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Calculate the Cabin Air Bind Effort on Door Closing Efforts for Passenger Vehicle

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Abstract

The door is the first system to interact with a vehicle's driver. It allows entry into the vehicle; therefore, priority has been given to its performance. The number of studies by automotive door engineers has increased during the past years, while the customer and the market have changed their quality standards. Air bind is the Pressure build up during the process to close the door until it reach to highest pressure that it called the pressure spike. The air bind is the major contributor of the door closing efforts and it contribute approximately 40-60% of the completely closing efforts. Predict the contribution of the air bind for the closing efforts will help to improve the door design to meet the door closing efforts with customer satisfaction.

Keywords Air bind, Pressure pike and door closing efforts

INTRODUCTION

The door closing effort is a quality issue concerning automobile designers and customers. However, the precise prediction of the door closing energy hasn't been fully developed.The number of studies by automotive door engineers has increased during the past years, while the customer and the market have changed their quality standards.

The functions of the automotive door seals are to prevent dust and water from entering the vehicle and to isolate noise. To achieve these design targets, a door seal should have a reaction force higher than a specific criterion, while the effort to close the door requires a minimum reaction force. The cabin air bind is the most contributor of the door closing efforts. Mathematical model needs to predict the air bind absorb energy that's lead to design the door with optimize the door closing efforts to meet the customer satisfaction.

Air Compression

The energy loss due to air bind is a substantial contributor to the overall door closing energy. When the air pressure in the inner cabin is greater than the atmospheric pressure, discharged air flows out through cabin pressure relief valve-also called an air extractor and the door opening. However, the airflow path during a door-closing action has been illustrated in Action. The closing door pushes the air ahead of itself and creates a pressure rise in the vehicle called the pressure spike as shown in Figure 2. Air pressure inside vehicle produces a torque on the door, slowing the door velocity. This must be overcome to close and latch the door [1].

The mathematical model will consider the door open detent angle 8°which means 0.25 seconds from the closing time. Because this is the first contact of the door's weatherstrips, the airflow out between the door and the body in Figure 1 is negligible in the mathematical model for this dissertation.

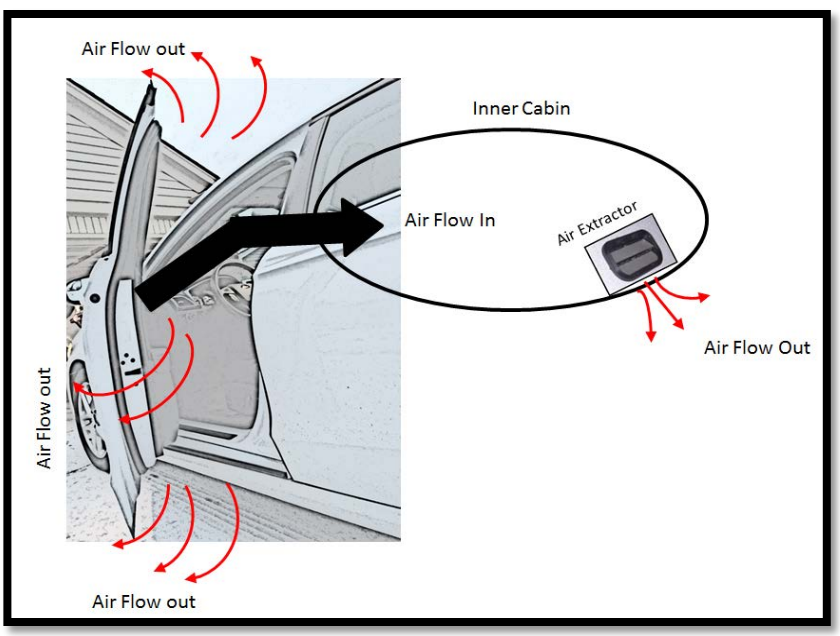

Figure 1. Airflow Path During a Door-Closing Action

The air pressure leaves the cabinet with an air path flow through the air extractors as shown in the Figure 1. An air extractor is shown in Figure 3.

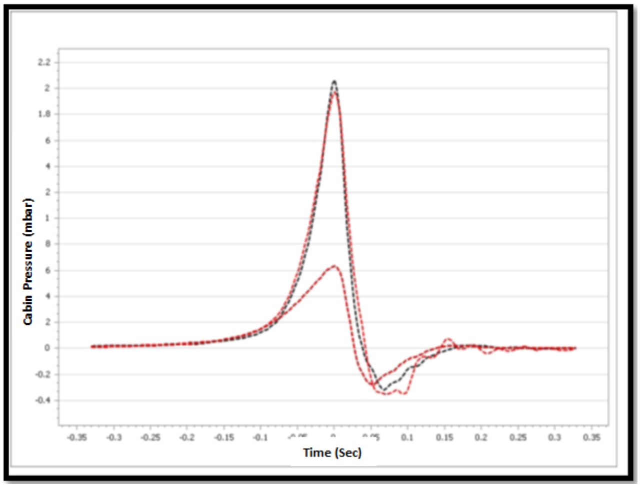

Figure 2. The Air Pressure Spike

Figure 3. The Air Extractor

These air extractors are necessary because vehicle cabins today are practically sealed air tight to prevent exterior noises from entering the passenger cabin and lowering the perceived quality of the vehicle. Since the cabins are sealed, any air source can build up pressure in the vehicle cabin when the windows are closed. This can either be caused by the heating, ventilation and air conditioning (HVAC) system or by the door closure event. Any perceptible increase in cabin pressure also lowers the perceived quality of a vehicle. Thus, the air extractors are installed in the vehicle to relieve the steady state airflow from HVAC or the pressure pulse wave from the door closure event. The air extractors also serve the purpose of allowing airflow so that the HVAC can defrost the windows properly [2].

Usually, the air extractors are located in the rear quarter panel as shown in Figure 4 behind the rear bumper, but sometimes they are located in the back panel for packaging issues. Either way, they need to have a clear airflow from the cabin to the air extractors and minimize the blockage.

Figure 4. The Air Extractor in the Rear Quarter Panel for a Vehicle

Air Compression or the Air Bind

Figure 5 illustrates an analytical model for the closing efforts which were created based on the control model for the air bind.

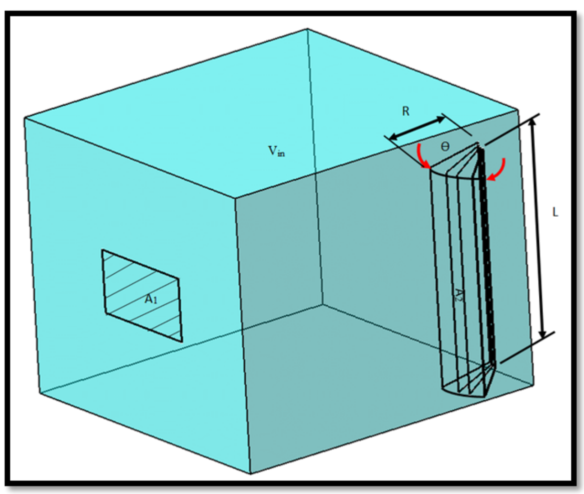

Figure 5. The Control Model for Pressure Calculation [3]

A_1 is the total area of the design air extractors and the body leakage. The volume (V_{in}) is the total cabin volume. A_2 is the area that the door closing parameter makes with the body side. The distance R and L are the door radius and the height, respectively. The angle θ is the door hinge open angle.

The simple equation for this model was shown in equation (1).

$$\frac{d(\rho V)}{dt} = -\sum \rho v_e A_e \quad \text{...............................(1)}$$

Where ρ is the air density, V is the air volume and v_e is the exit velocity of the air and A_e is the exit area. From the experimental

$$V_e = K_e\sqrt{\Delta p} \quad \text{...............................(2)}$$

Where Δp is gauge pressure inside the vehicle and K_e is the slop from plot the volumetric flow rate versus $\sqrt{\Delta p}$. By substituting equation (1) in equation (2) and after reconstructing, it simplifies the expression in equation (3)

$$V\frac{d\rho}{dt} + \rho\frac{dV}{dt} = -\rho(K_1\sqrt{\Delta p}\ \ A_1 + K_2\sqrt{\Delta p}\,A_2) \quad \text{...............................(3)}$$

K_1 and K_2 are the flow coefficients with the two exit area, $A_1$and A_2

Assume both exit areas exhaust to standard atmosphere conditions.

$$K_1 = K_2 = \sqrt{2/\rho_{atm}} \quad \text{...............................(4)}$$

The change in density with time during door closing is then,

$$\frac{d\rho}{dt} = \frac{1}{v}[-\rho_2(A_1K_1 + A_2K_2)\sqrt{p - p_2} - \rho\frac{dV}{dt}] \quad \text{...............................(5)}$$

ρ_2 is the atmosphere density and $p_2$is the atmosphere pressure.

v is the velocity of the air at the air extractors

By using the isentropic relation for pressure and density as shown in equation (6)

$$\frac{p}{\rho^\gamma} = constant. \quad \text{...............................(6)}$$

$$\therefore \rho = \frac{p^{\frac{1}{1.4}}}{C_1^{\frac{1}{1.4}}} \quad \text{...............................(7)}$$

$$so\ \frac{dp}{dt} = \frac{1}{C_1^{\frac{1}{1.4}}}(\frac{1}{1.4}p^{-\frac{2}{7}}\frac{dp}{dt}) \quad \text{...............................(8)}$$

By combining equations (7) and (8) into equation (5) and after rearranging, the equation to express the time deviation of pressure with air pressure deviation, area yield and volume is shown in equation (9).

$$\frac{dp}{dt} = -\,1.4\frac{C_1^{\frac{1}{1.4}}}{V}\left[\rho_{atm}\,(A_1 + A_2)Kp^{\frac{2}{7}}\sqrt{p - p_{atm}}\right] - (1.4.\frac{p}{V}\frac{dV}{dt}) \qquad \ldots\ldots\ldots(9)$$

Where,

t = time (sec).

P = internal cabin pressure (Pa).

C_1 = isentropic constant for air.

L = Door Length (m).

R = Door radius (m).

V = total volume of control volume (m^3) from Figure 5.

$$V = V_{in} + LR^2\frac{\theta}{2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots...(10)$$

Θ = door hinge angle (rad).

V_{in} = Internal volume (m^3) of the cabin, including the trunk.

ρ_{atm} = atmospheric density (Kg/m^3).

A_1 = constant exit area (m^2).

$A_1 = A_{leakage} + A_{air\ extractors}$ ……………..…………..……(11)

$A_{air\ extractor}$ = air extractor area (m^2).

A_2 = Area between the closing door and body.

A_2 = R (L+R) Θ. ………………………...…(12)

K = flow coefficient.

$$K = \sqrt{2/\rho_{atm}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(13)$$

Therefore, equation (9) is used in the mathematical model to predict the compression pressure with the changing time and hinge angle [4]. For the analytic modeling of the cabin pressure, the door angle $\theta(t)$ is required as a function of time. However, the steps to achieve that are the following:

One can take the overslam distance from experimental data and build the mathematical equation for the overslam relative to the door speed as shown in equation (14) and Figure 5.

$$y = -2.01831 + 0.0027507x \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(14)$$

Where,

y: Overslam (mm)

x: The door velocity (mm/sec)

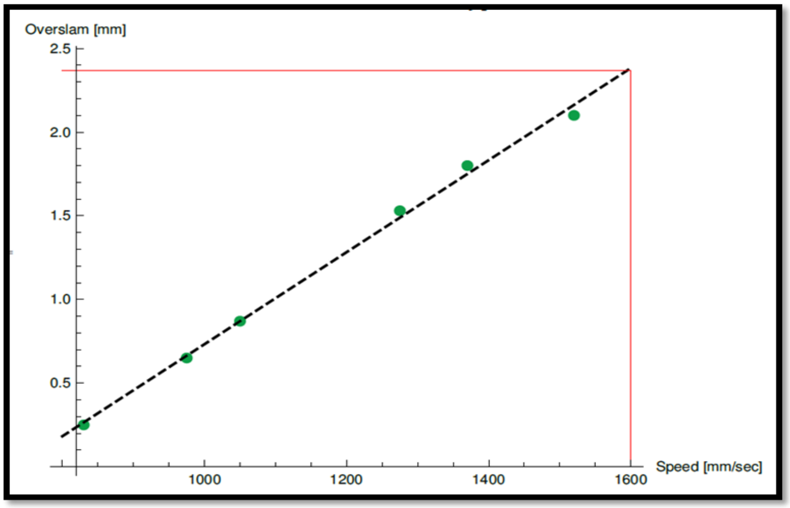

Figure 6. The Relation between the Door Overslam to the Door Speed

After obtain the overslam angle in [rad] by taking the Arctan(y) as shown in Figure 7.

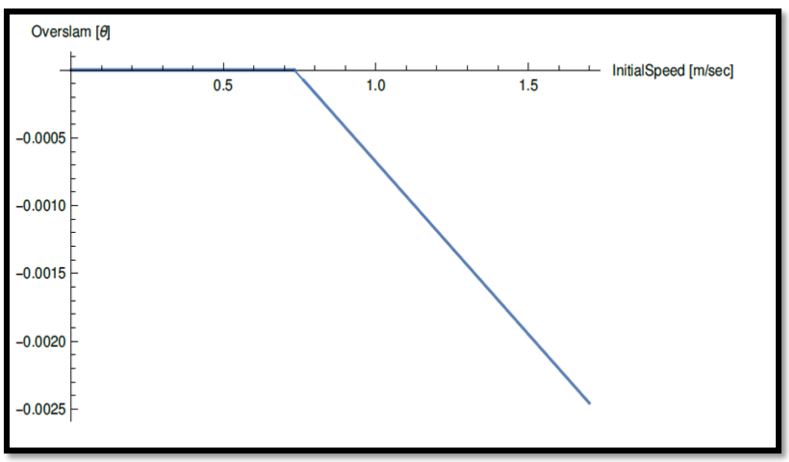

Figure 7. The Relation between the Door Speed and the Overslam [θ] rad

We assume the opening angle of the door is a quadratic polynomial in time t as shown in equation (16).

$$\theta(t) = at^2 + bt + c \quad \text{.................................(15)}$$

At time 0, the opening angle given as θ_0

$\theta(0) = c = \theta_0$ ………………………..…...(16)

At time 0, the derivative of the opening angle given as V_0

$\theta'[0] = b = -V_0/(R\cos[\theta_0])$ …………………………….....(17)

The minimum of the function evaluates to the overslam angle

$\theta\left[-\frac{b}{2a}\right] = -\frac{b^2}{4a} + C = Overslam\,[V_0]$ ……………..………...…(18)

The quadric polynomial curve plotted in Figure 8 represents the relationship between the door open angle $\theta[t]$ and the time to close the door, from equation (18) one can calculate V_0 and plot it as shown in Figure 9.

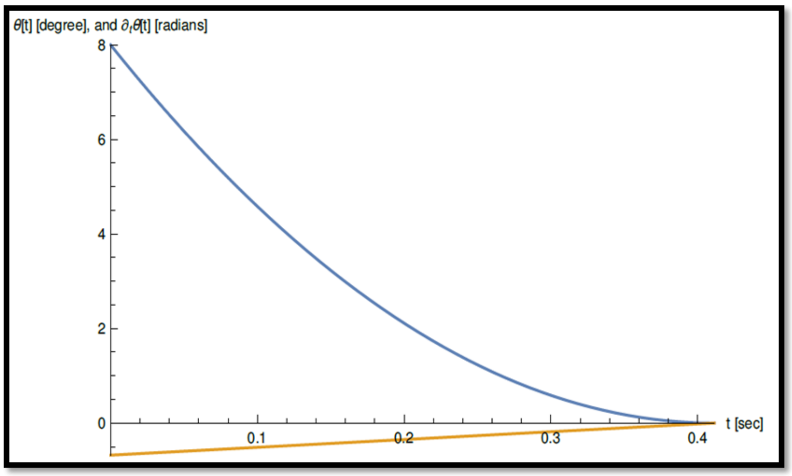

Figure 8. The Relation between the θ[t] in Degree and the Time in Second

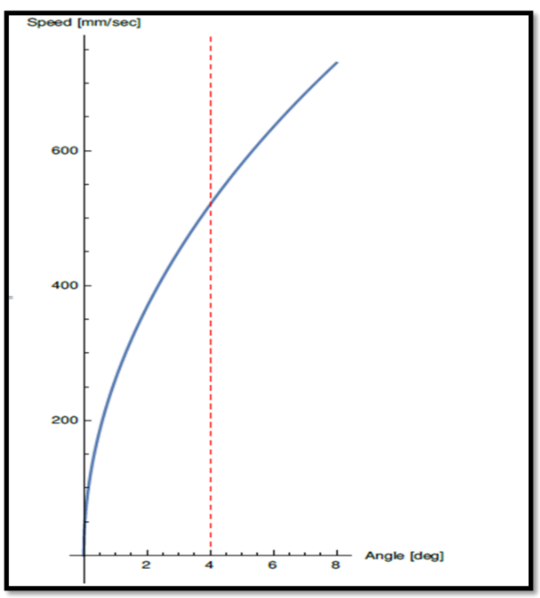

Figure 9. Illustrate the relation between Door Closing Speed to the Door Open Angle

The equation (9) can expressed by dp as follows in equation (19)

$$dp = \frac{7p^{\frac{2}{7}}(-dTLp^{\frac{5}{7}}R^2 - 327.411\sqrt{-101300 + p}\,(0.0630782 + ef + 35.9712Max[0, R\,(L + R)T]))}{10(3.0016 + 0.5\,L\,R^2\,T)} \quad ..(19)$$

However, the air leakage constant A_1 has a significant influence on the resulting pressure curve as shown in Figure 10. We assume the efficiency for the airflow through the air extractor was 85%.

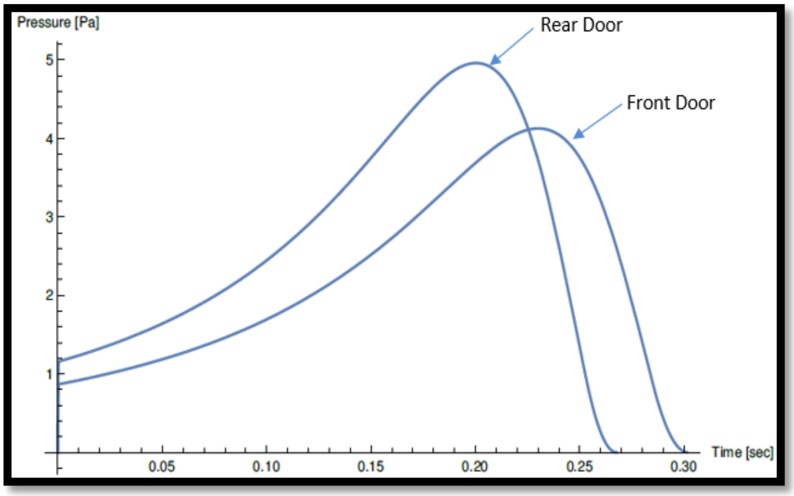

Figure 10. The Relation between Door Closing Velocity with the Door Open Angle

This model assumes the steady state airflow, the air is incompressible, and the results were within 80% of the experimental results. Consequently, the curves in Figure 10 multiply the result by the correction factor 1.2 to calibrate the results and is shown in Figure 10 which represents the pressure spike with time for front and rear door. Pressure spike increased with respect to the door closing velocity as shown in Figure 11 for the front door and Figure 12 for the rear door.

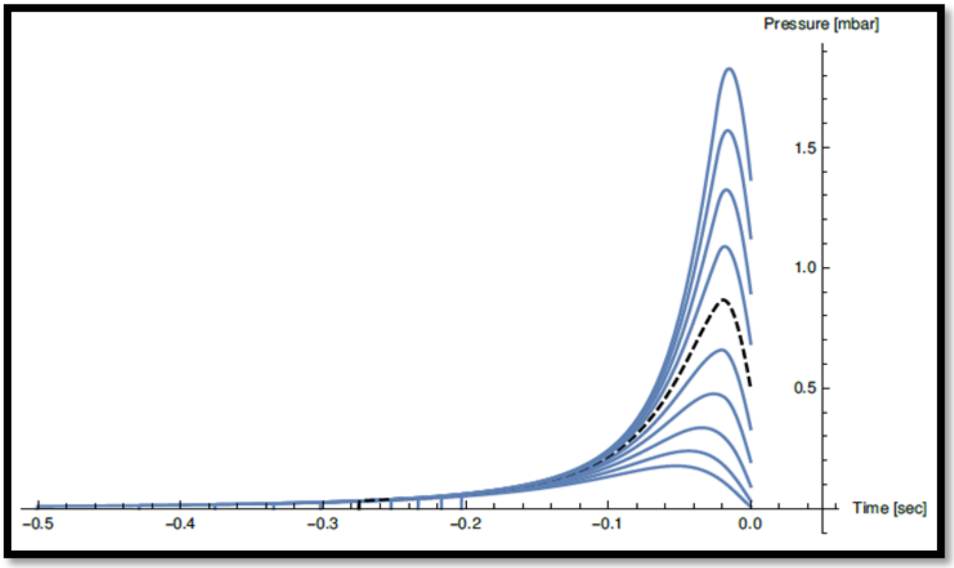

Figure 11. Front Door Pressure Spike with Time. The Multi-Curves Showing the Multi-Door Closing Velocities and the Black Dash Line is The Pressure Spike with The Minimum Closing Effort

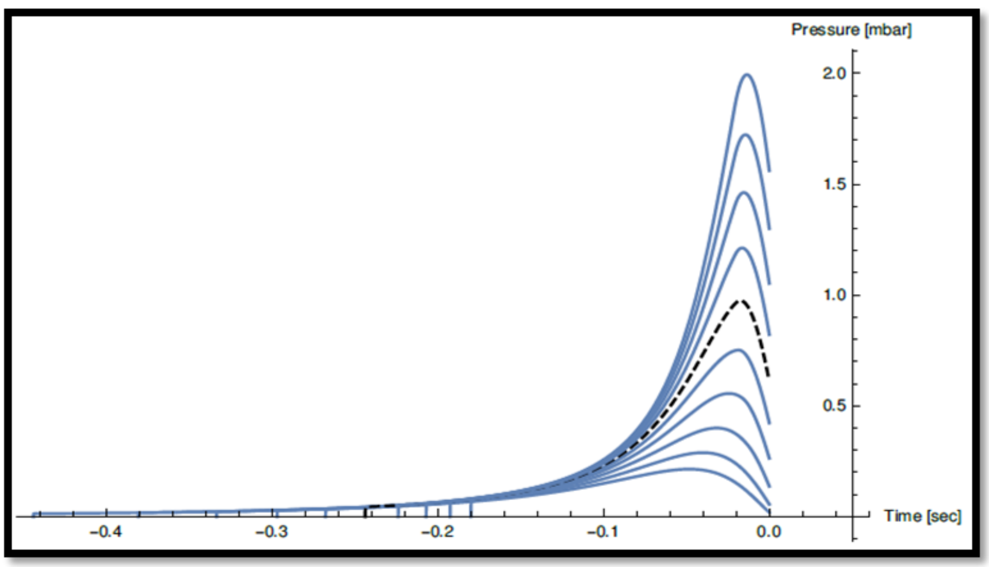

Figure 12. Rear Door Pressure Spike with Time. The Multi-Curves Showing the Multi-Door Closing Velocities and the Black Dash Line is The Pressure Spike with the Minimum Closing Effort

Figure 13 and 14 shown the door closing velocity that caused by the pressure spike, not the total door closing velocity for front and rear door respectively. Also, in Figure 13 and 14 the dashed line is a linear approximation of the green data points.

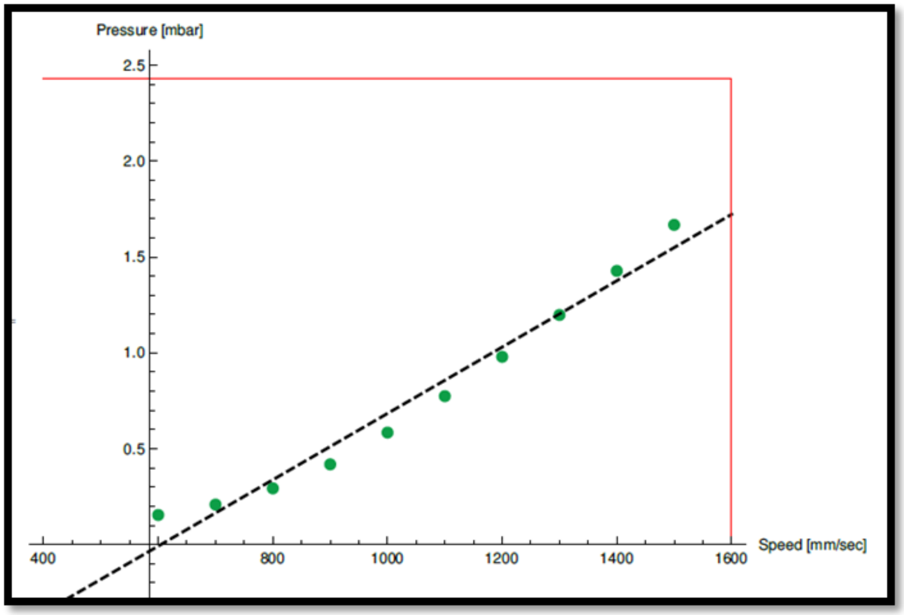

Figure 13. Front Door Pressure Spike with the Door Closing Velocity

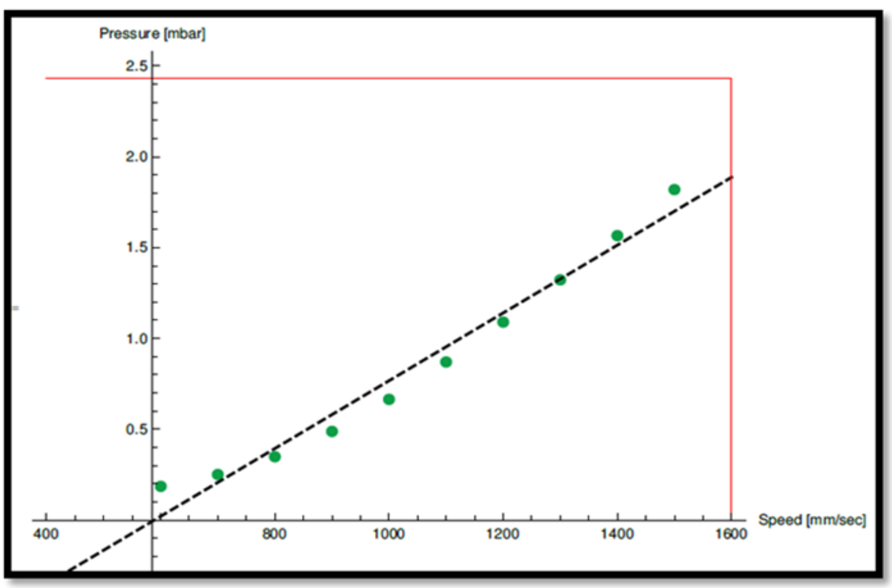

Figure 14. Rear Door Pressure Spike with the Door Closing Velocity

To calculate the energy that is absorbed by the air bind, One needs to calculate $E_{air\ bind}$ as illustrated in equation 21 and Figure 44.

$$E_{air\ bind} = \int_{s}^{0} p(s)A\,ds = \int_{\theta_0}^{0}(\theta)A\,d\theta = \int_{t_0}^{t_1} p\big(\theta(t)\big)|\theta'(t)|\,A\,dt \qquad \text{.................(20)}$$

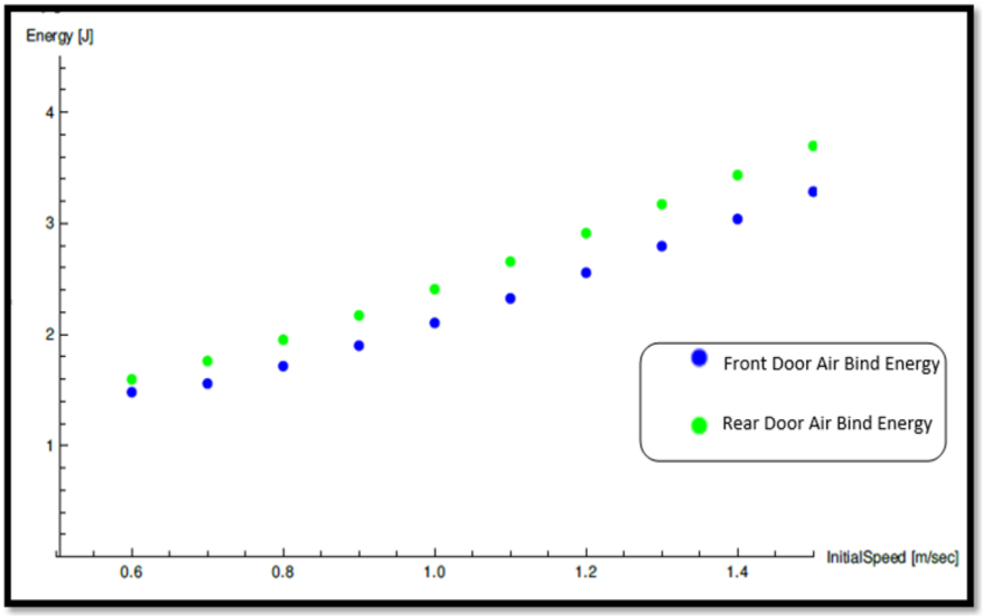

Figure 15. Air Bind Energy with Door Closing Speed for the Front and Rear Door

Conclusions

One of the customer's initial impressions regarding the quality of the vehicle will be the behavior of the opening and closing of the door and energy that are required to obtain full latching. In order to optimize the closing efforts, the air bind contribution needs to address. This paper calculate the air bind mathematically and compare it will the physical test. This model assumes the steady state airflow, the air is incompressible, and the results were within 80% of the experimental results for the front and the rear door.

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