

## Executive Summary

### Side Door: Structure Mass / System Mass

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In a 2015 Society of Automotive Engineers paper [1], it was observed that although there was a significant difference between door structure mass for aluminum and steel, the mass difference did not completely carry over to the door system.

The project described in this summary was a follow-up to this work with the objectives of confirming this observation with an expanded dataset, and to explain why the aluminum door system did not achieve the full mass reduction. Specific questions to be answered were:

- Is this observation 'real' or a distortion due to the particular sample of doors?
- How much mass reduction is 'lost' in going from structure to system?
- Where does the mass go? Which subsystems increase in mass?
- What are the physical reasons for the mass increase in these subsystems?

## 1. Statistical Benchmark Analysis of Door Structure and System Mass

Door teardown data from the a2mac1 database was analyzed. The expanded data included 291 steel and 20 aluminum doors. Graphical and regression analysis was performed and is included in the full presentation. Example regression models are shown below for the door structure mass (*kg*) and door system mass (*kg*) as a function of door length x width (*m*<sup>2</sup>).

$$m_{STRUCTURE} = 12.350 * (Area^{0.884}) * (0.647 \text{ if alum}) * (0.980 \text{ if premium})$$

$$m_{SYSTEM} = 23.390 * (Area^{1.014}) * (0.877 \text{ if alum}) * (1.045 \text{ if premium})$$

-After adjusting for door size and vehicle content, and focusing on premium doors, the average aluminum structure mass is 0.634x that of steel, while the aluminum door system mass is 0.916x than of steel, indicating that the mass reduction in structure does not fully carry over to door system mass.

-Door system mass for doors with aluminum structure have greater than expected mass for 87% of cases, after adjusting for door size and premium/non-premium vehicle type.

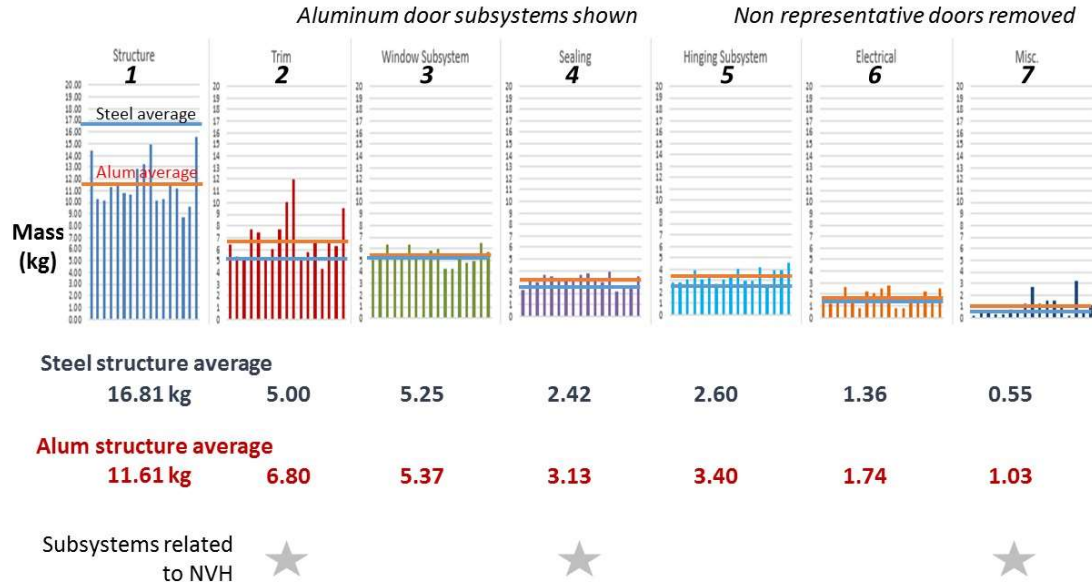
## 2. Analysis of Door Subsystem Mass

Regression analysis showed that the non-structural subsystems increased in mass as shown below.

$$m_{NON-STRUCT} = 11.059 * (Area^{1.130}) * (1.083 \text{ if alum}) * (1.114 \text{ if premium})$$

- The mass of other door subsystems increase for aluminum structure doors— 1.206x that of steel— particularly subsystems related to noise, vibration, and harshness—Inner panel, seals, insulation sheets, covers and plugs.

To understand which subsystems increased in mass, the door was partitioned into seven subsystems, and their masses compared between steel and aluminum. The largest difference occurred in those subsystems related to noise, vibration, harshness—NVH, as shown in the following illustration.



### 3. Physical Explanations for Mass Difference

The statistical analysis performed in this project cannot identify the explanation for the mass difference. A plausible hypothesis is that door structure is optimized during the design stage for primary stiffness and strength requirements. Later, during hardware development stage, NVH mediation leads to additional mass added for aluminum doors relative to steel. The well-known acoustic mass law, shown below, describes the relationship between panel mass and noise transmission through the panel

$$R_0 = 20 \log \left[ \frac{\pi f m}{\rho c} \right]$$

- $R_0$  = Sound Transmission Loss: Ratio of Sound Pressure Level,  $SPL$ , on either side of panel  
 $f$  = Frequency of sound (Hz)  
 $m$  = Panel mass per unit area ( $\rho_{PANEL} t$ ) ( $kg/m^2$ )  
 $\rho$  = Air density ( $kg/m^3$ )  
 $c$  = Speed of sound (m/s)  
 $SPL = 10 \log (Pressure^2 / Pressure_{REF}^2)$

A given value for transmission loss is required for acceptable noise levels, therefore for the lighter aluminum outer panel, mass must be added—inner trim, seals, insulation sheets, and mastic—to achieve acceptable noise levels.

### 4. Recommendation

Statistics can objectively demonstrate the above correlations, but cannot prove causality (Why there is a correlation). To prove that NVH subsystems in aluminum doors are disproportionately heavy, it is recommended that physical tests be performed on paired aluminum and steel doors. This would include:

- Measurements of transmission loss of door structures alone, and of the dressed doors.
- Close examination and comparison of tear down parts for loose structural reinforcements at attachment points for hinges, mirror, window regulator, door latch, and the use of mastics and coatings.