Can Altering Vehicle Pre-Crash Impact Angles Reduce Occupant Injuries?

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I. INTRODUCTION

Vehicle collisions constitute a predominant cause of global injuries and fatalities. To mitigate the effects of such incidents on occupants, ongoing research in automotive engineering focuses on enhancing vehicle safety systems. Conventional crash tests primarily employ a vertical (0-degree) collision angle while real-world collisions manifest at varied angles, potentially yielding diverse types and severities of occupant injuries. Consequently, the exploration of altering pre-crash angles' influence on occupant injuries bears substantial engineering relevance. Several studies have examined the effect of pre-crash angles on occupant injuries. Kitagawa *et al.* [1] demonstrated that collision angle has an effect on contact force to the occupant. Hu *et al.* [2] found that altering pre-crash angles significantly affects head and chest injuries of rear-seat occupants. A recent study on safety decision-making of automated vehicles indicated that the occupant injury risk under a particular collision angle is significantly higher [3]. These studies yield valuable research findings. However, few studies have comprehensively addressed the combined effect of different pre-crash angles on occupant injuries and proposed corresponding solutions.

While prior research has provided insights into the influence of pre-crash angles on occupant injuries, several unresolved issues and knowledge gaps persist. This study aims to address these gaps and further explore the potential of altering pre-crash angles to mitigate occupant injuries, thereby presenting insights and methodologies for the advancement of automotive safety technology.

II. METHODS

A two-stage collision parametric simulation was conducted (Fig. 1). In the first stage, a vehicle-rigid wall collision based on the Visaul Crash Studio (VCS) platform was simulated. This generated linear acceleration pulses in the X and Y directions, as well as angular acceleration pulses about the Z axis. These collision waveforms were utilised as inputs for the second stage, which involved simulating occupant collisions based on the MADYMO platform. The impact speed of the baseline model was 50 kph, the dummy height was 170 cm, and the Body Mass Index (BMI) was 21. The pre-crash angles ranged from -30 to 30 degrees with a 1-degree interval. For each angle, the collision scenario was simulated, and the resulting head injury criterion (HIC) and Combined Thoracic Index (CTI) values for occupants were examined. Through this methodology, the influence of different collision angles on occupant head/chest injuries, as measured by the HIC/CTI, were investigated.

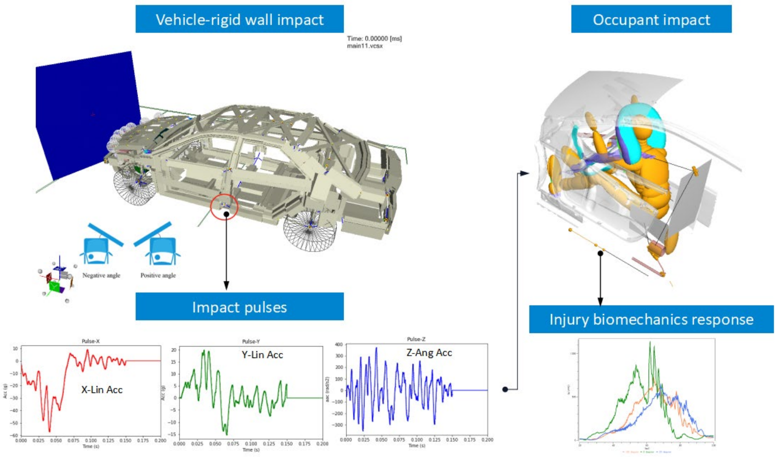

Fig. 1. Demonstrations of (**a**) proposal framework and (**b**) driving simulator and experimental procedure.

III. INITIAL FINDINGS

Through a series of parametric mathematical simulations, while keeping other variables (impact speed, overlap, occupant stature, etc.) constant and only altering the collision angle, the results, as shown in Fig. 2, reveal a distinct trend. It can be observed that when the vehicle collides nearly perpendicularly with the rigid

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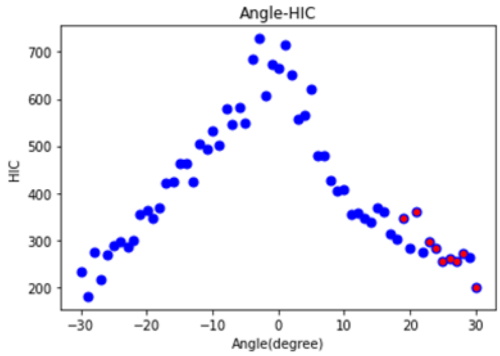
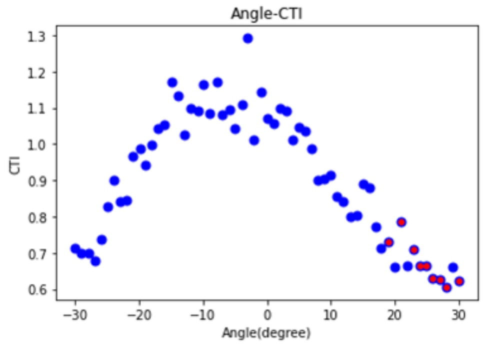
wall (collision angle of 0), the occupant head injury criterion HIC reaches its maximum value (greater than 700). However, as the collision angle increases (either positively or negatively), both HIC and CTI values exhibit a decreasing trend. For instance, when the angle is ±30 degrees, the HIC value is only 200 approximately. Collisions with the same magnitude of positive and negative angles result in similar injury criterion values.

The simulation suggests that oblique impacts lead to lower occupant HIC and CTI values compared to vertical impacts, necessitating a detailed analysis of human kinematics and dynamics. In oblique impacts, increased head motion in the Y-direction disperses impact energy in the X-direction, resulting in slightly reduced impacts on the head and chest, hence lower injuries. Additionally, shorter deployment and pretensioning times of airbags and seat belts correlate with earlier action and smaller impact, further explaining this phenomenon. However, due to different collision angles, delta-v values vary among cases (with the reference point below the driver's side B-pillar).



(a) Vehicle impact angle versus occupant HIC



(b) Vehicle impact angle versus occupant CTI

Fig. 2. The relationship between vehicle impact angles and occupant head injury criterion (HIC) and chest injury criterion (CTI) indices (data represented by the pink circles indicate simulated error data).

IV. DISCUSSION

Preliminary insight into the effect of vehicle impact angle on occupant injuries indicates that oblique impacts result in lower occupant HIC and CTI values compared to vertical impacts. Our previous study on vehicle decision-making to minimise occupant injury risk showed significant advantages of intelligent decisions (i.e., braking combined with steering) in hazardous scenarios over situations with only automatic emergency braking (AEB) systems, as demonstrated in Fig. 3. These findings can provide strategic guidance for optimising safety decision algorithms in future intelligent vehicles. However, the limitation of this study lies in solely altering the collision angle, whereas in real-world accidents, changes in vehicle collision angles may interact with other factors (such as occupant posture), necessitating further investigation.

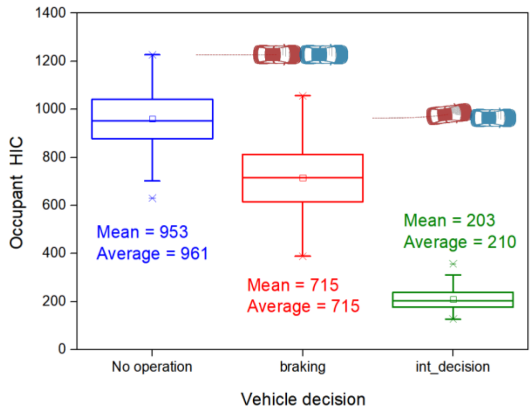


Fig. 3. The median and mean values of occupant HIC under different vehicle decisions.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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