A Process of Decoupling and Developing Body Structure for Safety Performance

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Keywords

LS-DYNA, optimization, decoupling, decomposition, crash, safety, automotive, structure, hydro-forming

Abstract

This paper describes a novel approach of decoupling and developing local structures for crash performance . The process discussed here enables quick development of local structure to address packaging changes in a mass efficient manner. Hundreds of design choices compatible with other design constraints were evaluated to select the optimized design. Here optimum is defined as the design that met the required parameters (crashworthiness, NVH, package, manufacturability and robustness) at the minimum mass. A large number of choices could be evaluated by using a highly simplified simulation process, since the goal was often making an A-to-B choice at a local level, as opposed to predicting exact performance at a system level. The primary focus of mass reduction was efficiency of the load path strategy, and exploitation of the unique geometrical shapes feasible in the hydroforming process. The designs were also rendered robust through a Montecarlo Simulation process for manufacturing variations and small variations in angle of impact. A subset of the new design was incorporated into a vehicle, which was tested full-scale under the ODB format. Cost constraints prevented complete rebuilding of the load path. The optimized test vehicle had comparable performance when compared to the original design, although the mass of load carrying members was reduced by 20%.

Introduction

Most of the time a new vehicle is developed from an existing platform. The decoupling process outlined here enables development of optimized local structures to address packaging changes or increased performance requirement.

In addition to safety performance, constraints imposed by other requirements such as N&V performance, packaging, common parts, manufacturing requirements etc. drive the design of an automobile body. In one sense the optimization of a structure for safety performance may be characterized as selecting the best choice from a set of choices that meet all requirements. This often reduces the problem to setting a direction as opposed to assessing system level safety performance for each choice. In some areas of the structure, such as the passenger cage, even linear static analysis can be used to identify the better choice, since the permitted plastic deformation is very small. This type of simplification enabled the evaluation of a large set of choices.

The decomposed subsets were developed through a combination of component level DYNA3D analyses, linear dynamic, linear static analyses and Genetic Algorithm techniques using HEEDS (a proprietary software). HEEDS is a multi disciplinary optimization tool within which all the traditional tools for structural development are deployed. In addition within HEEDS, the components could be made insensitive to variation in gage thickness, yield strength and small variation in angle of impact. Periodically system level analyses were performed to redefine the requirements on the decomposed subsets and to assess conformance to the strategy

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Body Structure Load Path Development Strategy

Process Model

First cycle for allocating performance requirements to regions of the load path can be established from legacy data. If such a body of knowledge is not readily available, cross sections can be introduced into legacy models to extract performance data at control points from system models. Energy absorption, actual forces and moments need to be monitored to manage performance. Regions or substructures are then developed using requirements and boundaries derived from this legacy information. Data generated by Engineering Technology Associates (ETA) was used for the first cycle.

Periodically components are assembled into the system models to evaluate vehicle level performance and to reallocate component requirements.

Figure 1 illustrates the steps involved in developing the load path. The process enabled evaluation of thousands of designs for the crush zones and hundreds in the transition and torque box areas.

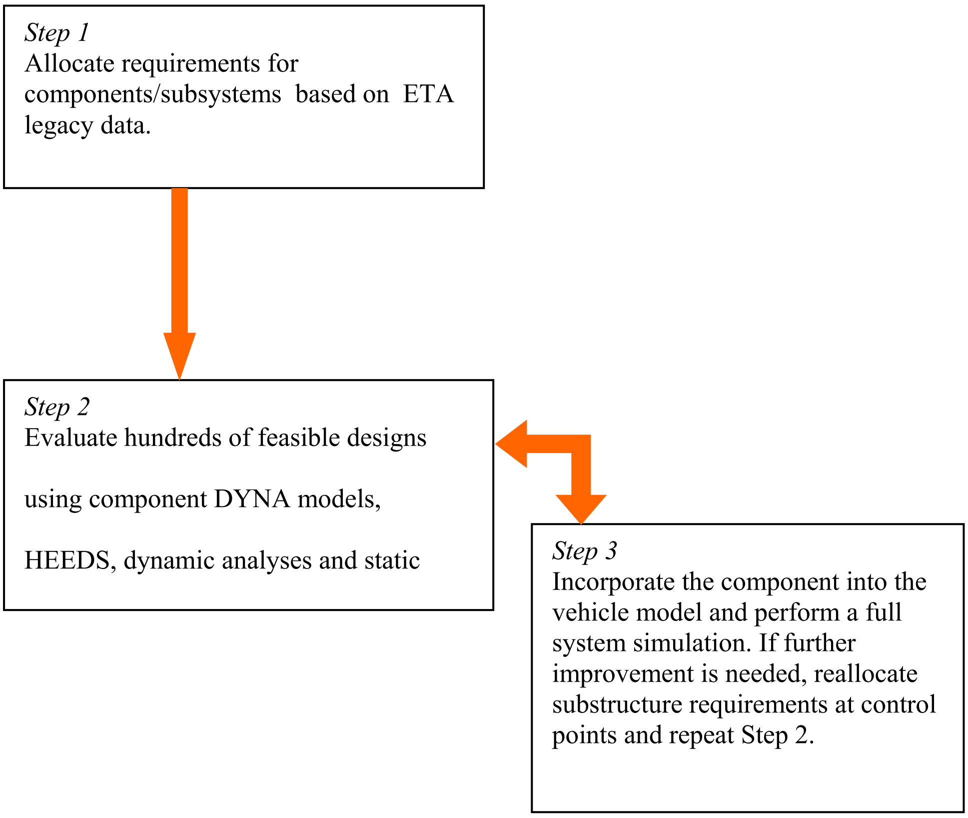


Figure 1- Process Model For Decoupled Development

Crash Energy and Mode Management Strategy

Experienced analysts deploy a number of techniques to diagnose the performance of the structure during development process. These techniques were employed through a more formalized process for this work. The process also served as a good communication tool between various disciplines. Though the crash performance is chaotic, the trends at control points can be used as dials to monitor and manage the energy and forces during crash events.

Crash Performance Mapping

The allocation strategy needs to consider the potential influence of all the members in the region on collision energy management process. Figure 2 indicates components in the motor compartment that can influence crush modes. This map shows the relationship between events and structures in space and time in a qualitative way. Controlling the crush modes of all the elements is critical to managing the global crush modes. A level of separation between the capacity of dominant members and other members is essential to ensure that stray mechanisms induced by material property variation or mode variation will not trigger unfavorable contact paths. For example, the high force capacity of the cradle - when compared to that of motor compartment rail - can increase the uncertainty in a mechanism that is rail dominant. The separation will ensure that variations in material properties or crush modes will not result in a significant shift of the contact trajectory.

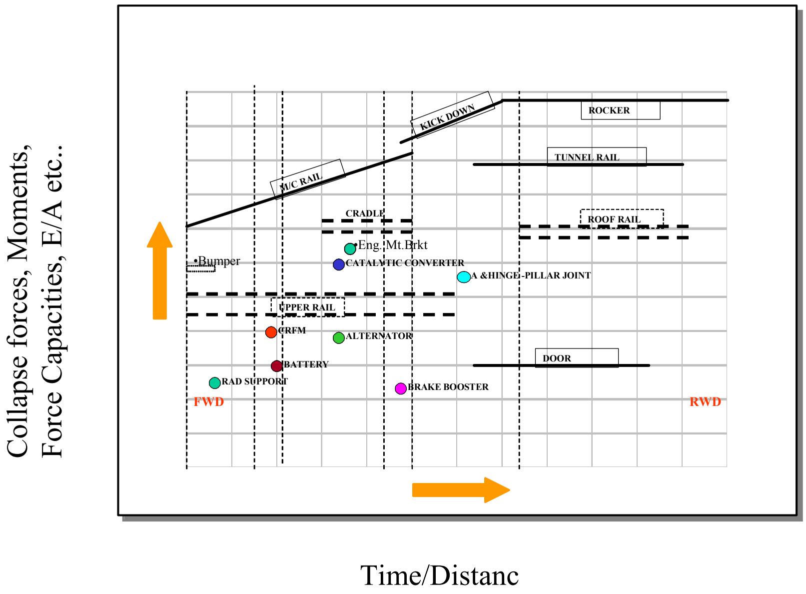


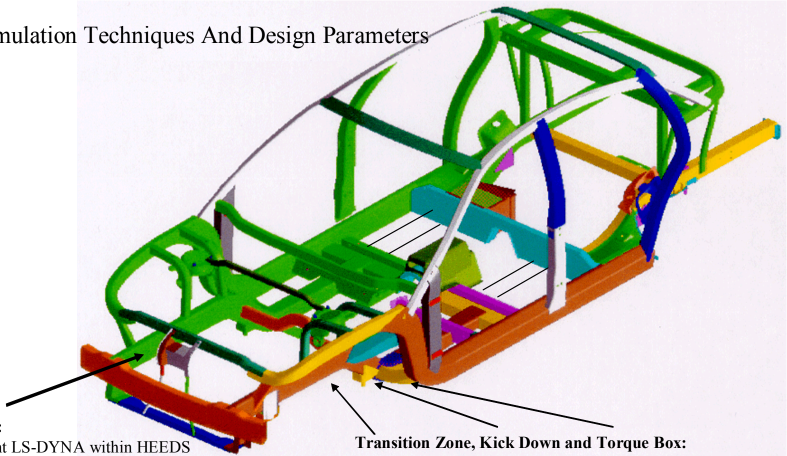
Figure2-Crash Performance Mapping.

Ideally if large amount of data is available for section forces, moments, energy absorption, etc. from legacy experience, trends seen in the data can be used to assess the effectiveness of the load path. Though the crash mechanism is very complex, past trend analysis is very useful in managing overall performance and establishing a glide path to the final solution. The trends can be thought of as quasi-substructure level performance requirement. For example, the consequence of not managing energy every millisecond is that greater forces will have to be managed later in time. The information gathered at various sections from the system model was used to assess the risks during the development cycle. The data was also to be used to confirm that the load path strategy is effective. The motor compartment rail was expected to absorb 30% of the total energy with a force capacity of 180 Kn.

Simulation Techniques

Figure 3 depicts the simulation techniques employed in each region of the load path.

Simulation Techniques And Design Parameters



E/A Zone:
Component LS-DYNA within HEEDS
Design Considerations:
Manufacturing and material property variation
Substructure load variation
Energy absorption
Force capacity
Moment capacity

Transition Zone, Kick Down and Torque Box:
HEEDS: Linear static, Linear dynamic, LS-DYNA substructure
Design Considerations:
Manufacturing and material property variation
Energy absorption
Deformation

Figure 3-Simulation Tools Deployed During Development.

New Load Path Strategy

The original design of the vehicle had the motor compartment rail extended to the #4 bar. The new load path strategy was focusing on higher energy absorption in the crush zone by utilizing the aggressive geometrical shapes feasible in the hydroforming process. In addition the deceleration force was directly transmitted to rocker (see Figure 4.4). This made the continuation of the motor compartment rail beyond #2 bar unnecessary.

Motor Compartment E/A and transition zone

The primary tool for developing the motor compartment region was HEEDS, within which DYNA3D component level simulation was utilized to develop an optimized robust solution. The capability embedded in HEEDS allowed evaluation of thousands of choices for the E/A region alone. The component was modeled with masses located at eccentric locations and impacted into a rigid wall. Locating masses at eccentric locations was a methodology employed to comprehend the moments induced by connecting structures such as the bumper, radiator tie bars and cradle. A force capacity of 180KN and E/A of 32% was selected as the performance requirement. The transition zone could not crush until the E/A zone was completely crushed. Within HEEDS, Monte Carlo simulation was used to perturb the design for gage thickness variation, yield strength variation and applied moment variations(See Figures 4-8).

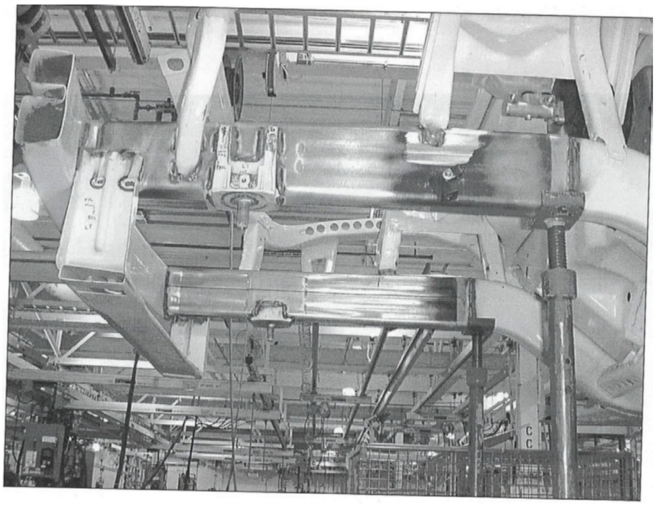


Figure 4-Portion of the new rail as installed in the test vehicle.

Figure5-Front portion of the hydroformed rail as manufactured.

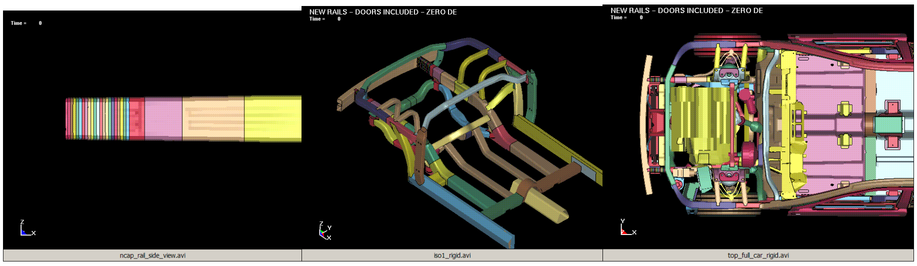


Figure 6- Longitudinal shape and size development using HEEDS

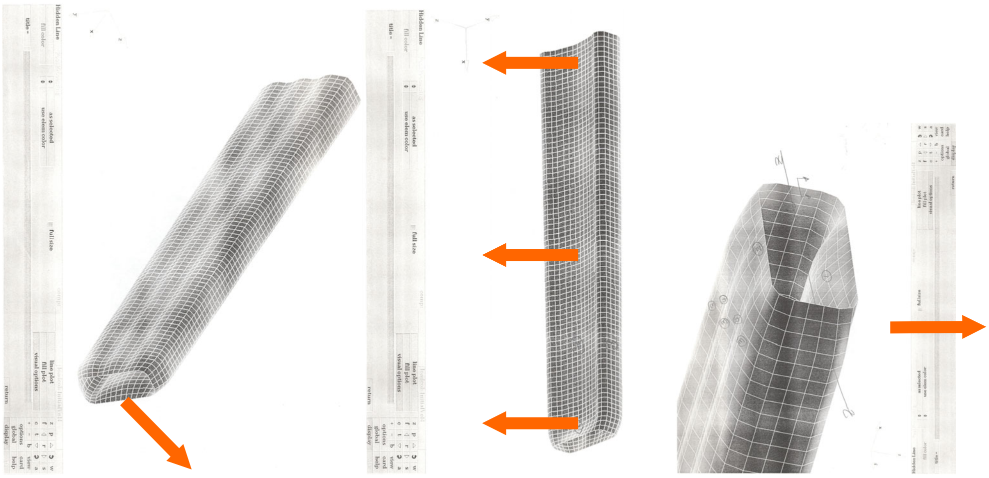


Figure7-Design for a splayed rail hydroformed. The concave walls bellow out - as indicated by arrows - at the point of crushing, thereby increasing the collapse strength and E/A.

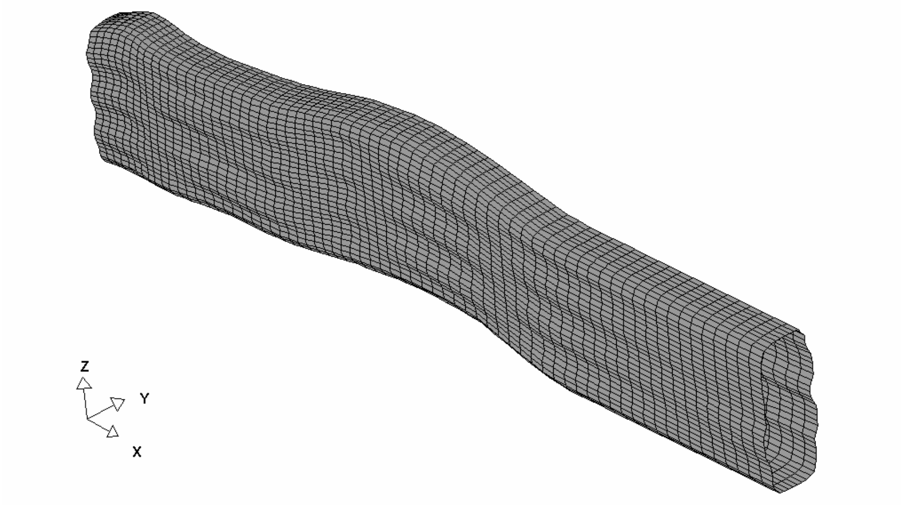


Figure 8-Design for a humped splayed rail (hydroformed)

Transition And Kick Down Area

The primary goal of the transition and kick-down area is to transmit the moments and forces induced in the mid-rail to the rocker and the #2 bar, at the same time, to absorb energy in a controlled deformation mode. This is considered to enable acceptable intrusion numbers. Aggressive use of beads developed with HEEDS increased the Mz and My moment capacities, which in turn lead to a mass efficient design although the design volume was quite restrictive.

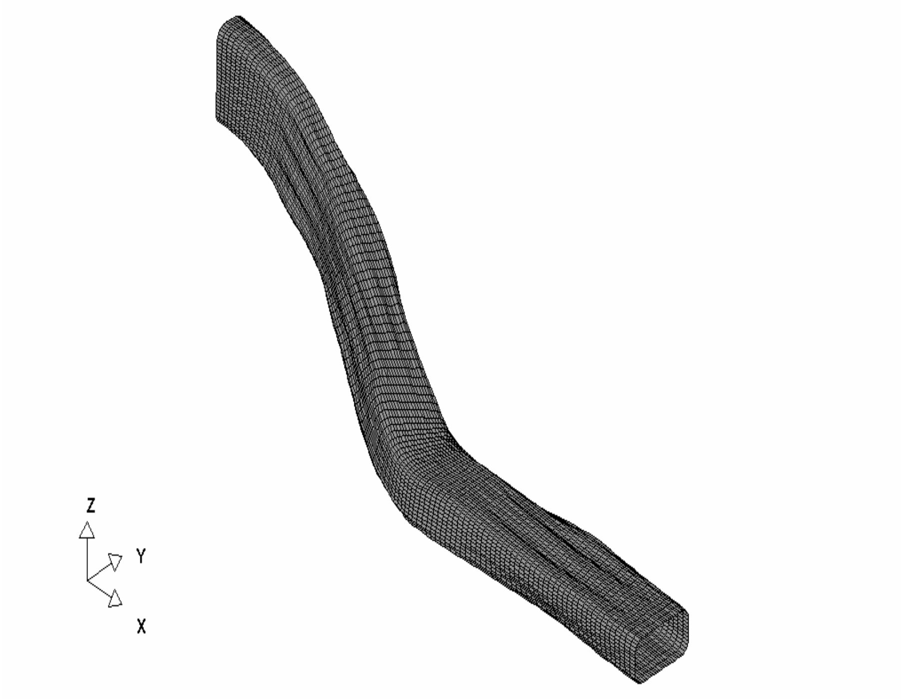


Figure 9-Kick down region of the rail.

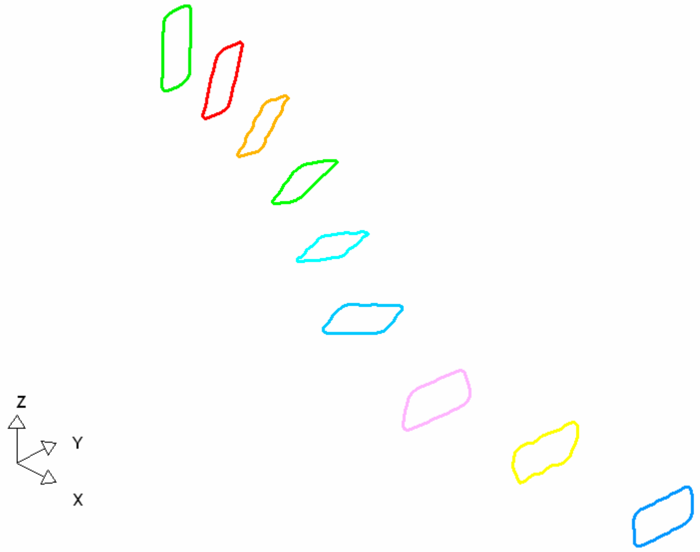


Figure 10-Wire-frame view of the kick down shows the cross-sectional shapes with their positions along the length of the rail.

Torque Box And Load Transfer To Rocker

The original design depended on a continuous load path of the motor compartment rail through to the #4 bar. The new load path strategy was to remove the rail between #2 and #4 bar and offset the rail to a reinforced rocker. The rocker needed to have the capacity to carry the high loads developed during tire impact. Fig. 4.4 shows two design concepts for this load transfer. On the test vehicle this mechanism was simulated through a shear plate in the torque box region to stay within budget.

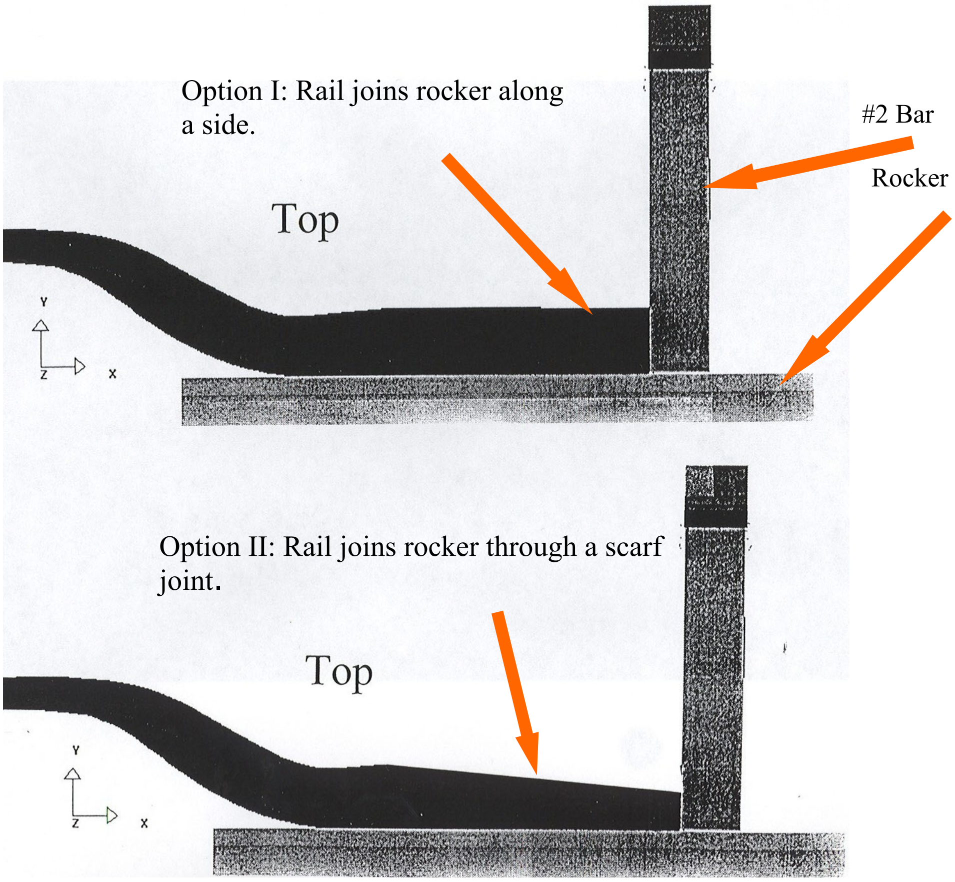


Figure 11-Kick Down To Rocker Load Transfer

Analysis and Verification

Based on load path strategy the subsystem model was verified first. The process for the verification of the strategy was to develop the subsystem model using HEEDS and then insert the model into a full system model for verification and modifications (see Figure-1). The two main ingredients of this approach were identification of the load path and energy dissipation in the system at any time and use of HEEDS to divert the load in the desired directions.

ODB Analysis to Test Comparisons

The results of this study showed that the full vehicle system test and simulation correlated well in ODB. The ODB test vehicle measurements in all the areas of dash intrusion, footwall intrusion, steering column intrusion, door open-ability, etc. ranked EXCELLENT.

The new optimized vehicle system can maintain the same or better performance while the mass of the vehicle is reduced. Figure 12 shows the comparison of two vehicle structures and Figure 13 shows the comparison of the deformation in test and simulation for the modified vehicle.

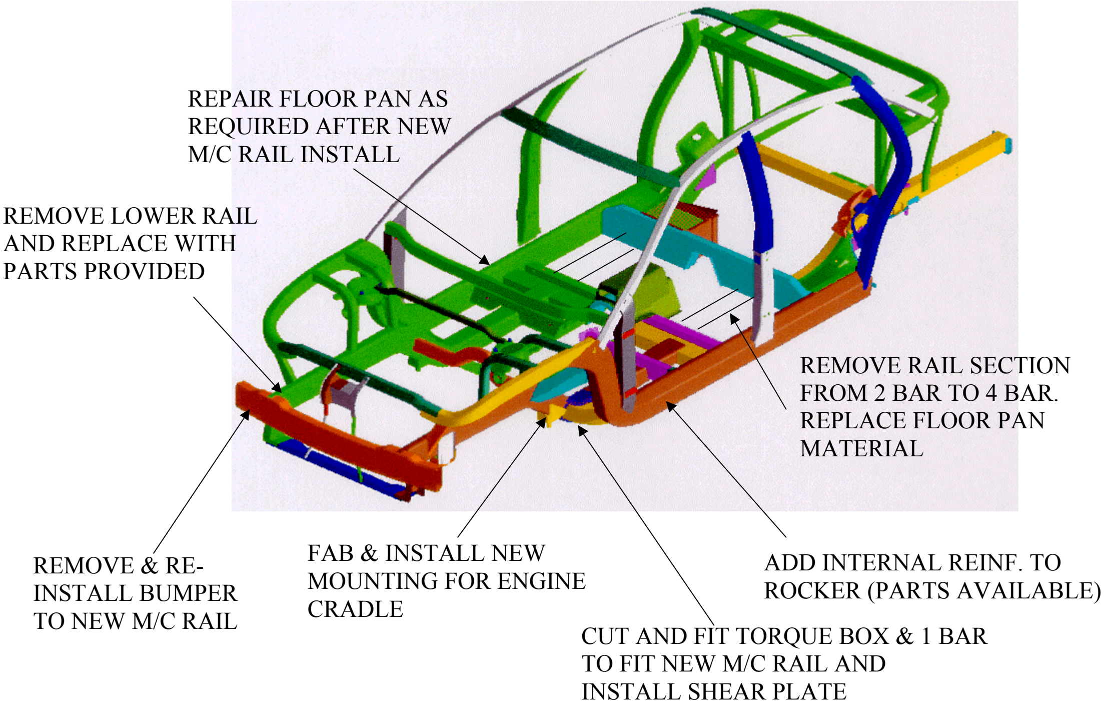


Figure 12- Regions where structure was modified for the test vehicle.

Figure 13- ODB test vehicle after crash and when door was opened with no deformation

Conclusions

A process for decoupling and developing an optimized automotive body structure for enhanced safety performance has been developed, implemented, and verified. The approach facilitates the development of a load path strategy and decoupling of a complex system into structural components or sub-systems, thus allowing for high-fidelity design optimization of a sub-system to meet desired performance targets. In the present study, the proposed approach was used to design a hydroformed motor compartment rail to meet the NCAP front crash and 40 mph 40% offset deformable barrier impact performance requirements, resulting in a 20% mass reduction and improved overall performance compared to a baseline design

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