A method for obtaining case-specific buck models based on vehicle side-view image for pedestrian collision simulations

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I. INTRODUCTION

Pedestrian injuries represent a major global health issue, with over 1.2 million people dying each year due to road traffic crashes [1], almost half of those being vulnerable road users (VRUs). Based on the characteristics of recorded cases, pedestrian head injuries are the most common severe and fatal injuries [2], and the hood and windshield have been identified as one of the main contact sources for head impact [3]. Hence, it has been an essential issue to understand the effects of vehicle shape on the kinematics and injury response of VRUs [4].

Vehicle models are needed to pair with human body models (HBMs) when performing Finite Element (FE) reconstructions of traffic accidents. Vehicle front-end structures can both influence the head kinematics and impact location, which can further affect the head injury outcome. Thus, case-specific vehicle models are needed for more reliable predictions of head impact response. However, developing detailed FE vehicle models from scratch is challenging and time-consuming. To address this issue, simplified vehicle FE [5] and buck model [6] have been developed and are widely used in simulations. Given that the buck model contains six major components (bumper lower, bumper, grille, hood edge, hood, and windshield) and has been validated against a full-scale pedestrian dummy [6], this study utilizes it as the basis for parameterisations.

II. METHODS

A method to generate case-specific buck models was obtained in this study. The effect on various vehicle front-end structures on the impact response of pedestrian-to-vehicle collisions was investigated to emphasize the importance of shape-matched vehicle models. First, the buck windshield was replaced by a glass windshield modeled with a non-local failure model developed by Alvarez and Kleiven [7]. Then, different parameterisations of the buck model were used in simulated lateral pedestrian impacts using the 50th percentile male Total Human Model of Safety Version 4 Series (THUMS AM50 V4.02) in LS-DYNA. The main process is as follows:

Pre-processing of a vehicle image: a standard side-view of the targeted vehicle to facilitate subsequent feature extraction of the front-end structure. Due to the horizontal position of two wheels in side-view, the perspective deviation of the vehicle images can be measured and processed [8]. *Extraction and validation of vehicle geometry*: the side-view image was binarised to calculate the contour curves using the 'Canny' edge algorithm in Matlab. By comparing the image size with the vehicle size, the full-size profile curve can be obtained by scaling. Considering only the front-end shape is used in simulation, the curve was selected from the bottom of the front wheel up to the top of roof, along the bumper, grille, hood and windshield. *Mapping and transformation of components*: by comparing the mapping relationship between the six components on the original buck and the corresponding positions on the targeted vehicle, the transformation matrix, including transform distance (x_i y_i, i = 1,2…6), rotation angle ϑ_i and scale factor λ_i, for each component can be calculated. The buck model components were parameterised and rigidly transformed to match the shape of the targeted vehicle using the transformation matrix. Figure 1 illustrates the above-described main process of the generation.

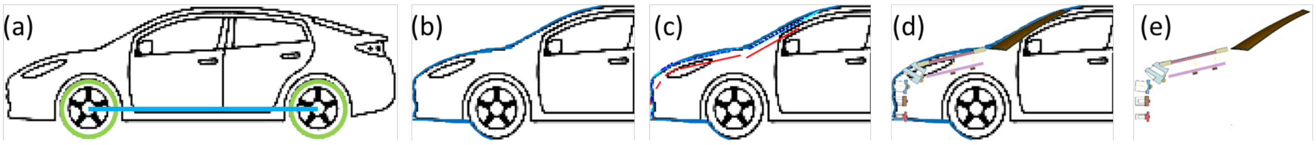

Fig. 1. Flowchart for establishing shape-matched buck model based on the side-view of accident vehicle: (a) pre-processing image, (b) vehicle geometry extraction, (c) mapping of six components, (d) transformation of six components, and (e) obtained shape-matched buck model.

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III. INITIAL FINDINGS

Three vehicle categories were selected: Family Car/Sedan (FCR), Roadster (RDS) and small Sport Utility Vehicle (SUV). Each category included two representative vehicles to maintain geometric diversity. The comparison between vehicle mid-section profiles and corresponding shape-matched buck models is illustrated in Fig. 2.

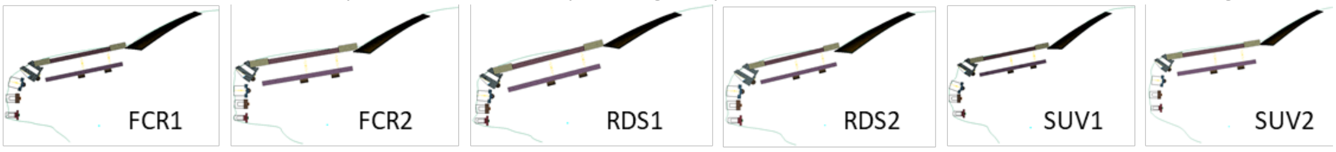

Fig. 2. Shape-matched buck models of three vehicle categories.

Figure 3 exhibits the impact configuration that the shape-matched buck models used in lateral impact simulations with the pedestrian HBM at an impact velocity of 40 km/h. The head trajectories with respect to the buck model are extracted from the head centre of gravity (CG) and are displayed in Figure 4.

It was found that the head trajectories differed notably within the same vehicle category. Figure 5 shows the HIC and peak angular velocities extracted from head CG. For FCR 1-2, there are approximately 55 mm deviation in wrap-around distance (WAD), 1.0% deviation in head injury criterion (HIC) and 15% deviation in peak angular velocity (PAV), respectively. Meanwhile, for RDS 1-2 and SUV 1-2, the differences in WAD, HIC and PAV are 71 mm/7.0%/27% and 120 mm/40%/9.0%, respectively.

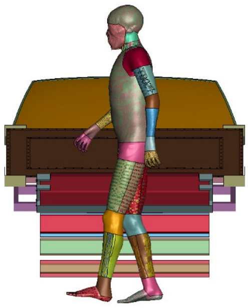

Fig. 3. Example of a pedestrian-vehicle collision simulation.

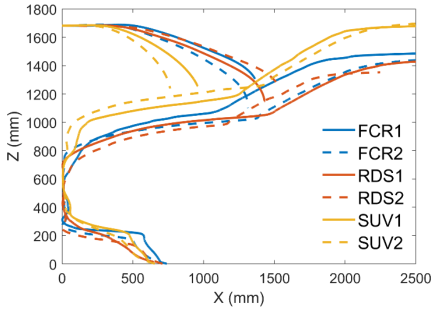

Fig. 4. Head CG trajectories against shape-matched buck models.

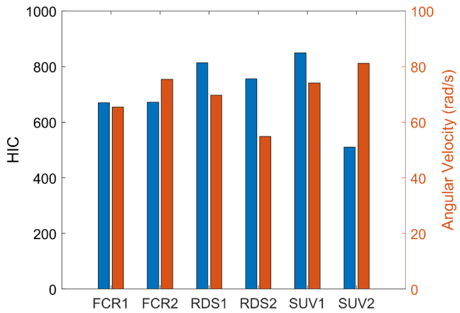

Fig. 5. HIC and PAV extracted from head CG.

IV. DISCUSSION

This study proposes a novel method for obtaining case-specific buck models based on vehicle side-view image. The material properties of the buck components have been previously assessed through impactor tests and full-body POLAR II impact tests [5][6]. The findings suggest that the front-end structures play a crucial role in determining the initial conditions for head impacts. Specifically, impacting different components, such as the hood and the windshield, significantly influences the impact angle and force, which ultimately affect the overall impact response. The discrepancies observed in the head kinematics among the same vehicle category emphasize the need for using case-specific vehicle models in accident reconstructions. Meanwhile, the proposed method provides a new approach for further analysis of the head injury response in vehicle collision simulations.

It should be noted that the buck model was developed and validated to represent the sedan category only, therefore the effectiveness of representing other categories, like roadster and small SUV, will require further investigation to assess its applicability.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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