# Optimization of a Vehicle Door to Minimize Mass

Red Cedar Technology

**Abstract**. An approach is presented to optimize a vehicle door using HEEDS® Professional. The goal of the study was to minimize the door mass through gauge optimization, while meeting the constraints on stress and deflection. Six static load cases were considered for each design iteration. HEEDS found a design that reduced the mass of the considered components by 18.6% over the baseline design, while meeting all of the performance requirements.

## Introduction

In cab and door-closure design, mass reduction provides numerous benefits in addition to reduced cost. Such benefits include reduced fatigue load and improvements in manufacturing assembly. As a result, there continues to be a critical push to reduce mass in vehicle body and door designs. This paper demonstrates the use of HEEDS Professional to optimize a vehicle door structure for mass savings.

## Problem Description

The goal of this study was to minimize mass, while meeting all performance targets. Starting with an initial vehicle door design (Figure 1), the design targets were collected, along with the detailed specifications of the baseline door. This baseline design had already undergone extensive manual optimization studies for mass reduction.

For this study, the gauge thicknesses of twelve components in the door assembly were investigated. These twelve design variables were allowed to vary within selected limits, while no changes in shape were considered. The gauges of the following components were allowed to vary during optimization:

- Anchor plate top
- Anchor plate bottom
- Mirror bracket upper
- Mirror reinforcement top
- Door inner front TWB
- Mirror bracket
- Inner belt reinforcement
- Glass module support
- Latch reinforcement
- Hinge reinforcement
- Mirror reinforcement bottom
- Outer belt reinforcement

## Analysis Model

For each design iteration, the maximum stresses and deflections corresponding to six linear static load cases were measured. These performance constraints were calculated using linear elastic finite element analysis models within NEi Nastran. The loading scenarios were:

**Door Sag** (Figure 2)—A vertical load was applied to the latch of the door, with the door in the fully open position.

**Door Over-Open** (Figure 3)—A horizontal load was applied to the latch, pushing the door into an over-open condition.

**Door Slam** (Figure 4)—A rotational acceleration was applied to the door with the latch constrained.

**Mirror Vertical and Fore-Aft Loading** (Figure 5) —A vertical load and wind resistance load were applied to the mirror.

**Outer Belt Stiffness** (Figure 6)—A pressure load was applied to the outer panel, pushing the outer belt inward.

## Door Mass Optimization

Door shape and material grades remained constant for this optimization study. Only gauge changes were considered, and the gauges were allowed to vary in discrete increments of 0.10mm to represent the typical gauges available from steel suppliers.

The search was performed using the hybrid and adaptive SHERPA optimization algorithm within HEEDS Professional. The goal of the study was to minimize the mass of the vehicle door with constraints on the maximum von Mises stress and deflection for each load case.

***Fig.1.*** *Baseline vehicle door model.*

***Fig.4.*** *Door slam loading.*

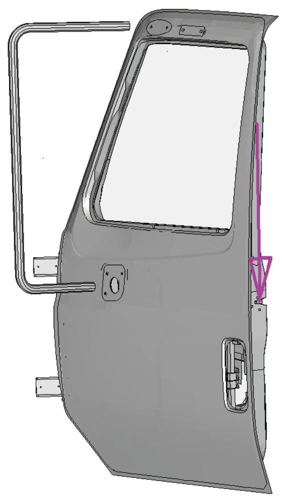

***Fig.2.*** *Vertical sag loading.*

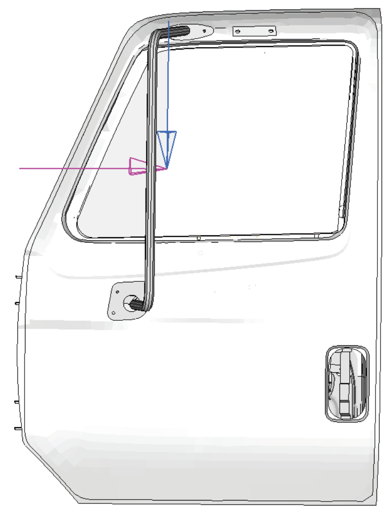

***Fig.5.*** *Mirror loading.*

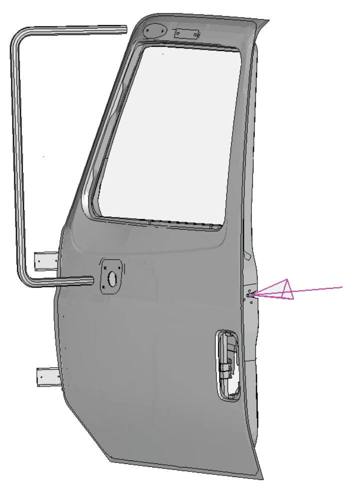

***Fig.3.*** *Over-open (check) loading.*

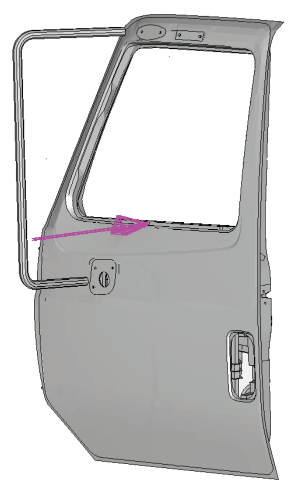

***Fig.6.*** *Belt loading.*

The optimization statement was as follows:

**Objective**: minimize Total Mass

**Subject to**:

Vertical sag max displacement $\leq \delta_1$
Vertical sag von Mises stress $\leq \sigma_1$
Over-open max displacement $\leq \delta_2$
Over-open von Mises stress $\leq \sigma_2$
Door slam max displacement $\leq \delta_3$
Door slam von Mises stress $\leq \sigma_3$
Mirror vert. max displacement $\leq \delta_4$
Mirror vert. von Mises stress $\leq \sigma_4$
Mirror horiz. max displacement $\leq \delta_5$
Mirror horiz. von Mises stress $\leq \sigma_5$
Belt stiffness max displacement $\leq \delta_6$
Belt stiffness von Mises stress $\leq \sigma_6$

**By varying**: Gauge thickness of

$t_{L1}$ ≤ Anchor plate top ≤ $t_{U1}$

$t_{L2}$ ≤ Anchor plate bottom ≤ $t_{U2}$

$t_{L3}$ ≤ Mirror bracket upper ≤ $t_{U3}$

$t_{L4}$ ≤ Mirror reinforcement top ≤ $t_{U4}$

$t_{L5}$ ≤ Door inner front TWB ≤ $t_{U5}$

$t_{L6}$ ≤ Mirror bracket ≤ $t_{U6}$

$t_{L7}$ ≤ Inner belt reinforcement ≤ $t_{U7}$

$t_{L8}$ ≤ Glass module support ≤ $t_{U8}$

$t_{L9}$ ≤ Latch reinforcement ≤ $t_{U9}$

$t_{L10}$ ≤ Hinge reinforcement ≤ $t_{U10}$

$t_{L11}$ ≤ Mirror reinforcement bottom ≤ $t_{U11}$

$t_{L12}$ ≤ Outer belt reinforcement ≤ $t_{U12}$

where $\delta_i$, $\sigma_i$ ($i$=1 to 6) and $t_{Lj}$, $t_{Uj}$ ($j$ = 1 to 12) are specified values used in the design study.

The automated design study progresses according to the process flow shown in Figure 7.

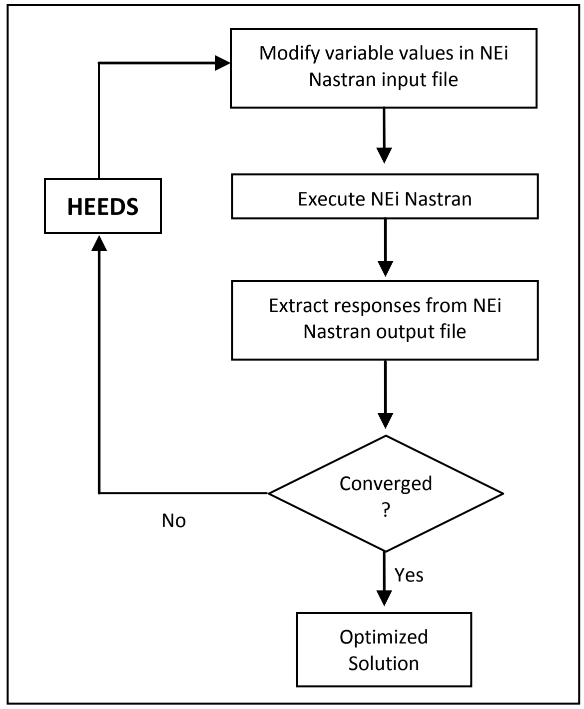


*Figure 7. Optimization process diagram.*

***Table 1.*** *Gauge Change. Optimized mass results from FEA with NEi Nastran.*

| Part | Gauge Change from Baseline (%) |
|---|---|
| Anchor plate top | -42.31 |
| Anchor plate bottom | +3.85 |
| Mirror bracket upper | -10.91 |
| Mirror reinforcement top | -76.92 |
| Door inner front TWB | -12.50 |
| Mirror bracket | -61.82 |
| Inner belt reinforcement | -57.14 |
| Glass module support | 0.0 |
| Latch reinforcement | +20.00 |
| Hinge reinforcement | -15.28 |
| Mirror reinforcement bottom | 0.00 |
| Outer belt reinforcement | +12.50 |
| **Savings in mass (%)** | **18.6** |

## Optimization Results

HEEDS found a design that reduced the mass of the components by 18.6% over the baseline, while meeting all of the performance requirements. This reduced the total door mass by 4.36%, and also reduced material cost significantly. The characteristics of the optimized design relative to the baseline design are listed in Table 1. Note that some gauges increased while others decreased, for a net decrease in overall mass. This is common in mass minimization problems. As the thickness of some panels increases so as to carry more load, the thickness of other panels is allowed to further decrease in order to achieve an overall mass reduction.

Figure 8 demonstrates the progression of mass savings in the door system as HEEDS optimized the gauge in the noted 12 components.

In addition to mass reduction, another important conclusion of the current study was that the inner gauge of the front door was reduced, allowing for the potential elimination of the Taylor-Welded blank and another significant cost reduction.

## Extensions of the Current Study

Although the present study focused on six linear static load conditions, additional nonlinear and or dynamic loading conditions could also have been included in the study. In fact, given any initial concept for a vehicle door, HEEDS can execute the design simulations and perform an efficient, yet thorough, search for an optimized design that meets the performance targets at the lowest possible mass.

Additional design features could be included by using a parameterized door model. Some examples of additional parameters include the following:

- The location of the TWB (Taylor Welded Blank) seam
- The top and bottom location of the hinge reinforcement
- Beginning and end locations of belt reinforcements
- Mirror reinforcement top and bottom locations.

These parameters (design variables) could be investigated along with the gauge variables to provide a more comprehensive design exploration and offer potentially even greater mass savings or performance improvements.

## Conclusions

With a door system that had already been through numerous manual optimization iterations, HEEDS found additional opportunities for mass reduction. For the load cases considered, an additional mass savings of 18.6% on the 12 components studied was achieved, while still meeting the performance requirements of the door system.

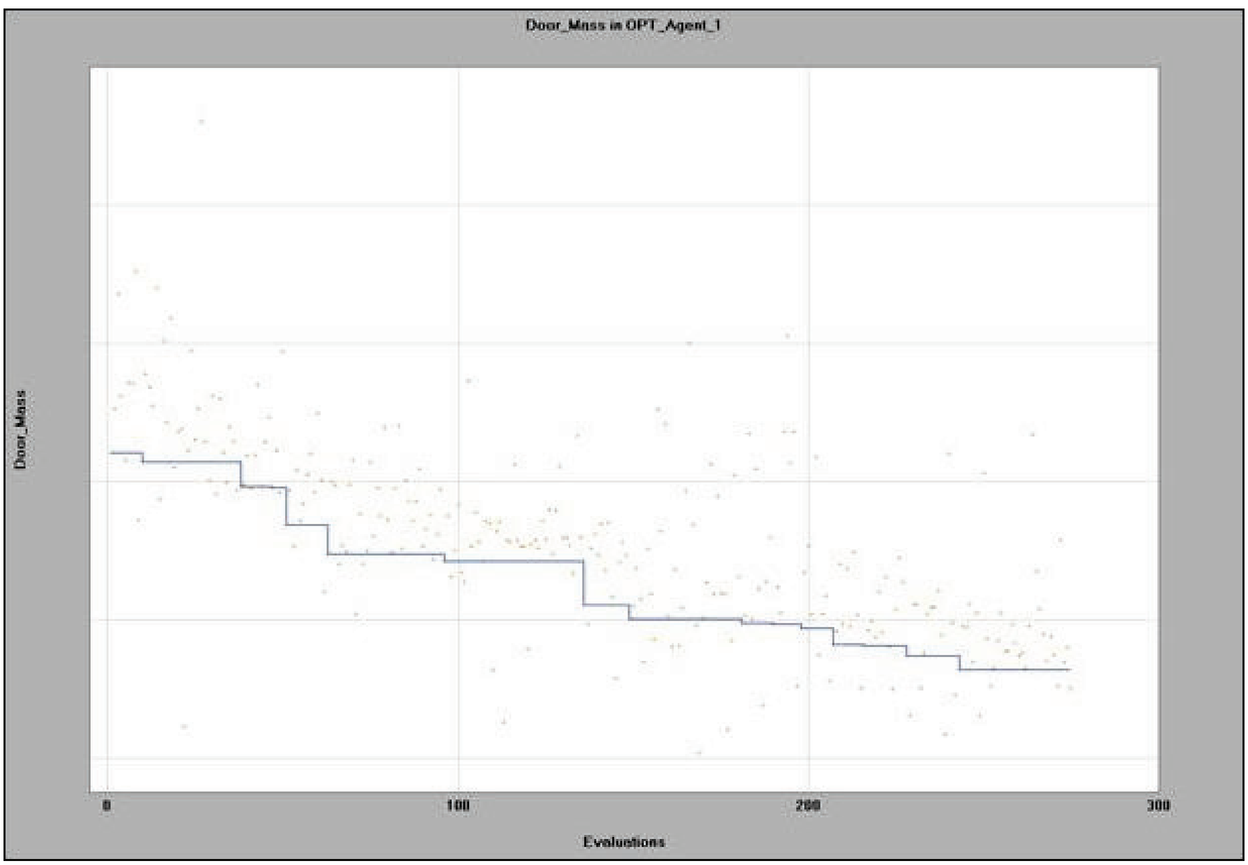


***Fig. 8.*** *Mass vs. Evaluation. Optimized mass results from FEA with NEi Nastran.*