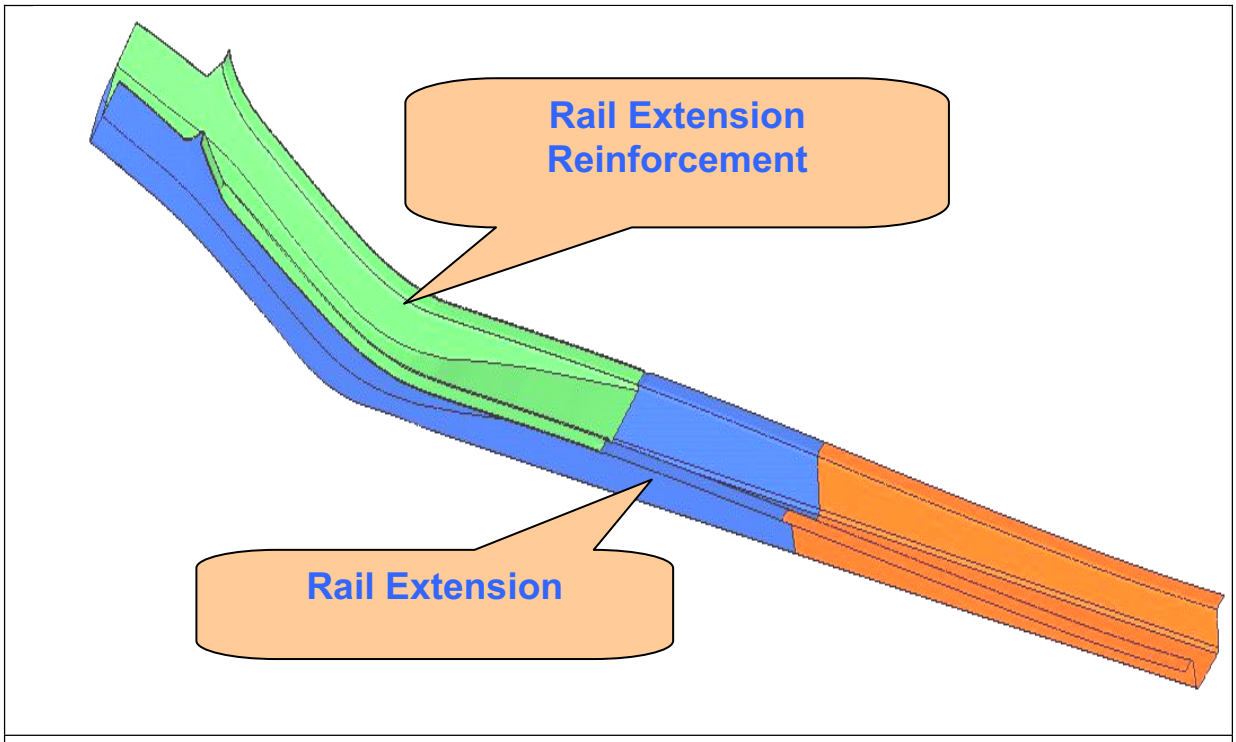


Figure 4: LH Rail Extension

3. IIHS Response Surface

Linear regression was employed to obtain response surfaces for the following IIHS responses.

- Left toepan intrusion
- Center toepan intrusion
- Right toepan intrusion
- A-B closure

Other IIHS responses were not monitored due noise in the data (*5)*.

Peak intrusion values were utilized to obtain the response surfaces, as the end values are not reliable due to oscillations in the responses.

The IIHS response surfaces will serve as inputs for the computer-aided optimization of the design.

4. FE Model - Output Location Summary

The nodes at which the desired NCAP and IIHS outputs were obtained are listed in *Table 2*.

The intrusions are measured at the nodes as specified in *Reference 3*.

The acceleration and intrusion node locations are shown in *Figure 5* and *Figure 6* below.

Table 2: Summary of Output Locations

Parameter	Location	Node Number
Accelerations	B-Pillar / Rocker - LH	5000001
	B-Pillar / Rocker - RH	5000002
Intrusions	Origin	6000000
	Plane Y-axis	6000001
	Plane Z-axis	6000002
	Steering Column	7000001
	Brake Pedal	7000002
	Toepan - Left	7000003
	Toepan - Center	7000004
	Toepan - Right	7000005
	Left Front Seat Bolt	7000006
	Right Front Seat Bolt	7000007
	Left Rear Seat Bolt	7000008
	Right Rear Seat Bolt	7000009
	AB Closure - A Pillar	7000010
	AB Closure - B Pillar	7000011

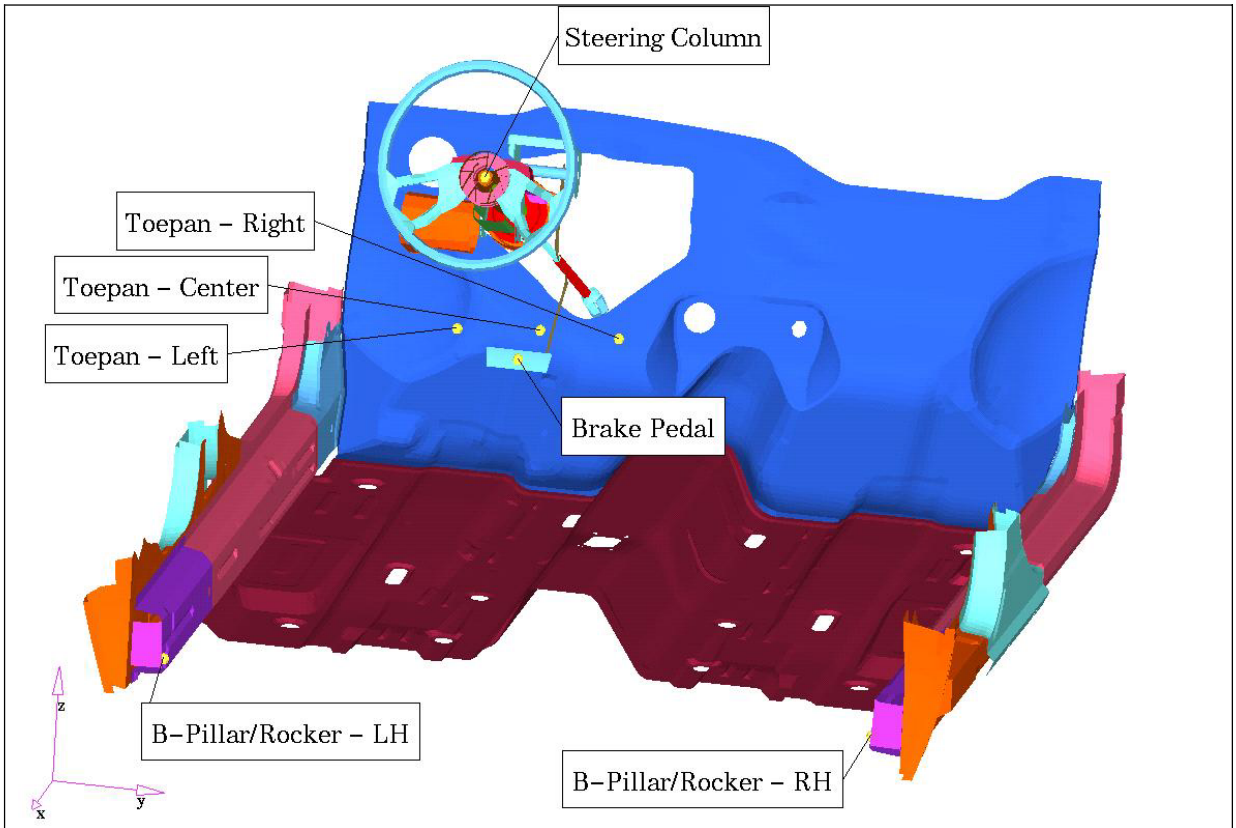


Figure 5: Output Locations for NCAP/IIHS



Figure 6: Output Locations for IIHS - AB Closure

5. Conclusions

An IIHS DOE study of the *Concept 2* design was conducted and response surfaces were derived for the computer-aided optimization of the design.

6. Future Work

Computer-aided optimization of the rail/bumper designs will be performed using the IIHS, NCAP, static and dynamic stiffness response surfaces. The final optimized design will be prototyped in the Phase II of the Lightweight Front End Structure Project.

7. References

1) *Validated FE Models, Milestone 5*, SPHINX, Phase II.

2) *Enhanced FE Models, Milestone 6*, SPHINX, Phase II.

3) *IIHS Crashworthiness Evaluation Offset Barrier Crash Test Protocol (Version IX), October 2002.*

4) *DOE FE Models, Milestone 7*, SPHINX, Phase II.

5) *Concept 2: Final Design, Milestone 15*, SPHINX, Phase II.

Final Optimized Design

Milestone 22

Lightweight Front End Structure Phase II

July 22, 2004



Auto/Steel Partnership

Abstract

This report documents the *Final Design* for prototyping the bumper and rail assemblies in *Phase II* of the *Lightweight Front End Structure Project*.

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1. Objectives

The effort of this study was aimed at deriving the *Final Optimized Design* with the new stamped rail and bumper assemblies. The optimized design was derived from the computer-aided optimization (CAO) of the response surfaces obtained from the *DOE* studies of *Concept 2*. The final optimized bumper and rail assemblies were prototyped and assembled into the full vehicle for NCAP testing.

2. Results Summary

The *Final Design* has the following features.

- Octagonal 3-piece tailor-welded rail inner and outer pieces with symmetric flanges and tapered front section.
- Two-piece rail tailor-welded extension design with a reinforcement.
- Rail inner reinforcement.
- Symmetric LH/RH rail assemblies.
- Two-piece double box bumper design with energy absorbing features.

The *Final Design* achieves a mass reduction of **8.77kg** (**22.36%**) compared to the *Baseline* design. The NCAP performance of the *Final Design* is superior to that of the *Baseline* design. The IIHS, static and dynamic stiffness performances are similar to those of the *Baseline* design.

The NCAP, IIHS, static and dynamic stiffness results are summarized in *Table 1*,*Table 2,*

Table 3: Static Stiffness Results

and *Table 4* respectively.

Table 1: NCAP Results

	Peak Acceleration	
B-Pillar Pulse	Baseline	Final Design
LH	36.7 g @ 58.7 ms	35.4 g @ 48.5 ms
RH	35.3 g @ 58.6 ms	35.6 g @ 57.2 ms

Table 2: IIHS Results

Location	Peak Intrusions (cm)	
	Baseline	Final Design
Left Toepan	18.2	15.1
Center Toepan	18.4	19.5
Right Toepan	19.4	19.5
A-B Pillar Closure	14.4	14.1

Table 3: Static Stiffness Results

Static Stiffness	Baseline	Final Design
Bending Stiffness (N/mm)	12638.9	12468.7
Torsional Stiffness (Nm/deg)	21002.3	20957.5

Table 4: Dynamic Stiffness Results

Mode	Frequency (Hz)	
	Baseline	Final Design
First Torsional Mode	21.06	25.25
First Bending Mode	24.38	22.73

3. Final Design

The *Final Design* was derived from the *Concept 2* design through CAO. The rail design is a 3-part stamped design with symmetric LH and RH rail assemblies (*Figure 1, Figure 2, Figure 3*). The inner and outer rails are 3-piece octagonal tailor-welded sections with symmetric flanges and beads. There is a reinforcement piece for the inner rail and the second tailor-weld line location in the rail inner/outer pieces is skewed. The front section of the rails is tapered. The rail extension is 2-piece tailor-welded and has a reinforcement. The total flange width for the rails is 21 mm, which includes a 5mm radius and 16mm flat. Please refer to *Concept 1* milestone report for details on rail flanges.

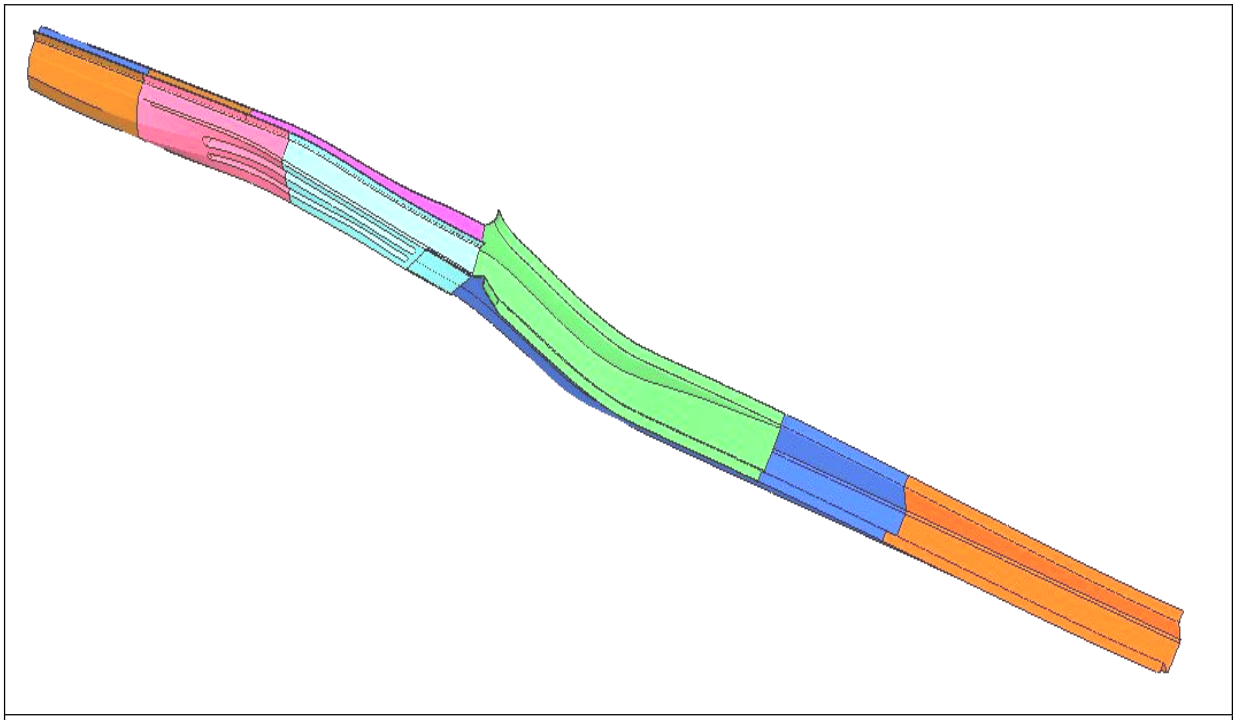


Figure 1: LH Rail Assembly

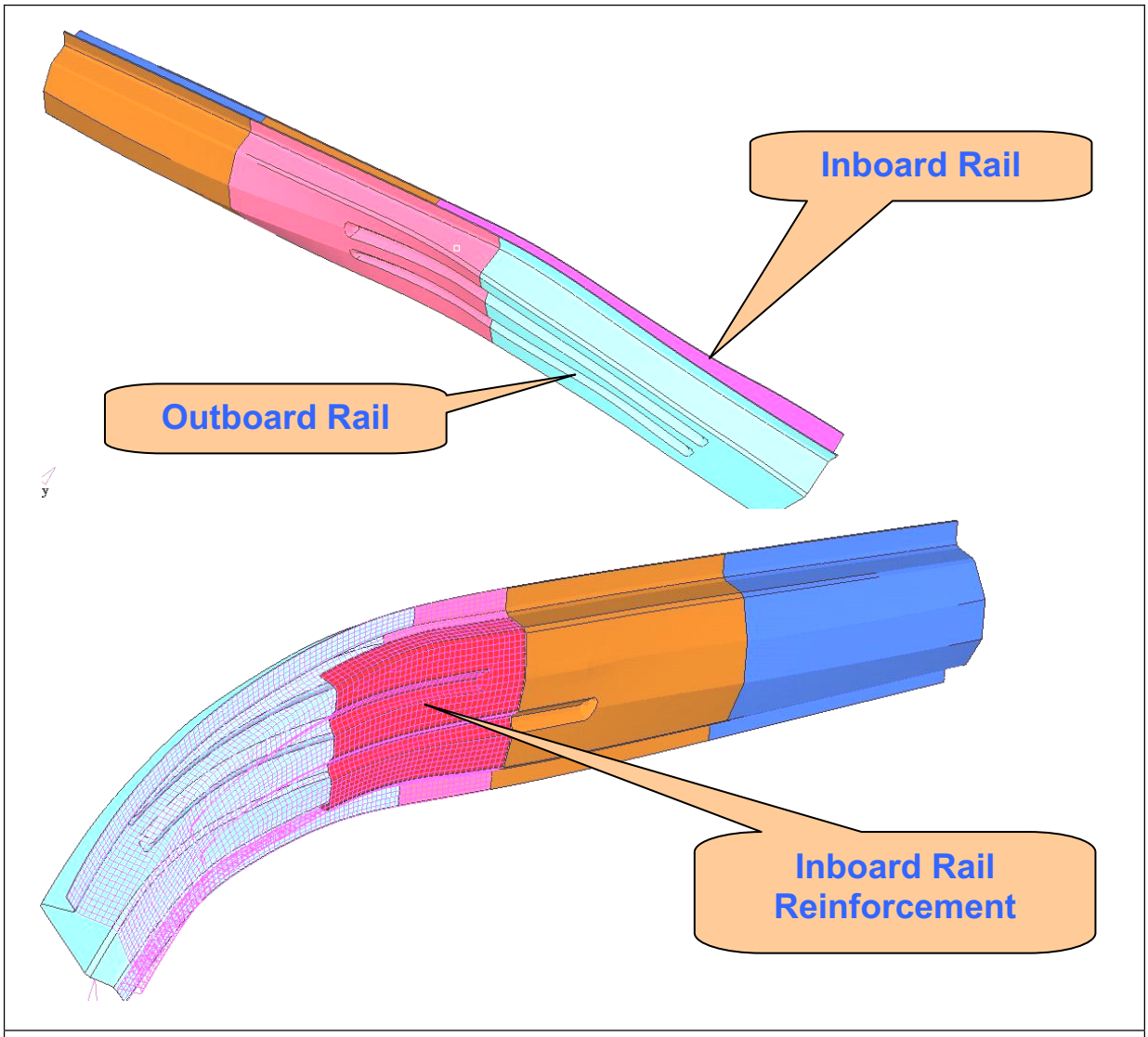


Figure 2: LH Inner & Outer Rails

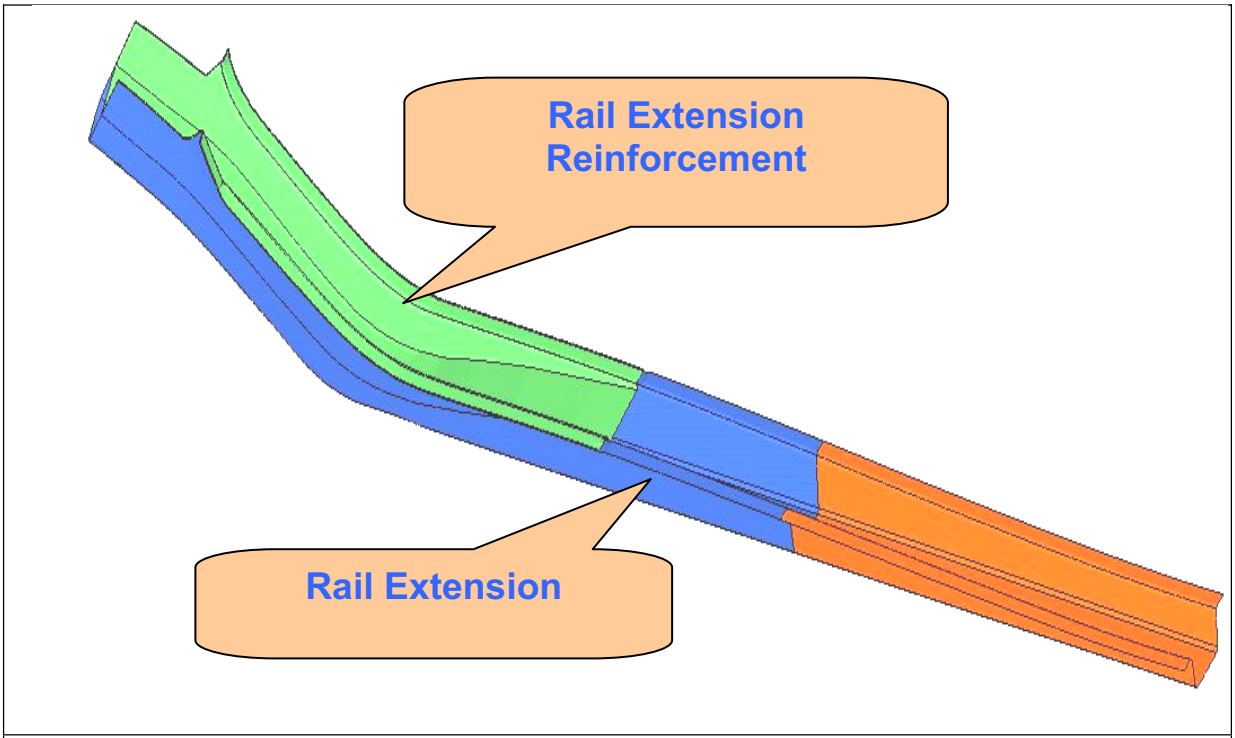


Figure 3: LH Rail Extension

The new bumper design (*Figure 4, Figure 5*) is functionally quite similar to the *Phase I Bumper 3* design. However, it has fewer manufacturing and welding concerns than the *Bumper 3* design. The new bumper design is a 2-piece double-box stamped design using DP980 steel. The bumper has vertical flanges and beads on the front and back plates. The new bumper design has good energy absorption capability in high-speed impacts and results in a high initial peak in the NCAP B-pillar pulse. In addition, the bumper is more formable than the *Phase I Bumper 3* design, and is easier to weld.

The bumper plates are attached to the front rails through an attachment plate. The plate is bolted to the bumper beam through four bolts. The plate has a hole of the same shape as the rail front section, but of a smaller size. The plate is MIG welded to the front rails. The bumper centerline matches that of the rail. This ensures a proper load transfer from the bumper to the rails. The bumper design passes the low-speed bumper requirements (7).

A mass summary for rail and bumper parts is included in *Table 5*.

A grade/gauge summary for rail and bumper parts is included in *Table 6*.

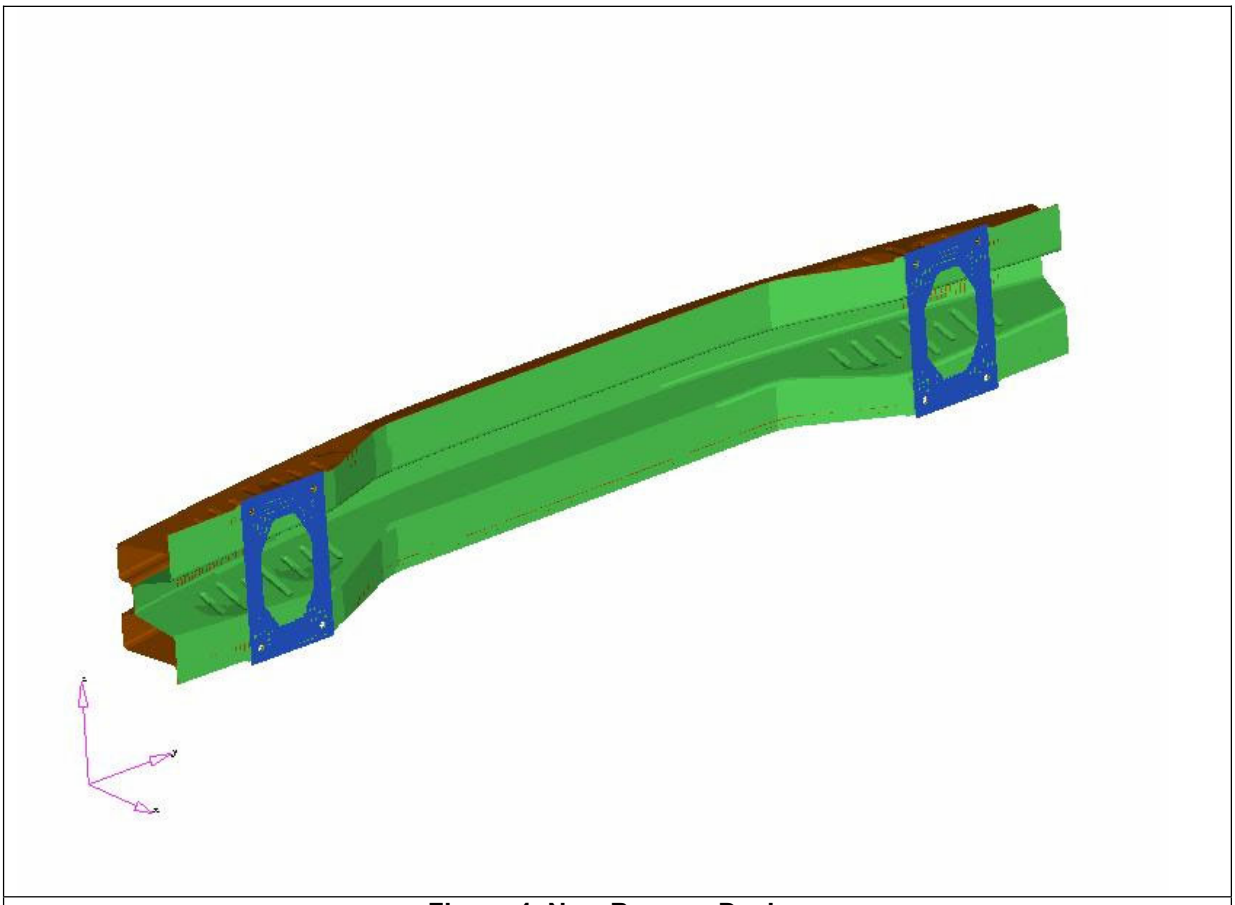


Figure 4: New Bumper Design

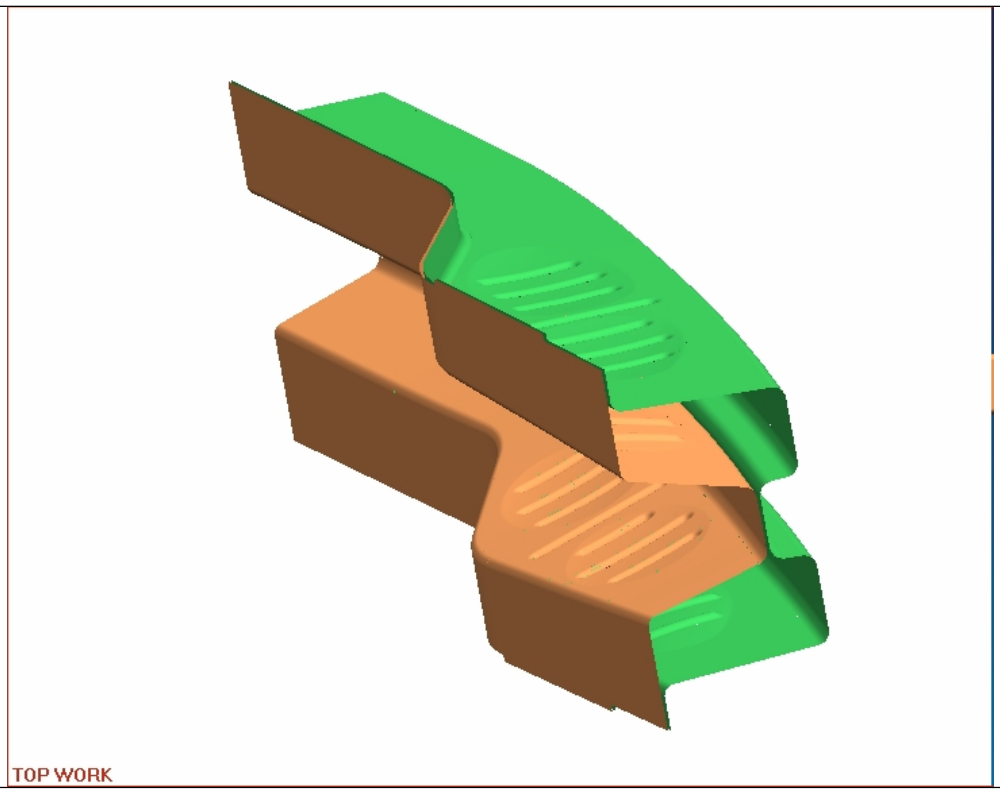


Figure 5: New Bumper Design – Close-up

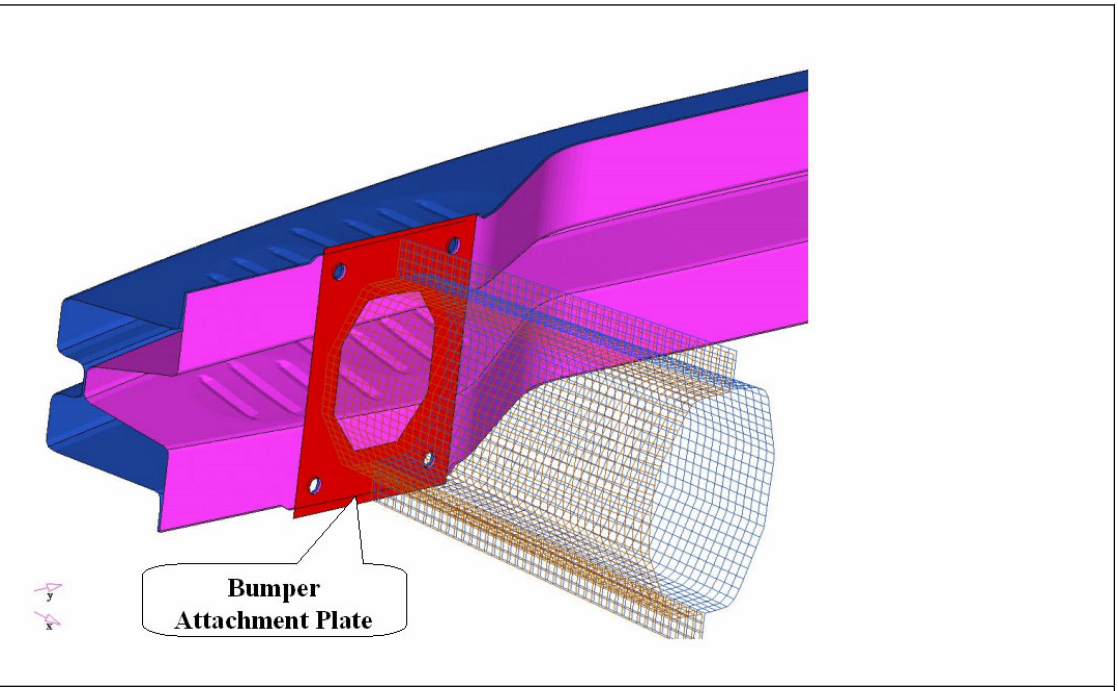


Figure 6: Bumper Attachment

Table 5: Mass Summary

Part	Mass (kg)	
	Baseline Design	Final Design
LH Rail Assembly	16.52	12.25
RH Rail Assembly	16.15	12.25
Bumper (without foam)	6.56	5.96
Total	39.23	30.46*

* 22.36% mass reduction with respect to *Baseline*

Table 6: Grade and Gauge Summary

Part	Final Design	
	Grade	Gauge (mm)
Rail Front Inner	DP 450/800	1.0
Rail Front Outer	DP 450/800	1.0
Rail Mid Inner	DP 450/800	1.2
Rail Mid Outer	DP 450/800	1.2
Rail Rear Inner	DP 450/800	1.4
Rail Rear Outer	DP 450/800	1.4
Rail Extension Front	DP 450/800	2.0
Rail Extension Rear	DP 450/800	1.2
Rail Extension Reinforcement	DP 450/800	1.4
Rail Inner Reinforcement	DP 450/800	2.0
Bumper Beam	DP 700/980	1.0

4. FE Model - Output Location Summary

The nodes at which the desired NCAP and IIHS outputs were obtained are listed in *Table 7*.

The intrusions are measured at the nodes as specified in *Reference 3*.

The acceleration and intrusion node locations are shown in *Figure 7* and *Figure 8* below.

Table 7: Summary of Output Locations

Parameter	Location	Node Number
Accelerations	B-Pillar / Rocker - LH	5000001
	B-Pillar / Rocker - RH	5000002
Intrusions	Origin	6000000
	Plane Y-axis	6000001
	Plane Z-axis	6000002
	Steering Column	7000001
	Brake Pedal	7000002
	Toepan - Left	7000003
	Toepan - Center	7000004
	Toepan - Right	7000005
	Left Front Seat Bolt	7000006
	Right Front Seat Bolt	7000007
	Left Rear Seat Bolt	7000008
	Right Rear Seat Bolt	7000009
	AB Closure - A Pillar	7000010
	AB Closure - B Pillar	7000011

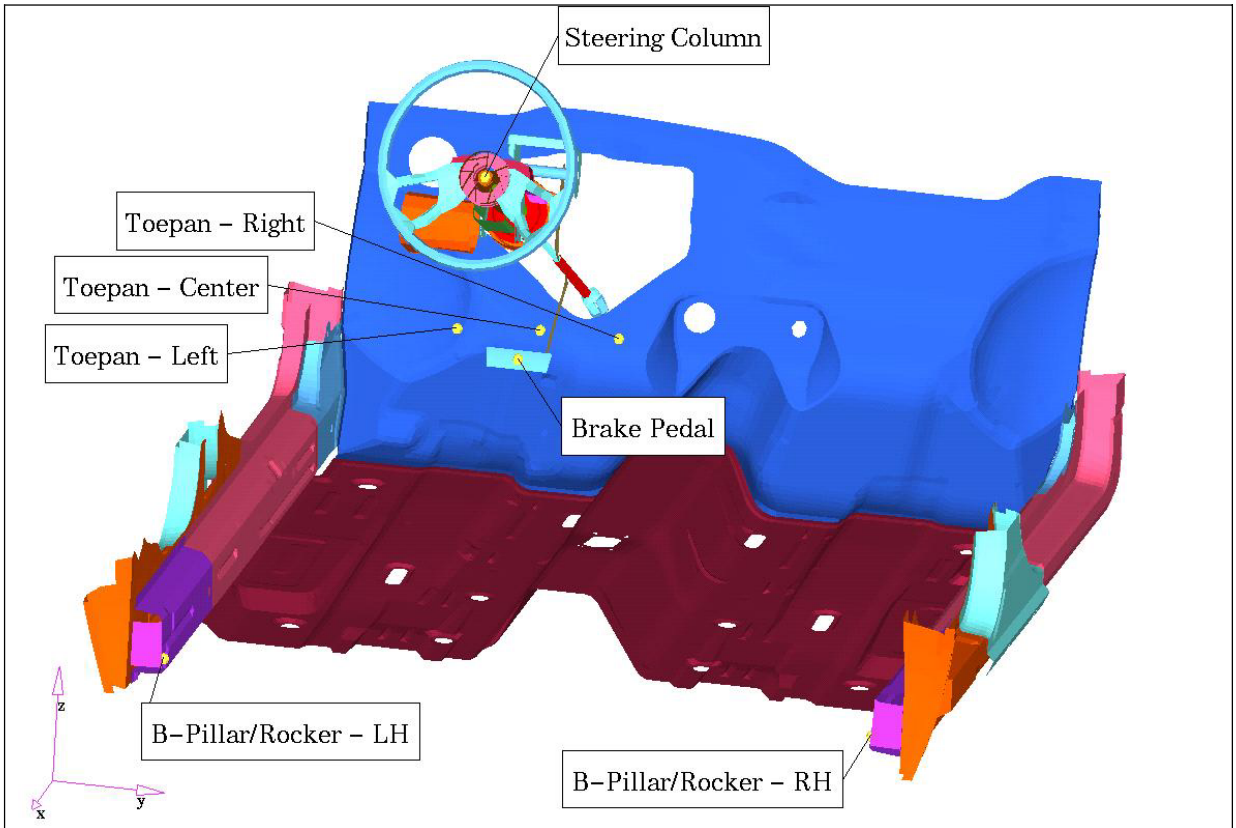


Figure 7: Output Locations for NCAP/IIHS



Figure 8: Output Locations for IIHS- AB Closure

5. NCAP Response

The figures below summarize the NCAP response of the *Final Design*.

Animation files are included in *Appendix A*.

The *Final Design* possesses a superior NCAP performance compared to the ***Baseline***. The initial peak is higher and the global peak is lower than the *Baseline Design.* Furthermore, the front of the rail (forward of the front cradle mount) crushes axially, resulting in good energy absorption.

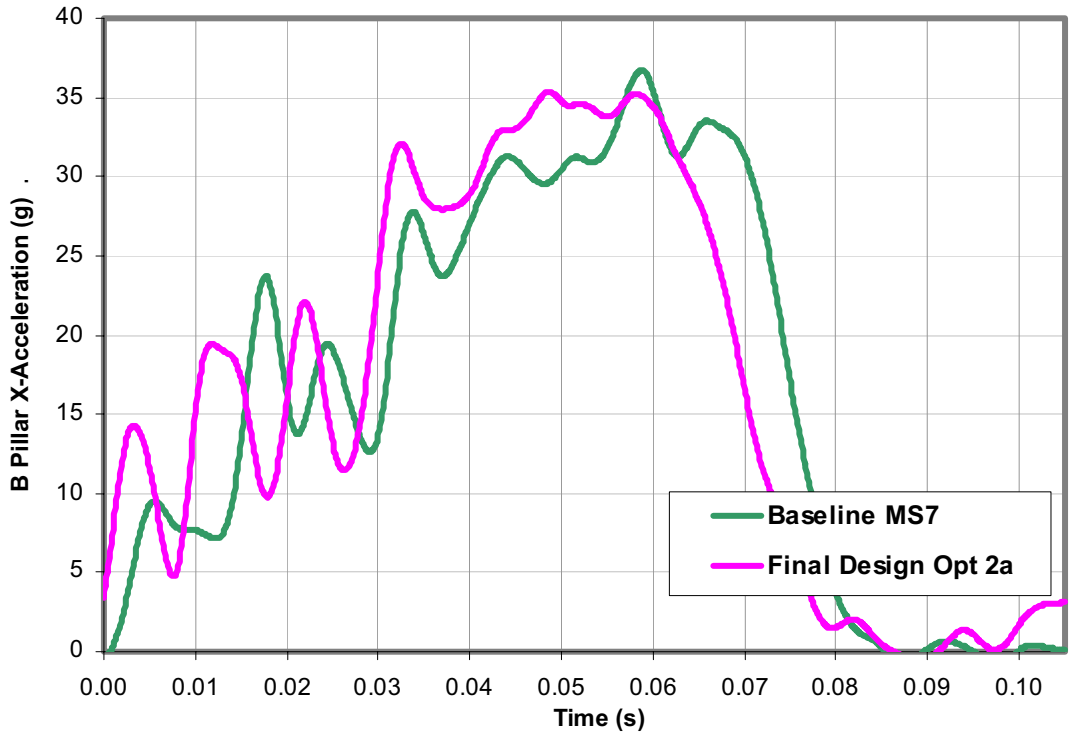


Figure 9: LH B-Pillar Pulse – Final Design Vs. Baseline

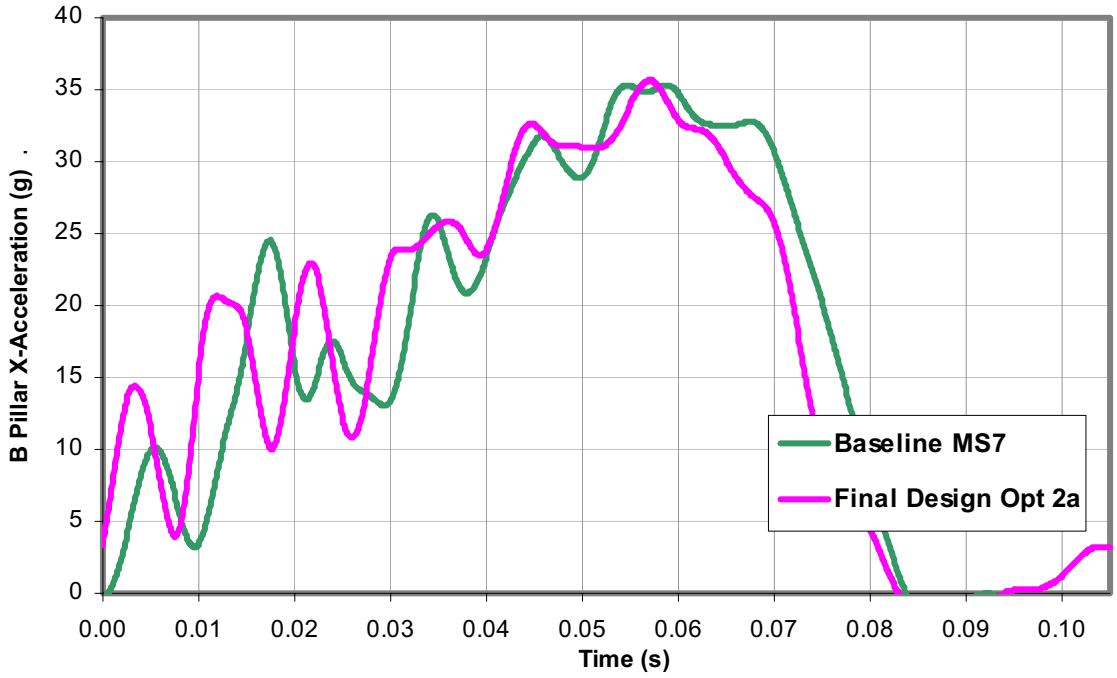


Figure 10: RH B-Pillar Pulse – Final Design Vs. Baseline

Table 8: NCAP Crash Events	
Time (ms)	**Crash Events**
0-15	Bumper absorbs energy
15-20	Engine hits the radiator, Cradle Extension Buckles, Cradle engaged
20-30	Cradle and LH rail buckling started
35-40	LH front wheel hits the LH rail
40-45	Engine hits to dash
45-50	RH front wheel hits the RH rail
55-60	LH wheel hits the front rigid wall
60-70	RH wheel hits the front rigid wall, LH wheel hits the rocker
70-75	RH wheel hits the rocker

6. IIHS Response

IIHS intrusions are summarized in *Table 2*.

Animation files are included in *Appendix A*.

Toepan, brake pedal and A-B closure intrusions oscillate after 200ms about a mean value. Hence, the peak intrusion values are used for comparison (*Table 2*).

The left toepan and A-B closure intrusions are lower than the *Baseline* values. The center and right toepan intrusions are slightly higher than the *Baseline* values.

7. Conclusions

The *Final Design* achieves a mass reduction of **8.77kg (22.36%)** compared to the *Baseline* design. The NCAP performance of the *Final Design* is superior to that of the *Baseline* design. The IIHS, static and dynamic stiffness performances are similar to those of the *Baseline* design.

8. Future Work

The *Final Design* was prototyped and assembled into the full vehicle for NCAP testing in *Phase II* of the *Lightweight Front End Structure Project*.

9. References

1) *Validated FE Models, Milestone 5*, SPHINX, Phase II.

2) *Enhanced FE Models, Milestone 6*, SPHINX, Phase II.

3) *IIHS Crashworthiness Evaluation Offset Barrier Crash Test Protocol (Version IX), October 2002.*

4) *DOE FE Models, Milestone 7*, SPHINX, Phase II.

5) *Third Bumper Design Report, Milestone 5*, SPHINX, Phase I.

6) *Concept 1: Preliminary Design, Milestone 10*, SPHINX, Phase II.

7) *FMVSS Part 581 Bumper Standard*.

8) *Concept 2: Preliminary Design, Milestone 13*, SPHINX, Phase II.

9) *Concept 2: Final Design, Milestone 15*, SPHINX, Phase II.

10) *NCAP DOE Response Surface, Milestone 20*, SPHINX, Phase II.

11) *IIHS DOE Response Surface, Milestone 21*, SPHINX, Phase II.

12) *Static Stiffness DOE Response Surface, Milestone 46*, SPHINX, Phase II.

13) *Dynamic Stiffness DOE Response Surface, Milestone 47*, SPHINX, Phase II.

10. Appendix A: Animations

The following animation files for the subsystem development can be viewed at the Auto/Steel Partnership website, www.a-sp.org.

You will need a Hyperview Player in order to view these animations at the site. You can download this free software at www.altair.com.

1. Baseline NCAP
2. Baseline IIHS
3. Final Design NCAP
4. Final Design IIHS

11. Appendix B: Summary of FE Model

Total Components	
Model Mass	1.778 tonnes

- Model mass is from LS-DYNA3D d3hsp file.

Analysis Of Vehicle With New Rail System

Milestone 34

Lightweight Front End Structure Phase II

December 3, 2004

Auto/Steel Partnership

Abstract

This report documents the changes made to the *Final Design* of the bumper assembly, rail assembly and their attached parts during prototyping and assembly, in *Phase II* of the *Lightweight Front End Structure Project*.

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1. Objectives

The effort of this study was aimed at modifying the *Final Design* of the bumper assembly, rail assembly and their attached parts, to reflect all changes made during prototyping and assembly, and to account for events observed in the NCAP test.

2. Results Summary

The following changes were made to the FE model of the *Final Design*:

- Take up beads in rail extension reinforcement
- Tooling holes and minor cross-sectional changes in rail components
- Front cradle front mounts (inner/outer)
- Tie bar bracket
- Front wheelhouse panel
- Battery tray support bracket
- LH Engine mount
- Front RH Cradle bolt connection to rails
- Front bumper hole locations
- Weld pattern modification
- Structural adhesive in the lower flange of the front rail inner and outer between the front cradle mount
- Front hood

Please refer to *Section 3* for details on all modifications.

The modifications resulted in a 2.5g drop in the initial LH/RH peaks and 1.5g/2.5g drop in the overall LH/RH peaks. There is a 3.8ms/1.4ms increase in the time for LH/RH velocity profiles to drop to zero. There was no significant change in the vehicle deformation.

The NCAP results are summarized in *Table 1*.

Table 1: NCAP Results of Final Design

	Peak Acceleration	
B-Pillar Pulse	**Original Model***	**Updated Model**
LH	**35.4 g @ 48.5 ms**	**32.9 g @ 41.9 ms**
RH	**35.6 g @ 57.2 ms**	**33.9 g @ 59.3 ms**

* ***Original Model*** results correspond to ***Milestone 22***.

3. Modifications to Final Design

The following changes were made in the *Final Design,* to reflect all modifications made during manufacturing and assembly, and to account for events observed in the NCAP test.

1. Take up beads were added to the rail extension reinforcement to allow for easier fabricating *(Figure 1).*

2. Tooling holes were added to the rail components.

3. Some minor manufacturing related cross-sectional changes were also updated.

4. Front cradle front mounts (inner/outer) were modified *(Figure 2).*
   - Parts were not fabricated by stamping; they were hand-fabricated and seam welded in places.
   - The design was changed slightly to remove the bump on the side near the rail attachment flanges.
   - CAD data was not available; hence FE model was updated using measured dimensions.
   - A gauge of 2.5mm was used, instead of the design gauge of 1.95mm, due to availability of sheet metal.

5. Tie bar bracket was re-designed during assembly and is thus different from the original tie bar bracket *(Figure 3).*
   - Tie bar bracket was seam welded to the rail.

6. The front wheelhouse panel was redesigned (*Figure 4*).

7. The battery tray support bracket was modified, as its design is different in the Donor vehicle than the FE model *(Figure 5).* The FE model has a stamped design, where the actual vehicle has a bent tubular design.

8. The following changes were made to the LH engine mount.
   - Material was changed from aluminum to steel.
   - Gauge was changed from 8mm to 3mm.
   - Mount failure option was removed, as the mount did not fail in test. Instead, the spotwelds between the LH engine mount and the cradle were failed at 22ms, as they were found to have failed in the NCAP test vehicle. The failure time was taken as the time at which the LH test pulse dropped almost to zero *(Ref. 15)*. ***This failure is only applicable to NCAP simulation and should not be used for IIHS simulation***.

9. The spring representing the front cradle mount bolt connection to rails was removed as the bolt failed in the NCAP test. ***This failure is only applicable to NCAP simulation and should not be used for IIHS simulation***.

10. Front bumper hole locations were repositioned slightly.

11. Weld pattern in the rail extension welds to the floor and dash was modified, due to drilling out of donor vehicle welds and puddle welding to the rail extension. In addition, a few welds between the rail extension and the dash were removed, as the test vehicle did not have them *(Figure 6).*

12. There is one less weld at the back of the lower flange on the front rail inner and outer due to the addition of a chamfer.

13. Structural adhesive was used on the lower flange of the front rail inner and outer between the front cradle mount, rather than welding. This was necessary due to lack of access for the weld gun in this area, due to the order of assembly. The adhesive was represented by a continuous rigid connection.

14. The front hood bolts were failed at 32ms, as observed in the test vehicle. The bolts in the test vehicle were 6mm in diameter, instead of the 8mm diameter bolts in the production vehicle. ***This failure is only applicable to NCAP simulation and should not be used for IIHS simulation***.

The following modifications could not be made to the FE model:

- The geometry of the engine mounts in the CAD/FE data is different from that of the actual mounts in the test vehicle. Consequently, the engine mount models could not be updated.
- An extra bracket on the side of the front cradle mount was not modeled as it was a non-structural part and no CAD data was available.

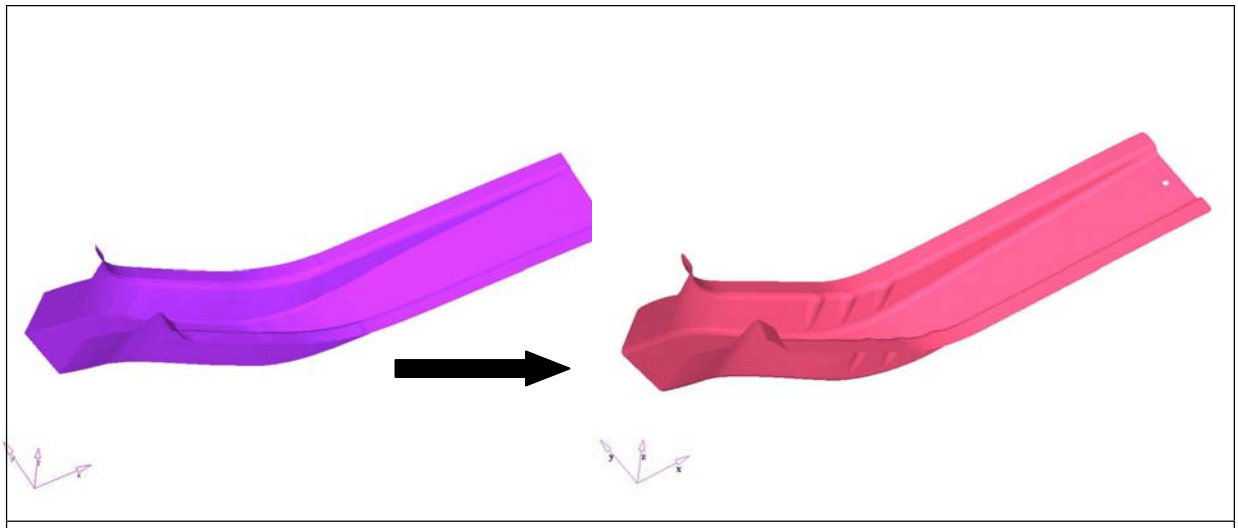


Figure 1: Rail Extension Reinforcement

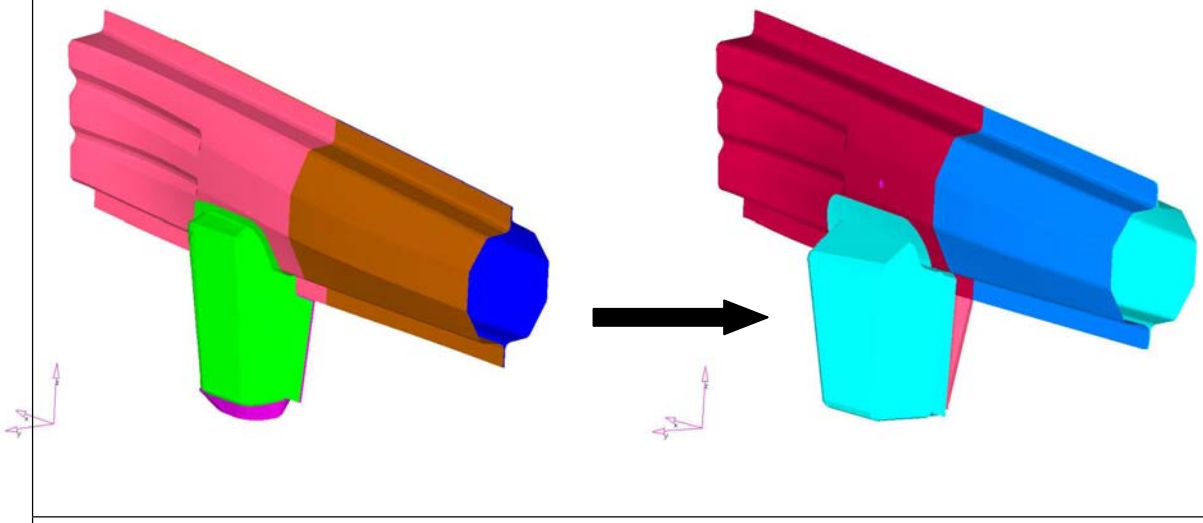


Figure 2: Front Cradle Mounts

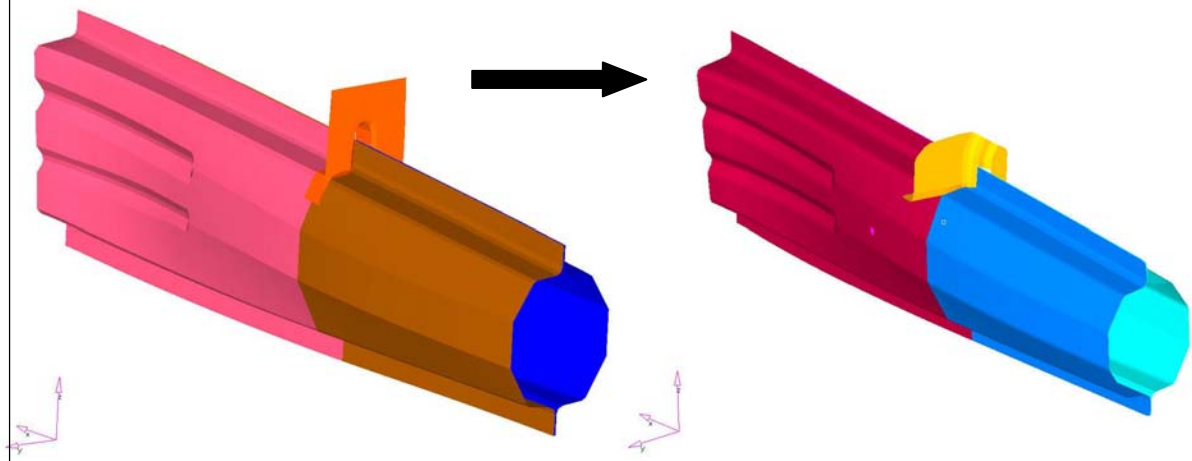


Figure 3: Tie Bar Bracket

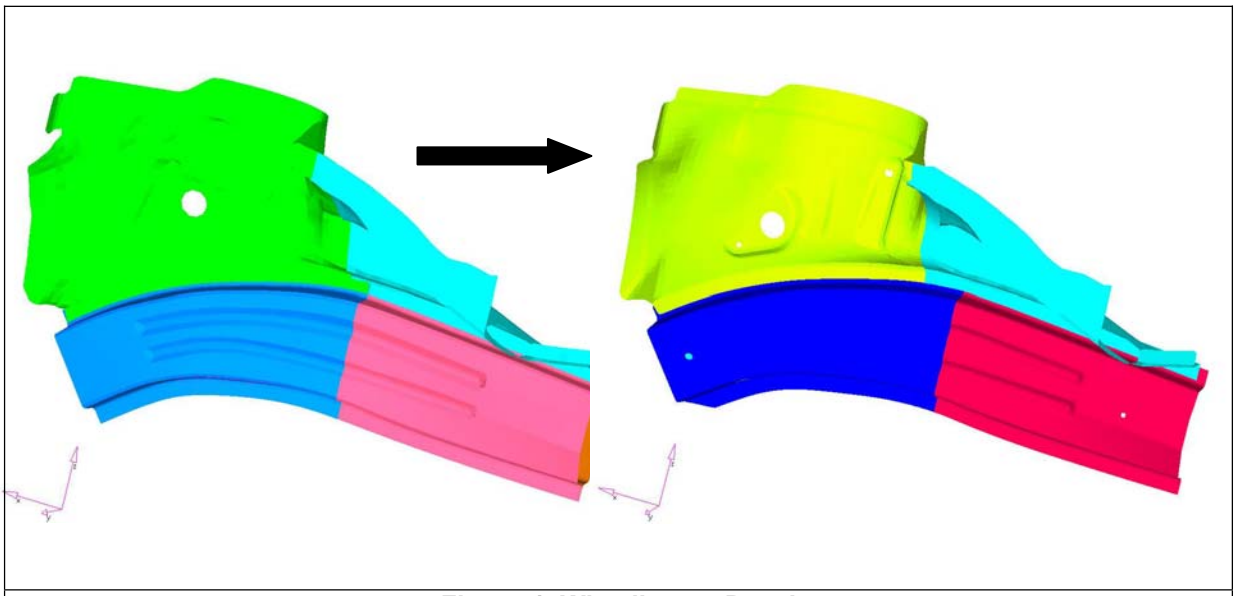


Figure 4: Wheelhouse Panel

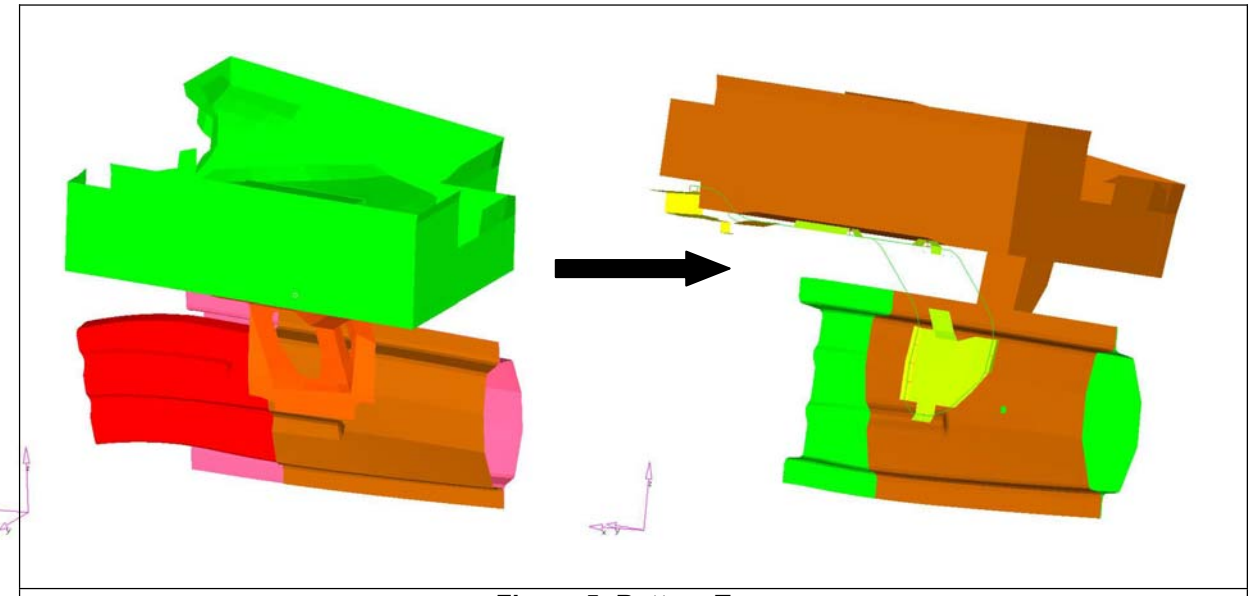


Figure 5: Battery Tray

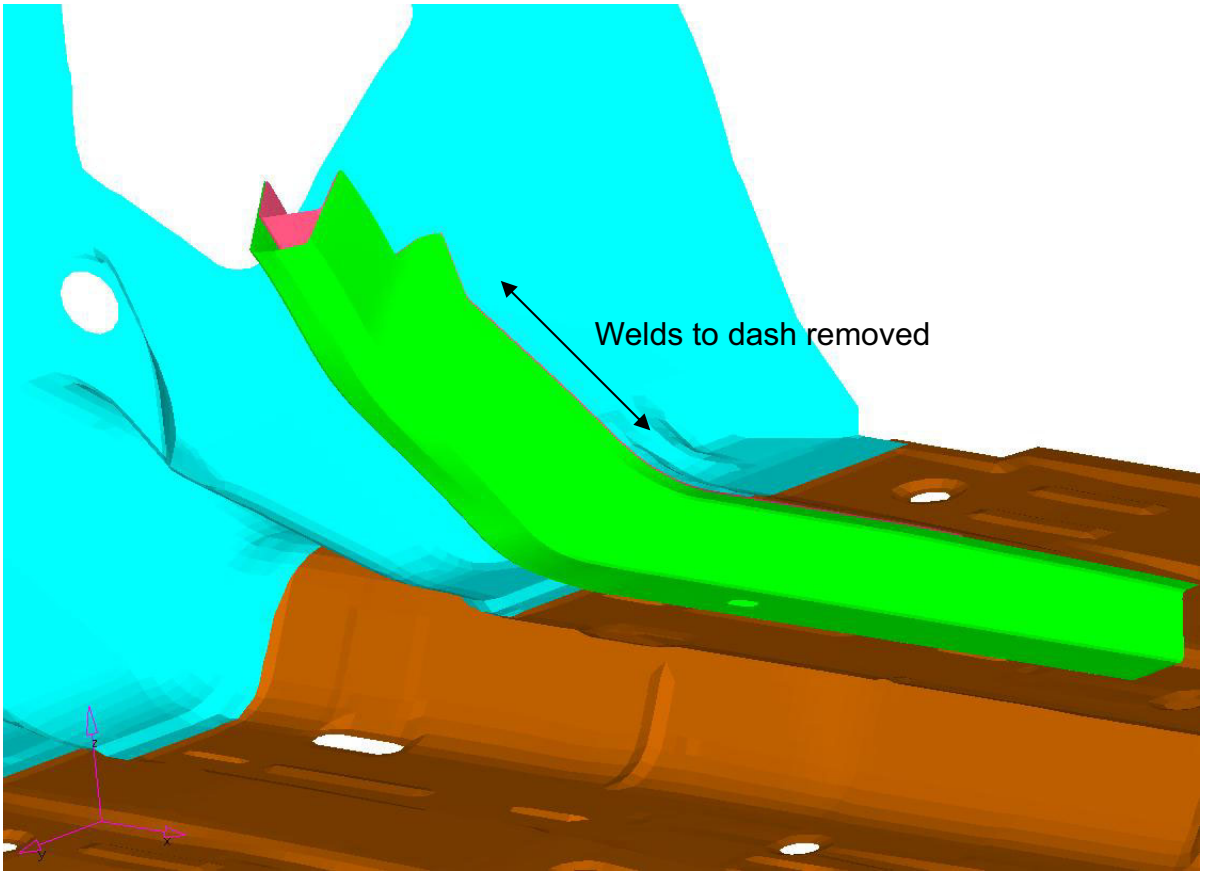


Figure 6: Rail Extension Welds

A mass summary for rail and bumper parts is included in *Table 2*.

A grade/gauge summary for rail and bumper parts is included in *Table 3*.

Table 2: Mass Summary

Part	Mass (kg)	
	Baseline Design	Final Design
LH Rail Assembly	16.52	12.25
RH Rail Assembly	16.15	12.25
Bumper (without foam)	6.56	5.96
Total	39.23	30.46*

* 22.36% mass reduction with respect to *Baseline*

Table 3: Grade and Gauge Summary

Part	Final Design	
	Grade	Gauge (mm)
Rail Front Inner	DP 450/800	1.0
Rail Front Outer	DP 450/800	1.0
Rail Mid Inner	DP 450/800	1.2
Rail Mid Outer	DP 450/800	1.2
Rail Rear Inner	DP 450/800	1.4
Rail Rear Outer	DP 450/800	1.4
Rail Extension Front	DP 450/800	2.0
Rail Extension Rear	DP 450/800	1.2
Rail Extension Reinforcement	DP 450/800	1.4
Rail Inner Reinforcement	DP 450/800	2.0
Bumper Beam	DP 700/980	1.0

4. FE Model - Output Location Summary

The nodes at which the desired NCAP and IIHS outputs were obtained are listed in *Table 4*.

The intrusions are measured at the nodes as specified in *Reference 3*.

The acceleration and intrusion node locations are shown in *Figure 7* and *Figure 8* below.

Table 4: Summary of Output Locations

Parameter	Location	Node Number
Accelerations	B-Pillar / Rocker - LH	5000001
	B-Pillar / Rocker - RH	5000002
Intrusions	Origin	6000000
	Plane Y-axis	6000001
	Plane Z-axis	6000002
	Steering Column	7000001
	Brake Pedal	7000002
	Toepan - Left	7000003
	Toepan - Center	7000004
	Toepan - Right	7000005
	Left Front Seat Bolt	7000006
	Right Front Seat Bolt	7000007
	Left Rear Seat Bolt	7000008
	Right Rear Seat Bolt	7000009
	AB Closure - A Pillar	7000010
	AB Closure - B Pillar	7000011

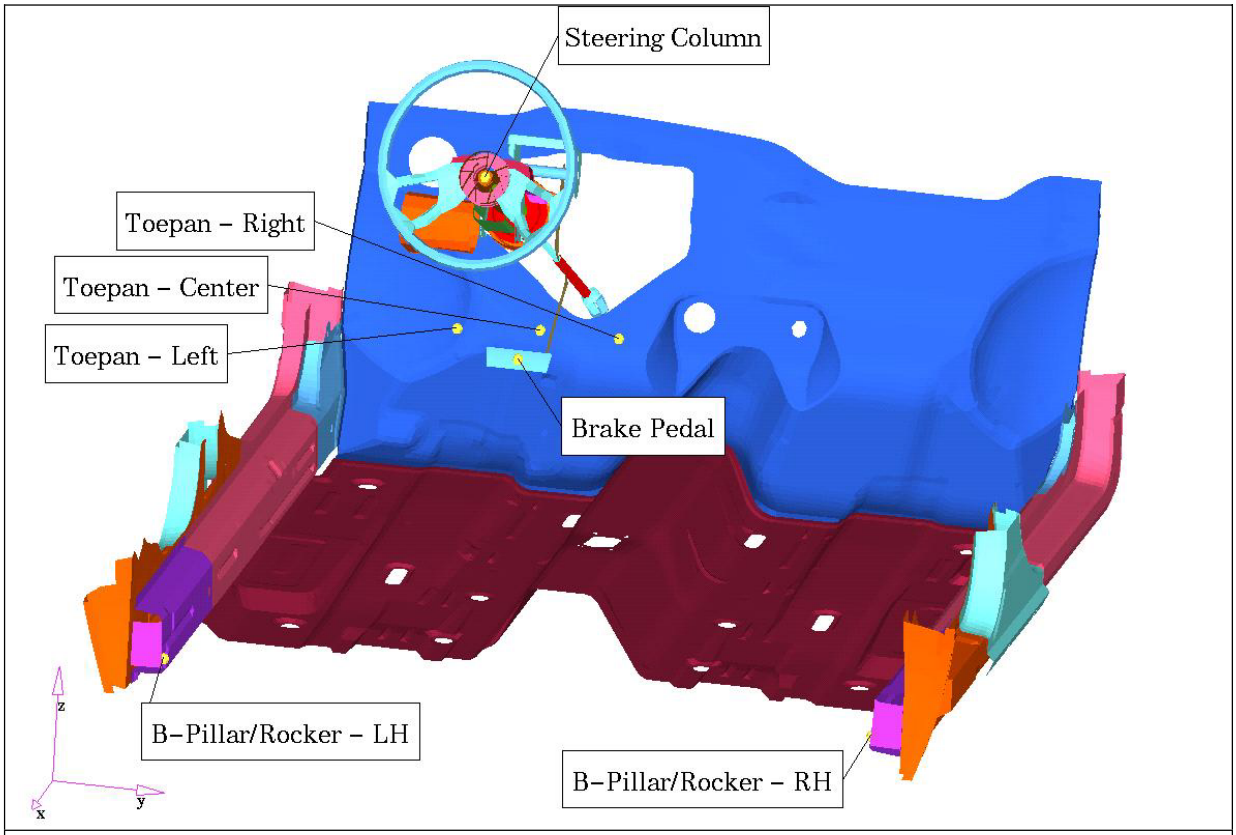


Figure 7: Output Locations for NCAP/IIHS



Figure 8: Output Locations for IIHS- AB Closure

5. NCAP Response

The figures below summarize the NCAP response of the *Final Design*. Animation files are included in *Appendix A*. The modifications resulted in a 2.5g drop in the initial LH/RH peaks and 1.5g/2.5g drop in the overall LH/RH peaks (*Figure 9, Figure 10*).

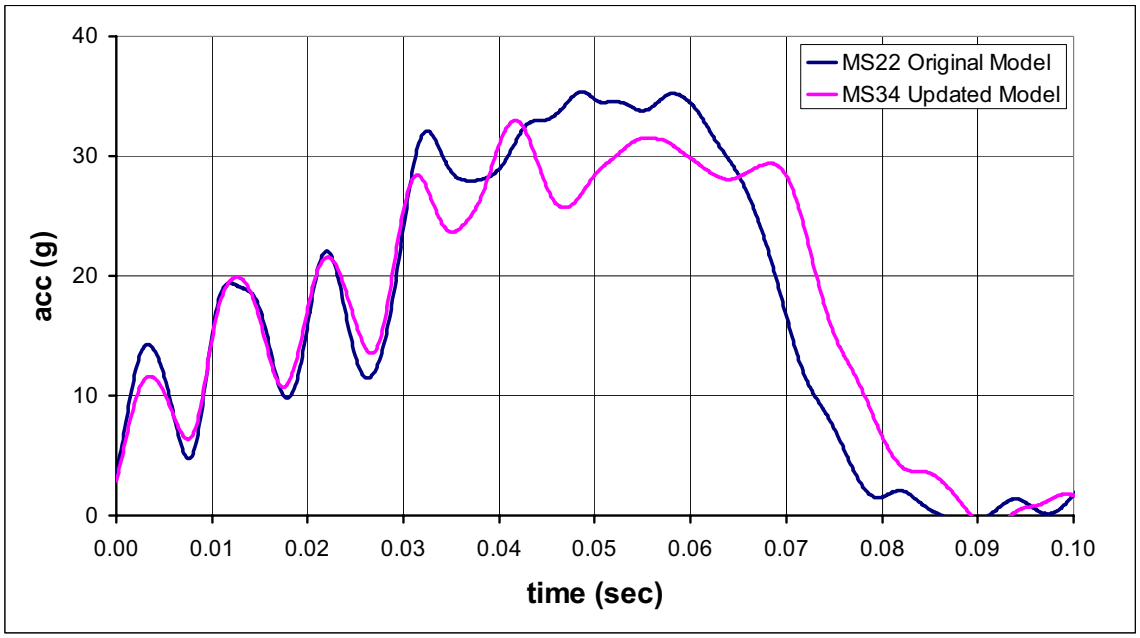


Figure 9: LH B-Pillar Pulse

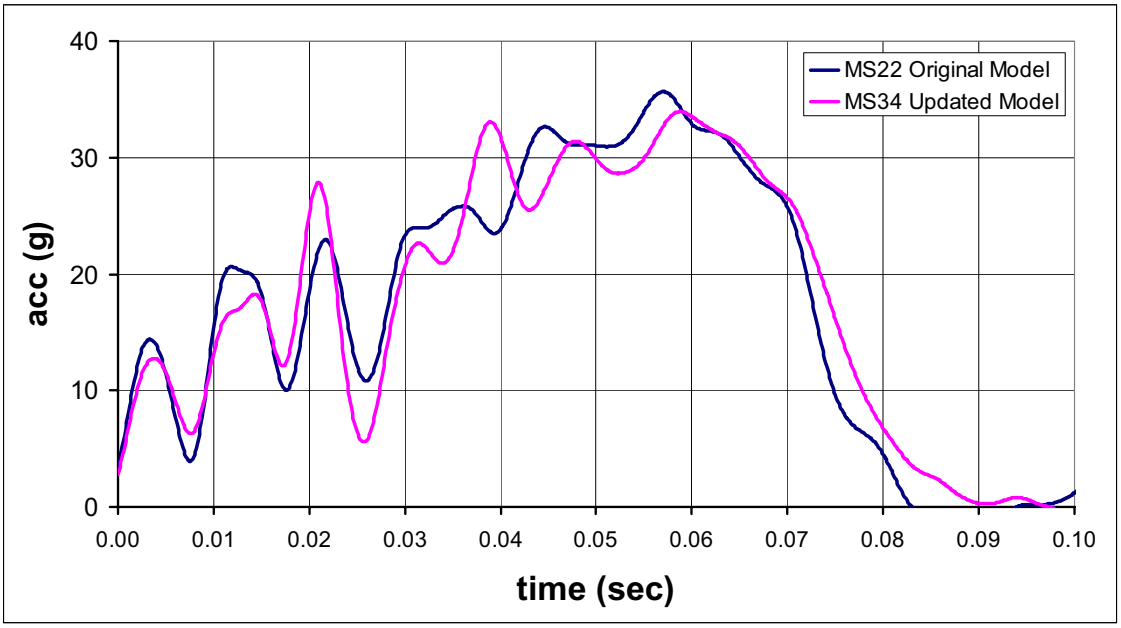


Figure 10: RH B-Pillar Pulse

The slope of the velocity profile after 40ms is slightly lower in the *Updated Model*. There is also a 3.8ms/1.4ms increase in the time for LH/RH velocity profiles to drop to zero (*Figure 11*, *Figure 12*).

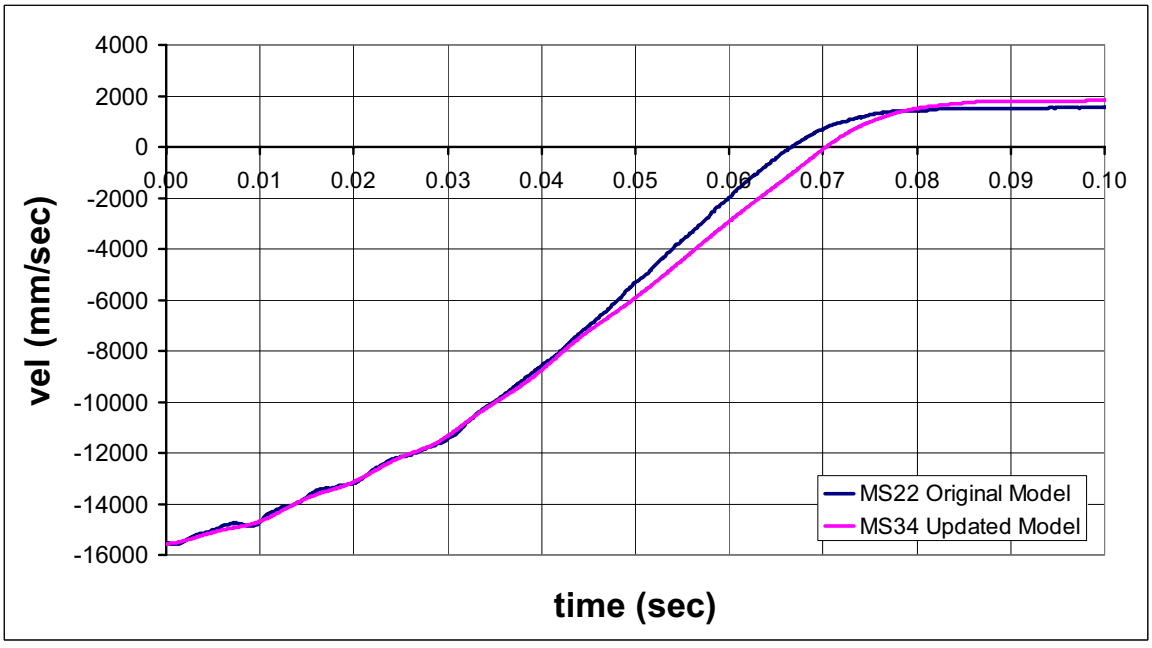


Figure 11: LH B-Pillar Velocity Profile

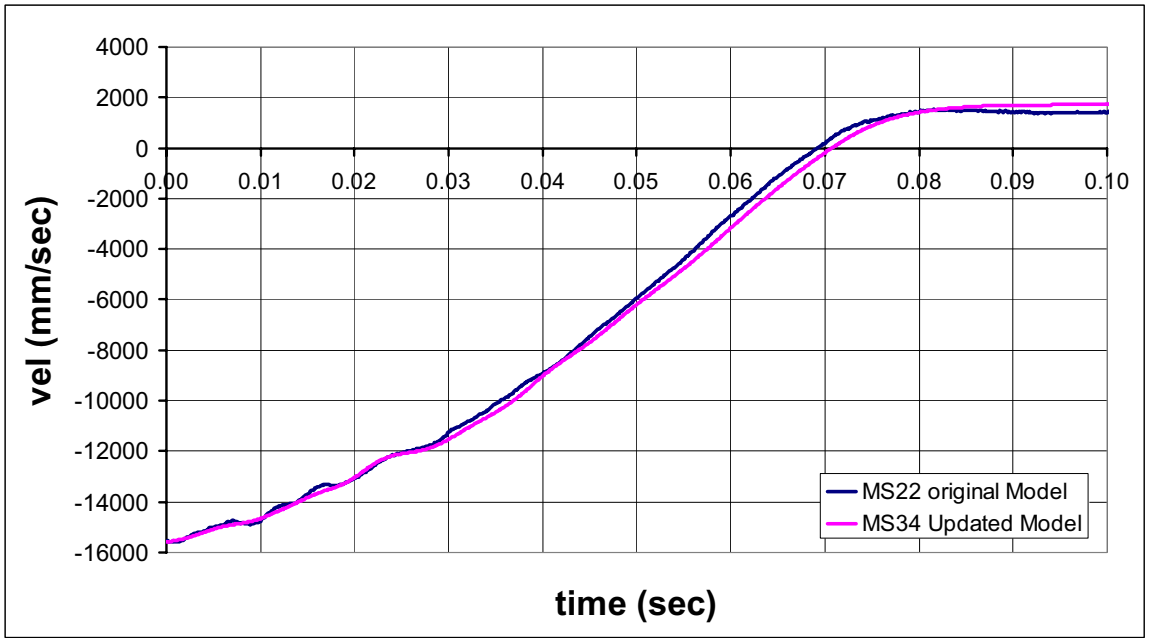


Figure 12: RH B-Pillar Velocity Profile

The peak barrier force (*Figure 13*) in the *Updated Model* is lower than in the *Original Model* by 37 kN. However, the initial peak in the *Updated Model* is higher than in the *Original Model* by 54 kN.

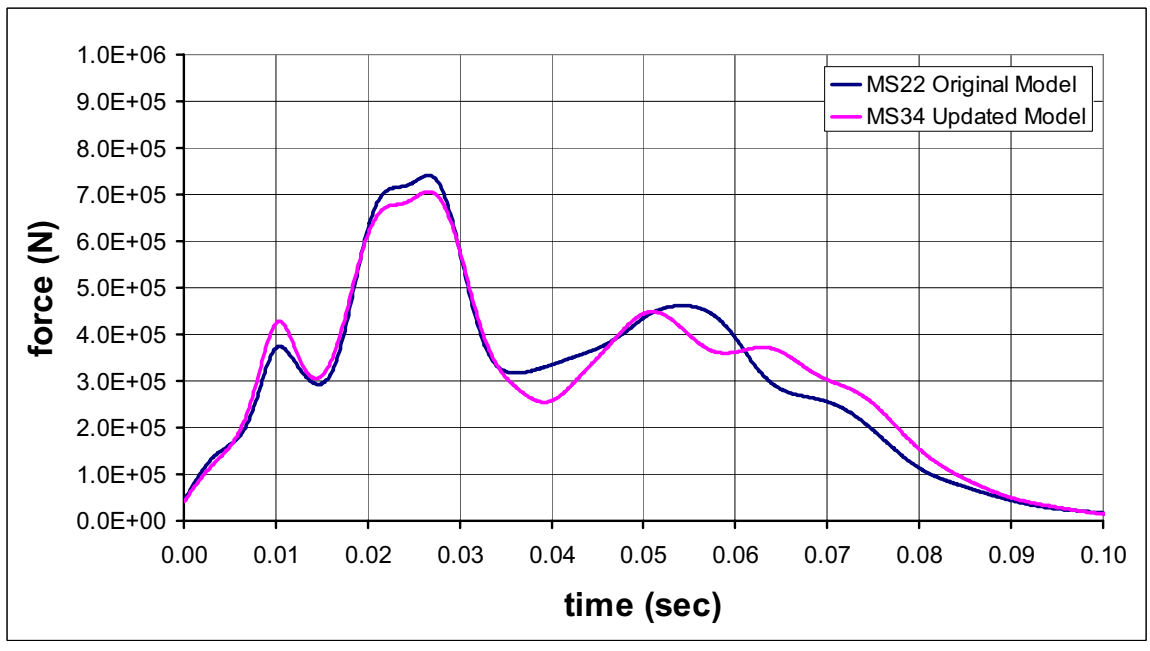


Figure 13: Barrier Force

6. Conclusions

The *Final Design* of the bumper assembly, rail assembly and their attached parts was modified, to reflect all changes made during prototyping and assembly, and to account for events observed in the NCAP test. The modifications resulted in a 2.5g drop in the initial LH/RH peaks and 1.5g/2.5g drop in the overall LH/RH peaks. There is a 3.8ms/1.4ms increase in the time for LH/RH velocity profiles to drop to zero. There was no significant change in the vehicle deformation.

7. Future Work

The FEA results of the *Updated Model* will be compared to the NCAP test results.

8. References

1) *Validated FE Models, Milestone 5*, SPHINX, Phase II.

2) *Enhanced FE Models, Milestone 6*, SPHINX, Phase II.

3) *IIHS Crashworthiness Evaluation Offset Barrier Crash Test Protocol (Version IX), October 2002.*

4) *DOE FE Models, Milestone 7*, SPHINX, Phase II.

5) *Third Bumper Design Report, Milestone 5*, SPHINX, Phase I.

6) *Concept 1: Preliminary Design, Milestone 10*, SPHINX, Phase II.

7) *FMVSS Part 581 Bumper Standard*.

8) *Concept 2: Preliminary Design, Milestone 13*, SPHINX, Phase II.

9) *Concept 2: Final Design, Milestone 15*, SPHINX, Phase II.

10) *NCAP DOE Response Surface, Milestone 20*, SPHINX, Phase II.

11) *IIHS DOE Response Surface, Milestone 21*, SPHINX, Phase II.

12) *Static Stiffness DOE Response Surface, Milestone 46*, SPHINX, Phase II.

13) *Dynamic Stiffness DOE Response Surface, Milestone 47*, SPHINX, Phase II.

14) *Final Optimized Design, Milestone 22*, SPHINX, Phase II.

15) *Correlation of Vehicle with New Rails/Bumper, Milestone 36*, SPHINX, Phase II.

9. Appendix A: Animations

The following animation files for the subsystem development can be viewed at the Auto/Steel Partnership website, www.a-sp.org.

You will need a Hyperview Player in order to view these animations at the site. You can download this free software at www.altair.com.

1. Original Model NCAP
2. Updated Model NCAP

10. Appendix B: Summary of FE Model

Model Mass	1.778 tonnes

- Model mass is from LS-DYNA3D d3hsp file.

Chevrolet Malibu 4-door

Into Load Cell Barrier

TRC Inc. Test Number: 040921-2

Final Report

September - October 2004

Notice

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Test Performed By: John Shultz, IL Supervisor

Report Approved By:



Date 10-11-04

Christopher Krouskop, Project Manager
Transportation Research Center Inc.

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Section 1.0

Purpose and Test Procedure

Purpose

This 56 km/h (35 mph) frontal barrier impact test was conducted for Quantech Global Services by Transportation Research Center Inc. (TRC Inc.).

The purpose of this test was to determine the vehicle response of the subject vehicle, a Chevrolet Malibu 4-door, in the 56 km/h (35 mph) modified NCAP impact mode.

Test Procedure

This 56 km/h (35 mph) test was conducted per Quantech Global Services' instructions in a modified version of the National Highway Traffic Safety Administration's (NHTSA's) Office of Crashworthiness Standards Laboratory Test Procedure for New Car Assessment Program, dated December 1999. Data was obtained relative to FMVSS 208, "Occupant Crash Protection".

The test vehicle was instrumented with thirteen (13) accelerometers to measure longitudinal axis accelerations, four (4) accelerometers to measure lateral axis accelerations and four (4) accelerometers to measure vertical axis accelerations. The vehicle impacted a frontal load cell barrier instrumented with thirty-six (36) barrier face load cells. The vehicle's specified impact velocity range was 55.5 to 57.1 km/h.

The test vehicle contained two (2) Part 572B 50th percentile adult male ballast anthropomorphic test devices (dummies). The dummies were positioned in the front outboard designated seating positions, no dummy measurements were taken. Each dummy was restrained with a 3-point unibelt. The dummies were uninstrumented.

The 57 data channels were digitally sampled and recorded at 12,500 samples per second and processed per Section 11.13 of the Laboratory Indicant Test Procedure.

The crash event was recorded by one (1) real-time panning motion picture camera and fifteen (15) high-speed motion picture cameras. The pre- and post-test conditions were recorded by one (1) real-time motion picture camera.

The vehicle and load cell barrier data are presented in Section 2.0. The camera and vehicle measurements are presented in Section 3.0. Appendix A contains the still photographic prints. Appendix B contains the vehicle, and load cell barrier data plots. Appendix C contains miscellaneous test information.

Section 2.0

Impact Test Summary

Test Results Summary

This frontal load cell barrier test was conducted by TRC Inc. on September 21, 2004.

The test vehicle, a Chevrolet Malibu 4-door, was equipped with a transverse engine, automatic transmission, power steering, and power brakes. The vehicle's test weight was 1769.0 kg. The vehicle's impact speed was 56.5 km/h. The vehicle sustained 520 mm of static crush during the impact.

Data Acquisition Explanations

The passenger vehicle's engine top of block X-axis acceleration data channel, ENGTXG, exceeded its full scale value at approximately 135 milliseconds.

The passenger vehicle's engine bottom of block X-axis acceleration data channel, ENGBXG, recorded questionable data after approximately 48 milliseconds.

Table 1 Crash Test Summary

Test mode:	Frontal load cell barrier			
Test date:	09/21/04			
Test time:	15:27			
Ambient temperature:	21° C			
Vehicle year/make/ model/body style:	2004/Chevrolet/Malibu/4-door			
Vehicle test weight:	1769.0 kg			
Impact angle[1]:	0°			
Impact velocity[2]:	56.5 km/h			
Maximum static crush:	520 mm			
Average rebound:	2087 mm			
Number of data channels:	57			
Number of cameras:	High-speed	15	Real-time	1
Door Opening Data:	Left		Right	
Front	Easy		Easy	
Rear	Easy		Easy	
Front Seat Data:	Driver		Passenger	
Seat Track Shift	None		None	
Seat Back Failure	None		None	

[1] With respect to tow track centerline.
[2] Speed trap measurement (± .08 km/h accuracy)

Table 2 General Test and Vehicle Parameter Data

Vehicle year/make/ model/body style:	2004/Chevrolet/Malibu/4-door			
VIN:	1G1NE54F54X6490EX			
Color:	White			
Engine data:				
Cylinders:	6			
Displacement	N/A liters			
Cylinder placement:	V			
Engine placement:	Transverse			
Transmission data:	_2_speed,	___manual,	_X_automatic,	___overdrive
Final drive:	_X_FWD,	___RWD,	___4WD	

Major Options:

Air conditioning	Yes
Power steering	Yes
Power brakes	Yes
Power windows	Yes
Power door locks	Yes
Tilting steering wheel	Yes

Date vehicle received:	09/07/04
Odometer reading:	N/A
Dealer's name and address:	N/A

Certification data from vehicle's label:[1]

Vehicle manufactured by:		N/A	
Date of manufacture:		N/A	
VIN:		N/A	
GVWR:		N/A lbs.	(N/A kg)
GAWR:	Front:	N/A lbs.	(N/A kg)
	Rear:	N/A lbs.	(N/A kg)

[1] The vehicle did not contain a label stating certification data.

Table 2 General Test and Vehicle Parameter Data, Cont'd.

Data from Tires:

Tire pressure with maximum capacity vehicle load:

Front:	44 psi	(300 kPa)
Rear:	44 psi	(300 kPa)

Size of tires on test vehicle: P205/65R15

Manufacturer of tires: Bridgestone

Tire & capacity data from vehicle's label:[1]

Recommended tire size:	N/A	
Recommended cold tire pressure:	N/A	
Front:	N/A psi	(N/A kPa)
Rear:	N/A psi	(N/A kPa)

Vehicle Capacity Data:[1]

Type of front seats:	Bucket	
Number of Occupants (Designated seating capacity):		
Front	2	
Rear	3	
Total	5	
Vehicle capacity weight:		N/A kg
No. of Occupants X 68 kg:		N/A kg
Rated Cargo/Luggage Weight (RCLW)		N/A kg

[1] Vehicle did not contain a tire information label.

Table 2 General Test and Vehicle Parameter Data Cont'd

Test vehicle's target test weight:[1]

Target test weight	1769.0 kg

Weight of test vehicle with required dummies and cargo weight:

Right front	465.0 kg	Right rear	385.4 kg
Left front	502.8 kg	Left rear	415.8 kg
Total front weight	967.8 kg	(54.7% of total vehicle weight)	
Total rear weight	801.2 kg	(45.3% of total vehicle weight)	
Total test weight	1769.0 kg	(at target test weight)	

Weight of ballast secured in vehicle: 90.7 kg of plate weight in trunk
90.7 kg on floorboard behind driver's seat

Components removed to meet target test weight: trunk seal, left rear door seal

Test vehicle attitude:

Delivered attitude:	LF	702 mm;	RF	711 mm;	LR	720 mm;	RR	725 mm
Pre-test attitude:	LF	677 mm;	RF	695 mm;	LR	632 mm;	RR	650 mm
Post-test attitude:	LF	720 mm;	RF	795 mm;	LR	625 mm;	RR	655 mm

Vehicle's Wheelbase: 2705 mm

Location of Vehicle's CG: 1225 mm rearward of front wheel centerline

[1] Target test weight provided by Quantech Global Services.

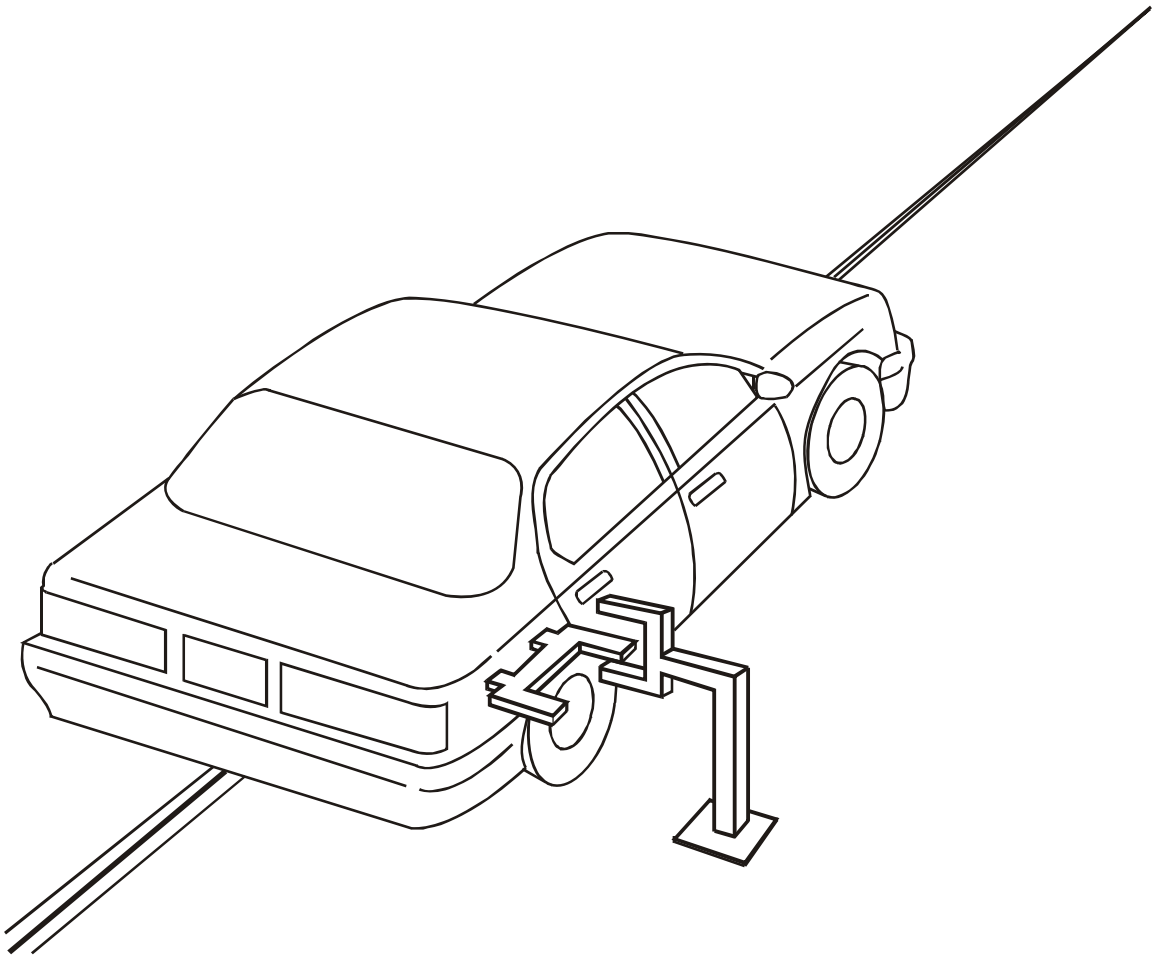
Table 2 General Test and Vehicle Parameter Data Cont'd

Fuel system capacity:	N/A liters (from owner's manual)
Usable capacity:	60.6 liters
Test volume range:	55.8 to 57.0 liters (92-94% of usable)
Actual test volume:	56.4 liters (with entire fuel system filled)
Test fluid type:	Stoddard
Specific gravity:	0.764
Kinematic viscosity:	0.99 centistoke
Test fluid color:	Purple
Type of fuel pump:	Electric
Did electric fuel pump operate with ignition switch "on" and the engine not operating?	No
Details of fuel system:	The fuel tank is located under the second row seat area. The fuel filler neck is located in the right rear quarter panel. The fuel filler cap is located at the exterior end of the fuel filler neck. The fuel lines run forward along the right frame rail.

Table 3 Post-Impact Data

Test type:	Frontal load cell barrier				
Impact angle:	0°				
Test date:	09/21/04				
Test time:	15:27				
Ambient temperature at impact area:	21° C				
Required impact velocity range:	55.5 to 57.1 km/h				
Barrier impact velocity:	56.5 km/h				
Distance from vehicle to barrier:					
Entering velocity trap:	661 mm				
Exiting velocity trap:	51 mm				
Vehicle static crush:					
Overall length of test vehicle:					
Pre-test:	L 4602 mm;	C 4785 mm;	R 4603 mm		
Post-test:	L 4184 mm;	C 4274 mm;	R 4273 mm		
Total crush:	L 418 mm;	C 511 mm;	R 330 mm		
Average crush:	420 mm				
Vehicle rebound from flat rigid barrier:					
Distance from test vehicle to barrier impact point:					
Post-test:	L 2130 mm;	C 2110 mm;	R 2020 mm		
Average rebound:	2087 mm				

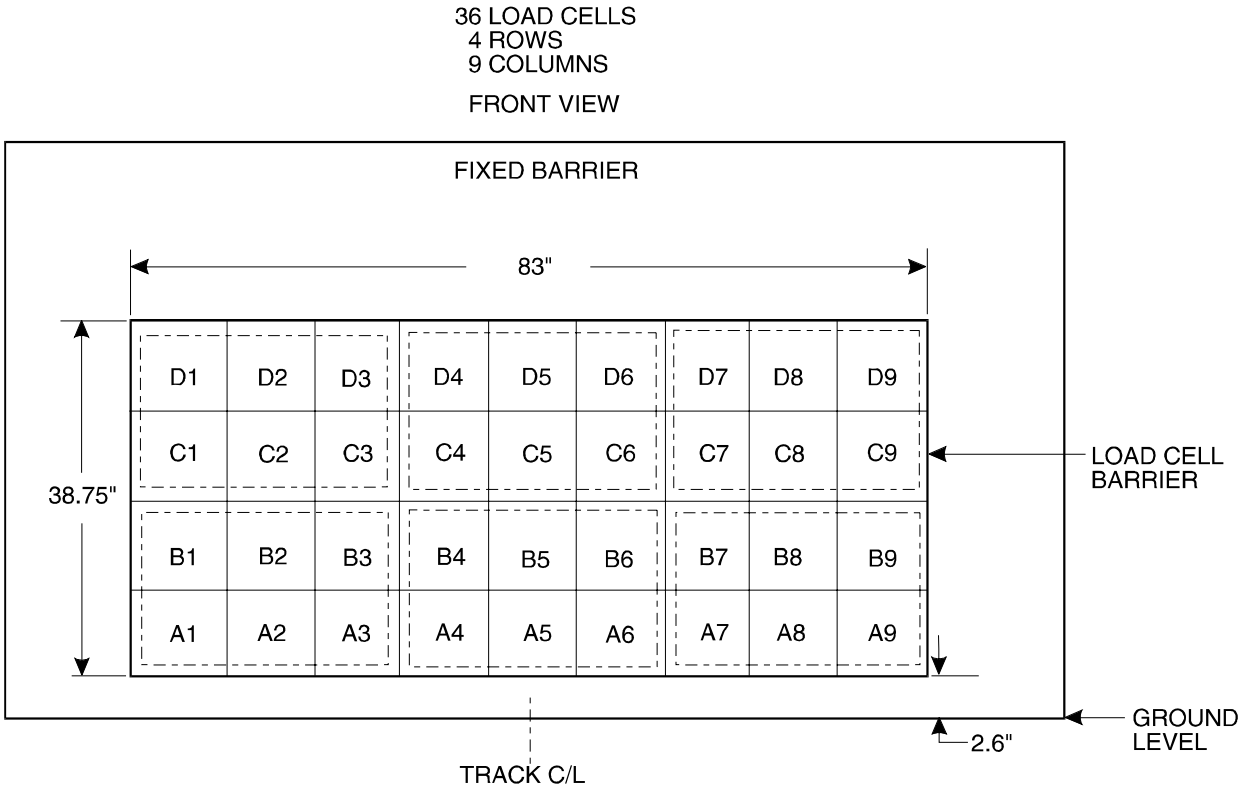
Figure 1 Impact Velocity Measurement System



The final vane clears the final emitter/receiver pair 51 mm before impact.

The vanes have 610 mm spacing.

Figure 2 Load Cell Barrier Configuration



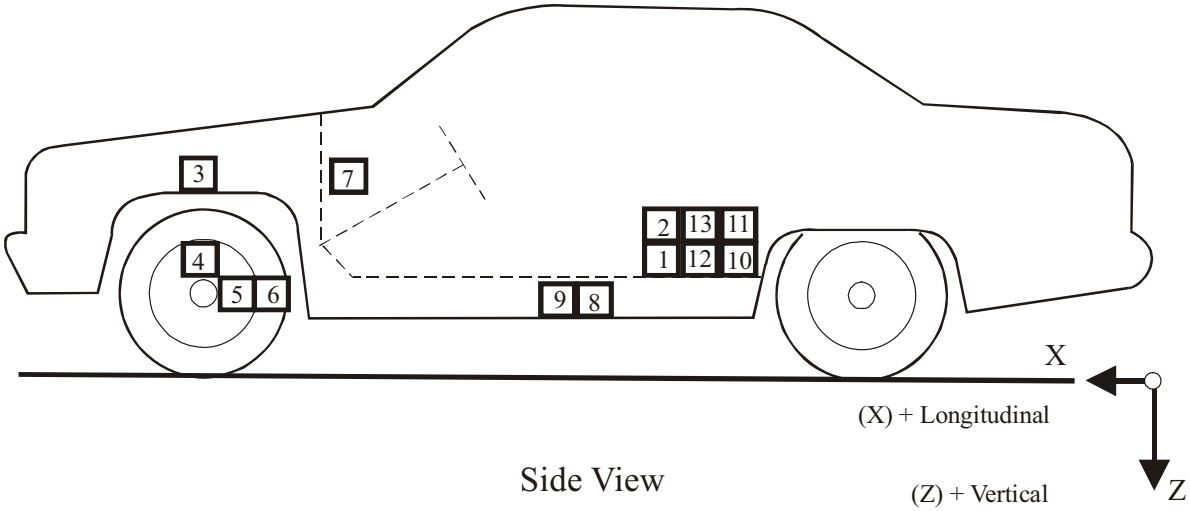
Group	Location	Force (N) per Group
1	A1 through B3	132,744.0
2	A4 through B6	483,916.1
3	A7 through B9	60,062.1
4	C1 through D3	32,917.8
5	C4 through D6	68,778.8
6	C7 through D9	49,506.8

Total Force (N) at Barrier: 750,351.5

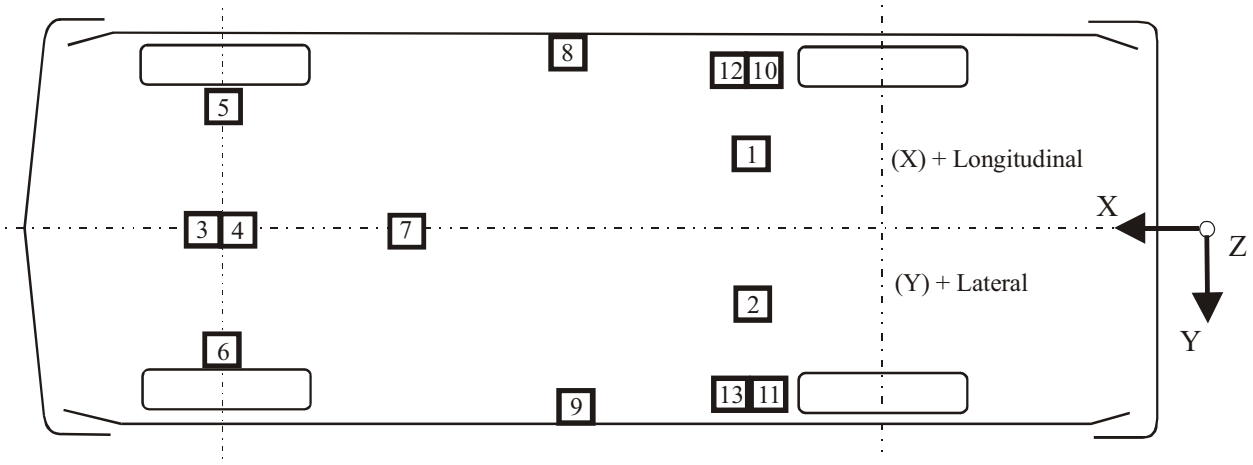
Section 3.0

Vehicle and Camera Information

Figure 3 Vehicle Accelerometer Placement



Side View



Bottom View

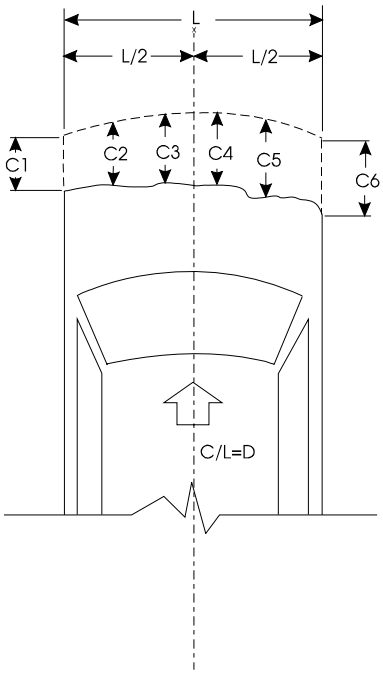
Table 4 Vehicle Accelerometer Locations and Data Summary

Accel. No.	Location		Positive Direction Max. (g)	Positive Direction Time (ms)	Negative Direction Max. (g)	Negative Direction Time (ms)
1	Rear Seat Crossmember Left	X	2.8	115.4	39.6	31.4
2	Rear Seat Crossmember Right	X	2.1	116.6	44.0	32.3
3	Engine Top of Block[1]	X	----	----	----	----
4	Engine Bottom of Block[1]	X	----	----	----	----
5	Left Brake Caliper	X	35.3	61.5	95.0	45.5
6	Right Brake Caliper	X	50.0	75.3	72.5	33.9
7	Center of Instrument Panel	X	17.5	94.7	59.9	42.6
8	B-Pillar Left Side Bottom	X	2.2	114.9	36.9	31.5
9	B-Pillar Right Side Bottom	X	1.9	117.5	41.8	32.7
10	Rear Panel Nearest Left Rear	X	2.1	113.8	36.2	31.6
		Y	9.6	39.2	3.7	34.6
		Z	11.3	29.0	12.8	35.7
11	Rear Panel Nearest Right Rear	X	1.7	118.1	41.7	32.9
		Y	4.1	48.6	4.0	14.2
		Z	6.2	27.4	15.4	38.2
12	Rear Panel Nearest Left Rear Redundant	X	1.6	115.2	36.4	31.4
		Y	4.7	38.9	7.1	33.8
		Z	6.8	28.2	14.8	35.4
13	Rear Panel Nearest Right Rear Redundant	X	1.8	118.2	41.9	33.0
		Y	5.6	48.4	2.7	39.0
		Z	6.2	27.3	14.7	38.2

[1] See Data Acquisition Explanations.

Figure 4 Vehicle Crush Data

Vehicle year/make/ model/body style:	2004/Chevrolet/Malibu/4-door
VIN:	1G1NE54F54X6490EX
Test date:	09/21/04
Test weight:	1769.0 kg
Vehicle wheelbase:	2705 mm
Maximum width:	1780 mm
Front overhang:	945 mm
Collision Deformation Classification (CDC) code:	12FDEW2



Crush depth measurements:

Location	Pre-test	Post-test	Difference
C1	4602 mm	4184 mm	418 mm
C2	4726 mm	4260 mm	466 mm
C3	4786 mm	4268 mm	518 mm
C4	4781 mm	4261 mm	520 mm
C5	4727 mm	4271 mm	456 mm
C6	4603 mm	4273 mm	330 mm
CL	4785 mm	4274 mm	511 mm

Midpoint of damage: D: Vehicle Longitudinal Centerline

Length of damaged region: L: 1525 mm

L/2: 762 mm

Table 5 Vehicle Structural Measurements[1]

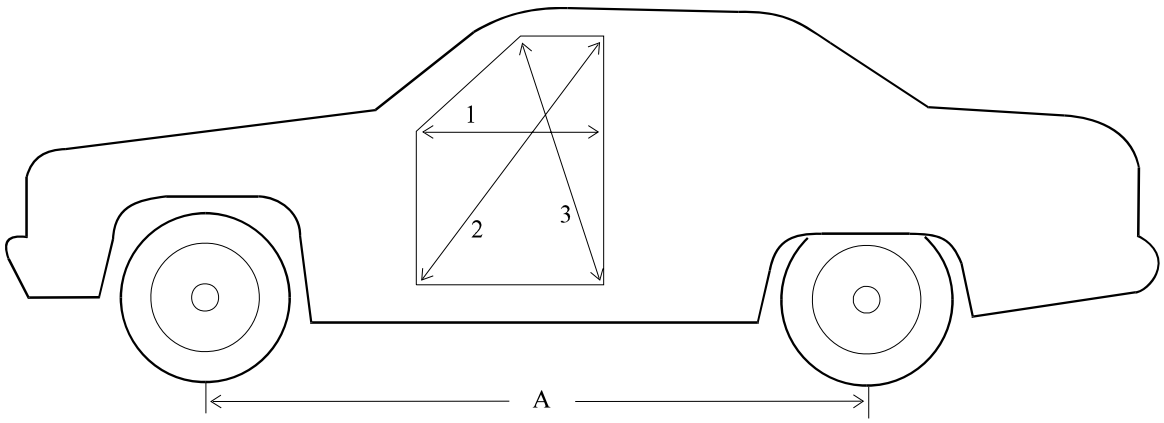
	Elements	Pre-Test
1	Total Length	4274
2	Total Width at Midpoint of Vehicle	1780
3	Bumper Top Height	533
4	Bumper Bottom Height	418
5	Longitudinal Member Top Height	503
6	Longitudinal Member Bottom Height	393
7	Distance Between Longitudinal Members	1070
7′	Longitudinal Member Width	90
8	Engine Top Height	820
9	Engine Bottom Height	167
10	Engine and Gearbox Width	606
11	Front Bumper - Engine Distance	546
12	Front Shock Absorber Fixing Height	870
13	Bonnet Leading Edge Height	707
14	Front Shock Absorber Fixing Width	1140
15	Front Bumper - Front Axle Distance	945
16	Front Axle - A Pillar Distance	510
17	A Pillar - B Pillar Distance	1080
18	B Pillar - Rear Axle Distance	1121
19	B Pillar - C Pillar Distance	922
20	Roof Sill Bottom Height	1258
21	Roof Sill Top Height	1362
22	Floor Sill Bottom Height	303
23	Floor Sill Top Height	335

All distance measurements are in millimeters.

[1] Taken from INSIA report, “Structural Survey of Cars, Methodology of the Main Resistant Elements in the Car Body”, March 1999.

Figure 5 Vehicle Intrusion Measurements

Door Opening Width

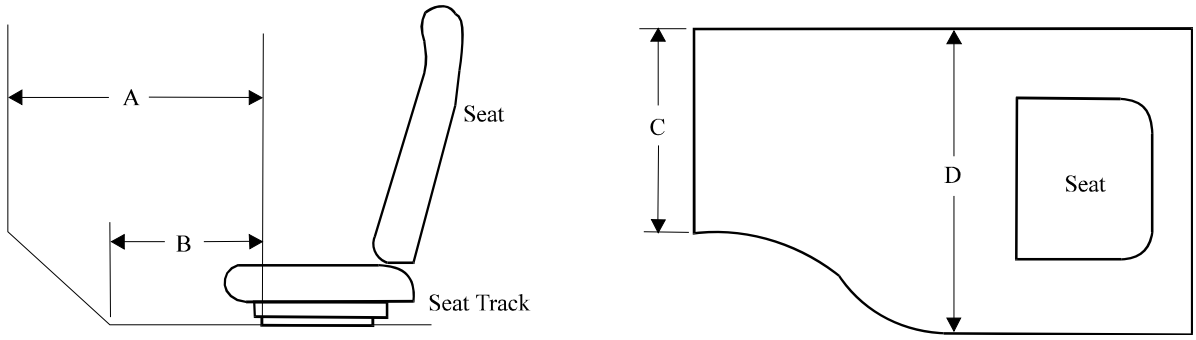


Units (mm)	Left			Right		
Measurement	1	2	3	1	2	3
Pre-Test	1010 mm	1450 mm	975 mm	1020 mm	1440 mm	946 mm
Post-Test	1005 mm	1445 mm	978 mm	1020mm	1437 mm	945 mm
Difference	5 mm	5 mm	-3 mm	0 mm	3 mm	1 mm

Units (mm)	A = Wheelbase Left	A = Wheelbase Right
Pre-Test	2705 mm	2705 mm
Post-Test	2625 mm	2625 mm
Difference	80 mm	80 mm

Figure 6 Vehicle Intrusion Measurements

Static Footwell Deformation



Driver's Side

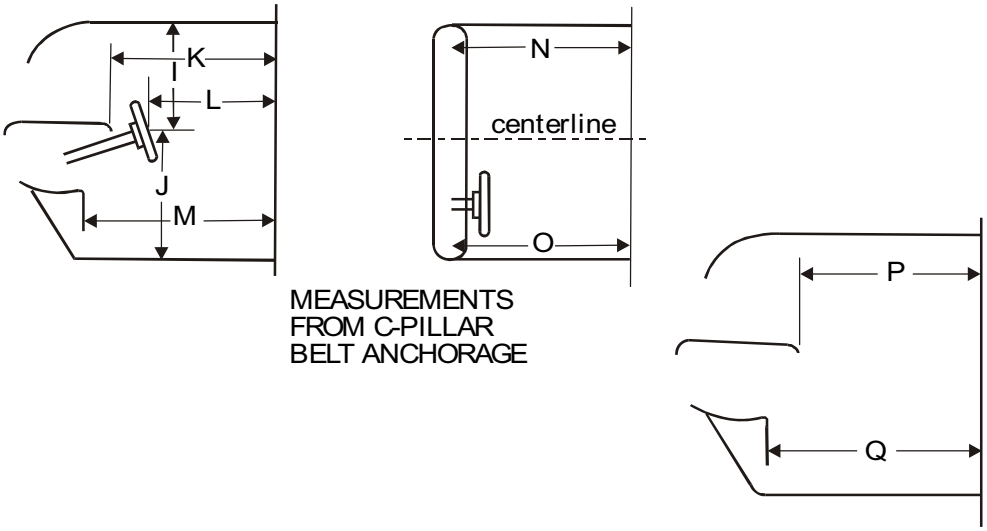
Measurement	Pre-Test	Post-Test	Difference
A	707 mm	693 mm	14 mm
B	560 mm	545 mm	15 mm
C	455 mm	450 mm	5 mm
D	475 mm	480 mm	-5 mm

Passenger's Side

Measurement	Pre-Test	Post-Test	Difference
A	675 mm	670 mm	5 mm
B	517 mm	515 mm	2 mm
C	462 mm	460 mm	2 mm
D	480 mm	500 mm	-20 mm

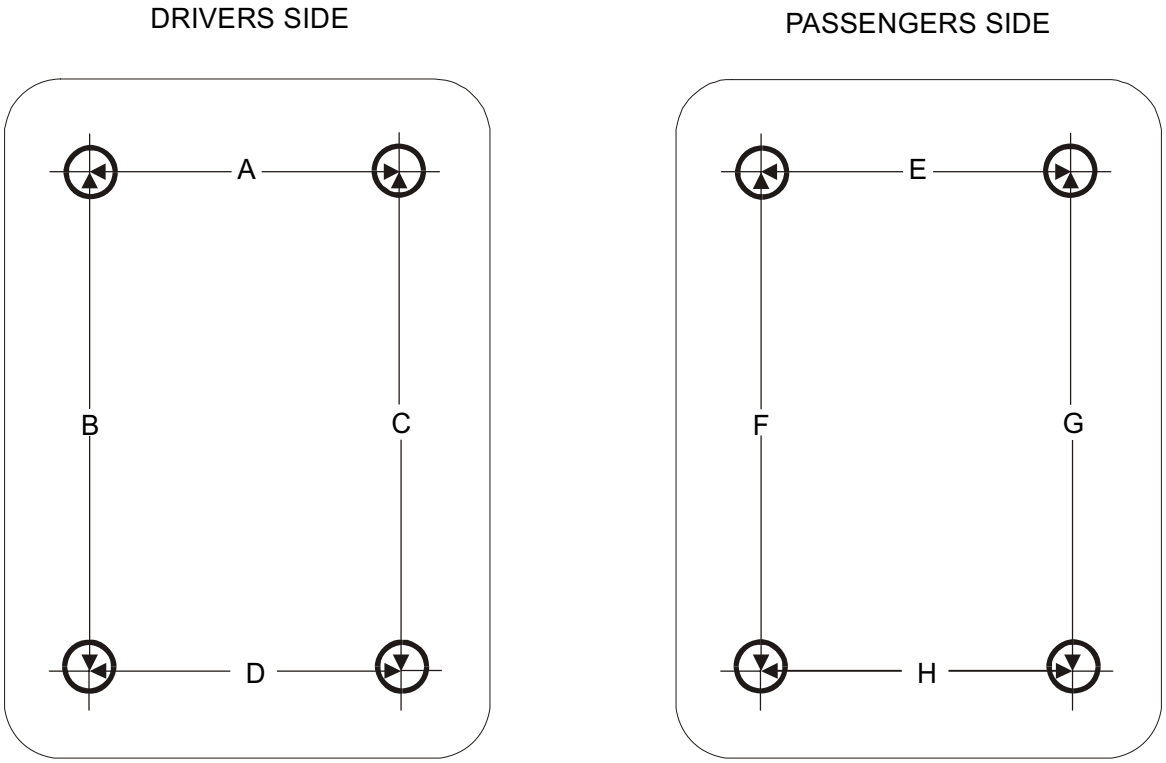
Figure 7 Vehicle Intrusion Measurements

Static Passenger Compartment Intrusion



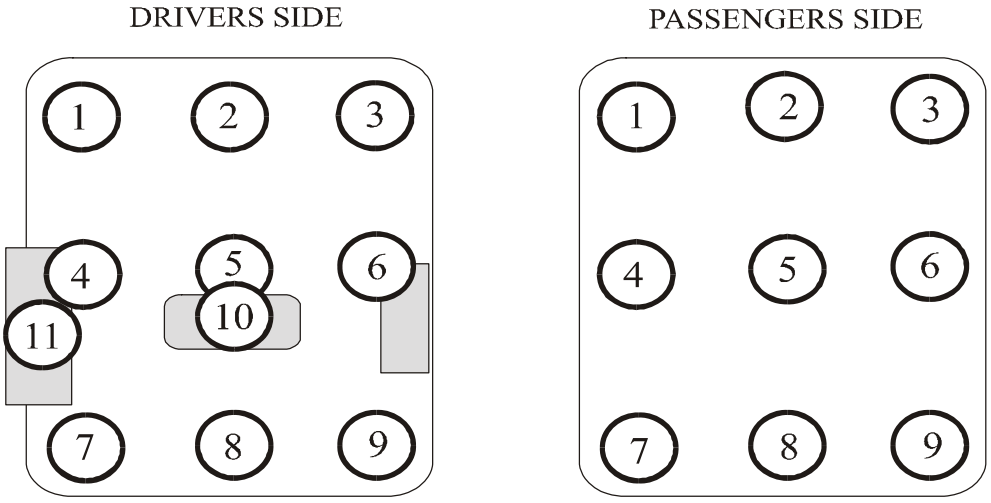
Measurement	Pre-Test	Post-Test	Difference
I	440 mm	495 mm	-55 mm
J	655 mm	623 mm	32 mm
K (driver's side)	2080 mm	2023 mm	57 mm
L	1757 mm	1770 mm	-13 mm
M (driver's side)	2130 mm	2110 mm	20 mm
N (passenger's side)	1951 mm	1938 mm	13 mm
O (driver's side)	1947 mm	1893 mm	54 mm
P (passenger's side)	2070 mm	2051 mm	19 mm
Q (passenger's side)	2127 mm	2129 mm	-2 mm

Figure 8 Floorboard Deformation



Measurement	Pre-Test	Post-Test	Difference
A	455 mm	450 mm	5 mm
B	515 mm	515 mm	0 mm
C	525 mm	520 mm	5 mm
D	475 mm	480 mm	-5 mm
E	462 mm	460 mm	2 mm
F	495 mm	525 mm	-30 mm
G	505 mm	510 mm	-5 mm
H	480 mm	500 mm	-20 mm

Figure 9 Vehicle Toeboard Measurements



Driver Toe Pan

Pre-Test				Post-Test			Difference		
Index	Xmm	Ymm	Zmm	Xmm	Ymm	Zmm	Xmm	Ymm	Zmm
1	3213	-621	211	3191	-619	194	22	-2	17
2	3322	-435	234	3220	-418	206	102	-17	28
3	3294	-189	334	3216	-178	295	78	-11	39
4	3173	-630	336	3164	-619	317	9	-11	19
5	3215	-420	347	3188	-403	313	27	-17	34
6	3213	-148	384	3173	-138	357	40	-10	27
7	3072	-621	433	3068	-608	418	4	-13	15
8	3076	-407	423	3059	-393	403	17	-14	20
9	3086	-167	446	3070	-163	451	16	-4	-5
10	3108	-350	222	3058	-343	212	50	-7	10
11	3172	-592	367	3157	-578	345	15	-14	22

Passenger Toe Pan

Pre-Test				Post-Test			Difference		
Index	Xmm	Ymm	Zmm	Xmm	Ymm	Zmm	Xmm	Ymm	Zmm
1	3310	228	281	3259	211	261	51	17	20
2	3307	404	278	3280	384	257	27	20	21
3	3193	657	230	3182	651	224	11	6	6
4	3187	197	370	3168	187	377	19	10	-7
5	3171	398	371	3156	385	362	15	13	9
6	3124	662	331	3118	651	326	6	11	5
7	3043	182	448	3031	180	460	12	2	-12
8	3047	399	428	3035	390	425	12	9	3
9	3038	645	425	3031	635	419	7	10	6

Reference: +X forward from rear bumper; +Y rightward from vehicle centerline; +Z downward from vehicle reference point

Table 6 Vehicle Intrusion of Upper Instrument Panel

Driver Instrument Panel - Lower

Pre-Test				Post-Test			Difference		
Index	Xmm	Ymm	Zmm	Xmm	Ymm	Zmm	Xmm	Ymm	Zmm
Left	2834	-487	-9	2811	-479	-7	23	-8	-2
Right	2848	-190	8	2830	-182	1	18	-8	7

Driver Knees

Pre-Test				Post-Test			Difference		
Index	Xmm	Ymm	Zmm	Xmm	Ymm	Zmm	Xmm	Ymm	Zmm
Left	2782	-511	-82	2758	-497	-83	24	-14	1
Right	2784	-215	-89	2768	-198	-68	16	-17	-21

Passenger Knees

Pre-Test				Post-Test			Difference		
Index	Xmm	Ymm	Zmm	Xmm	Ymm	Zmm	Xmm	Ymm	Zmm
Left	2827	297	-50	2815	301	-51	12	-4	1
Right	2828	496	-50	2819	501	-45	9	-5	-5

Steering Column

Pre-Test				Post-Test			Difference		
Index	Xmm	Ymm	Zmm	Xmm	Ymm	Zmm	Xmm	Ymm	Zmm
1	2609	-364	-208	2596	-367	-158	13	3	-50

Driver Front Outboard Seat Attachment Bolt

Pre-Test				Post-Test			Difference		
Index	Xmm	Ymm	Zmm	Xmm	Ymm	Zmm	Xmm	Ymm	Zmm
1	2519	-602	353	2521	-598	365	-2	-4	-12

Passenger Front Outboard Seat Attachment Bolt

Pre-Test				Post-Test			Difference		
Index	Xmm	Ymm	Zmm	Xmm	Ymm	Zmm	Xmm	Ymm	Zmm
1	2522	598	343	2521	597	346	1	1	-3

Knee intrusions are points measured pre and post, which are located just above where the four knees would be expected to contact the instrument panel.
+X: Forward from rear bumper
+Y: Rightward from centerline
+Z: Downward from vehicle reference point

Figure 10 Camera Positions

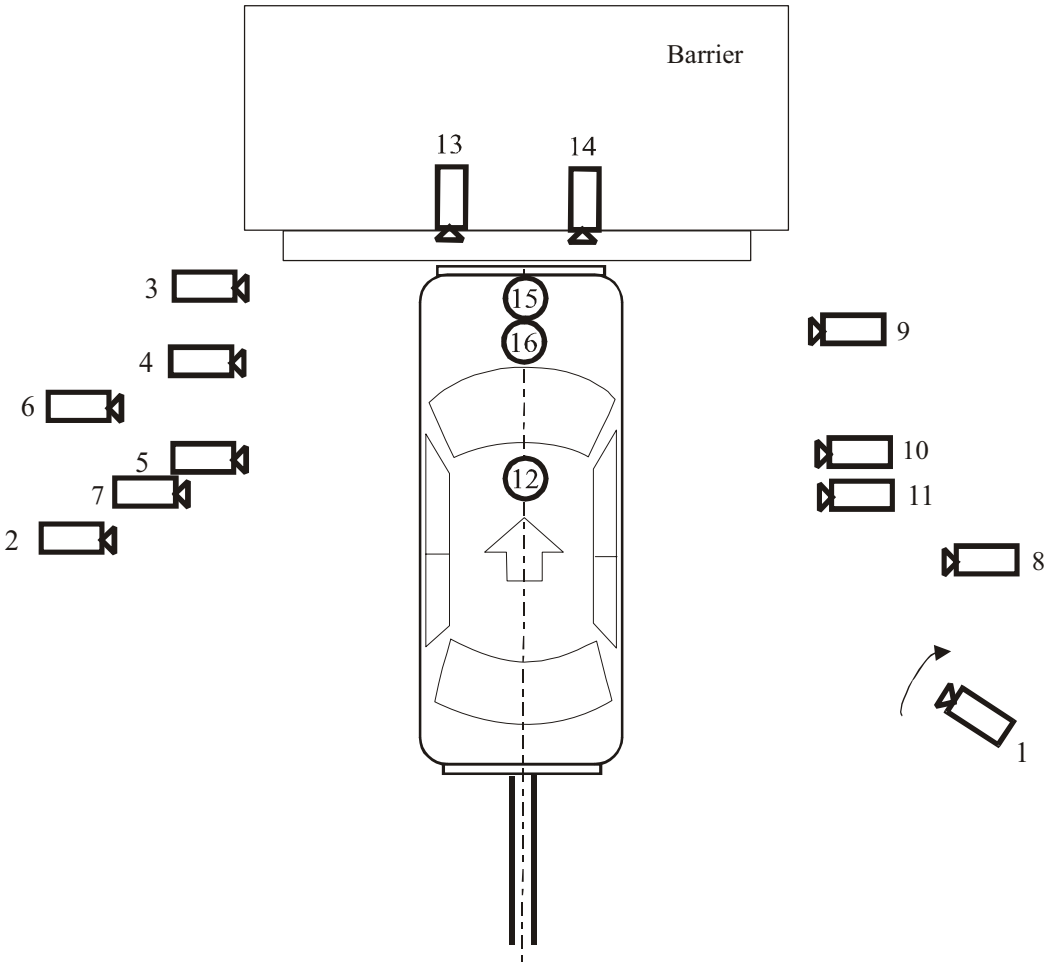
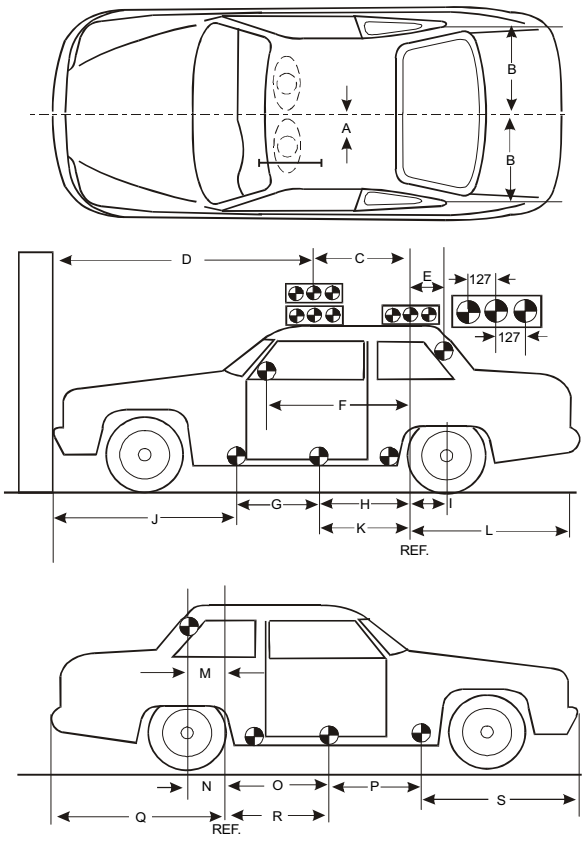


Table 7 Motion Picture Camera Locations

Camera Number	Location	Type	Lens (mm)	Speed (frames/s)	Purpose of Camera Data
1	Panning/documentary	Panasonic	Zoom	30	Vehicle dynamics
2	Left medium tight barrier to B-pillar	Redlake	13	1000	Vehicle dynamics
3	Left tight on bumper	Visario	50	1000	Vehicle dynamics
4	Left tight bumper to A-pillar	Redlake	25	1000	Vehicle dynamics
5	Left tight A-pillar to B-pillar	Redlake	50	1000	Vehicle dynamics
6	Left medium tight A-pillar to B-pillar	Visario	50	1000	Vehicle dynamics
7	Left medium tight at steering wheel	Visario	50	1000	Vehicle dynamics
8	Right wide	Redlake	13	1000	Vehicle dynamics
9	Right tight bumper to A-pillar	Visario	50	1000	Vehicle dynamics
10	Right tight A-pillar to B-pillar	Visario	50	1000	Vehicle dynamics
11	Right medium tight door to roof targets	Redlake	50	1000	Vehicle dynamics
12	Overhead medium tight	Visario	Zoom	1000	Vehicle dynamics
13	Barrier driver	Redlake	13	1000	Vehicle dynamics
14	Barrier passenger	Redlake	13	1000	Vehicle dynamics
15	Pit medium tight on engine	Redlake	25	1000	Vehicle dynamics
16	Pit front medium tight	Redlake	13	500	Vehicle dynamics

Figure 11 Vehicle Reference Photo Target Locations



Measurement	Pre-Test
A	375 mm
B	738 mm
C	610 mm
D	1850 mm
E	820 mm
F	1187 mm
G	907 mm
H	905 mm
I	-307 mm[1]
J	1240 mm
K	602 mm
L	1853 mm
M	776 mm
N	-298 mm[1]
O	920 mm
P	909 mm
Q	1813 mm
R	631 mm
S	1250 mm

[1] Negative number because the roof target is forward of the rear sill.

Appendix A

Photographs

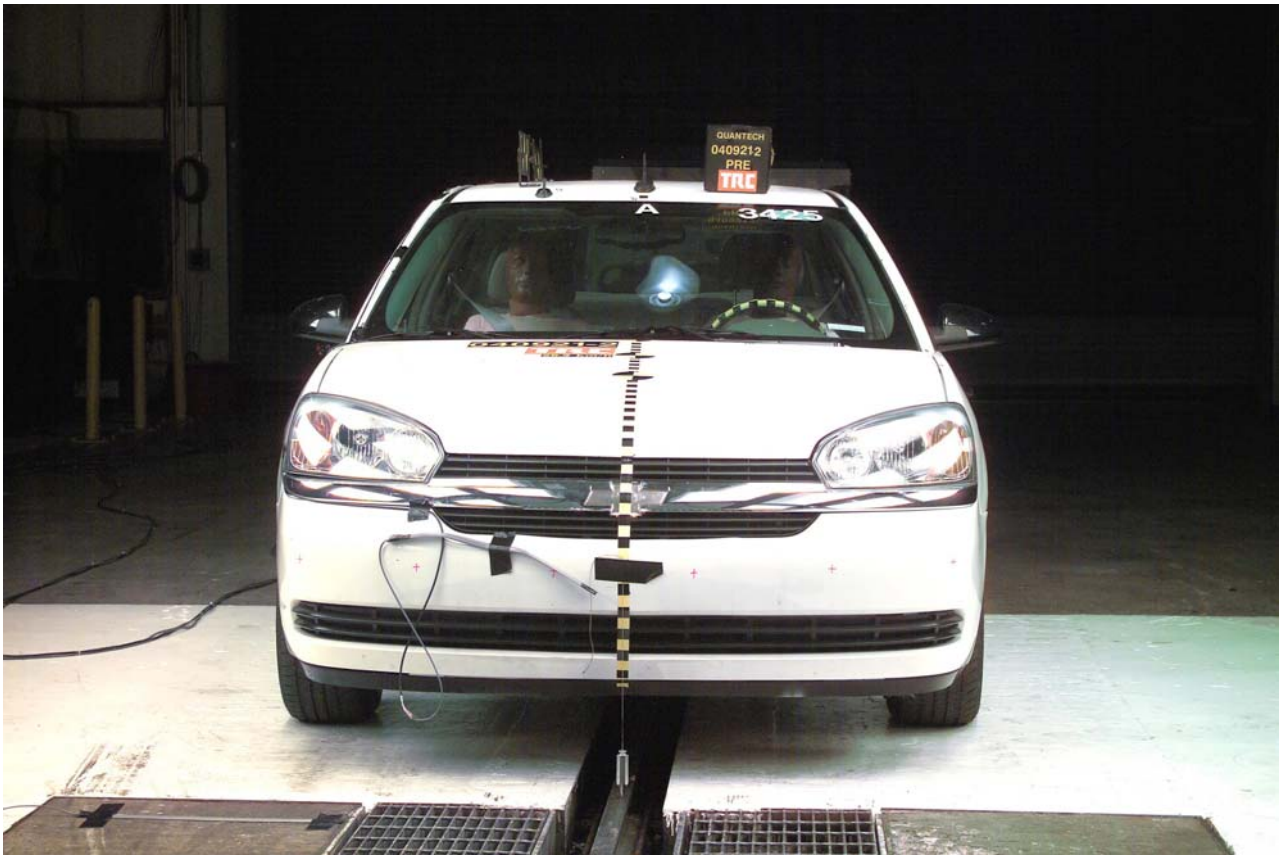


Figure A-1 Pre-Test Front View



Figure A-2 Post-Test Front View



Figure A-3 Pre-Test Left Front Three-Quarter View



Figure A-4 Post-Test Left Front Three-Quarter View



Figure A-5 Pre-Test Left Side View



Figure A-6 Post-Test Left Side View



Figure A-7 Pre-Test Left Rear Three-Quarter View



Figure A-8 Post-Test Left Rear Three-Quarter View



Figure A-9 Pre-Test Rear View

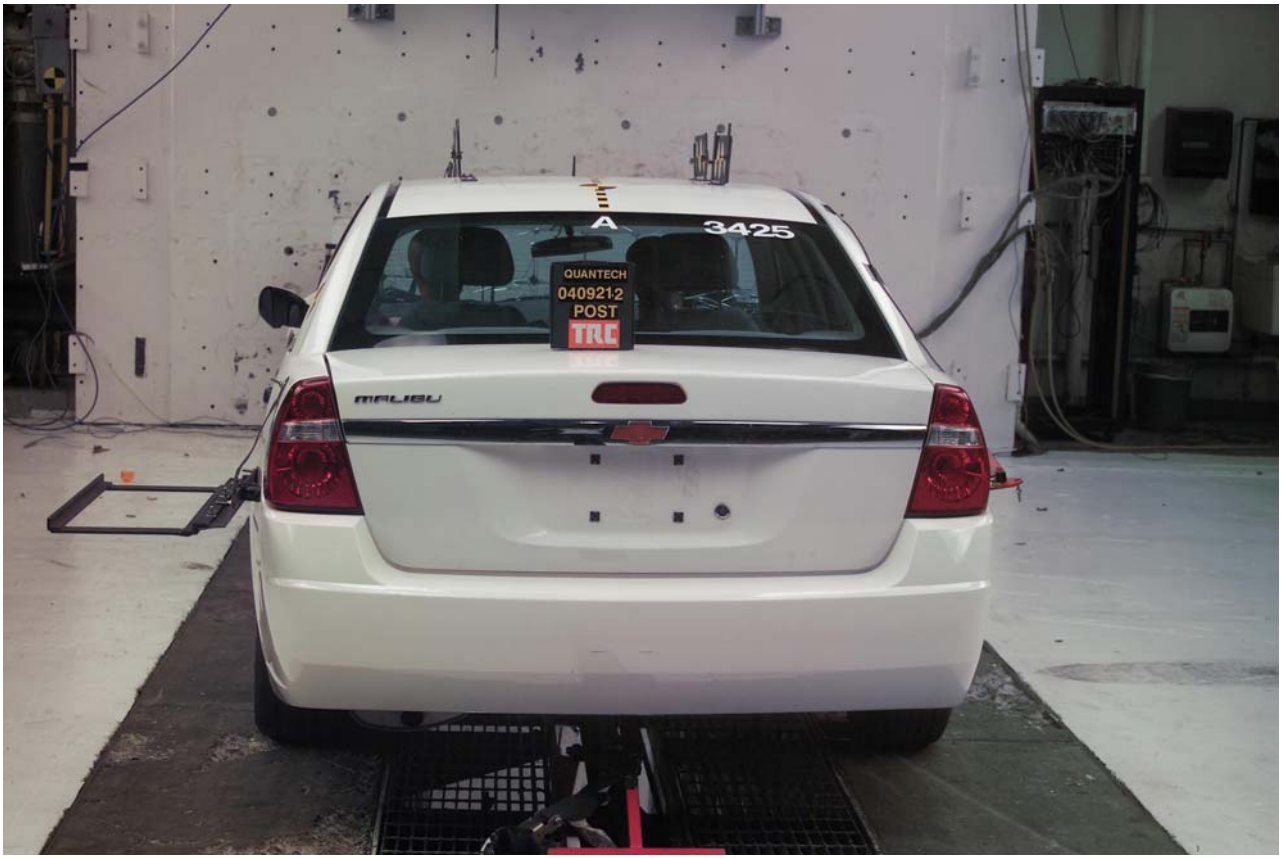


Figure A-10 Post-Test Rear View



Figure A-11 Pre-Test Right Rear Three-Quarter View



Figure A-12 Post-Test Right Rear Three-Quarter View



Figure A-13 Pre-Test Right Side View



Figure A-14 Post-Test Right Side View



Figure A-15 Pre-Test Right Front Three-Quarter View



Figure A-16 Post-Test Right Front Three-Quarter View

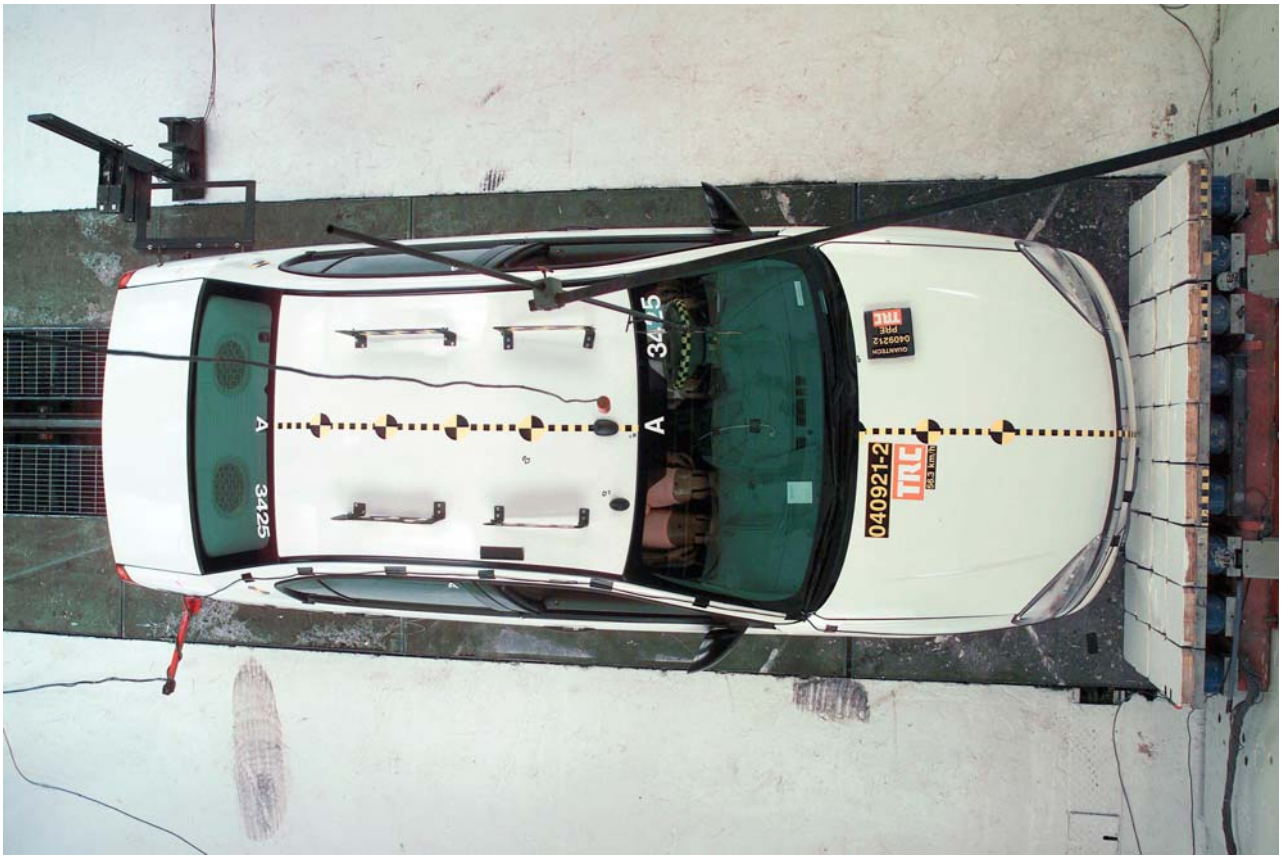


Figure A-17 Pre-Test Overhead View

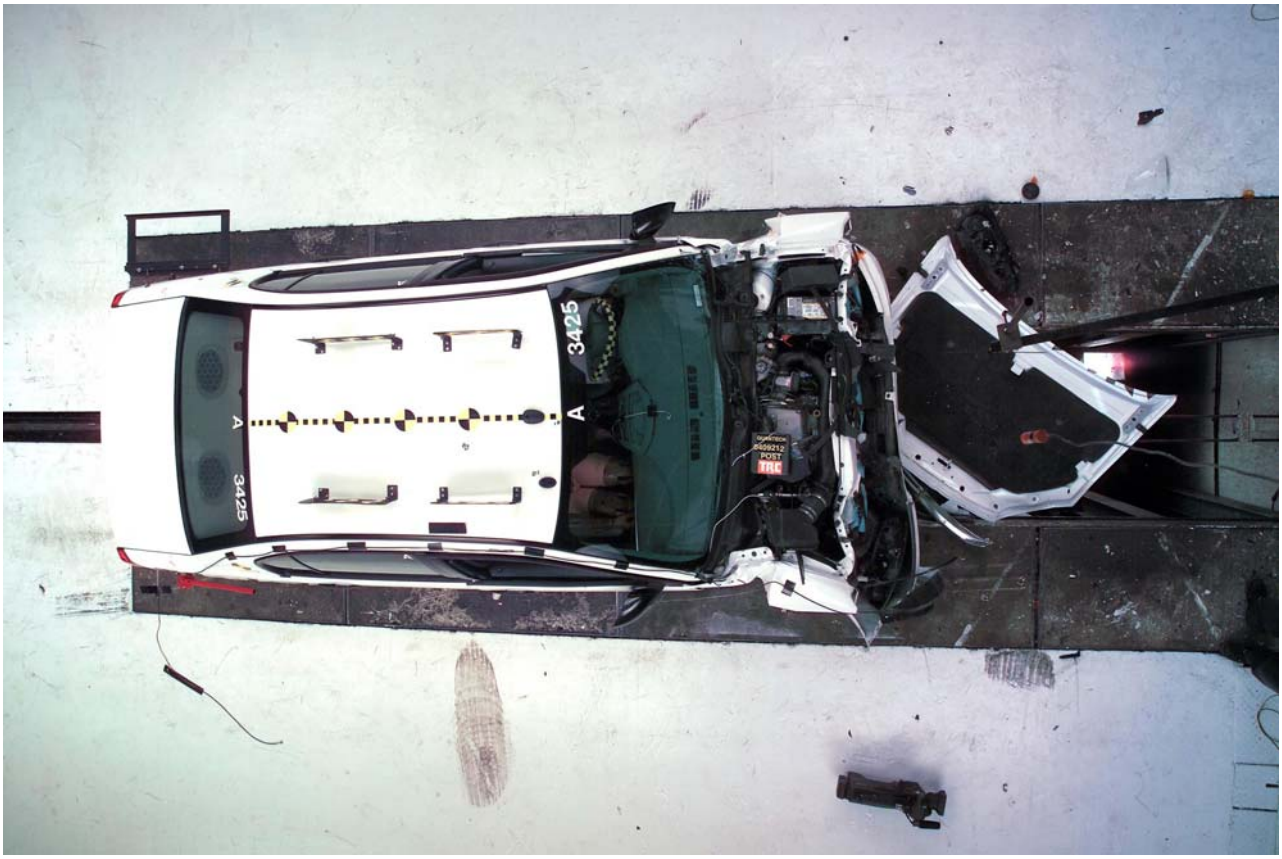


Figure A-18 Post-Test Overhead View



Figure A-19 Pre-Test Overhead Close-up View

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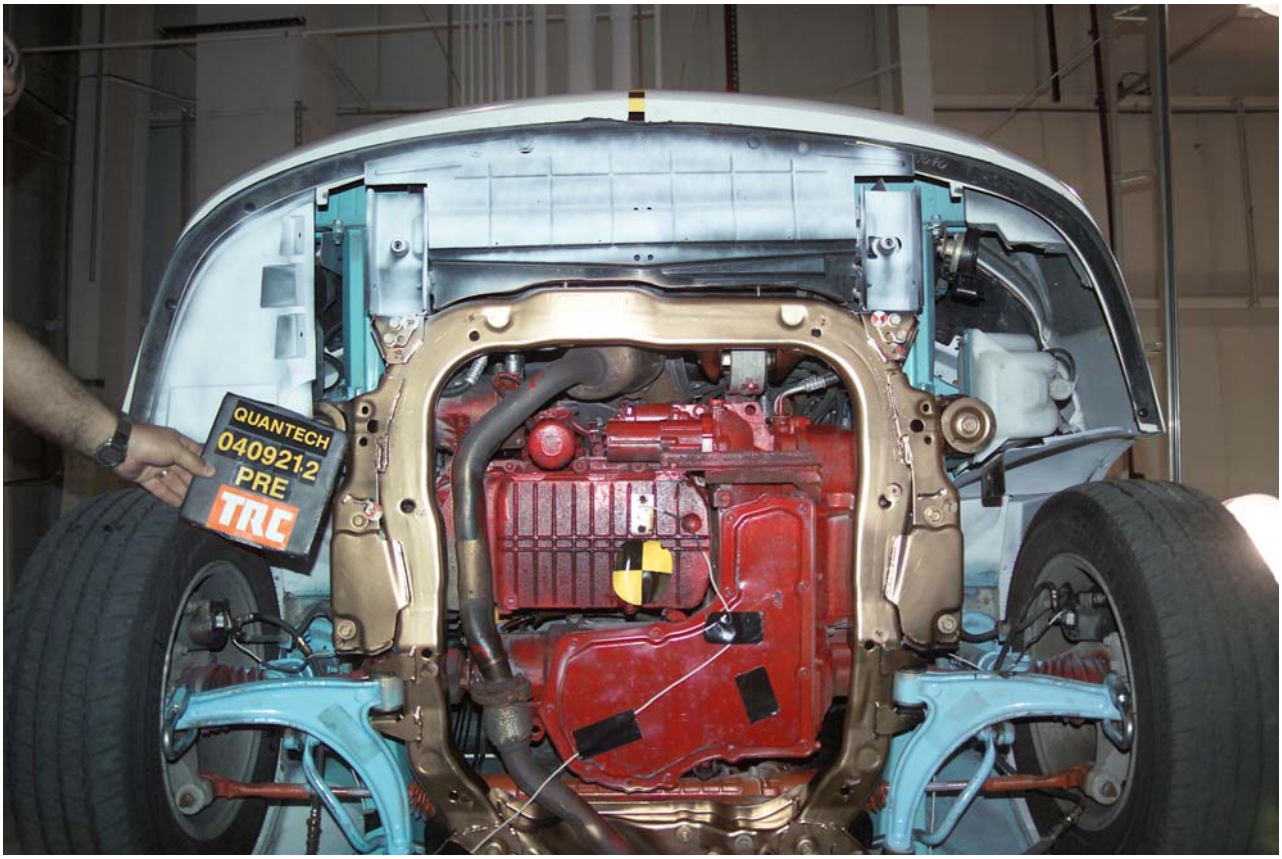


Figure A-20 Pre-Test Front Underbody View



Figure A-21 Post-Test Front Underbody View

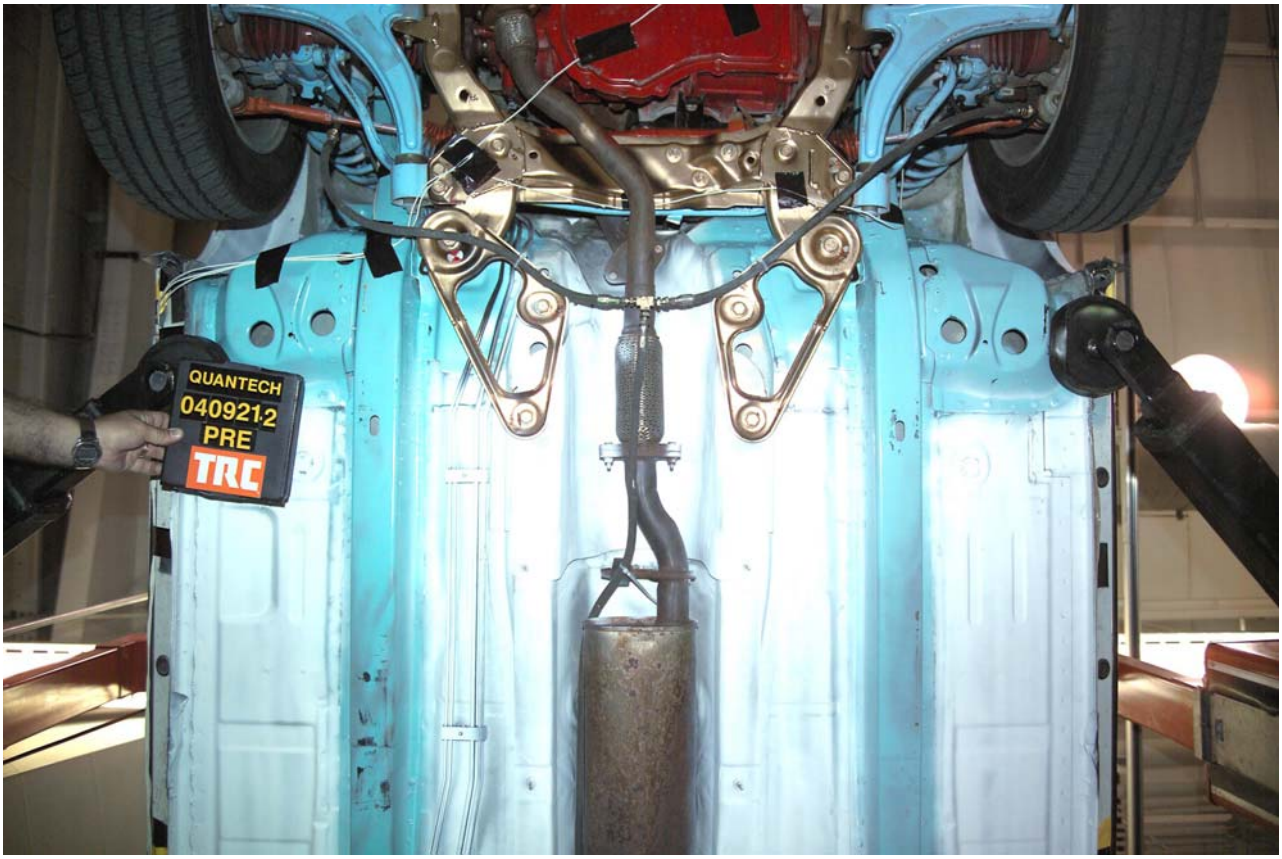


Figure A-22 Pre-Test Mid Front Underbody View



Figure A-23 Post-Test Mid Front Underbody View



Figure A-24 Pre-Test Mid Underbody View



Figure A-25 Post-Test Mid Underbody View

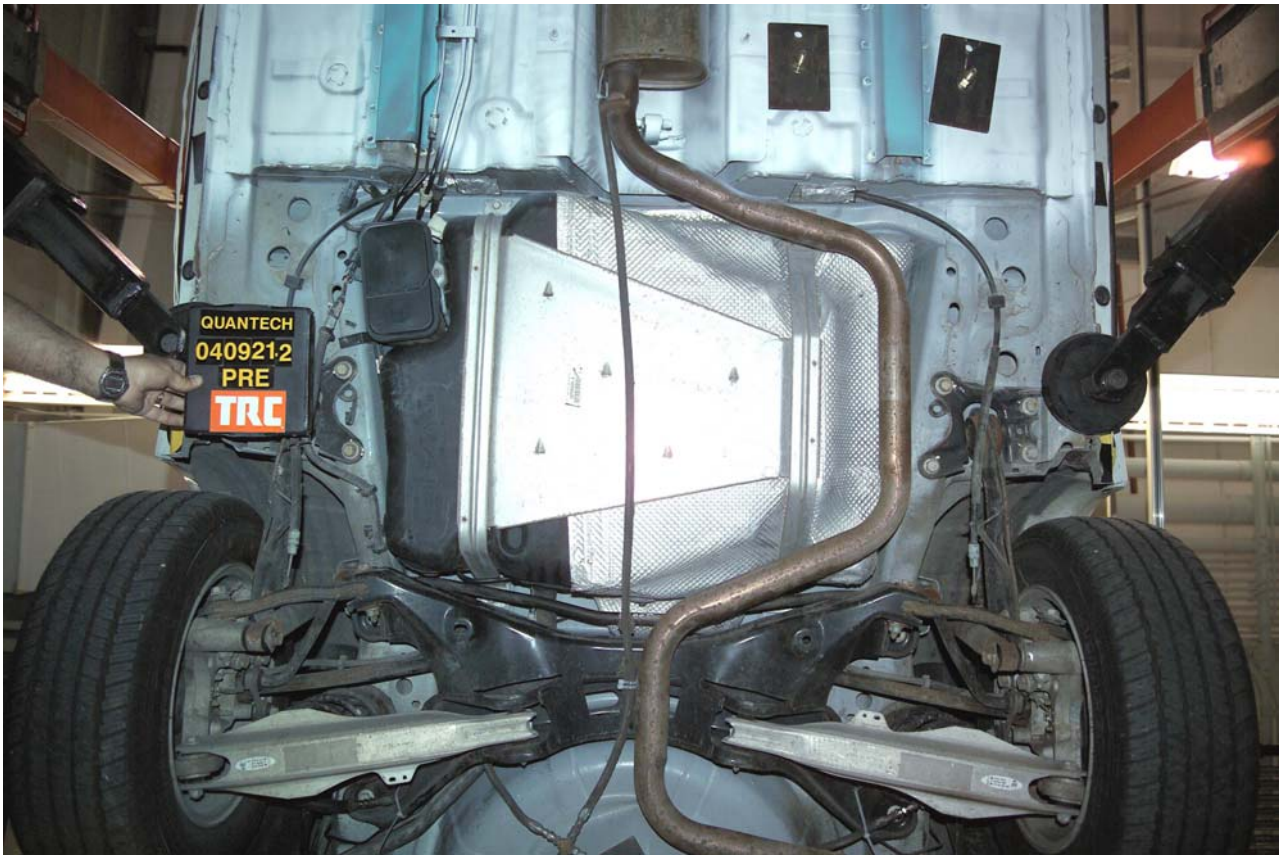


Figure A-26 Pre-Test Mid Rear Underbody View

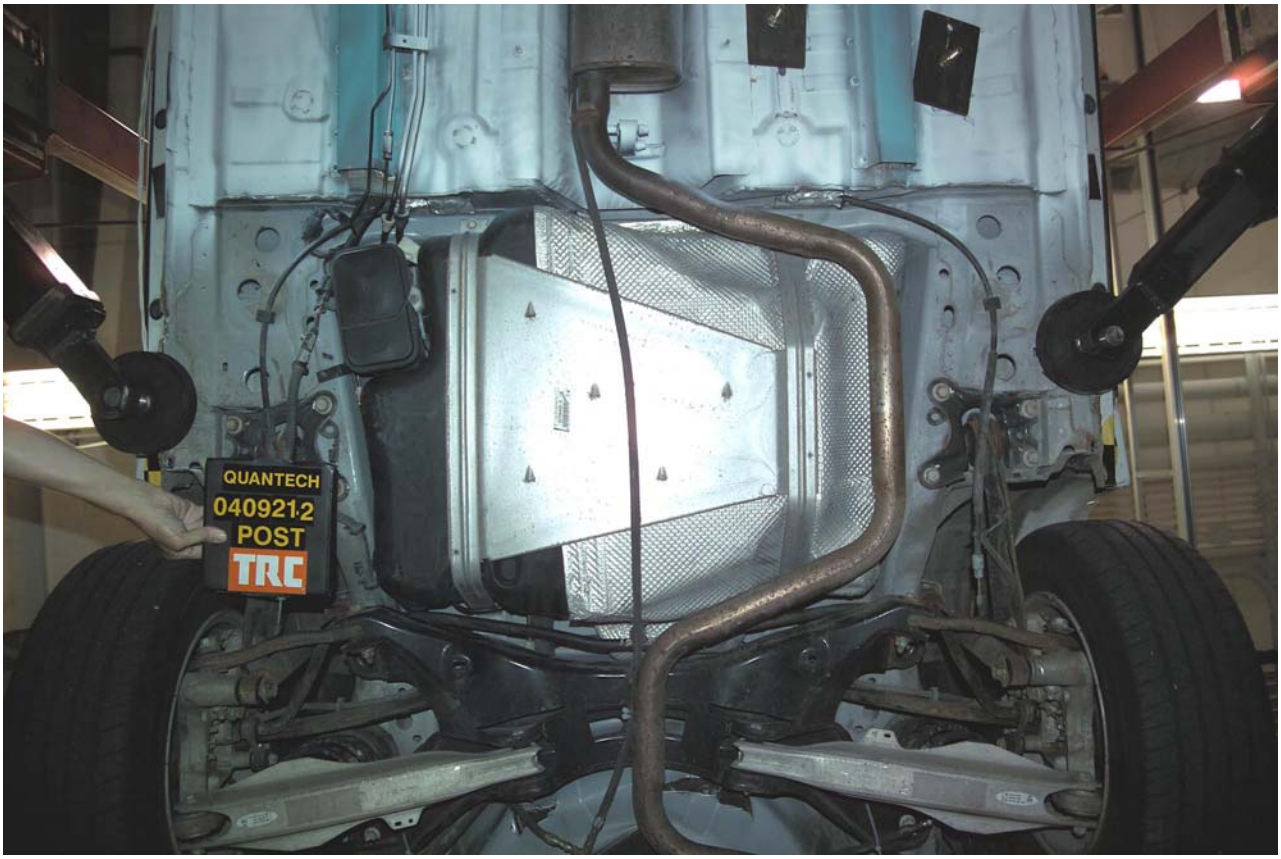


Figure A-27 Post-Test Mid Rear Underbody View

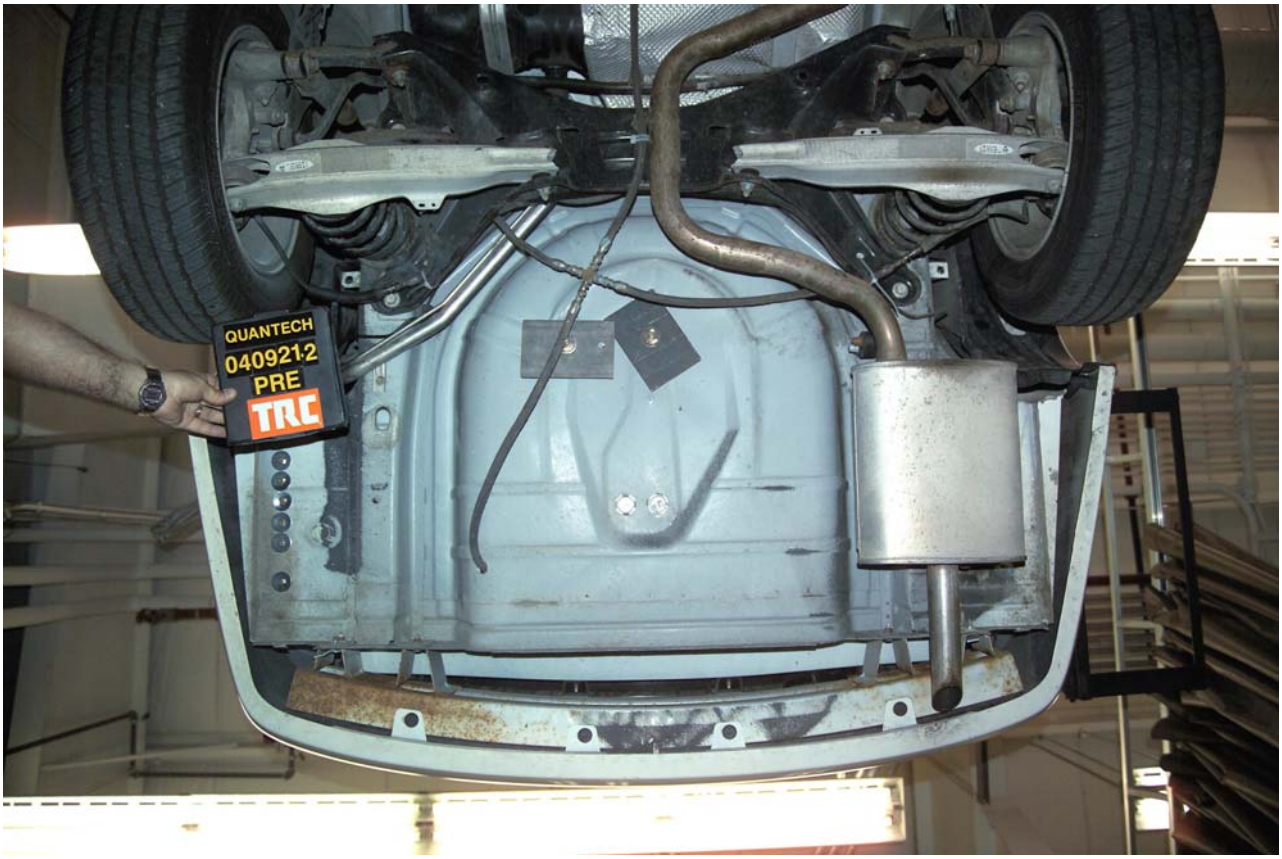


Figure A-28 Pre-Test Rear Underbody View

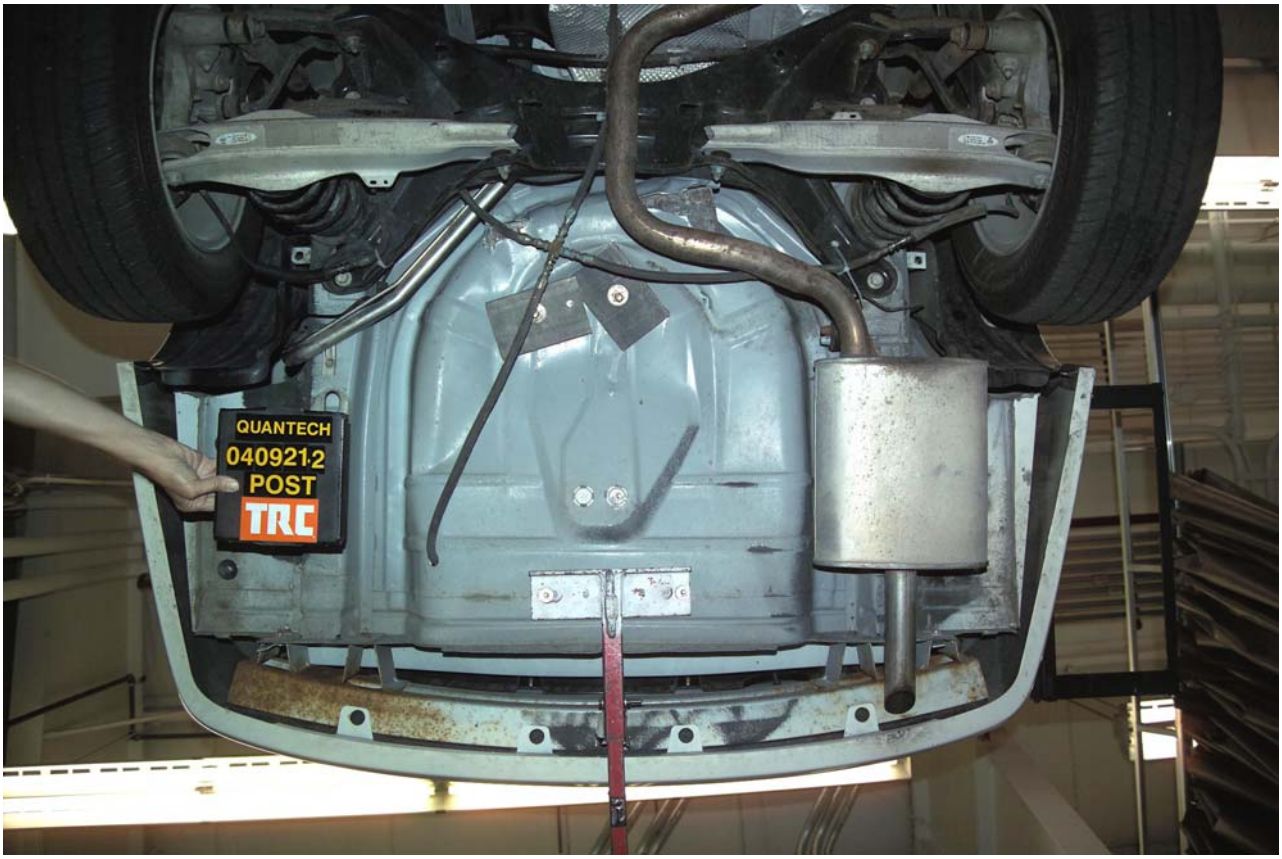


Figure A-29 Post-Test Rear Underbody View

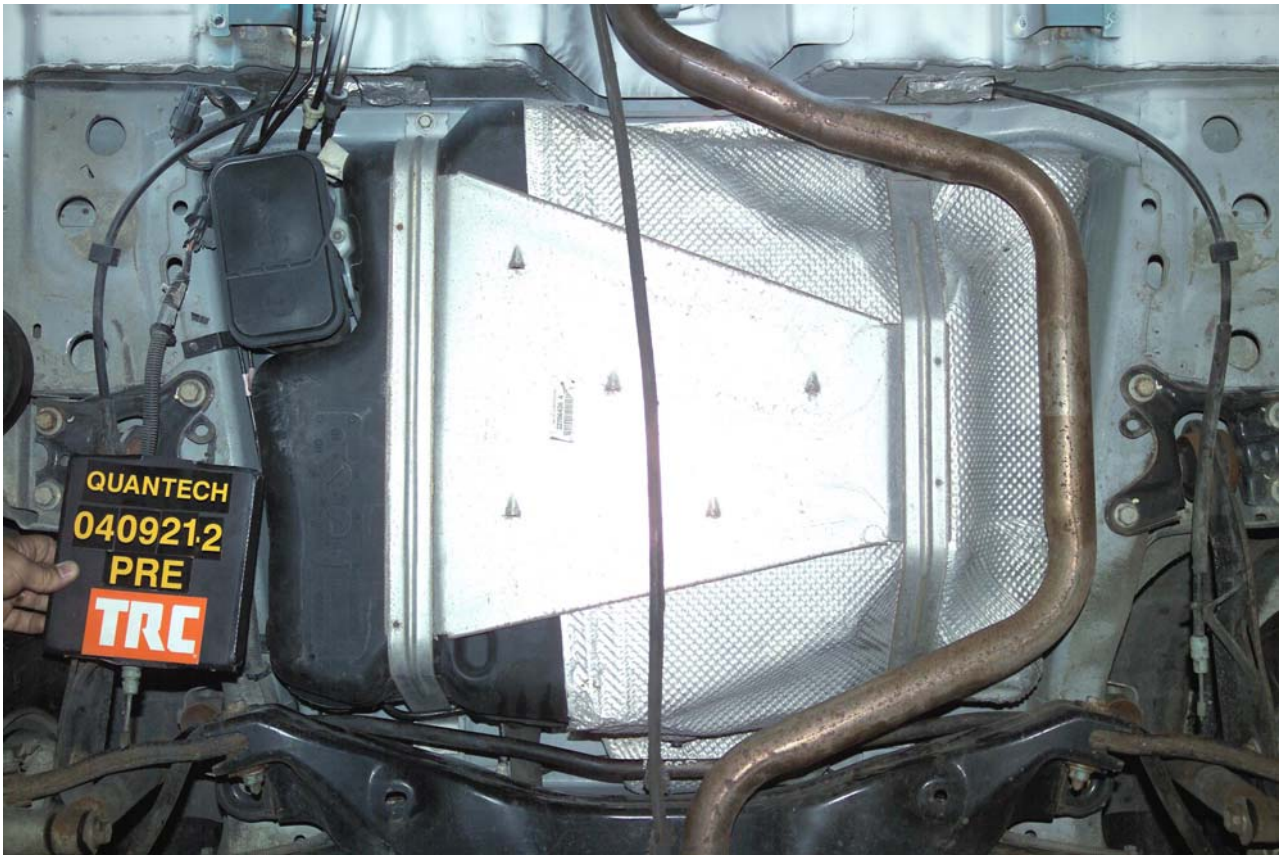


Figure A-30 Pre-Test Fuel Tank View



Figure A-31 Post-Test Fuel Tank View



Figure A-32 Pre-Test Fuel Filler Neck View



Figure A-33 Post-Test Fuel Filler Neck View



Figure A-34 Pre-Test Engine Compartment View

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Figure A-35 Pre-Test Windshield View



Figure A-36 Post-Test Windshield View



Figure A-37 Pre-Test Left Front Windshield View

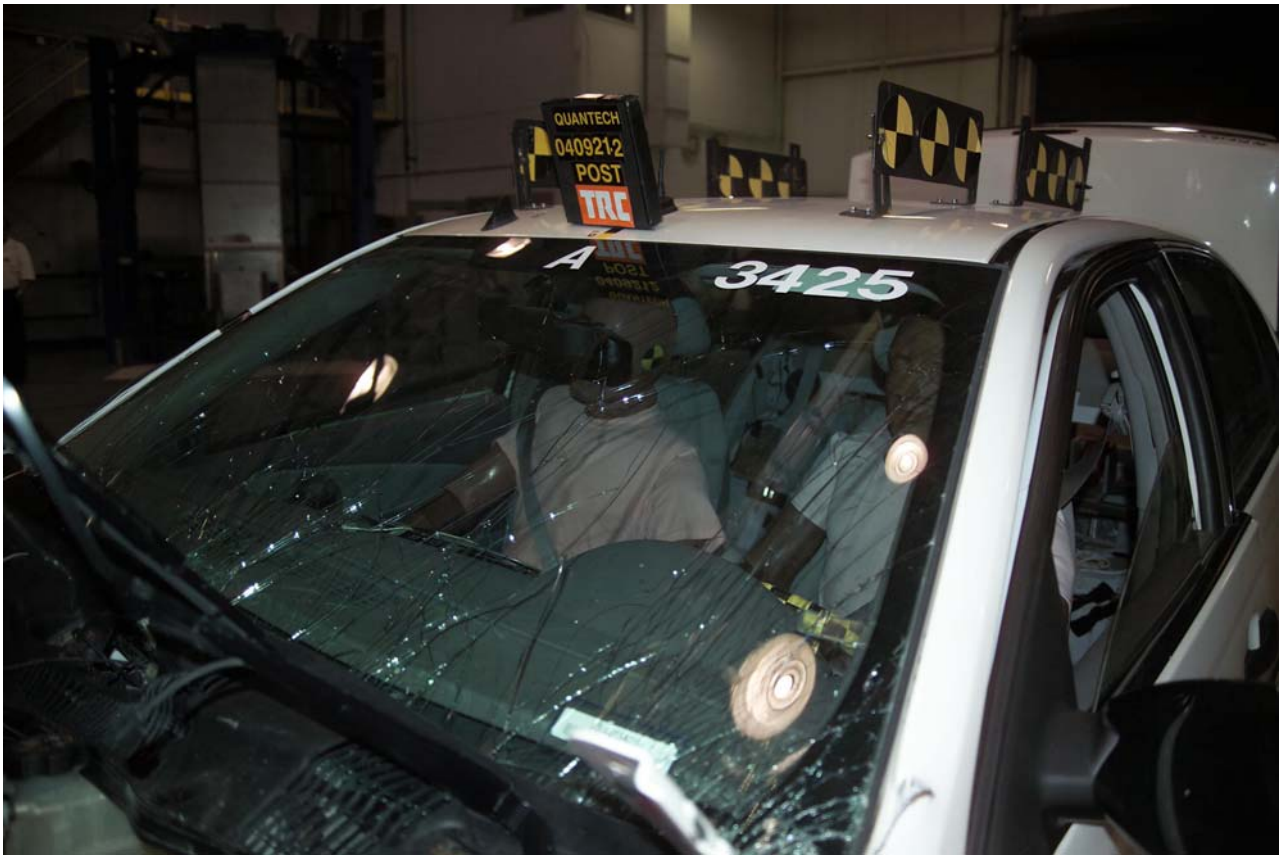


Figure A-38 Post-Test Left Front Windshield View



Figure A-39 Pre-Test Right Front Windshield View



Figure A-40 Post-Test Right Front Windshield View

Appendix B

Vehicle and Load Cell Barrier Data Plots

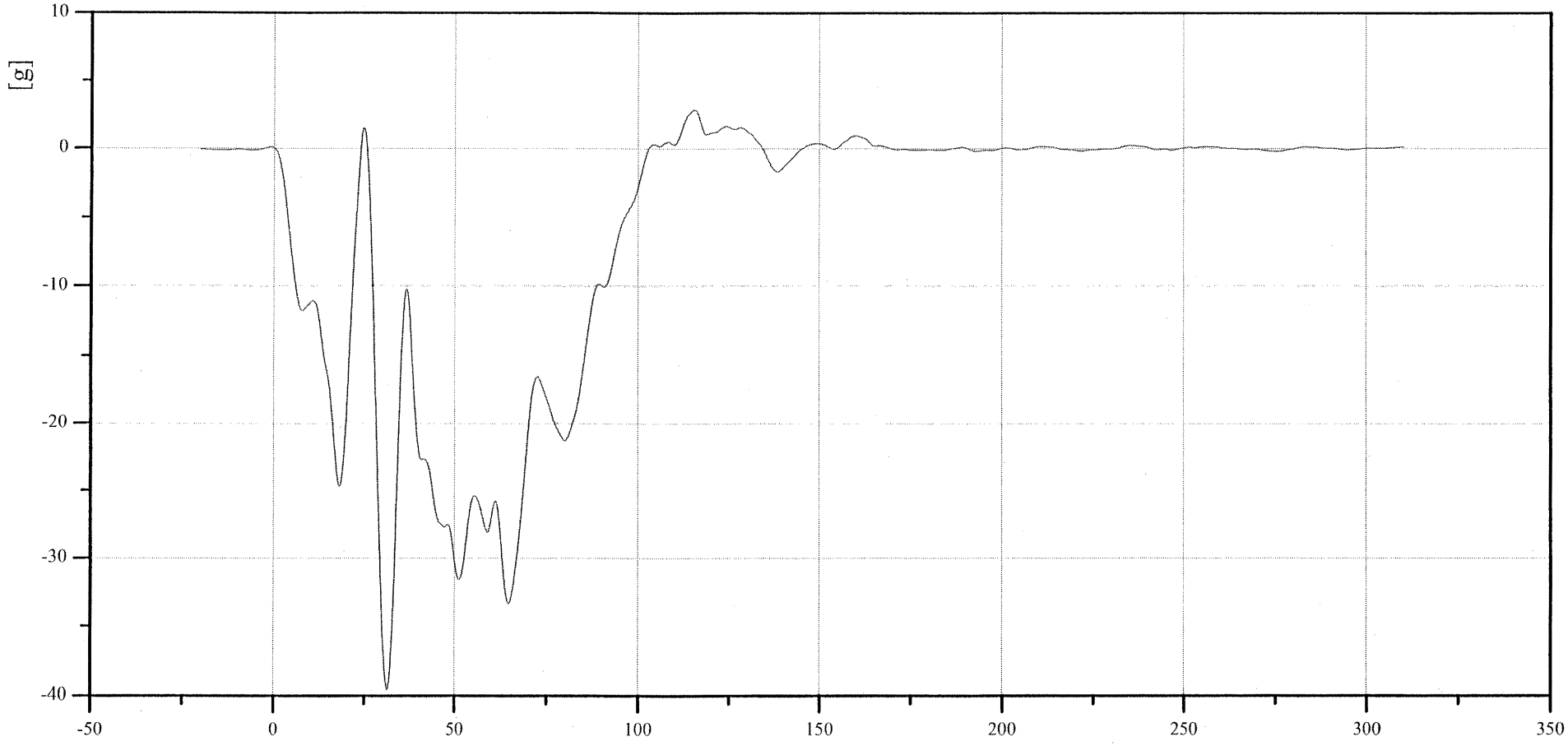
Transportation Research Center, Inc.

Rear Seat Crossmember Left Side Vehicle X

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

RCXLXG



<Min Value>
-39.56 g at 31.36 ms

<Max Value>
2.84 g at 115.44 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

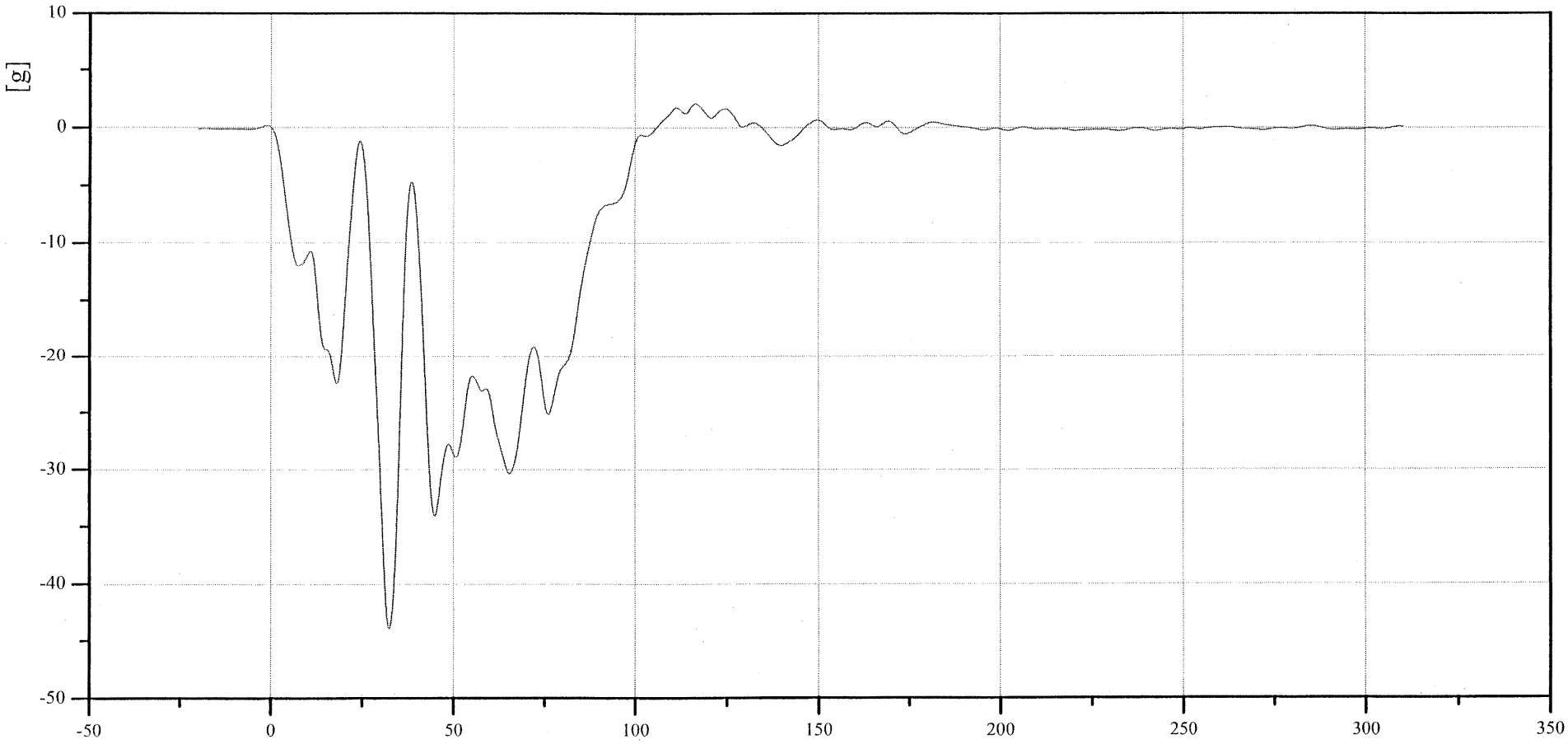
Transportation Research Center, Inc.

Rear Seat Crossmember Right Side Vehicle X

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

RCXRXG



<Min Value>
-43.96 g at 32.32 ms

<Max Value>
2.08 g at 116.56 ms

Time [ms]

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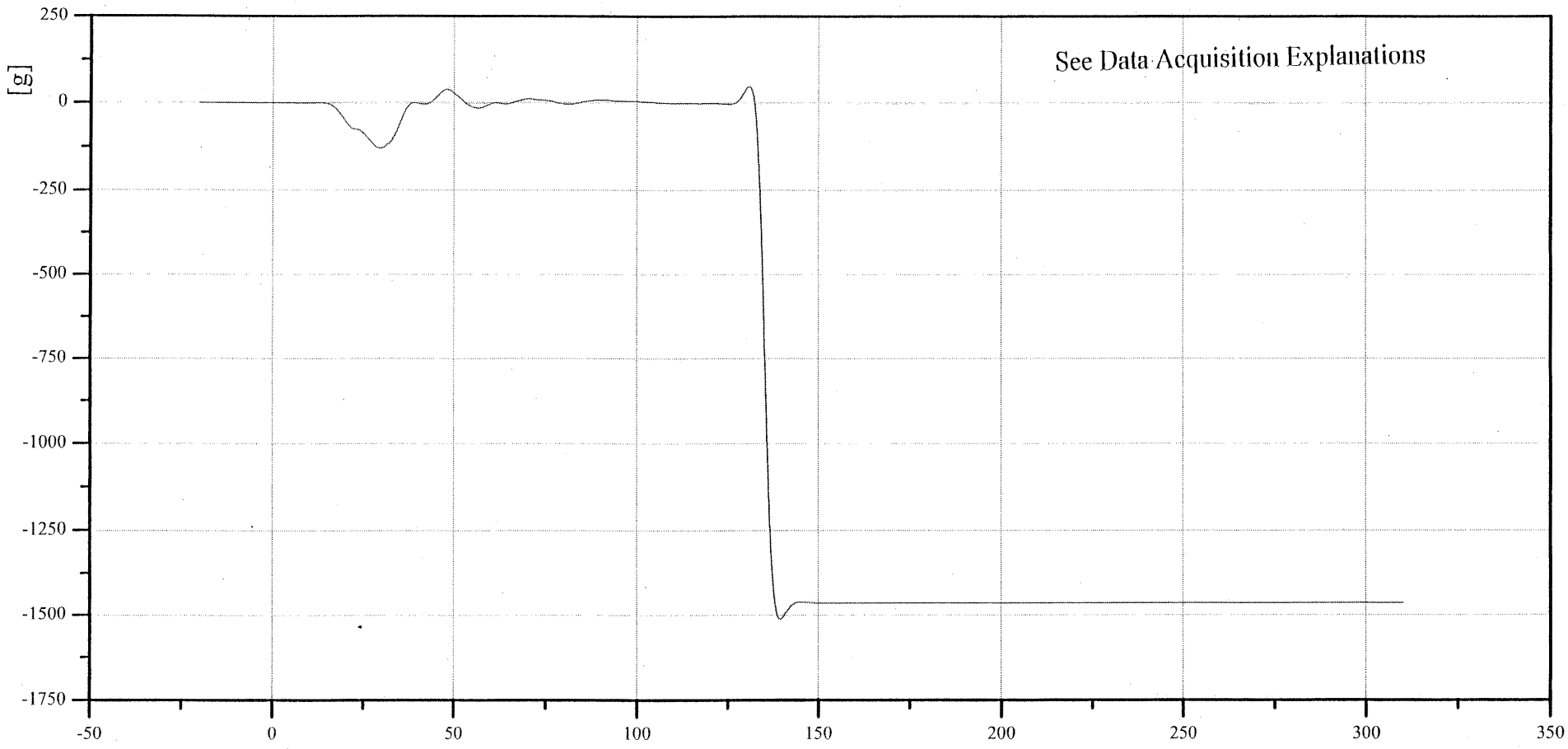
Transportation Research Center, Inc.

Engine Top of Block X

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

ENGTXG



<Min Value>
-1513.89 g at 139.44 ms

<Max Value>
47.60 g at 130.88 ms

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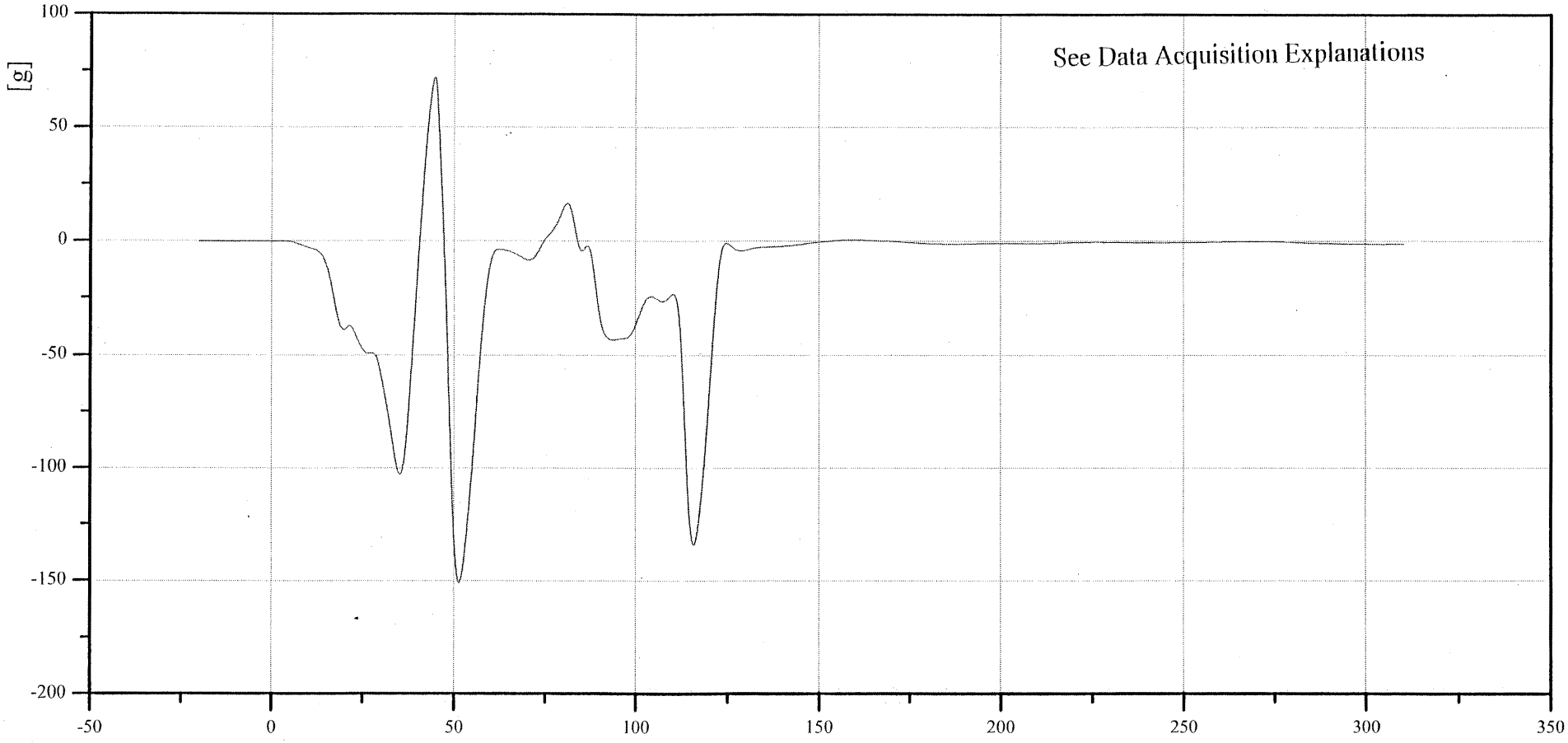
Transportation Research Center, Inc.

Engine Bottom of Block X

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

ENGBXG



<Min Value>
-150.99 g at 51.36 ms

<Max Value>
72.09 g at 44.72 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

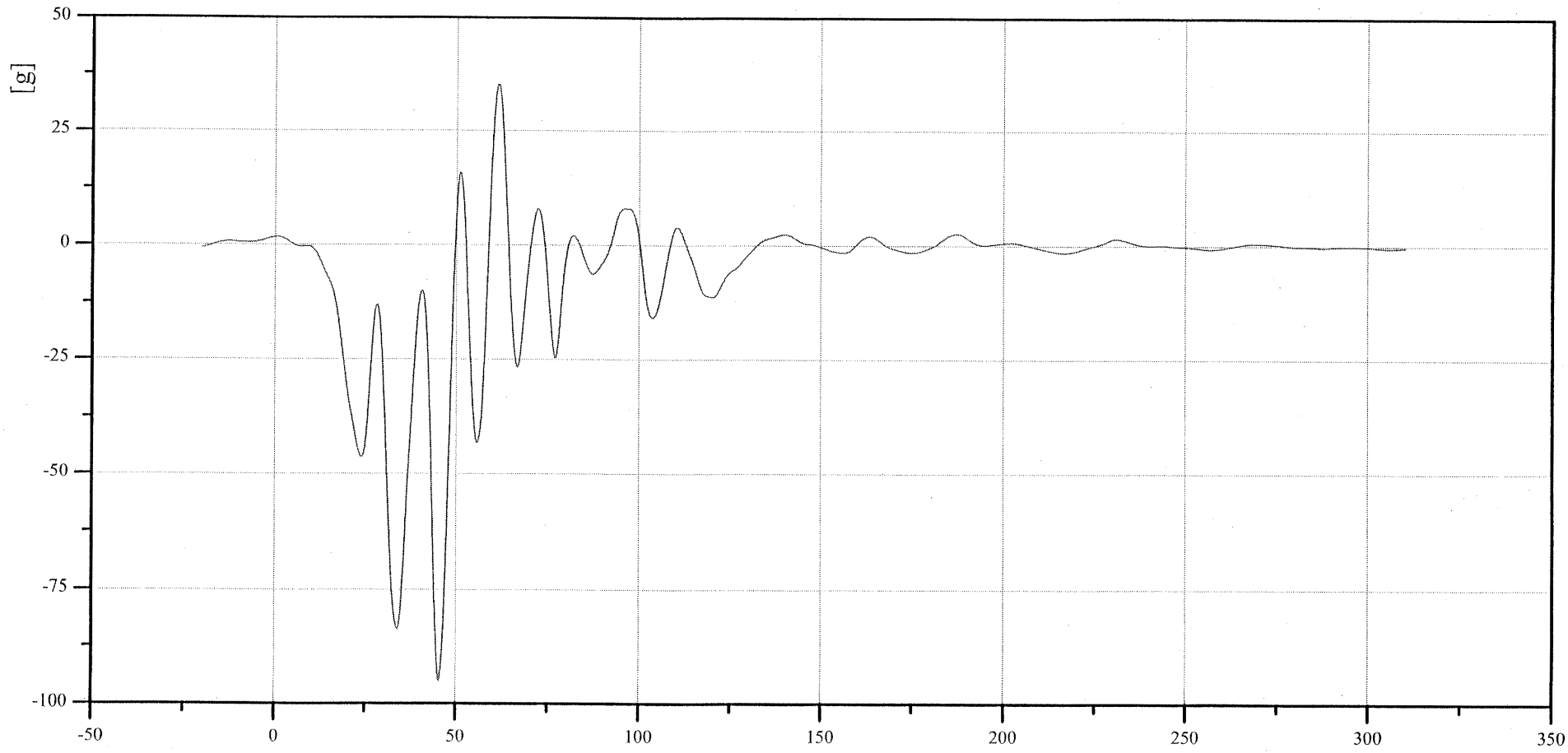
Transportation Research Center, Inc.

Left Brake Caliper X

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BRCLXG



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-94.99 g at 45.52 ms

<Max Value>
35.26 g at 61.52 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

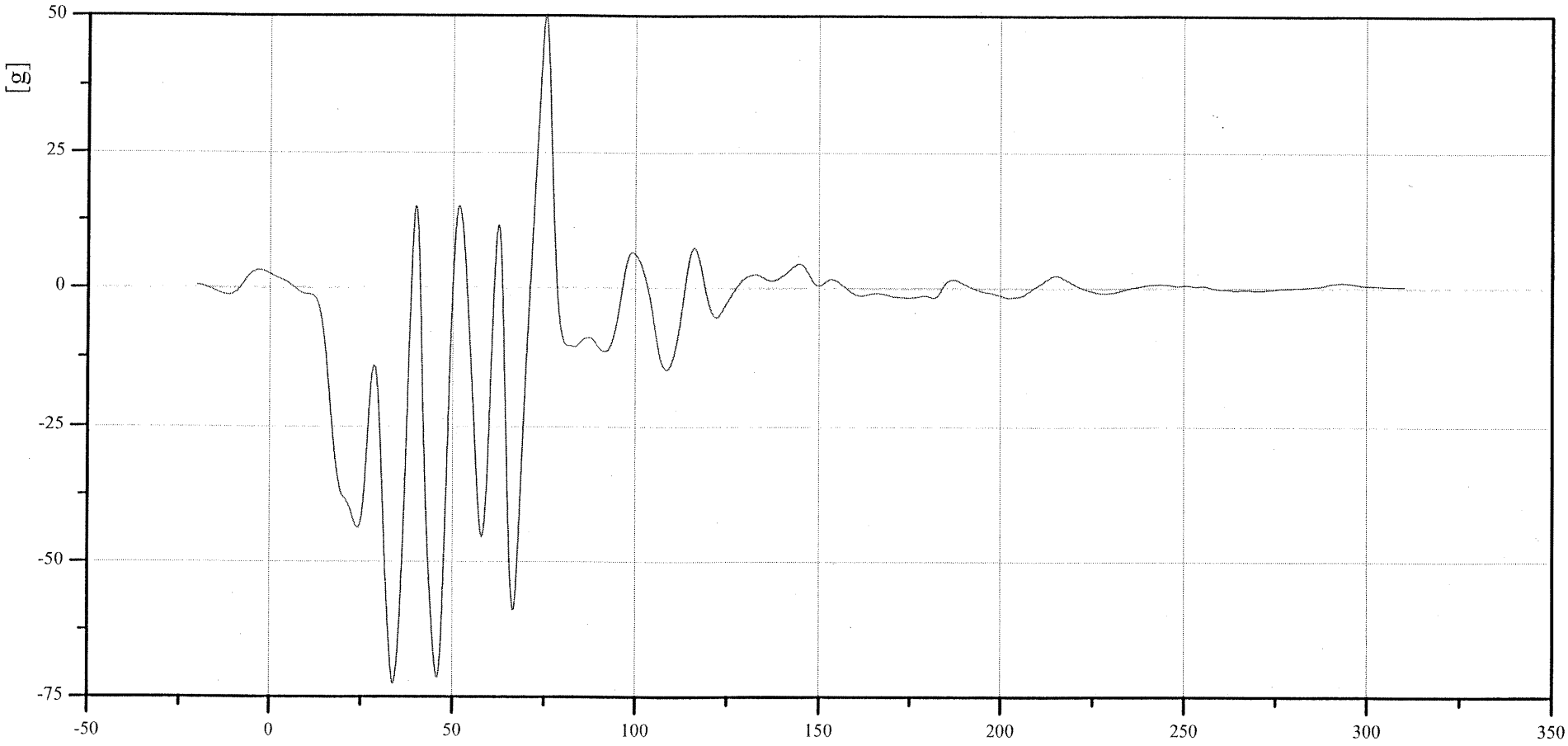
Transportation Research Center, Inc.

Right Brake Caliper X

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BRCRXG



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<Max Value>
50.01 g at 75.28 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

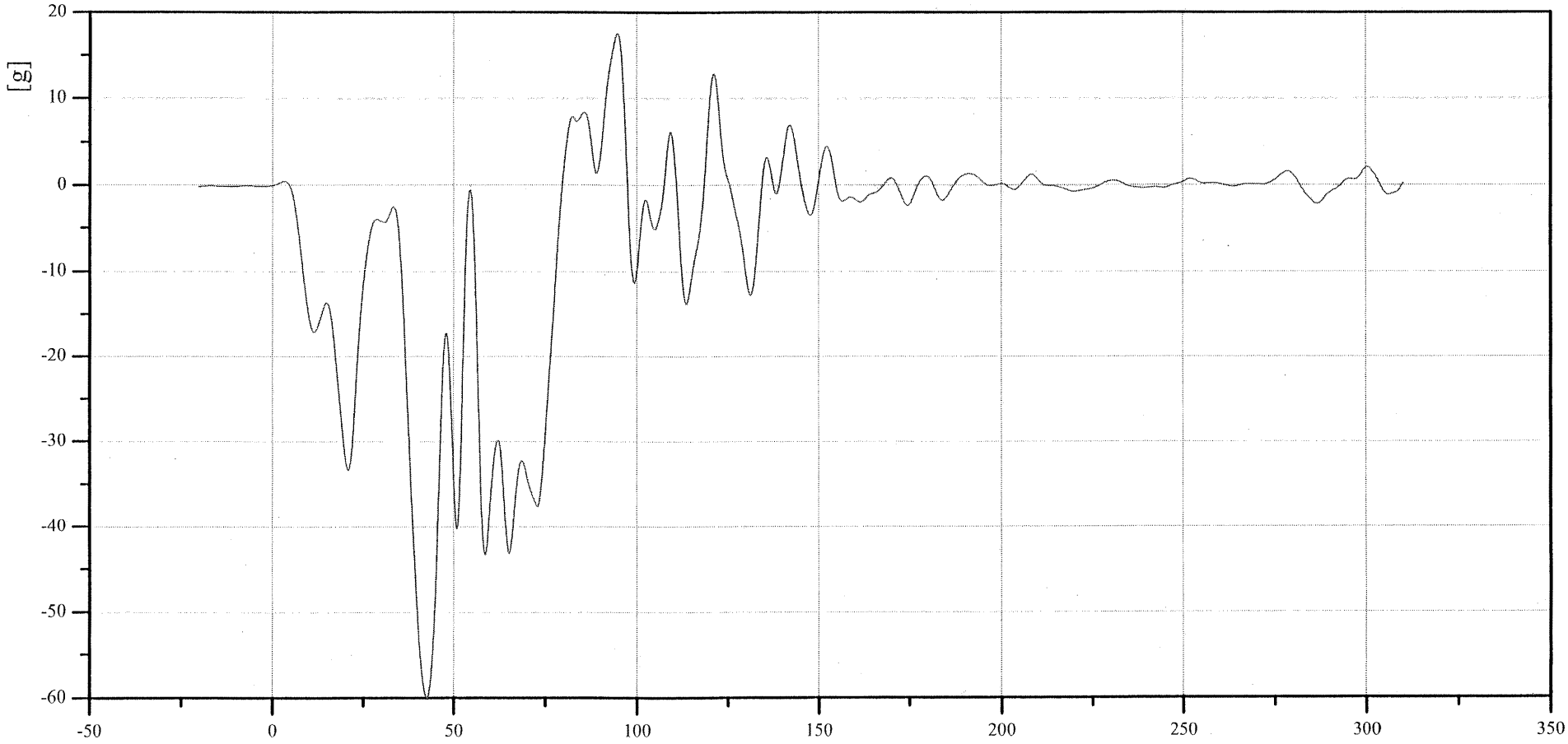
Transportation Research Center, Inc.

Center of Instrument Panel X

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

IPCXG



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-59.92 g at 42.64 ms

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17.51 g at 94.72 ms

Time [ms]

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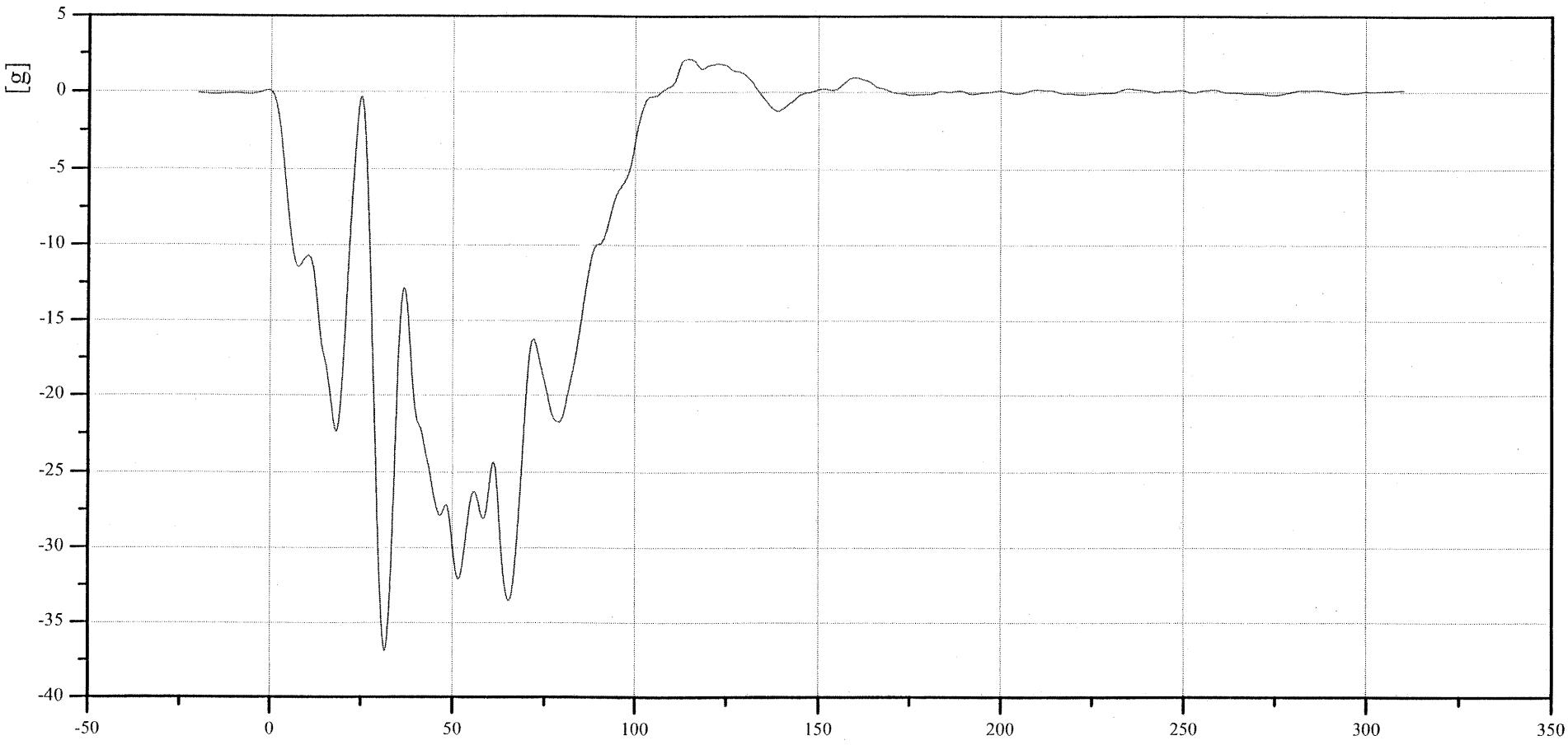
Transportation Research Center, Inc.

B-Pillar Left Side Bottom of Vehicle X

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BPLBXG



<Min Value>
-36.89 g at 31.52 ms

<Max Value>
2.17 g at 114.88 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

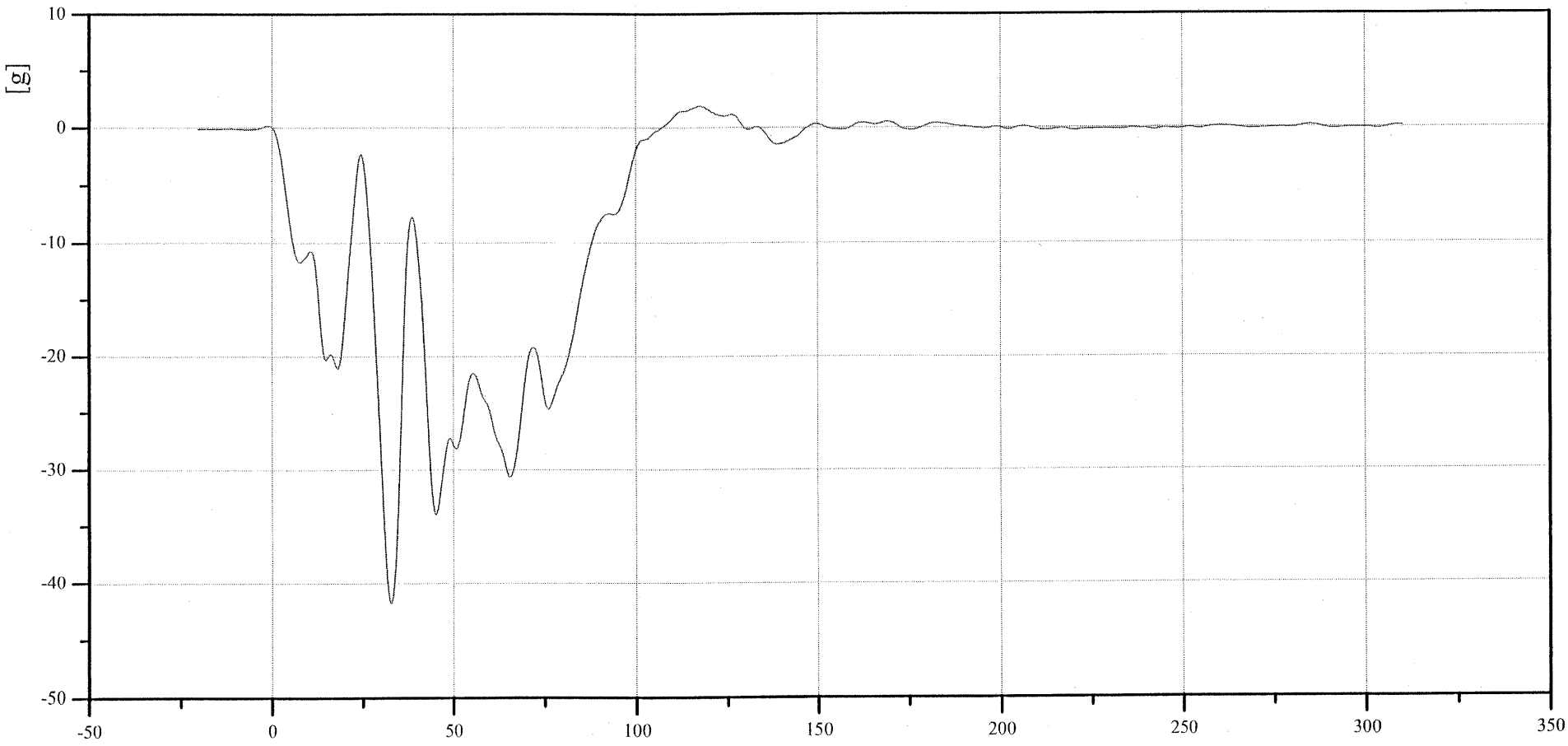
Transportation Research Center, Inc.

B-Pillar Right Side Bottom of Vehicle X

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BPRBXG



<Min Value>
-41.77 g at 32.72 ms

<Max Value>
1.91 g at 117.52 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

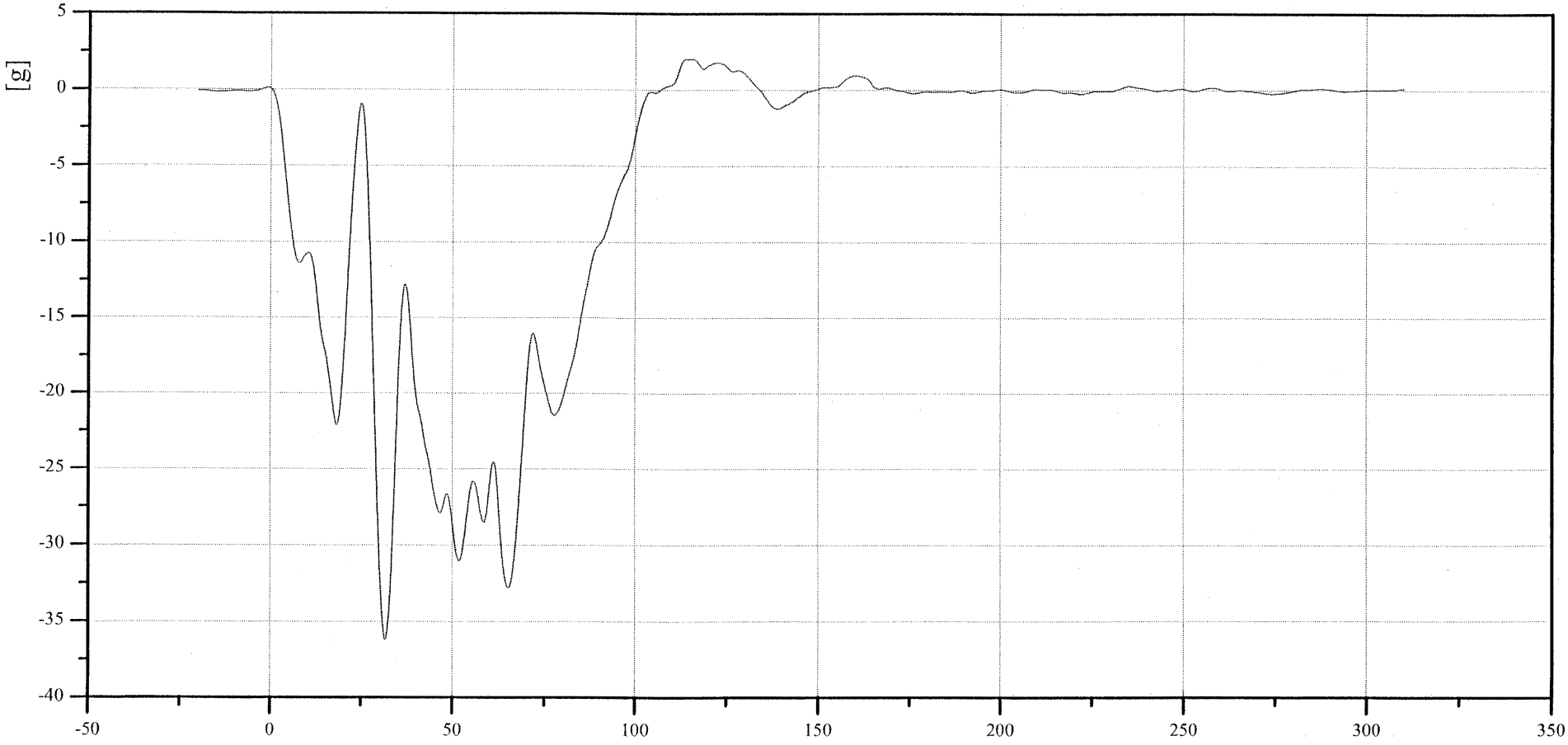
Transportation Research Center, Inc.

Rear Panel nearest left Rear Tire X-Axis Accel

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

RPRLXG



<Min Value>
-36.23 g at 31.60 ms

<Max Value>
2.05 g at 113.76 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

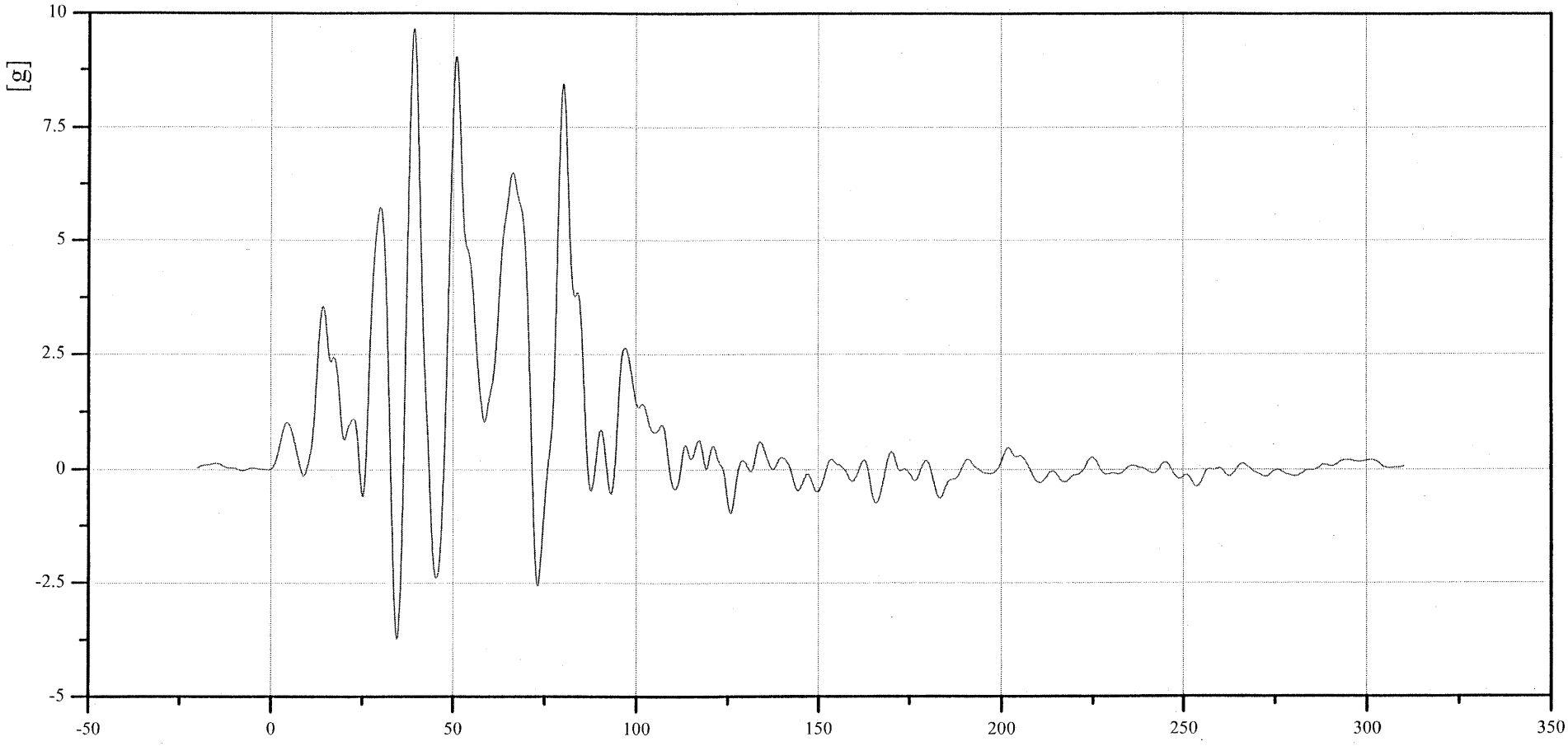
Transportation Research Center, Inc.

Rear Panel nearest left Rear Tire Y-Axis Accel

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

RPRLYG



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-3.73 g at 34.64 ms

<Max Value>
9.64 g at 39.20 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

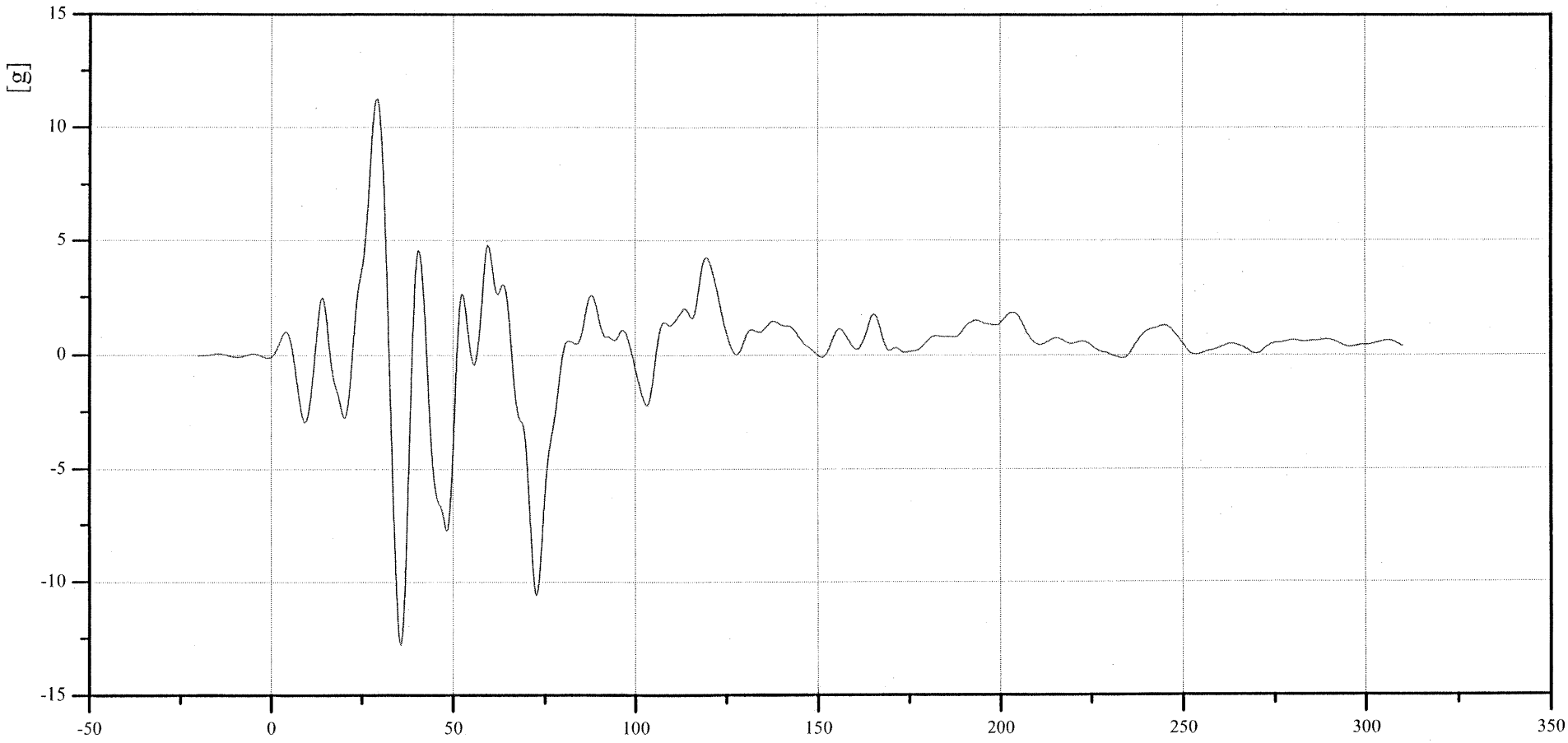
Transportation Research Center, Inc.

Rear Panel nearest left Rear Tire Z-Axis Accel

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

RPRLZG



<Min Value>
-12.79 g at 35.68 ms

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11.27 g at 29.04 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

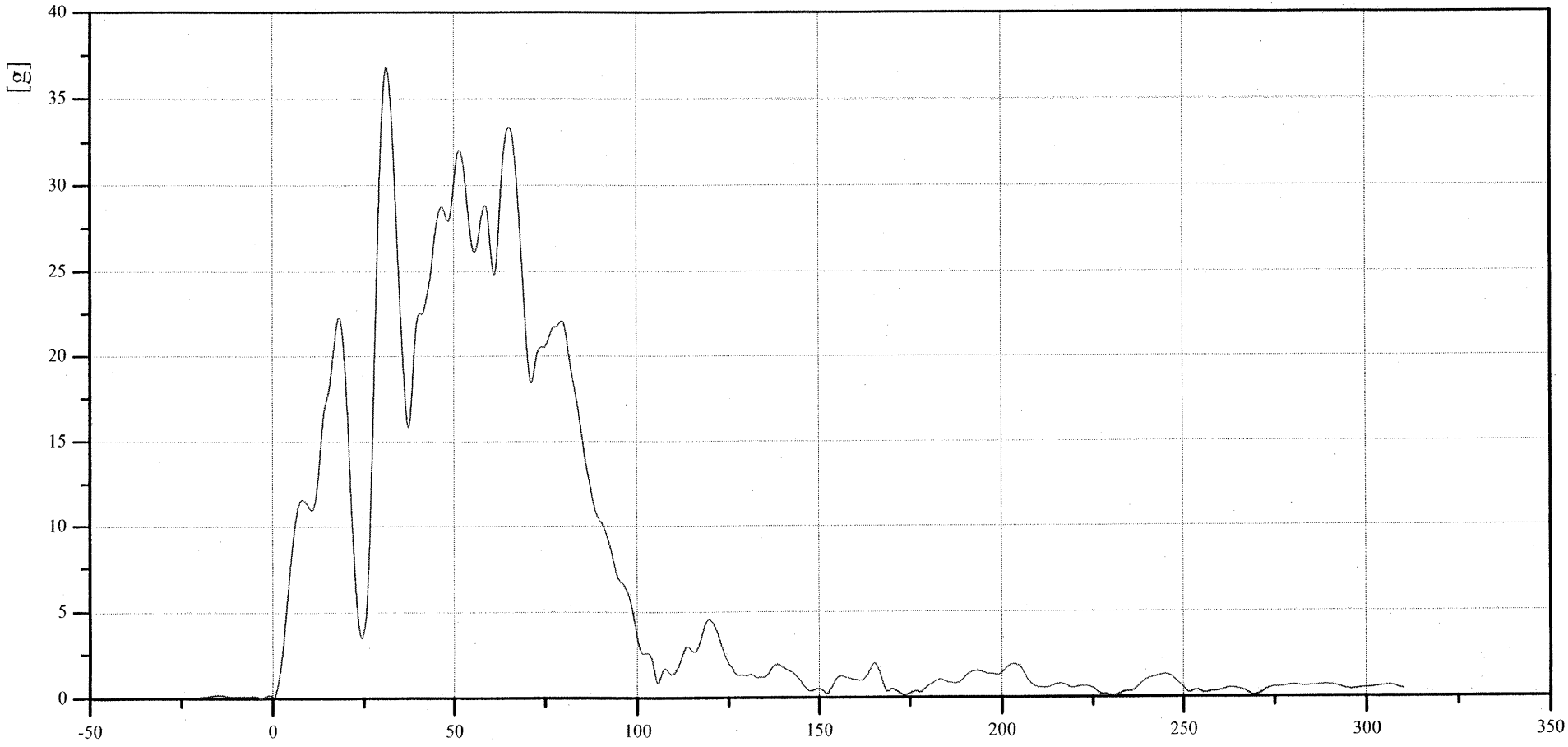
Transportation Research Center, Inc.

Rear Panel Nearest Left Rear Tire Resultant Acceleration

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

RPRLRG



<Min Value>
0.02 g at -2.96 ms

<Max Value>
36.81 g at 31.36 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

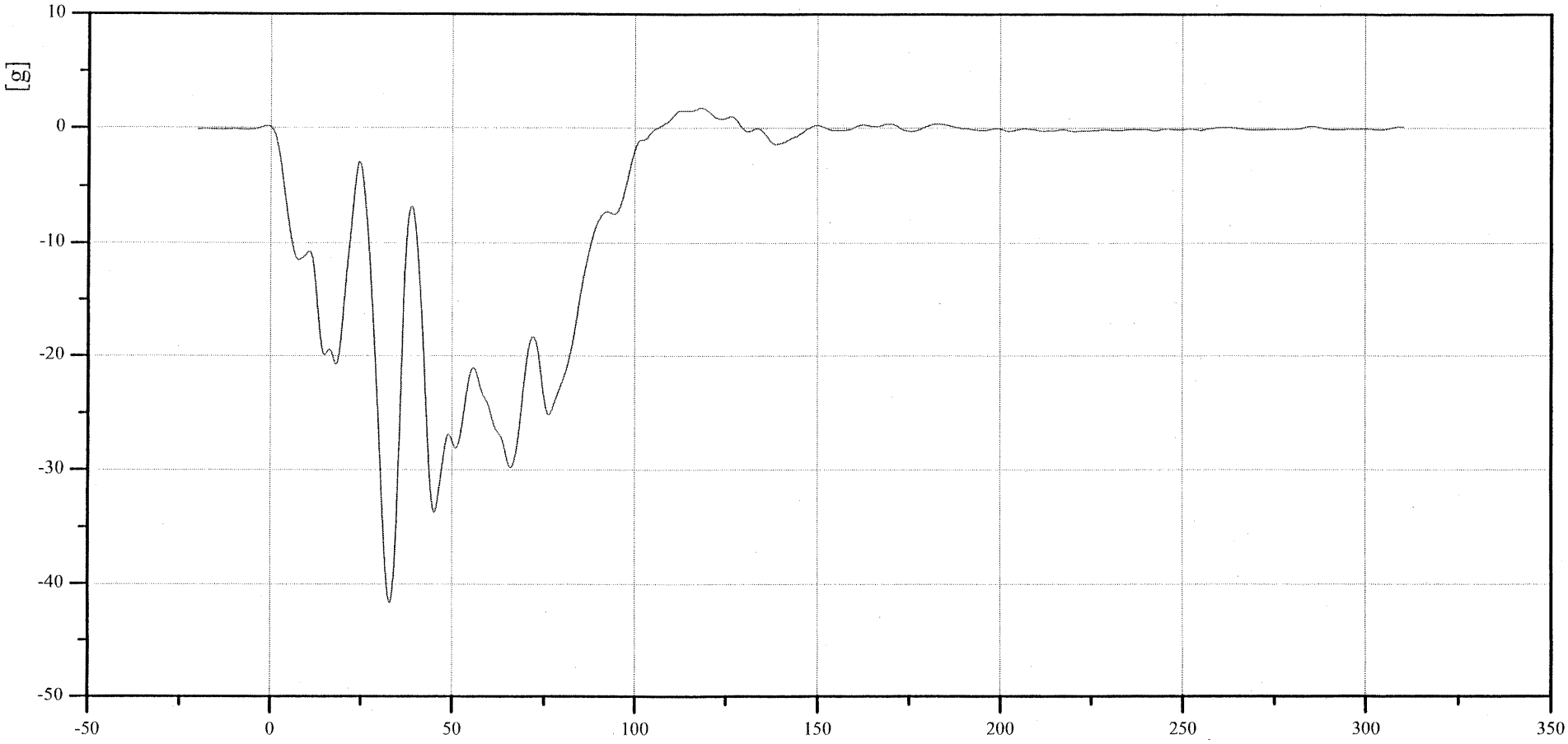
Transportation Research Center, Inc.

Rear Panel nearest right Rear Tire X-Axis Accel

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

RPRRXG



<Min Value>
-41.68 g at 32.88 ms

<Max Value>
1.75 g at 118.08 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

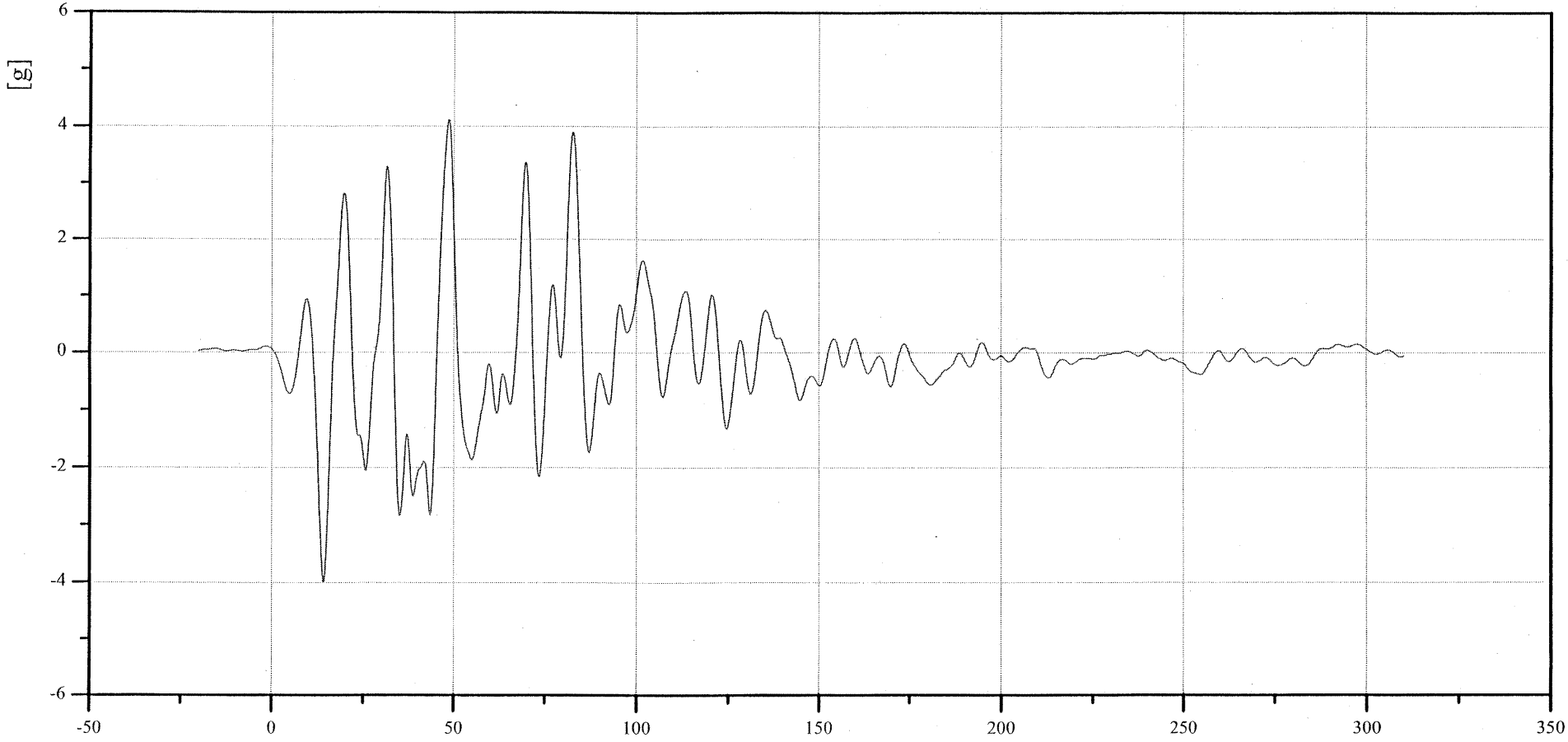
Transportation Research Center, Inc.

Rear Panel nearest right Rear Tire Y-Axis Accel

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

RPRRYG



<Min Value>
-4.00 g at 14.16 ms

<Max Value>
4.11 g at 48.56 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

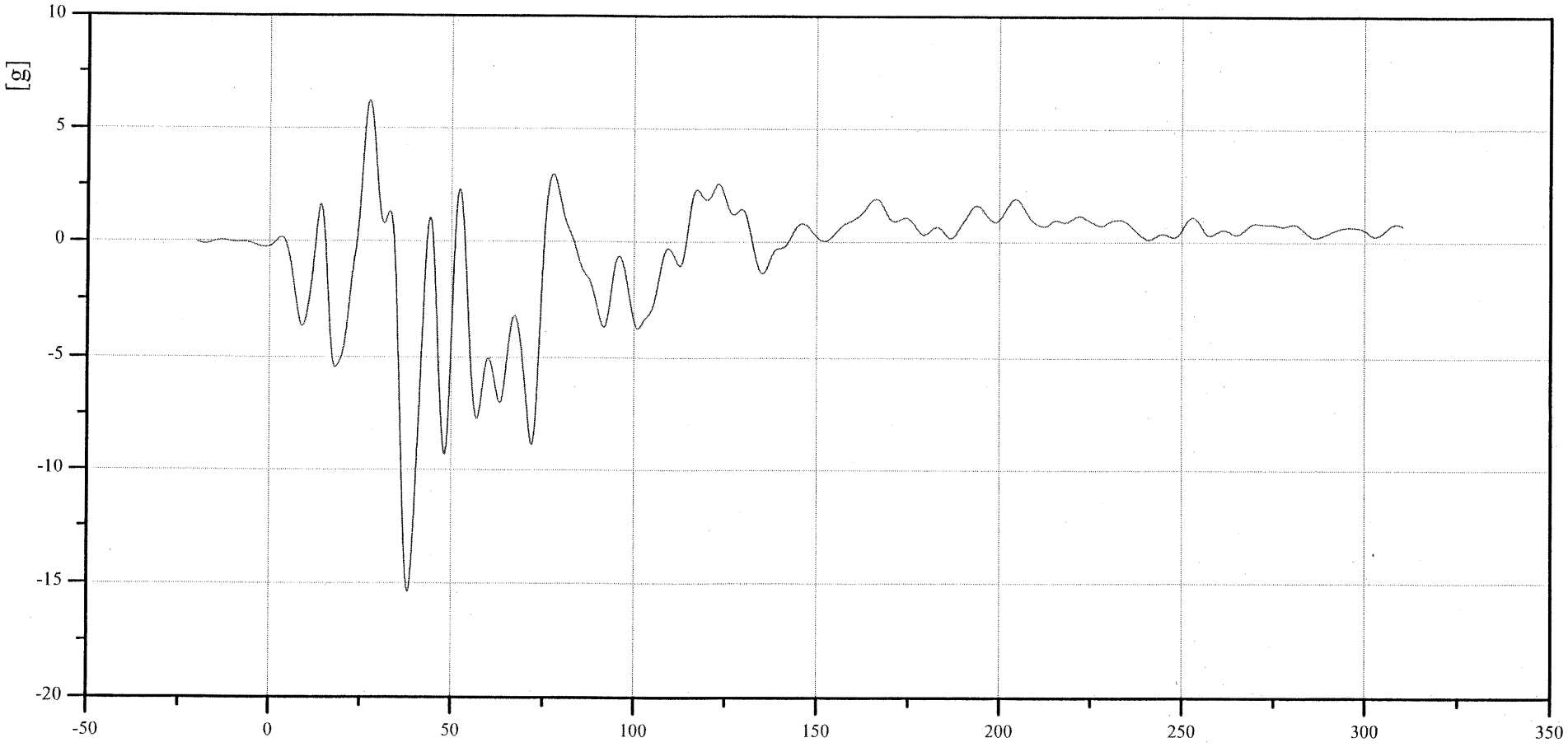
Transportation Research Center, Inc.

Rear Panel nearest right Rear Tire Z-Axis Accel

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

RPRRZG



<Min Value>
-15.40 g at 38.16 ms

<Max Value>
6.22 g at 27.44 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

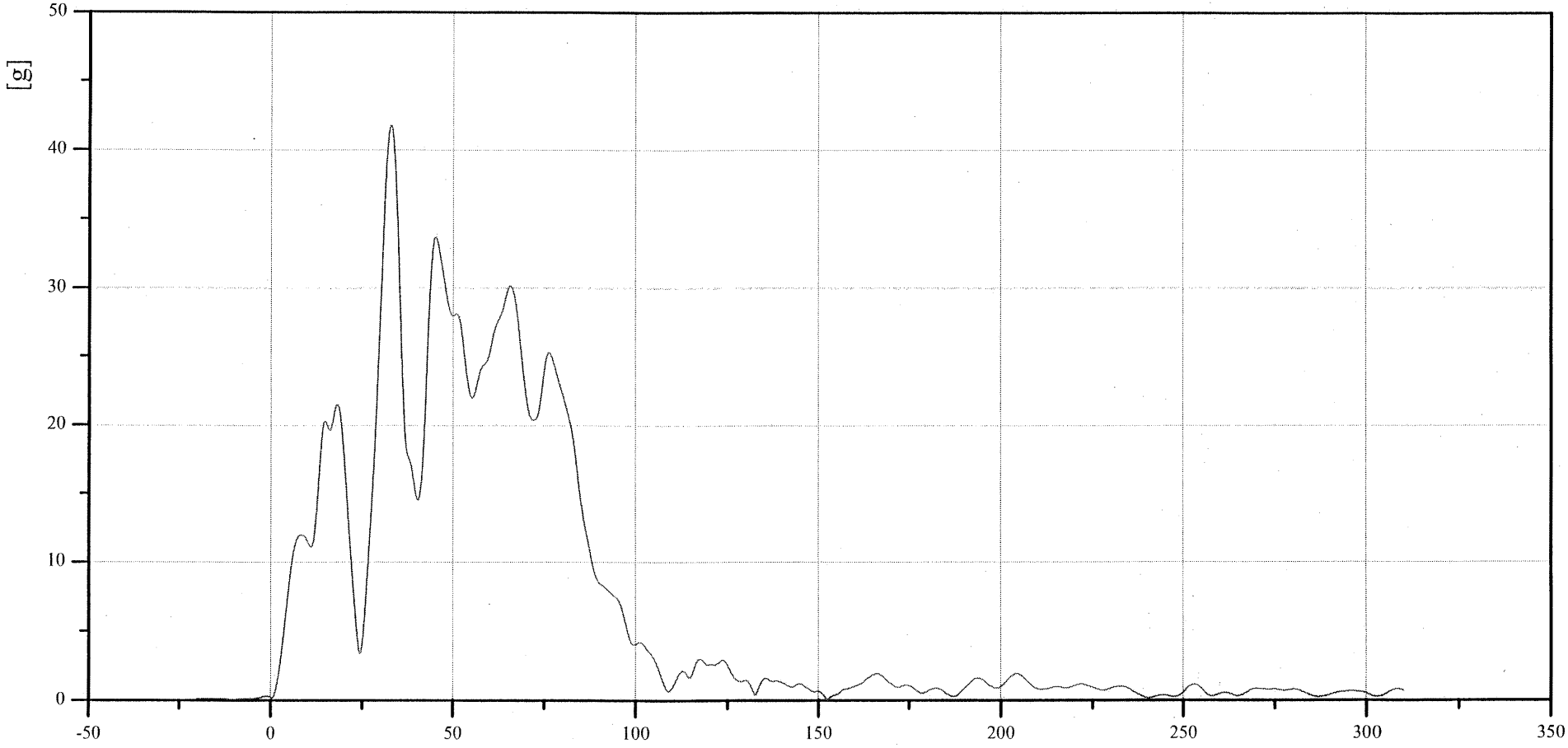
Transportation Research Center, Inc.

Rear Panel Nearest Right Rear Tire Resultant Acceleration

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

RPRRRG



<Min Value>
0.07 g at 152.48 ms

<Max Value>
41.74 g at 32.88 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

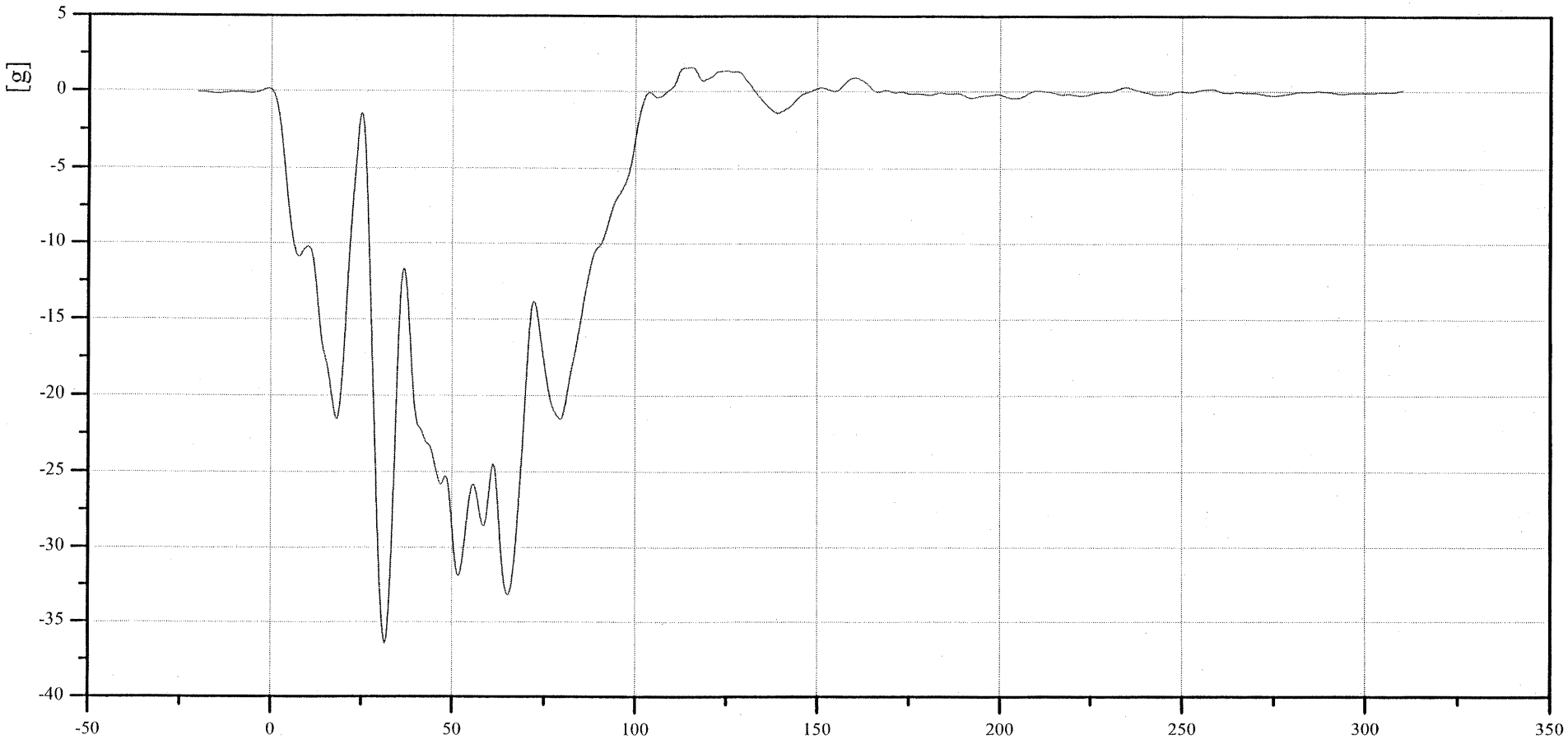
Transportation Research Center, Inc.

Rear Panel nearest left Rear Tire X-Axis Accel Redund.

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

RRRLXG



<Min Value>
-36.45 g at 31.44 ms

<Max Value>
1.61 g at 115.20 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

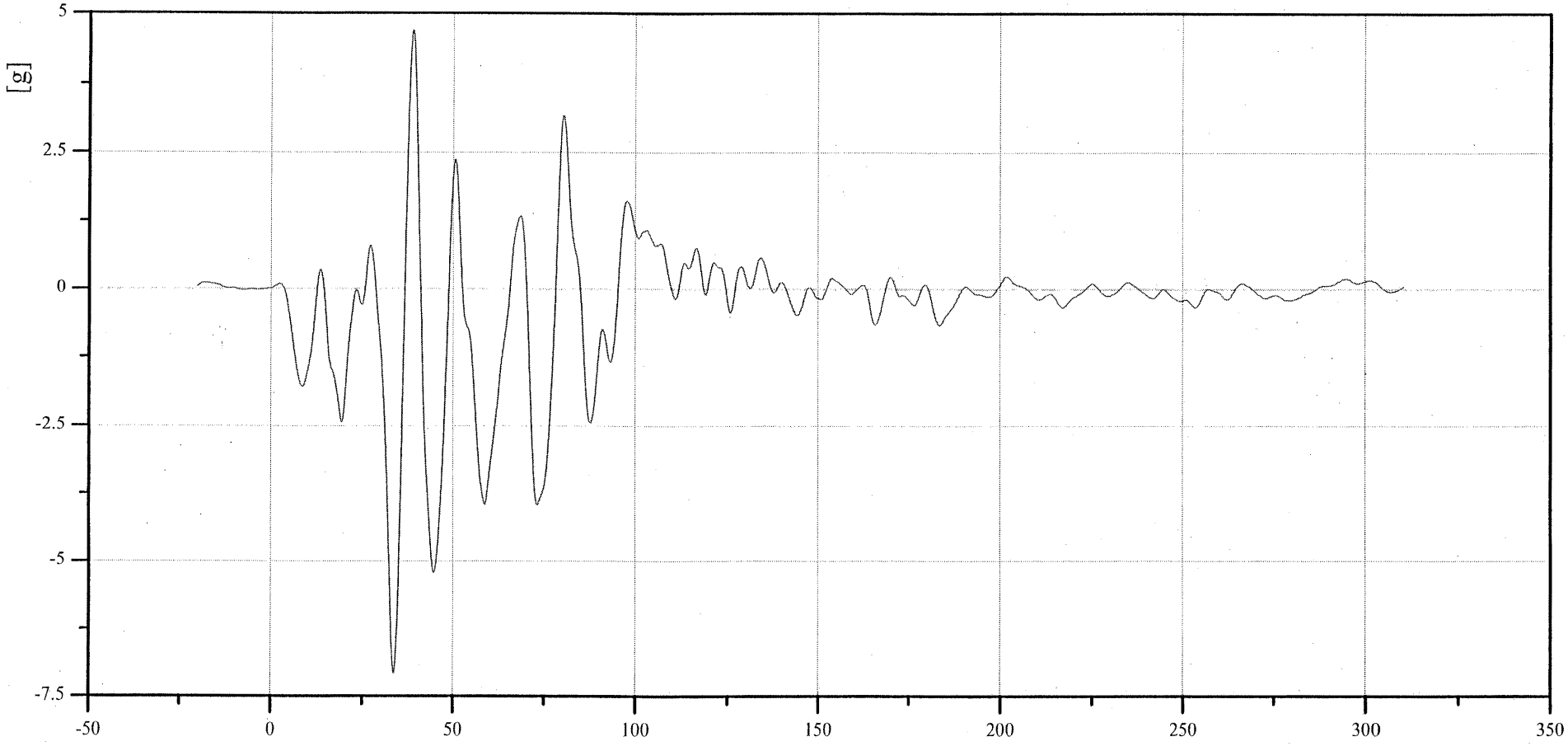
Transportation Research Center, Inc.

Rear Panel nearest left Rear Tire Y-Axis Accel Redund.

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

RRRLYG



<Min Value>
-7.05 g at 33.84 ms

<Max Value>
4.69 g at 38.88 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

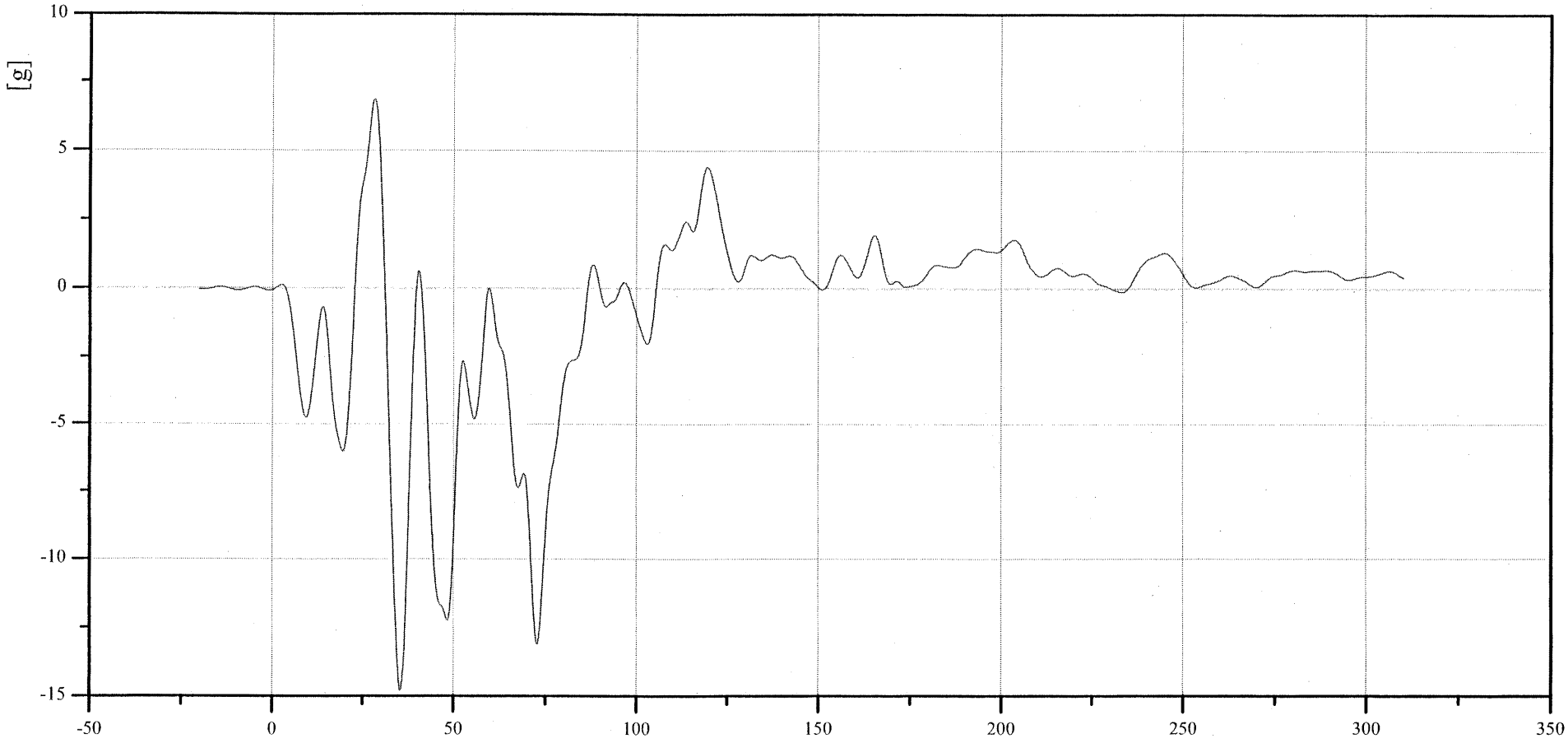
Transportation Research Center, Inc.

Rear Panel nearest left Rear Tire Z-Axis Accel Redund.

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

RRRLZG



<Min Value>
-14.78 g at 35.44 ms

<Max Value>
6.84 g at 28.24 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

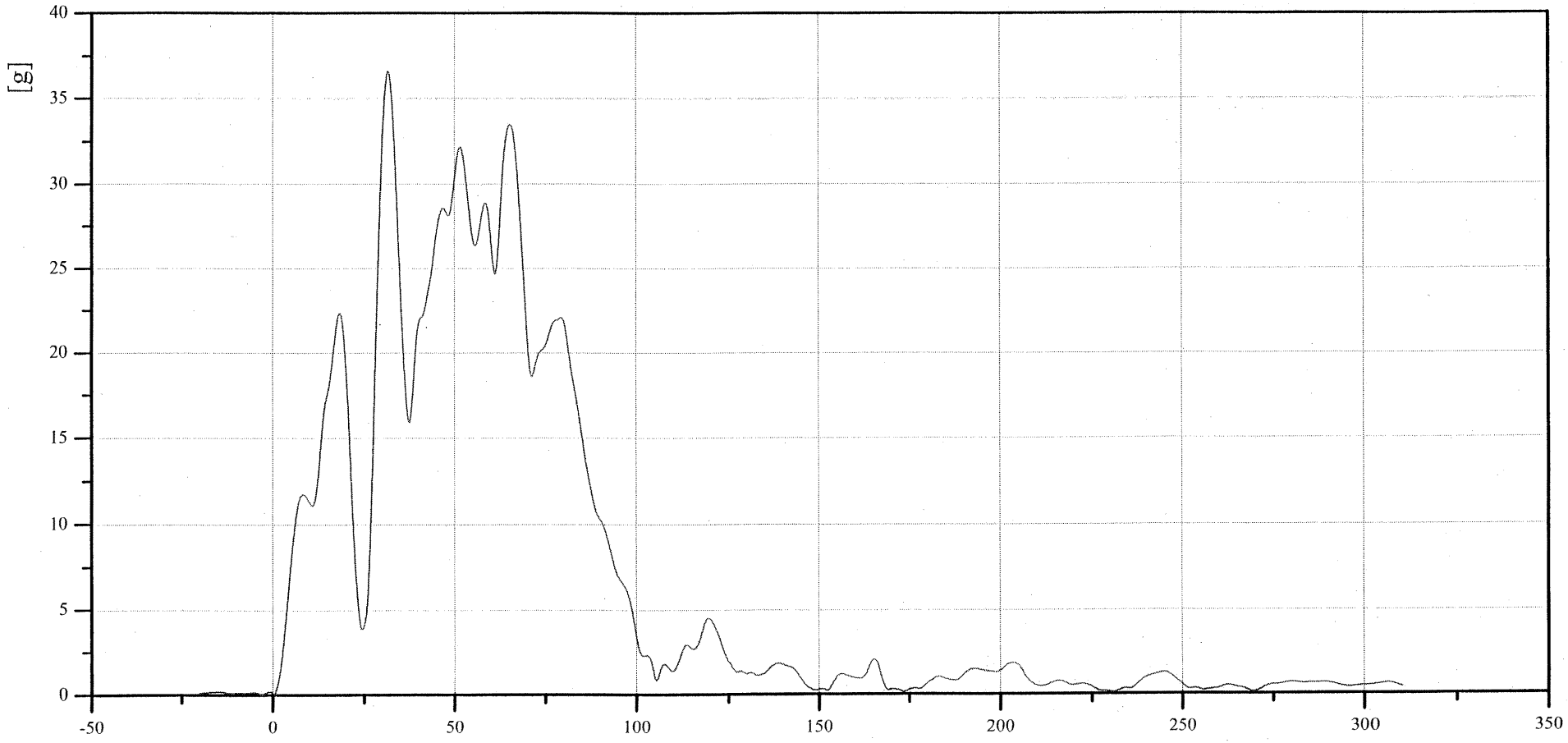
Transportation Research Center, Inc.

Rear Panel Nearest Left Rear Tire Resultant Acceleration

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

RRRLRG



<Min Value>
0.03 g at -2.88 ms

<Max Value>
36.60 g at 31.52 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

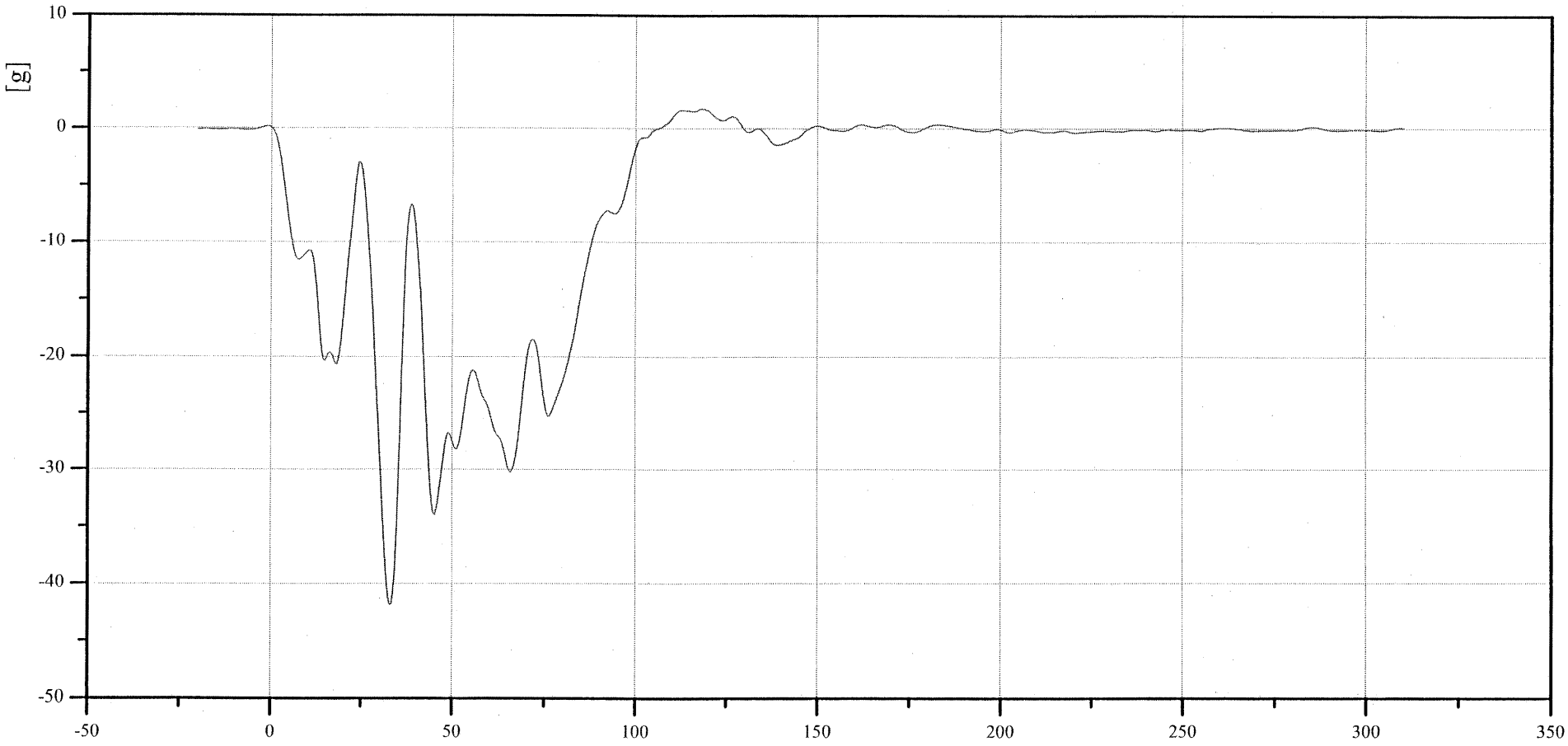
Transportation Research Center, Inc.

Rear Panel nearest right Rear Tire X-Axis Accel Redund.

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

RRRRXG



<Min Value>
-41.92 g at 32.96 ms

<Max Value>
1.77 g at 118.24 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

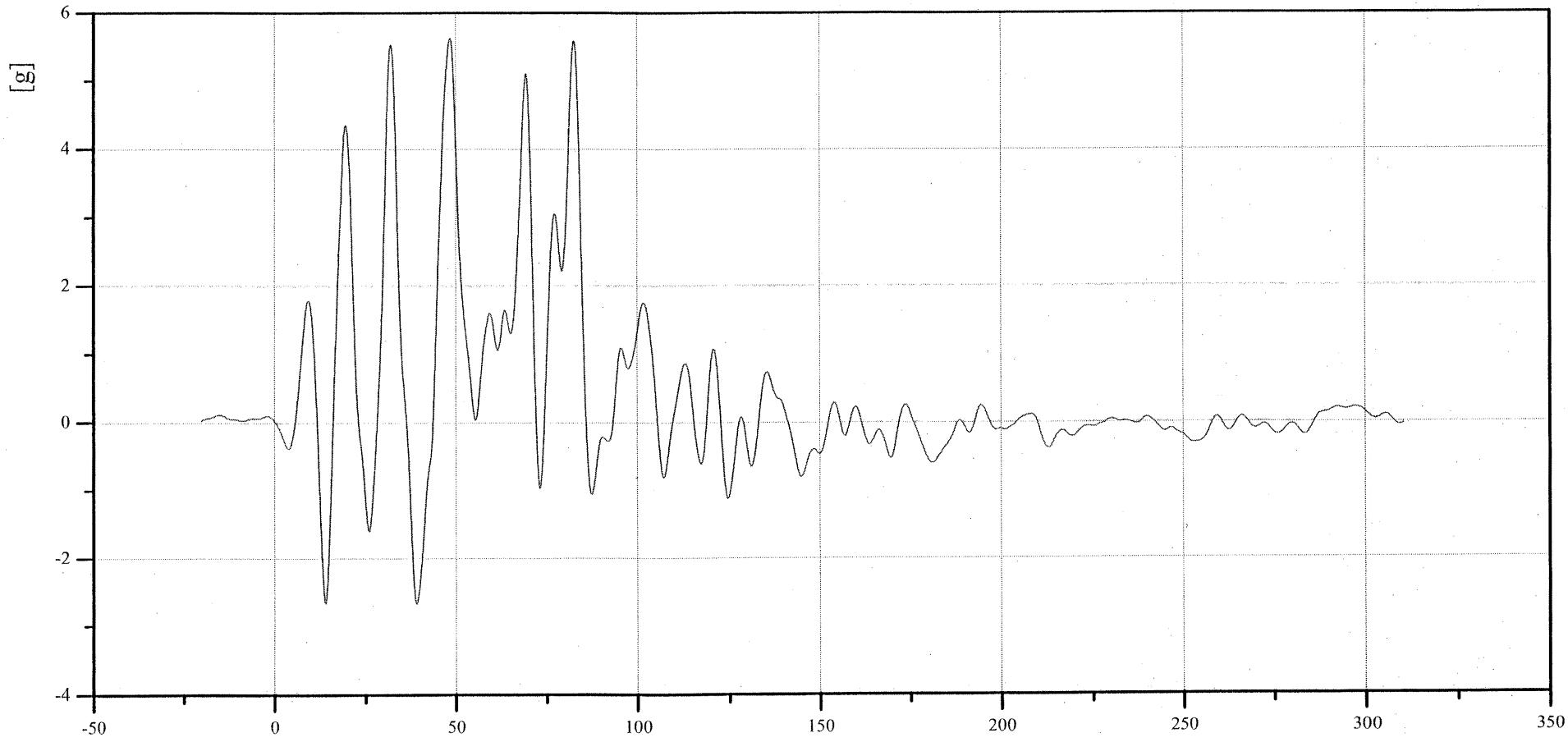
Transportation Research Center, Inc.

Rear Panel nearest right Rear Tire Y-Axis Accel Redund.

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

RRRRYG



<Min Value>
-2.67 g at 39.04 ms

<Max Value>
5.63 g at 48.40 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

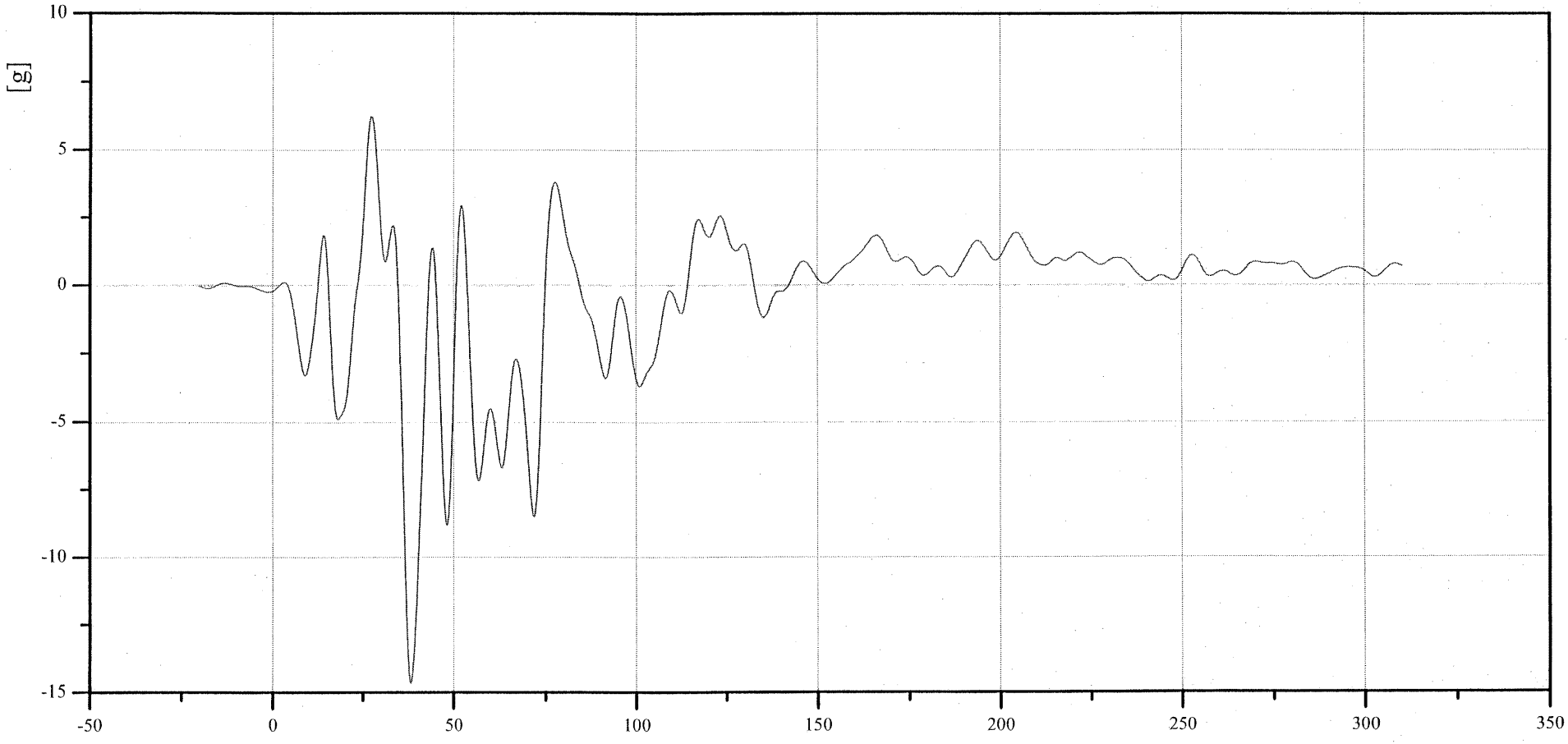
Transportation Research Center, Inc.

Rear Panel nearest right Rear Tire Z-Axis Accel Redund.

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

RRRRZG



<Min Value>
-14.65 g at 38.24 ms

<Max Value>
6.22 g at 27.28 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

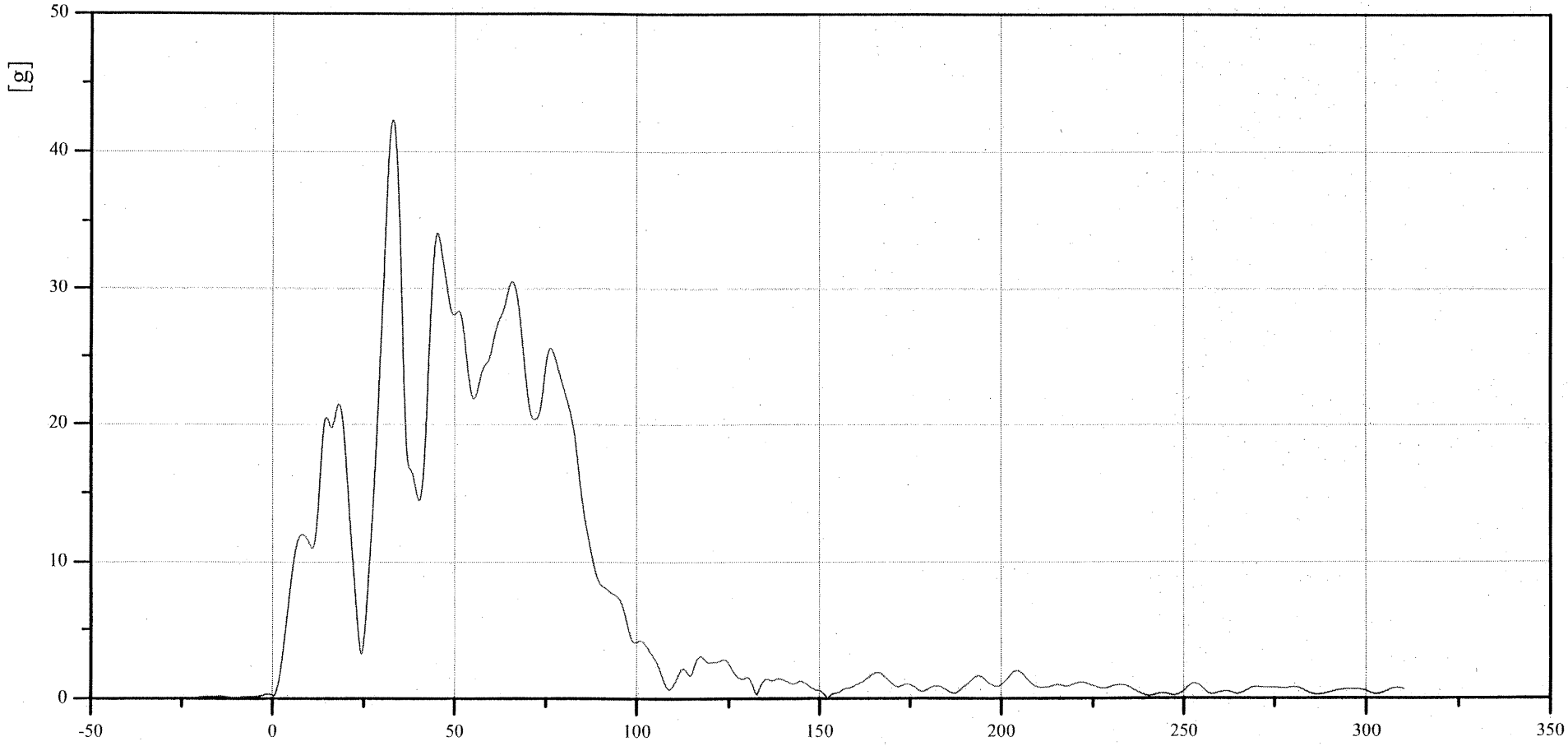
Transportation Research Center, Inc.

Rear Panel Nearest Right Rear Tire Resultant Acceleration

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

RRRRRG



<Min Value>
0.07 g at -10.40 ms

<Max Value>
42.25 g at 32.88 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

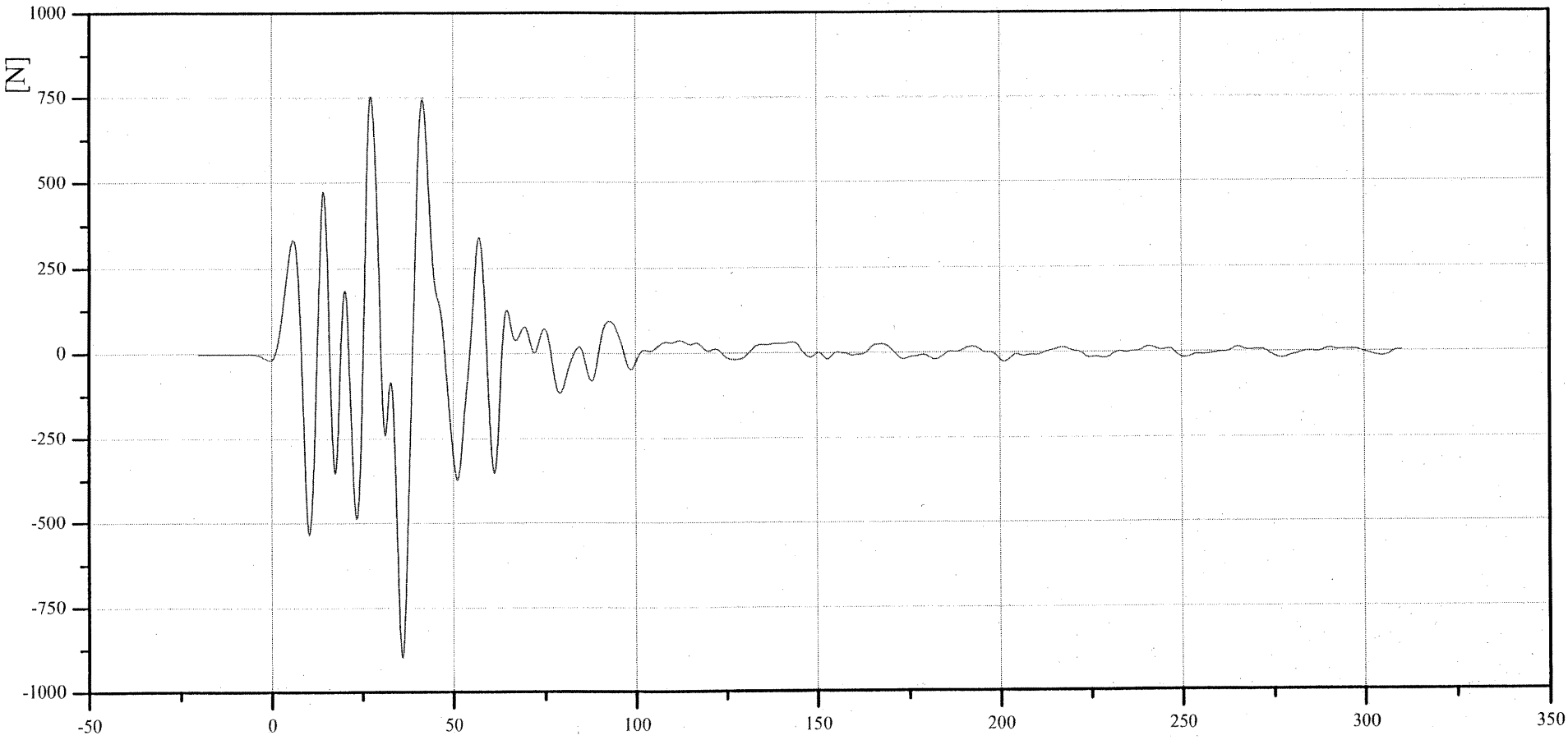
Transportation Research Center, Inc.

ROW A CELL 1

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BA1F



<Min Value>
-900.20 N at 35.92 ms

<Max Value>
752.66 N at 27.36 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

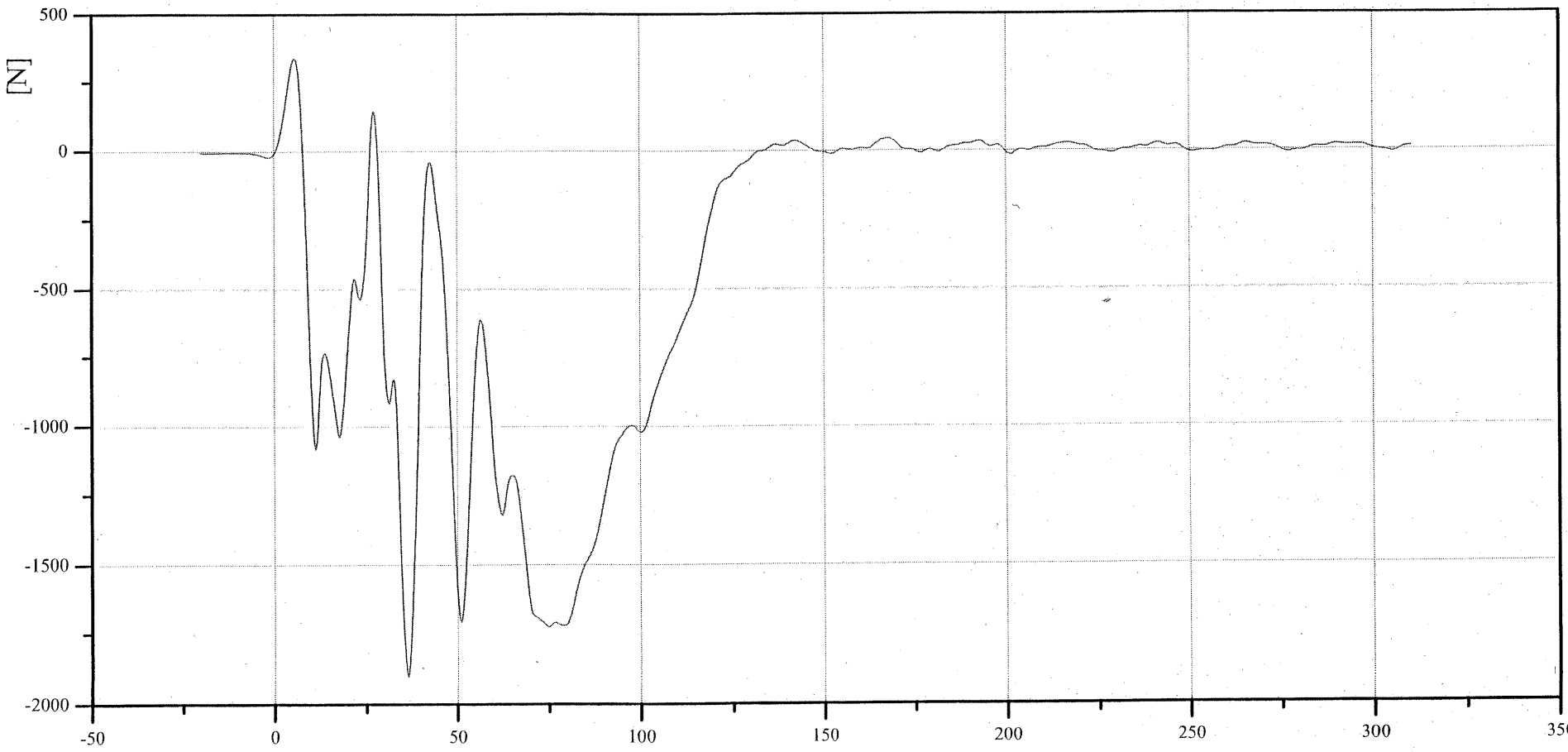
Transportation Research Center, Inc.

ROW A CELL 2

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BA2F



<Min Value>
-1899.30 N at 36.40 ms

<Max Value>
338.28 N at 5.52 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

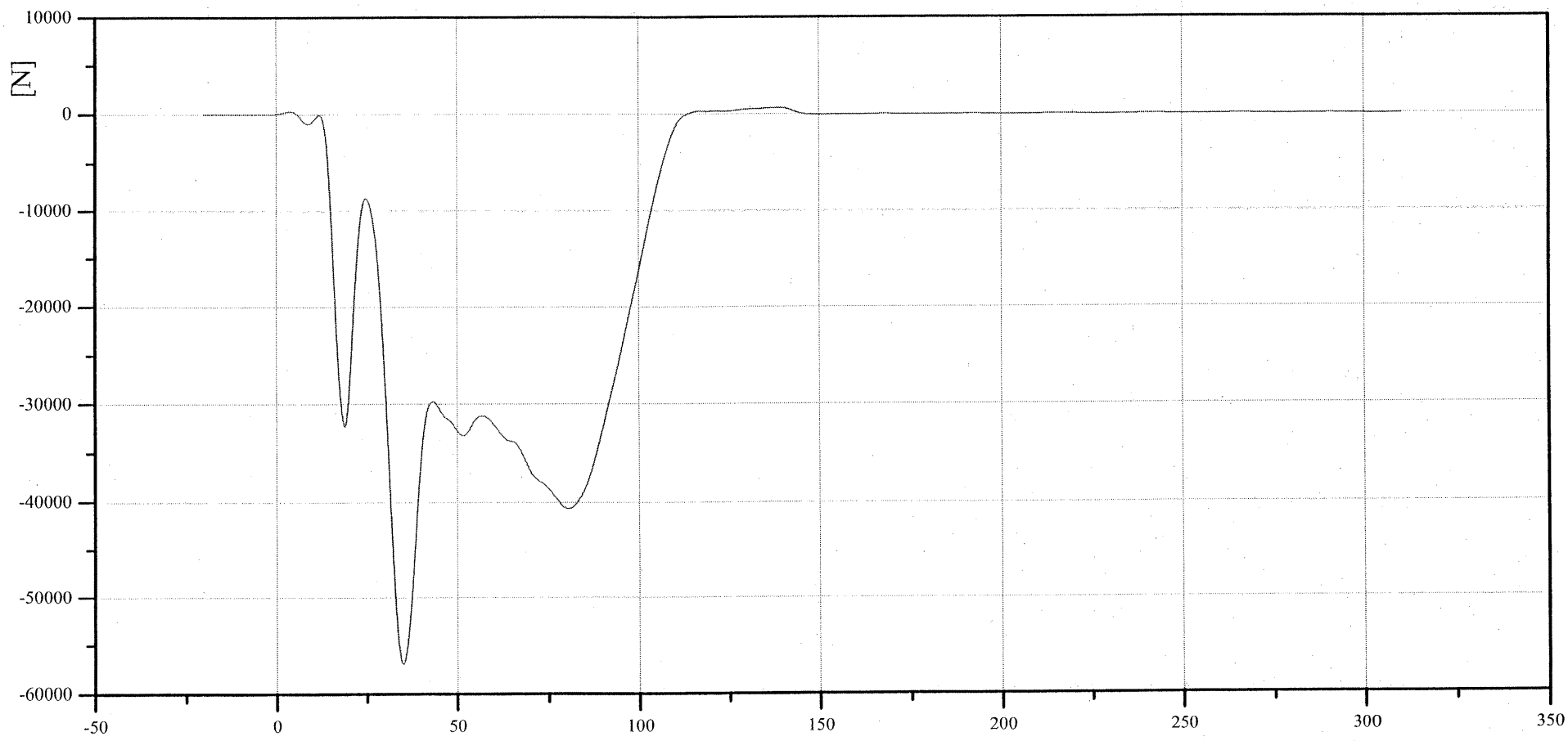
Transportation Research Center, Inc.

ROW A CELL 3

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BA3F



<Min Value>
-56914.86 N at 34.96 ms

<Max Value>
617.06 N at 139.28 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

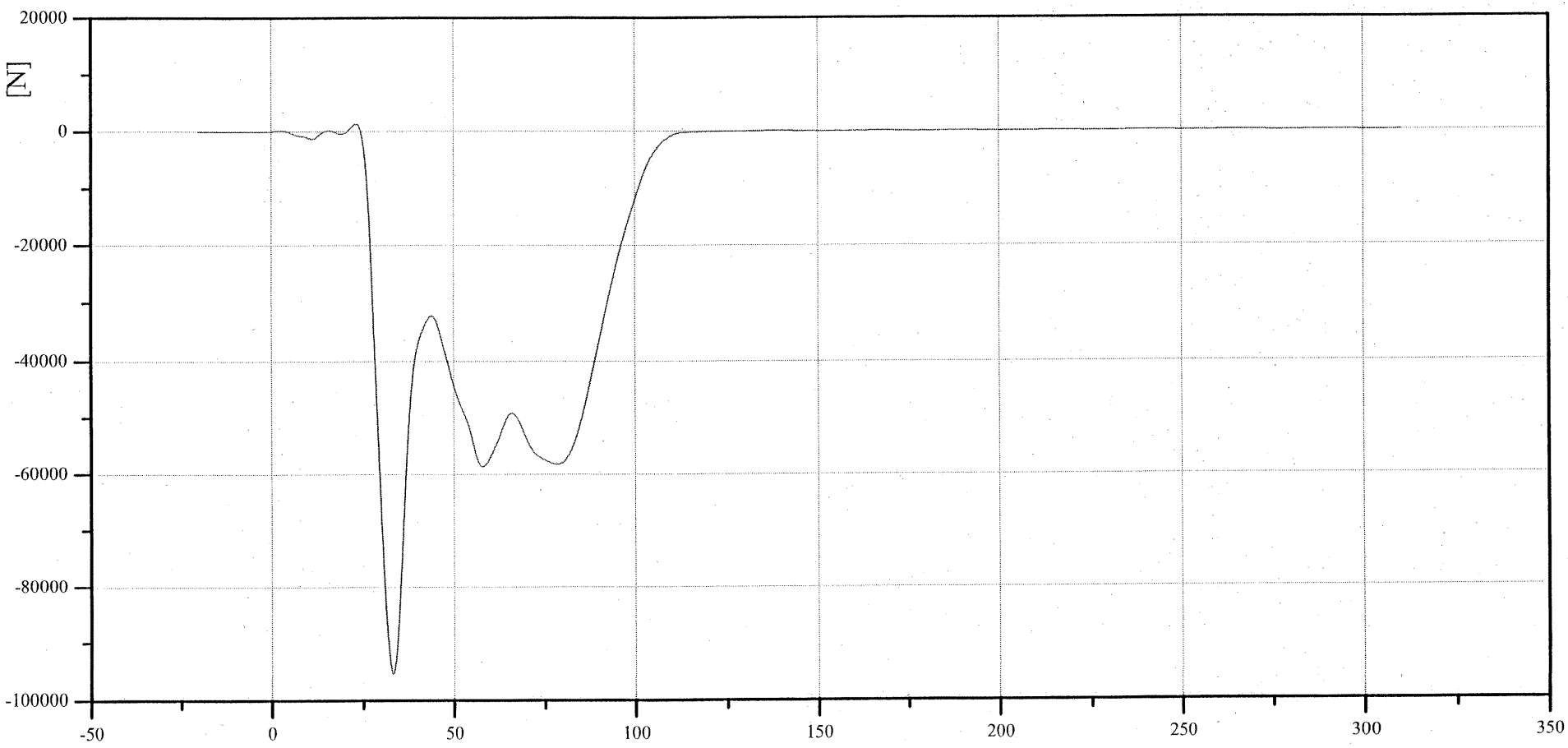
Transportation Research Center, Inc.

ROW A CELL 4

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BA4F



<Min Value>
-95283.98 N at 33.12 ms

<Max Value>
1335.20 N at 23.12 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

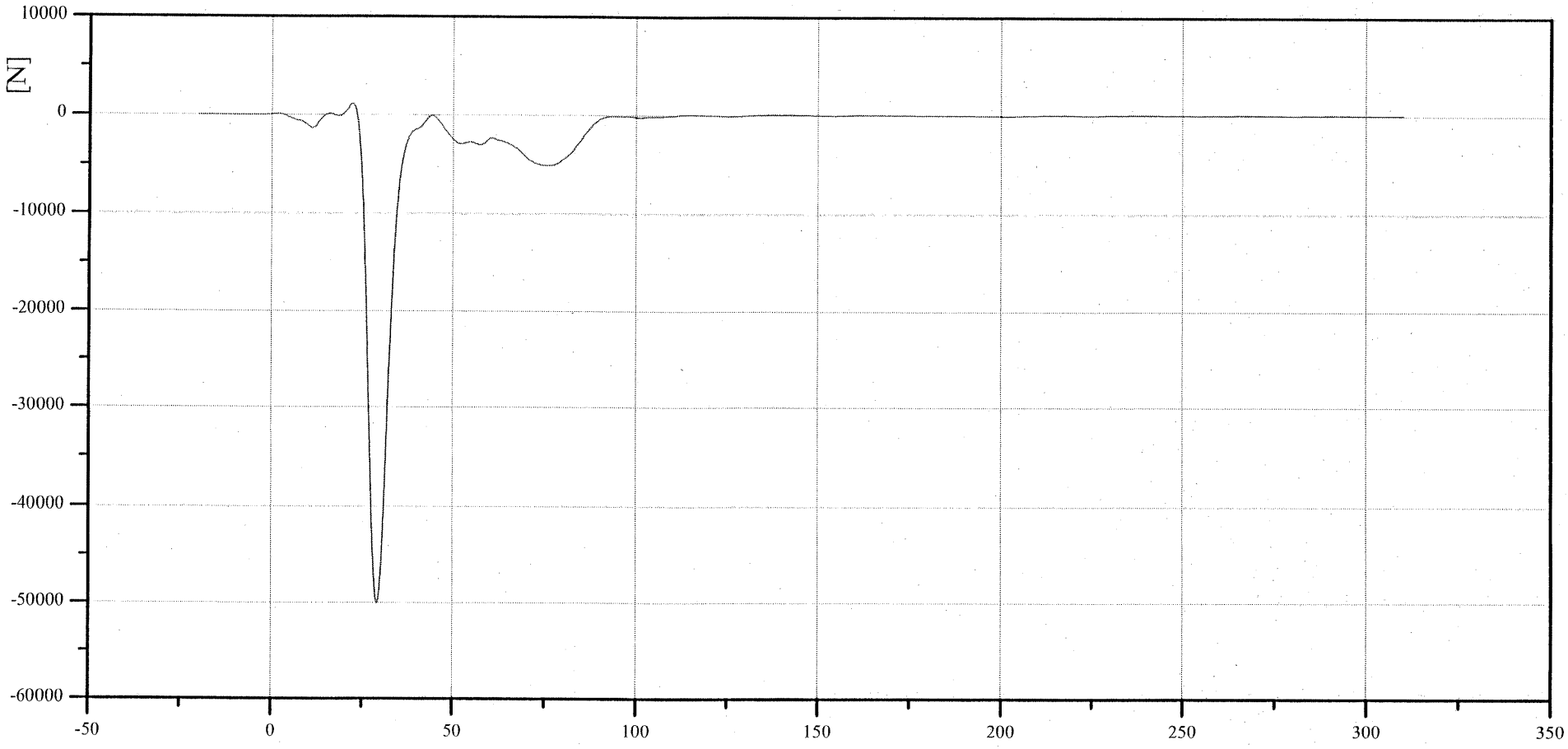
Transportation Research Center, Inc.

ROW A CELL 5

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BA5F



<Min Value>
-50078.11 N at 29.12 ms

<Max Value>
1136.41 N at 22.24 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

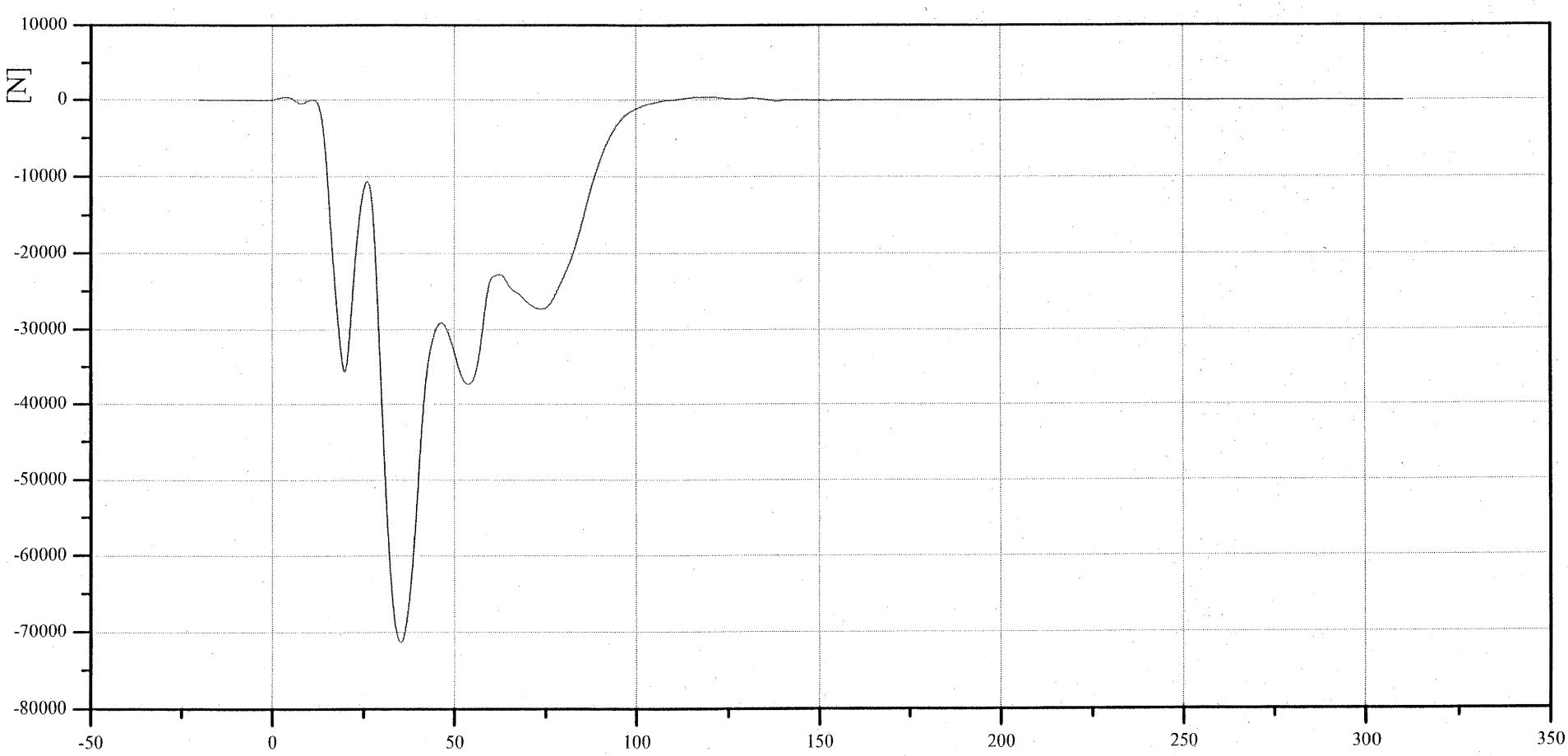
Transportation Research Center, Inc.

ROW A CELL 6

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BA6F



<Min Value>
-71411.64 N at 35.28 ms

<Max Value>
378.36 N at 3.76 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

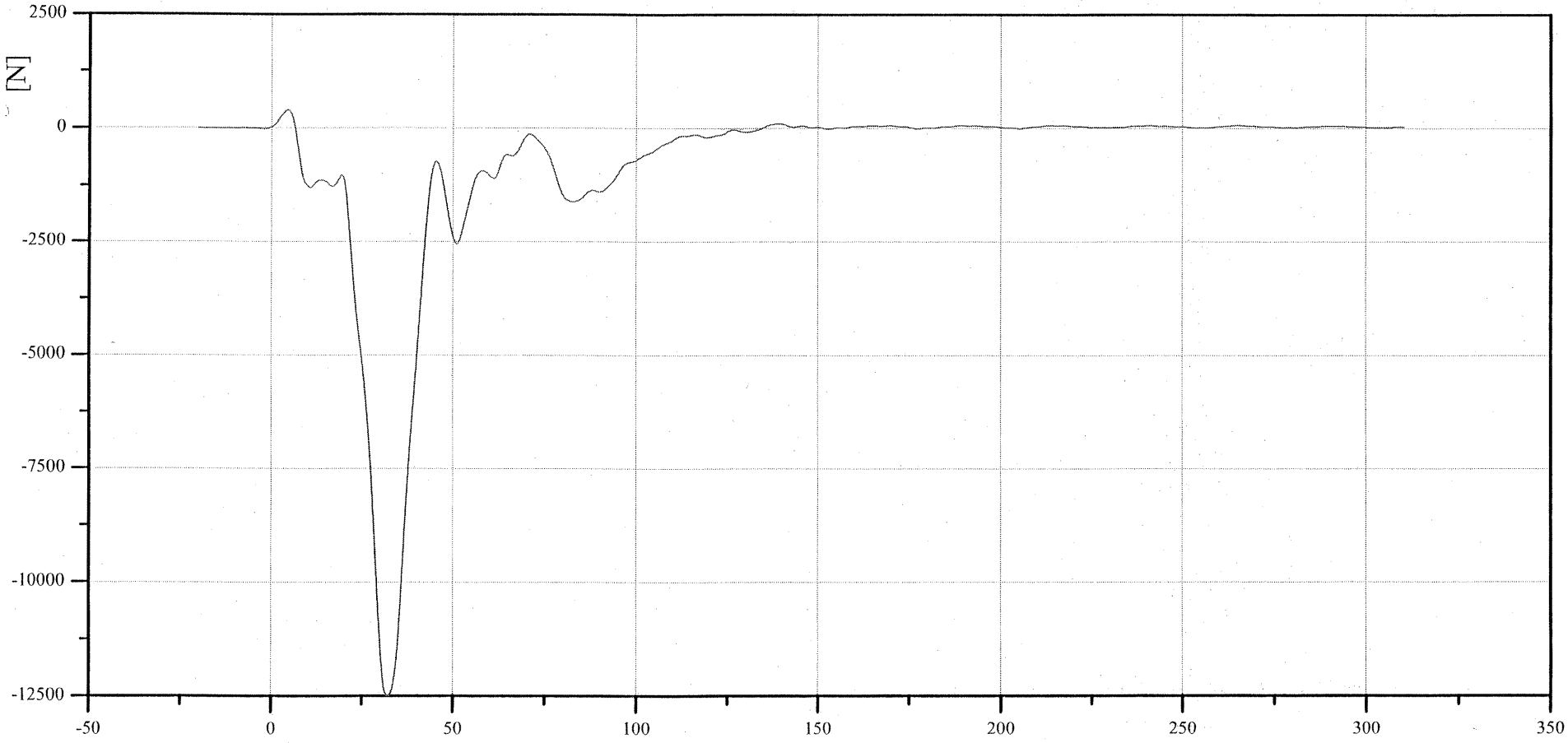
Transportation Research Center, Inc.

ROW A CELL 7

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BA7F



<Min Value>
-12483.91 N at 32.08 ms

<Max Value>
398.45 N at 4.40 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

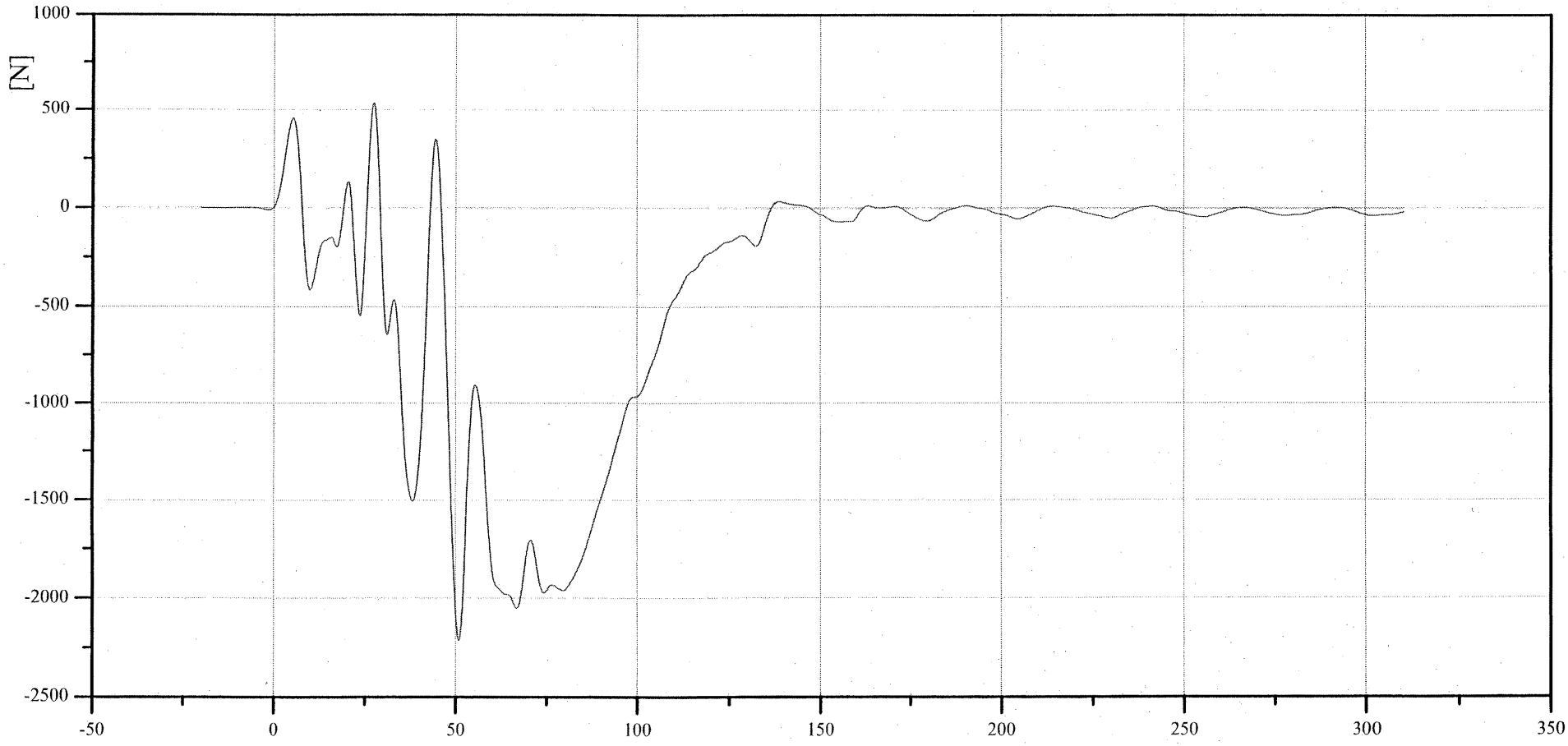
Transportation Research Center, Inc.

ROW A CELL 8

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BA8F



<Min Value>
-2215.37 N at 50.88 ms

<Max Value>
533.13 N at 27.44 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

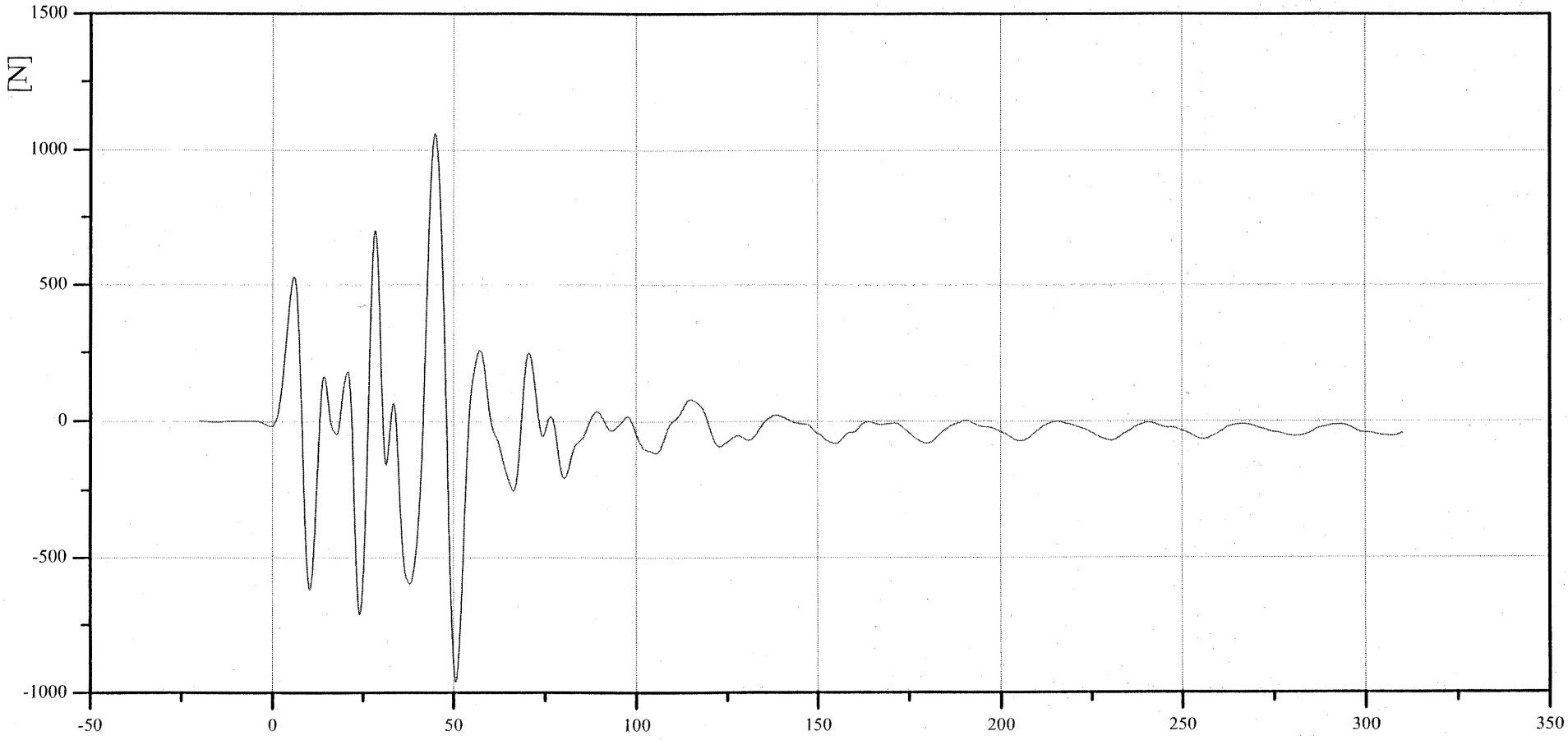
Transportation Research Center, Inc.

ROW A CELL 9

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BA9F



<Min Value>
-957.04 N at 50.56 ms

<Max Value>
1058.12 N at 45.04 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

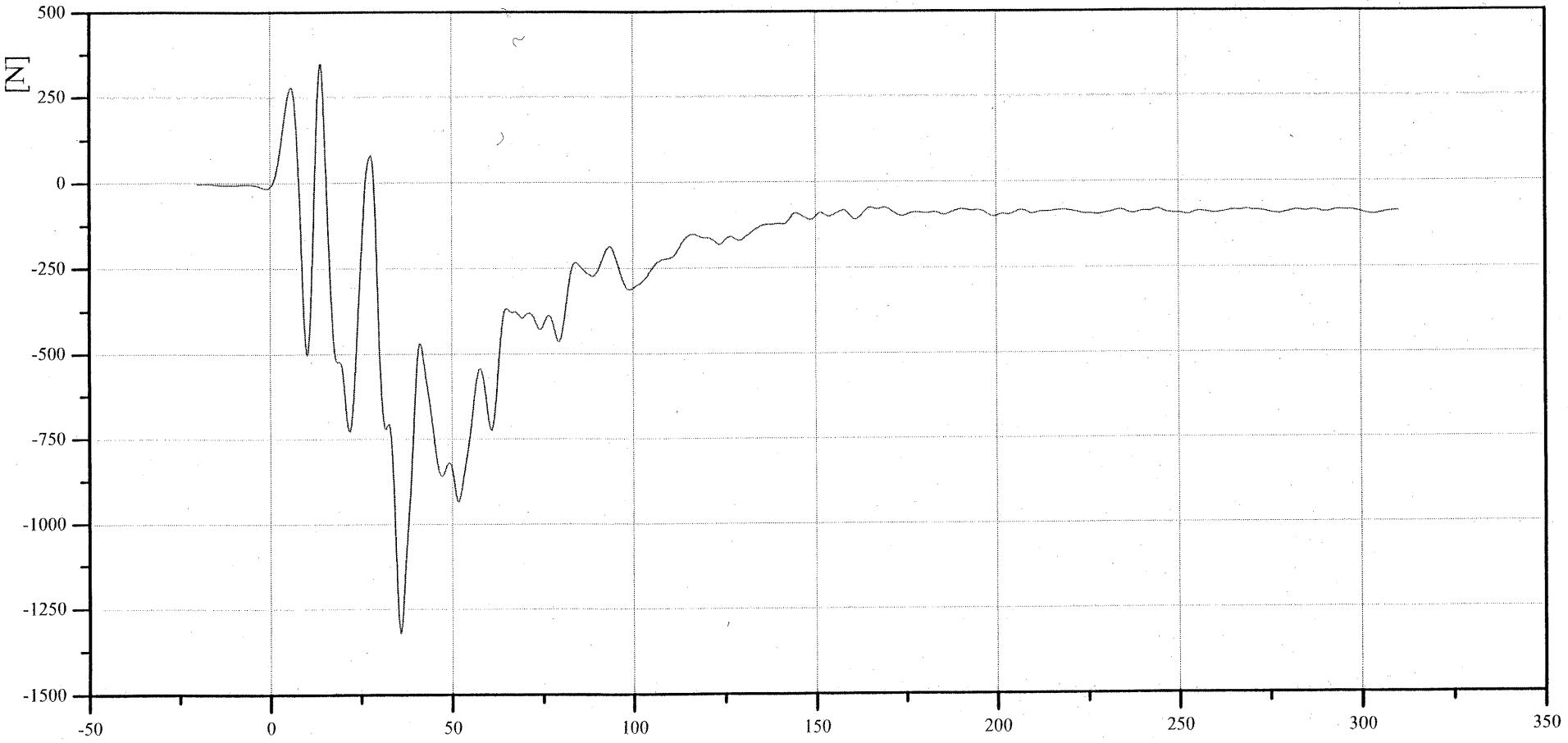
Transportation Research Center, Inc.

ROW B CELL 1

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BB1F



<Min Value>
-1320.79 N at 35.76 ms

<Max Value>
346.96 N at 13.84 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

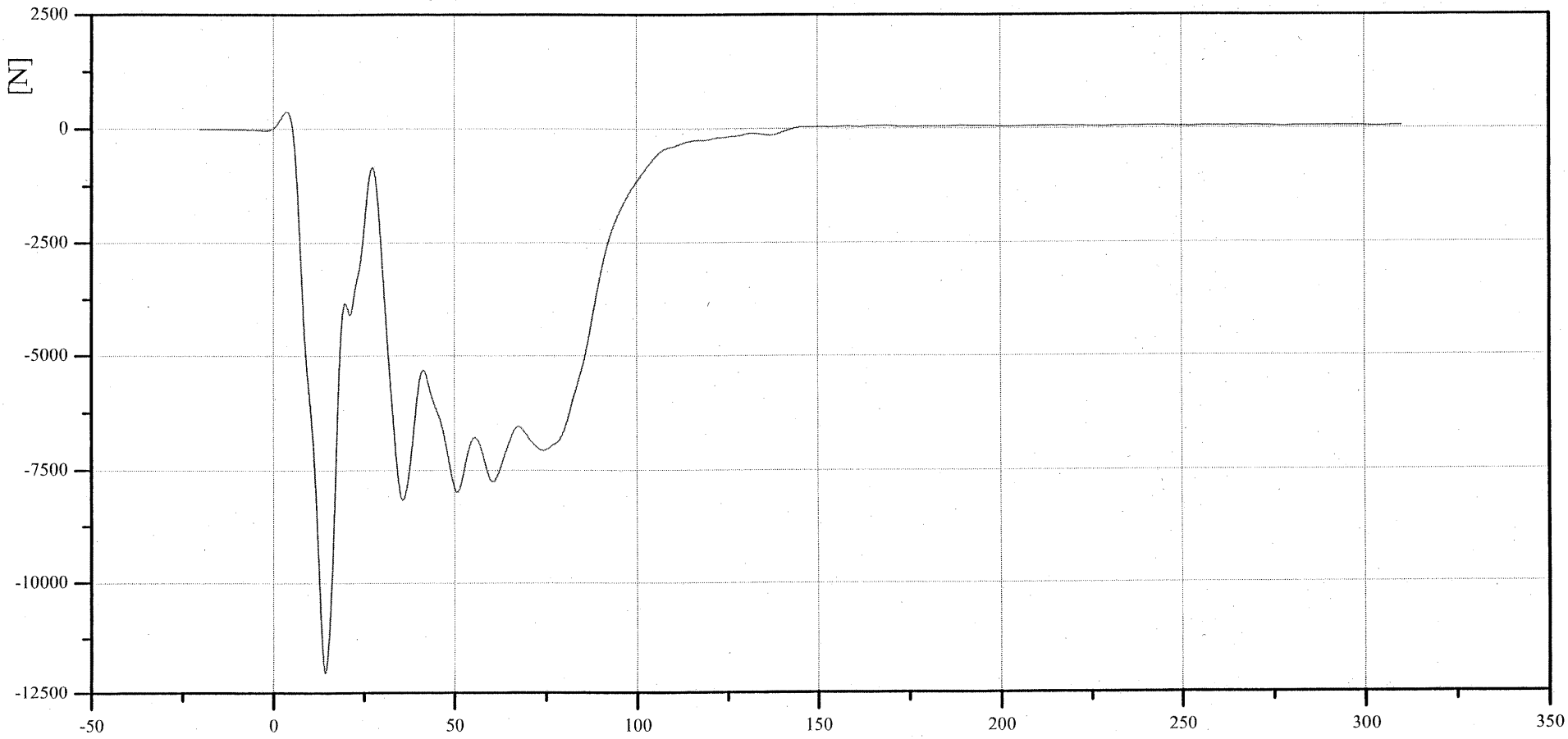
Transportation Research Center, Inc.

ROW B CELL 2

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BB2F



<Min Value>
-12026.28 N at 14.24 ms

<Max Value>
375.22 N at 3.68 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

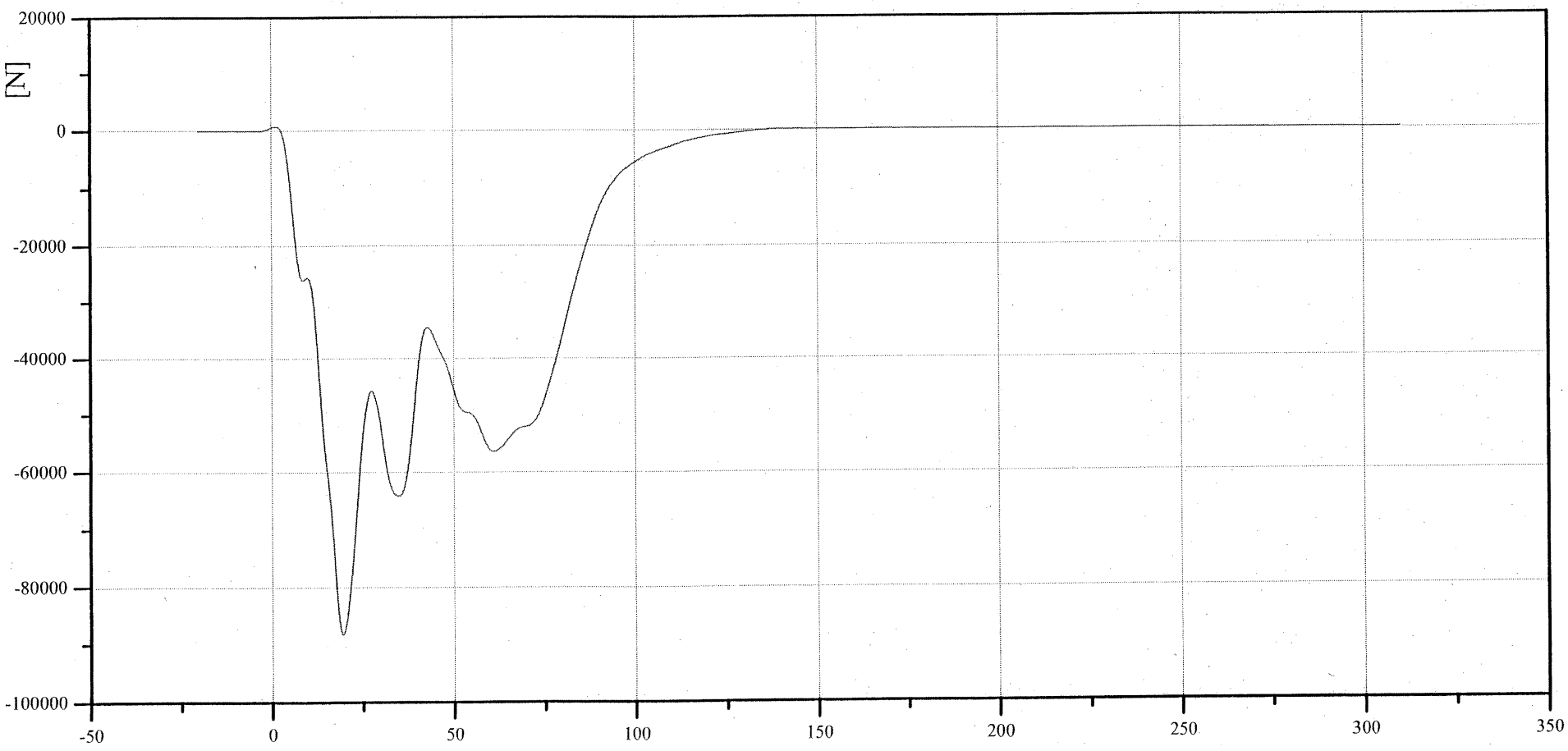
Transportation Research Center, Inc.

ROW B CELL 3

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BB3F



<Min Value>
-88282.78 N at 19.36 ms

<Max Value>
788.15 N at 1.20 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

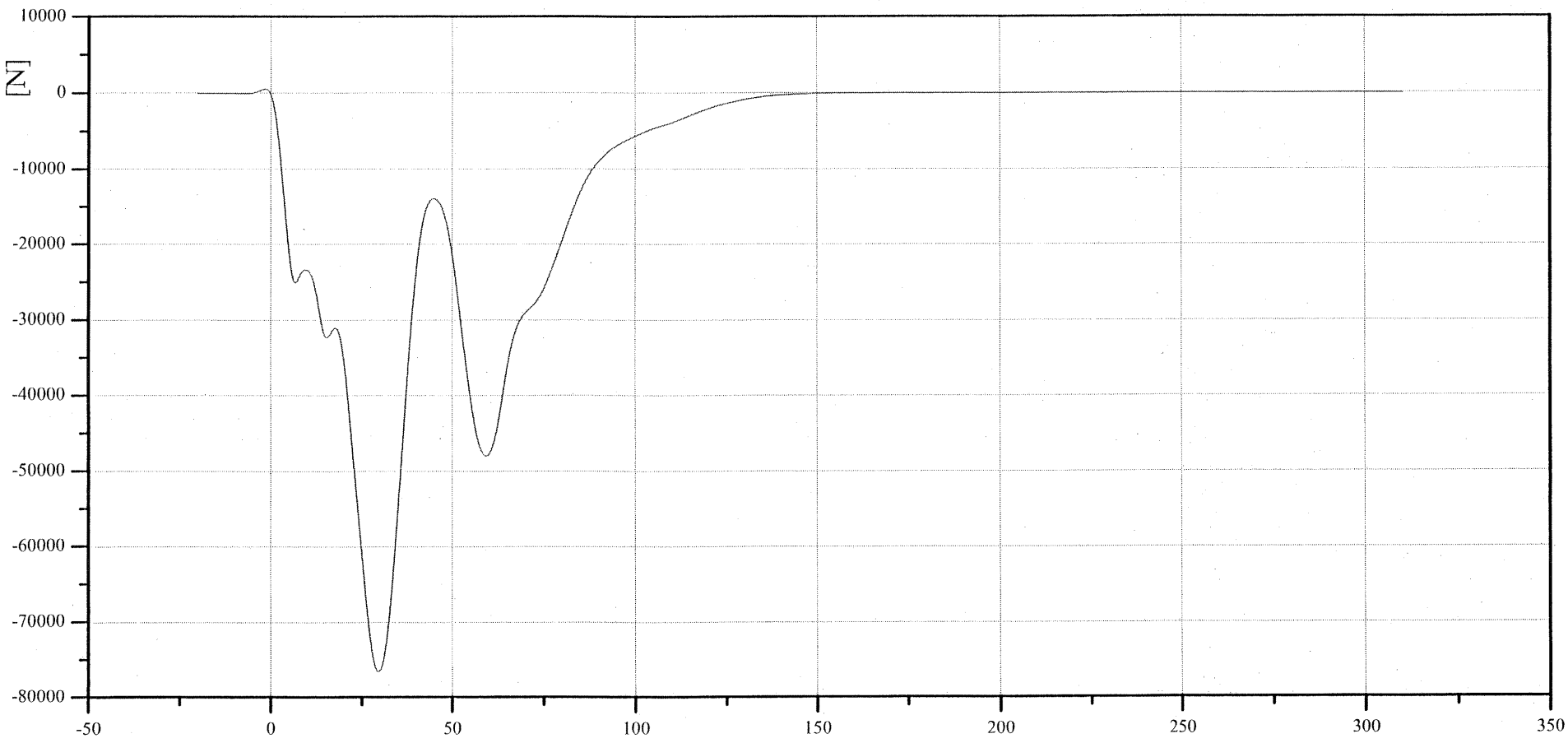
Transportation Research Center, Inc.

ROW B CELL 4

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BB4F



<Min Value>
-76623.13 N at 29.60 ms

<Max Value>
553.72 N at -1.60 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

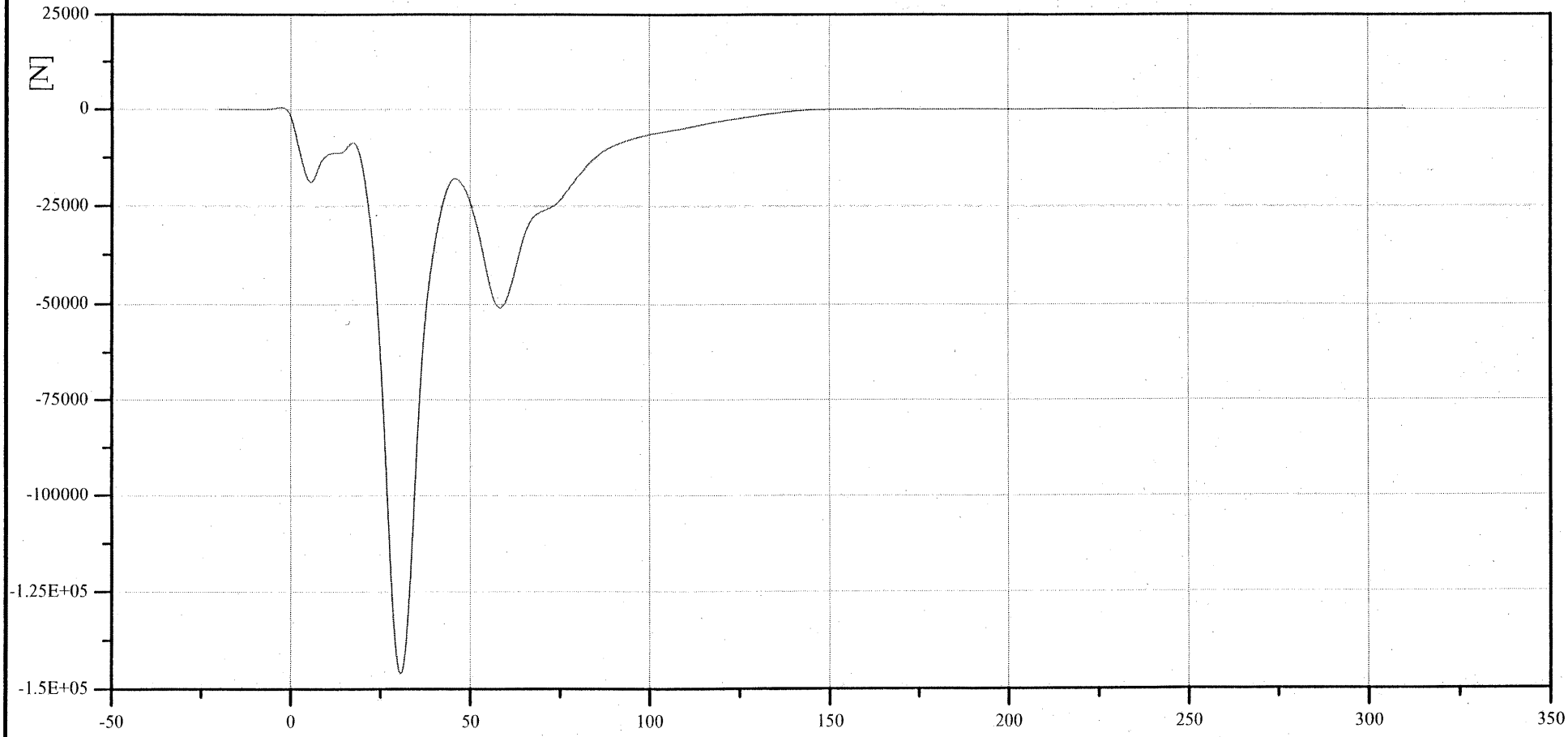
Transportation Research Center, Inc.

ROW B CELL 5

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BB5F



<Min Value>
-145954.07 N at 30.56 ms

<Max Value>
472.05 N at -2.72 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

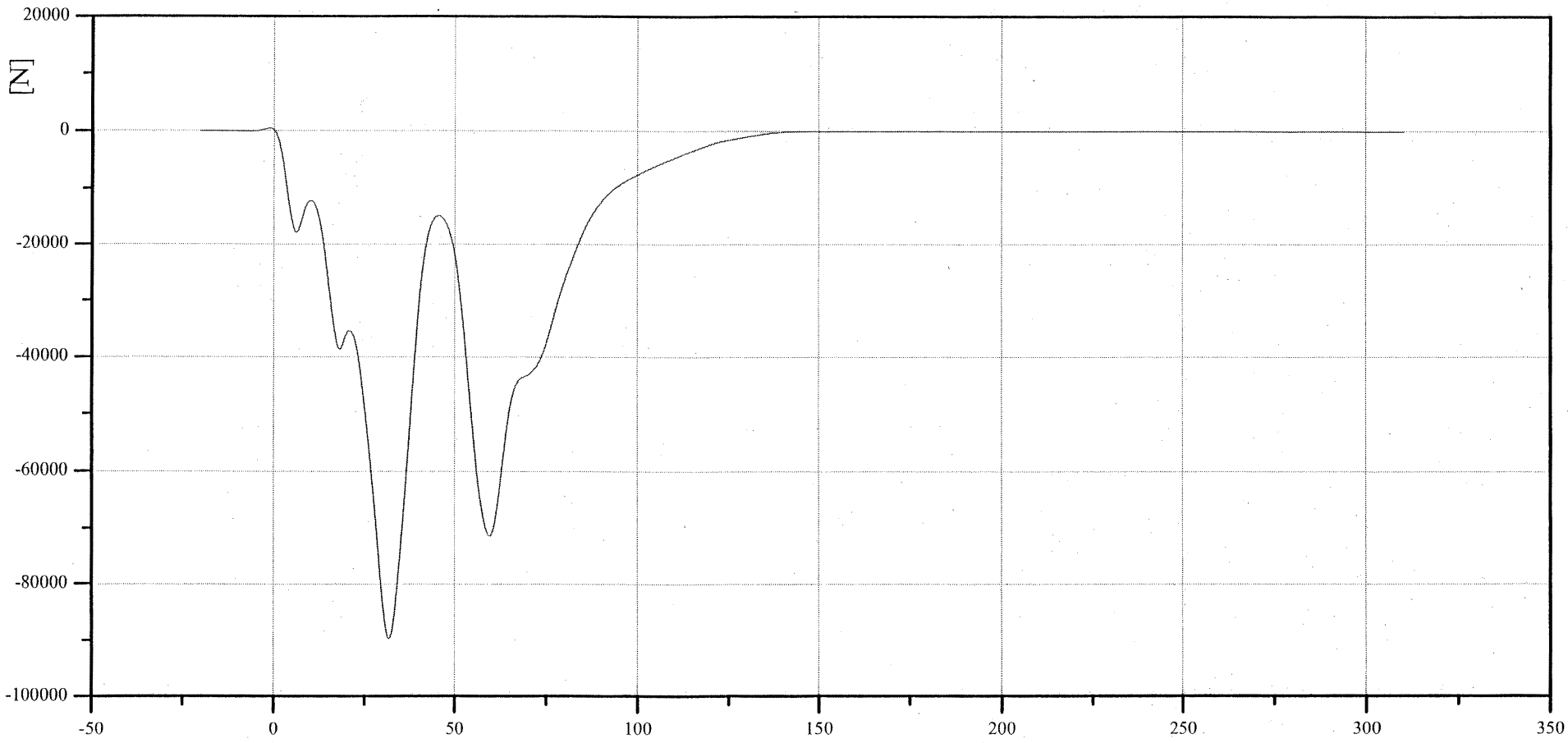
Transportation Research Center, Inc.

ROW B CELL 6

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BB6F



<Min Value>
-89730.13 N at 31.84 ms

<Max Value>
479.04 N at -1.20 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

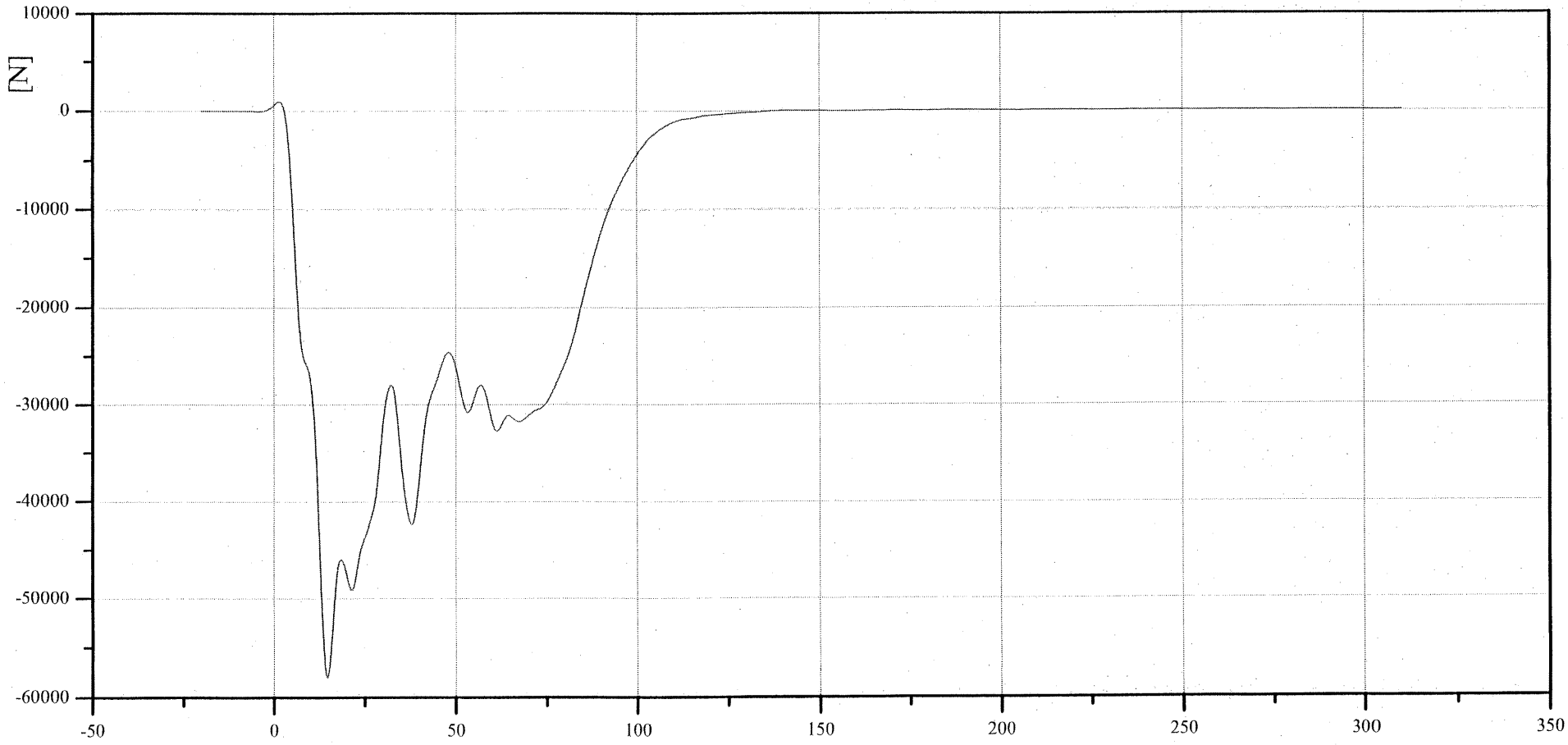
Transportation Research Center, Inc.

ROW B CELL 7

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BB7F



<Min Value>
-57924.68 N at 14.64 ms

<Max Value>
948.41 N at 1.44 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

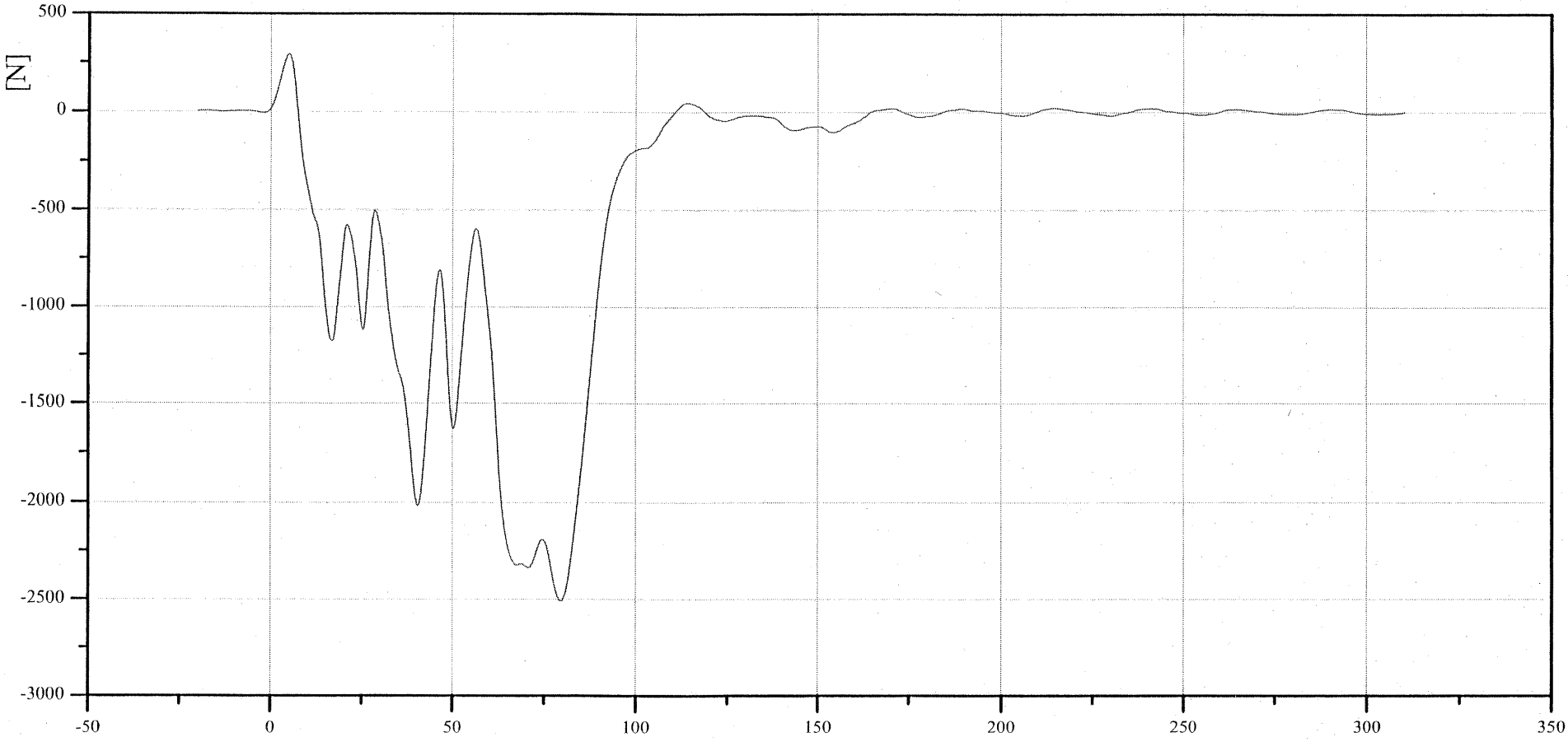
Transportation Research Center, Inc.

ROW B CELL 8

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BB8F



<Min Value>
-2508.81 N at 79.68 ms

<Max Value>
290.22 N at 4.88 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

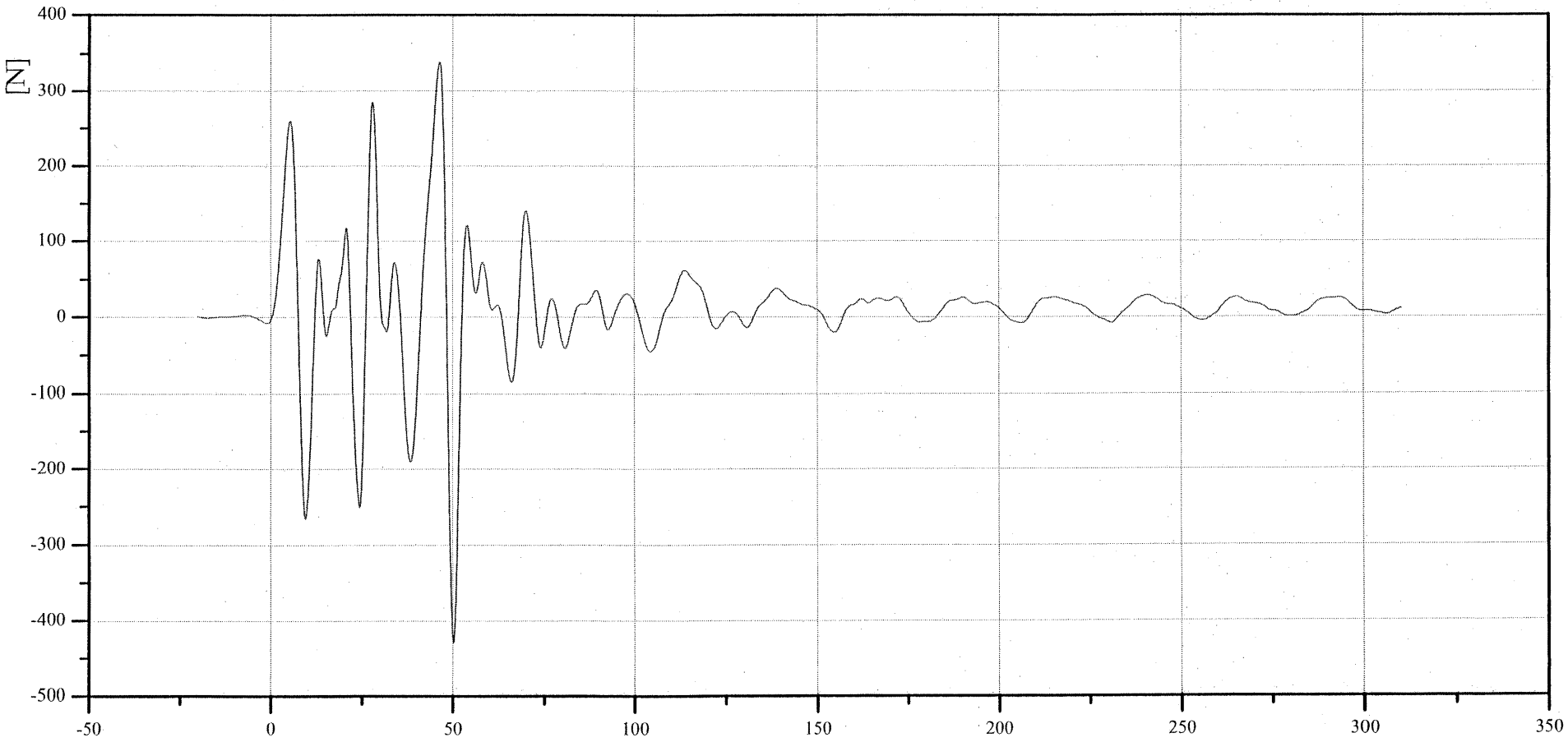
Transportation Research Center, Inc.

ROW B CELL 9

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BB9F



<Min Value>
-429.87 N at 50.24 ms

<Max Value>
338.35 N at 46.32 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

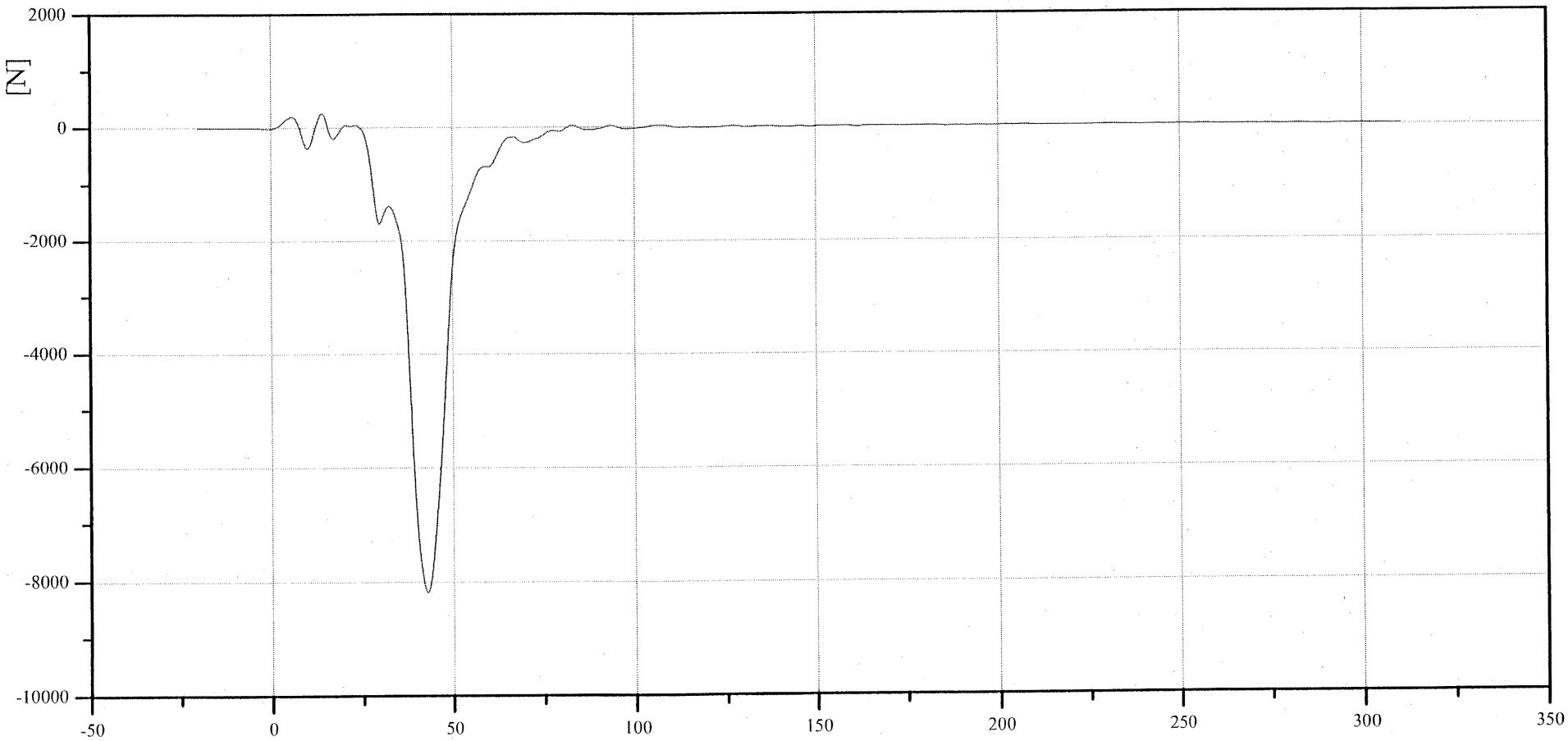
Transportation Research Center, Inc.

ROW C CELL 1

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BC1F



<Min Value>
-8197.48 N at 42.88 ms

<Max Value>
256.58 N at 13.92 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

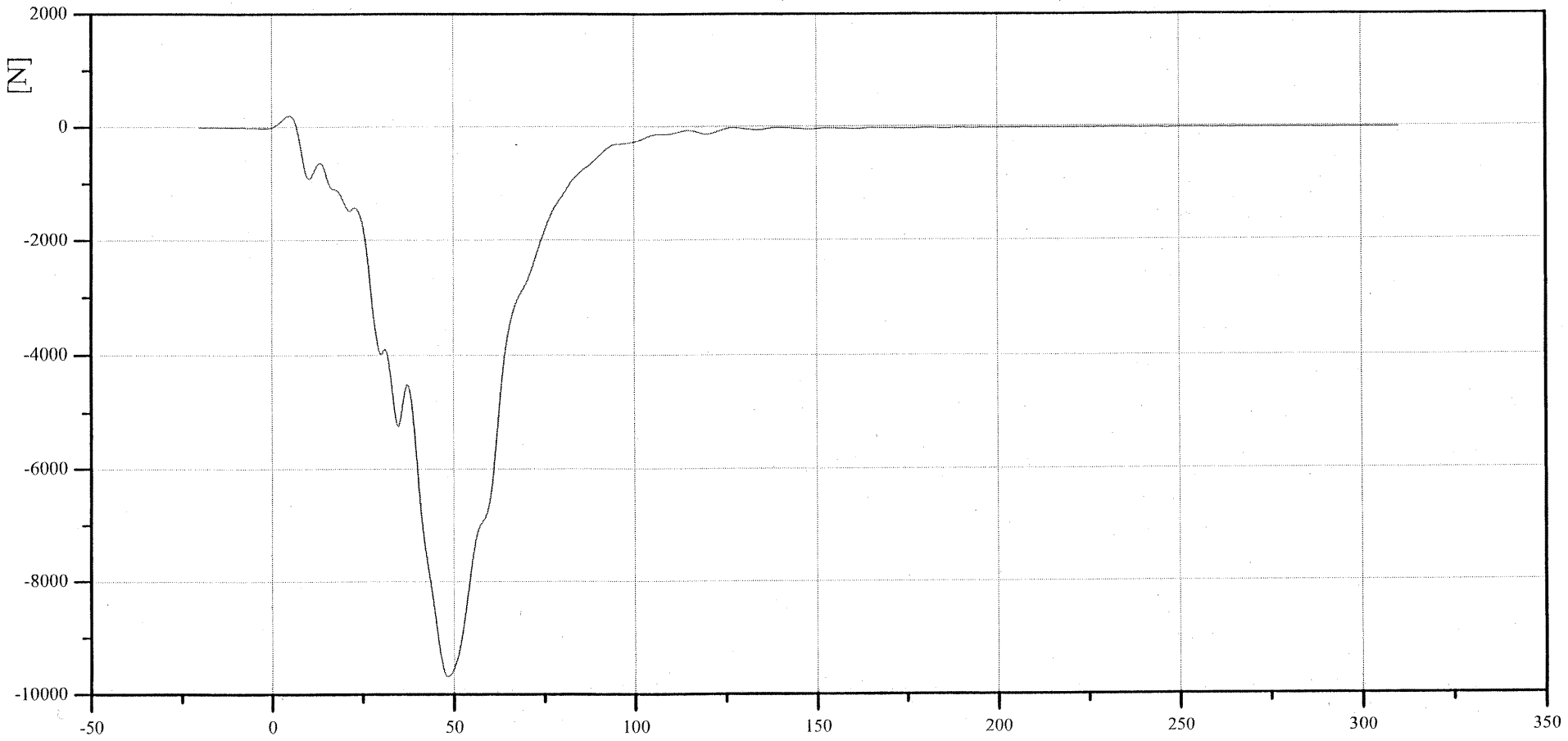
Transportation Research Center, Inc.

ROW C CELL 2

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BC2F



<Min Value>
-9674.01 N at 48.32 ms

<Max Value>
201.95 N at 4.80 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

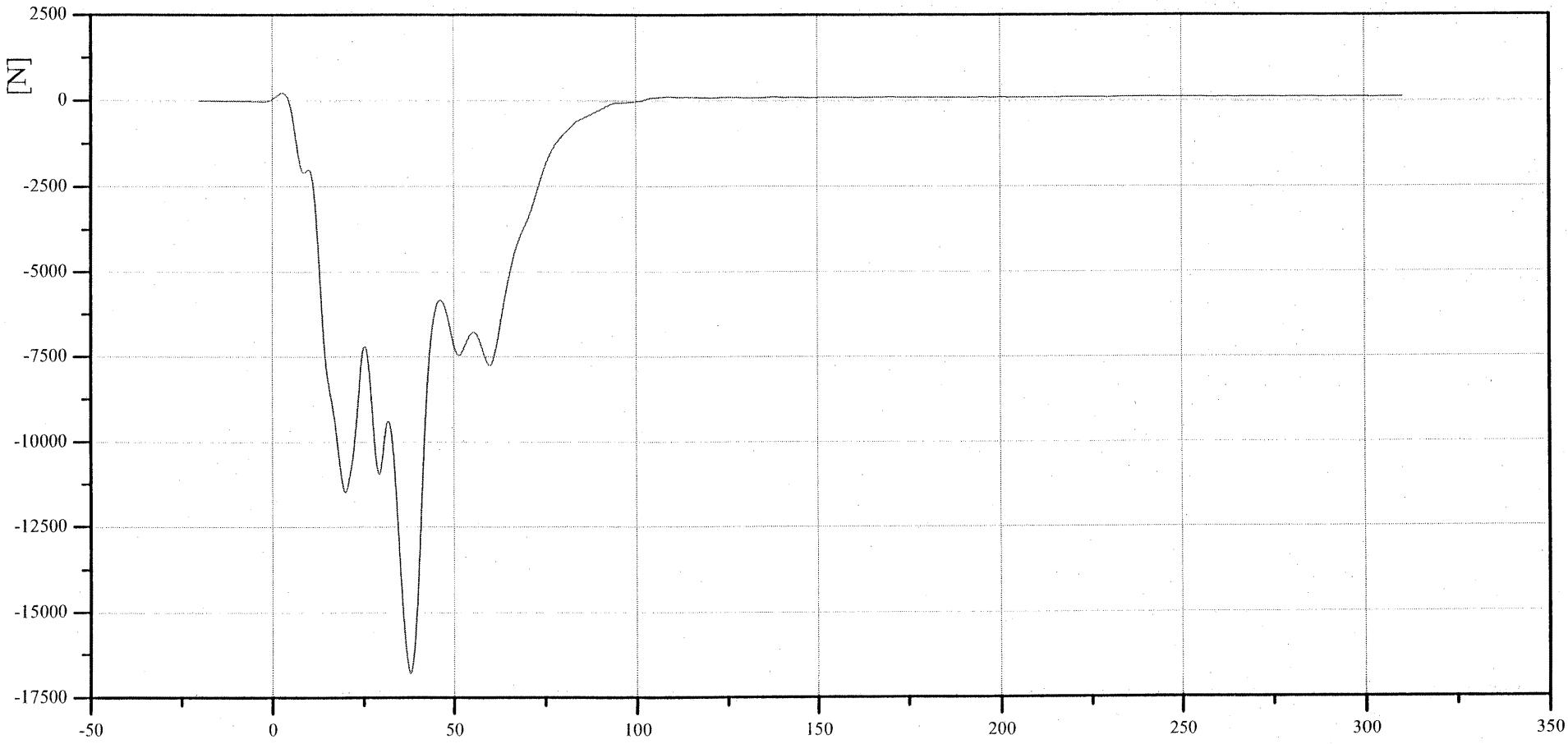
Transportation Research Center, Inc.

ROW C CELL 3

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BC3F



<Min Value>
-16799.06 N at 38.00 ms

<Max Value>
227.53 N at 2.72 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

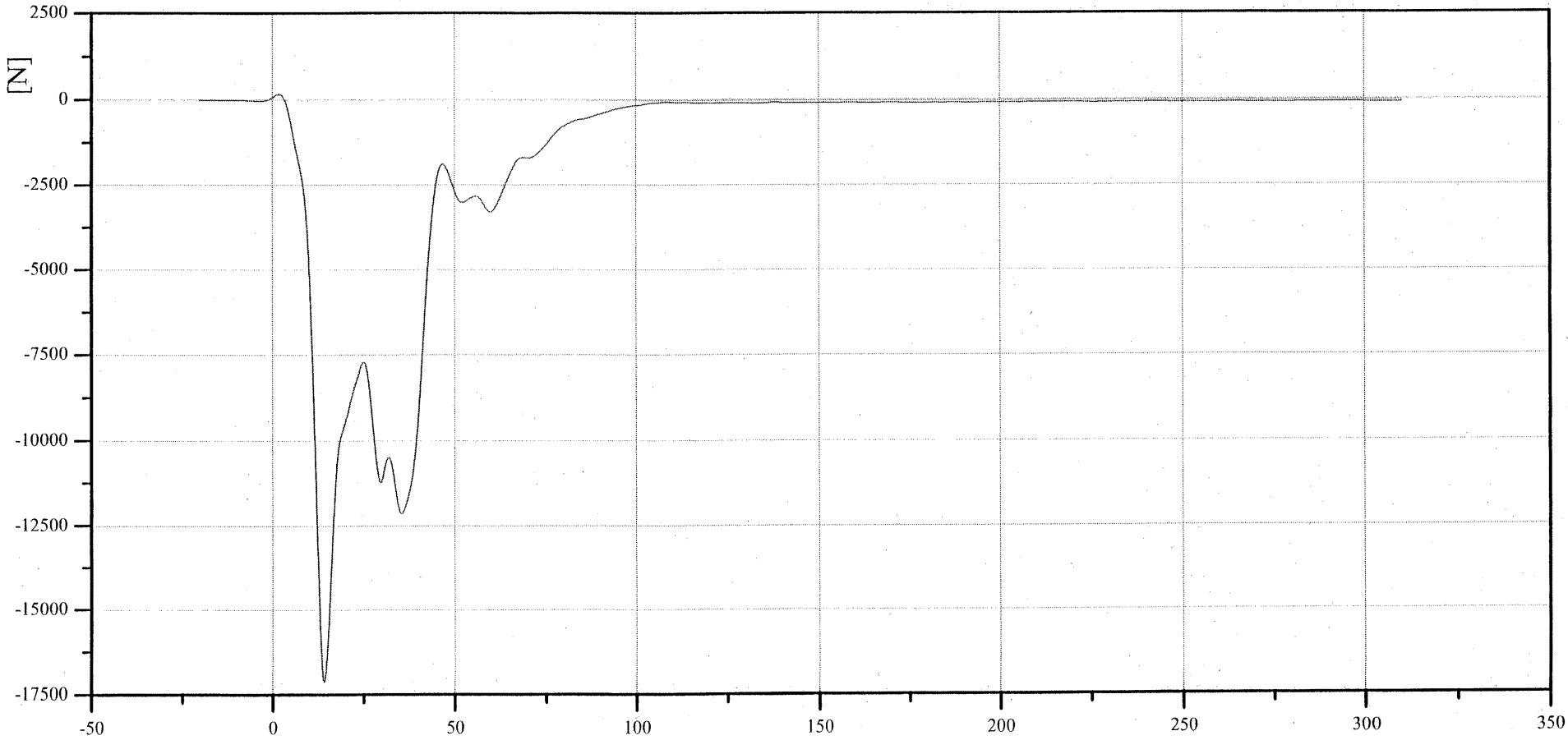
Transportation Research Center, Inc.

ROW C CELL 4

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BC4F



<Min Value>
-17126.73 N at 14.08 ms

<Max Value>
161.41 N at 1.84 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

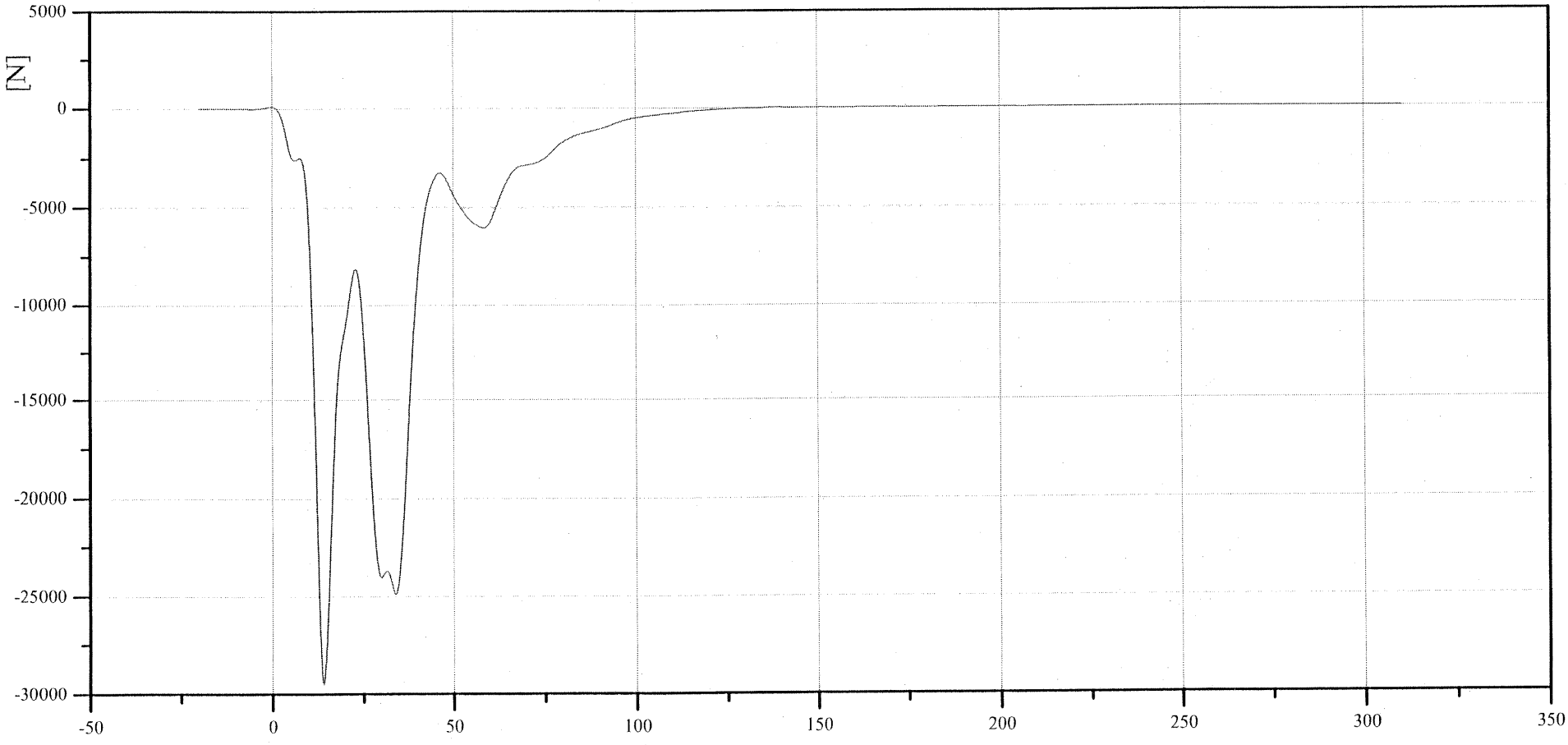
Transportation Research Center, Inc.

ROW C CELL 5

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BC5F



<Min Value>
-29453.38 N at 13.92 ms

<Max Value>
99.85 N at -0.16 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

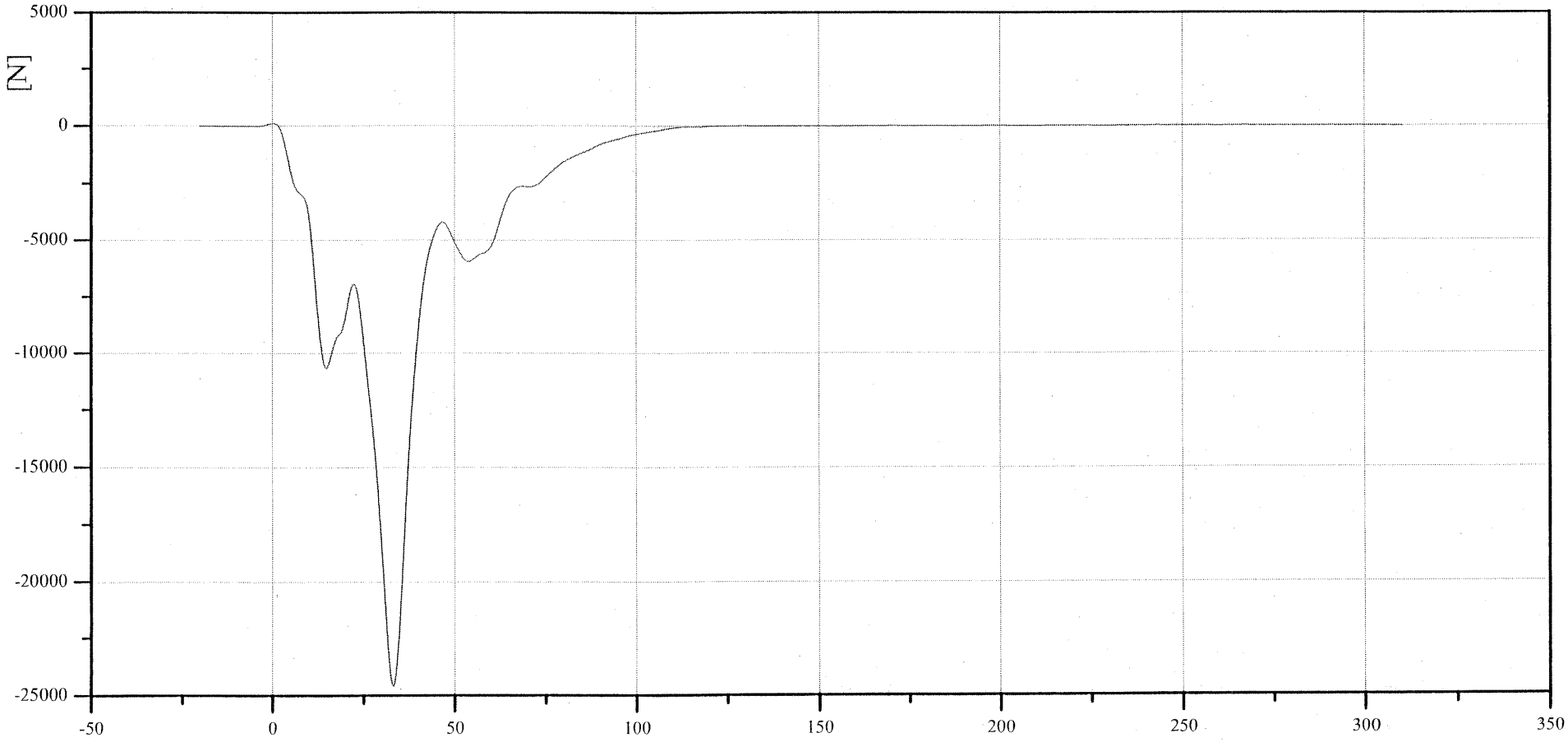
Transportation Research Center, Inc.

ROW C CELL 6

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BC6F



<Min Value>
-24570.33 N at 33.12 ms

<Max Value>
116.56 N at 0.24 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

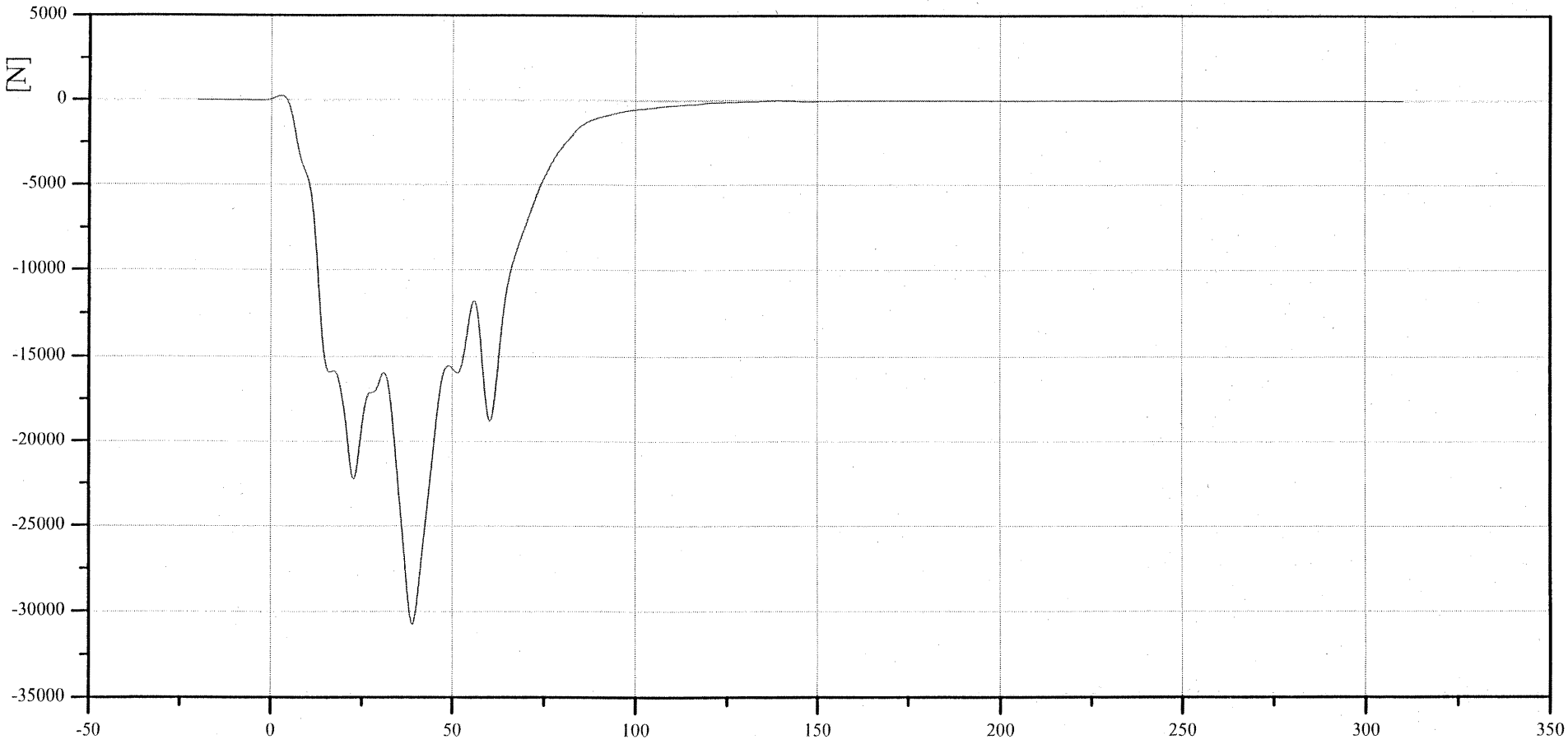
Transportation Research Center, Inc.

ROW C CELL 7

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BC7F



<Min Value>
-30754.46 N at 38.96 ms

<Max Value>
258.90 N at 2.72 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

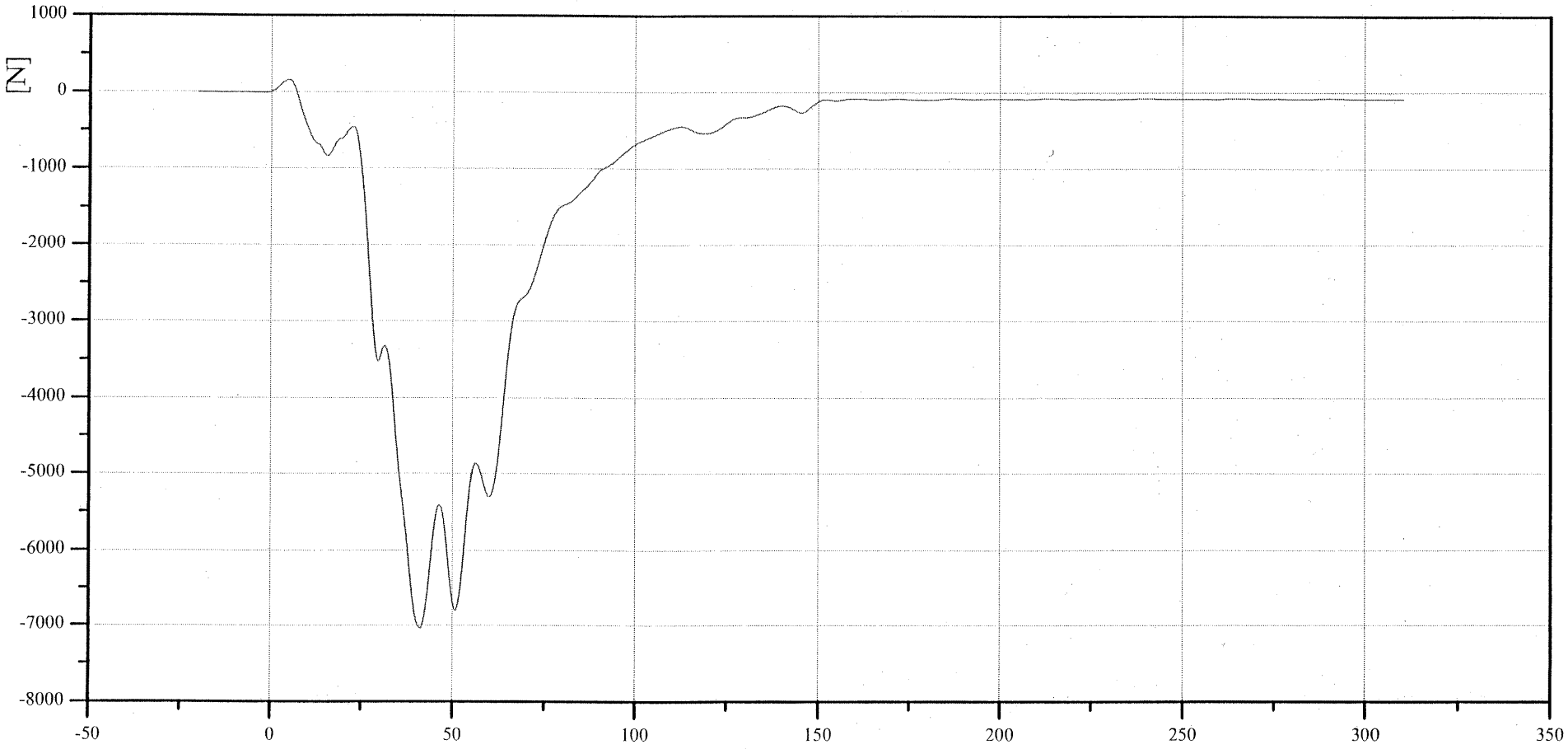
Transportation Research Center, Inc.

ROW C CELL 8

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BC8F



<Min Value>
-7043.52 N at 41.12 ms

<Max Value>
163.71 N at 4.88 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

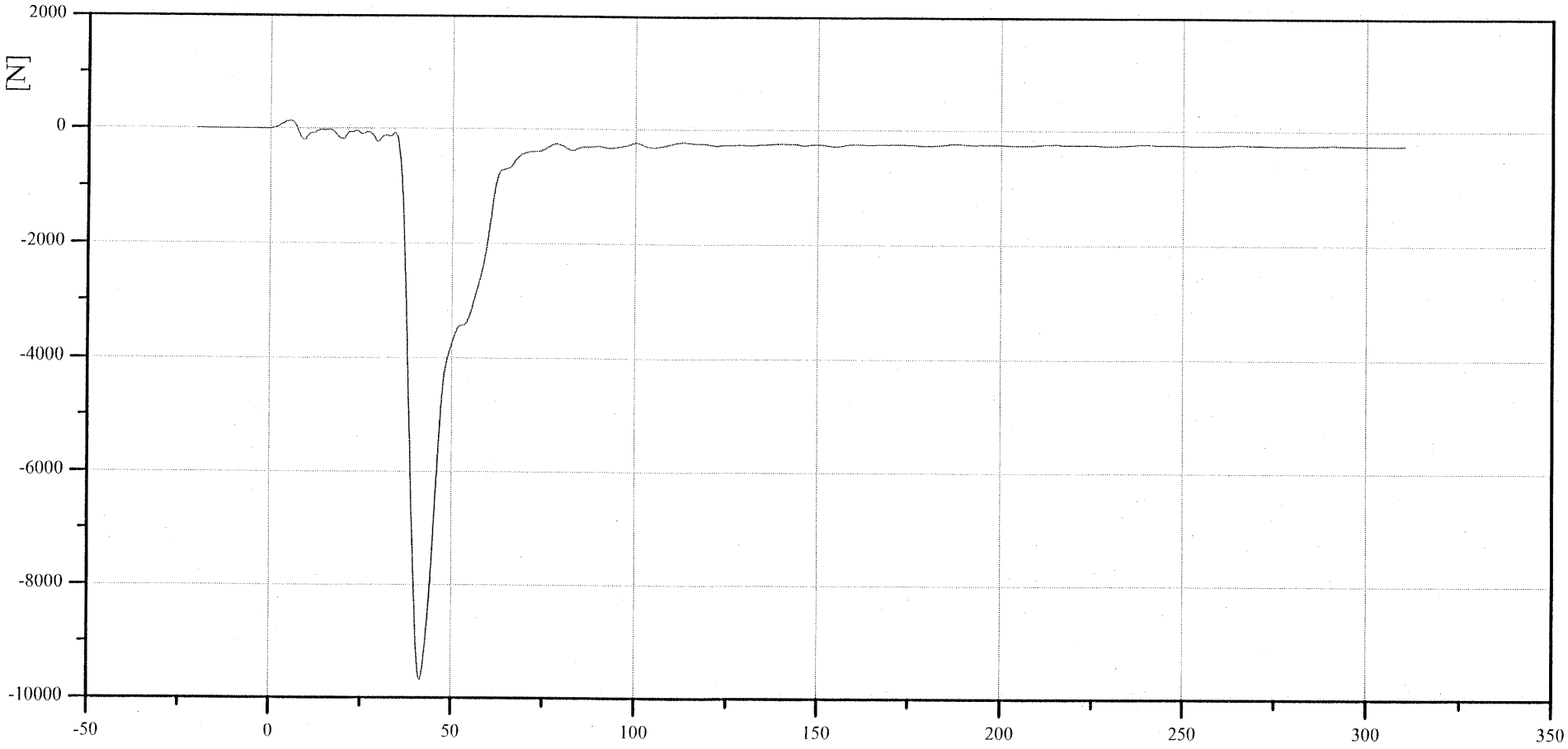
Transportation Research Center, Inc.

ROW C CELL 9

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BC9F



<Min Value>
-9676.92 N at 41.52 ms

<Max Value>
134.04 N at 5.28 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

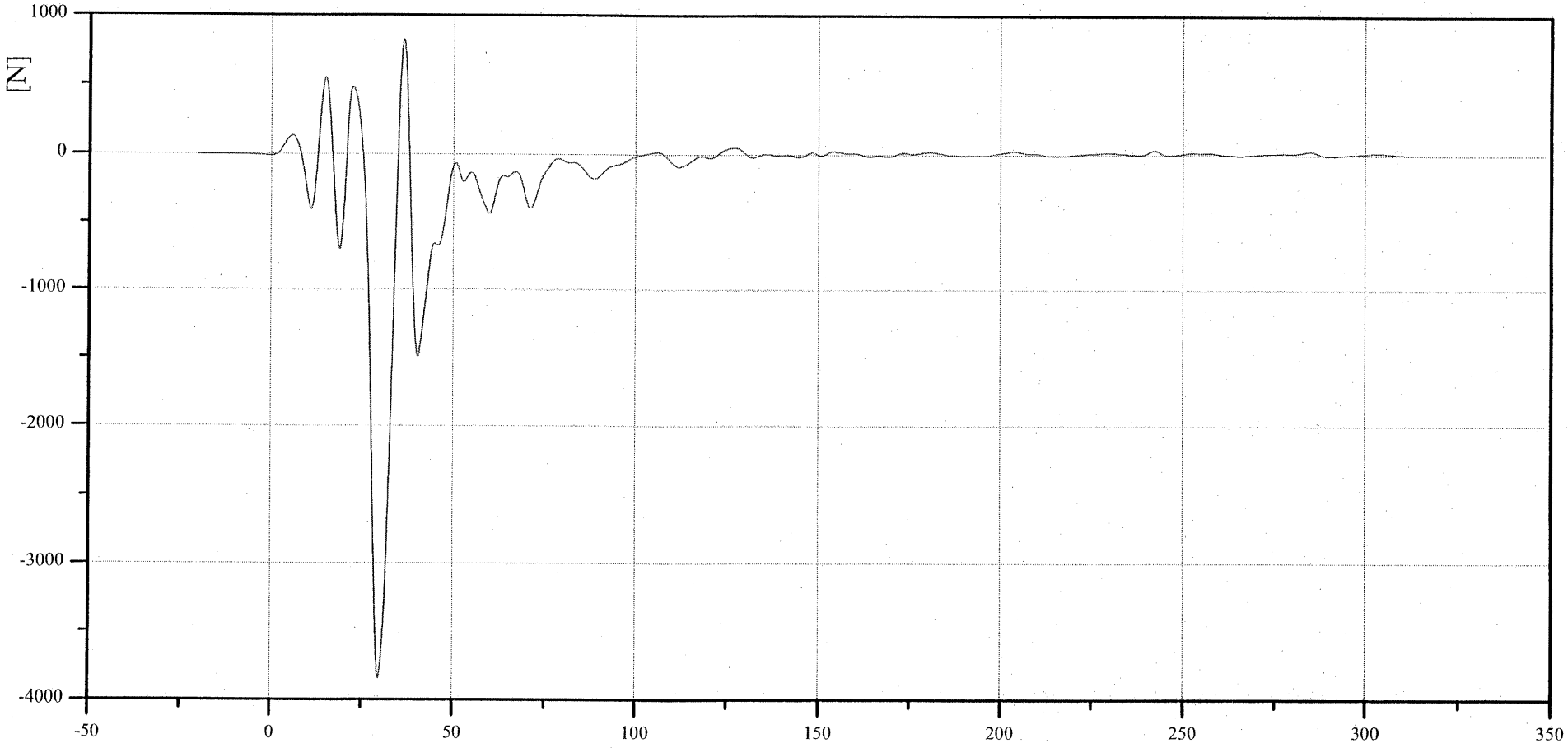
Transportation Research Center, Inc.

ROW D CELL 1

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BD1F



<Min Value>
-3843.14 N at 29.68 ms

<Max Value>
823.57 N at 36.24 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

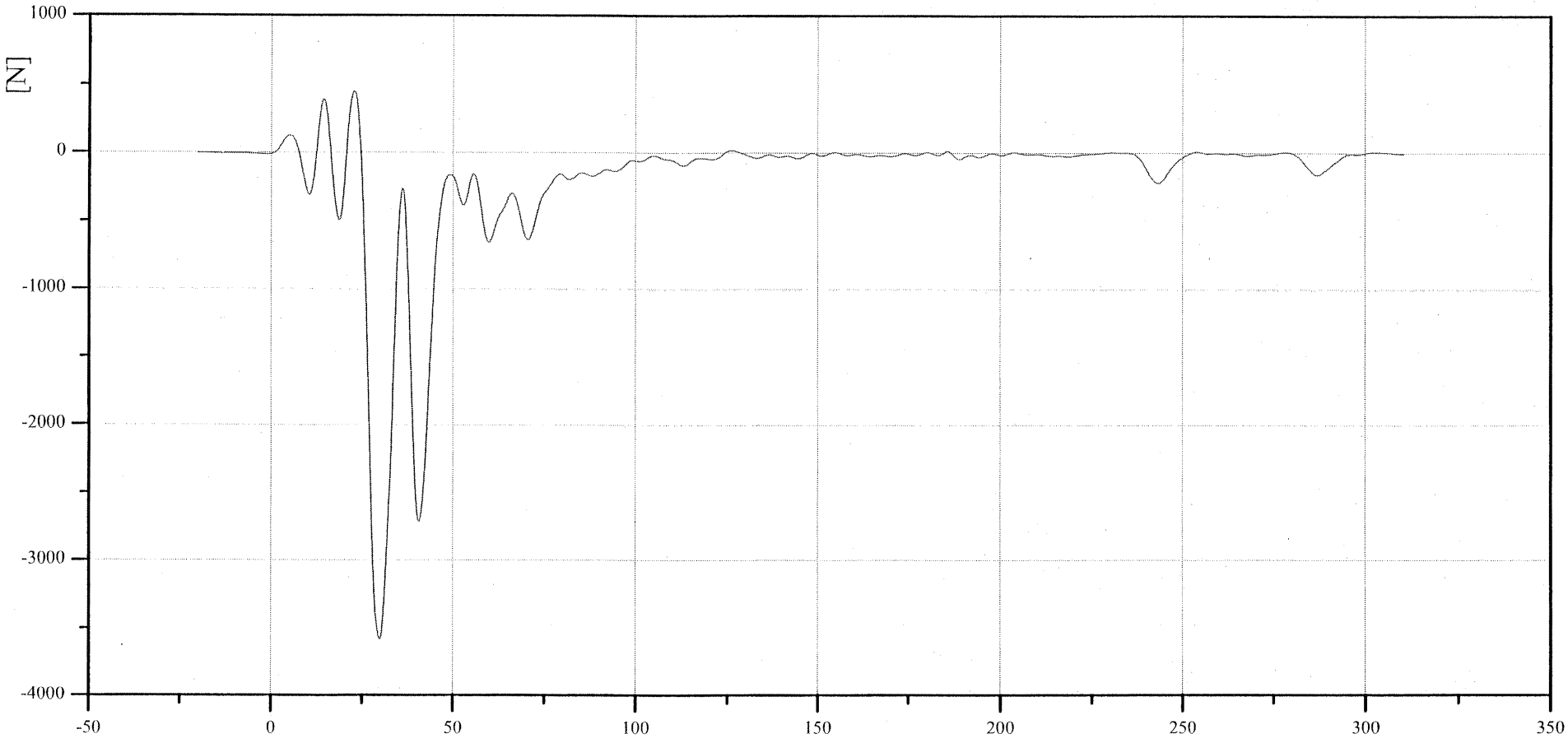
Transportation Research Center, Inc.

ROW D CELL 2

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BD2F



<Min Value>
-3577.18 N at 29.92 ms

<Max Value>
448.35 N at 22.72 ms

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

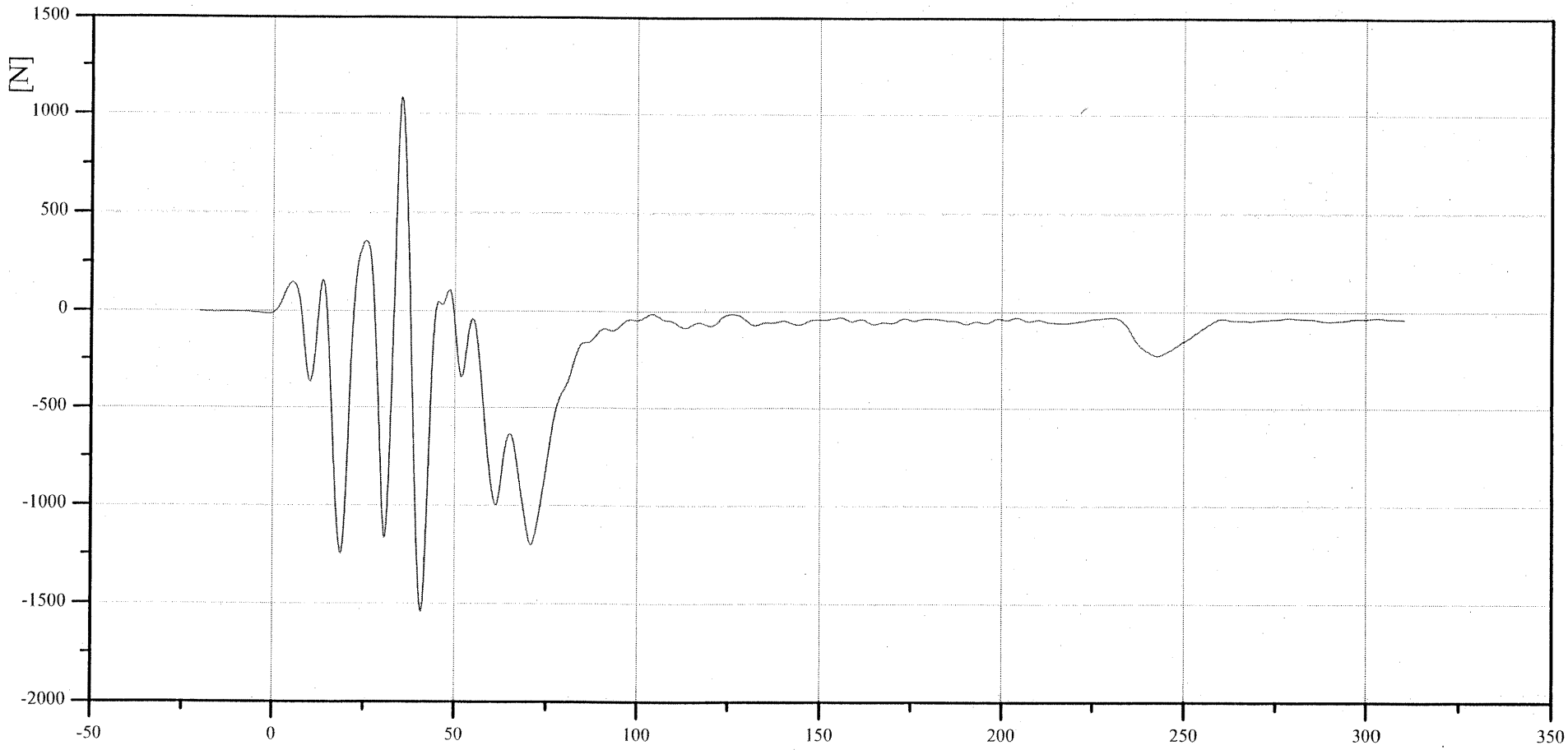
Transportation Research Center, Inc.

ROW D CELL 3

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BD3F



<Min Value>
-1540.97 N at 40.88 ms

<Max Value>
1082.01 N at 35.28 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

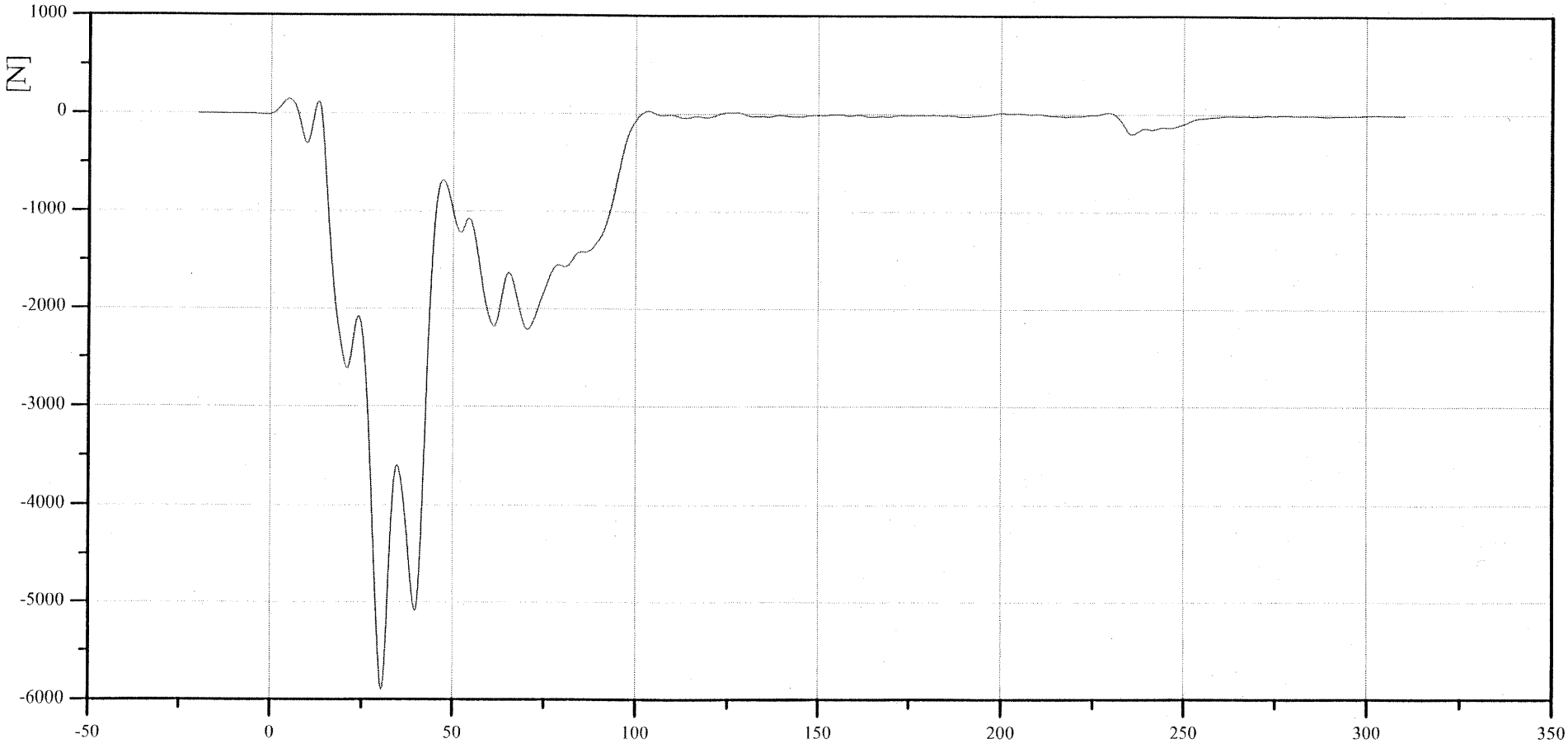
Transportation Research Center, Inc.

ROW D CELL 4

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BD4F



<Min Value>
-5893.83 N at 30.48 ms

<Max Value>
142.11 N at 4.96 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

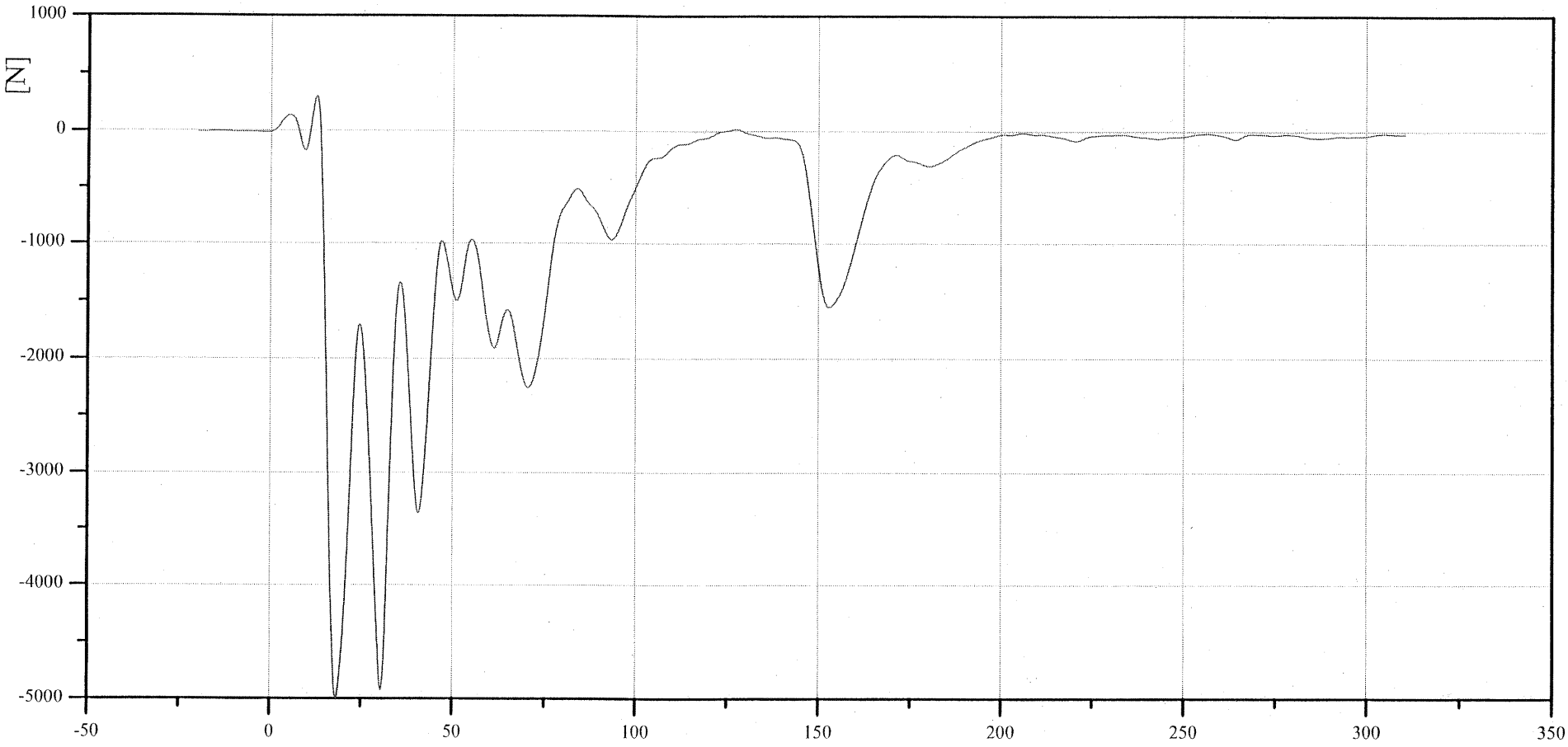
Transportation Research Center, Inc.

ROW D CELL 5

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BD5F



<Min Value>
-4997.07 N at 18.24 ms

<Max Value>
302.86 N at 12.56 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

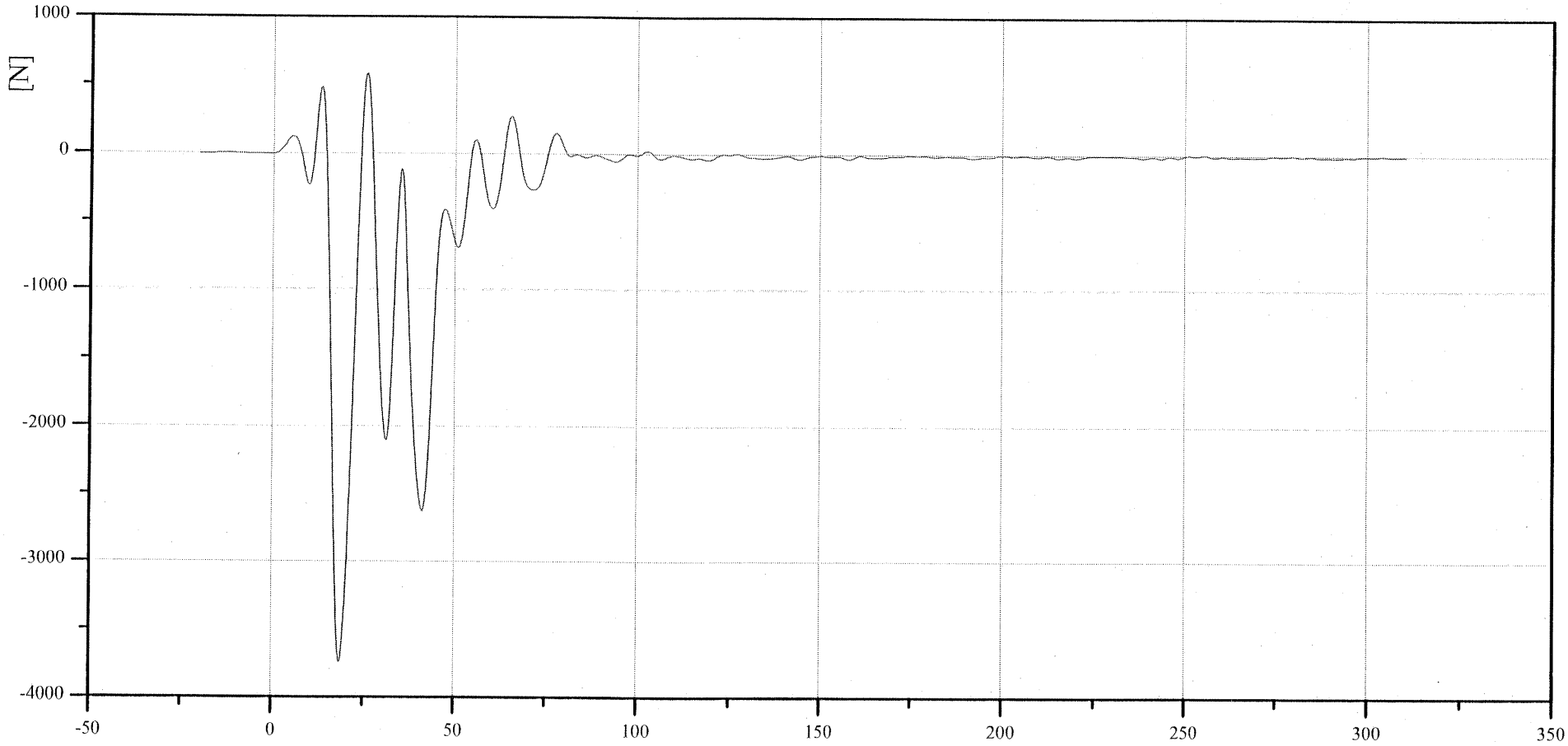
Transportation Research Center, Inc.

ROW D CELL 6

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BD6F



CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

<Min Value>
-3743.84 N at 18.64 ms

<Max Value>
577.86 N at 25.52 ms

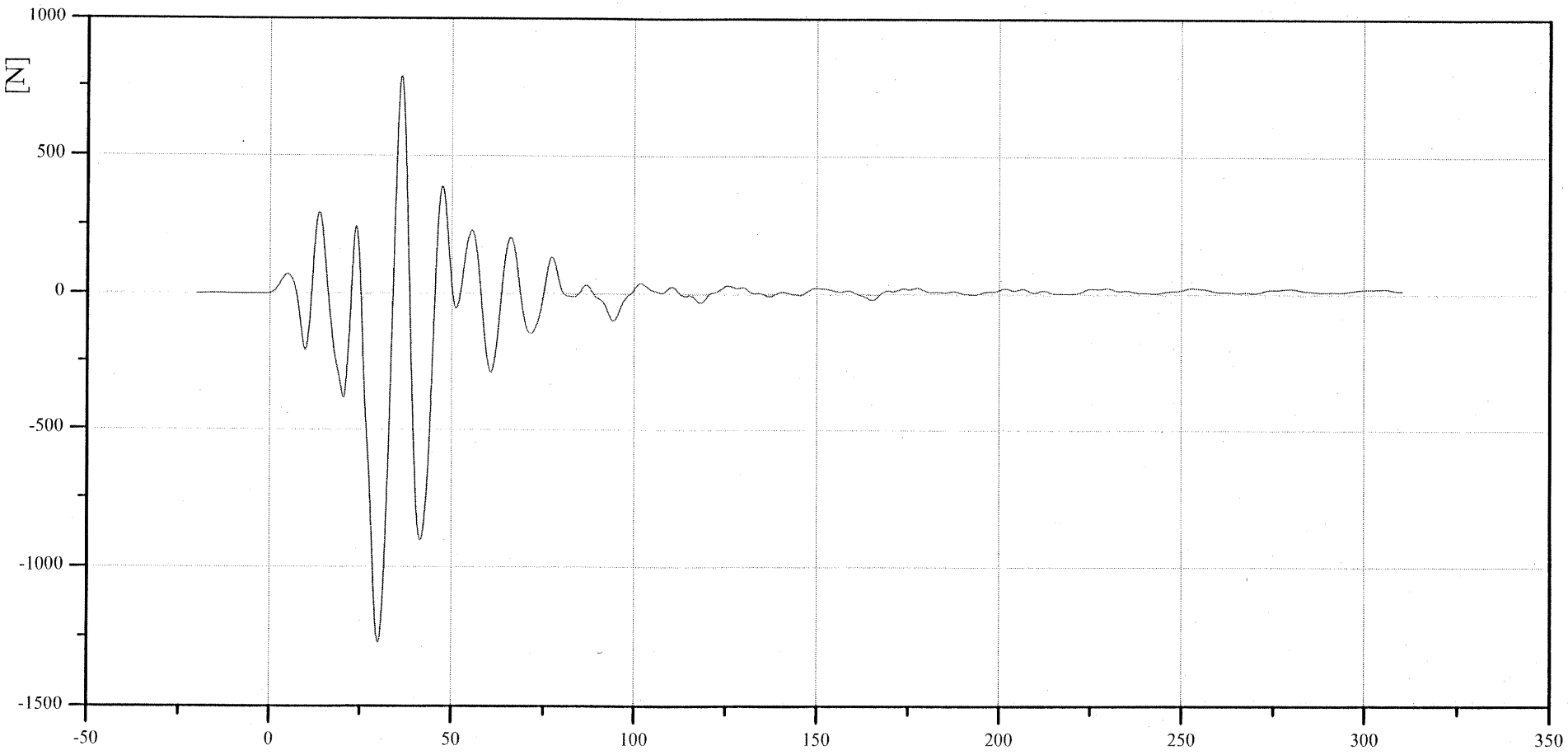
Transportation Research Center, Inc.

ROW D CELL 7

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BD7F



<Min Value>	<Max Value>
-1272.20 N at 29.92 ms	784.42 N at 36.24 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

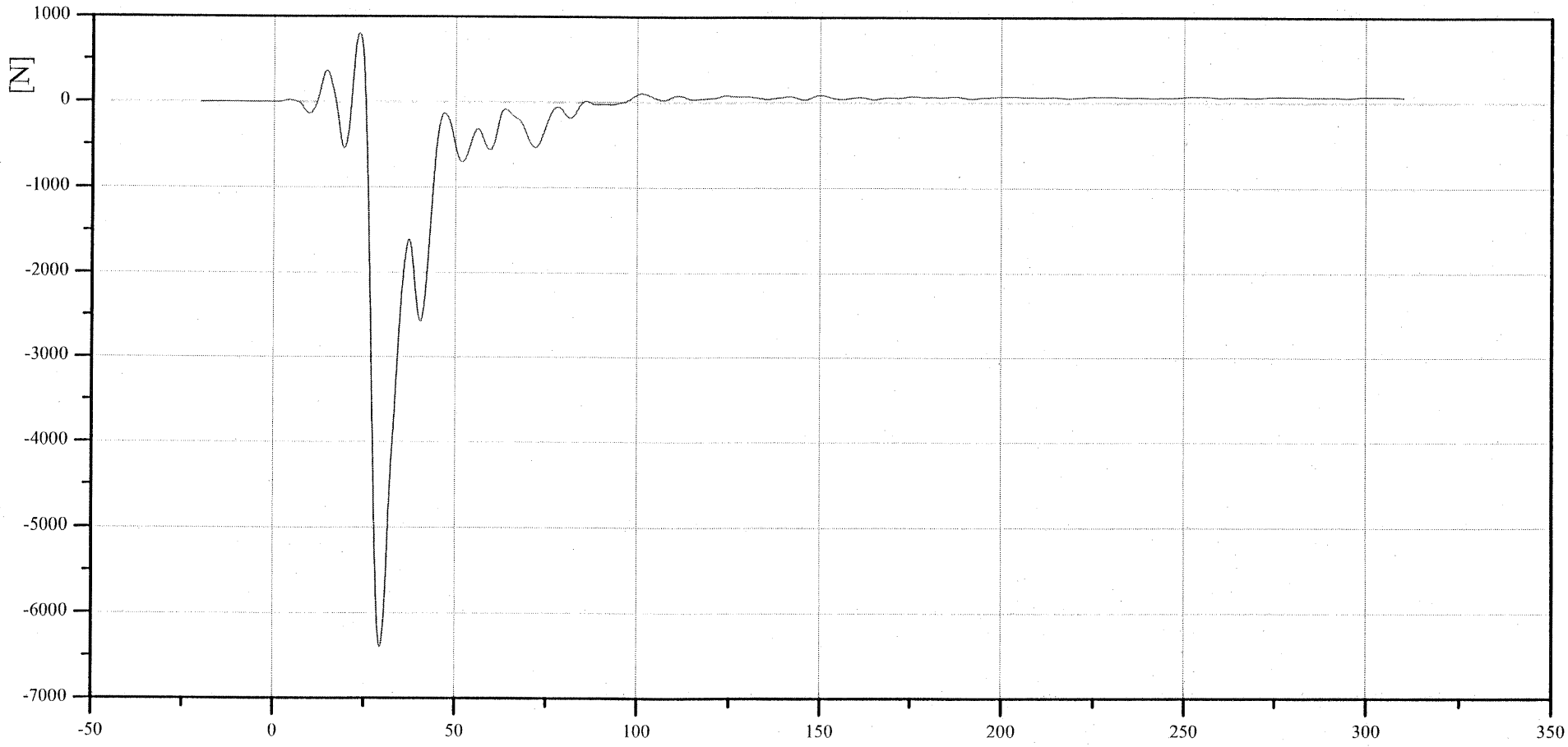
Transportation Research Center, Inc.

ROW D CELL 8

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BD8F



<Min Value>
-6394.47 N at 29.36 ms

<Max Value>
799.63 N at 23.52 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

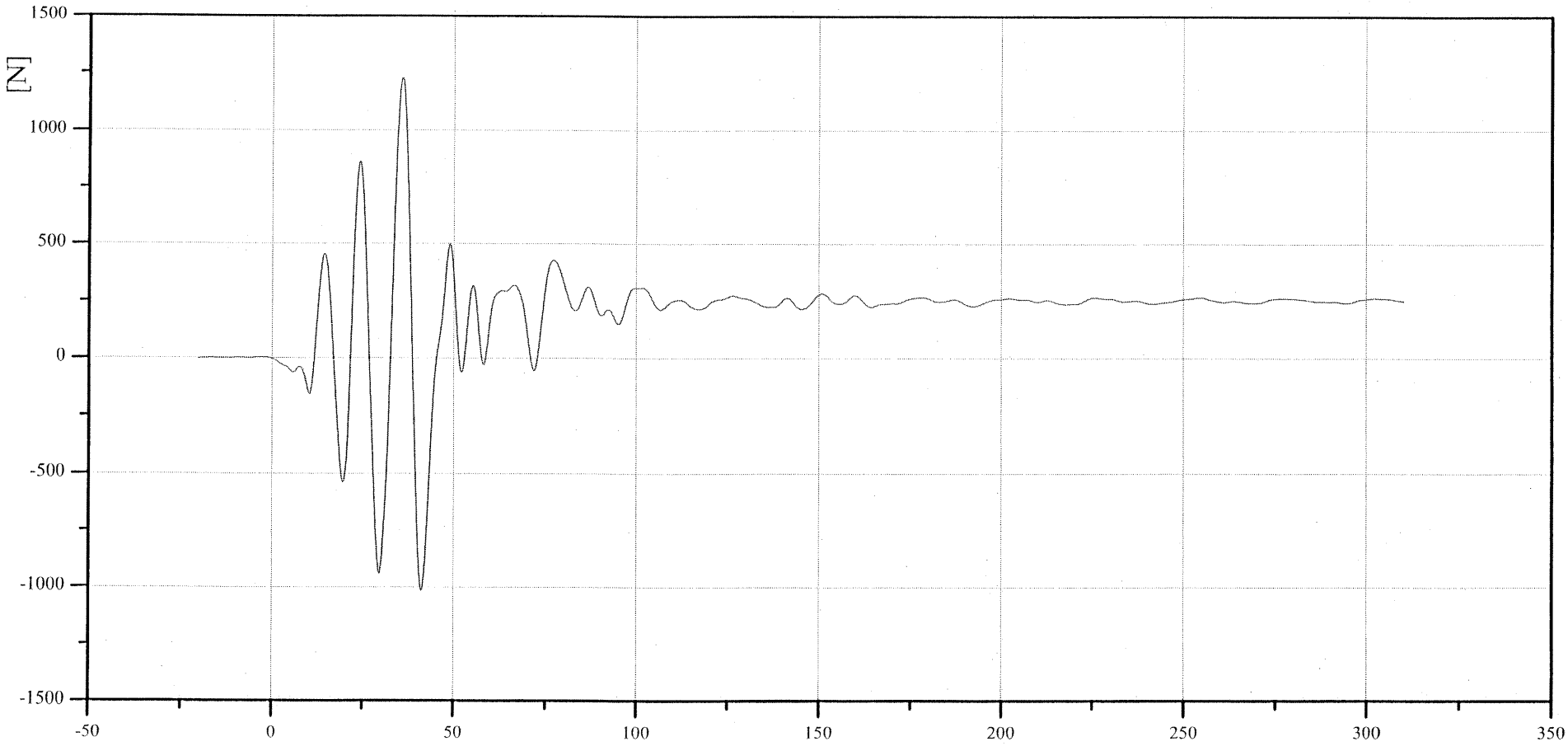
Transportation Research Center, Inc.

ROW D CELL 9

Date: 09/21/2004
Time: 15:29:30

Test Lab: CTF
Customer: QUANTECH
Test Number: 040921-2

BD9F



<Min Value>
-1016.18 N at 41.36 ms

<Max Value>
1228.09 N at 35.84 ms

Time [ms]

CFC60 [SAE J211 Polarity, Biased Removed and Filtered]

Appendix C

Miscellaneous Test Instrumentation

Channel Report

9/21/2004 1:29:41 PM

Name of Test 040921-2 **System** MINIDAU **Name of DAU** DAUD

Chan.#	Sensor #	Mnemonic	Description	Dir.	Range		Pol.	Cal.		Group	Mfg.	Model
0001	P33603	RCXLXG	Rear Seat Crossmember Left	RR	1538.0918	g	-	3/17/2004	---	-1	Endevco	7264C-2K-2-180
0002	P29180	RCXRXG	Rear Seat Crossmember Right	FWD	1479.7439	g	+	8/19/2004	OK	-1	Endevco	7264C-2K-2-180
0003	P37751	ENGTXG	Engine Top of Block X	FWD	1465.3608	g	+	8/24/2004	OK	-1	Endevco	7264C-2K-2-180
0004	P33874	ENGBXG	Engine Bottom of Block X	FWD	1521.9804	g	+	8/24/2004	OK	-1	Endevco	7264C-2K-2-180
0005	P33974	BRCLXG	Left Brake Caliper X	FWD	1505.5015	g	+	8/24/2004	OK	-1	Endevco	7264C-2K-2-180
0006	P32767	BRCRXG	Right Brake Caliper X	FWD	1497.2511	g	+	8/24/2004	OK	-1	Endevco	7264C-2K-2-180
0007	P33554	IPCXG	Center of Instrument Panel X	FWD	1527.6285	g	+	3/17/2004	---	-1	Endevco	7264C-2K-2-180
0008	P33667	BPLBXG	B-Pillar Left Side Bottom of	RR	1526.8086	g	-	3/17/2004	---	-1	Endevco	7264C-2K-2-180
0009	P33613	BPRBXG	B-Pillar Right Side Bottom of	FWD	1480.7102	g	+	3/16/2004	---	-1	Endevco	7264C-2K-2-180
0010	P33709	RPRLXG	Rear Panel nearest left Rear	RR	1524.9659	g	-	9/17/2004	OK	-1	Endevco	7264C-2K-2-180
0011	P28094	RPRLYG	Rear Panel nearest left Rear	RT	1519.3396	g	+	8/2/2004	OK	-1	Endevco	7264C-2K-2-180
0012	P27408	RPRLZG	Rear Panel nearest left Rear	UP	1518.1616	g	-	4/8/2004	OK	-1	Endevco	7264C-2K-2-180
0013	P33819	RPRRXG	Rear Panel nearest right Rear	RR	1513.0166	g	-	8/27/2004	OK	-1	Endevco	7264C-2K-2-180
0014	P37759	RPRRYG	Rear Panel nearest right Rear	LT	1489.7579	g	-	6/7/2004	OK	-1	Endevco	7264C-2K-2-180
0015	P33615	RPRRZG	Rear Panel nearest right Rear	UP	1530.1020	g	-	9/17/2004	OK	-1	Endevco	7264C-2K-2-180
0016	P28320	RRRLXG	Rear Panel nearest left Rear	RR	1504.3337	g	-	4/8/2004	OK	-1	Endevco	7264C-2K-2-180
0017	P34966	RRRLYG	Rear Panel nearest left Rear	RT	1494.5274	g	+	8/24/2004	OK	-1	Endevco	7264C-2K-2-180
0018	P34347	RRRLZG	Rear Panel nearest left Rear	UP	1458.4800	g	-	8/24/2004	OK	-1	Endevco	7264C-2K-2-180
0019	P33812	RRRRXG	Rear Panel nearest right Rear	FWD	1525.0804	g	+	3/31/2004	OK	-1	Endevco	7264C-2K-2-180
0020	P33585	RRRRYG	Rear Panel nearest right Rear	LT	1534.3361	g	-	9/17/2004	OK	-1	Endevco	7264C-2K-2-180
0021	P33851	RRRRZG	Rear Panel nearest right Rear	DN	1511.8407	g	+	3/31/2004	OK	-1	Endevco	7264C-2K-2-180

Channel Report

9/21/2004 1:29:42 PM

Name of Test 040921-2 **System** MINIDAU **Name of DAU** DAUE

Chan.#	Sensor #	Mnemonic	Description	Dir.	Range		Pol.	Cal.		Group	Mfg.	Model
0001	EVENT	EVENT	EVENT		5.12	V	+	4/19/2004	OK	-1	TRC	Event
0002	62467	BA1F	ROW A CELL 1		221731.41	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0003	122042A	BA2F	ROW A CELL 2		222977.09	N	+	12/19/2003	---	TRC	Interface	1220BZY-50K
0004	68054	BA3F	ROW A CELL 3		222977.09	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0005	68061	BA4F	ROW A CELL 4		221731.41	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0006	68058	BA5F	ROW A CELL 5		222977.09	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0007	68042	BA6F	ROW A CELL 6		221731.41	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0008	68032	BA7F	ROW A CELL 7		222977.09	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0009	68026	BA8F	ROW A CELL 8		221731.41	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0010	68045	BA9F	ROW A CELL 9		222977.09	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0011	68027	BB1F	ROW B CELL 1		222977.09	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0012	68055	BB2F	ROW B CELL 2		221731.41	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0013	68046	BB3F	ROW B CELL 3		221731.41	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0014	68068	BB4F	ROW B CELL 4		221731.41	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0015	68024	BB5F	ROW B CELL 5		222977.09	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0016	68044	BB6F	ROW B CELL 6		221731.41	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0017	68069	BB7F	ROW B CELL 7		221731.41	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0018	68034	BB8F	ROW B CELL 8		222977.09	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0019	68047	BB9F	ROW B CELL 9		222977.09	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0020	62466	BC1F	ROW C CELL 1		221731.41	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0021	62510	BC2F	ROW C CELL 2		221731.41	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0022	68052	BC3F	ROW C CELL 3		221731.41	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0023	68028	BC4F	ROW C CELL 4		222977.09	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0024	68064	BC5F	ROW C CELL 5		222977.09	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0025	68012	BC6F	ROW C CELL 6		222977.09	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0026	68063	BC7F	ROW C CELL 7		221731.41	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0027	68015	BC8F	ROW C CELL 8		222977.09	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0028	62453	BC9F	ROW C CELL 9		221731.41	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0029	68050	BD1F	ROW D CELL 1		221731.41	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0030	68021	BD2F	ROW D CELL 2		222977.09	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0031	68039	BD3F	ROW D CELL 3		222977.09	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0032	68018	BD4F	ROW D CELL 4		222977.09	N	+	12/19/2003	---	TRC	Interface	1220TX-50K

Channel Report

9/21/2004 1:29:42 PM

0043	68067	BD5F	ROW D CELL 5	222977.09	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0044	62456	BD6F	ROW D CELL 6	221731.41	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0045	68014	BD7F	ROW D CELL 7	221731.41	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0047	68051	BD8F	ROW D CELL 8	222977.09	N	+	12/19/2003	---	TRC	Interface	1220TX-50K
0048	68033	BD9F	ROW D CELL 9	222977.09	N	+	12/19/2003	---	TRC	Interface	1220TX-50K

Sign Convention
SAE J211 MAR95

Accelerometers:	+X: Forward	
	+Y: Rightward	
	+Z: Downward	
Potentiometers:	+Chest longitudinal deflection:	Outward
	+Chest lateral deflection:	Leftward
	+Seat belt displacement:	Outward
	+Seat belt extension:	Elongation
	+Knee slider displacement:	Distance between femur and tibia increased (in relation to a seated dummy)

Rotation potentiometers:

	+About the X-axis:	Left foot-eversion
		Right foot-inversion
	+About the Y-axis:	Left/right foot-dorsiflexion
	+About the Z-axis:	Left foot-internal
		Right foot-external

Load cells:	+Femur force:	Tension
	+Seat belt force:	Tension
	+Barrier force:	Tension

Neck load cells:	+X force:	Head pushed rearward
	+Y force:	Head pushed leftward
	+Z force:	Head pulled upward (tension on neck)
	+X moment:	Left ear rotating toward left shoulder
	+Y moment:	Chin rotating toward chest
	+Z moment:	Chin rotating toward left shoulder

Tibia load cells:	+X force:	Ankle forward, knee rearward
	+Y force:	Ankle rightward, knee leftward
	+Z force:	Tension
	+X moment:	Bottom of tibia moving leftward
	+Y moment:	Bottom of tibia moving rearward

Frequency Response Classes
SAE J211 MAR95

Typical Test Measurements	Channel Class
Vehicle Structural Accelerations for use in:	
Total vehicle comparison	60
Collision simulation input	60
Component analysis	600
Integration for velocity or displacement	180
Barrier Face Forces	60
Belt Restraint System Loads	60
Anthropomorphic Test Device	
Head accelerations (linear and angular)	1000
Neck	
Forces	1000
Moments	600
Thorax	
Spine accelerations	180
Rib accelerations	1000
Sternum accelerations	1000
Deflections	180
Lumbar	
Forces	1000
Moments	1000
Pelvis	
Accelerations	1000
Forces	1000
Moments	1000
Femur/Knee/Tibia/Ankle	
Forces	600
Moments	600
Displacements	180
Sled Accelerations	60
Steering Column Loads	600
Head form accelerations	1000

Correlation of Vehicle with New Rails and Bumper

Milestone 36

Lightweight Front End Structure Phase II

December 7, 2004

A/S P

Auto/Steel Partnership

Abstract

This report documents the correlation of the **NCAP** 35mph crash test results with the FEA simulation of the vehicle with the new rail and bumper assemblies, in *Phase II* of the *Lightweight Front End Structure Project*.

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1. Objectives

The effort of this study was aimed at comparing the **NCAP** 35mph crash test results with the FEA simulation of the vehicle with the new rail and bumper assemblies.

2. Results Summary

An NCAP 35mph rigid barrier crash test of the donor vehicle fitted with the *new AHSS rail and bumper assemblies*, was performed at the *Transportation and Research Center*, Ohio, on September 21st 2004. Digital photographic data and accelerometer data were recorded in order to assess the performance of the vehicle. Please refer to the *Milestone 35* for crash test details.

The crushing of the bumper and the front section of the rails was quite similar in the crash test and FE simulation. The buckling of the rails and deformation of the cage were also quite similar in nature.

The overall LH/RH B-pillar acceleration peaks in the crash test were 3.6g/7.9g higher than the FEA results and occurred earlier. The slopes of the velocity profiles were similar, although the times to reach zero velocities were longer in the crash test.

The major difference in the B-pillar pulse occurs when the acceleration drops at about 25ms followed by a sharp rise. This effect is much mores pronounced in the crash test. A possible explanation for this mismatch is the ***inability of the analytical model to simulate the engine mount behavior***.

The NCAP results are summarized in *Table 1*. Please refer to *Section 3* for detailed comparison and *Milestone 34* for all FE model modifications.

Table 1: NCAP Results Comparison

	Peak Acceleration	
B-Pillar Pulse	**Test**	**FEA***
LH	**36.5 g @ 31.9 ms**	**32.9 g @ 41.9 ms**
RH	**41.8 g @ 32.8 ms**	**33.9 g @ 59.3 ms**

* ***FEA*** results correspond to ***Milestone 34***.

3. NCAP Response

The cage sustained very little damage in the crash test, as predicted by the FE simulation (*Figure 1, Figure 2*). All four doors opened easily and there was no abnormal deformation of the A-pillar, B-pillar or the roof rails.

The front hood came off in the crash test due to the shearing of its bolts. This is because 6mm dia bolts were used in the test vehicle as opposed to 8mm dia bolts in the production vehicle. This failure was introduced in the FE simulation.

There was no visible damage to the rail extension segment under the floor, as predicted by the FE simulation, indicating good energy absorption in the front rails and bumper (*Figure 7 thru Figure 10*).

The bumper and the front sections exhibited good crush, which was predicted by FE the simulation (*Figure 3, Figure 6*). The buckling of the rails was also of the same nature as in the FE simulation.

The front cradle mount bolt on RH side sheared off in test. This failure was introduced in the FE simulation.

The LH engine mount detached from the cradle in the crash test. This failure mode was introduced in the FE simulation.

The overall LH/RH B-pillar acceleration peaks in the crash test were 3.6g/7.9g higher than the FEA results and occurred earlier (*Figure 11, Figure 12*). The slopes of the velocity profiles were similar, although the times to reach zero velocities were longer in the crash test (*Figure 13*, *Figure 14*).

The peak barrier force (*Figure 15*) in the FE simulation was lower than in the crash test by 42 kN. However, the initial peak in the FE simulation was higher than in the crash test by 58 kN. Both peaks occurred earlier in the FE simulation.

The major difference in the B-pillar pulse occurs when the acceleration drops at about 25ms followed by a sharp rise. This effect is much mores pronounced in the crash test. A possible explanation for this mismatch is the ***inability of the analytical model to simulate the engine mount behavior***. The FE/CAD model geometry of the engine mounts is different from the mounts used in the test vehicle. Furthermore, FE models cannot model material failure accurately.

It should be noted that the engine mounts used in the test vehicle were obtained from the vehicle from the first aborted test and ***may have suffered plastic deformation***. In addition, the test vehicle had been driven prior to the test, which could have resulted in further changes to the vehicle response.

Animation files for the crash test and FE simulation are included in *Appendix A*.



Figure 1: Left Side View – Crash Test

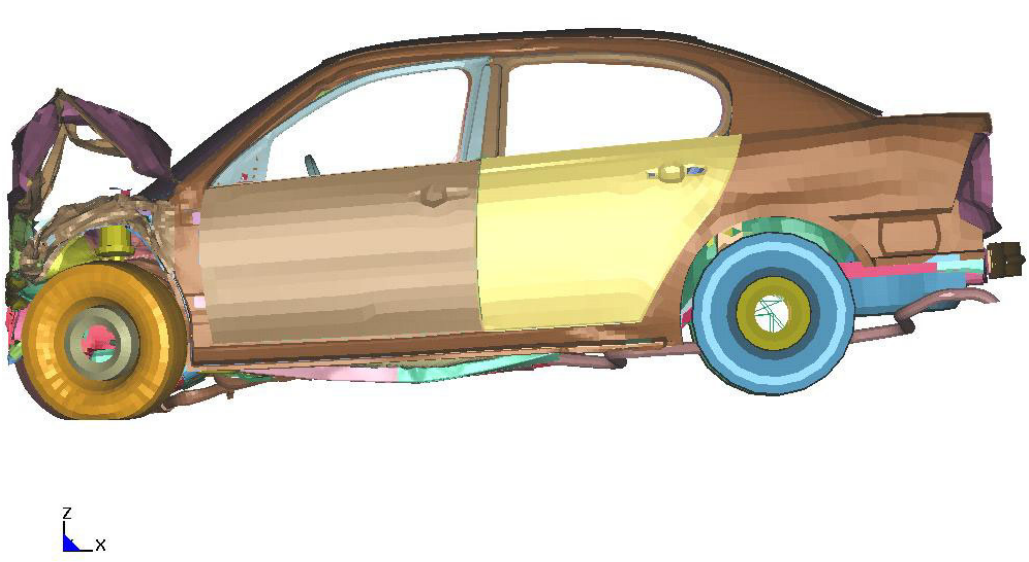


Figure 2: Left Side View – FEA



Figure 3: Front Close-up – Crash Test

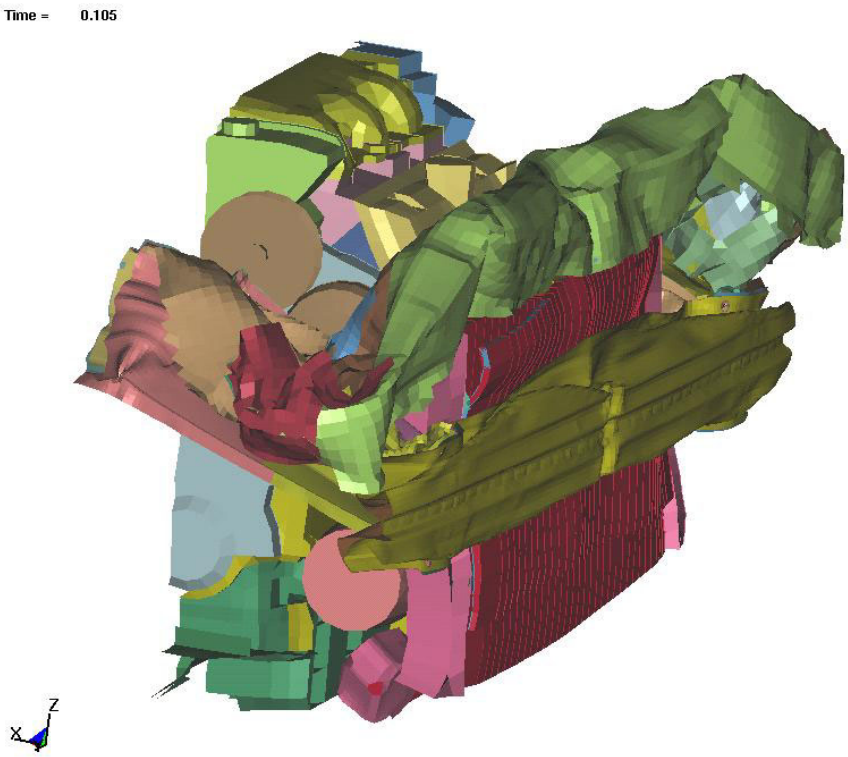


Figure 4: Front Close-up - FEA



Figure 5: LH Front Rails – Crash Test

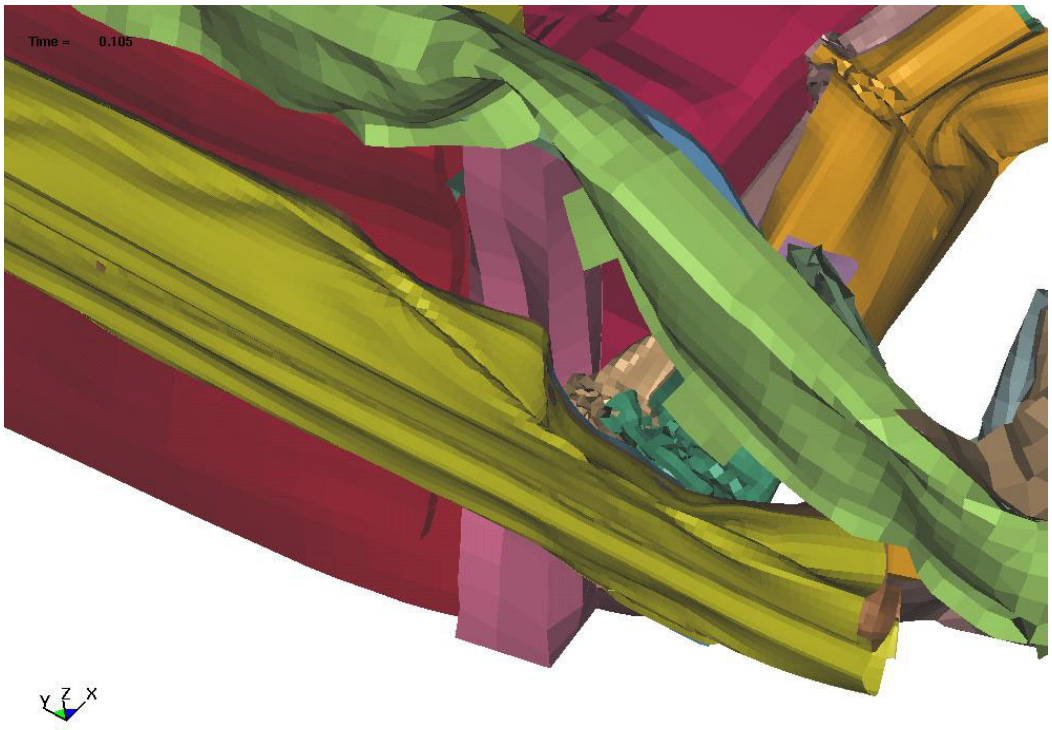


Figure 6: LH Front Rails - FEA



Figure 7: Front Underbody – Crash Test

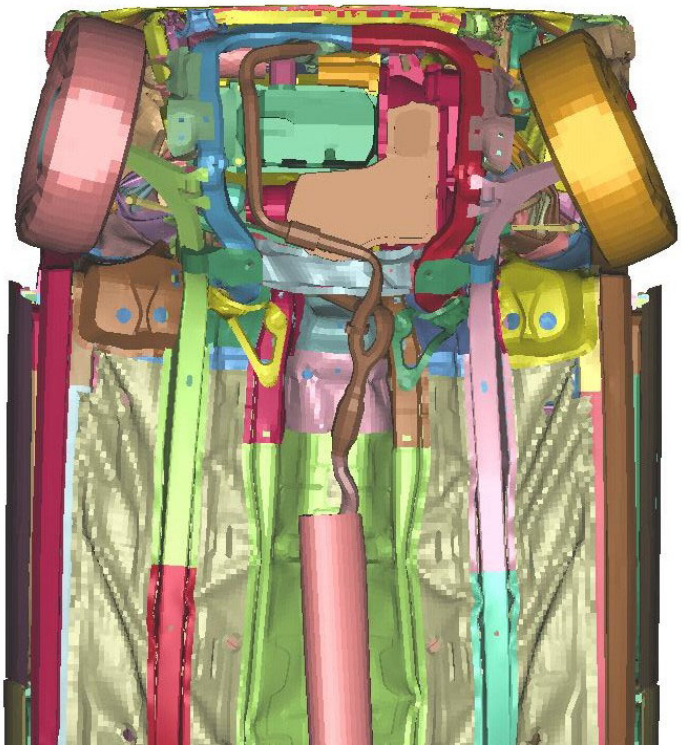


Figure 8: Front Underbody - FEA



Figure 9: Mid Underbody – Crash Test

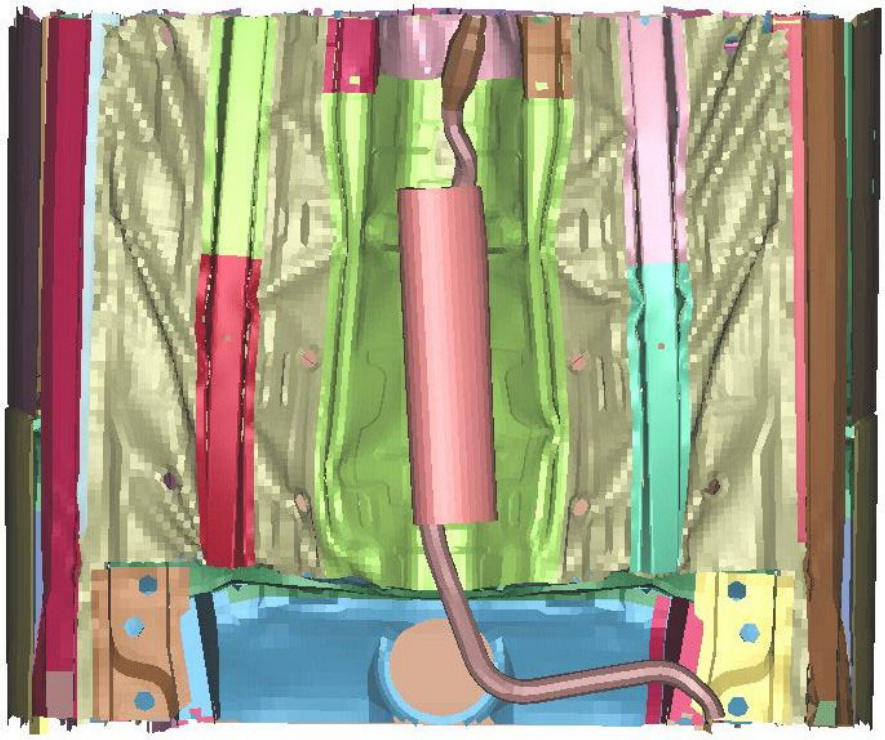


Figure 10: Mid Underbody - FEA

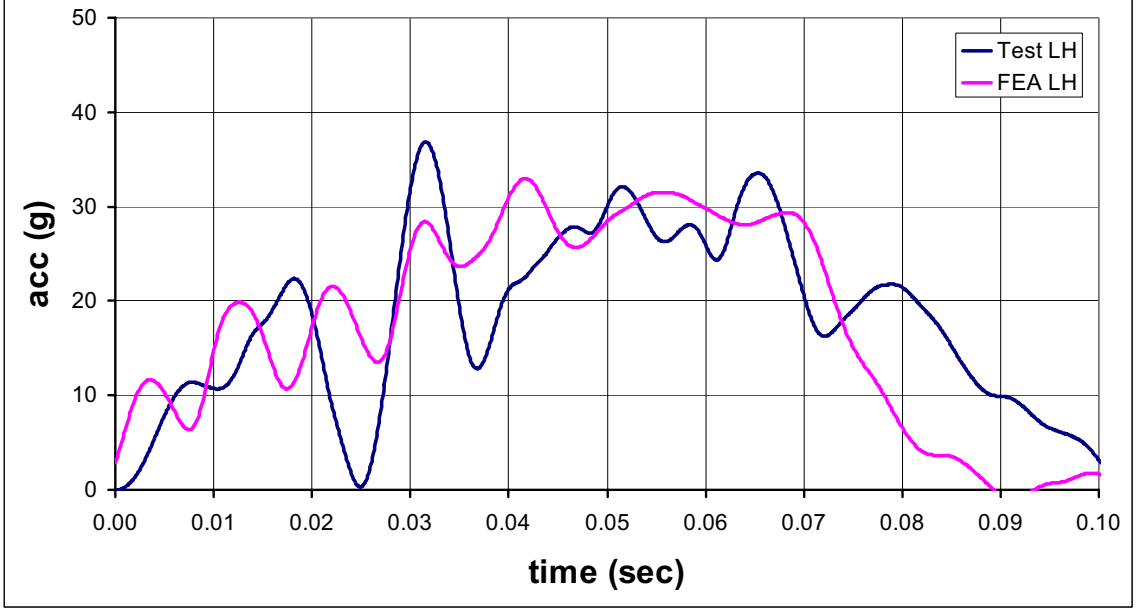


Figure 11: LH B-Pillar Pulse

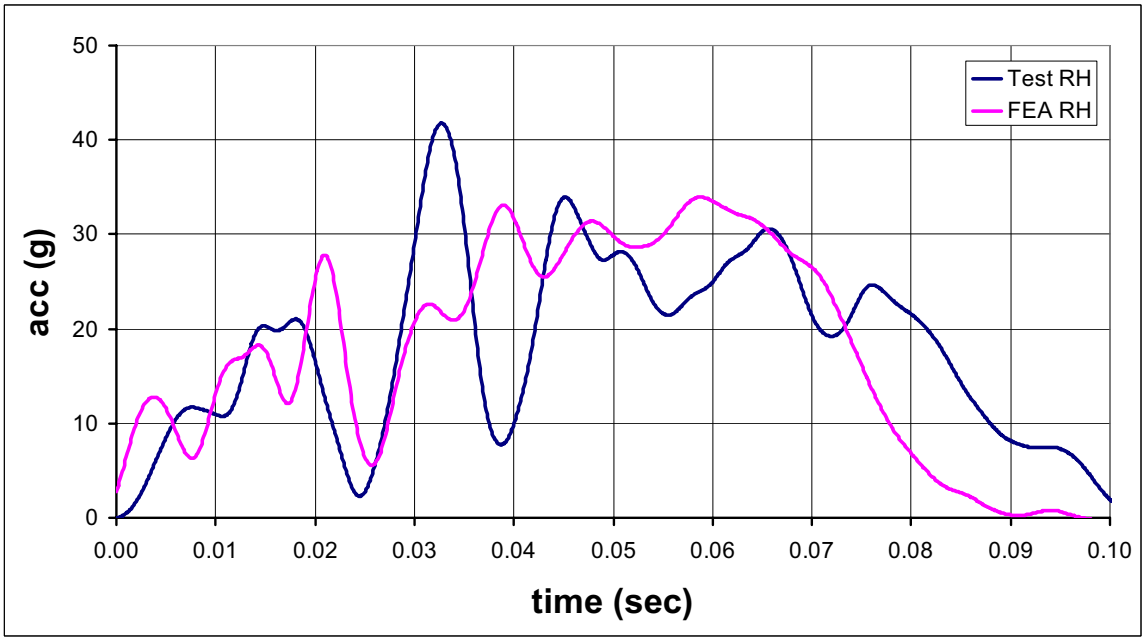


Figure 12: RH B-Pillar Pulse

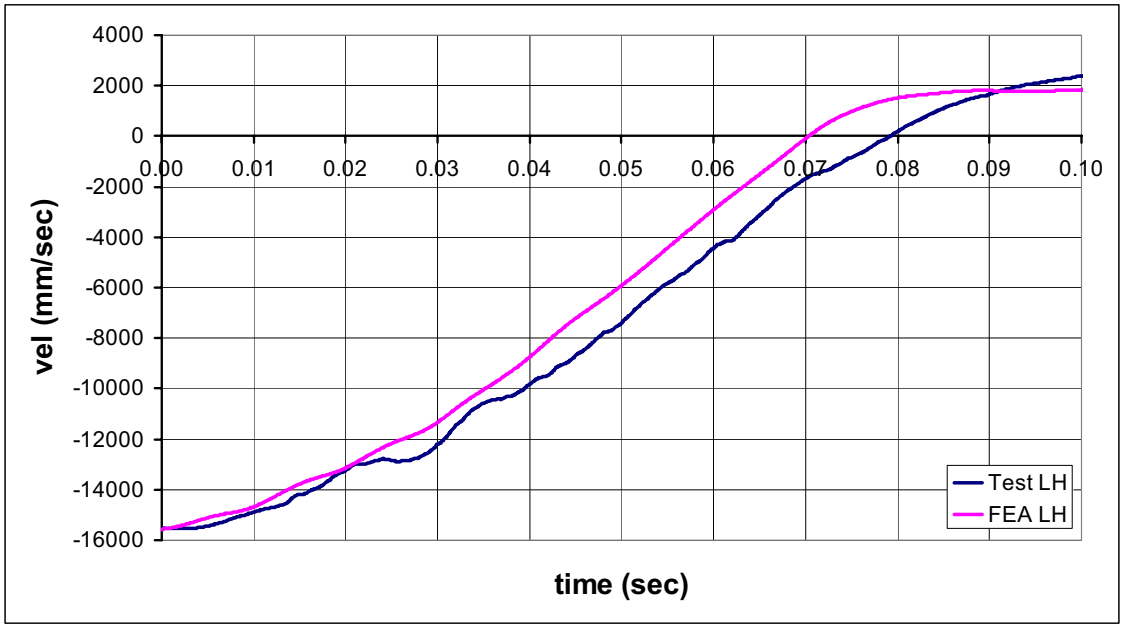


Figure 13: LH B-Pillar Velocity Profile

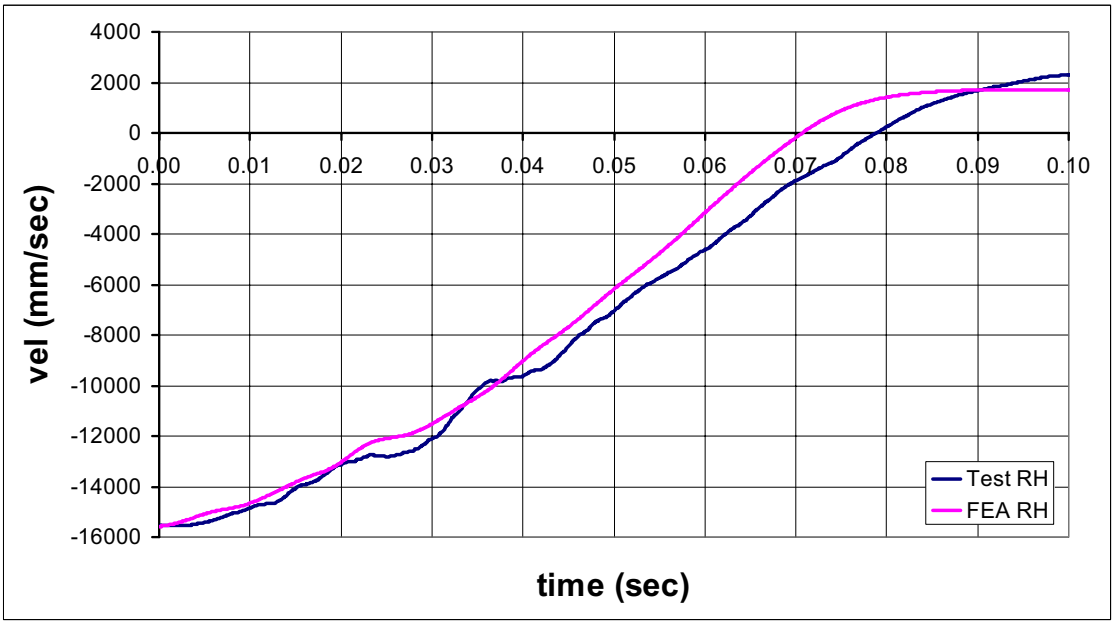


Figure 14: RH B-Pillar Velocity Profile

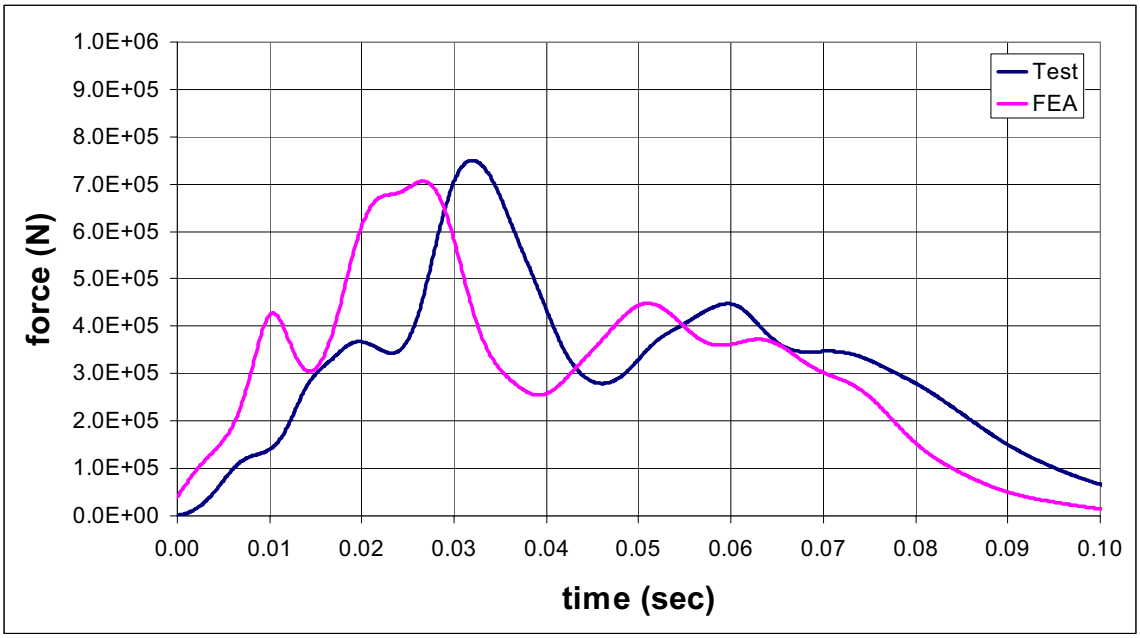


Figure 15: Barrier Force

4. FE Model - Output Location Summary

The nodes at which the desired NCAP and IIHS outputs were obtained are listed in *Table 2*.

The intrusions are measured at the nodes as specified in *Reference 3*.

The acceleration and intrusion node locations are shown in *Figure 16* and *Figure 17* below.

Table 2: Summary of Output Locations

Parameter	Location	Node Number
Accelerations	B-Pillar / Rocker - LH	5000001
	B-Pillar / Rocker - RH	5000002
Intrusions	Origin	6000000
	Plane Y-axis	6000001
	Plane Z-axis	6000002
	Steering Column	7000001
	Brake Pedal	7000002
	Toepan - Left	7000003
	Toepan - Center	7000004
	Toepan - Right	7000005
	Left Front Seat Bolt	7000006
	Right Front Seat Bolt	7000007
	Left Rear Seat Bolt	7000008
	Right Rear Seat Bolt	7000009
	AB Closure - A Pillar	7000010
	AB Closure - B Pillar	7000011

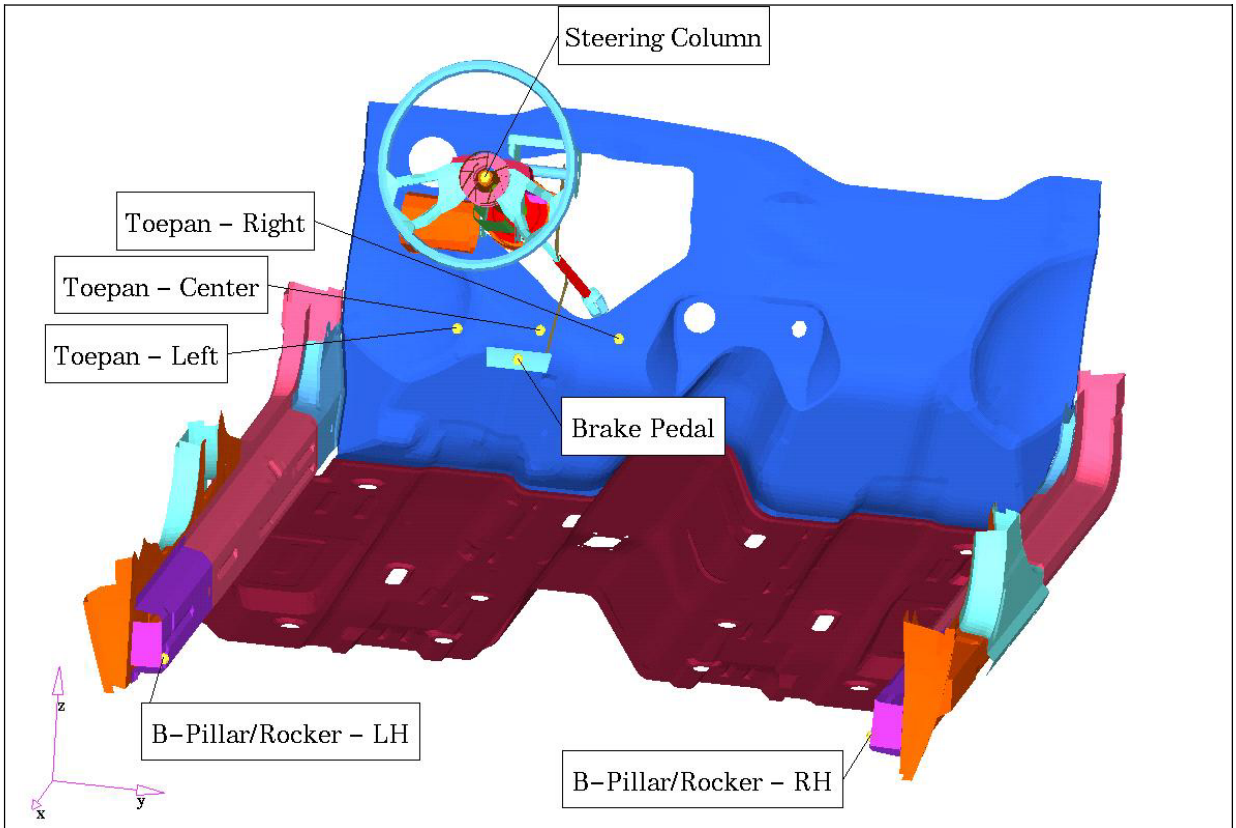


Figure 16: Output Locations for NCAP/IIHS



Figure 17: Output Locations for IIHS- AB Closure

5. Conclusions

The NCAP 35mph crash test results were compared to the FEA simulation of the vehicle with the new rail and bumper assemblies. The crushing of the bumper and the front section of the rails was quite similar in the crash test and FE simulation. The buckling of the rails and deformation of the cage were also quite similar in nature.

The overall LH/RH B-pillar acceleration peaks in the crash test were 3.6g/7.9g higher than the FEA results and occurred earlier. The slopes of the velocity profiles were similar, although the times to reach zero velocities were longer in the crash test.

The major difference in the B-pillar pulse occurs when the acceleration drops at about 25ms followed by a sharp rise. This effect is much mores pronounced in the crash test. A possible explanation for this mismatch is the ***inability of the analytical model to simulate the engine mount behavior***.

6. Future Work

This milestone achieves the final goal of *Phase II* of the *Lightweight Front End Structure Project*.

7. References

1) *Validated FE Models, Milestone 5*, SPHINX, Phase II.

2) *Enhanced FE Models, Milestone 6*, SPHINX, Phase II.

3) *IIHS Crashworthiness Evaluation Offset Barrier Crash Test Protocol (Version IX), October 2002.*

4) *DOE FE Models, Milestone 7*, SPHINX, Phase II.

5) *Third Bumper Design Report, Milestone 5*, SPHINX, Phase I.

6) *Concept 1: Preliminary Design, Milestone 10*, SPHINX, Phase II.

7) *FMVSS Part 581 Bumper Standard*.

8) *Concept 2: Preliminary Design, Milestone 13*, SPHINX, Phase II.

9) *Concept 2: Final Design, Milestone 15*, SPHINX, Phase II.

10) *NCAP DOE Response Surface, Milestone 20*, SPHINX, Phase II.

11) *IIHS DOE Response Surface, Milestone 21*, SPHINX, Phase II.

12) *Static Stiffness DOE Response Surface, Milestone 46*, SPHINX, Phase II.

13) *Dynamic Stiffness DOE Response Surface, Milestone 47*, SPHINX, Phase II.

14) *Final Optimized Design, Milestone 22*, SPHINX, Phase II.

15) *Analysis of Vehicle with New Rail System, Milestone 34*, SPHINX, Phase II.

16) *NCAP Test Results of Vehicle with New Rails/Bumper, Milestone 35*, SPHINX, Phase II.

8. Appendix A: Animations

The following animation files for the subsystem development can be viewed at the Auto/Steel Partnership website, www.a-sp.org.

You will need a Hyperview Player in order to view these animations at the site. You can download this free software at www.altair.com.

1. NCAP Crash Test

2. NCAP FE Simulations

9. Appendix B: Summary of FE Model

Model Mass	1.778 tonnes

- Model mass is from LS-DYNA3D d3hsp file.



Quantech
Global Services

Proteus Manual

Lightweight Front End Structure

May 13, 2005

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Quantech
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Proteus Guidelines

Lightweight Front End Structure

Prepared for

Auto/ Steel Partnership

By

Quantech Global Services
Okemos, Troy
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March 7, 2005

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Proteus Guidelines

1 Introduction

The knowledge base tool, ***Proteus***, allows for early cost, mass, and options trade-off decisions to be made in support of vehicle development timing reductions, for a given vehicle performance. Proteus incorporates a knowledge base from the ***Design of Experiments*** (DoE) optimization study and a sophisticated ***Cost Model***. It takes a set of ***design parameters*** as input, and estimates the corresponding ***responses*** - mass, cost, and performance. Three kinds of parameters are taken into consideration: gauge, grade, and topological. *Proteus* is secure, extensible, and user friendly. *Proteus* has two versions – web-based and *Windows*-based. Access to the web-based *Proteus* is restricted through login and passwords. It can be accessed from anywhere on the Internet or intranet using a web browser. The stand-alone *Window*-based version does not have user logins. Please note that the web-based version has been discontinued and all future enhancements will be made only on the *Window*-based version. The Optimization module is available only in the *Window*-based version.

2 Proteus Knowledge Base

Currently, *Proteus* has databases for several architectures in its knowledge base. A typical database for an architecture has the following information.

- **Parameters**
  - Grade
  - Gauge
  - Topology
- **Responses**
  - Mass
  - Cost
  - Static Stiffness – torsional and bending
  - Dynamic Stiffness – first torsional and bending modes
  - NCAP – B-pillar pulse, crush, time-to-zero velocity
  - IIHS – footwell intrusions, AB closure

The parameters and responses for different architectures may be different.

By default, one architecture is always loaded into *Proteus*. Additional architectures can be easily added to the knowledge base.

3 DoE Parameters and Response Estimation

Supplement documents accessible through *Online Help* summarize the parameters and responses available for the architectures stored in the *Proteus* knowledge base. It should be noted that since not all parameters are included in every DoE study, the responses corresponding to that study might not change if some parameters are varied. For example, material grades are not involved in static or dynamic stiffness study. Consequently, the bending/torsional stiffness and modes remain invariant if the grades are changed. Similarly, some parameters are part of the IIHS study but are not included in the NCAP study, due to their lesser effect on the NCAP response.

Details for the DoE studies of the available architectures may be obtained from the architecture-specific document, including parametric levels and error estimates. Please refer to the ***final report*** and the ***milestone reports*** for in-depth analysis of the DoE studies. The reports are archived on the web management tool, ***SPHINX***.

It should be noted that the same parameter may have different levels for two different DoE studies of an architecture. This should be borne in mind when estimating the error of the DoE response. The error in a response is less when the levels are close to the levels in the actual DoE study. *Proteus* does not place any restrictions on the parameter bounds. It is the responsibility of the user to choose levels that are not significantly beyond the bounds of the DoE levels.

The error of interpolation/extrapolation is lower for gauge parameters, as compared to grade and topological parameters. This is due to the fact that gauge parameters are continuous variables, as opposed to the discrete nature of the grade and topological parameters.

The error estimates for NCAP and IIHS responses are included in the architecture documents. The error estimates for static and dynamic stiffness responses are not included as the errors are very small (less than 3%).

An important fact to consider is that the maximum error for a response is likely to be less when a large number of parameters are varied. Therefore, it is suggested that *Proteus* should be employed to estimate the effect of a large number of parameters changed concurrently, as opposed to one parameter at-a-time variation. Of course, the ideal way to use the database is by linking it to an optimizer. This way the user can obtain optimal designs in the design space, in real time. Manual search cannot be exhaustive, as there are an infinite number of combinations possible. *Proteus* has an Optimization module that can be employed for computer-aided optimization (CAO) of a given architecture.

Please note that the *Cost Model* is relevant only for the architectures based on the *ULSAB*. This limits its use to the *Initial Front-end Package* and the *Upgraded*

Powertrain Front-end Package of *Phase I*. It should also be borne in mind that the DoE parameters for these two architectures do not always correspond to the parts in the *Cost Model*. The parts in the *Cost Model* correspond exactly to the actual *ULSAB* front-end parts. However, in the DoE study some parts are combined, whereas, others are split into multiple parts. Therefore, the cost estimate is not exact in some cases. The front-end mass is also obtained from the cost model and in some cases is slightly different from the exact mass obtained directly from the DoE study. This was done so that the mass and cost breakdowns were consistent with each other.

Both the mass and cost values are relative to the baseline values of the respective front-end packages. Therefore, the mass and cost of the *Initial Front-end Package* should not be compared with those of the *Upgraded Package*. Furthermore, no cost can be determined for bumper and cradle parts, as they are not included in the cost model. Hence, the total delta cost and mass values represent the change in cost and mass for the BIW parts only, compared to the baseline BIW parts of the respective front-end packages.

4 Library of Designs

Library of Designs archive designs derived from the optimization of the architectures, using DoE response surfaces. The following typical information is archived:

- **Parameters**
  - Grade
  - Gauge
  - Topology
- **Responses**
  - Mass
  - Cost
  - Static Stiffness – torsional and bending
  - Dynamic Stiffness – first torsional and bending modes
  - NCAP – B-pillar pulse, crush, time-to-zero velocity
  - IIHS – footwell intrusions, AB closure

The **responses** are the values obtained from **FE simulations**. The *Estimate* page is therefore not active when a design from the Library of Designs (LoD) is loaded. The *User Design* feature should be employed when it is desired to manipulate a LoD.

5 User Designs

A *User Design* is any design saved by a user. For convenience, the *Library of Designs* has been saved as user designs, for manipulation and modifications. Please note that the same design therefore exists in the *LoD* as well as a *User Design*. The responses are however different – *LoD* has the exact FEA responses, whereas, User Designs have the estimated DoE responses.

Use *Library of Designs* option for determining exact FEA responses.

Use *User Designs* option for modifying a design from the *Library of Designs* or for estimating the DoE responses.

6 Proteus Options

6.1 Load Architecture

This option is used to perform the following functions:

1. Add a new architecture
2. Delete an existing architecture
3. Load an architecture

The current loaded architecture is marked on the menu.

6.2 Estimate

The *Estimate* option is used to list the parameters of a design and estimate the DoE responses. By default, the baseline design of the active architecture is loaded. The parameters can be modified and new responses can be obtained. This new design may be saved as a *User Design*.

The *Estimate* option is active when a user enters *Proteus*, loads an architecture or loads a *User Design*.

The *Estimate* option is not active when a user loads a design from the *Library of Design* (*LoD*).

Responses are computed using the *Compute Response* button at the bottom of the *Estimate* page, which brings up the *Results* page. The following additional options are available through the *Results* page:

- Details – mass and cost breakdown of each part
- Parameters – summary of DoE parameters

- LH and RH Pulse – NCAP B-pillar pulse
- Error Graph – DoE response errors
- Print – prints results table
- Save – saves design as a *User Design*

6.3 Library of Designs

This option is used to load a design from the *Library of Designs*. *Library of Designs* cannot be deleted.

6.4 User Designs

This option is used to load or delete a *User Design*.

A design is saved as a *User Design* through the *Estimate*/*Compute Response*/*Save* options.

6.5 Compare

This option is used to compare any two designs within the same architecture. The following comparisons are possible:

- *LoD* with *LoD*
- *LoD* with *User Design*
- *User Design* with *User Design*

6.6 Optimization

This option is used for the computer-aided optimization (CAO) of a given architecture. The following features are available in the *Optimization* module.

- *Select any set of parameters as design variables*
- *Define any limits for parameters*
- *Choose parameters to be continuous or discrete*
- *Select any response as objective function*
- *Define any set of responses as constraints*

7 Sample Tutorial

This tutorial guides the user through all *Proteus* operations explained in the previous sections.

To activate the *Windows* version of *Proteus*, click on the *Proteus* icon on the desktop or select it from the *Programs* menu. The *Windows* version displays the *Estimate* page upon launching, as it does not require user ids.

Various tasks can be selected from the options available in the menu bar on the top-right corner (*Figure 1*). Some tasks can be selected through icons as well.

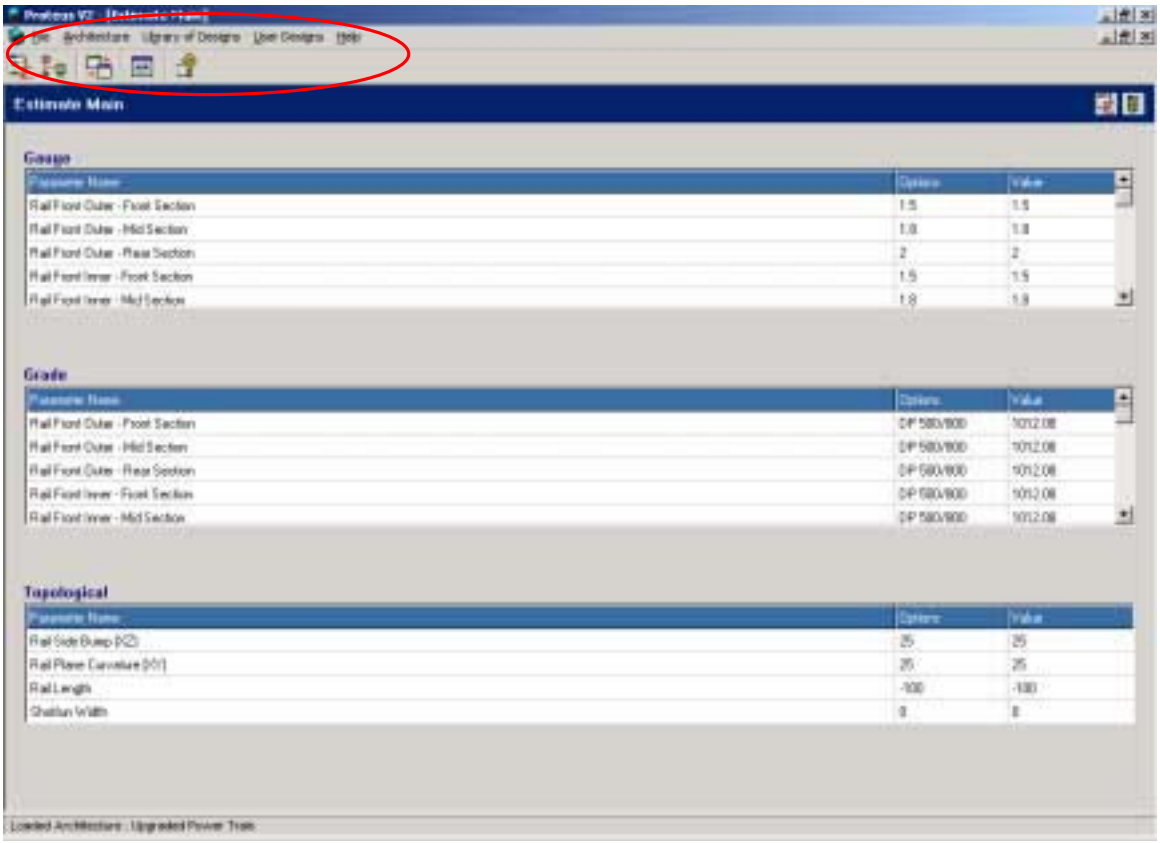


Figure 1: Proteus Menu Options and Icons

7.1 Online Help

Click on the *Help* option in the menu bar menu bar on the top-left corner, in order to access the *Proteus* help (*Figure 2*). Select *Online Help* option for a brief description of all *Proteus* operations. Alternatively, click on the *Online Help* icon in the menu bar. Select *Proteus Manual* to display document that you are currently reading as well as supplement documents that describe the available architectures.

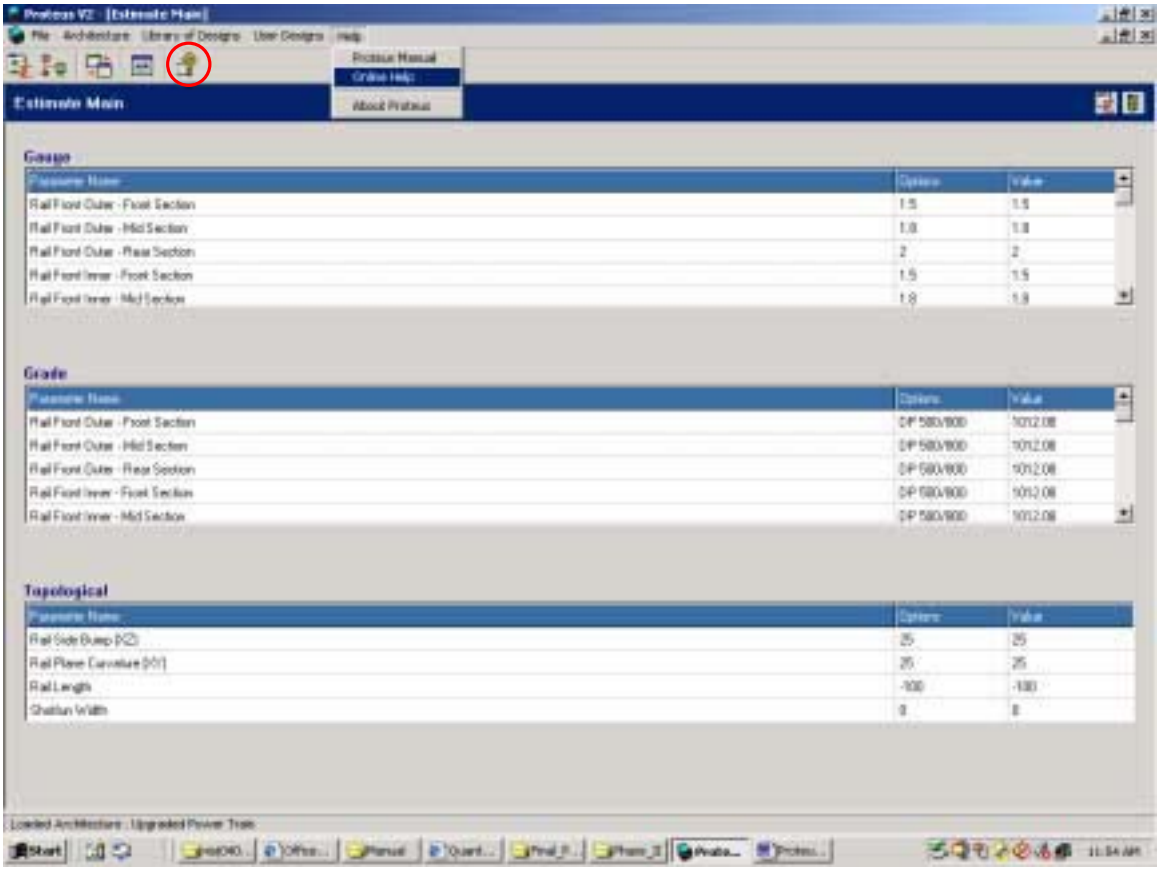


Figure 2: Proteus Help

7.2 Manipulate Architectures

Load an Architecture

Click on the *Architecture* option in the menu bar menu bar on the top-left corner, in order to display the available architectures (*Figure 3*). The architecture that is current loaded into the database, has a tick mark placed before it.

Click on *Upgraded Powertrain* to load the *Upgraded Powertrain* architecture.

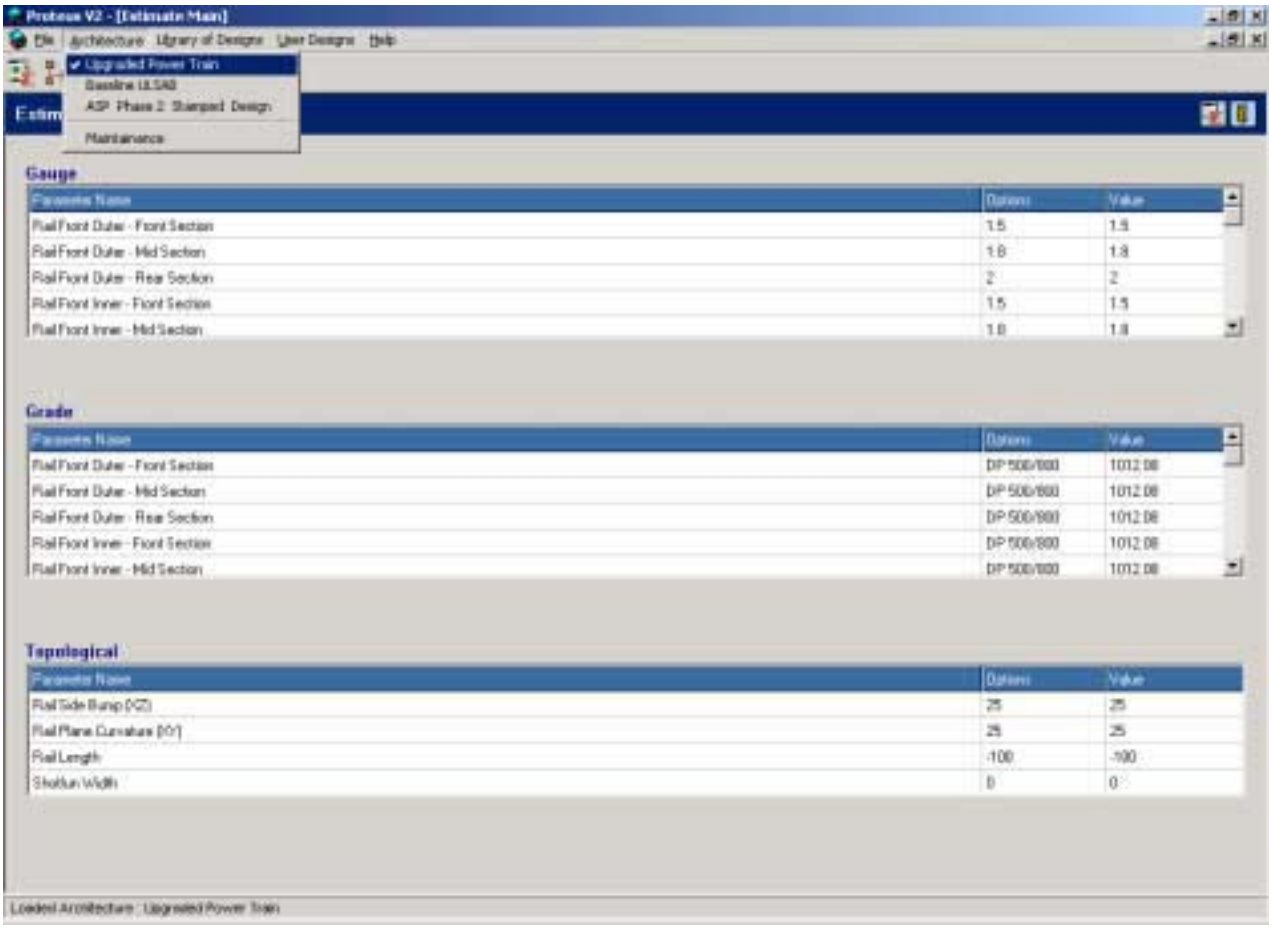


Figure 3: Proteus Architecture Selection

Add or Delete an Architecture

Click on the *Architecture* option in the menu bar and select *Maintenance* in order to add or delete architectures (*Figure 4*). Alternatively, click on the *Architecture* icon in the menu bar. A list of available architectures and their location is displayed. Click on the *Add*/*Delete* icons on the top-right corner to add or delete architectures.

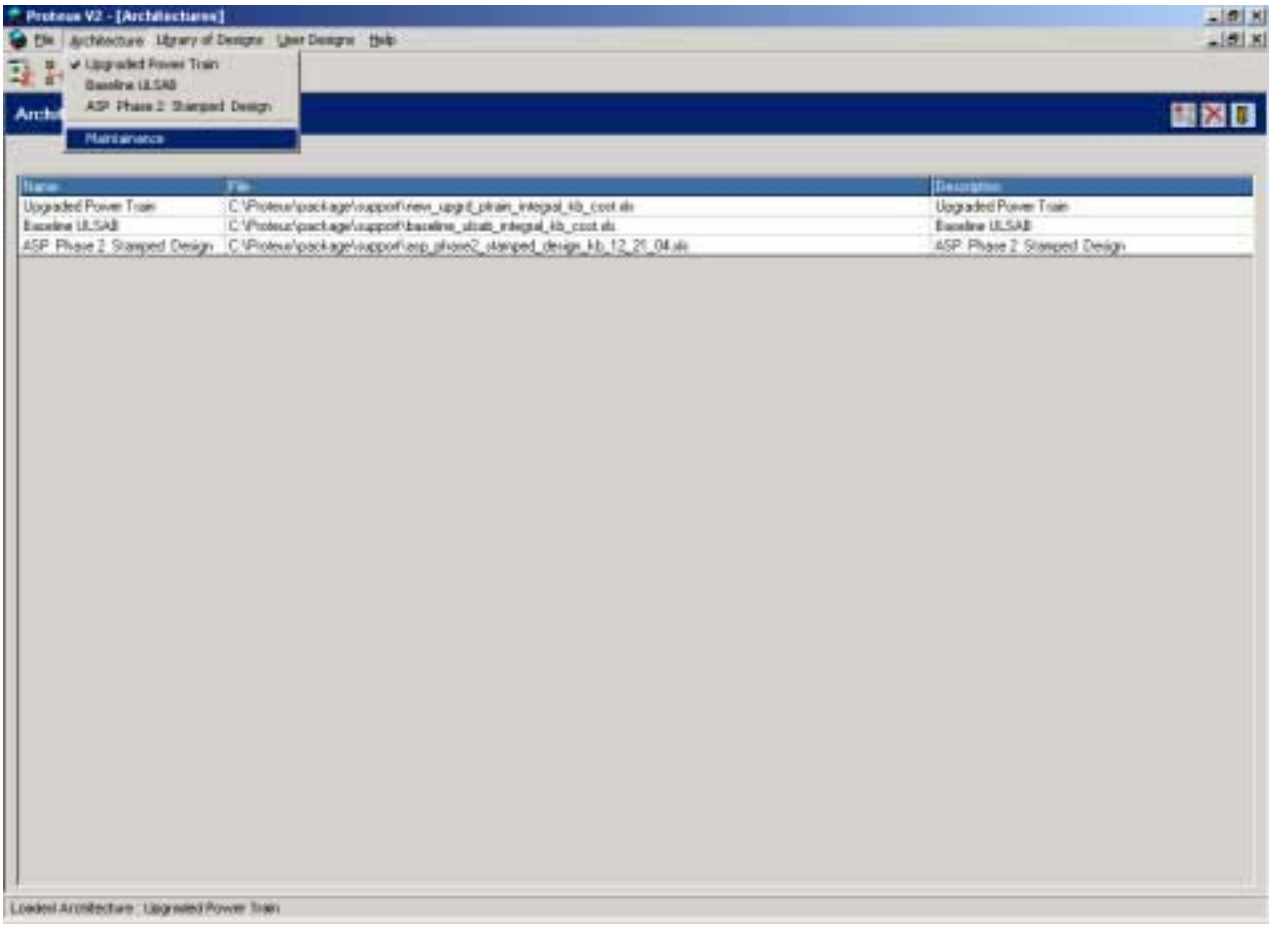


Figure 4: Proteus Architecture Maintenance

7.3 Estimate Design

Click on the *File* option in the menu bar on the top-left corner and select *Estimate*, in order to display the *Estimate Main* page in order to manipulate designs (*Figure 5*). Alternatively, click on the *Estimate* icon in the menu bar. The *Estimate Main* page is displayed by default when the *Windows* version of *Proteus* is launched.

A list of parameters is displayed in three categories – *gauge*, *grade* and *topological*. The user may select pre-set values through pull down lists or can enter any value in the boxes. Please refer to supplement documents accessible through *Online Help* for a description of parameters that are relevant for a specific architecture. By default, baseline values are displayed.

For grades, the pull-down values are actual grade names, where as the box values are the mean stress for the grades. Please note that if the mean stress does not correspond to the drop-down values, there may not be a real material that corresponds to the mean stress entered by the user.

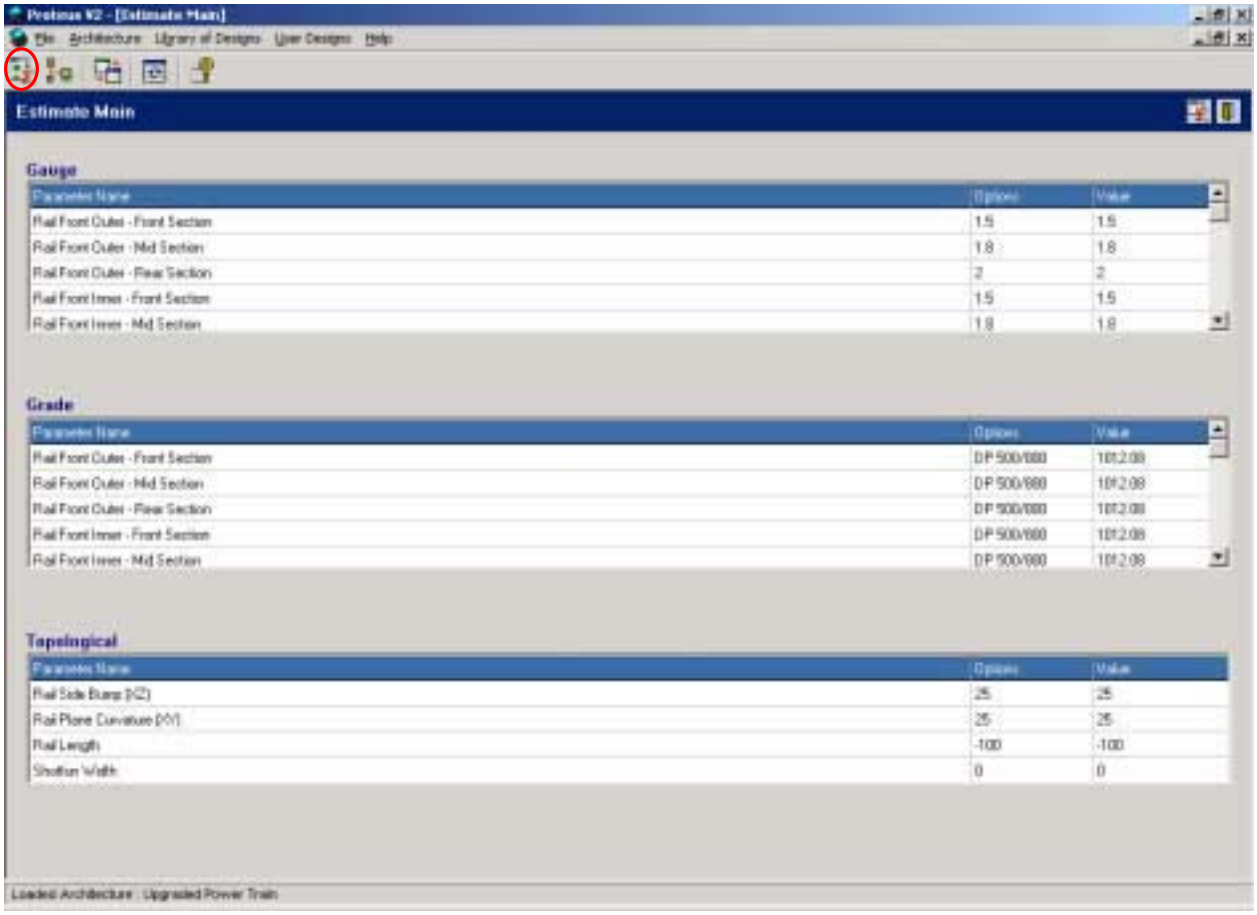


Figure 5: Proteus Estimate Main Page

7.4 Compute Response

Scroll down the list of parameters and click on the *Estimate* icon on the top-right corner of the *Estimate Main* page (*Figure 5*), in order to estimate the responses.

Computation of the responses may take a few seconds, depending on the user computer configuration. The *Estimate Details* page displays cost, mass and DoE responses (*Figure 6*). Please refer to *Online Help* for a list of responses that can be obtained for a specific architecture.

All values in *black* satisfy targets established for the *Lightweight Front-End* project, whereas, all values in *red* fail to met the targets.

Additional results can be obtained by clicking any one of the icons at the top-right corner of the *Estimate Details* page.

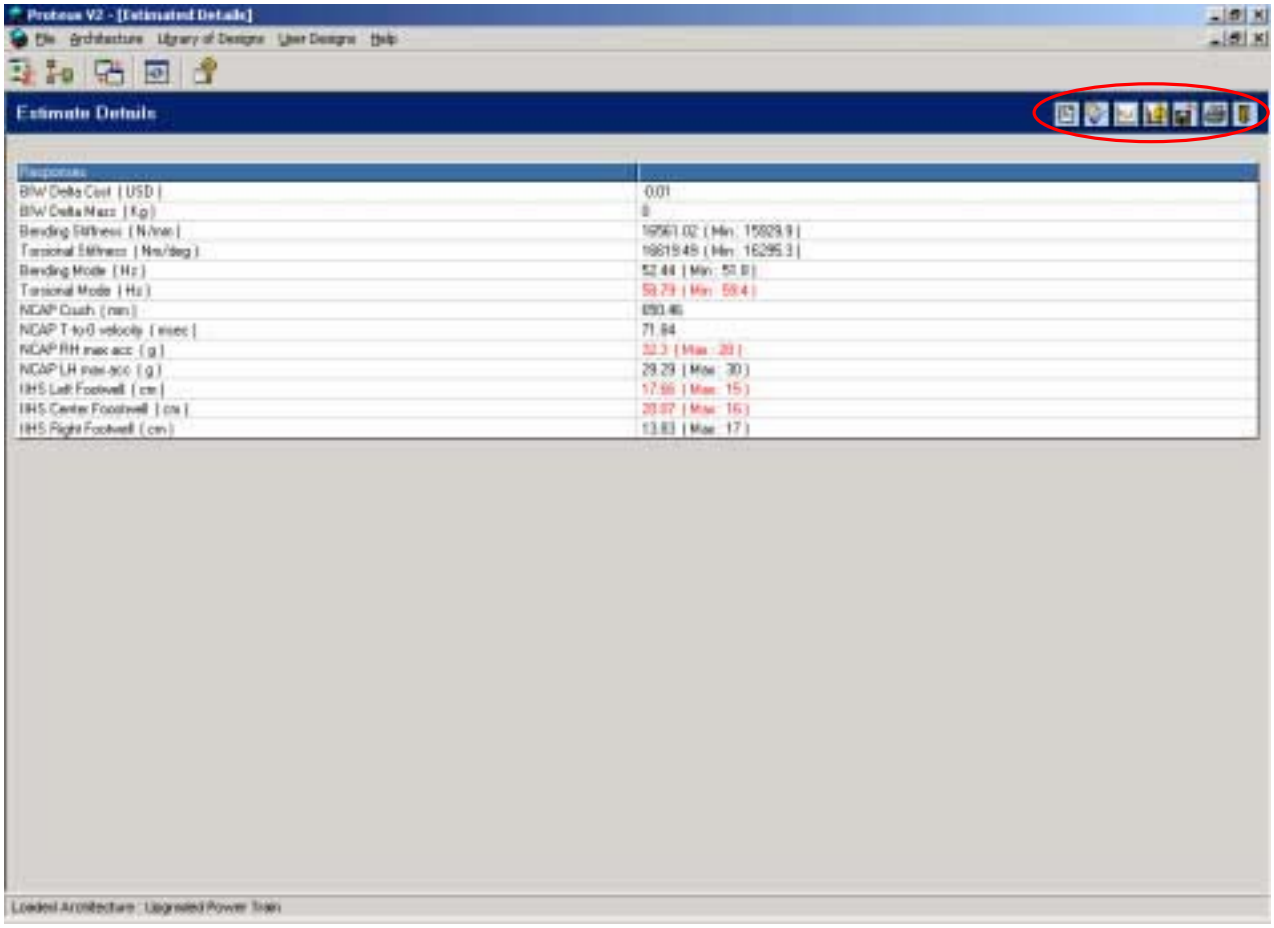


Figure 6: Proteus Estimate Details Page

Mass and Cost Details

Click on *Details* icon on the top-right corner of the *Estimate Details* page (*Figure 6*) in order to obtain a breakdown of part mass and cost (*Figure 7*). The breakdown for the ULSAB-based architectures is according to the *ULSAB* part list, and not according to the DoE part ID. This is because the cost model is based on the *ULSAB* part list.

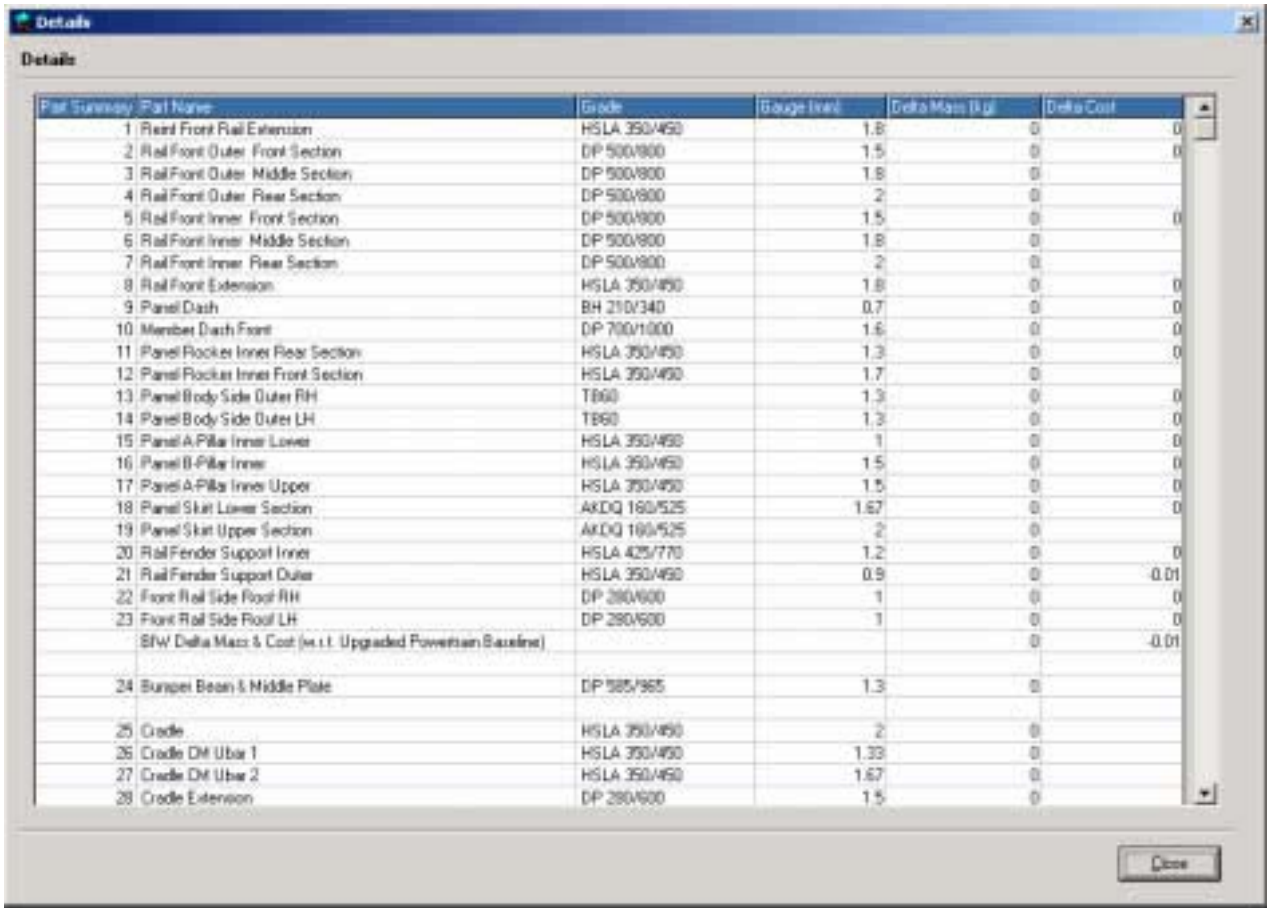


Figure 7: Proteus Details Table

DoE Parameters

Click on the *Parameters* icon on the top-right corner of the *Estimate Details* page (*Figure 6*) to obtain a summary of the DoE parts. The *Parameters* table (*Figure 8)* is identical to the parameters appearing on the *Estimate* page.

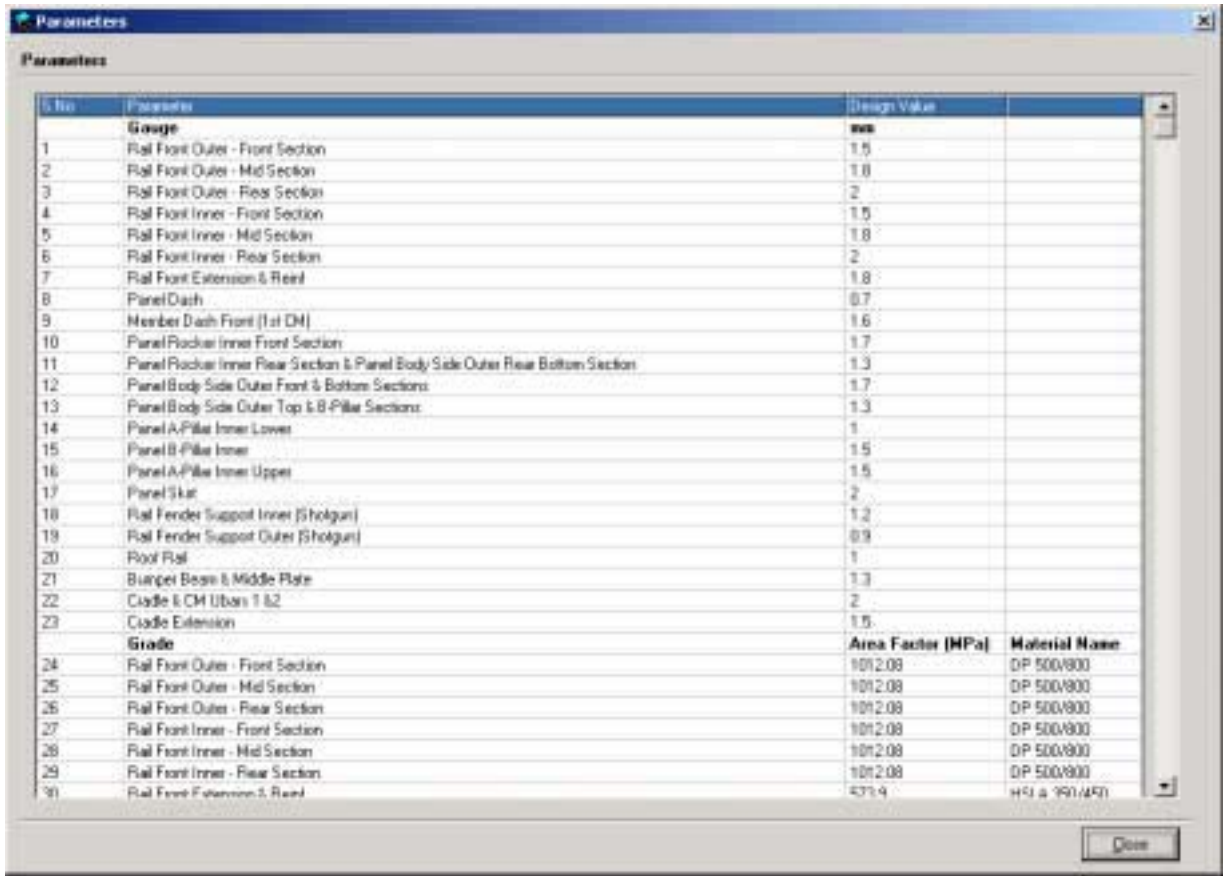


Figure 8: Proteus Parameters Table

Pulse Plotting

Click on the *LH and RH Pulse* icon on the top-right corner of the *Estimate Details* page (*Figure 6*), in order to plot the B-Pillar acceleration pulse (*Figure 9*). Set the toggle to *With Markers* or *Without Markers* to plot the pulse as desired. It may be prudent to plot the pulses obtained through the *Estimate* option with markers, and the pulses obtained through the archived *Library of Designs* without markers.

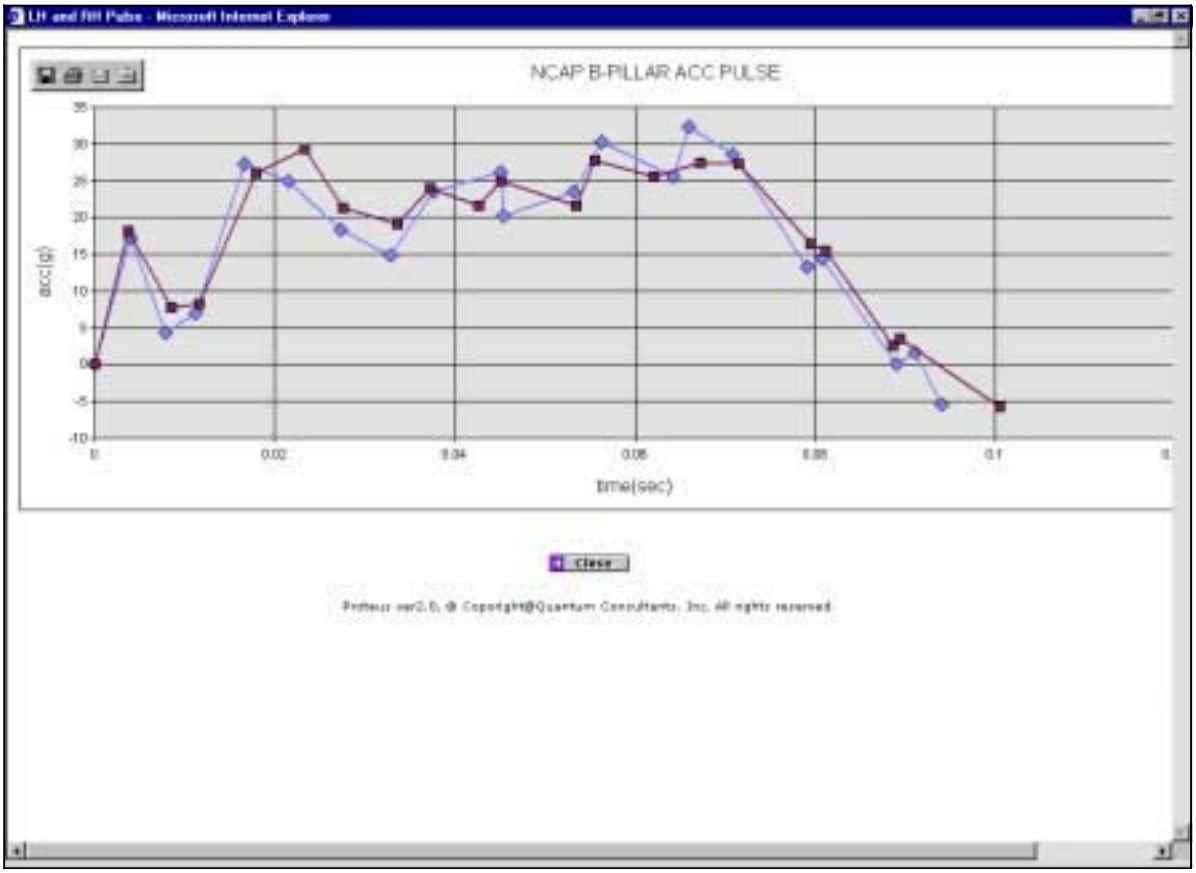


Figure 9: Proteus Pulse Plot

Error Plots

Click on the *Error Graph* icon on the top-right corner of the *Estimate Details* page (*Figure 6*), in order to display error plots.

Select the *NCAP RH Max Acc Error* graph for display (*Figure 10*).

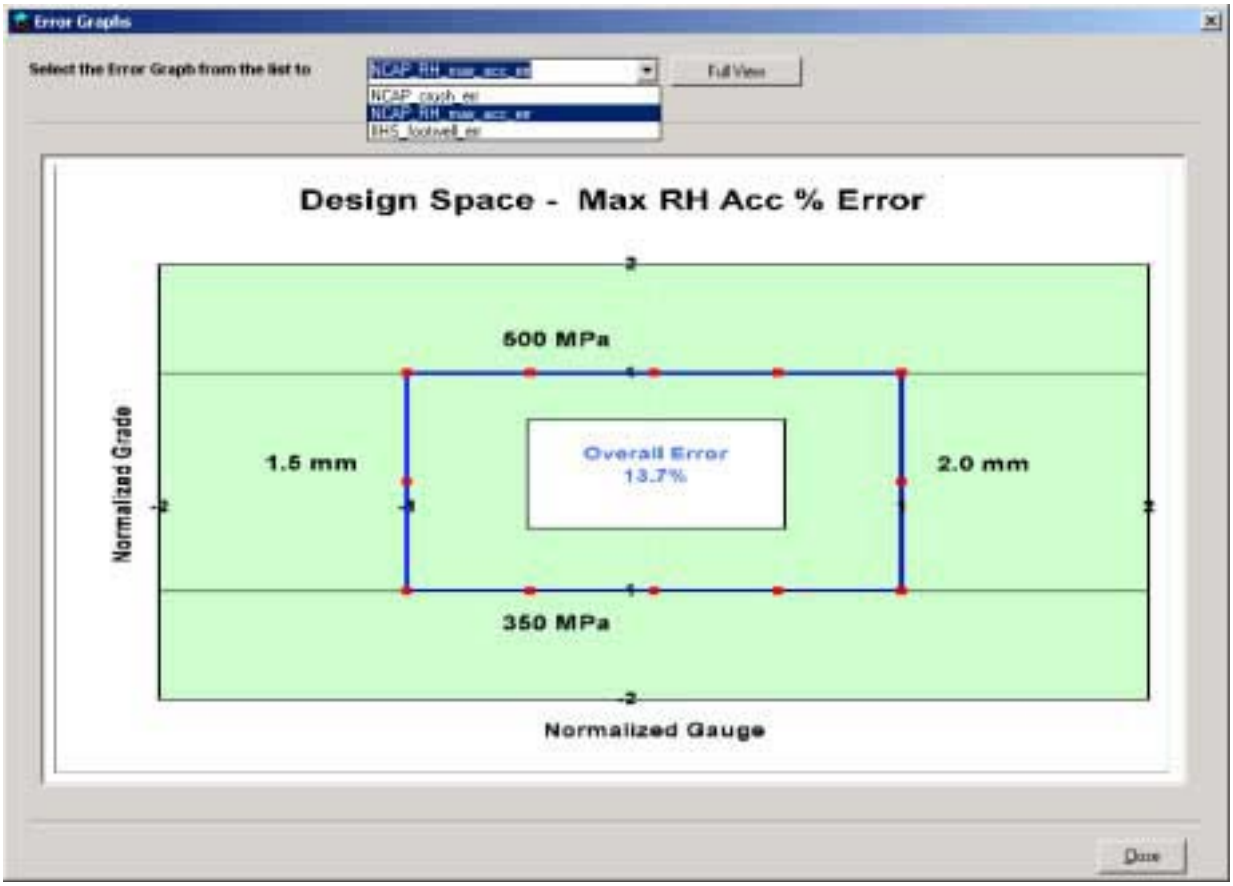


Figure 10: Proteus Error Plots

Save Design as a User Design

Click on the *Save* icon on the top-right corner of the *Estimate Details* page (*Figure 6*), in order to archive the current design for future use.

Enter any name to identify the design (*Figure 11*).

The user design may be recalled for computing responses or for modifications by selecting the *User Design* option in the menu bar.

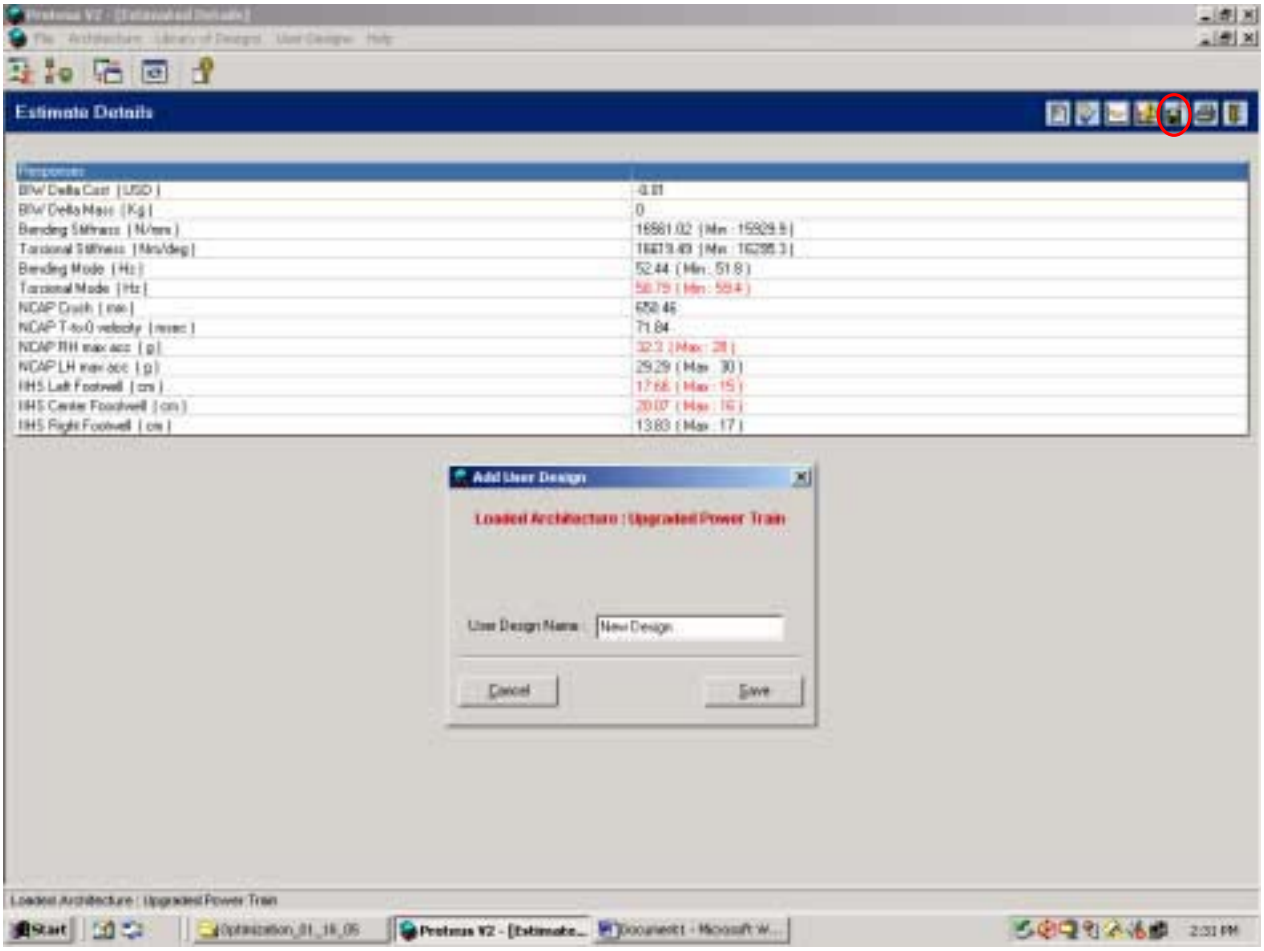


Figure 11: Saving User Designs

7.5 Load a Design from the Library of Designs

Click on the *Library of Designs* option in the menu bar on the top-left corner, in order to load a design from the *Library of Design* (*Figure 12*).

Click on *Design 9* to load the *Upgraded Powertrain* package design.

The *Estimate Main* page is not displayed on selecting this option. Instead, the *Results* page is displayed directly. This is because the *Library of Designs* has results from the actual FE simulations. Hence, designs cannot be manipulated through the *Library of Designs* option. Furthermore, designs in the *Library of Designs* are permanent and cannot be deleted.

Use the *User Designs* feature to manipulate a design from the *Library of Designs*. Please note that if the *User Designs* option is employed, the responses are estimated from the DoE response surfaces.

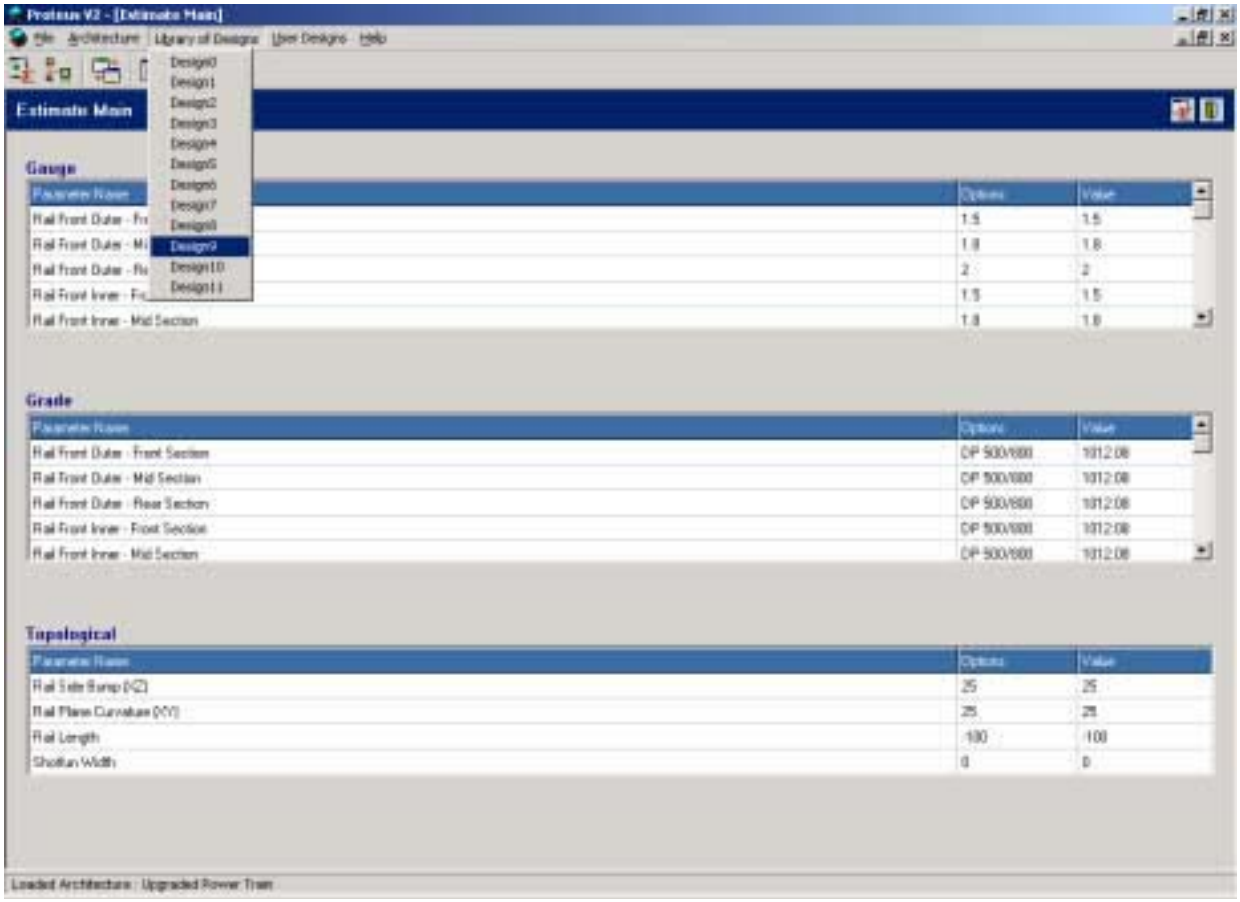


Figure 12: Proteus Library of Design Maintenance Page

7.6 Load A User Design

Click on the *User Designs* option in the menu bar on the top-left corner, in order to load a design saved earlier by the user (*Figure 13*).

Click on *New Design 2* to load the *Upgraded Powertrain* package design.

New Design 2 may now be modified and the responses can be estimated from the DoE response surfaces.

The *Estimate Main* page is displayed upon selecting this option. The user design name is also displayed at the top-left corner. The user may modify the values of the parameters and compute responses as explained earlier.

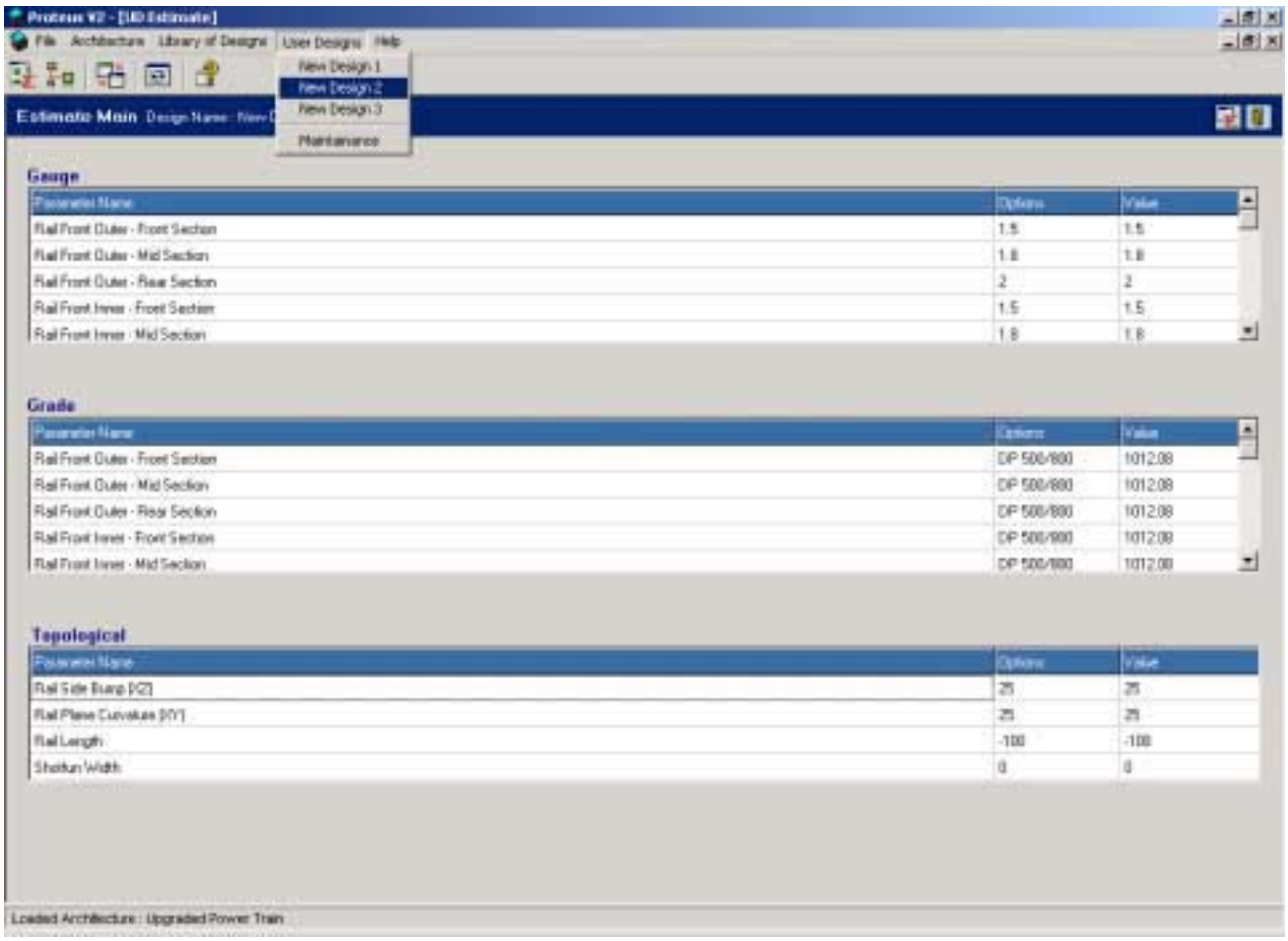


Figure 13: Proteus User Design Maintenance Page

Deleting a User Design

Click on the *User Designs* option in the menu bar on the top-left corner, and select *Maintenance* in order to delete an existing user design (*Figure 13*). Highlight the user design to be deleted and click *Delete*.

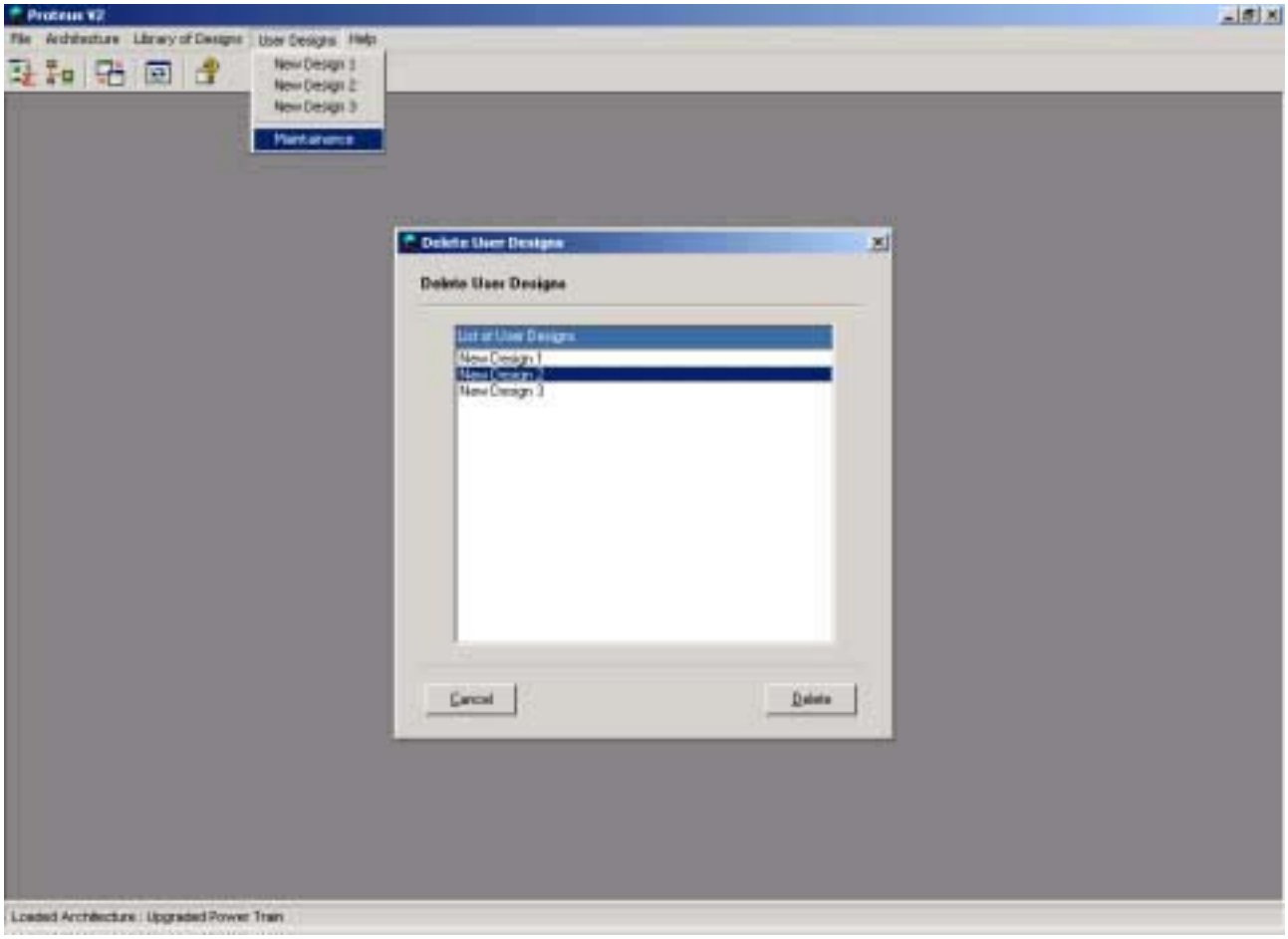


Figure 14: Proteus User Design Maintenance Page

7.7 Compare Designs

Click on the *File* option in the menu bar on the top-left corner and select *Compare Designs* (*Figure 15*), in order to compare any two designs from the *Library of Designs* or *User Designs*. Alternatively, click on the *Compare Designs* icon in the menu bar.

Select *Design 9* from *Library of Designs* and *New Design 2* from *User Designs* for comparison (*Figure 15*).

The *Estimate* page is not displayed on selecting this option. Instead, the *Results* page is displayed directly. This is because this option simply compares two designs. Designs from the *Library of Designs* have results from the actual FEA simulations, where as, the *User Designs* have results from DoE response surfaces. It is therefore prudent not to compare a design from the *Library of Designs* with a *User Design*.

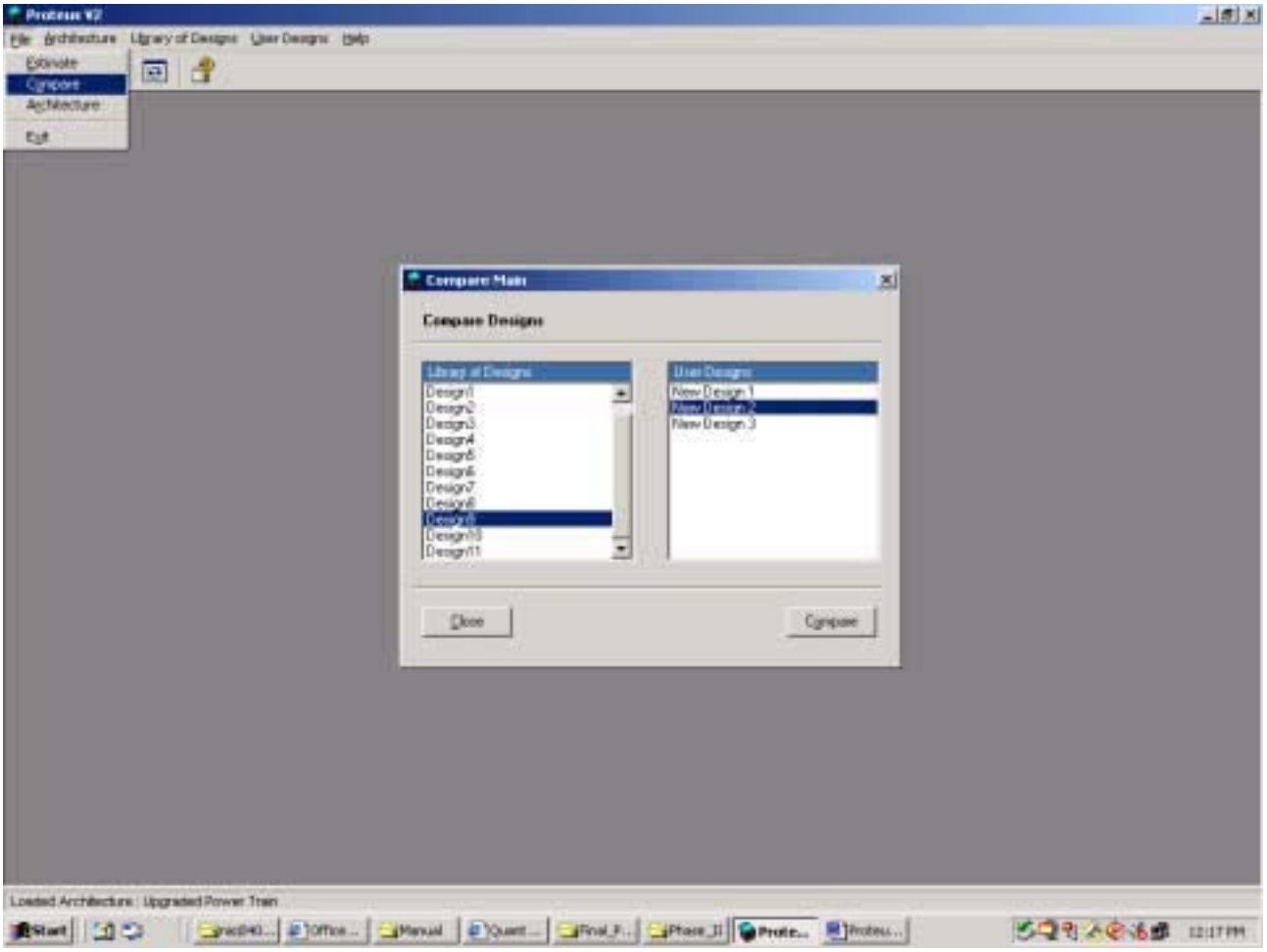


Figure 15: Proteus Design Comparison

7.8 Optimize Design

Click on the *Optimize* icon in the menu bar on the top-left corner, in order to display the *Optimizer* page (*Figure 16*).

Use the right-most *Optimize* column to set the optimization design variables. By default all parameters are active design variables (*Yes*). In order to deactivate a parameter, toggle the entry from *Yes* to *No*.

The minimum and maximum allowable values for the parameters can be modified in the *Min* and *Max* columns. Any value may be entered for gauge and topological parameters. However, optimization results are accurate only within the DoE bounds. Range for the grade parameters is pre-defined and cannot be modified as they are treated as discrete variables.

The starting values of parameters can be modified through the *Starting-Value* column. The default starting values are the baseline values for the architecture. Any value maybe entered for gauge and topological parameters. The starting value for grade parameters is limited to the options available in the *Material* column.

Select objective and constraints from the *Objective* column of the *Constraints* section at the bottom. Any of the available responses can be set as the objective function. By default no objective or constraints are selected (*None*). Toggle the entry to *Minimize* or *Maximize* in order to identify the response as the objective function for optimization. Only one response can be selected as the objective function. Selecting any other response subsequently as the objective function will set that response as the new objective function.

Select *Constrain* in order to identify the response as a constraint function. Any number of responses maybe selected as constraints. The values entered in *Min* and *Max* columns serve as the lower and upper bounds for constraints. If either *Min* or *Max* value is undefined, the corresponding bound is inactive. Default values are displayed for some responses. Any value maybe entered in *Min* and *Max* columns.

Click on the *Optimize* icon on the top right corner to start the optimization. Optimization of the responses may take a few minutes, depending on the specifications of the user computer. The *Optimizer Details* page is displayed upon completion of the optimization (*Figure 17*). It summarizes the initial responses, optimized responses and change in responses. Additional results can be obtained by clicking on the options in the top right corner (refer to *Compute Response* section for details).

Setup the following optimization problem for *ASP Phase II Stamped Design* architecture.

Min Mass

Subject:

Bending Stiffness > 12500 N/mm
Torsional Stiffness > 20000 Nm/deg

1. Select the *ASP Phase II Stamped Design* architecture from the Architecture menu option.

2. Click on the *Optimize* icon.

3. Make all *Parameters* active for the optimization - *Optimize* column set to *Yes* (default).

4. Use default *Min*/*Max* values for *Parameters*.

5. In *Constraints* section set *Objective* column for the desired responses ().

6. Enter the stiffness bounds in the *Min* column.

7. Click on the *Optimize* icon on the top right corner to start the optimization.

In this example, the *Optimizer* finds a solution (*Final Values*) that is 7.01kg lighter than the *Baseline Design* for the architecture. The initial design (*Base Values*) is 4.77kg lighter than the *Baseline Design.* Hence, the optimized design is 2.24kg lighter than the initial design and satisfies the stiffness constraints.

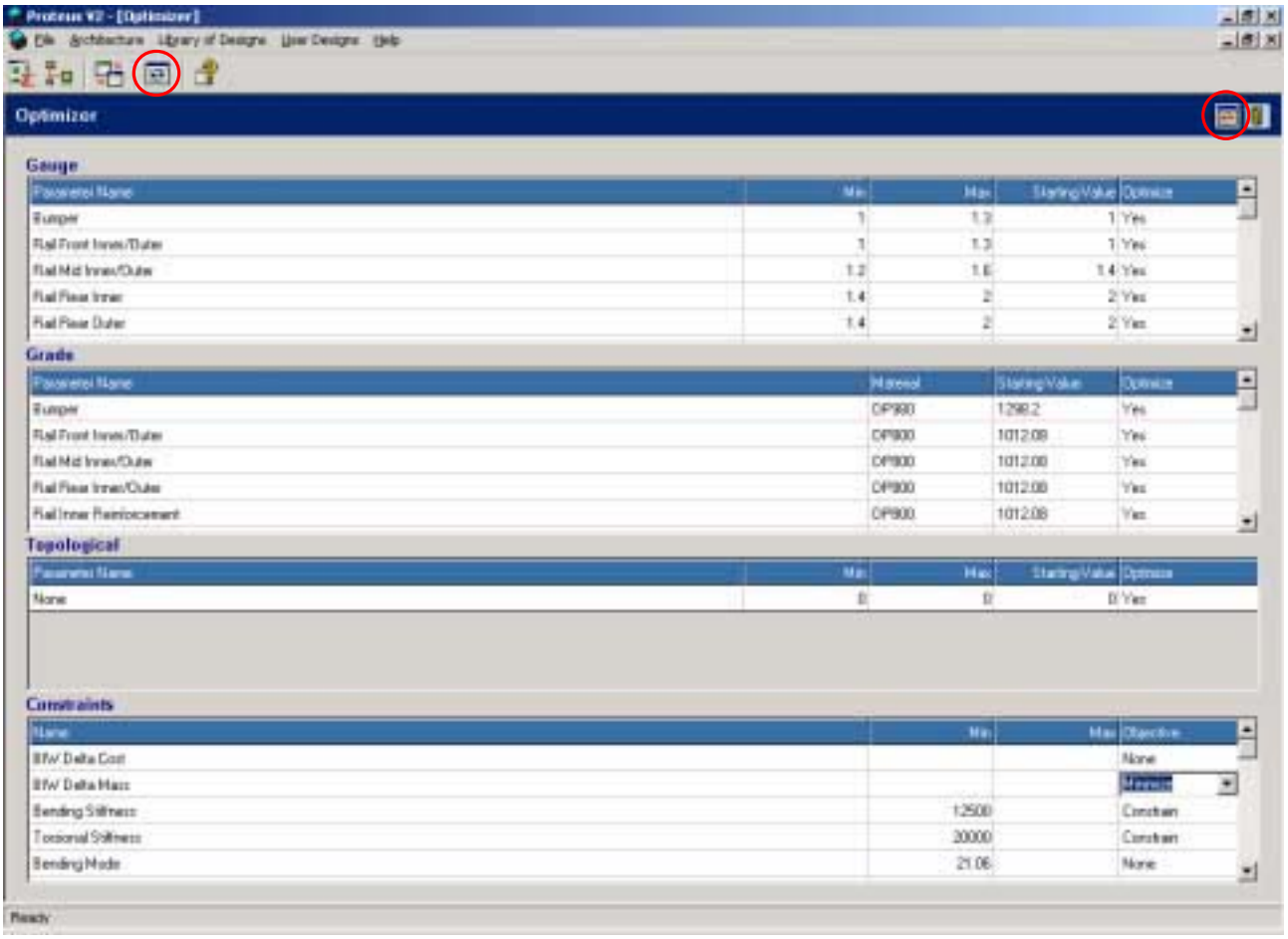


Figure 16: Proteus Optimizer Page

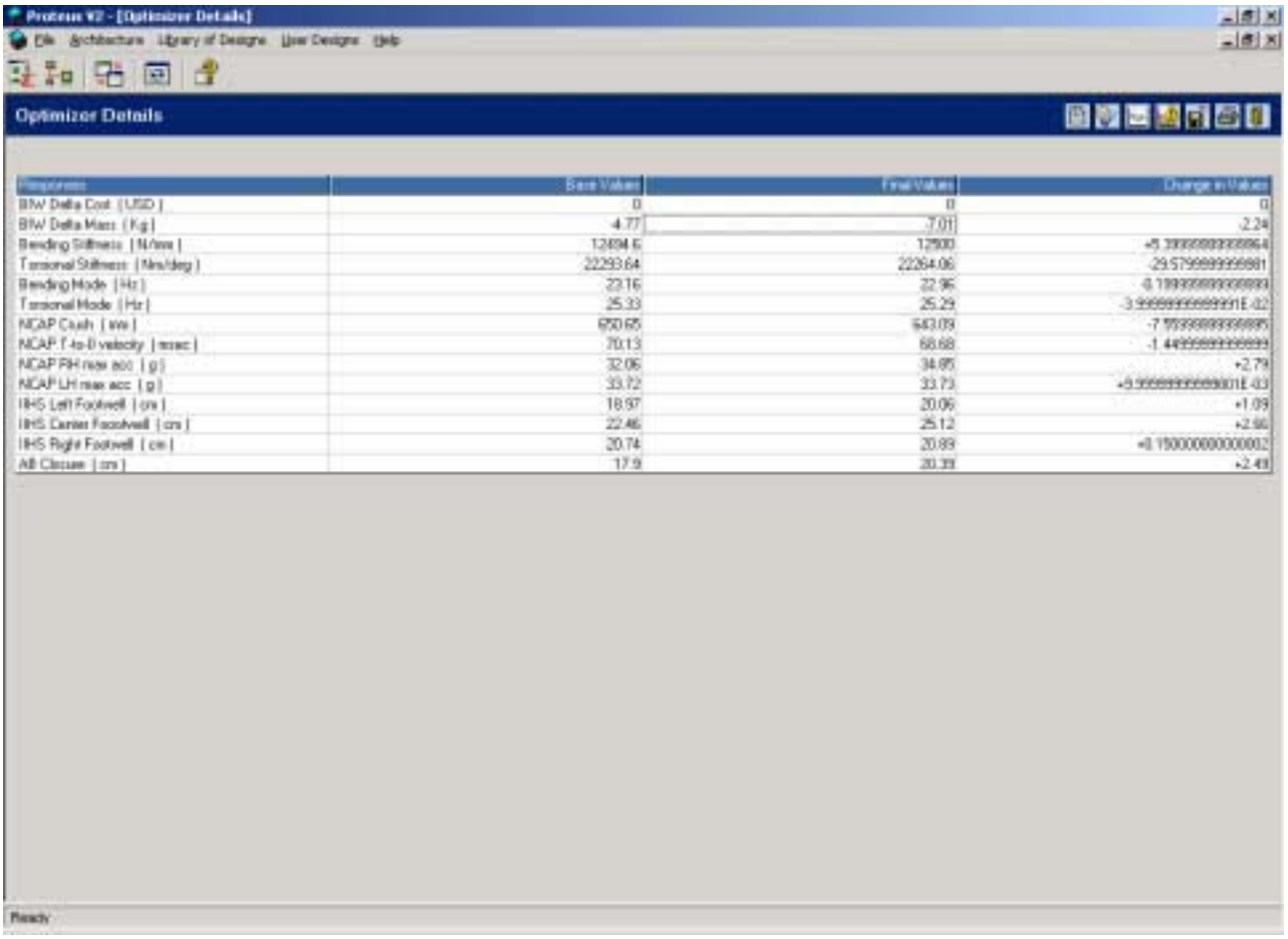


Figure 17: Proteus Optimizer Details Page

Quantech
Global Services

Initial Front-End Package: Phase I

Lightweight Front End Structure

Prepared for

Auto/ Steel Partnership

By

Quantech Global Services
Okemos, Troy
Michigan

January 28, 2005

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Initial Front-End Package: Phase I

1 Front-End DoE Parameters

Table 1: Parameters and Responses: Initial Front-End Package

S.N.	Initial Front End Package Parameters	Static Stiffness	Dynamic Stiffness	NCAP	IIHS	ULSAB Part ID	DOE LH Part ID
	Gauge						
1	Rail Front Outer - Front Section	y	y	y	n	008/009	60011
2	Rail Front Outer - Mid Section	y	y	y	n	008/009	60012
3	Rail Front Outer - Rear Section	y	y	y	n	008/009	60013
4	Rail Front Inner - Front Section	y	y	y	n	010/011	60021
5	Rail Front Inner - Mid Section	y	y	y	n	010/011	60022
6	Rail Front Inner - Rear Section	y	y	y	n	010/011	60023
7	Rail Front Extension & Reinf	y	n	n	n	012/013+002/003	60035+60033
8	Panel Dash	y	y	n	n	021	60071
9	Member Dash Front (1st CM)	y	y	y	n	26	60031
10	Panel Rocker Inner Front & Rear Sections	y	y	n	n	042/043	6022+60222
11	Panel Body Side Outer Front & Bottom Sections	y	y	n	n	060/061 Front & Bottom Section	60278+60277
12	Panel Body Side Outer Top/B-Pillar & Rear Bottom Sections	y	y	n	n	060/061 Top/B-Pillar & Rear Bottom Sections	60273+60274
13	Panel A-Pillar Inner Lower	y	y	n	n	062/063	60226
14	Panel B-Pillar Inner	y	y	n	n	064/065	60261
15	Panel A-Pillar Inner Upper	y	y	n	n	074/075	60225
16	Panel Skirt	y	n	n	n	096/097	60040+60039
17	Rail Fender Support Inner (Shotgun)	y	y	y	n	104/105	60049
18	Rail Fender Support Outer (Shotgun)	y	y	y	n	106/107	60051
19	Roof Rail	y	y	n	n	072/073 Fwd of B-Pillar	60241
20	Bumper C-Section	y	y	y	n	-	
21	Cradle	n	n	y	n	-	60703
22	Cradle CM Ubars 1 & 2	n	n	y	n	-	60701+60702
23	Cradle Extension	n	n	y	n	-	60705
	Grade						
24	Rail Front Outer - Front Section	n	n	y	n	008/009	60011
25	Rail Front Outer - Mid Section	n	n	y	n	008/009	60012
26	Rail Front Outer - Rear Section	n	n	y	n	008/009	60013
27	Rail Front Inner - Front Section	n	n	y	n	010/011	60021
28	Rail Front Inner - Mid Section	n	n	y	n	010/011	60022
29	Rail Front Inner - Rear Section	n	n	y	n	010/011	60023
30	Member Dash Front (1st CM)	n	n	y	n	26	600031
31	Rail Fender Support Inner (Shotgun)	n	n	y	n	104/105	60049
32	Rail Fender Support Outer (Shotgun)	n	n	y	n	106/107	60051
33	Bumper C-Section	n	n	y	n	-	400021+400023+400022
34	Cradle	n	n	y	n	-	60703+60701 +60702
35	Cradle CM Ubars 1 & 2	n	n	y	n	-	60701+60702
36	Cradle Extension	n	n	y	n	-	60705

2 Static Stiffness Study

Table 2: Levels of Parameters – Static Stiffness Study of Initial Front-End Package

S.N.	Component Name	L81 Col	PID	Level 1	Level 2*	Level 3
1	Bumper C-Section	26	400000	1.3	1.6	2.0*
2	Rail Front Inner	36	65021	1.0	1.5	2.0
3	Rail Front Outer	38	65011	1.0	1.5	2.0
4	Rail Mid Inner	10	65022	1.0	1.6	2.0
5	Rail Mid Outer	18	65012	1.0	1.6	2.0
6	Rail Rear Inner	13	65023	1.0	1.8	2.0
7	Rail Rear Outer	20	65013	1.0	1.5	2.0*
8	Shot Gun Inner	12	65049	0.7	1.2	2.0
9	Shot Gun Outer	15	65051	0.7	0.9	2.0
10a	Rail Extension	32	65035	1.0	1.4	2.0
10b	Rail Extension Reinf	32		0.8	1.0	1.2
11	Ist Cross Member	9	60031	0.7	1.2	2.0
12a	Skirt 1	17	65039	1.0	1.6	2.0
12b	Skirt 2	17	65040	1.0	1.5	2.0*
13	A-Pillar Upper	23	65225	1.0	1.5	2.0
14	A-Pillar Body Side Outer	21	65278	1.0	1.7	2.0
15	A-Pillar Hinge Pillar	1	65226	1.0*	1.5	2.0
16	B-Pillar Inner	2	65261	1.0	1.5	2.0
17	B-Pillar Body Side Outer	16	65273	1.0	1.3	2.0
18	Rocker Inner	5	65221	1.0	1.7	2.0
19	Roof Rail	37	65241	0.8	1.0	1.2
20	Dash Panel	14	60071	0.6	0.7	1.2

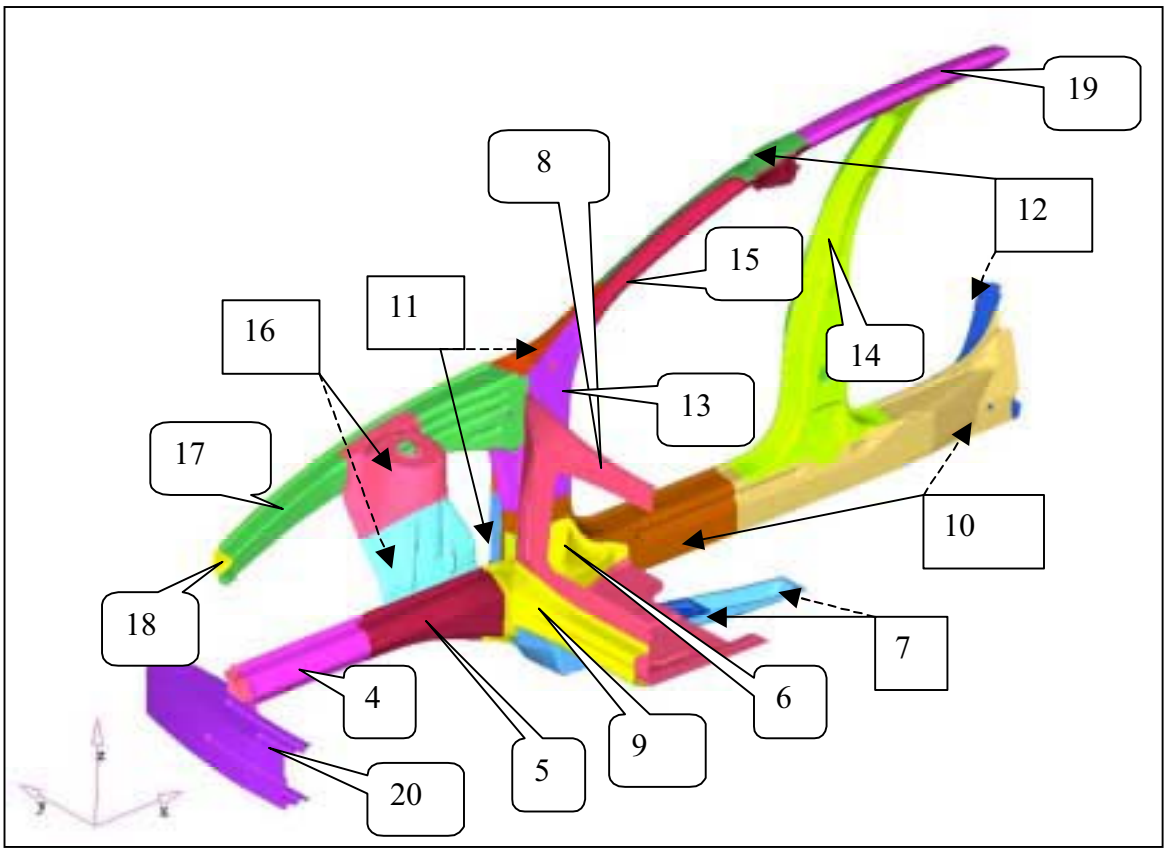


Figure 1: Front-End Parts - Static Stiffness Study of Initial Front-End Package

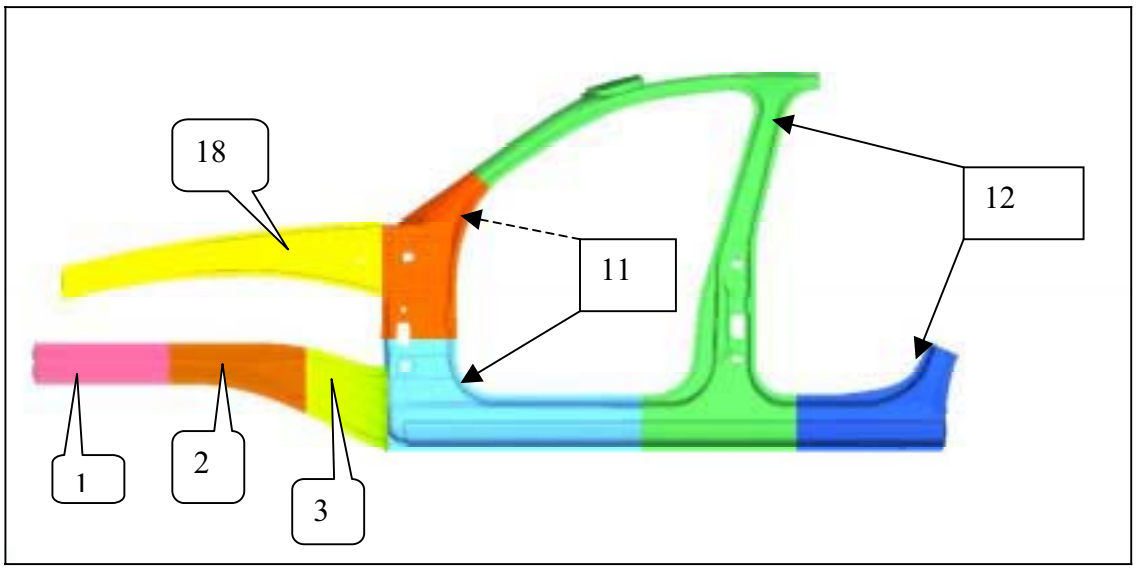


Figure 2: Front-End Parts - Static Stiffness Study of Initial Front-End Package

Note: solid line = primary gauge, dashed line = gauge derived from primary gauge

3 Dynamic Stiffness Study

Table 3: Levels of Parameters - Dynamic Stiffness Study of Initial Front-End Package

Parameters	D.O.E. Array Column Number	Thickness (mm)		
		Level 1 *	Level 2	Level 3
Rail Front Inner	1	1.5	1.0	2.0
Rail Mid Inner	2	1.6	1.0	2.0
Rail Rear Inner	5	1.8	1.0	2.0
Rail Front Outer	9	1.5	1.0	2.0
Rail Mid Outer	10	1.6	1.0	2.0
Rail Rear Outer	12	1.5	1.0	2.0*
Shot Gun Inner	3	1.2	0.7	2.0
Shot Gun Outer	13	0.9	0.7	2.0
1st Cross Member	4	1.2	0.7	2.0
Dash Panel	6	0.7	0.6	1.2
Rail Side Roof	11	1.0	0.8	1.2
Hinge Pillar and Assembly	7			
Hinge Pillar	7	1.5	1.0	2.0
Rocker Inner	7	1.7	1.0	2.0
Body Side Outer A Pillar	7	1.5	1.0	2.0
Body Side Outer A Pillar	7	1.7	1.0	2.0
A Pillar Upper	7	1.5	1.0	2.0
B Pillar and Assembly	8			
B Pillar Inner	8	1.5	1.0	2.0
Body Side Outer B Pillar	8	1.3	1.0	2.0

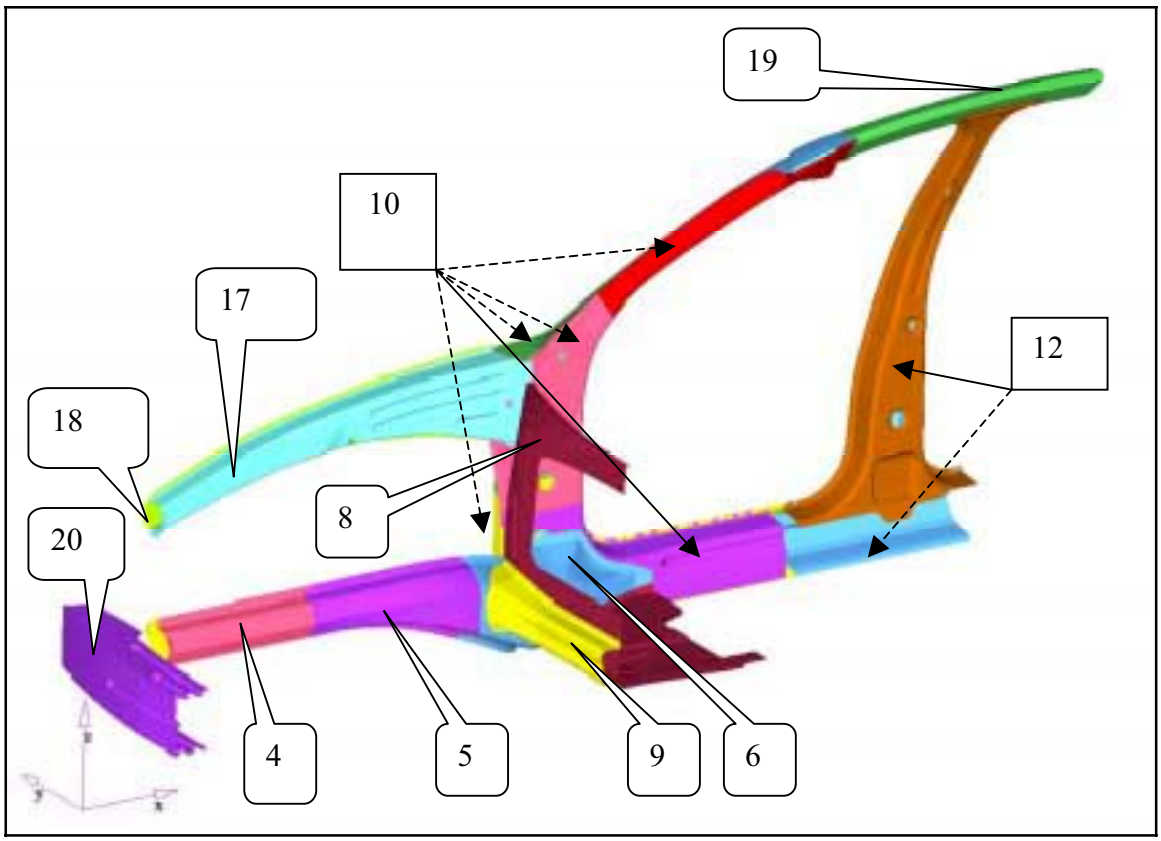


Figure 3: Front-End Parts - Dynamic Stiffness Study of Initial Front-End Package

4 NCAP Study

Table 4: Levels of Parameters - NCAP Study of Initial Front-End Package

	Component	Thickness (mm)		Material Yield / Ultimate (MPa)	
		Level 1	Level 2 *	Level 1 *	Level 2
1	Bumper C-Section	1.3	2.0	HSLA 350/450	DP 500/800
2	Rail Front Inner	1.0	1.5	HSLA 350/450	DP 500/800
3	Rail Front Outer	1.0	1.5	HSLA 350/450	DP 500/800
4	Rail Mid Inner	1.0	1.6	HSLA 350/450	DP 500/800
5	Rail Mid Outer	1.0	1.6	HSLA 350/450	DP 500/800
6	Rail Rear Inner	1.2	1.8	HSLA 350/450	DP 500/800
7	Rail Rear Outer	1.3	2.0	HSLA 350/450	DP 500/800
8	Shot Gun Inner	0.8	1.2	HSLA 425/770	DP 500/800
9	Shot Gun Outer	0.7	0.9	HSLA 350/450	DP 500/800
10	Cradle Cross Mbr 1st Ubar1	1.0	1.3	HSLA 350/450	DP 500/800
	Cradle Cross Mbr 2nd Ubar2	1.0	1.6	HSLA 350/450	DP 500/800
11	Cradle	1.3	2.0	HSLA 350/450	DP 500/800
12	Cradle Extension	1.0	1.5	DP 280/600	DP 500/800
13	Ist Cross Member	0.8	1.2	HSLA 425/770	DP 700/1000 *

1,2 - Combined Parameters *Indicates baseline values

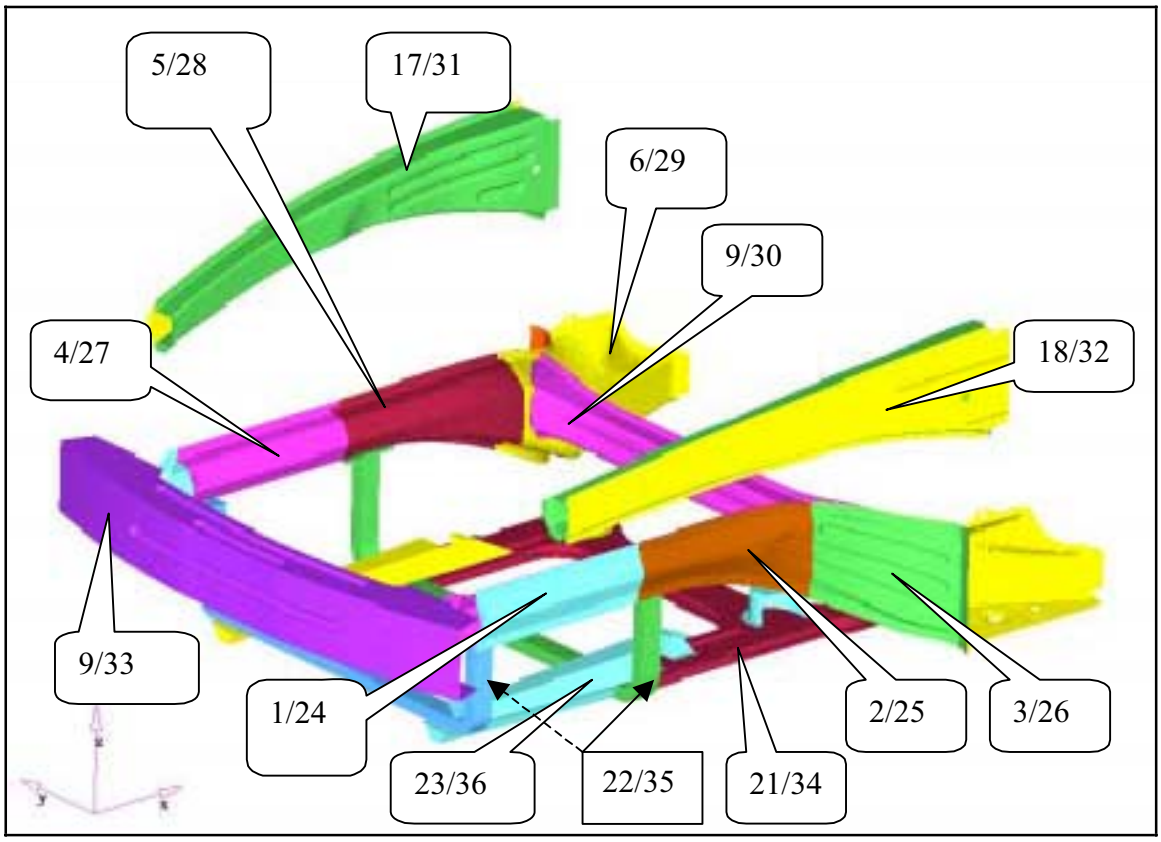


Figure 4: Front-End Parts - NCAP Study of Initial Front-End Package

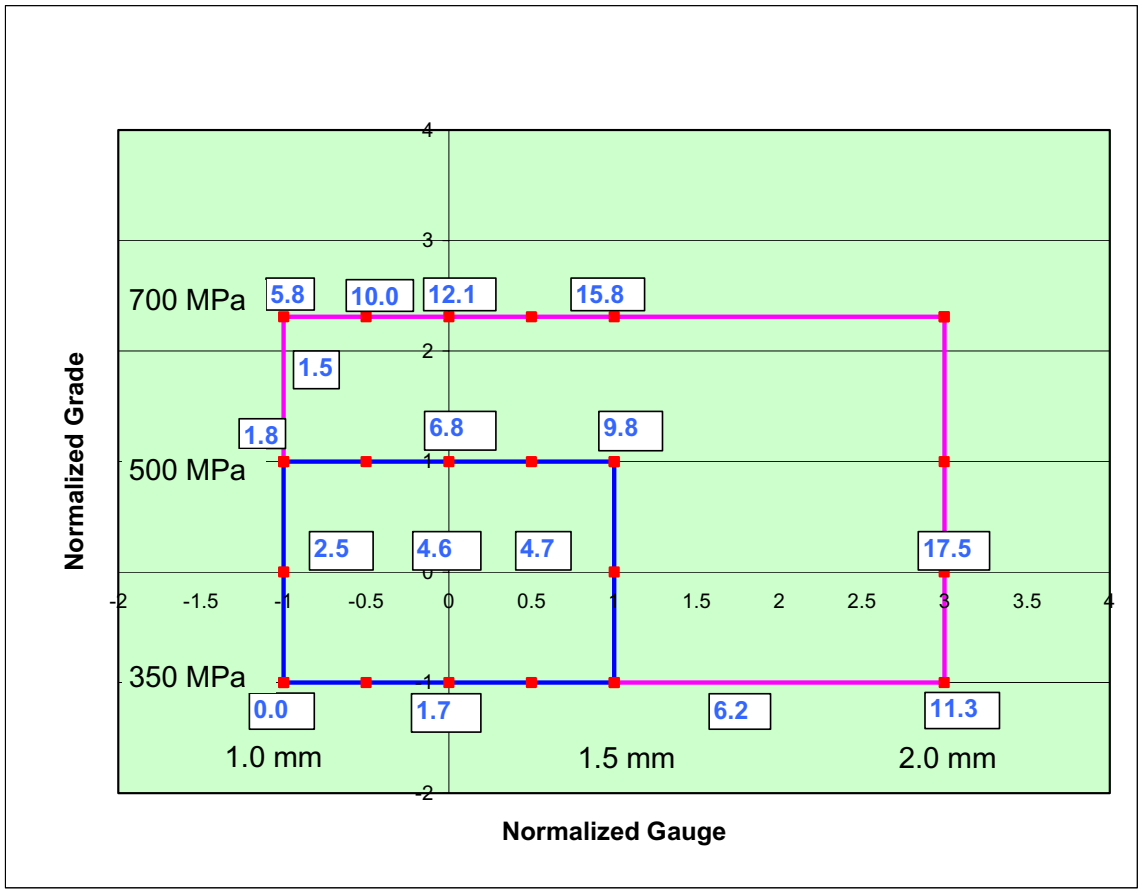


Figure 5: Design Space - Crush % Error

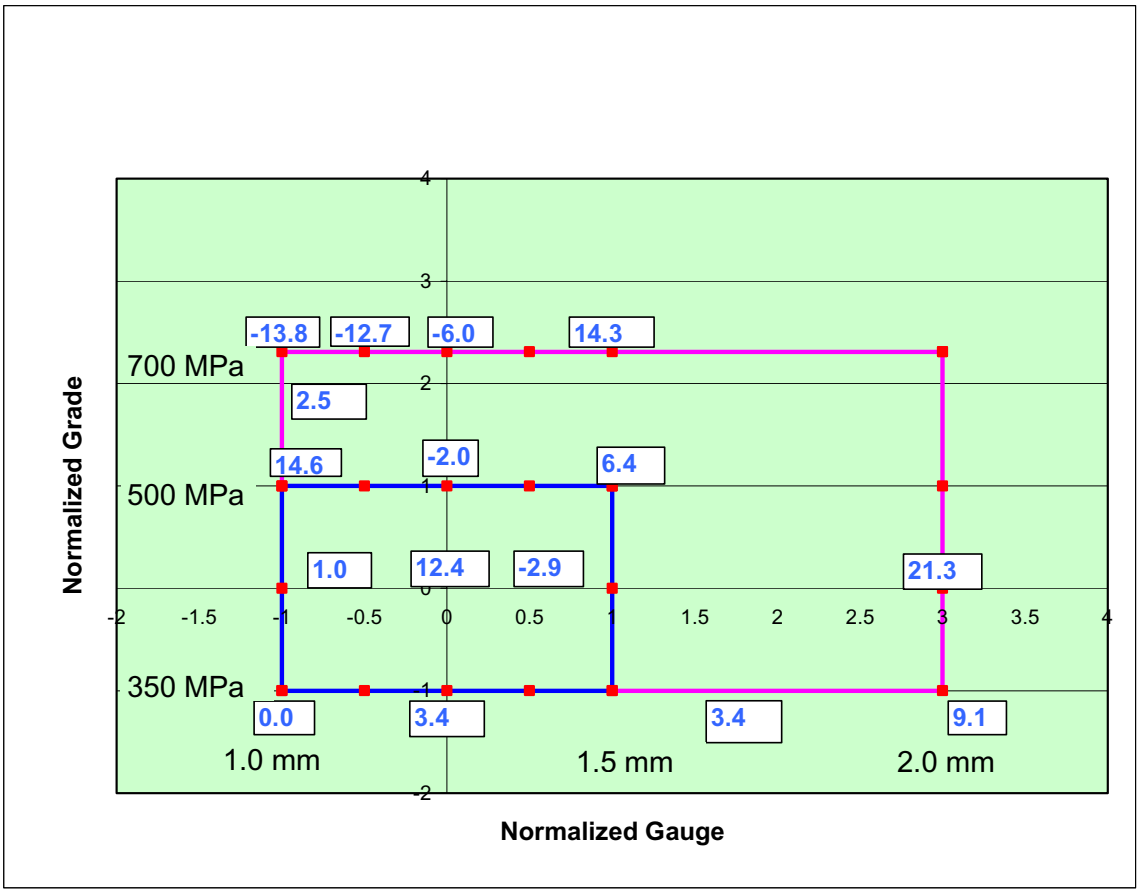


Figure 6: Design Space - 50-70 ms Acceleration % Error

Quantech
Global Services

Upgraded Front-End Package: Phase I

Lightweight Front End Structure

Prepared for

Auto/ Steel Partnership

By

Quantech Global Services
Okemos, Troy
Michigan

January 28, 2005

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Upgraded Front-End Package: Phase I

1 Front-End DoE Parameters

Table 1: Parameters and Responses: Upgraded Front-End Package

S.N.	Upgraded Front End Package Parameters	Static/ Dynamic Stiffness	NCAP	IIHS	ULSAB Part ID	DOE LH Part ID
	Gauge					
1	Rail Front Outer - Front Section	y	y	y	008/009	60011
2	Rail Front Outer - Mid Section	y	y	y	008/009	60012
3	Rail Front Outer - Rear Section	y	y	y	008/009	60013
4	Rail Front Inner - Front Section	y	y	y	010/011	60021
5	Rail Front Inner - Mid Section	y	y	y	010/011	60022
6	Rail Front Inner - Rear Section	y	y	y	010/011	60023
7	Rail Front Extension & Reinf	y	y	y	012/013 + 002/003	60035 + 60033
8	Panel Dash	y	n	n	021	60071
9	Member Dash Front (1st CM)	y	y	y	26	60031
10	Panel Rocker Inner Front Section	y	n	y	042/043 - Front Section	60221
11	Panel Rocker Inner Rear Section & Panel Body Side Outer Rear Bottom Section	y	n	n	042/043 Rear Section+ 060/061 Rear Bottom Section	60222 + 60274
12	Panel Body Side Outer Front & Bottom Sections	y	n	y	060/061 Front & Bottom Section	60278 + 60277
13	Panel Body Side Outer Top & B-Pillar Sections	y	n	y	060/061 Top & B-Pillar Sections	60273
14	Panel A-Pillar Inner Lower	y	n	y	062/063	60226
15	Panel B-Pillar Inner	y	n	y	064/065	60261
16	Panel A-Pillar Inner Upper	y	n	y	074/075	60225
17	Panel Skirt	y	y	y	096/097	60040 + 60039
18	Rail Fender Support Inner (Shotgun)	y	y	y	104/105	60049
19	Rail Fender Support Outer (Shotgun)	y	y	y	106/107	60051
20	Roof Rail	y	n	y	072/073 Fwd of B-Pillar	60241
21	Bumper Beam & Middle Plate	y	y	y	-	400021 + 400023 + 400022
22	Cradle & CM Ubars 1 &2	n	y	y	-	60703 + 60701 + 60702
23	Cradle Extension	n	y	y	-	60705
	Grade					
24	Rail Front Outer - Front Section	n	y	y	008/009	60011
25	Rail Front Outer - Mid Section	n	y	y	008/009	60012
26	Rail Front Outer - Rear Section	n	y	y	008/009	60013
27	Rail Front Inner - Front Section	n	y	y	010/011	60021
28	Rail Front Inner - Mid Section	n	y	y	010/011	60022
29	Rail Front Inner - Rear Section	n	y	y	010/011	60023
30	Rail Front Extension & Reinf	n	y	y	012/013 + 002/003	60035 + 60033
31	Member Dash Front (1st CM)	n	y	y	26	60031
32	Panel Rocker Inner Front Section	n	n	y	042/043 - Front Section	60221
33	Panel Body Side Outer Front & Bottom Sections	n	n	y	060/061 Front & Bottom Section	60278 + 60277

34	Panel Body Side Outer Top & B-Pillar Sections	n	n	y	060/061 Top & B-Pillar Sections	60273
35	Panel A-Pillar Inner Lower	n	n	y	062/063	60226
36	Panel B-Pillar Inner	n	n	y	064/065	60261
37	Panel A-Pillar Inner Upper	n	n	y	074/075	60225
38	Panel Skirt	n	y	y	096/097	60040 + 60039
39	Rail Fender Support Inner (Shotgun)	n	y	y	104/105	60049
40	Rail Fender Support Outer (Shotgun)	n	y	y	106/107	60051
41	Roof Rail	n	n	y	072/073 Fwd of B-Pillar	60241
42	Bumper Beam & Middle Plate	n	y	y	-	400021 + 400023 + 400022
43	Cradle & CM Ubars 1 &2	n	n	y	-	60703 + 60701 + 60702
44	Cradle Extension	n	y	y	-	60705
	Topological					
45	Rail Side Bump (XZ)	n	y	y		
46	Rail Plane Curvature (XY)	y	y	y		
47	Rail Length	y	y	y		
48	Shotgun Width	y	y	y		

2 Static/Dynamic Stiffness Study of Upgraded Front-End Package

S.N.	Component Name	L81 Col	PID	Level 1	Level 2*	Level 3
1a	Bumper Middle Section	26	400021	1.3	1.6	2.0*
1b	Bumper End Section	26	400023	1.3	1.6	2.0*
1c	Bumper Middle Plate	26	400022	1.3	1.6	2.0*
2	Rail Front Inner	36	65021	1.0	1.5	2.0
3	Rail Front Outer	38	65011	1.0	1.5	2.0
4	Rail Mid Inner	10	65022	1.0	1.6	2.0
5	Rail Mid Outer	18	65012	1.0	1.6	2.0
6	Rail Rear Inner	13	65023	1.0	1.8	2.0
7	Rail Rear Outer	20	65013	1.0	1.5	2.0*
8	Shot Gun Inner	12	65049	0.7	1.2	2.0
9	Shot Gun Outer	15	65051	0.7	0.9	2.0
10a	Rail Extension	32	65035	1.0	1.4	2.0
10b	Rail Extension Reinf	32		0.8	1.0	1.2
11	Ist Cross Member	9	60031	0.7	1.2	2.0
12a	Skirt 1	17	65039	1.0	1.6	2.0
12b	Skirt 2	17	65040	1.0	1.5	2.0*
13	A-Pillar Upper	23	65225	1.0	1.5	2.0
14a	A-Pillar Body Side Outer	21	65277	1.0	1.5	2.0
14b	A-Pillar Body Side Outer	21	65278	1.0	1.7	2.0
15	A-Pillar Hinge Pillar	1	65226	1.0*	1.5	2.0
16	B-Pillar Inner	2	65261	1.0	1.5	2.0
17	B-Pillar Body Side Outer	16	65273	1.0	1.3	2.0
18	Rocker Inner	5	65221	1.0	1.7	2.0
19a	B-Pillar Body Side Outer	33	65274	0.9*	1.5	2.0
19b	Rocker Inner	33	65222	1.0	1.3	2.0
20	Roof Rail	37	65241	0.8	1.0	1.2
21	Dash Panel	14	60071	0.6	0.7	1.2
22	XY Curve	29	-	High	Low	-
23	Shot Gun Width	34	-	Baseline	Baseline+10-mm	-
24	Rail Length	28	-	Baseline	Baseline+50-mm	-

Table 2: Levels of Parameters – Static/Dynamic Stiffness Study of Upgraded Front-End Package

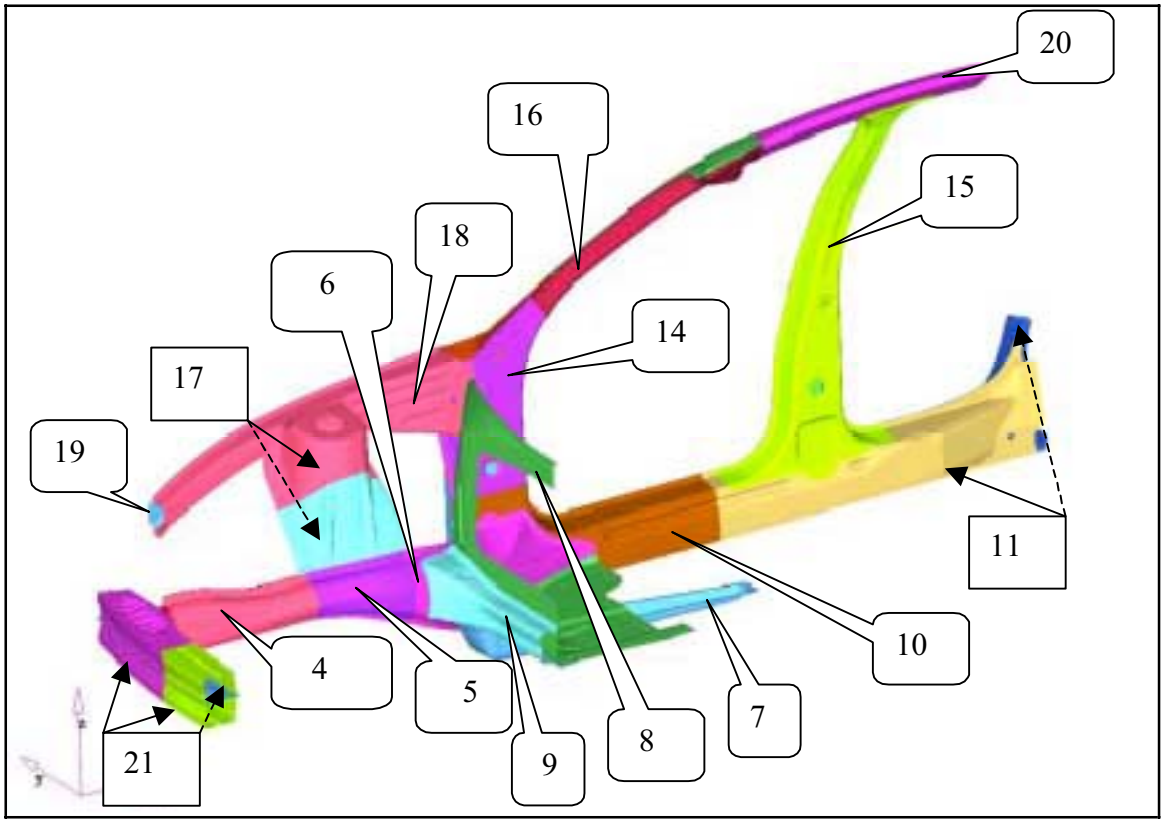


Figure 1: Front-End Parts - Static/Dynamic Stiffness Study of Upgraded Front-End Package

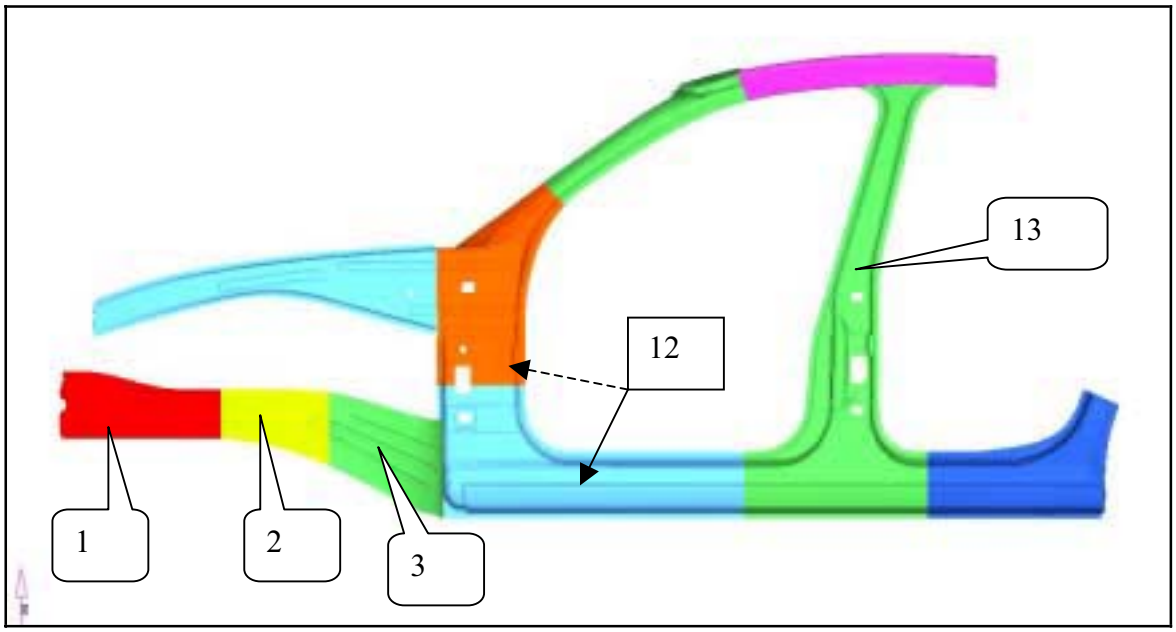


Figure 2: Front-End Parts - Static/Dynamic Stiffness Study of Upgraded Front-End Package

3 NCAP Study of Upgraded Front-End Package

Table 3: Levels of Parameters – NCAP Study of Upgraded Front-End Package

S.N.	Component	Thickness (mm)		Material Yield / Ultimate (MPa)	
		Level 1*	Level 2**	Level 1	Level 2
1a	Bumper Middle Section	1.2	1.6	Post Bake DP 585/965	DP 700/1000
1b	Bumper End Sections	1.2	1.6	Post Bake DP 585/965	DP 700/1000
1c	Bumper Middle Plate	1.2	1.6	Post Bake DP 585/965	DP 700/1000
2	Rail Front Inner	1.4	1.9	HSLA 350/450	DP 500/800
3	Rail Front Outer	1.4	1.9	HSLA 350/450	DP 500/800
4	Rail Mid Inner	1.5	2.0	HSLA 350/450	DP 500/800
5	Rail Mid Outer	1.5	2.0	HSLA 350/450	DP 500/800
6	Rail Rear Inner	1.6	2.2	HSLA 350/450	DP 500/800
7	Rail Rear Outer	1.8	2.4	HSLA 350/450	DP 500/800
8	Shot Gun Inner	1.1	1.5	HSLA 425/770	DP 500/800
9	Shot Gun Outer	0.8	1.1	HSLA 350/450	DP 500/800
10a	Rail Extension	1.3	1.8	HSLA 350/450	DP 500/800
10b	Rail Extension Reinf.	1.3	1.8	HSLA 350/450	DP 500/800
11	Cradle Extension	1.4	1.9	DP 280/600	DP 500/800
12	Ist Cross Member	1.1	1.5	HSLA 425/770	DP 700/1000
13a	Skirt 1	1.5	2.0	AKDQ 160/525	DP 280/600
13b	Skirt 2	1.8	2.4	AKDQ 160/525	DP 280/600
14a	Cradle CM Ubar 1	1.2	1.6	DP 500/800	DP 500/800
14b	Cradle CM Ubar 2	1.5	2.0	DP 500/800	DP 500/800
14c	Cradle	1.8	2.4	DP 500/800	DP 500/800

* Level 1 = 10% less than Initial Front End Package baseline
** Level 2 = 20% more than Initial Front End Package baseline

Table 4: Topological Parameters – NCAP Study of Upgraded Front-End Package

S.N.	Topological Parameter	Upgraded Powertrain Baseline	Level 1	Level 2
1	Elevation (XZ) Curvature of LH Rail	Higher Bump Height = 2h	Higher Bump Height = 2h	Lower Bump Height = h
2	Plan (XY) Curvature of both LH and RH Rails	Higher Curvature Height = 2h	Higher Curvature Height = 2h	Lower Curvature Height = h
3	Rail Length	l =100 mm less than Baseline ULSAB	l	l + 50 mm
4	Shotgun Width	Width = w	w	w +10 mm

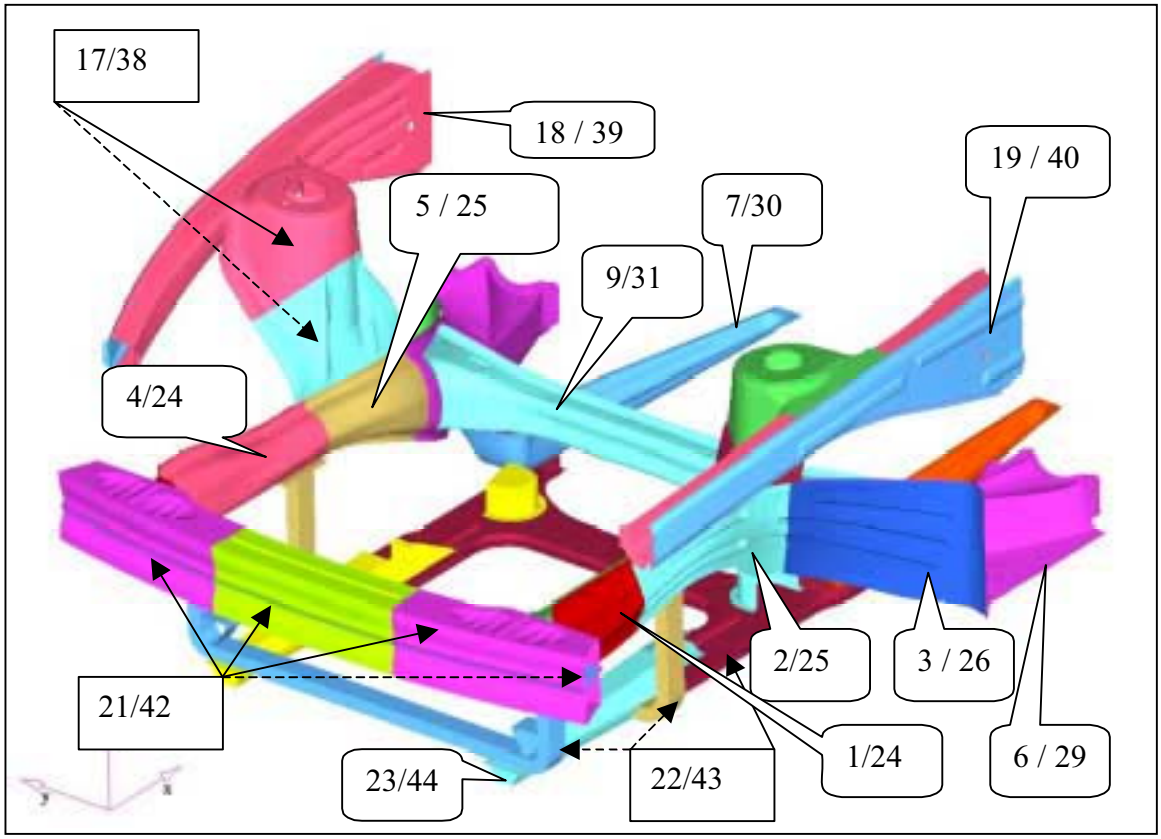


Figure 3: Front-End Parts - NCAP Study of Upgraded Front-End Package

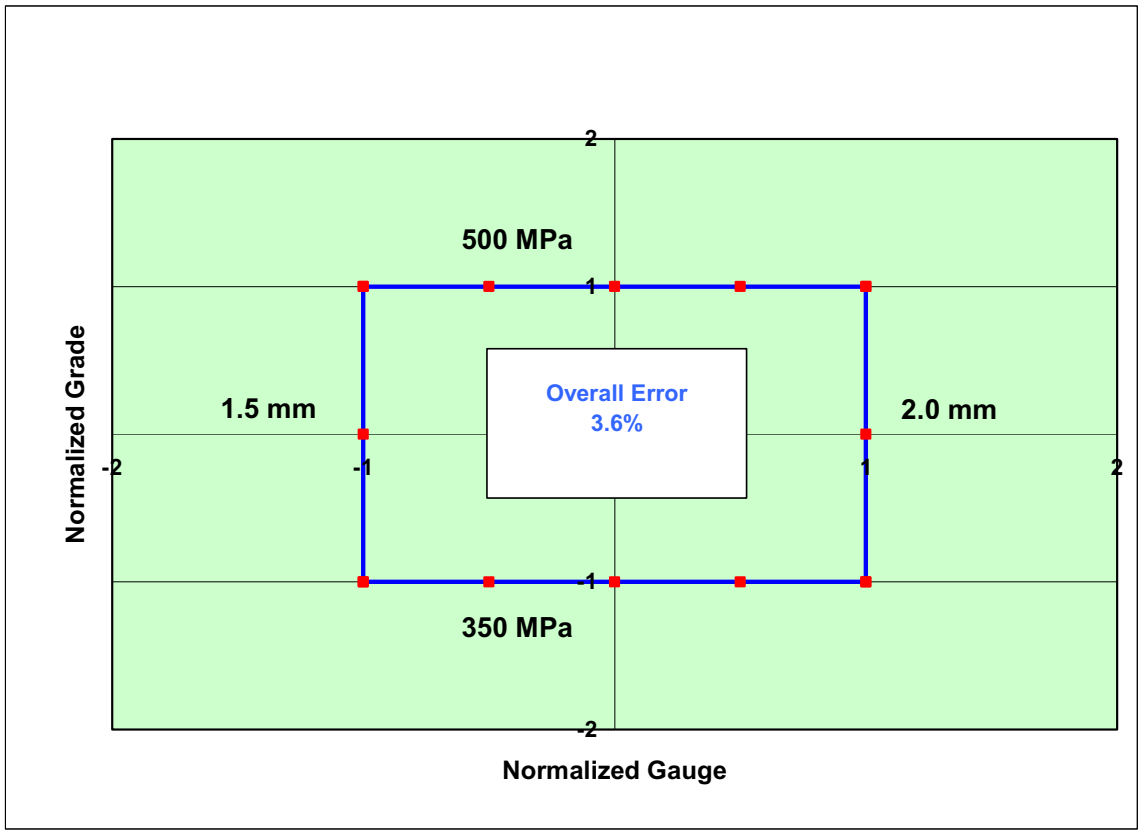


Figure 4: Design Space - Crush % Error

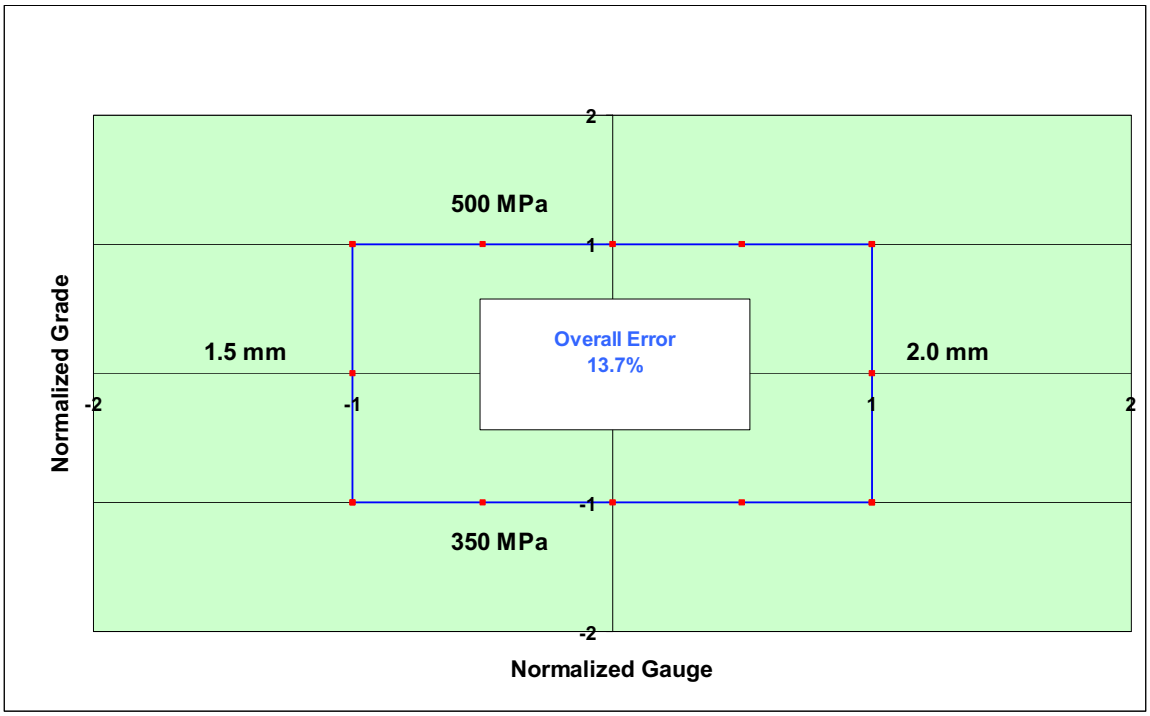


Figure 5: Design Space - Max RH Acc % Error

4 IIHS Study of Upgraded Front-End Package

S.N.	Component	Thickness (mm)		Material Yield / Ultimate (MPa)	
		Level 1*	Level 2**	Level 1	Level 2
1a	Bumper Middle Section	1.2	1.6	Post Bake DP 585/965	DP 700/1000
1b	Bumper End Sections	1.2	1.6	Post Bake DP 585/965	DP 700/1000
1c	Bumper Middle Plate	1.2	1.6	Post Bake DP 585/965	DP 700/1000
2	Rail Front Inner	1.4	1.9	HSLA 350/450	DP 500/800
3	Rail Front Outer	1.4	1.9	HSLA 350/450	DP 500/800
4	Rail Mid Inner	1.5	2.0	HSLA 350/450	DP 500/800
5	Rail Mid Outer	1.5	2.0	HSLA 350/450	DP 500/800
6	Rail Rear Inner	1.6	2.2	HSLA 350/450	DP 500/800
7	Rail Rear Outer	1.8	2.4	HSLA 350/450	DP 500/800
8	Shot Gun Inner	1.1	1.5	HSLA 425/770	DP 500/800
9	Shot Gun Outer	0.8	1.1	HSLA 350/450	DP 500/800
10a	Rail Extension	1.3	1.8	HSLA 350/450	DP 500/800
10b	Rail Extension Reinf.	1.3	1.8	HSLA 350/450	DP 500/800
11	Cradle Extension	1.4	1.9	DP 280/600	DP 500/800
12	Ist Cross Member	1.1	1.5	HSLA 425/770	DP 700/1000
13a	Skirt 1	1.5	2.0	AKDQ 160/525	DP 280/600
13b	Skirt 2	1.8	2.4	AKDQ 160/525	DP 280/600
14a	Cradle CM Ubar 1	1.2	1.6	HSLA 350/450	DP 500/800
14b	Cradle CM Ubar 2	1.5	2.0	HSLA 350/450	DP 500/800
14c	Cradle	1.8	2.4	HSLA 350/450	DP 500/800
	Hinge Pillar and Assembly				
15	Rocker Inner	1.5	2.0	HSLA 350 / 450	DP 500/800
16	Hinge Pillar	0.9	1.2	HSLA 350 / 450	DP 500/800
17	A-Pillar Upper	1.3	1.8	HSLA 350 / 450	DP 500/800
18a	Body Side Otr A-Pillar m	1.3	1.8	HSLA 350 / 450	DP 500/800
18b	Body Side Otr A-Pillar	1.5	2.0	HSLA 350 / 450	DP 500/800
	B Pillar / Roof Rail Asm				
19	B-Pillar Inner	1.3	1.8	HSLA 350 / 450	DP 500/800
20	Body Side Otr B-Pillar	1.2	1.6	DP 280 / 600	DP 500/800
21	Roof Side Rail	0.9	1.2	DP 280 / 600	DP 500/800

*Level 1 = 10% less than Initial Front End Package baseline
** Level 2 = 20% more than Initial Front End Package baseline

Table 5: Levels of Parameters – IIHS Study of Upgraded Front-End Package

Table 6: Topological Parameters – IIHS Study of Upgraded Front-End Package

S. N.	Topological Parameter	Upgraded PowertrainBaseline	Level 1	Level 2
1	Elevation (XZ) Curvature of LH Rail	Higher Bump Height = 2h	Higher BumpHeight = 2h	Lower BumpHeight = h
2	Plan (XY) Curvature of both LH and RH Rails	Higher Curvature Height = 2h	Higher CurvatureHeight = 2h	Lower CurvatureHeight = h
3	Rail Length	l =100 mm less than Baseline Model	l	l + 50 mm
4	Shotgun Width	Width = w	w	w +10 mm

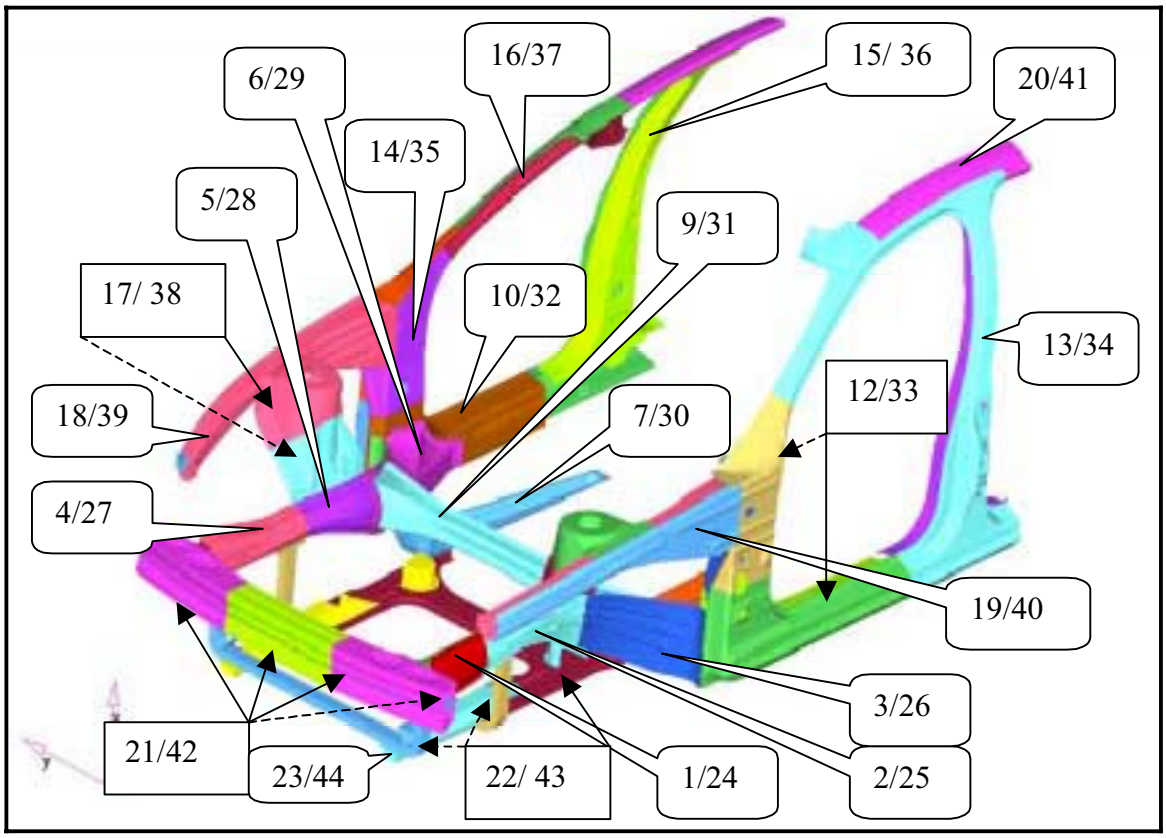


Figure 6: Front-End Parts - IIHS Study of Upgraded Front-End Package

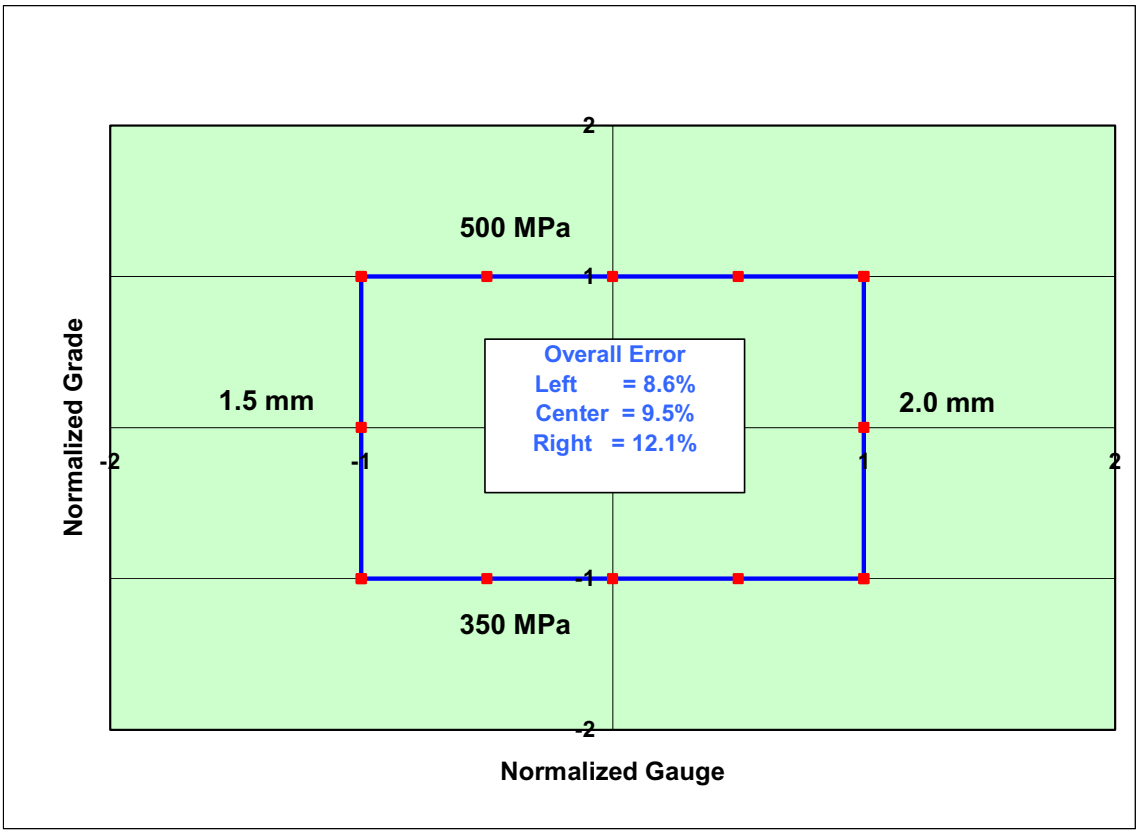


Figure 7: Design Space - Footwell Intrusion % Error

Quantech
Global Services

Stamped Design: Phase II

Lightweight Front End Structure

January 31, 2005

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Stamped Design: Phase II

1 DOE Parts

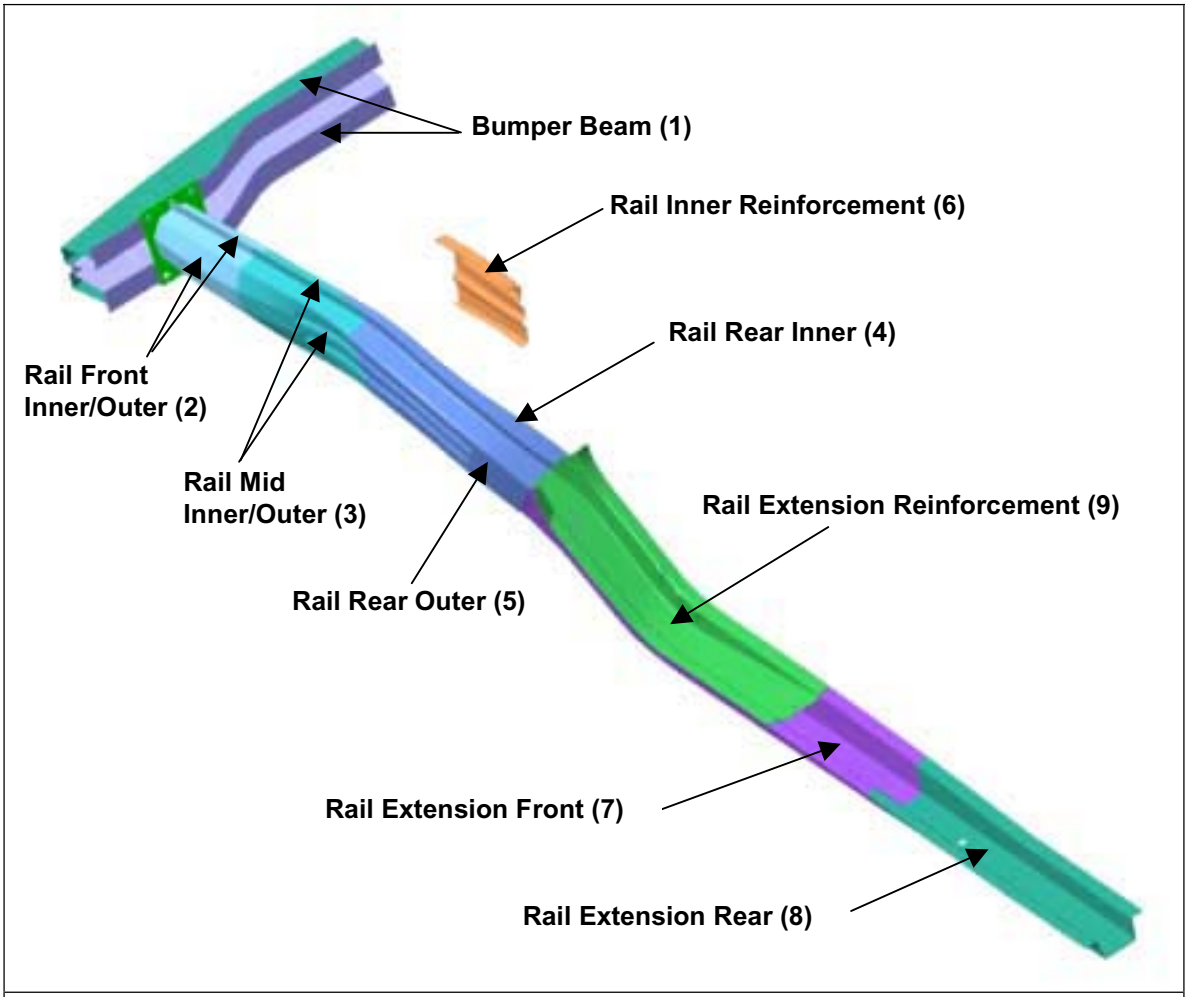


Figure 1: DOE Parts

2 Static/Dynamic Stiffness Study

The Static/Dynamic Stiffness DOE studies incorporate the following features.

- Static stiffness analysis/free-free modal analysis.
- Bending and torsional stiffness/bending and torsional modes as responses.
- 2-level L32 Orthogonal Array.
- Bumper and rail gauges as design parameters.
- 9 factors and 22 interactions.

DOE parameters and their levels are summarized in ***Table 1***.

Table 1: Static/Dynamic Stiffness DOE Parameters

	Part	Level 1 Gauge (mm)	Level 2 Gauge (mm)
1	Bumper	1.0	1.3
2	Rail Front Inner/Outer	1.0	1.3
3	Rail Mid Inner/Outer	1.2	1.6
4	Rail Rear Inner	1.4	2.0
5	Rail Rear Outer	1.4	2.0
6	Rail Inner Reinforcement	1.4	2.0
7	Rail Extension Front	1.4	2.0
8	Rail Extension Rear	1.2	1.6
9	Rail Extension Reinf	1.4	2.0

- Level 1 gauges correspond to 30% mass reduction compared to the *Donor Vehicle*.
- Level 2 gauges are 130% of Level 1 gauges.

3 NCAP/IIHS Studies

The NCAP/IIHS DOE studies incorporate the following features.

- NCAP load case up to 100 ms and IIHS load case up to 150 ms.
- NCAP B-pillar acceleration pulse and IIHS intrusions as responses
- 2-level L32 Orthogonal Array.
- Bumper and rail grades/gauges as design parameters.
- 16 factors and 16 interactions.

DOE parameters and their levels are summarized in ***Table 2***.

Table 2: NCAP/IIHS DOE Parameters

	Part	Level 1 Gauge (mm)	Level 2 Gauge (mm)
1	Bumper	1.0	1.3
2	Rail Front Inner/Outer	1.0	1.3
3	Rail Mid Inner/Outer	1.2	1.6
4	Rail Rear Inner	1.4	2.0
5	Rail Rear Outer	1.4	2.0
6	Rail Inner Reinforcement	1.4	2.0
7	Rail Extension Front	1.4	2.0
8	Rail Extension Rear	1.2	1.6
9	Rail Extension Reinf	1.4	2.0
	Part	**Level 1 Grade**	**Level 2 Grade**
10	Bumper	DP800	DP980
11	Rail Front Inner/Outer	DP600	DP800
12	Rail Mid Inner/Outer	DP600	DP800
13	Rail Rear Inner/Outer	DP600	DP800
14	Rail Inner Reinforcement	DP600	DP800
15	Rail Extension Front/Rear	DP600	DP800
16	Rail Extension Reinf	DP600	DP800

- Level 1 gauges correspond to 30% mass reduction compared to the *Donor Vehicle*.
- Level 2 gauges are 130% of Level 1 gauges.

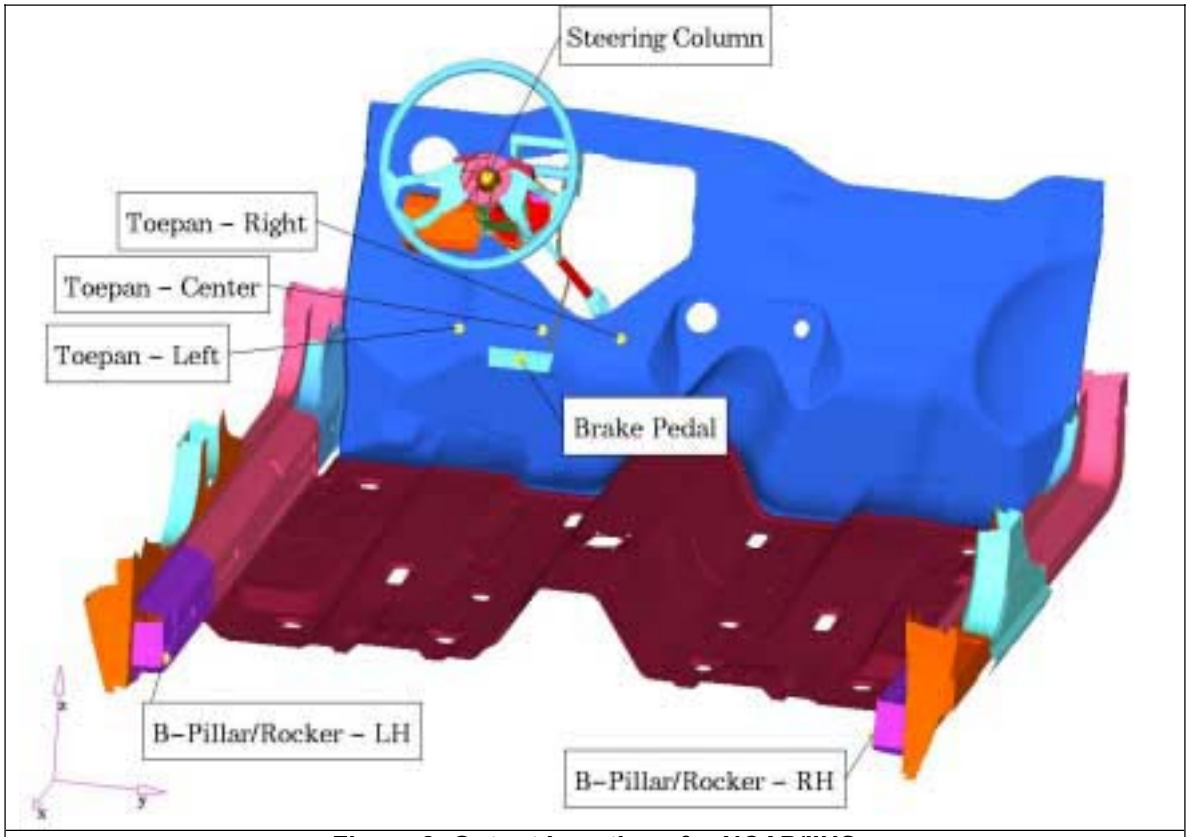


Figure 2: Output Locations for NCAP/IIHS

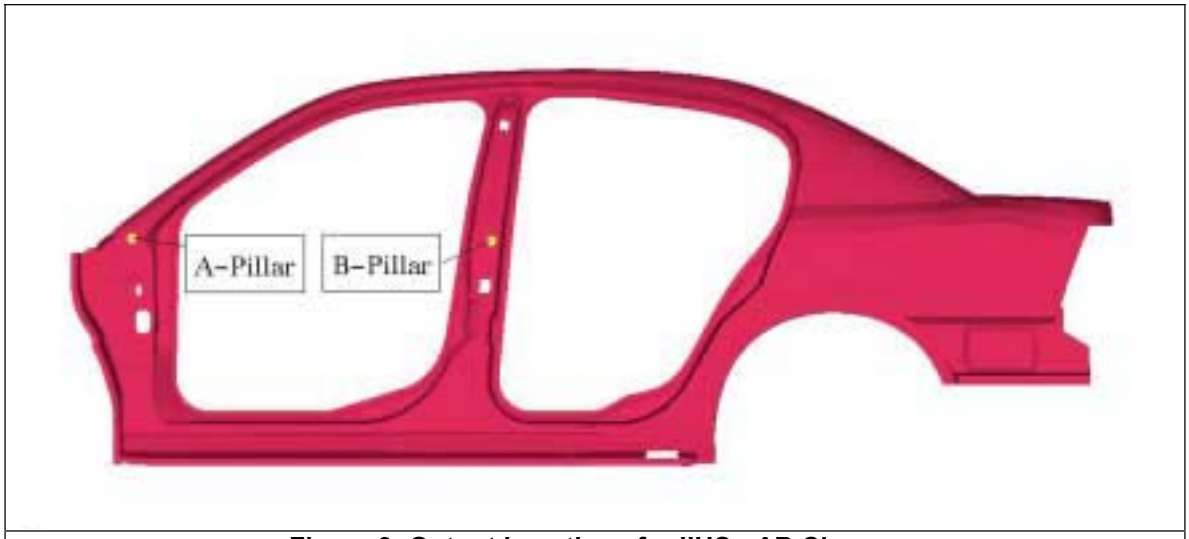


Figure 3: Output Locations for IIHS - AB Closure

4 References

1) *DOE FE Models, Milestone 7*, SPHINX, Phase II.

2) *Concept 2: Final Design, Milestone 15*, SPHINX, Phase II.

3) *NCAP DOE Response Surface, Milestone 20*, SPHINX, Phase II.

4) *IIHS DOE Response Surface, Milestone 21*, SPHINX, Phase II.

5) *Final Optimized Design, Milestone 22*, SPHINX, Phase II.

6) *Static Stiffness DOE Response Surface, Milestone 46*, SPHINX, Phase II.

7) *Dynamic Stiffness DOE Response Surface, Milestone 46*, SPHINX, Phase II.

Static Dynamic Stiffness DOE FE Models

Milestone 45

Lightweight Front End Structure Phase II

July 15, 2004

A/S P

Auto/Steel Partnership

Abstract

This report documents the modifications made to the donor vehicle static and dynamic stiffness FE models. The modified FE models serve as the baseline for DOE studies and for assessing various rail and bumper concepts developed in Phase II of the Lightweight Front End Structure Project.

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1. Objectives

The aim of this effort was to modify the donor vehicle static and dynamic stiffness FE models, in order to render them suitable for DOE studies. A comprehensive model checking was undertaken and appropriate modifications were made. These FE models serve as the baseline for DOE studies and for assessing various rail and bumper concepts developed in Phase II of the Lightweight Front End Structure Project.

2. Results

The following modifications were made to the donor vehicle FE models.

- Front Cradle Reinforcement was removed as it was not present in the crash model.
- Suitable load and boundary conditions were defined for the static stiffness analyses.
- Node sets were defined for post-processing.

The static and dynamic stiffness results are summarized in *Table 1* and *Table 2* respectively. The stiffness responses were calculated using the procedure outline in (*1)*. The BIW FE model is illustrated in *Figure 1*. Corrected vertical displacements for bending stiffness and twist angles for torsional stiffness are plotted as a function of longitudinal (fore-aft) distance in *Figure 2* and *Figure 3* respectively. In both cases, the X-axis intercepts correspond to constrained points.

Table 1: Static Stiffness Results

Stiffness	Value
Bending (N/mm)	12638.92
Torsion (Nm/deg)	21002.25

Table 2: Dynamic Stiffness Results

Mode	Frequency (Hz)	Mode Shape
1	21.06	Torsion
2	24.38	Bending Fore-Aft
3	25.71	Bending Fore-Aft
4	26.22	Bending Fore-Aft/Lateral
5	27.02	Torsion
6	27.33	Bending/Torsion
7	29.46	Torsion
8	30.55	Bending/Torsion

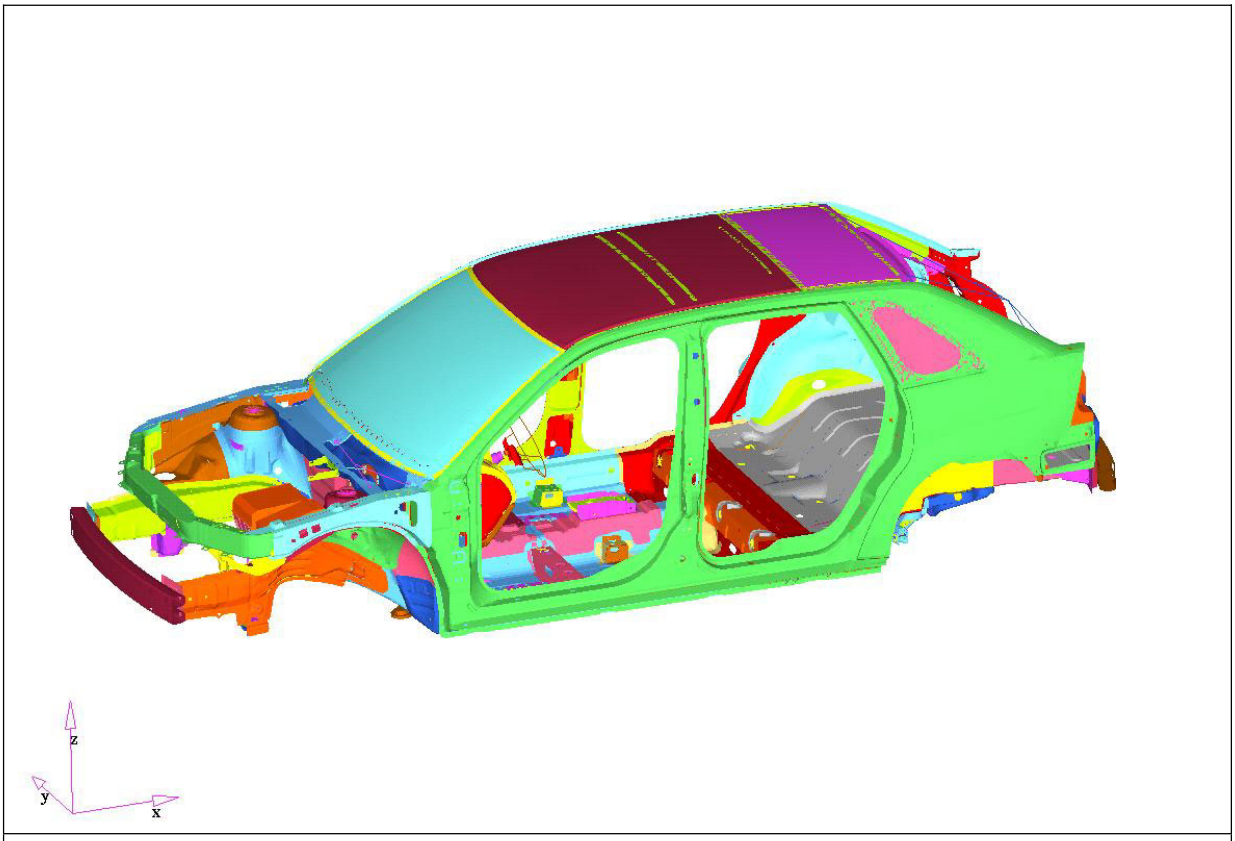


Figure 1: Donor Vehicle BIW Model for Static and Dynamic Analyses

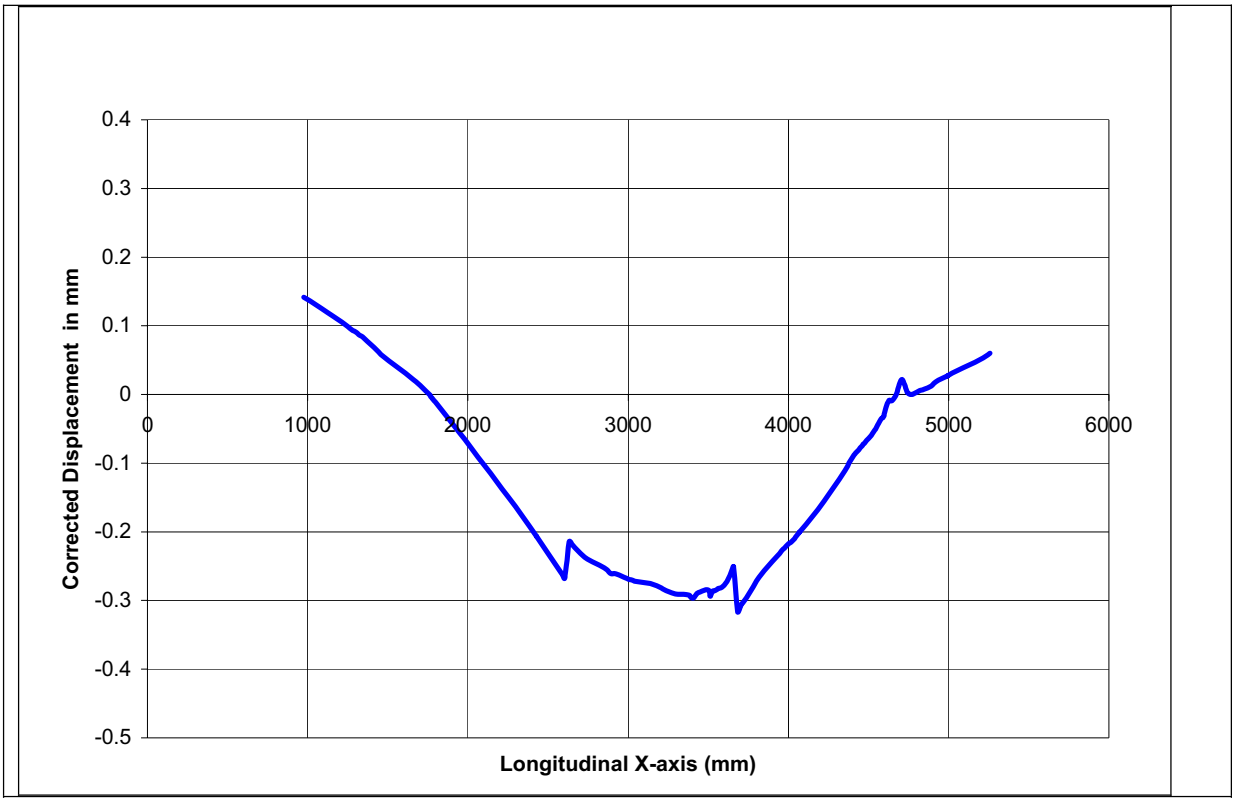


Figure 2: Bending Stiffness - Corrected Vertical Displacement Vs. Longitudinal Axis

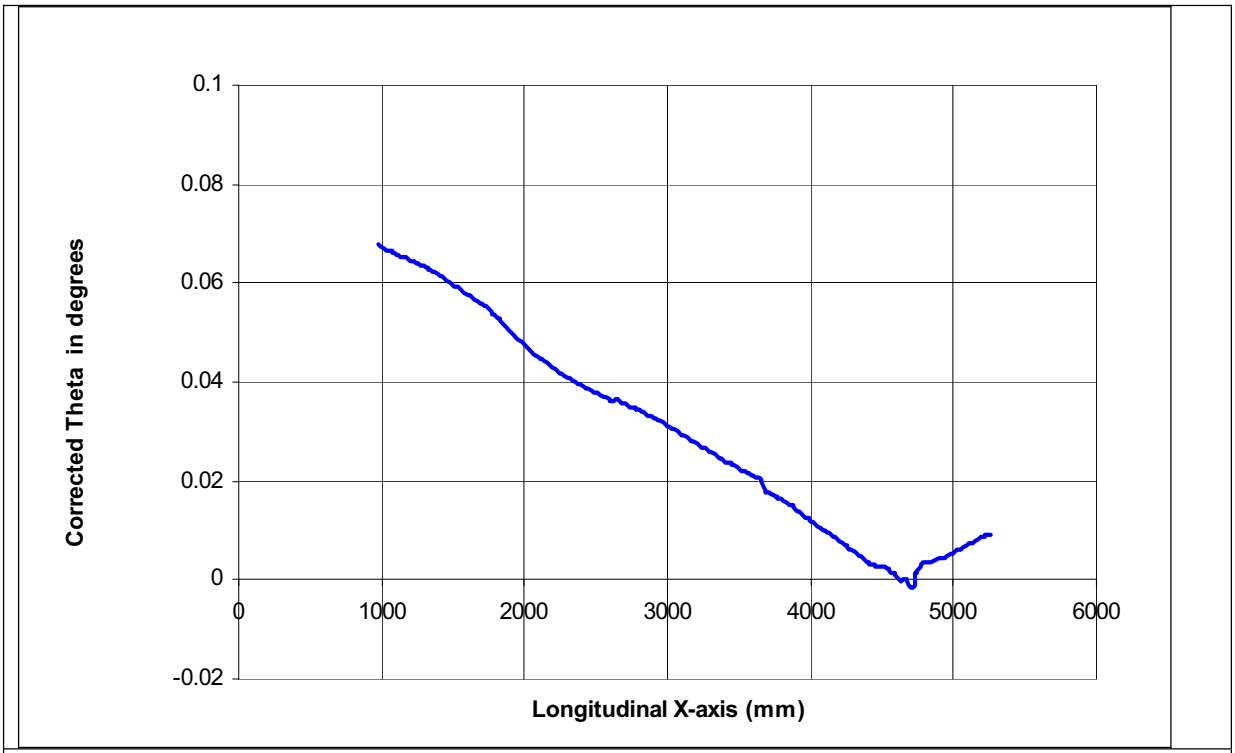


Figure 3: Torsional Stiffness - Corrected Twist Angle Vs. Longitudinal Axis

3. Conclusions

Baseline FE models were established for static and dynamic stiffness analyses.

These models serve as the baseline for DOE studies and for assessing various rail and bumper concepts developed in Phase II of the Lightweight Front End Structure Project.

4. References

1) *ULSAB Model with Upgraded Powertrain, Milestone 14*, SPHINX, Phase I.

Static Stiffness DOE Response Surface

Milestone 46

Lightweight Front End Structure Phase II

July 15, 2004



Auto/Steel Partnership

Abstract

This report documents the Static Stiffness DOE study for the final *Concept 2* design that has a new stamped rail design and a new stamped bumper design. The response surface obtained from the Static Stiffness DOE study was utilized for the computer-aided optimization of the *Concept 2* design.

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1. Objectives

The effort of this study was aimed at conducting a Static Stiffness DOE study for the final *Concept 2* design that has a new stamped rail design and a new stamped bumper design. The response surface obtained from the Static Stiffness DOE study was utilized for the computer-aided optimization of the *Concept 2* design.

2. DOE Model

The Static Stiffness DOE study incorporates the following features.

- Static stiffness load cases.
- 2-level L32 Orthogonal Array.
- Bumper and rail gauges as design parameters.
- 9 factors and 22 interactions.
- Bending and torsional stiffness as responses.

DOE parameters and their levels are summarized in *Table 1* and *Figure 1-Figure 4*.

Table 1: DOE Model

	Part	Level 1 Gauge (mm)	Level 2 Gauge (mm)
1	Bumper	1.0	1.3
2	Rail Front Inner/Outer	1.0	1.3
3	Rail Mid Inner/Outer	1.2	1.6
4	Rail Rear Inner	1.4	2.0
5	Rail Rear Outer	1.4	2.0
6	Rail Reinforcement	1.4	2.0
7	Rail Extension Front	1.4	2.0
8	Rail Extension Rear	1.2	1.6
9	Rail Extension Reinf	1.4	2.0

- Level 1 gauges correspond to 30% mass reduction compared to the *Donor Vehicle*.
- Level 2 gauges are 130% of Level 1 gauges.

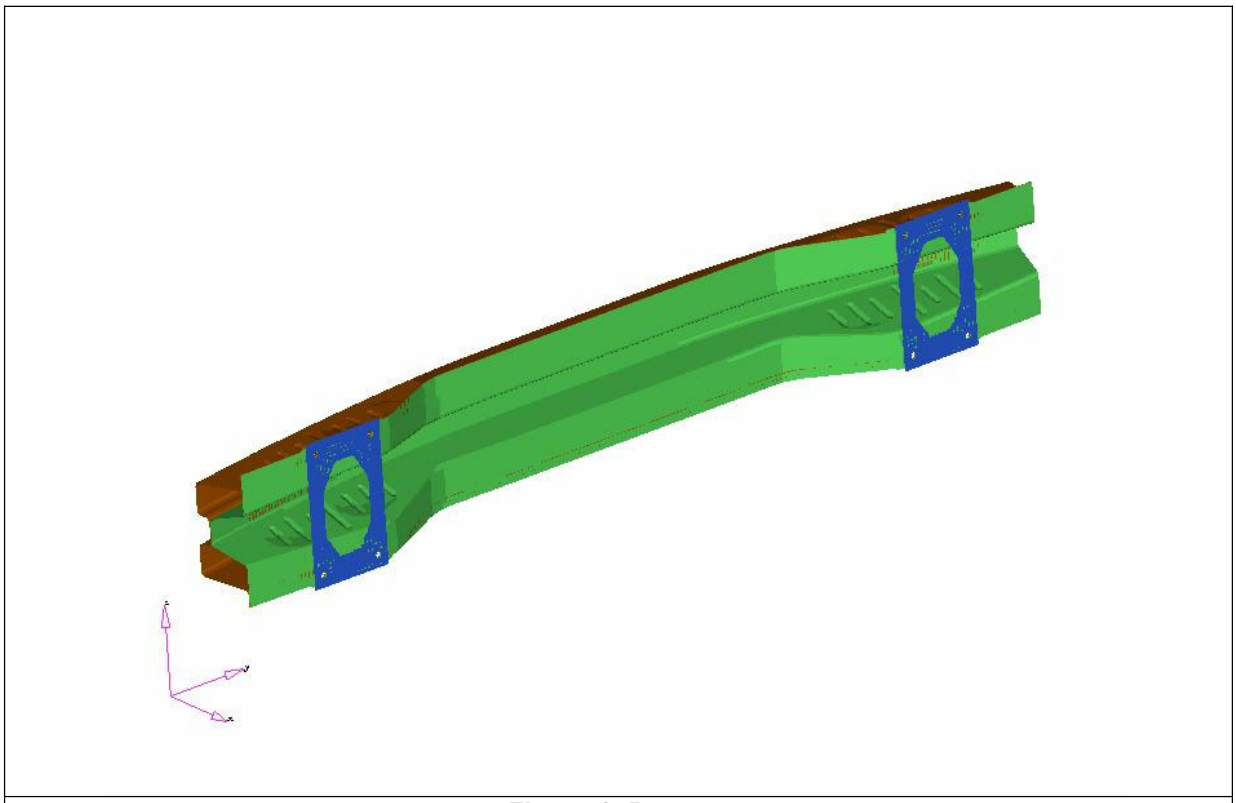


Figure 1: Bumper

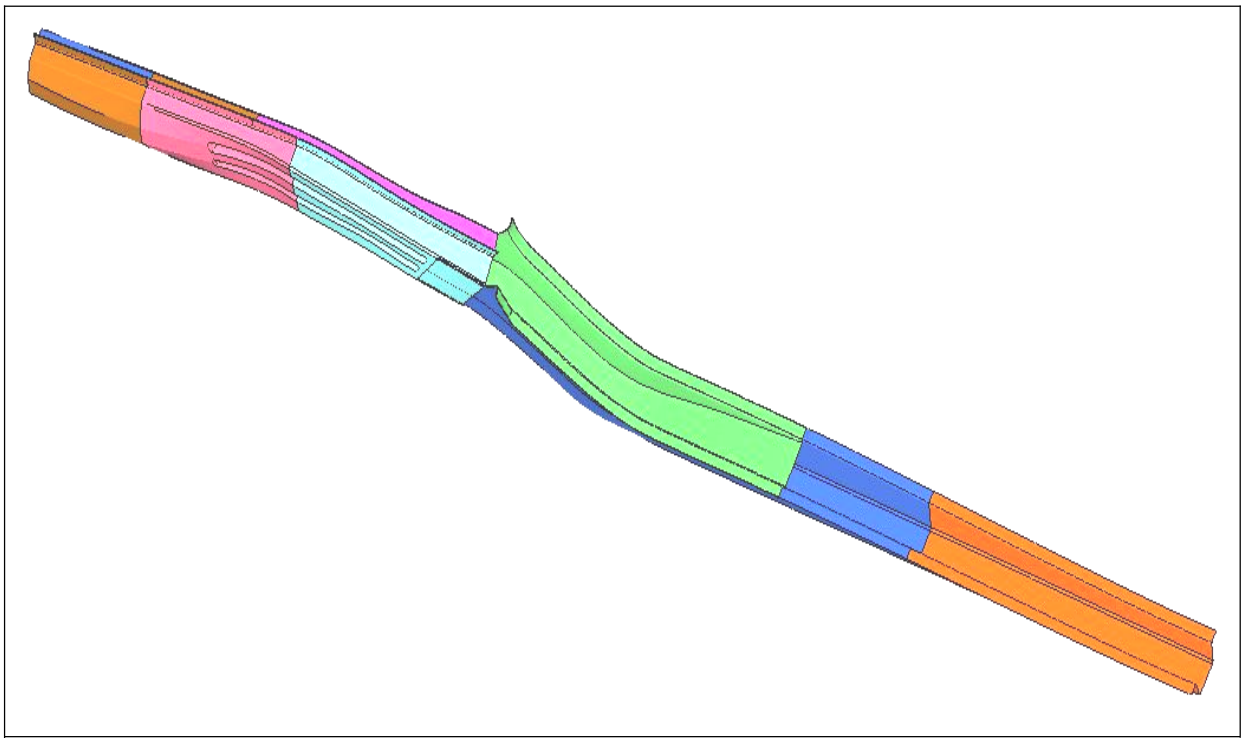


Figure 2: LH Rail Assembly

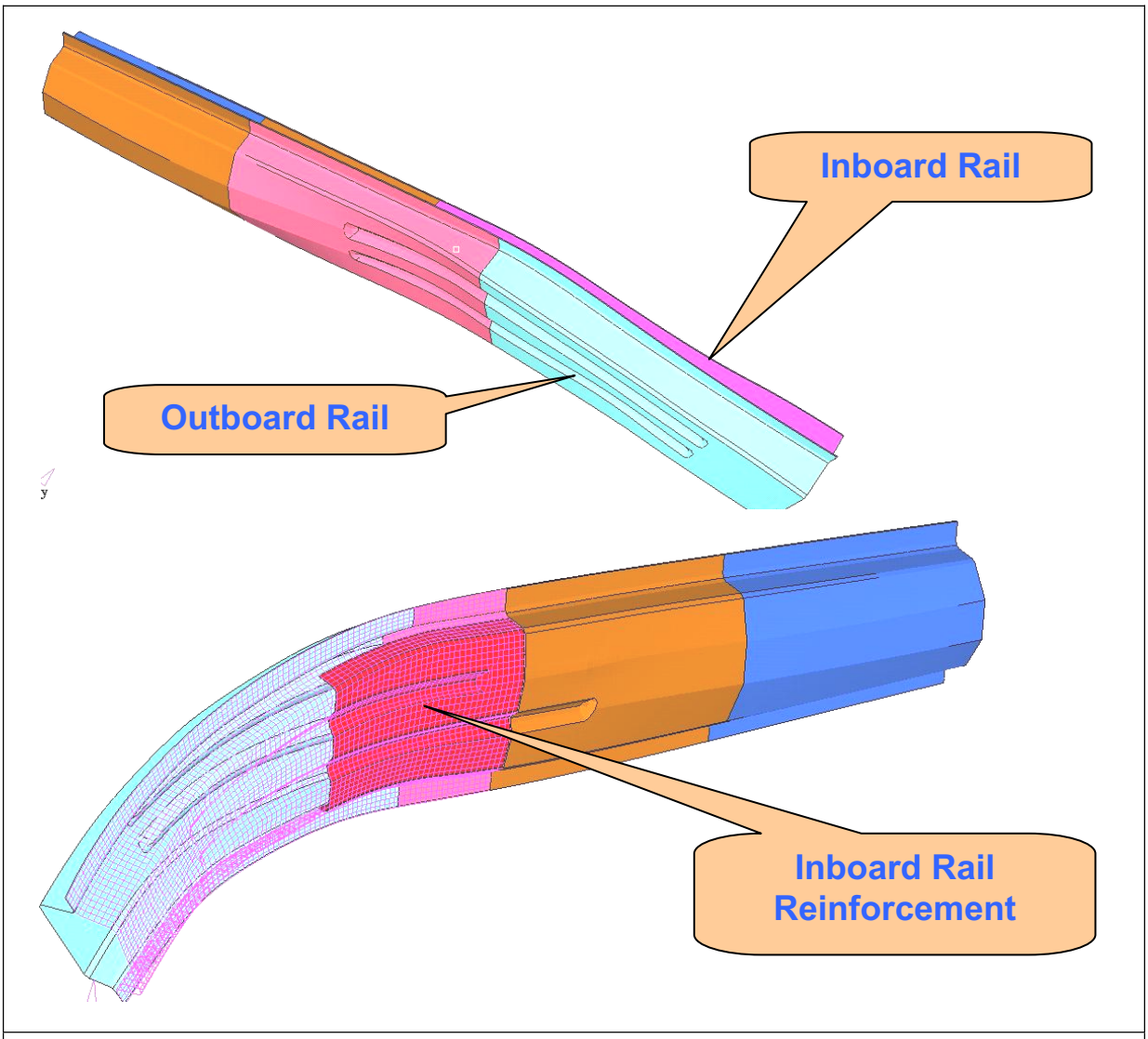


Figure 3: LH Inner & Outer Rails

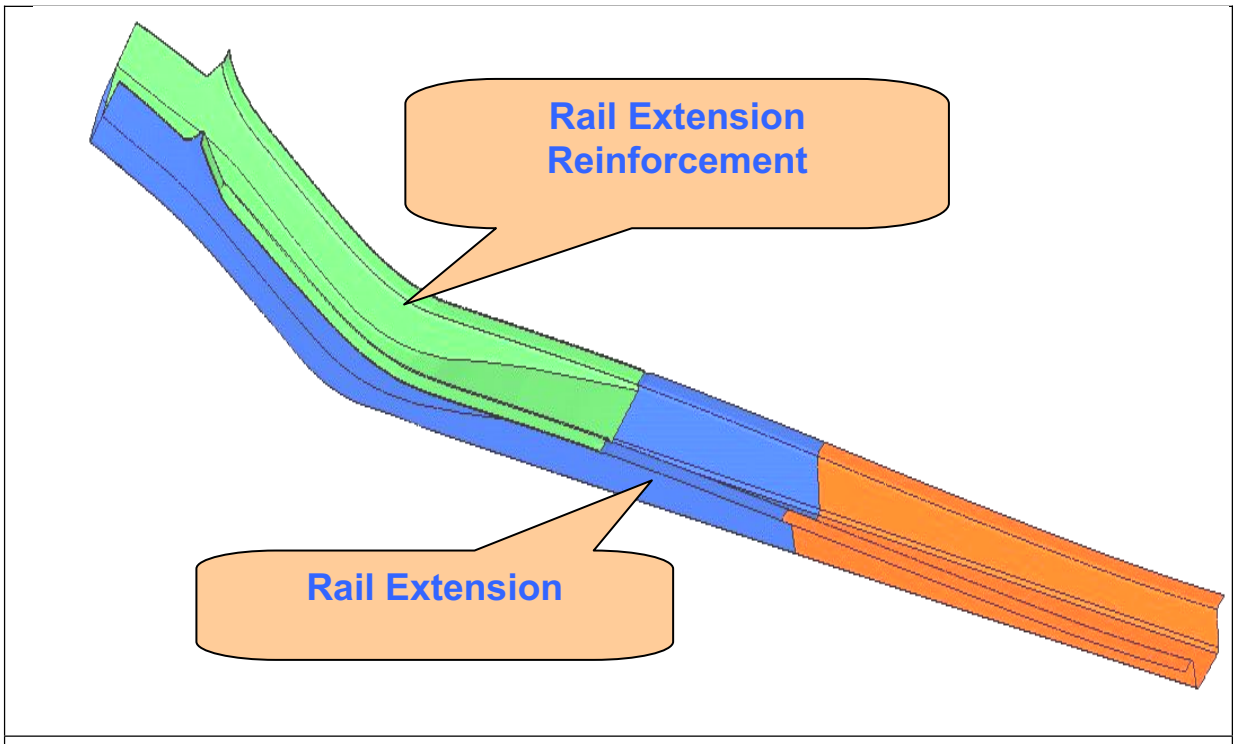


Figure 4: LH Rail Extension

3. Model Modifications

The following modifications were made to the *Baseline Static Stiffness DOE Model*.

1. The *Final Concept 2 Design* for the rail and bumper assemblies was imported from the crash model into the existing Donor Vehicle BIW *Baseline Static Stiffness DOE Model,* along with their attached parts. The following components were imported:

   - Bumper Assembly
   - Rail Assembly
   - Torque Box
   - Cradle Mountings
   - Front Panel (Skirt),
   - Tiebars
   - Battery Tray, ECM, Battery Fill etc.

2. The imported components were connected to the rest of the vehicle through RBE2s and existing RSM connections near the interface were removed. The parts imported from the crash model also had RBE2 connections for spotwelds. The remaining BIW has RSM connections for spotwelds.

3. The units of the imported parts (from the LS-DYNA3D FE Model) were converted to the units of the BIW stiffness model.

4. The existing lumped masses near the bumper and rail assemblies were adjusted to make them consistent with the new design.

5. Node sets were created for post-processing.

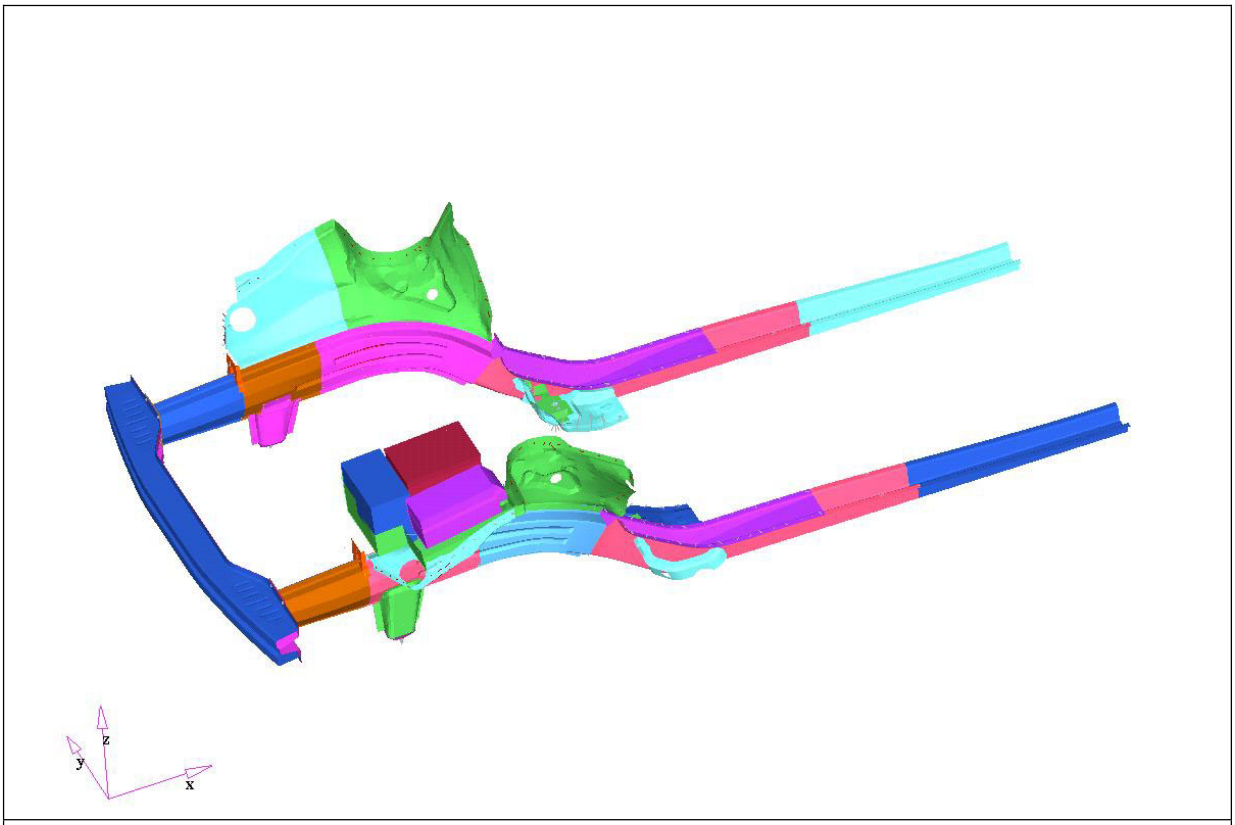


Figure 5: Final Concept 2 Design of Rail-Bumper Assemblies and Attached Parts

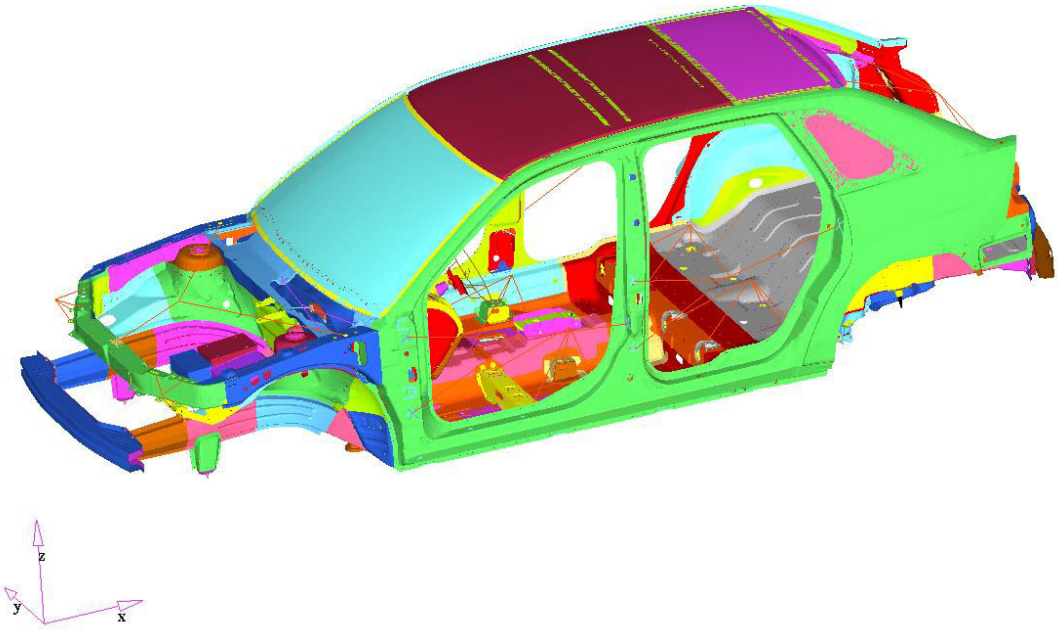


Figure 6: Final Concept 2 Design BIW Model



Figure 7: Donor Vehicle Baseline BIW Model

4. Static Stiffness Response Surface

The *Concept 2* baseline static stiffness responses as well as DOE responses are summarized in *Table 2*. Corrected vertical displacements for bending stiffness and twist angles for torsional stiffness for the *Concept 2* baseline model are plotted as a function of longitudinal (fore-aft) distance in *Figure 8* and *Figure 9* respectively. In both cases, the X-axis intercepts correspond to constrained points.

The stiffness responses were calculated using the procedure outline in (*6).* Linear regression was employed to obtain response surfaces for the following responses.

- Bending stiffness
- Torsional stiffness

There is a very small variation in bending and torsional stiffness with change in DOE parameters. This is expected as the contribution of rails and bumper to bending and torsional stiffness is minimal.

The static stiffness response surfaces will serve as inputs for the computer-aided optimization of the *Concept 2* design.

Table 2: Stiffness Variation in DOE

	Bending Stiffness (N/mm)	Torsional Stiffness (Nm/deg)
Concept 2 Baseline	**12494.8**	**22278.1**
DOE Minimum	**12439.8**	**21847.6**
DOE Maximum	**12522.6**	**22367.8**
DOE Average	**12483.5**	**22127.1**
% Change Min w.r.t. Average	**-0.35%**	**-1.26%**
% Change Max w.r.t. Average	**0.31%**	**1.09%**

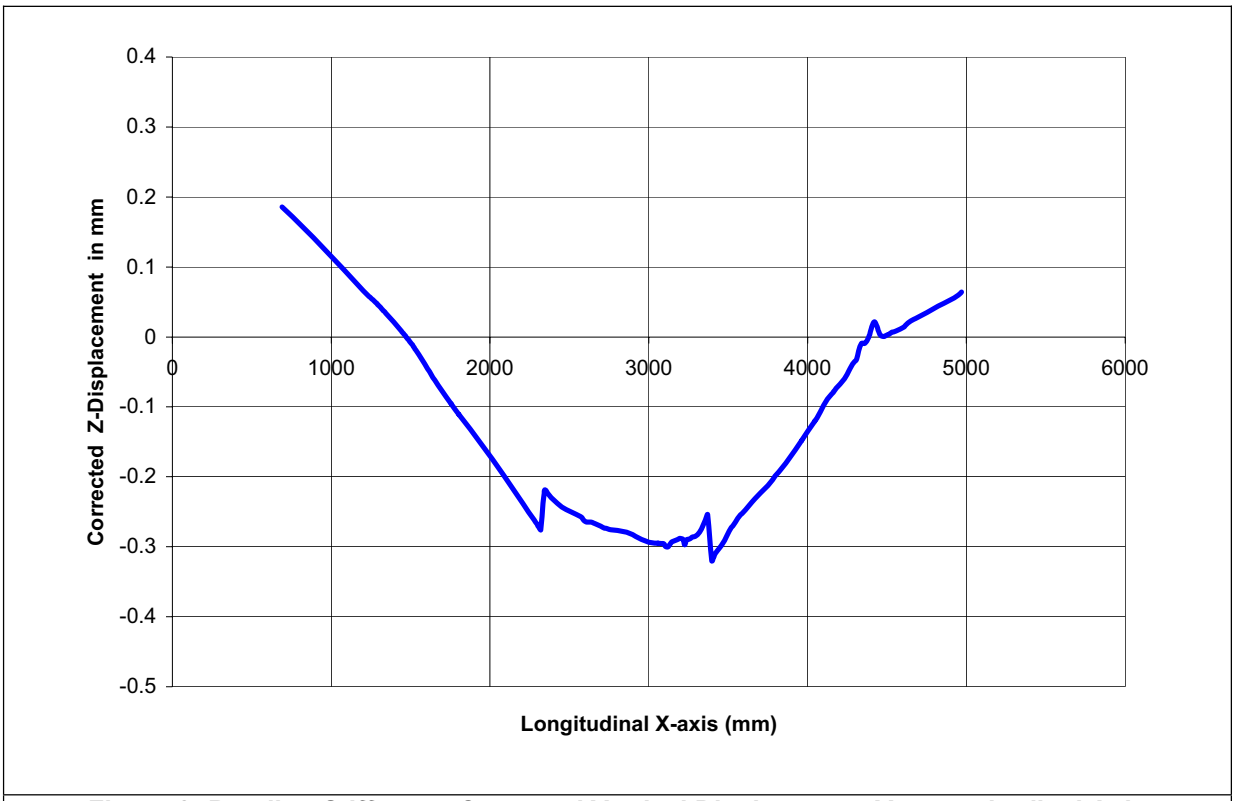


Figure 8: Bending Stiffness - Corrected Vertical Displacement Vs. Longitudinal Axis

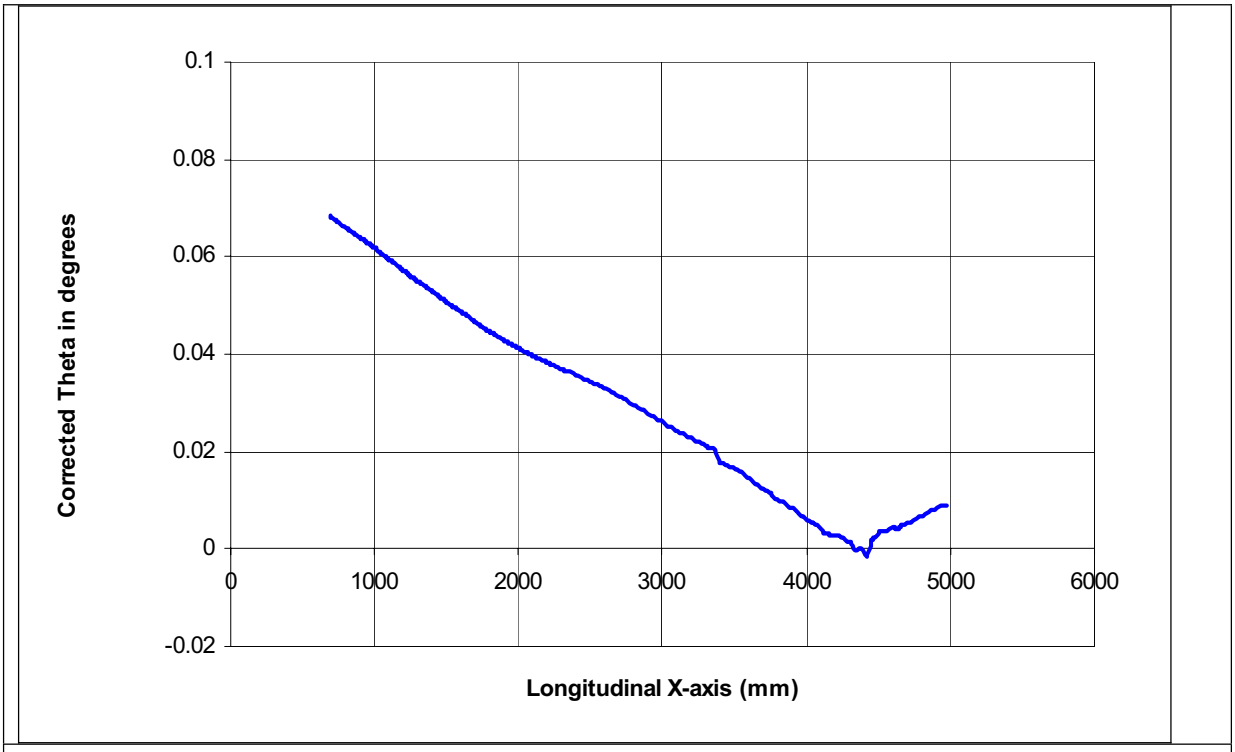


Figure 9: Torsional Stiffness - Corrected Torsion Vs. Longitudinal Axis

5. Conclusions

A static stiffness DOE study of the *Concept 2* design was conducted and response surfaces were derived for the computer-aided optimization of the *Concept 2* design.

6. Future Work

Computer-aided optimization of the rail/bumper designs was performed using the IIHS, NCAP, static and dynamic stiffness response surfaces.

7. References

1) *Validated FE Models, Milestone 5*, SPHINX, Phase II.

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Dynamic Stiffness DOE Response Surface

Milestone 47

Lightweight Front End Structure Phase II

July 28, 2004



Auto/Steel Partnership

Abstract

This report documents the Dynamic Stiffness DOE study for the final *Concept 2* design that has a new stamped rail design and a new stamped bumper design. The response surface obtained from the Dynamic Stiffness DOE study was utilized for the computer-aided optimization of the *Concept 2* design.

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The effort of this study was aimed at conducting a Dynamic Stiffness DOE study for the final *Concept 2* design that has a new stamped rail design and a new stamped bumper design. The response surface obtained from the Dynamic Stiffness DOE study was utilized for the computer-aided optimization of the *Concept 2* design.

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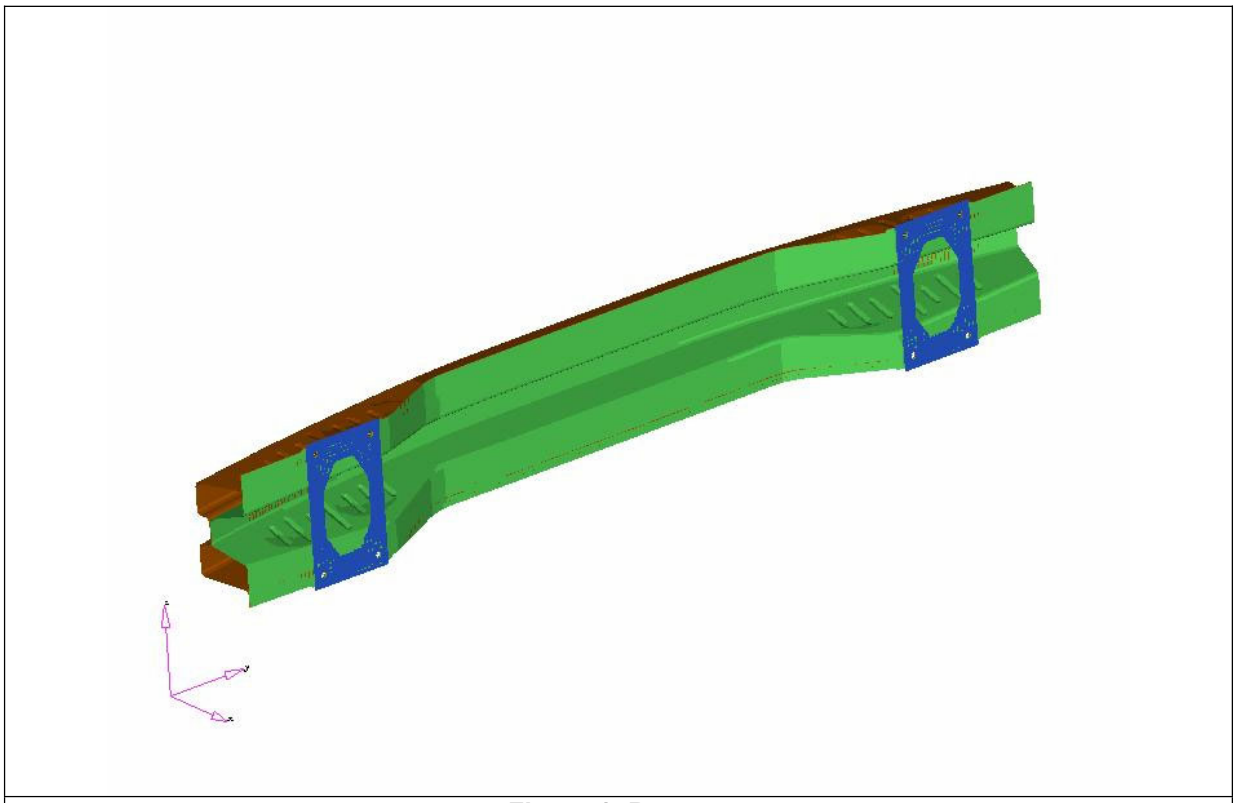


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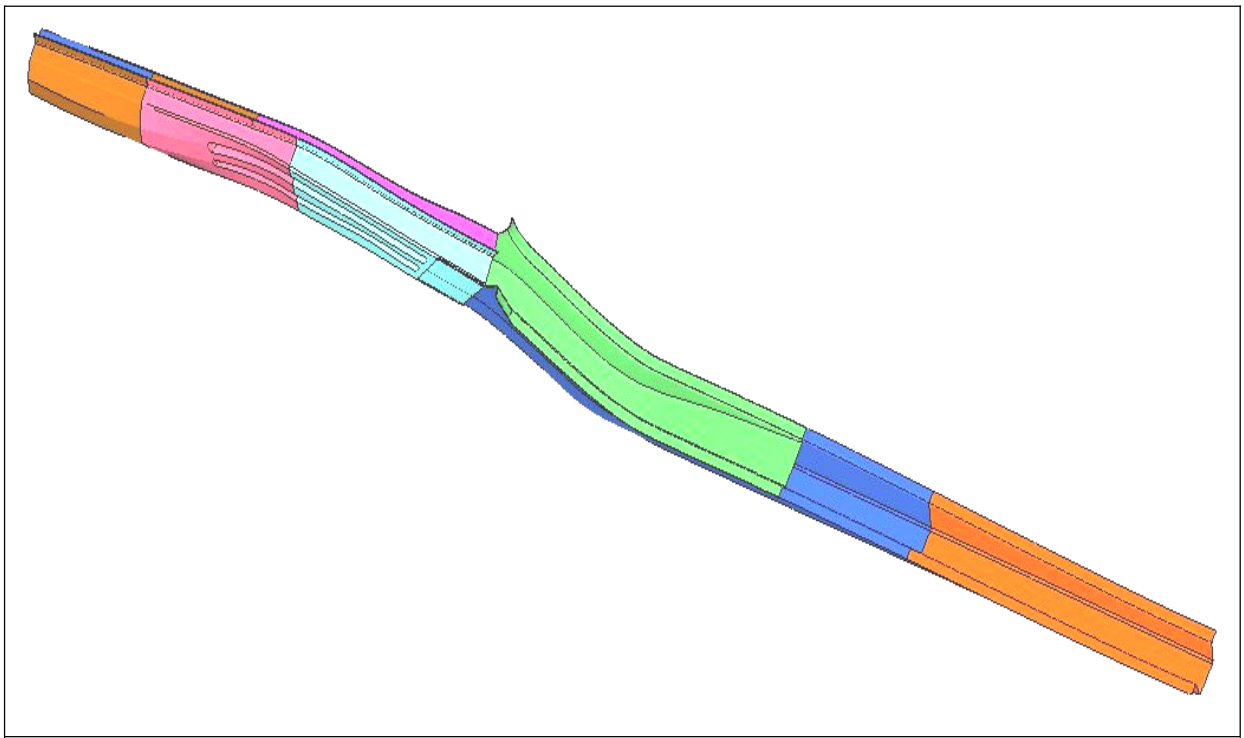


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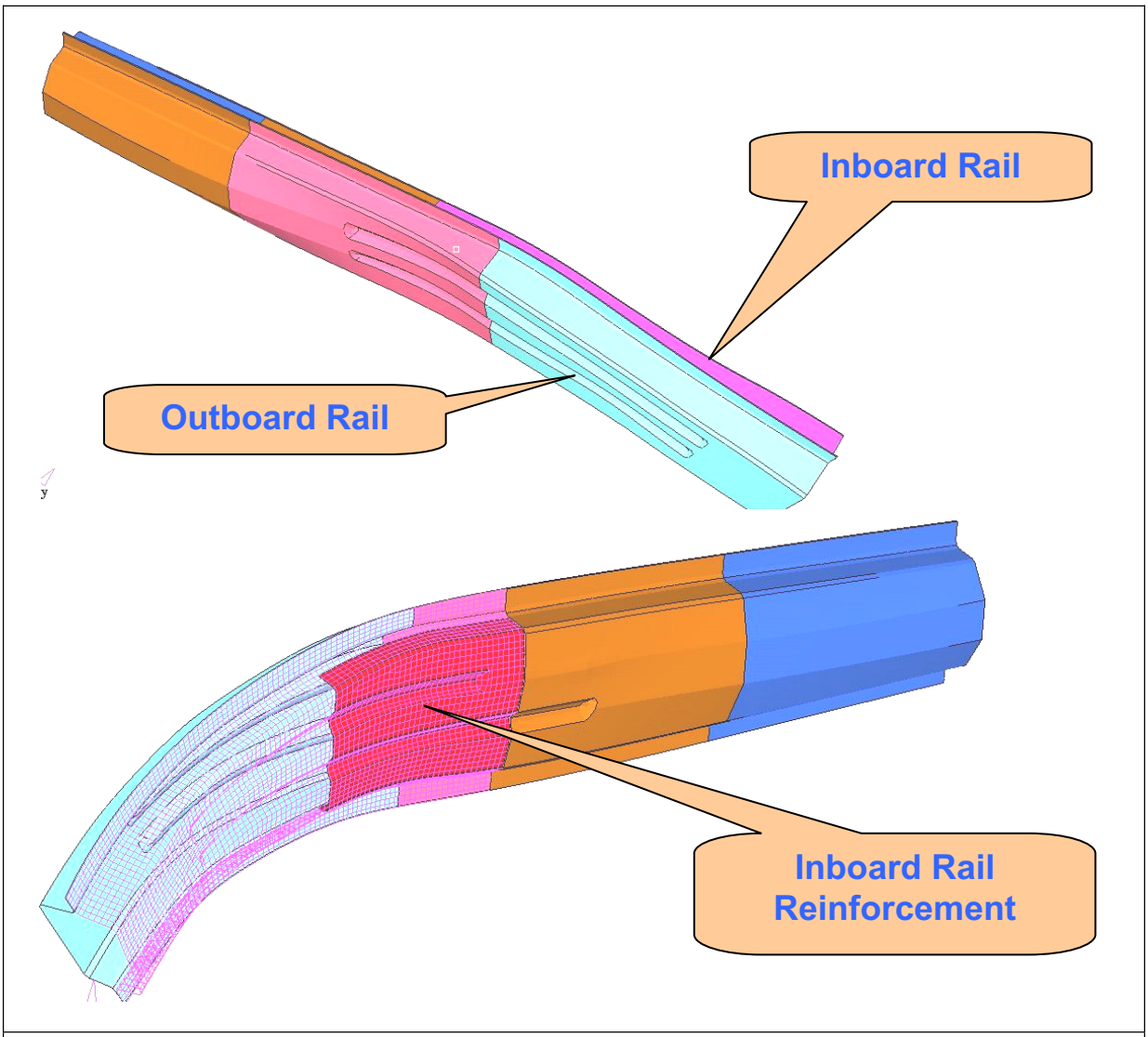


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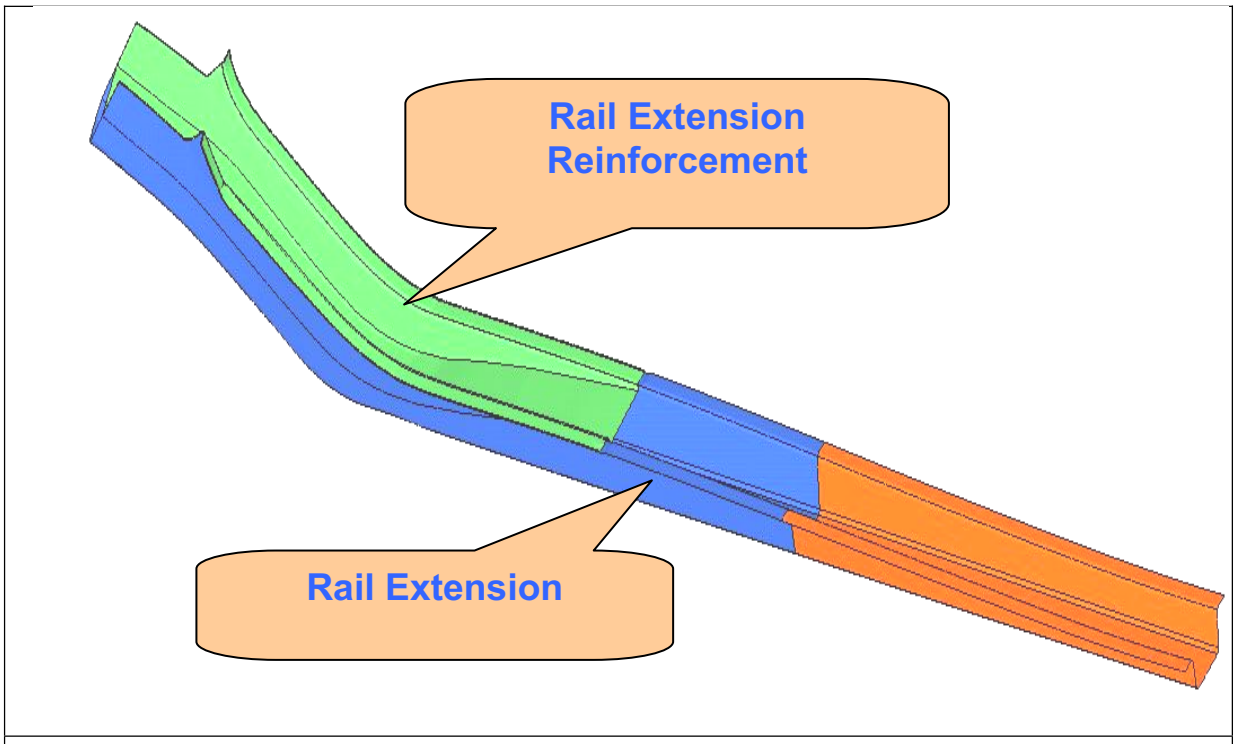


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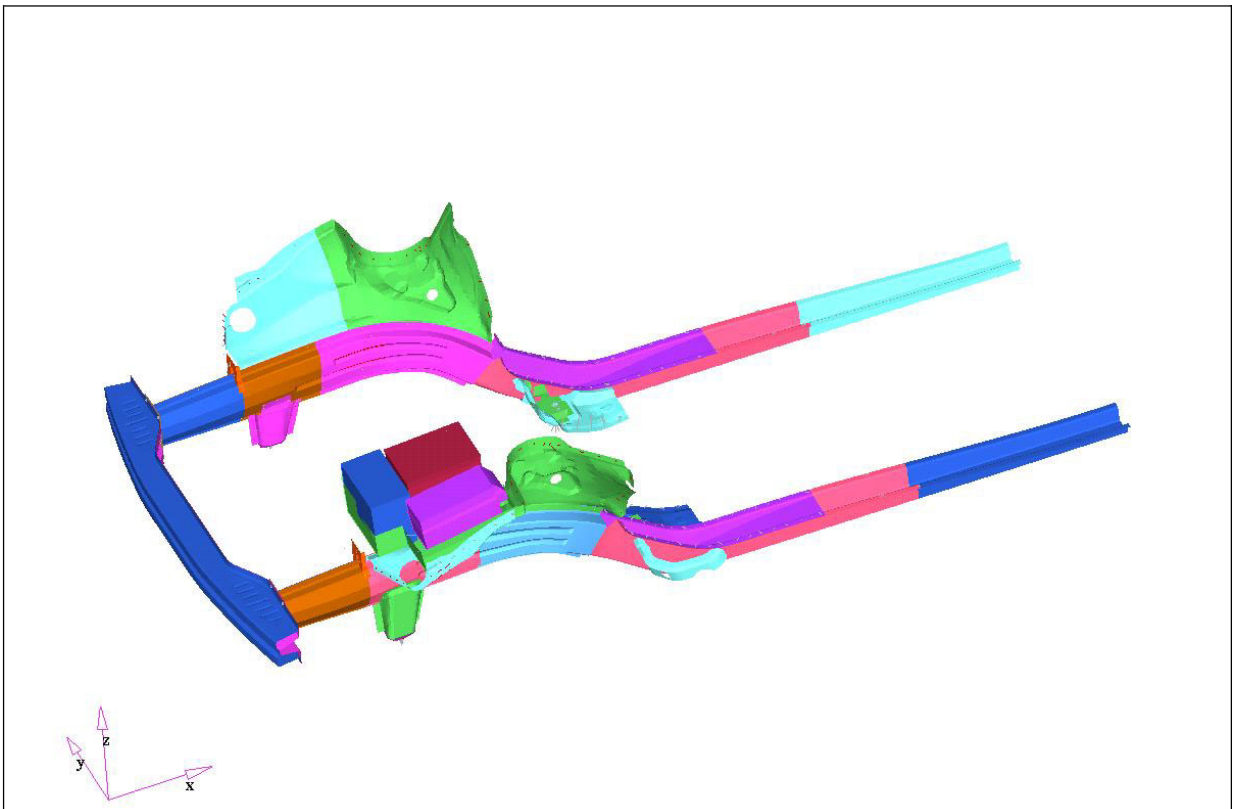


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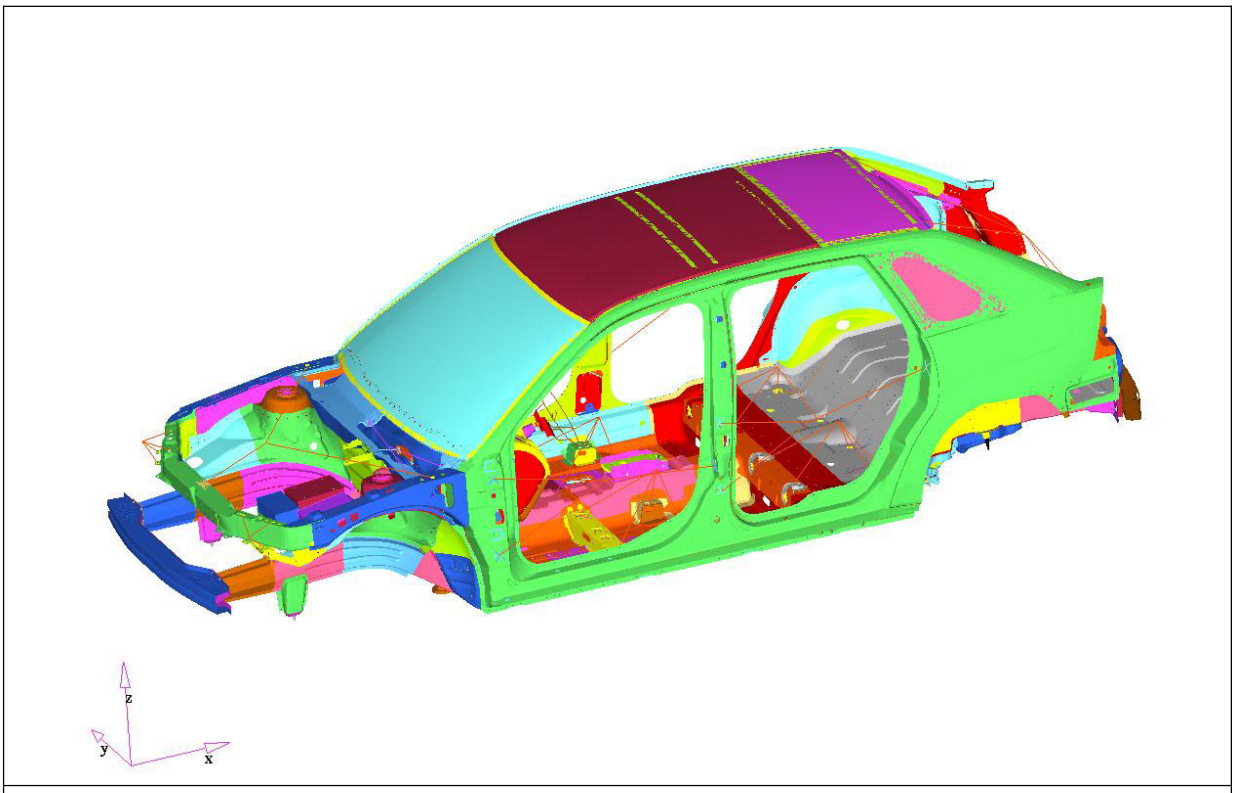


Figure 6: Final Concept 2 Design BIW Model

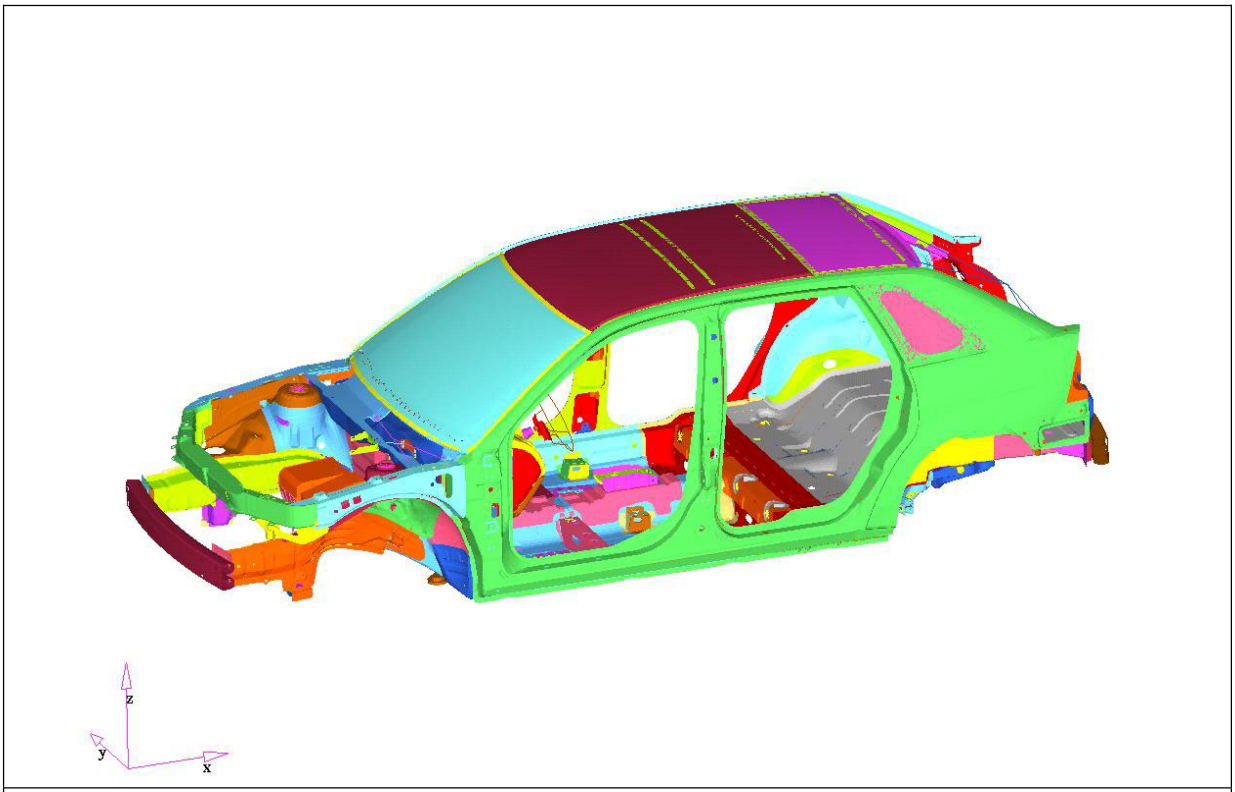


Figure 7: Donor Vehicle Baseline BIW Model

4. Dynamic Stiffness Response Surface

The *Concept 2* baseline dynamic stiffness responses as well as DOE responses are summarized in *Table 2*. Free-free modal analyses were undertaken and linear regression was employed to obtain response surfaces for the following responses.

- First Bending Mode
- First Torsional Mode

There is a very small variation in bending and torsional modes with change in DOE parameters. This is expected as the contribution of rails and bumper to bending and torsional modes is minimal.

The dynamic stiffness response surfaces serve as inputs for the computer-aided optimization of the *Concept 2* design.

Table 2: Natural Mode Variation in DOE

	First Bending Mode (Hz)	First Torsional Mode (Hz)
Concept 2 Baseline	**23.1**	**25.3**
DOE Minimum	**22.6**	**25.2**
DOE Maximum	**23.5**	**25.3**
DOE Average	**23.0**	**25.3**
% Change Min w.r.t. Average	**-1.9**	**-0.4**
% Change Max w.r.t. Average	**2.1**	**0.3**

5. Conclusions

A dynamic stiffness DOE study of the *Concept 2* design was conducted and response surfaces were derived for the computer-aided optimization of the *Concept 2* design.

6. Future Work

Computer-aided optimization of the rail/bumper designs was performed using the IIHS, NCAP, static and dynamic stiffness response surfaces.

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6) *ULSAB Model with Upgraded Powertrain, Milestone 14*, SPHINX, Phase I.

The A/SP Lightweight Front End Structure team included representatives from DaimlerChrysler, Ford and General Motors in addition to steel company members and representatives from Quantech Global Services, the engineering analysis resource used exclusively in the execution of this project.





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