

Influence of Feature Lines of Vehicle Hood Styling on Headform Kinematics and Injury Evaluation in Car-to-Pedestrian Impact Simulations

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ABSTRACT

Vehicle hood styling has significant influence on headform kinematics in assessment tests of pedestrian impact protection performance. Pedestrian headform kinematics on vehicle front-end models with different hood styling characteristics is analyzed based on finite element modeling. More elevated feature lines near hood boundary and the following continuous hood surface towards fender will result in a different headform motion. It can lead to larger deformation space, more rotation and earlier rebound of the headform impactor, which will benefit the head impact protection performance. In addition, hood geometry characteristics such as hood angle and curvature have effects on structural stiffness. Therefore, inclusion of considerations on pedestrian head protection into the vehicle hood styling design stage may lead to a more effective and efficient engineering design process on headform impact analysis.

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INTRODUCTION

Pedestrian protection has been drawing attention for more than two decades with the rising global motorization. In 2008, pedestrian fatalities made up 12%-33% of all road fatalities in the US, European Union, and Japan [1-2]. Pedestrian injury ratio in China is even higher due to the mixed traffic on road, which is up to about 25% according to the official statistics [3]. Human head injury accounts for a significant portion of all pedestrian fatalities in car-pedestrian accidents [4]. Vehicle hood surface is a main area of pedestrian head contact, producing injuries of varying severities at different impact locations [5-6].

Impact tests of pedestrian headform on vehicle front-end have been developed by European Enhanced Vehicle-Safety Committee (EEVC) to assess the protection performance on human head [7]. The pedestrian component tests are also used in European New Car Assessment Program (Euro NCAP) to calculate the vehicle pedestrian protection rating [8]. Both the adult headform (4.5 kg) and the child headform (3.5 kg) are included. The headform impactor is composed of inner rigid sphere and outer rubber skin, with accelerometer installed at the CG location of the headform. In an impact test, the resultant translational acceleration time histories $a(t)$ at the CG location of the headform is recorded (hereafter referred to as

impact pulse). The Head Injury Criterion (HIC) has been employed to evaluate pedestrian head protection performance, which is calculated as [7]

$$HIC = \max_{t_1 < t_2, t_2 - t_1 \leq 15 \text{ ms}} \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t) dt \right]^{2.5} (t_2 - t_1) \right\} \quad (1)$$

The impact area is defined by reference lines at the vehicle front, including wrap around distance (WAD) and hood boundary reference lines. The impact area for child headform is specified within WAD 1000 mm – 1700 mm range, which covers a main portion on hood surface for many sedan models. Therefore, pedestrian child headform is taken as the study object in this study.

Styling and structural design of vehicle hood have significant influence on pedestrian head injury. With underhood deformation space taken as a constraint, impact force on pedestrian headform from vehicle hood can be simply divided into two parts [9, 10]. In case the available underhood deformation space is fully utilized, the impact pulse usually exhibit multi-peaks [11]. The first peak is dominated by the active mass, defined as the mass on vehicle hood that is accelerated under the headform impact due to the inertia

effect. At the beginning of the impact, the active mass becomes greater and greater as the headform goes further. The first peak comes down after a quick, initial increase [12]. As the impact goes on, the contact force due to the active mass will decrease because the involved area at the impact location cannot further expand due to the decreasing velocity. In contrast, the second peak usually comes from the hood structural stiffness as it deforms.

To fulfill the pedestrian headform impact requirement, two main principles are considered in current vehicle design. Sufficient deformation space under hood surface is to be ensured and reasonable hood deformation stiffness is to be realized [9]. Hu et al have summarized current vehicle designs for improving pedestrian safety [13]. With given underhood deformation space, adding energy-absorbing materials is usually taken as the most cost-effective way to tune the structure stiffness, including different kinds of inner hood or absorbing material design. However, styling characteristics of vehicle outer hood are rarely considered in current research on pedestrian head impact protection.

More and more individualized design features and characteristics are being adopted in current vehicle front-end design. In some vehicle models, elevated feature lines near hood boundary are designed. The following continuous surface may influence pedestrian headform impact kinematics when impacting on vehicle hood surface. This study is to exploit how the vehicle front-end styling design influences the pedestrian head impact protection performance using finite element modeling. Two vehicle models with different hood styling characteristics are selected. Pedestrian headform impactor kinematics at different impact locations near hood feature lines are compared and analyzed.

METHODOLOGY

Model Setup

To analyze the influence of vehicle front-end styling on pedestrian headform impact protection performance, two detailed vehicle front-end models with different hood styling characteristics are selected (hereafter referred to as vehicle model A and model B). Both models are LS-DYNA based finite element model, consisting of all the front-end parts related to pedestrian headform impact, including inner and outer hood, hood supporting parts, upper grill, bumper, fender, etc. Taking vehicle model A for example, it is cut off at the cross section near pillar A, where the translational degrees of freedom for all the nodes are constrained. The model has about 1,500 parts and 140,000 elements. Pedestrian head impact is centralized in local area of vehicle front-end, with relatively low input kinematics energy. High fidelity of the vehicle model is preferred. The calculation results will be applied to compare the headform kinematics at different impact locations or difference vehicle models at a relative level; therefore, modeling validation is not discussed. Model A and model B are

similar in size while have different trends in hood styling. The geometrical information of the vehicle hood feature lines will be discussed in more detail at a later stage.

Schematic of pedestrian headform impacting on vehicle hood is shown in Figure 1, with an impact angle γ . The initial impact velocity of the headform impactor is 40 km/h, and the impact angle is 50° , as regulated in the pedestrian headform test methods developed by EEVC for vehicle protection performance assessment on pedestrian head [7]. The hood angle θ is defined as the angle between the tangent line of hood surface and the horizontal plane. In case the underhood deformation space is fully utilized, the headform impactor will first contact with hood and then with the underhood along the impact direction. Some underhood parts, such as the engine and battery, due to their high structural stiffness, may be considered as rigid bodies under headform impact. The available deformation space could be defined by either intrusion distance I (along the impact direction) or underhood space Δ (in the vertical direction).

In this study, the structural stiffness is characterized using static stiffness measurement approach. It is also assumed that for nearby impact locations, the active mass is close to each other, and the resultant impact response will be dominated by structural stiffness and geometrical factors of hood styling.

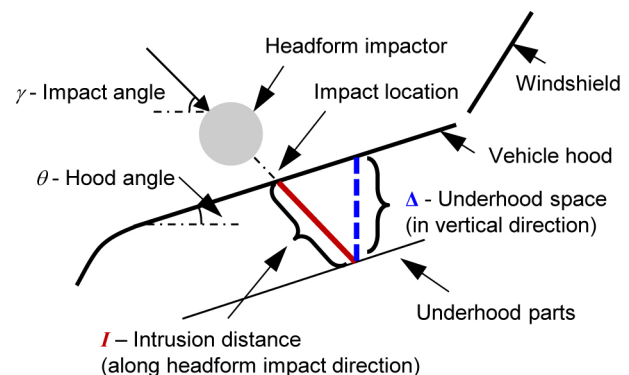


Figure 1. Impact of pedestrian headform on vehicle hood [15]

Hood Styling Characteristics in Headform Impact Area

More and more individualized design features and characteristics are being adopted in current vehicle front-end design. In some vehicle models, more elevated feature lines near hood boundary are designed. In some of the vehicle hood styling designs, feature lines on the surface will usually extend from A-pillar to hood front, which lead to a following continuous hood surface towards fender. This continuous hood surface due to elevated hood feature lines is usually referred to as concave/convex surface [14], as shown in Figure 2(a). One example of a vehicle hood design with concave surface at fender area is shown in Figure 2(b). In case of vehicle hood design with elevated feature lines, radius and normal direction of the curved shape on the cross section will only have a

range in the lateral plane of the vehicle. The concave/convex surface is served as a transition among the curvature with different radius.

The concave surface is usually close to the hood supporting parts, such as the fender. With the sudden change of the curvature radius, it usually has relatively higher structural stiffness regarding pedestrian head impact. Geometry design of the concave surface may influence the headform impact kinematics in two aspects. On one hand, reasonable feature lines may initiate headform rotation and decrease the intrusion distance in the impact direction. Therefore, too high translational acceleration may be avoided under the relatively high structural stiffness, which will benefit the HIC evaluation. On the other hand, local rise on the hood surface is realized with strict restrictions on hood surface height. In this paper, the influence of vehicle styling on pedestrian headform impact kinematics will be studied quantitatively using finite element method.

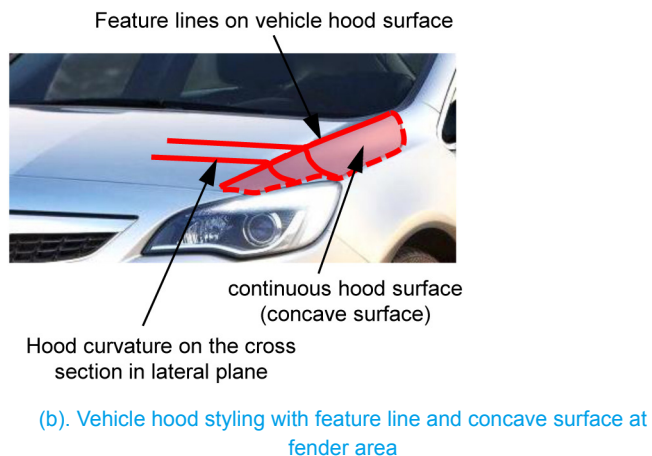
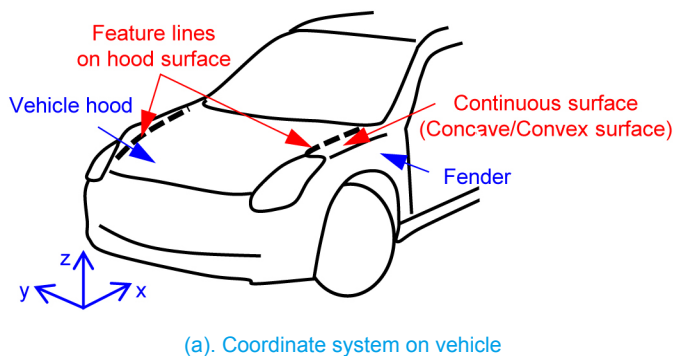


Figure 2. Hood styling at pedestrian head impact area

Static Stiffness Measurement

To isolate the effect of vehicle styling influence on headform motion under impact, the structural stiffness under static loading is measured using pedestrian headform impactor, as shown in Figure 3. The headform impactor is used to impact on the vehicle hood at a constant, relatively low velocity (1m/s) with 1-D motion. Therefore, the inertia effect under high velocity can be eliminated. Other parameters, including the impact angle, contact characteristics are all kept the same as

that in the simulation of headform impactor tests. The headform displacement along impact direction and translational acceleration at the CG location are output as a indicator of the structural stiffness. That is, resultant acceleration at the headform CG, equivalent to the reaction force from the hood structure deformation, is taken as a quantitative characterization of the structural stiffness under headform impacts.

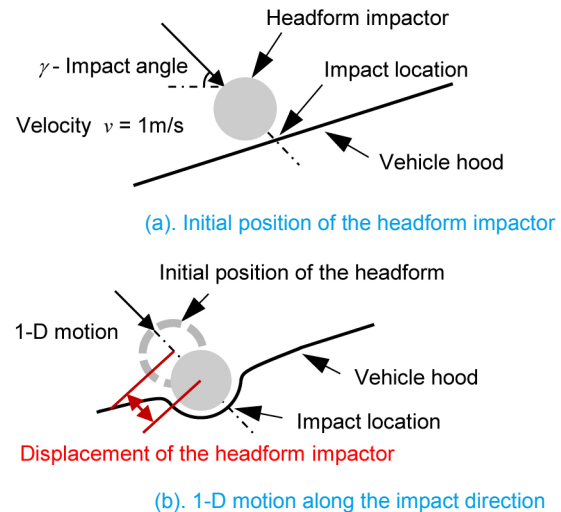


Figure 3. Measurement of the static structural stiffness of the hood

RESULTS

Headform Kinematics with Hood Feature Lines

Take the vehicle model A for example, with a typical hood design of continuous concave surface at fender area, the hood cross section at the lateral plane is shown in Figure 4. To analyze the influence of such elevated feature lines on pedestrian head impact kinematics, impact at location 1 and location 2 (Figure 4) are conducted and compared. These two locations have a 100 mm interval in y-direction and the active mass could be taken as the same. The resultant acceleration time histories are shown in Figure 5 with an obvious difference. The impact pulse at location 1 slopes gently without obvious peak, with the HIC calculation window covering almost all the 15 ms window. The resultant HIC is only 591. In comparison, at location 2, the impact pulse increase when impact begins, with the first peak up to 110 g. The HIC calculation window is dominated by both peaks, resulting in HIC value of 955, which is much higher than that at location 1.

To better understand the impact process, the static structural stiffness and rotation angle along x-axis of the headform are shown in Figure 6 and Figure 7, respectively. It can be found that the structural stiffness at location 1 is relatively higher due to the elevated feature lines near fender. The equivalent acceleration by structural stiffness is about 25 g higher than that at location 2. However, when impacted at location 1, the headform gets contact with the feature line first and then rotates towards the concave surface along -y direction.

Kinematics of the headform and the acceleration at CG along