1+1>2: Simulating Occupant Dynamics in a Vehicle Crash

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Introduction

Vehicle collision simulation software is commonly used to reconstruct the collision scene and define vehicle dynamics. However, it is difficult to precisely reconstruct the occupants' dynamics and therefore typically requires multiple assumptions to understand the injury solely based on vehicle dynamics. The combined use of vehicle simulation software and occupant simulation software reduces the number of assumptions needed and can accurately simulate occupant dynamics under various conditions. A recent case involving a complicated vehicle collision illustrates how the outputs of vehicle dynamics simulation can be used to drive the occupant's dynamics simulation in an additional software package specific to occupants' injury verification.

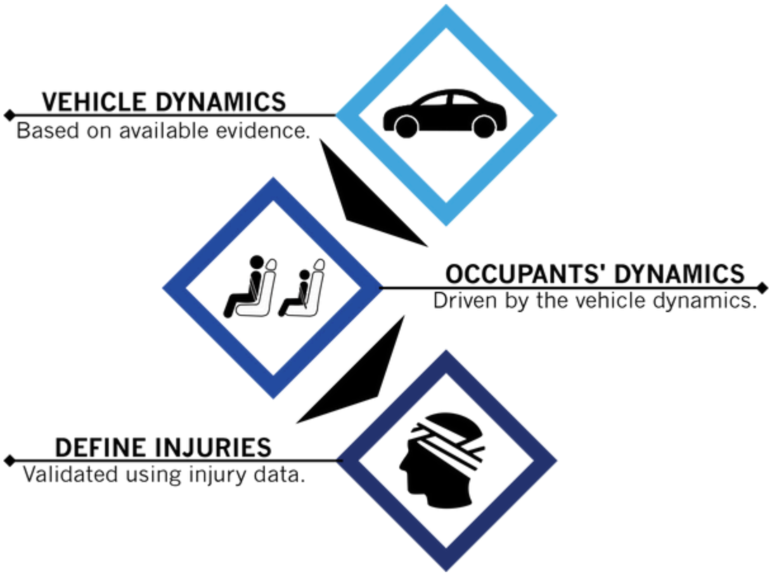

Figure 1: Process followed by current study.

Background

In August 2020, a Chevrolet Silverado with a fully loaded trailer was travelling at approximately 120 km/h on the highway. A Porsche Cayenne was followed by a Chevrolet Cruze sedan, carrying a family of four with parents in the front seat and two children in the rear seat. The Cruze was travelling in front of the Silverado at a much lower speed (30km/h). The Silverado rear-ended the Cruze pushing it forward and into the rear of the Porsche. The two children in the back seat of the Cruze were severely injured. One child died due to multiple blunt trauma injuries and the other child sustained a fractured leg and severe traumatic brain injury. The principal question in this investigation was to find out if the in-vehicle seatbelts or the use of a Child Restraint System (CRS) would reduce the level of injury of the children. In order to answer this question, the dynamics of the vehicles need to be defined and then, evaluate and compare the force exerted on the children in the various sitting conditions (with and without seatbelts and use of a CRS).

Methods

In order to define vehicle dynamics, a simulation of the sequence of collisions between the Silverado and the Cruze and between the Cruze and the Porsche was conducted using Virtual Crash, a vehicle collision reconstruction software. Initial conditions for Virtual Crash were set to closely match existing evidence, including estimated impact points obtained from on-site crash measurements, the initial velocities of the vehicles, and the separation velocities as recorded by their respective on-board event data recorders (EDRs). More evidence used to define the simulation included the skid marks from the certified crash scene report, and final resting positions of three (3) vehicles.

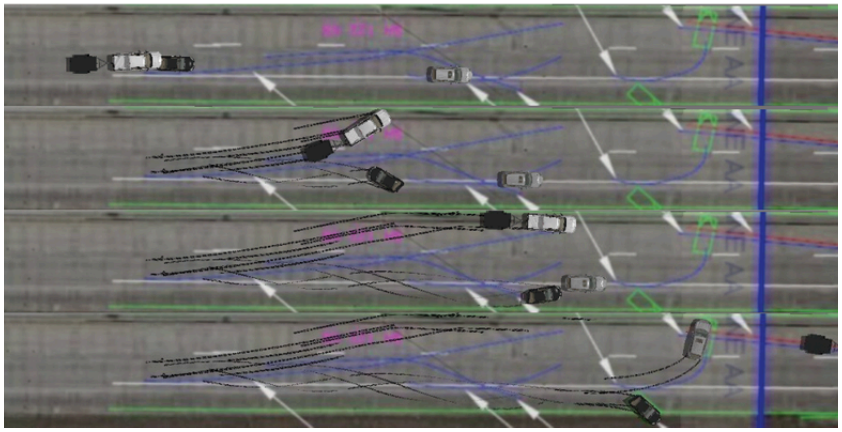

Figure 2: Chronological sequence of images from Virtual Crash simulation results.

Figure 2 illustrates a chronological sequence of images from the Virtual Crash simulation from the time of the first impact to the final positions. The Silverado is shown in white, Cruze in black and Porsche in light grey. The blue lines show the skid mark drawing from the scene, and the green boxes show the final positions of the vehicles. Virtual Crash results are consistent with scene evidence including skid marks, vehicle paths, and the final resting place of all three (3) vehicles. Therefore, the angular motion of the Cruze is presumed to be valid and is sufficiently accurate to be used in simulating the effect of the collision on the occupants of the Cruze.

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Occupant dynamics were simulated in MADYMO. The simulation used scaled anthropometric models of the vehicle occupants based on their height and weight. MADYMO passenger models consist of ellipsoids which represent the various body segments, notably legs, arms, torso and head. The resistance at each joint is based on nominal values that have been determined to approximate the motion of human body segments subjected to impacts.

In MADYMO, instead of making large assumptions for the vehicle dynamics, the simulation of the occupants' dynamics is completely driven by the results from Virtual Crash where the vehicle parameters including the velocity, acceleration, angular velocity, and angular acceleration were exported. Figure 3 illustrates the elements included in the MADYMO model.

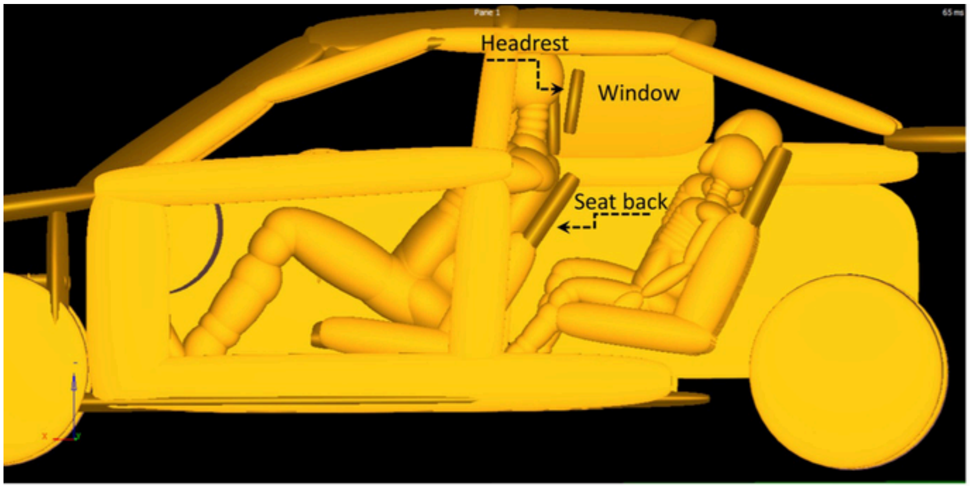

Figure 3: Interior view of MADYMO model in Cruze, showing position of the seats and occupants.

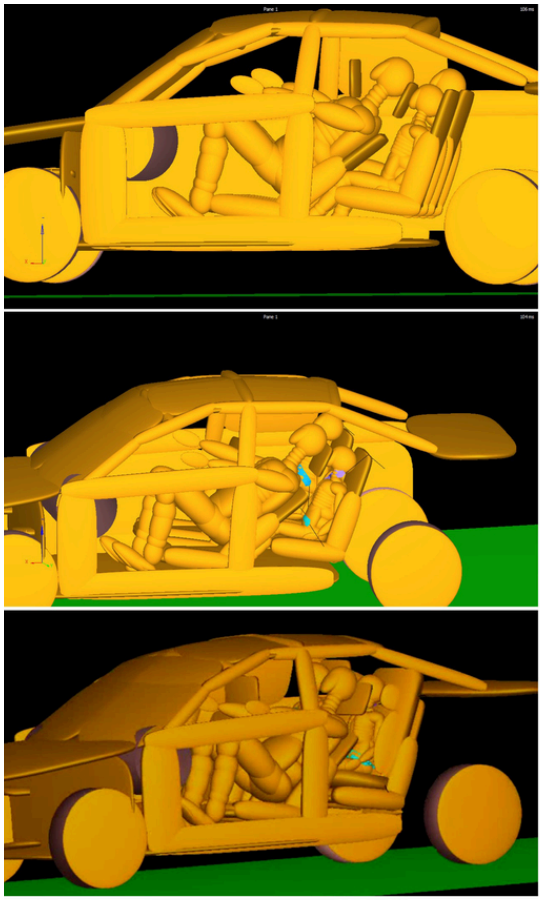

Figure 4: MADYMO simulation without seatbelts (top), with seatbelts (centre) and with CRS back and booster (bottom).

Results

Three (3) different sitting conditions were simulated in MADYMO, including without seatbelts (actual incident), with seatbelts on, and with the use of a Child Restraint System (CRS). As shown in Figure 4, the peak linear head acceleration experienced by child 1 resulted in a Head Injury Criteria (HIC) well above 99% probability for severe head injury (AIS ≥ 4).[1,2] This result is verified by child 1's documented skull fracture. Although implementing the CRS largely reduced the HIC value, it is still well above 95% probability for severe head injury. For the peak angular head acceleration, the result from the "without seatbelts" condition is well above the recognized threshold of 10,000 rad/s2[2] for brain injury,[3] while the "seatbelts on" condition and "CRS use" condition did not show overall protection for the child in this rear-end collision scenario.

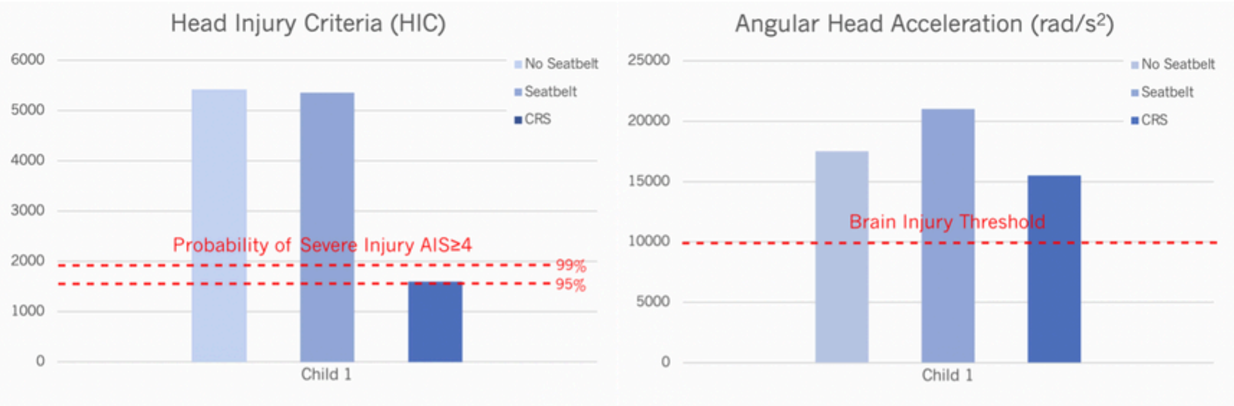

Figure 5: Head Injury Criteria (HIC) based on Equation 6 in Mariotti et al.[2] and peak angular head acceleration where dashed line shows threshold for brain injury

SUMMER 2024
VOLUME 56 ISSUE 1

Conclusion

By using results from a well-defined vehicle dynamics simulation to drive the simulation of occupants' dynamics, one can successfully verify occupant injury and predict potential injury severity in various intravehicular conditions. The approach avoids making large assumptions to define either vehicle or occupant dynamics and allows for multiple points of verification during the process.

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Dr. Desmoulin is the Principal of GTD Scientific Inc. GTD offers Biomechanical Consulting Services to clients throughout North America and abroad. Focused practice areas include Injury Biomechanics, Incident Reconstruction and Physical Testing with a sub-specialty in the Science of Violence®. GTD has been retained in significant complex injury litigation cases involving municipal police department use of force, violent encounters, and TASER International. Dr. Desmoulin's landmark testing and shooting reconstruction methodology was recently upheld as reliable and admissible by the U.S. Federal District Court for the 9th District of California. This methodology is now publicly available at gtdscientific.com.

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[1] https://aci.health.nsw.gov.au/networks/institute-of-trauma-and-injury-management/data/injury-scoring/abbreviated_injury_scale

[2] Mariotti, V.G., Golfo, S., Nigrelli, V. & Carollo, F. (2019) Head Injury Criterion: Mini Review. American Journal of Biomedical Science & Research, 5: 406-407.

[3] Depreitere, B., van Lierde, C., Sloten, J. V., Van Audekercke, R., Van Der Perre, G., Plets, C., & Goffin, J. (2006). Mechanics of acute subdural hematomas resulting from bridging vein rupture, Journal of Neurosurgery, 104: 950-956.