DESIGN OPTIMIZATION AND RAPID PROTOTYPE OF CAR FRONT DOOR STRUCTURAL COMPONENTS

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Abstract - *In developing nations, the car manufactures are focusing more on fuel-efficient cars due to increase in price of petroleum products. As the weight of the vehicle is related to the fuel efficiency, lowering the vehicle weight can achieve increase in mileage. The car door comprises around 10~15% of total vehicle weight and can be considered as one of major parts to be considered for optimization. The reduction in mass to increase the fuel efficiency can result in decrease in strength of door. Loss of stiffness of car can be sensitive to sag and over open performance of car. In addition, outer panel buckling is also sensitive to panel thickness incurred due to body leaning on car or during the car cleaning. The project focuses on understanding the existing conventional car door design, and to explore the potential optimization parameters to save the mass as this is the one area each designer in automotive industry is looking forward to increase the fuel efficiency and cost of manufacture. In most of the industries, the potential studies are carried out to optimize the parts, as some of the structures may not designed optimally during the product development phase. The reason for this can be due to the short timeline for the product release or change in performance target (lowered) due to studies like benchmarking or costing etc. In this study, the capability of virtual simulation (CAE) is used to evaluate the performance of the door structure and to optimize the parts. Another innovative trend in the automotive industry is the use of rapid proto-type techniques. Rapid proto-type model helps to understand the manufacturing feasibility and to have a feel of the part before actual tool development. In this study, we are exploring the easily available and cost effective rapid proto-type technique to develop a scaled proto-type model of one of the car components.*

***Key Words*: Car door, Optimization, Cost, Weight, Fuel efficiency, Virtual simulation, CAE, Rapid prototype, Sag, Over-open.**

1. INTRODUCTION

Doors are highly complex structures that contain just about everything that a car as a whole contains except for power train elements. Customers interact intimately with doors. Doors are one of the major components in a car, which provide easy access for passengers into the car. Doors also comprise both interior and exterior elements, causing them to be links between these two domains of the car. Many of the attributes conflict: for example, better water leakage and wind noise behavior will make it more difficult to close the door; better side intrusion protection will make the door heavier; better leakage around the glass makes it harder to raise the glass, requiring stronger motors, making the door heavier. Door system mainly consists of window glass, window regulator assembly, door latch, sealing and structural components of the door assembly. Traditionally these parts are designed, manufactured and procured separately.

1.1 Objective of the Project

Intention of the project is to reduce the weight of the car front door by changing the tailor welded blank to a single piece design and adding reinforcement at hinge pillar area which will aim for 20% mass reduction. As the automotive industry is going ahead to increase fuel efficiency by checking all possible weight saving options; the ideas like beta-patch, gauge reduction and all are gaining substantial momentum. The study will also focus on further optimization of the car components near the door hinge area. This mass reduction also helps to reduce the sag on the door. The performance needs to evaluated for the strength load-cases like sag-set, Static over check and oil-canning performance , another reason for choosing this because door is one of the complex systems in auto industry and most used system by the customer. This counts for the right design performance integrating weight and strength performance. Also, intention is to develop a scaled rapid proto-type model of one of the car components by using one of the easily available rapid proto-type techniques in the industry and to have a feel of the part.

1.2 Project Flow Chart

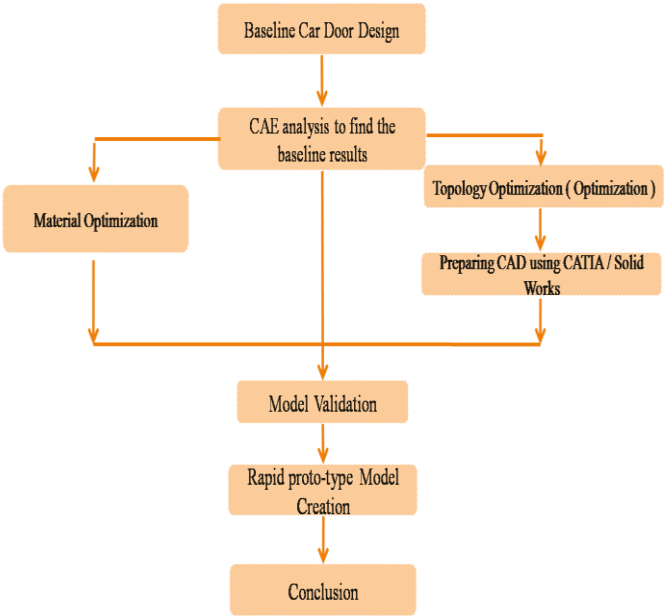


Fig -1: Flow Process of Front Door Structural Components

2. DESIGN DETAILS & DIFFERENT LOAD CASES

2.1 Design Details

Door assembly and the other components considered shown in Figure 2, consists of inner panel, outer panel, belt reinforcements, hinges , impact beam etc

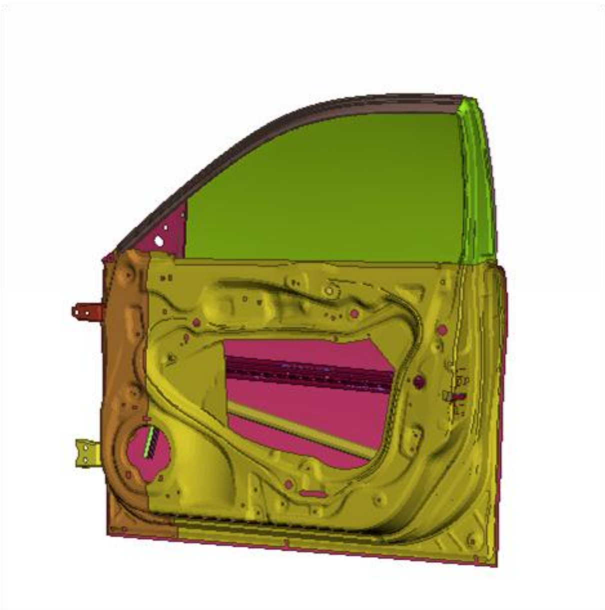


Fig -2: Front Door Assembly

2.2 Door parts considered for hinge side optimization

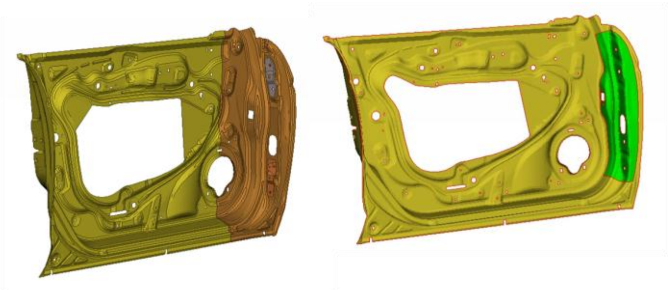


Fig -3: Door Inner Panel

Baseline design is having Tailor welded inner panel design and the new design identified for robust optimization is single piece inner panel with hinge reinforcement , Robust optimization door properties considered for simulation

Table -1: Physical properties of Baseline door

S.No.	Door Parts	Material	Thickness (mm)
1	Inner panel (Thick / Thin)	Steel	1.5/0.8
2	Tapping plate (Upper / Lower)	Steel	1.8/1.8
3	Hinges	Steel	5

Table -2: Physical properties of New design door

S.No.	Door Parts	Material	Thickness (mm)
1	Inner panel	Steel	0.8
2	Tapping plate (Upper / Lower)	Steel	1.2/1.2
3	Hinges	Steel/Al	5
4	Hinge Reinforcement	Steel	1.5

2.3 Material Description

Here, Aluminum and Steel are considered for the structural improvement and optimization study, both the materials have commonly used materials in all the sectors due to its feasible structural characteristics like corrosion resistance, high strength, low weight, etc

Table -3: Mechanical properties of Steel and Aluminium

S.No	Name of material	Young's modulus (MPa)	Poisson's ratio	Density Tonnes/mm³
1	Steel	210000	0.3	7.89E-9
2	Aluminium	70000	0.33	2.67E-9

2.4 Car Front Door Modeling

The geometric model of Car Door Assembly by using CATIA V5 and all Finite Element Setup by using ANSA, the entire assembly is meshed with shell elements, element size used between 2 to 10mm and maintained standard quality checks, meshed model is shown in Fig -4

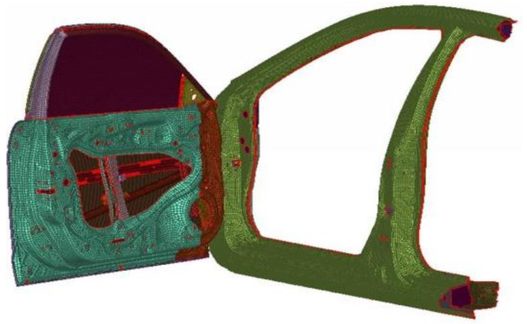


Fig -4: Finite Element Model of Front Door Assembly

2.5 Model Setup for Different Load Cases

2.5.1 Sag Set: Load & Boundary Conditions

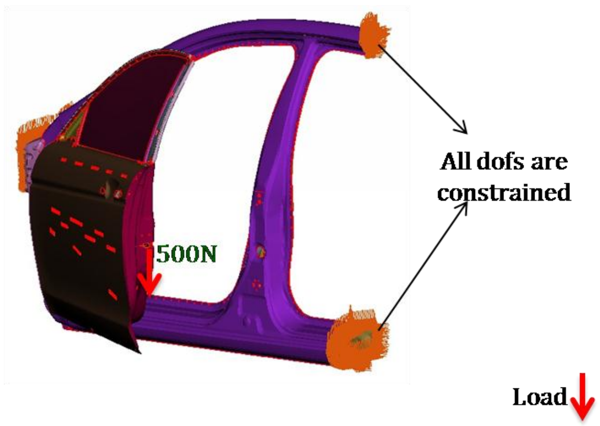


Fig -5: Sag Set model setup

1. Front Door sag set is carried out three steps of loading @ 25deg open positioned door:

- Self weight of the door, followed by
- Loading of 500N load at latch center applied in vertically downward direction
- Unloading of door

2. Boundary Conditions:

- Body-side cut section nodes constrained in all DOF
- Latch node constrained in normal to door DOF for all steps to avoid rigid body motion in other direction.

3. Target : Sag <8mm and Permanent set should be Less than 1mm

2.5.2 Static Over Check: Load & Boundary Conditions

Fig -6: Static Over Check model setup

1. SOC is carried out three steps of loading @ 65deg open positioned door:

- Self weight of the door, followed by
- Follower load of 300N(65 deg door) load applied at latch center in normal to door
- Unloading of door

2. Boundary Conditions:

- For all 3 steps, constrained all nodes at cut section of the body
- For first step in addition to above boundary condition; constrain latch node in direction normal to door and reset the same in second step.

3. Target : Permanent set should be Less than 5mm

2.5.3 Oil Canning: Load & Boundary Conditions

- This is to simulate the person leaning on door or to check the panel strength during the cleaning.

1. Boundary Conditions:

- Hinge and Latch locations are constrained in all Degrees of freedom
- Normal load of 200N is applied on the outer panel.

2. Target : Permanent set should be Less than 0.25mm

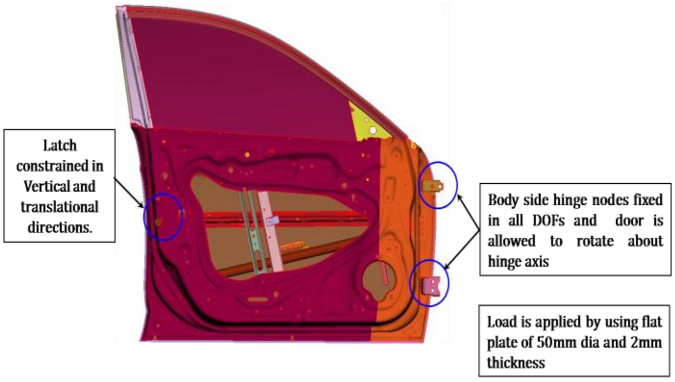


Fig -7: Oil Canning model setup

Locations #	X	Y	Z
1	1555.852	-879.817	834.3037
2	1551.94	-908.383	685.0851
3	1557.135	-910.98	604.3207
4	1566.528	-908.192	512.7267
5	1573.533	-901.993	425.5046
6	1588.065	-891.151	299.5745

Fig -8: Oil Canning locations

3. VIRTUAL ANALYSIS RESULTS

Table -4: Sag Set - Baseline vs Optimized

Automotive Front Door	Target, mm	Baseline Door	Optimized Door	Optimized Door Aluminum Hinges
Sag	< 8.0	3.30	4.50	6.23
Set	< 1	0.00	0.00	0.06

Automotive Front Door design met Sag and Set performance requirements for 25deg open angle.

Table -5: Static Over Check - Baseline vs Optimized

Automotive Front Door	Target, mm	Baseline Door	Optimized Door	Optimized Door Aluminum Hinges
Set at Ajar condition	< 5.0	0.20	2.62	2.98

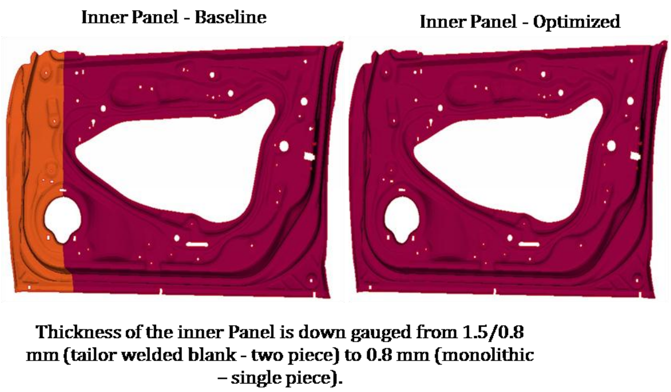
Automotive Front Door design met set requirement for SOC load.

Table -6: Oil Canning - Baseline vs Optimized

Location #	Max Panel Deflection <=10mm @ 200N		Permanent Set <0.25mm	
	Baseline	Optimized	Baseline	Optimized
1	1.0	1.0	0.03	0.04
2	2.7	2.3	0.07	0.04
3	2.7	2.6	0.03	0.02
4	3.1	2.7	0.03	0.01
5	1.3	1.1	0.00	0.01
6	1.1	1.0	0.01	0.04

Automotive Front Door design met set requirement for Oil canning load at the outer panel.

3.2 Baseline vs Mass Saving Comparison



The car door results are generated for both baseline and optimized models from strength perspective. The oil canning, sag set and static over check results was showing comparable performance between baseline and optimized model. All the results was within the performance target with minimal degradation from the baseline model. The Aluminum hinge model along with single piece inner panel and hinge reinforcement with the optimized gauges was showing as best from the study. Following table shows the mass saving information.

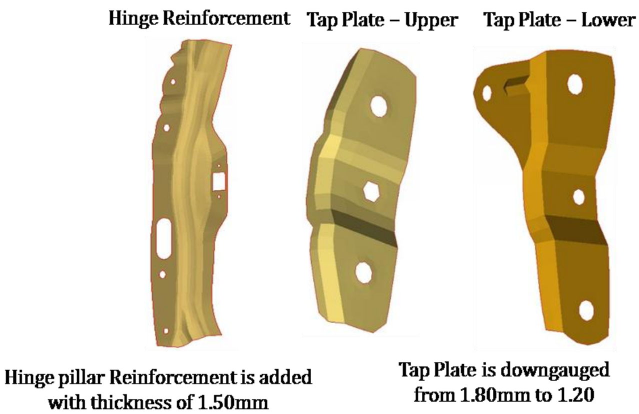


Fig -9: Baseline vs Optimized Door Inner Panel

Table -7: Mass Details - Baseline vs Optimized

Parts	Baseline (kg) per vehicle	Optimized (kg) per vehicle	Mass saving per vehicle (kg)
Inner Panel	12.08	10.00	
Tap Plate (Upper & Lower)	0.32	0.20	1.20
Hinge Reinforcement	**	1.00	

4. RAPID PROTOTYPE MODEL

Rapid proto-type model helps to understand the manufacturing feasibility and to have a feel of the part before actual tool development. A scaled hinge reinforcement part was developed using Fused Deposition Modeling(FDM) method and by using PLA material.

Fig -10: FDM of Hinge Reinforcement

4. CONCLUSION

The various types of car door architecture was studied in a detailed manner from various literatures. Swing car door structure and the related major strength load cases was identified for the optimization study. The robust design model idea was generated which consists of single piece inner panel and hinge reinforcement design. The earlier baseline design model was having the tailor welded blank inner panel without hinge reinforcement. The optimized gauge and material was identified by CAE simulation by using iteration methods. This study helped to conclude an optimized model with a massing saving of 1.2kg per vehicle. A scaled rapid proto-type model of hinge reinforcement using FDM method was generated finally.

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