

Vehicle Front-End Architecture as a Driving Factor in Occupant Injury Risk During Vehicle-Guardrail Impacts: A Hybrid III Dummy-Based Numerical Study

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Introduction:

The performance of Midwest Guardrail Systems (MGS) during impact with electric vehicles (EV) has raised concerns with recent observations demonstrating a higher susceptibility to rail-failures. These failures are hypothesized to be related to EV-specific design geometries, including increased vehicle curb mass, lower vehicle center of gravity and variations in front-end geometry resulting from the absence of conventional powertrain. Guardrail designs are evaluated in crash tests using a representative small car and pickup truck to span the range of vehicle sizes and weights in the vehicle fleet. Reliance on two vehicle configurations implies that the barrier performance could be sensitive to variations in front end geometry, potentially leading to unanticipated impact responses. However, the extent to which geometry influences occupant injury risks and trends during vehicle guardrail impact remains insufficiently investigated.

Objective:

The objective of this study is to quantify the influence of vehicle front-end geometry on occupant injury risk during vehicle-guardrail impacts using finite element simulations. Occupant injury risk is analyzed using Hybrid III dummy-based injury criteria and flail space-based vehicle severity metrics to identify trends and relationship between geometric variations and injury probability.

Methodology:

Front end geometry data obtained from the Insurance Institute of Highway Safety (IIHS) was analyzed to identify parameters and ranges associated with adverse response outcomes with MGS installation. Based on vehicle alignment with the w-beam, hood leading edge height, hood leading edge angle, and bumper height were morphed on the Toyota Yaris model. Efficient design space exploration with computational cost minimization prompted selection of a Latin hypercube design of experiments, yielding 13 unique configurations for detailed analysis. Using LS-Dyna, full scale Manual for Assessing Safety Hardware (MASH) Test Level 3 finite element simulations were then performed between the morphed vehicle models integrated with Hybrid III 50th percentile male dummy and MGS guardrail. Occupant injury metrics, including Head Injury Criteria (HIC), N_{ij} for the neck, maximum chest deflection (CD), chest acceleration, and femur load for thigh, were extracted alongside vehicle-based crash severity measures.

Results:

All vehicle geometries fulfilled MASH criteria with occupant impact velocity (OIV) and occupant ridedown acceleration (ORA) within tolerance with no rail rupture. Sobol sensitivity analysis revealed that for small car, hood leading edge height was most consequential for both longitudinal and lateral OIV (64.2%, 58.6%). Longitudinal and lateral ORA (71.4%, 43.2%) and dynamic and set rail deflection (51.8%, 56.6%) were primarily influenced by bumper height. Preliminary simulations suggest that Hybrid III injury metrics varied with changes in vehicle configurations however, no significant difference in overall injury risk was observed.

Conclusions:

While front-end geometry influences occupant kinematics, resulting injury metrics and vehicle-guardrail interaction characteristics, it does not independently govern occupant injury risk. The blunt front-end configuration was associated with decreased occupant injury risk relative to the more sloped design, which showed signs of under-riding. Although, the MASH tests have the same outcome as the geometries studied, increased EV mass could interact with the geometry leading to barrier failure, which will be explored in future work.

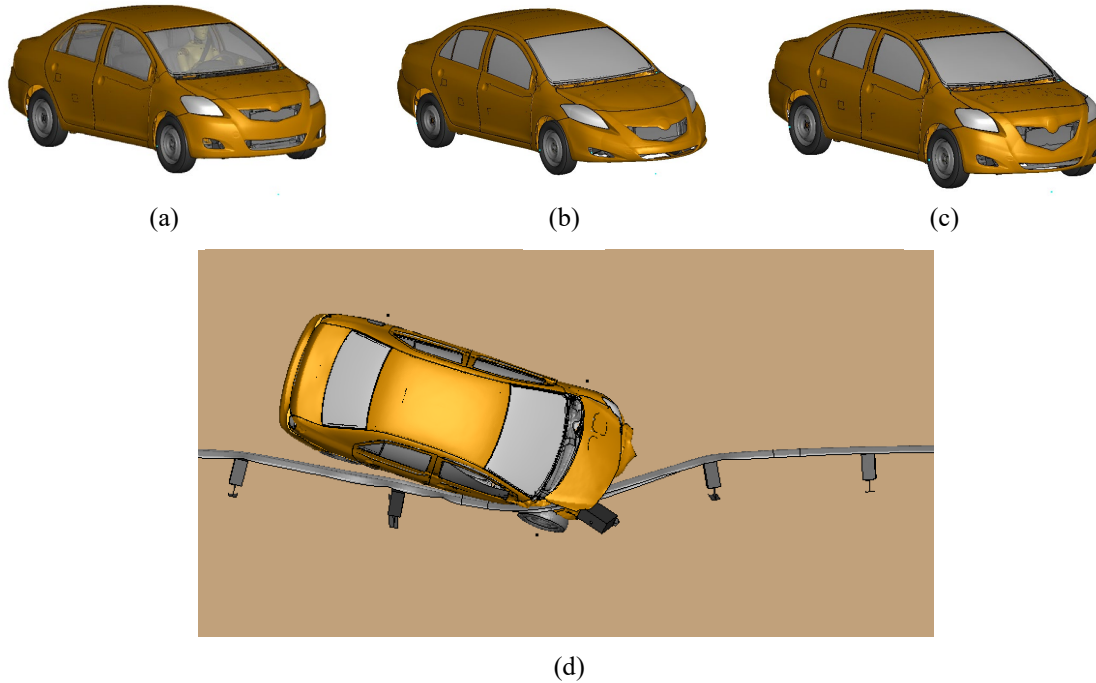


Figure 1. (a) Baseline small car FE model; (b) DP-01 FE model; (c) DP-07 FE model; (d) Top view of DP-07 small car impact with MGS installation under MASH TL 3 crash scenario.

