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AXIOMATIC DESIGN OF THE LIFTGATE WEDGES IN SPORTS UTILITY VEHICLES

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ABSTRACT

The liftgate system of the sports utility vehicles (SUV) or minivans has multiple functional requirements and design parameters. A wedge is a small piece of hardware to stabilize the liftgate especially in cross car direction by providing the load path from the liftgate to the surrounding structures. On the other hand wedge may increase the closing effort due to the reaction force in the swing direction. Furthermore, wedges need to accommodate the gap variation to bridge the liftgate and the body frame. This paper presents the characteristics of two different types of wedges in the axiomatic design viewpoint and their effects on the liftgate system.

Keywords: liftgate, SUV, wedge, closing effort, gap, variation,

1. INTRODUCTION

The liftgate of the sports utility vehicles (SUV) or minivans is a closure system attached at the end of the vehicle. It provides large accessibility to the cargo compartment. The liftgate system has multiple functional requirements and design parameters. These requirements and design parameters are significantly coupled due to the complexity of the system. The requirements can be divided into structural integrity, functional performance, seal and hardware areas. These requirements are dependent on geometry of the gate, material properties, and hardware such as gas struts and wedges. The hardwares attached to the liftgate are shown in Figure 1. Among the hardwares, a wedge is a small piece of rubber or plastic to stabilize the liftgate, especially in cross-car direction. It provides the load path from the liftgate to the surrounding structures. On the other hand, wedges may increase the closing effort due to the reaction force in the swing-line direction. Furthermore, wedges need to accommodate the gap variation to bridge the liftgate and the body frame. Due to these multiple requirements, a wedge needs a systematic design synthesis and analysis process in the early stage of the vehicle development program. There currently are two types of wedges in the market: a spring-loaded type and a rubber block type. This paper presents the characteristics of these two wedges in the axiomatic design viewpoint and their effects on the liftgate system. Also the analysis and design procedures were discussed.

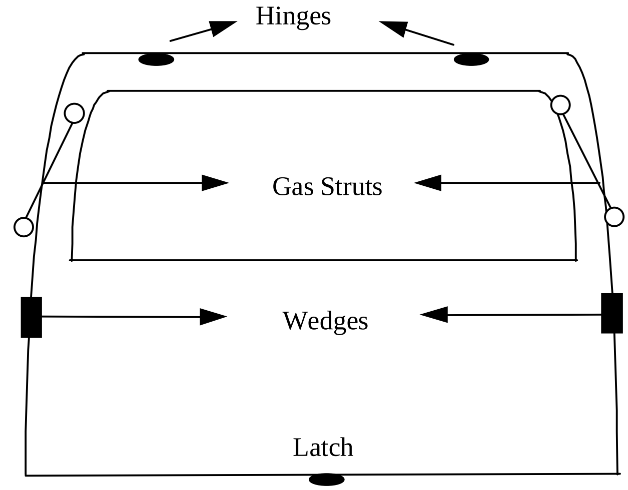


Figure 1. Hardwares in Liftgate

2. FUNCTIONAL REQUIREMENTS OF WEDGES

The liftgate wedge must meet the following functional requirements:

1. *Provide sufficient support in cross-car direction* (FR1);
   The wedge needs to provide sufficient cross-car stiffness to prevent the excessive motion that may cause the latch failure, or squeak and rattle. The amount of stiffness varies depending on the liftgate geometry, mass, and the location of hardware.
2. *Minimize the effect on closing effort* (FR2);
   To satisfy the FR1, the wedge needs to be in contact with the liftgate. This may dramatically increase the closing effort. Therefore, the wedge must be designed to avoid the big impact on the closing effort.
3. *Accommodate the gap and flushness variation* (FR3);
   Due to the body build variation, the gap and flushness around the liftgate vary car to car during the assembly.

Therefore, the wedge must satisfy FR1 and FR2 even in the presence of body build variations.

There are two types of wedges commonly used in SUV's and minivans: Spring-loaded type and Rubber-block type.
The spring –loaded type wedge uses a soft spring to take the load in the swing direction, while the wedge block with a sloped surface comes in contact with the liftgate. This slope angle and the spring can automatically accommodate the gap variation. Consequently, the wedge can provide the load path from the liftgate to the body frame as shown in Figure 2.
The rubber-block type wedge simply uses the rubber block with a slope to fill the gap as shown in Figure 3. The rubber block must be designed to minimize the stiffness in swing direction while maintaining the strong stiffness in cross-car direction. To accommodate the gap variation, this type of wedge needs an adjustment mechanism such as a slot or a ratchet. The final position of the plastic will affect the rubber compression and the gap, therefore, will affect the reaction force from the rubber. The design matrices for these two types of wedges are shown in Figure 4.

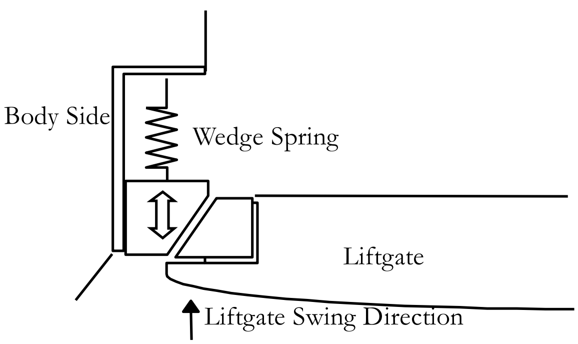


Figure 2. Spring-Loaded Type Wedge

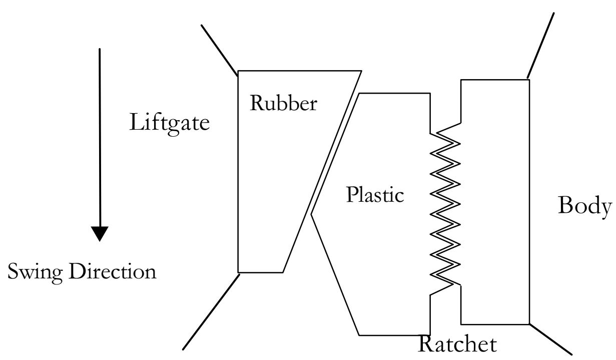


Figure 3. Rubber Block Type Wedge

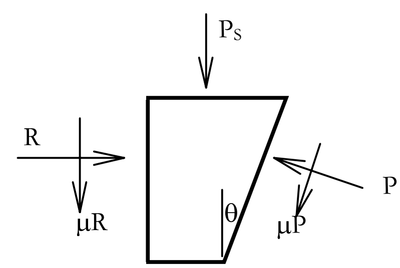
$$\begin{Bmatrix} FR1 \\ FR2 \\ FR3 \end{Bmatrix} = \begin{bmatrix} X & & X \\ & X & X \\ & & X \end{bmatrix} \begin{Bmatrix} \text{Friction} \\ \text{Spring} \\ \text{Slope} \end{Bmatrix} \quad \text{For spring-loaded type}$$

$$\begin{Bmatrix} FR1 \\ FR2 \\ FR3 \end{Bmatrix} = \begin{bmatrix} X & X & X \\ X & X & X \\ & X & X \end{bmatrix} \begin{Bmatrix} \text{Durometer} \\ \text{Ratchet} \\ \text{Slope} \end{Bmatrix} \quad \text{For rubber-block type}$$

Figure 4. Design Matrices for Two Types of Wedges

3. DESIGN OF THE SPRING-LOADED TYPE WEDGE

According to the design matrix as shown in Figure 4, the spring-loaded type wedge is a decoupled system. The wedge blocks of the spring-loaded type wedge must be a hard plastic to deliver a strong cross-car direction support. If these blocks are made of softer materials such as rubber, the stiffness of the material becomes another parameter. This will create an over-coupled system, which is not desirable.
It is logical to start the design from deciding the slope angle. If this angle is too big, the body side block may slip along the swing direction when the liftgate moves in the cross-car direction. If this angle is too small, this wedge system cannot accommodate gap variation. Therefore, there is a relationship between the angle and the spring constant to meet both functional requirements. This relationship can be derived from a simple free body diagram as shown in Figure 5.



R : Reaction from the body
P : Reaction from the gate
P_s : Spring force

Figure 5. Forces Acting on the Wedge

From Figure 5, the force equilibrium yields Eq(1).

$$P_s = \frac{(1-\mu^2)\tan\theta - 2\mu}{1+\mu\tan\theta} R \qquad (1)$$

From Eq(1), P_s can be small with certain combination of friction and slope angle. This combination will give little effect on the closing effort. Therefore, all the functional requirements will be satisfied by choosing the right slope angle, friction coefficient, and spring. Figure 6 shows the relationship between friction coefficient and the maximum allowable slope angle to avoid any slip of the wedge block. Even though there are other factors to consider such as cost, squeak and rattle, this type of wedge is inherently a good design as shown in Figure 4.

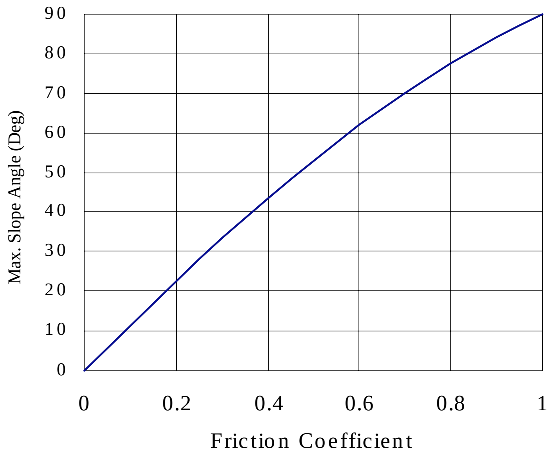


Figure 6. Friction Coefficient – Max. Slope Angle Relation

4. DESIGN OF RUBBER BLOCK TYPE WEDGE

As shown in Figure 4, a rubber block type wedge is highly coupled design. Even though this is a coupled design, this type of wedge can give several advantages over the spring loaded type wedge. They are : low cost, damping effect, and better for squeak and rattle. One of the ways to resolve the coupling in this type is using a very loose ratchet. Then, the assembler closes the lift-gate such that the lift-gate engages the latch and the lift-gate edges are flush with the body. During this process the movable plastic wedge smoothly ratchets on the fixed part of the body-side wedge. In the closed position, the body-side plastic wedge assembly is in full contact with the lift-gate side rubber wedge. (See Figure 2.) The operator would then open the lift-gate and tighten the plastic body-side wedge into the newly adjusted position. This is the price to have the coupled design. This may cause very delicate adjustment procedure in the assembly line. Also it is operator sensitive process. By doing this, FR1 and FR2 can be achieved at the same time.

The next step is to design the rubber block. The rubber block needs to provide high cross-car direction stiffness with low swing-line direction force. Furthermore, this characteristics needs to be insensitive to the contact position variation due to the cross car assembly variation as shown in Figure 7. There are several parameters in the rubber block design such as contact surface shape, metal insert, and material property. Five potential designs as shown in Figure 8 are analyzed by finite element analysis to predict the stiffness in cross-car and swing-line directions. The stiffness variation due to the contact position variation was also predicted.

Among the wedge designs that were evaluated, swing line force – displacement curve for wedge_1 design was not generated. The reason for this is that, wedge_1 is a very stiff piece and hence is recommended only when the ratcheting force is small and the rubber consistently touches the body-side plastic.

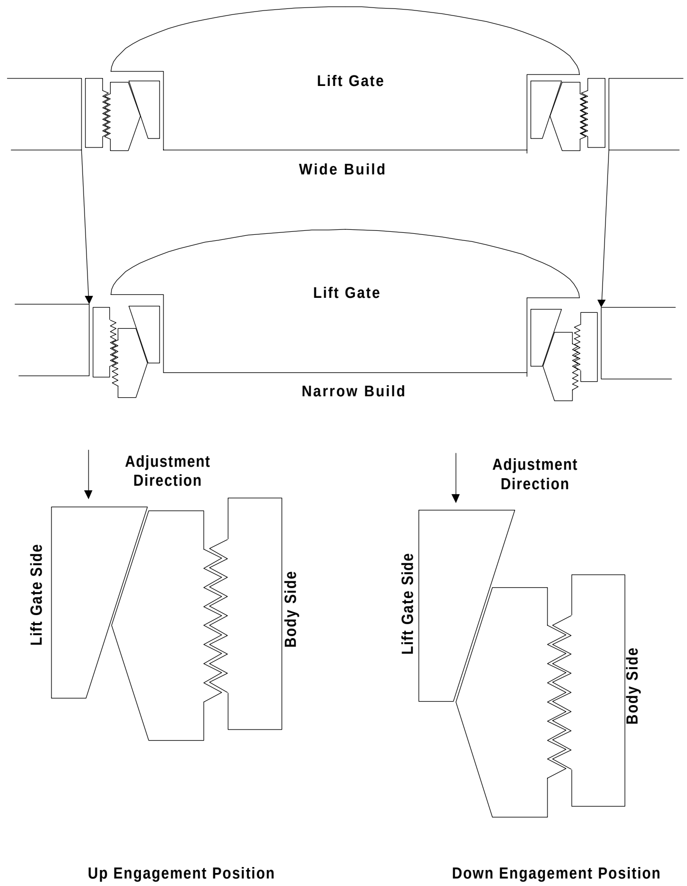


Figure 7. Contact Position Variation due to the Cross-car Build Variation

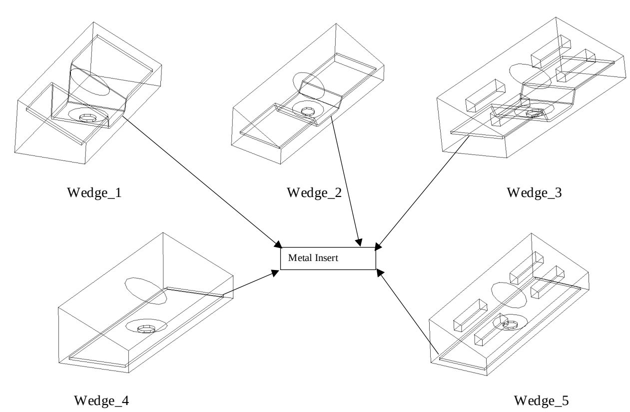


Figure 8. Rubber Wedge Designs Evaluated

The other wedge designs that were studied (wedge_2 – wedge_5) are meant to be used when the adjustment procedure results in compression of the rubber wedge in the lift-gate closed position. The swing line force displacement curves were generated at the nominal contacting position of the two wedge pieces as well as at the up and low contacting position due to cross-car assembly variation, for these four wedge designs. ABAQUS was used for generating the stiffness and force-deflection characteristics of the rubber wedge. The rubber wedge was modeled using hyper-elastic material model. The body-side side wedge was modeled as a rigid surface. The body-side wedge was moved in the cross-car direction to study the force displacement characteristics. Full 3-D contact between the body-side and lift-gate side wedges was considered. In addition, the contact between the base of the lift-gate side rubber wedge and the lift-gate inner was modeled. Coefficient of friction between the contacting surfaces was assumed to be 0.3.

Figure 9 shows the swing-line force-displacement curves for the different wedge designs at the nominal position. Figure 10 shows the swing-line force-displacement curves for the wedge designs at the up and low contacting positions due to cross-car assembly variation. Table 1 shows the cross-car stiffness mean and standard deviation for the different wedge designs. Figure 11 shows the stiffness variation graphically. Variation in the cross-car stiffness arises due to different contacting location on the rubber wedge caused by cross-car assembly and build variation. From these analyses, wedge_4 would provide a good compromise between good engagement and cross-car stiffness. The mean cross-car stiffness value is dependent on liftgate geometry, mass, and hardware locations. Also the effect of the stiffness variation on the structural performances must be assured by additional analysis. Wedge 5 shows a small variation but not enough cross-car stiffness. Wedges 2 and 3 show strong cross-car support but the variation is huge. These wedges will cause unpredictable problems due to the variation.

Table 1. Cross-Car Stiffness for the different wedges

Design Iteration	Mean (N/mm)	Standard Deviation (N/mm)
Wedge_1	915	-----
Wedge_2	797	167
Wedge_3	562	121
Wedge_4	387	54
Wedge_5	297	40

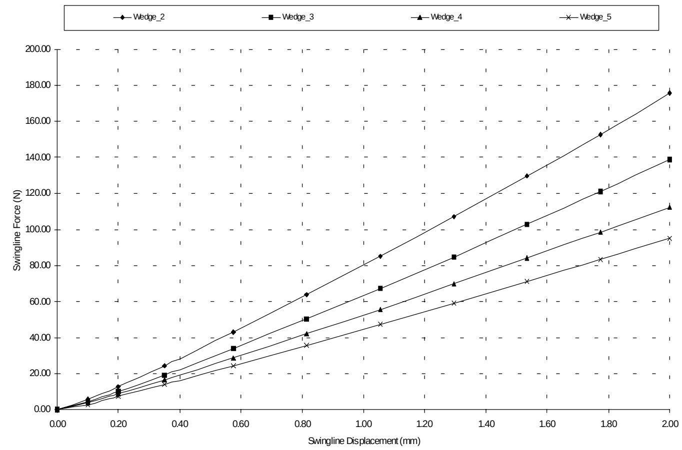


Figure 9. Nominal Swing Line Force Vs Displacement Curve

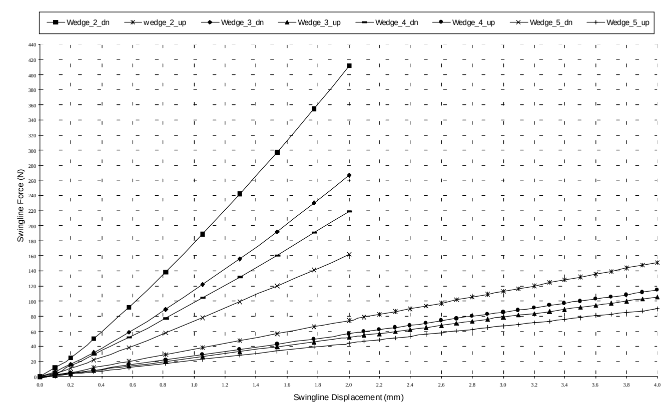


Figure 10. Upper and Lower Limit Swing Line Force Vs Displacement curve

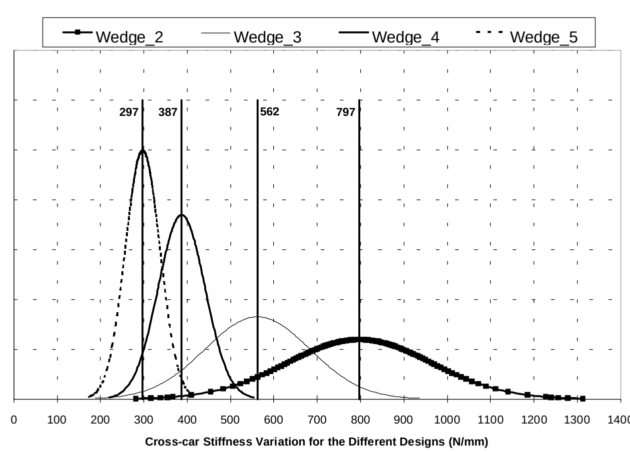


Figure 11. Cross-car Stiffness Variation for the Different Designs (N/mm)

5. CONCLUSION

Two types of the liftgate wedge design were discussed. The spring-loaded type meets the independent axiom better than the rubber block type. The spring-loaded type can satisfy all the functional requirements without much difficulty. The rubber block type is not fully decoupled system. Therefore, it needs more attention in assembly process for adjustment and more analyses to optimize the rubber block. The rubber block type, however, can provide other advantages such as low cost and damping effect. Especially, it can work as an over-slam bumper at the same time. It is less likely to cause squeak and rattle problem too. In case of choosing the rubber block type wedges, special analysis procedures discussed in this paper must be carefully followed.

6. REFERENCES

[1] Hibbitt, Karlsson & Sorensen, Inc., *ABAQUS/ Standard User's Manual*, 1996

[2] Suh N.P., *The Principles of Design*, New York: Oxford University Press, 1990. ISBN 0-19-504345-6

[3] Phadke, M.S., *Quality Engineering Using Robust Design*, London: Prentice-Hall, 1989, ISBN 0-13-745167-9