ACP Process : 3B Forming Optimization
An Integrated Optimization Manufacturing Process

Akbar Farahani, Ph.D.[1], Divesh Mittal[1], Jody Shaw[2]

[1]Engineering Technology Associates, Inc.

[2]US. Steel

1 Abstract

The automotive and steel industries have several initiatives such as the development of 3rd Generation Advanced High Strength Steels (AHSS), the Nonlinear Strain Path Project and the A/SP AHSS Stamping Team Projects. These initiatives are efforts to expand the forming design space with AHSS to enable increased part complexity, which will allow AHSS to be incorporated into more vehicle components and enable mass reduction. The proposed approach discussed in this presentation will provide a new tool in the effort to expand the forming design space of AHSS.

The final design of the Future Steel vehicle (FSV) Project was released in May of 2011. Its development used a new optimization-led design methodology, the Accelerated Concept to Product (ACP) Process®, which produced highly non-intuitive designs. Component geometry utilized natural, very organic shapes combined with minimum gauge selections. While these non-intuitive designs have the potential to produce lightweight, low-cost, yet structural efficient products; these types of solutions also create significant manufacturing challenges [1].

Exploiting the flexibility of AHSS and modern, advanced steel manufacturing technologies, these types of designs are now possible in the real-world production environment. However, due to severe formability challenges, many design iterations are required to create such solutions. As a subset of the ACP Process, formability analysis using DYNAFORM has now been integrated directly into the optimization based design process.

An Integrated Incremental 3B (Draw Bead, Blank Geometry and Binder Pressure) Forming Optimization approach balances forming parameters such as draw Bead force and geometry, Blank shape and size and Binder pressure and then perform gauge optimization of the product itself to create the lightest, most structurally and cost efficient design possible that meets the vehicle performance targets. It achieves this by optimizing the component design for formability while simultaneously validating its in-vehicle crash performance.

This paper will explain the quick forming process based on the ACP Process. It will describe the methodology as applied to forming the most challenging FSV components to form through the use of 3B forming optimization and key enablers of the process, including DYNAFORM, LS-DYNA, HEEDS and ANSA.

2 Introduction

The design of automotive body structures is driven by many competing criteria such as lower cost, weight reduction, enhanced multi-disciplinary performance, and manufacturability. In addition, the introduction of new manufacturing processes and materials (e.g., AHSS) significantly increases the available design space, or the set of all possible designs for an automotive system.

In order to explore this large design space more effectively while trying to reduce design cycle times, engineers can now take advantage of an automated design optimization process. These tools can greatly decrease the time required to identify a set of feasible, or even near-optimal, designs prior to building and testing the first prototype. Moreover, these tools can also compensate for the limitations of human intuition and provide design engineers with the freedom and power to seek creative solutions that are not obvious to even the most experienced engineer. The Accelerated Concept to

Product (ACP) Process® in the Concept phase can establish an initial skeleton of structure based on material requirements under multidisciplinary loading conditions. ACP-3G (Geometry, Grade and Gauge) optimization is the driving force behind ETA's design process, Accelerated Concept to Product (ACP) [3,4,5,6,7].

World Auto Steel's objective in the FutureSteelVehicle (FSV) Program was to develop detailed design concepts and fully optimize a radically different body structure vehicle for production in the 2015-2020 timeframe utilizing the latest grades of advanced and ultra-high strength steels. FSV achieved 35 percent mass reduction at no additional cost over a conventional steel body, while achieving simulated crash test performance with a 5-star safety rating.

Using different types of AHSS for different vehicle components with new non-intuitive shapes provides a significant challenge for formability and manufacturability. These challenges required a new process using simulation tools that can make the parts formable as quickly and as efficiently as possible.

3 ACP-3B Forming Optimization Process

The process requires an optimization software package which allows manufacturing process engineers to automatically and concurrently explore balancing different tool design countermeasures. These design countermeasures are normally used to make the parts manufacturable using an iterative process without exploring the effect of other countermeasures at the same time.

These countermeasures are normally used to remove cracks and wrinkles while parts are being formed. The process uses draw beads to control material flow rate, adjusts binder pressure to control the tonnage forces applied and uses blank size geometry to control the blank size and material.

Bead size, Blank Size and Binder Pressure are the 3 countermeasures available to the manufacturer to make the parts formable. These countermeasures are what will be referred to as the "3B's" [Figure 1].

ETA's Engineering Team has developed the ACP-3B Forming optimization process that incorporates DYNAFORM, LS-DYNA and optimization software such as LS-OPT and/or HEEDS. It balances the 3B's so the parts become formable by preventing cracks and wrinkles in the final formed parts.

Once the incremental forming processes are setup within the DYNAFORM Optimization Platform (OP) module, the bead size and binder pressure are setup to be used for optimization process.

To optimize the blank shape, the blank is parameterized using ANSA. The automatically runs through many iterations, which will consider hundreds of designs of bead sizes at the perimeter of the parts and balances the Binder pressure and size of Blanks.

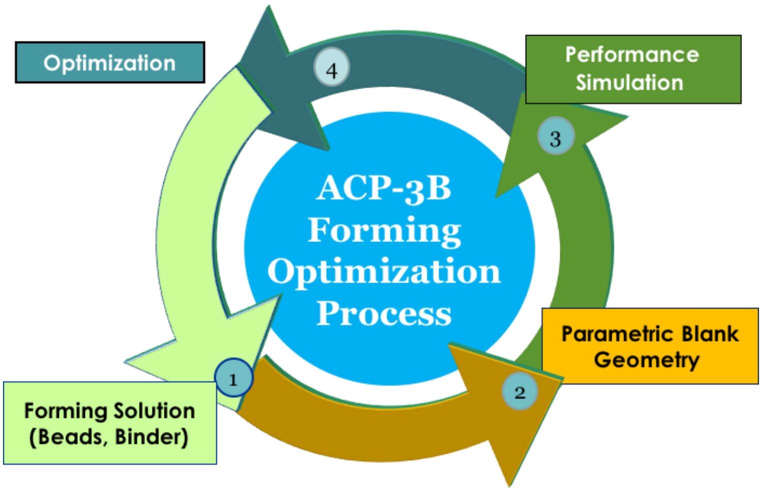
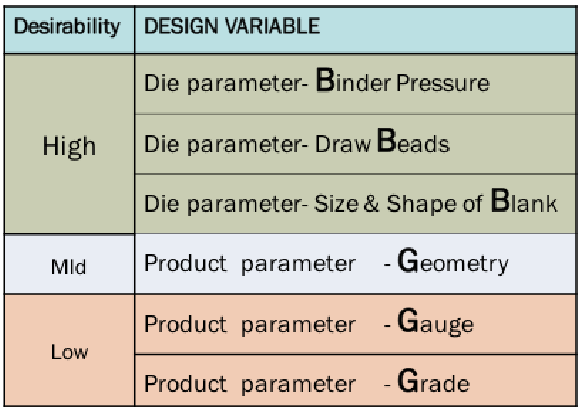


Figure 1 ACP 3B Optimization Life Cycle

3.1 FSV Upper and Lower Rail 3B Forming Optimization Process

The following process was executed on very unusual parts of the FSV vehicle, which were the upper and lower front longitudinal rails. The desirability design variables for 3B Forming optimization for these parts are shown in Figure 2



Desirability	DESIGN VARIABLE
High	Die parameter- Binder Pressure
	Die parameter- Draw Beads
	Die parameter- Size & Shape of Blank
MId	Product parameter - Geometry
Low	Product parameter - Gauge
	Product parameter - Grade

Figure 2 Design Variables

Using ACP 3B-Forming process, the most desirable variables are used and when the number of cracks and wrinkles due to geometry design flaws are reduced, minor modifications are applied to the geometry to remove the final cracks.

3.2 Forming Targets

1. No material folding

Material folding is not acceptable, since folding can lead to poor performance under any type of loading. It can initiate high stress concentration under severe static loads and create undesired buckling under crash/impact loads.

2. No Cracks

No major cracks at geometry of products are allowed. The process uses the following FLD curve [Figure 4] as a guideline to indicate cracking, risks of cracking, safe, wrinkle tendencies, wrinkling, severe wrinkling and insufficient stretch.(Figure 3 and 4)

Figure 3 Forming Targets

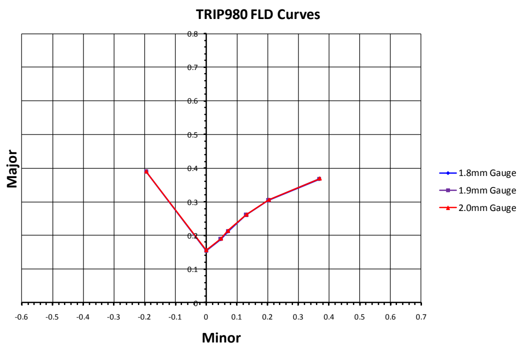


Figure 4 FLD Curve for TRIP 980 Steel

3.3 Longitudinal Rail Products

The product geometry was designed based on FSV design targets to meet 5-star front crash performance, which keeps the vehicle average pulse under 35G's. The geometry of product and i gauge are shown in Figure 5. The material is TRIP steel, stamped using a laser-welded blank manufacturing process. The total weight is just under 19 Kg.

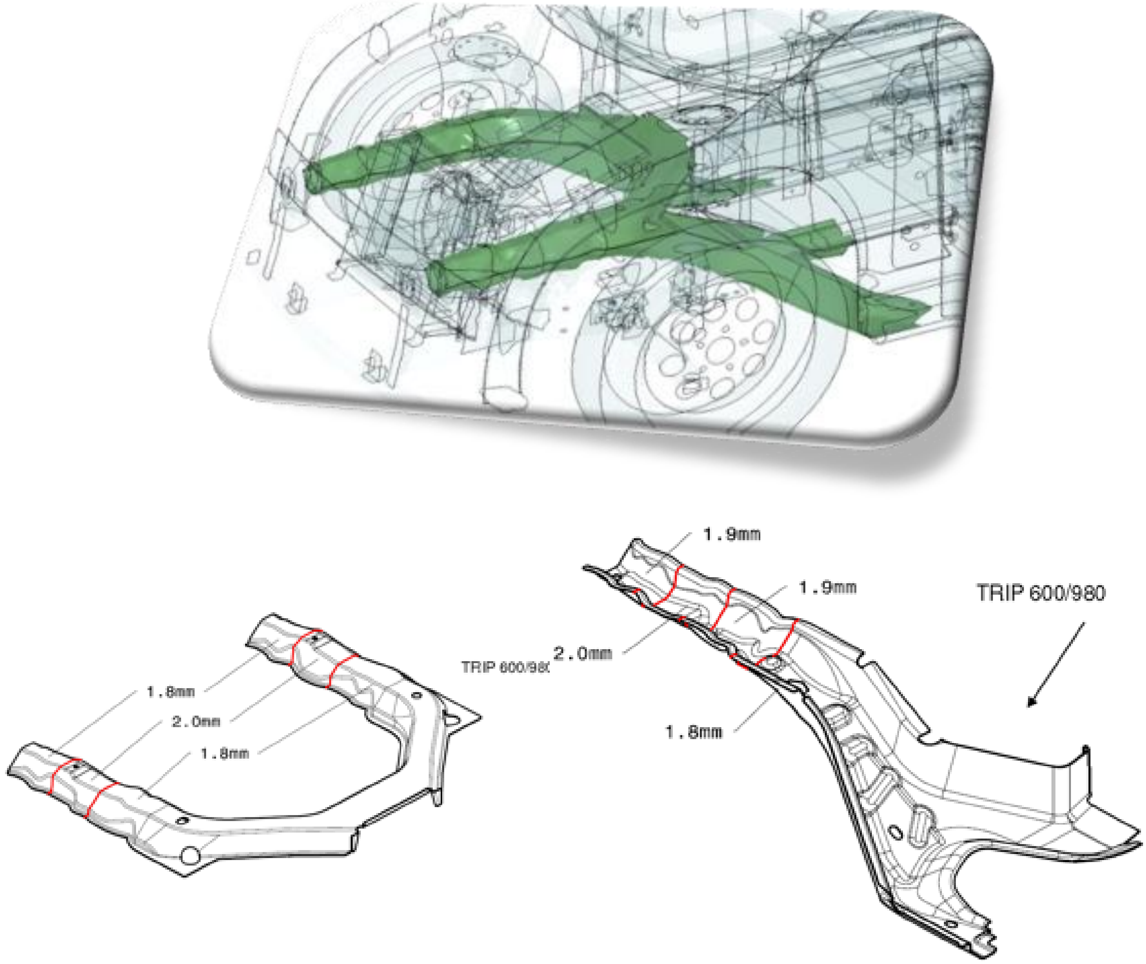


Figure 5 Longitudinal Rail Geometry (Upper and Lower)

3.4 Incremental Forming Setup

The upper rail and lower rail upper and lower rail binder, die and punch are designed using DYNAFORM as shown in Figure 6.

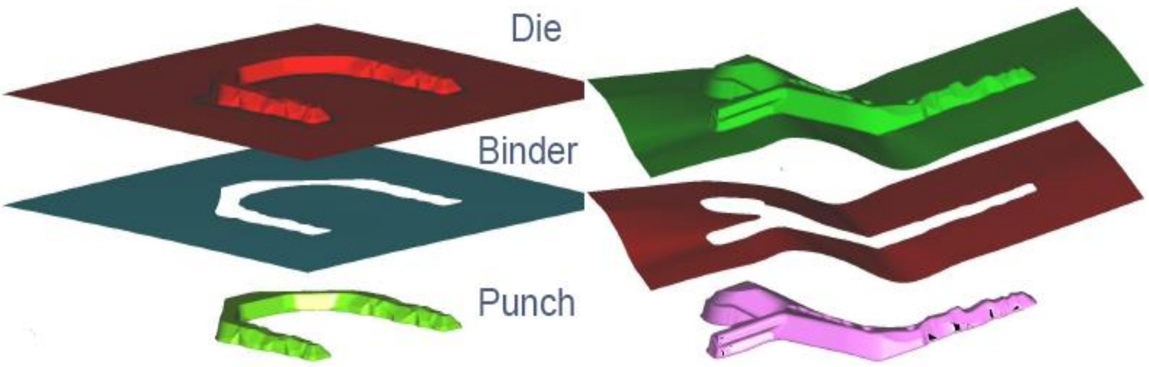


Figure 6 Die Face Engineering-Upper and Lower Rails

3.5 3B'S Optimization Setup

The following sections describe the 3-B Optimization Process Setup used in the FSV Program for the longitudinal rails.

3.5.1 Bead Optimization

Beads are designed using the geometry of line beads in DYNAFORM. For the FSV longitudinal rails, beads are designed and parameterized within ANSA and DYNAFORM. The line beads allow changes in geometry of beads and control the flow of the material into the parts. Figure 7 shows the line bead design variables for both the upper and lower parts.

- Line beads are added to control material flow
- Line beads are non-geometric representations of draw bead geometry & forces
- Each line bead (color) is unique, allowing localized fine-tuning of the beads
- In this case there was a total of 57 line beads in upper frame & 35 in lower rail.

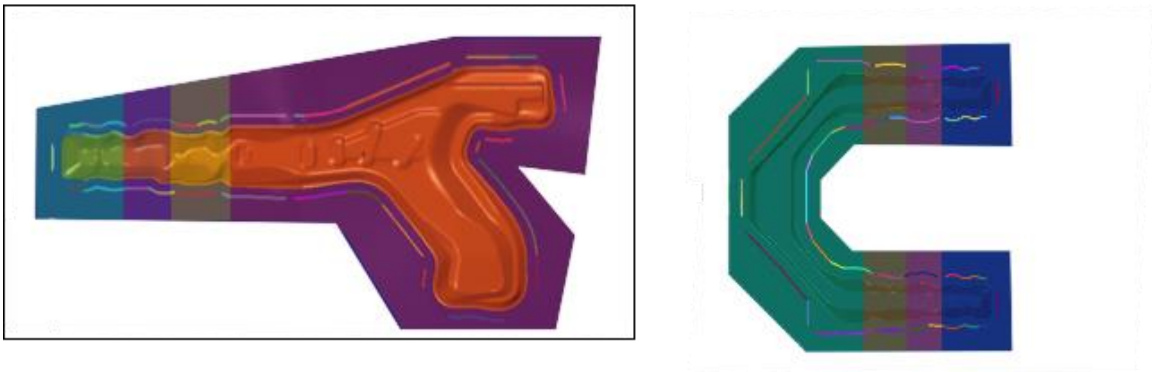


Figure 7 DrawBead Optimization

3.5.2 Binder Pressure

Binder pressure controls material flow into the draw uniformly as shown in Figure 8.

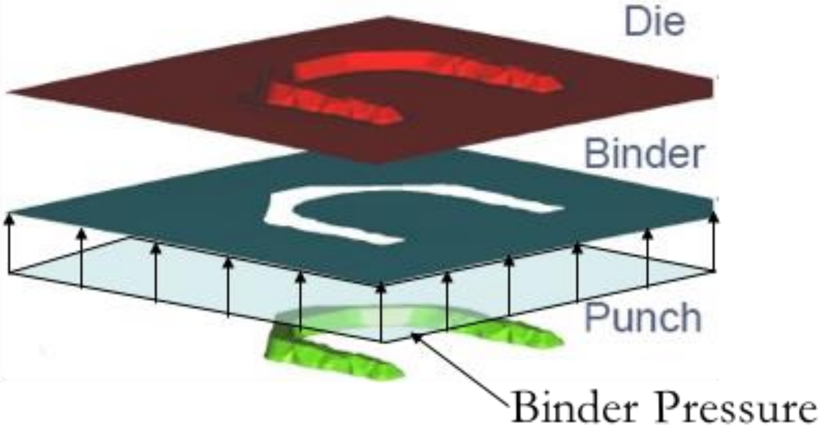


Figure 8 Binder Pressure Optimization

3.5.3 Blank Geometry

The blank geometry plays a major role in balancing the non-intutive shape of the blank geometry. The following is the upper rail which was parameterized within ANSA for shape optimization as shown in Figure 9.

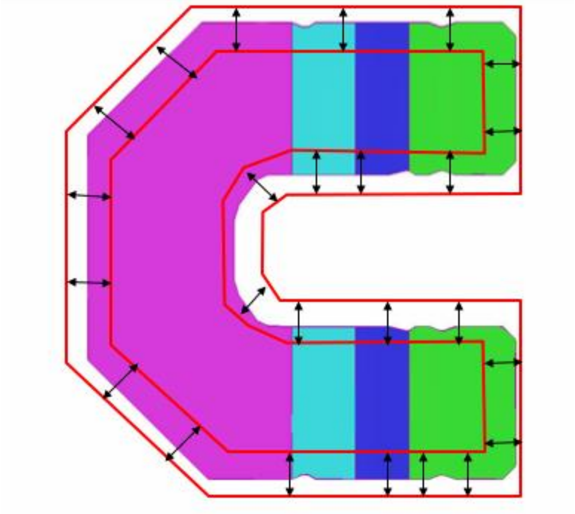
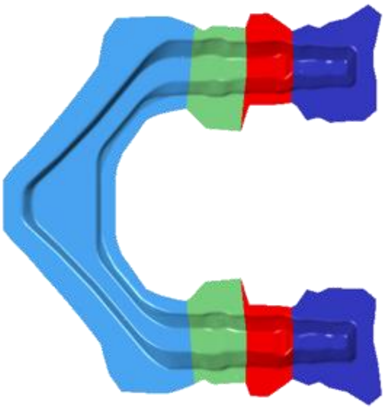


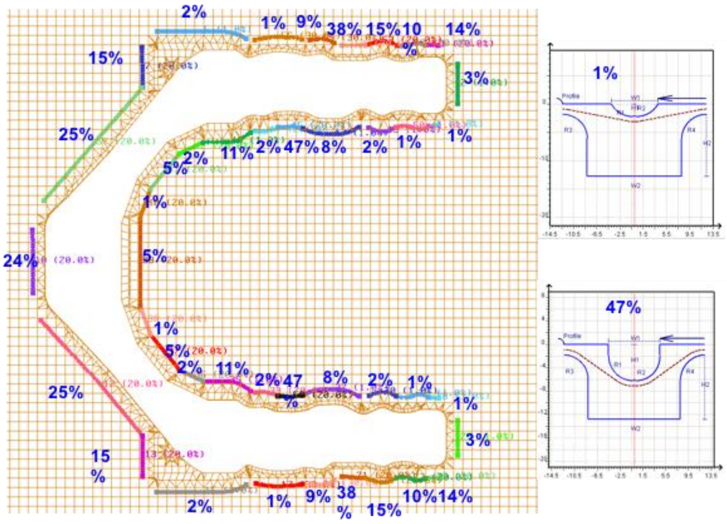
Figure 9 Blank shape Optimization

3.6 3B Forming Optimization Results

The following results were obtained during 3B Forming Optimization [Figure 10], using ANSA, DYNAFORM and LS-DYNA for the calculations.



The line bead forces provide a series of bead variations in size that, when balanced with blank size optimization and Binder pressure, provide very efficient design results. Design iteration 1959 for the lower part [Figure 12] and design iteration 1664 [Figure 11] for the upper part, were selected as the optimal designs, showing the least amount of cracking and wrinkling.



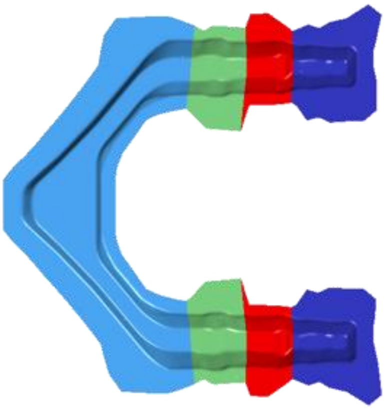
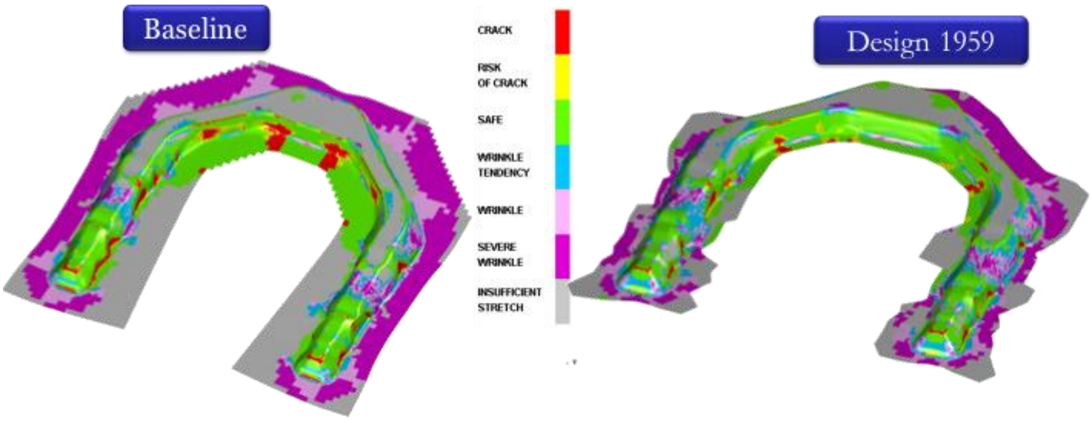
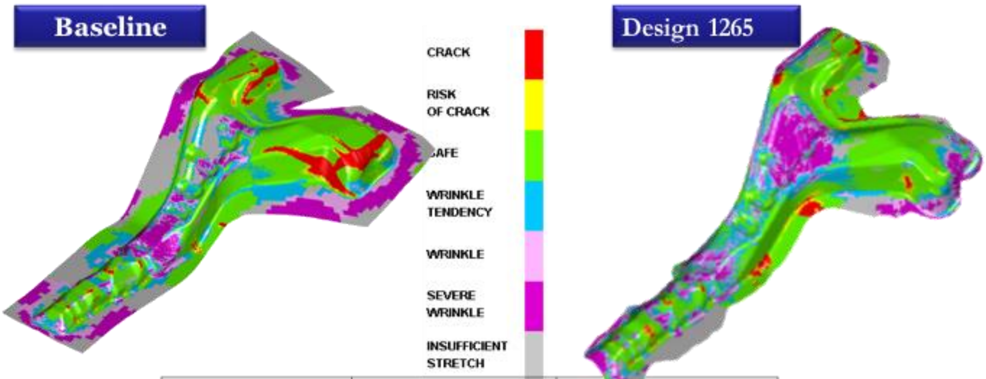


Figure 10 Optimized Draw Bead Forces and optimized blank geometry -Upper Rail



Upper Rail Results	Num of Crack Points	Num of Wrinkle Points
Baseline	3017	3253
Design 1959	88	117

Figure 11 Result of 3B Optimization-Upper Rail



Upper Rail Results	Num of Crack Points	Num of Wrinkle Points
Baseline	1413	1568
Design 1265	284	366

Figure 12 Result of 3B Optimization-Lower Rail

The final results in Figure 11 and Figure 12 show that 98% and 80% of wrinkles and cracks were removed from the upper rail and lower rail, respectively.

Later minor geometry modifications were used to remove the remaining cracks and wrinkles in the parts.

The final product was then put back into full vehicle system and optimized for performance. The final results of front crash testing (NCAP and 40% ODB) are shown in Figure 13 [4,5,6].

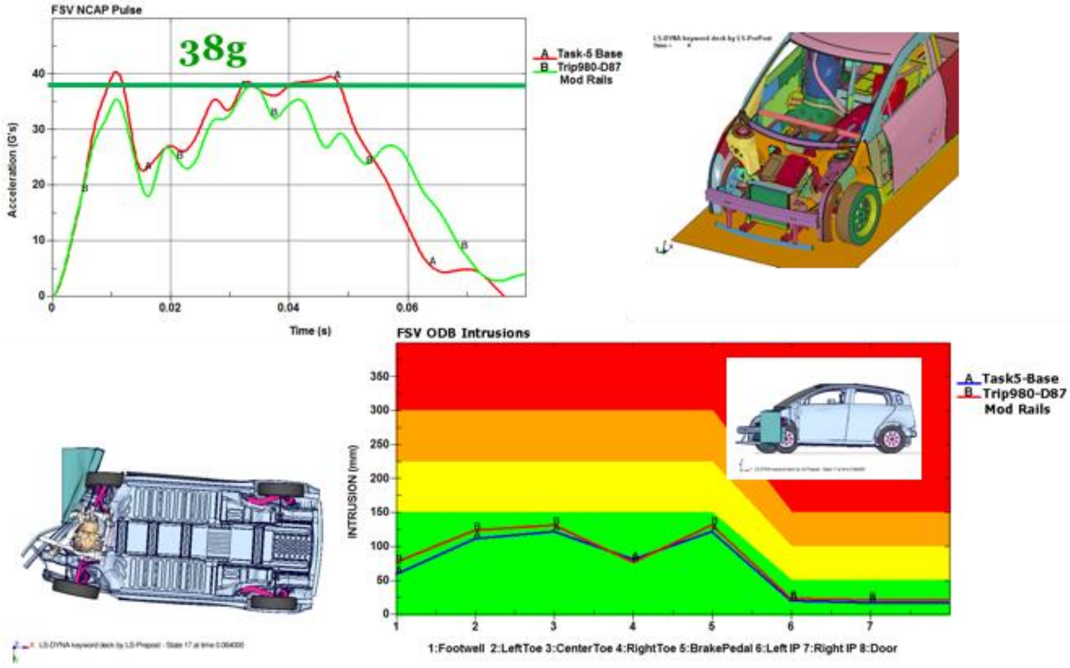


Figure 13 Front Crash Confirmation Run-Post 3B Optimization

The final results of the front crash tests were the same for both rails.

4.0 Summary

- A multidisciplinary optimization approach can effectively balance Draw Beads, Binder Pressure, and Blank Geometry to address the formability of complex parts.
- Optimization has been a proven and effective tool for finding solutions to complex forming issues, while maintaining crash and other key performance requirements.
- A software suite to encompass this process is under development and will feature non-linear capabilities and will interact with other non-linear software for impact analysis (such as LS-DYNA).
- The use of optimization software within this process is a key enabler for improving any engineering system (structural, thermal, fluid, electrical, etc.) including those in multi-disciplinary scenarios.
- ACP 3B forming optimization applied to structural designs uses optimization to search for designs that simultaneously satisfy the objectives and targets for manufacturing and vehicle performance.

5.0 Literature

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