INJURY PATTERNS AND EFFECTIVE COUNTERMEASURES FOR VEHICLE COLLISION COMPATIBILITY

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ABSTRACT

This paper examines the NASS-CDS statistics to identify the significant parameters associated with injuries in LTV to car frontal collisions. These parameters of interest are the ΔV of the colliding vehicles, the direction of impact as well as any under-ride of the smaller vehicle. It is observed that the cumulative ΔV curve of car occupants in frontal tow-away collisions with LTVs becomes asymptotic at 30 miles per hour and that over 97% of those car occupants are in cars with a ΔV of 35 mph or less. The relationship of injuries with the reported under-ride in the NASS database is more complex and in several ΔV ranges, the presence of under-ride is related to a lower risk of injuries. Based on these findings, evaluations of compatibility improvement are conducted for frontal impact between an LTV and a small car at approximate ΔV of 35 mph and intrusion levels are calculated for the struck car. It is concluded from the data presented here that lowering the height of LTVs to increase the vertical overlap with a smaller vehicle may, in many cases, increase the intrusion levels in the smaller vehicle as well as increase the crash energy in the smaller vehicle. The addition of a secondary structure to LTVs for the purpose of increasing structural interaction is also investigated and it is shown that the effect of this in the studied cases is to reduce the calculated intrusion in the smaller vehicle.

INTRODUCTION

Several studies published in the recent literature have discussed the factors influencing collision compatibility between different sized automobiles and the possible ways of improving this compatibility. Although most of the societal harm in vehicle-to-vehicle collisions is attributable to lateral impacts[1], almost all of the published studies have looked at frontal impacts only.

It is important to emphasize that the objective of 'improved collision compatibility between vehicles' is that of improving the safety of the occupants of a smaller vehicle in collisions against a larger automobile. Therefore, any criteria proposed as measurement of compatibility improvement must demonstrate strong, monotonic relationship to the reduction of injury probability of occupants in the smaller vehicle. Such relationship is yet to be demonstrated for any of the criteria or test procedures published so far.

Several authors[2-5] have suggested measurements of compatibility in frontal crashes by using data from discrete load cells on a fixed barrier, the test procedure consisting of the larger vehicle in the collision pair (often referred to as 'the striking vehicle') being impacted into such a barrier at a certain speed. These barriers have generally consisted of a fixed, rigid surface with or without a layer of deformable material. The quantities measured in such tests are of course limited to forces at the various load cells and the crush of the barrier material. The proposed measures of collision compatibility have been mathematical functions of the measured quantities, e.g. height of force, peak force levels, homogeneity of force distribution, etc. As mentioned above, none of these mathematical functions meet the criteria[6] necessary to be a reliable indicator of collision compatibility of the vehicles. Several other published studies have been attempted to identify the significant factors influencing the vehicle compatibility from investigation of vehicle-to-vehicle impacts[7, 8].

The present paper discusses the definition of proper evaluation conditions that are representative of crash statistics in the USA. The possible solutions for improving compatibility are then studied in these 'field representative' conditions. Of course, collision compatibility is only one aspect of the total traffic safety and it is necessary that any improvements in collision compatibility be also evaluated for the effect on the overall safety.

FRONT-END FORCES OF A VEHICLE

Considerable attention has been paid in the published literature to the premise that the measurement of the forces exerted by a vehicle in a frontal impact against a barrier can be transformed into a compatibility measurement. However, an examination of the front structure of automobiles shows that the principal load paths in frontal crashes consist of structural components with generally hollow sections (such as the frame rail, rockers, engine cradle, etc) and other 'non-structural' components (such as engine, transmission, tires, etc). The forces generated in any crash are then the aggregation of the response of all these components of the automobile as well as those from the other collision partner. Since the structural properties of the vehicle components are highly nonlinear functions of the loading direction, load magnitudes, the loading area, time, etc, it is to be expected that the forces generated by the vehicle in an impact are also time- and space-dependent, nonlinear functions of 'what' these components impact and 'how' they interact (the direction of loading, deformation modes, interaction dynamics such as sliding, rotating, etc).

For such nonlinear, highly directional and non-uniform structures, it is not possible to predict the force generated in a specific mode of impact from that measured in another mode. Thus, the forces in a vehicle-to-vehicle impact will be vastly different from those generated in a fixed barrier impact. Similarly, the forces in vehicle-to-vehicle impact will be dependent on the location of impact, the direction of impact, the speed etc.

The design of front-end structures is governed by the fundamental principle of the crashworthiness in that they have to meet the various regulatory and non-regulatory requirements for front crashes. Thus, these front structures dissipate the total energy of the crash in the crush space available in the vehicle in the most efficient manner possible. The crash energy (or the pre-impact kinetic energy) is proportional to the mass of the vehicle. This relationship has been discussed in an earlier publication[9] and is also supported by available test results, e.g. those in the US NCAP database of the National Highway Traffic Safety Administration. Since the pre-impact kinetic energy of the vehicle is translated principally into structural deformation of the vehicle (ignoring the small portion used in post-crash translation and into other forms of energy), it is to be expected that the average force (averaged over the crush depth) measured on the barrier will be proportional to the mass of the vehicle, other factors remaining the same.

That such is indeed the case[9] is shown in Figure 1, which is a plot of the vehicle mass versus the 'average force' calculated from frontal NCAP tests. This 'average force' is not a physical parameter but a hypothetical number which, when multiplied by the total distance of crush of the vehicle, is indicative of the pre-impact kinetic energy of the vehicle.

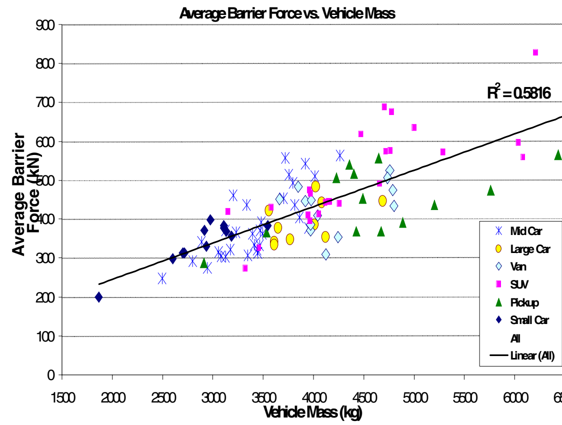

Figure 1: Relationship of Front-end force to Vehicle Mass in NCAP tests

As is to be expected, a slightly stronger correlation exists between the average force and the parameter 'vehicle mass divided by the dynamic crush distance of the vehicle (Figure 2). The relatively slight change of correlation (when the crush distance is used as one

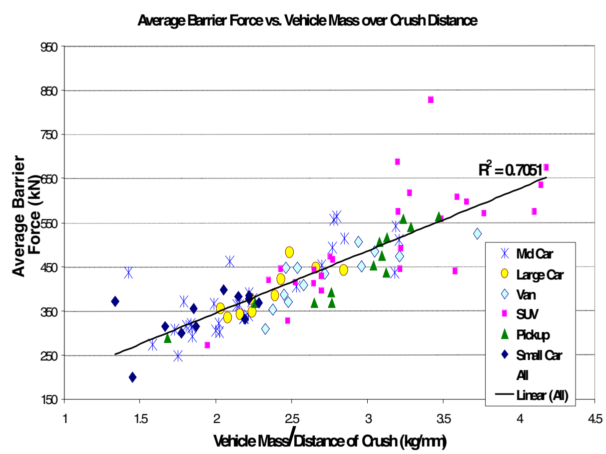

Figure 2: Front end Force relationship to Mass and crush distance in NCAP Tests

of the variables) is an indication that this parameter (vehicle's crush space) is relatively invariant for the vehicle population.

If the vehicle were to impact another vehicle, the forces generated will be different from those measured against a fixed barrier for the reasons mentioned earlier. It is important, therefore that determination of collision compatibility be based on the dynamics of vehicle-to-vehicle crash and that any measurement of compatibility improvement be ultimately linked to evaluation in a vehicle-to-vehicle crash in a 'field representative' test condition.

FIELD REPRESENTATIVE TEST CONDITION

Shown in Figure 3 is the distribution of harm in

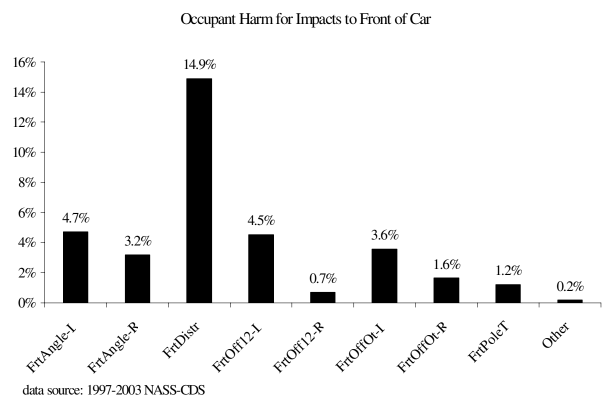

Figure 3: Distribution of harm in LTV-to-car front impacts by location & direction

frontal crashes between light truck based vehicles (referred to as LTVs) and passenger cars, obtained from the 1997-2003 NASS-CDS database. It is observed that the category of 'Front Distributed' crashes is the largest single category associated with harm in frontal collisions. Similarly, the estimated change in velocity (ΔV) of cars in frontal impacts with LTVs is shown in Figure 4 from the same

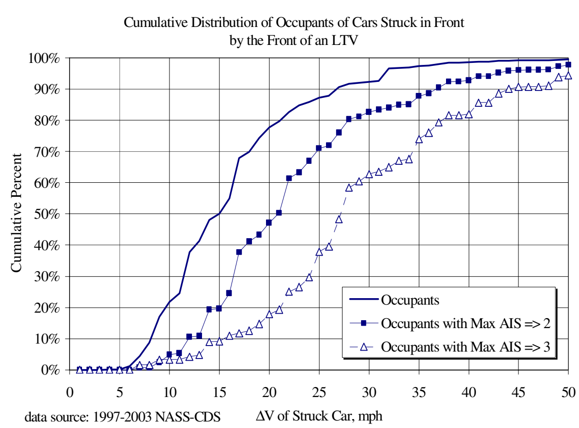

Figure 4: ΔV of cars; Frontal Collisions with LTV

NASS-CDS database. It is seen that for these crashes, more than ninety percent of the occupants (and sixty three percent of the occupants with reported injuries of AIS greater than or equal to 3) were in cars with a ΔV of 30 mph or less. A threshold of ΔV =35mph includes over ninety-seven percent of all the occupants and about seventy four percent of those occupants where the injury reported was of AIS $\geq$ 3.

It can therefore be stated that a 'field representative' condition for evaluation of collision compatibility is a full frontal test between two vehicles where the ΔV in the struck car is 35 mph

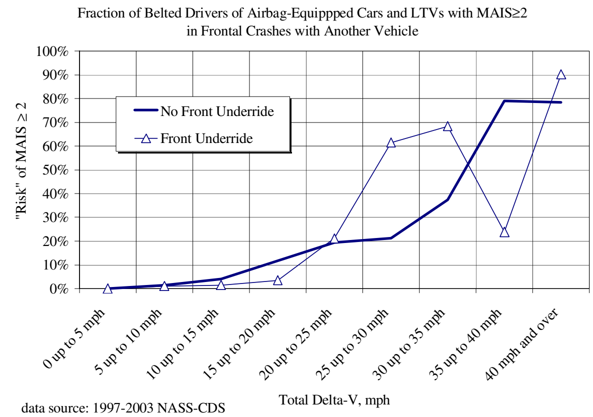

Figure 5: Vehicle Under-ride and MAIS Risk

There is no consistent relationship observed between under-ride reported in the database and the probability of injury (Figure 5).

COUNTERMEASURES FOR COMPATIBILITY IMPROVEMENT

For two vehicles of different heights, ensuring the structural interaction between the colliding vehicles is generally considered to be a step towards increased compatibility. For the US fleet, the issue of compatibility is often interpreted to be that of collision between LTVs and passenger cars and the improved structural interaction has been mentioned as a step towards preventing the higher LTV over-riding a lower automobile.

From an examination of the automobile structures, it is easy to conclude that any such 'increased structural interaction between vehicles' needs to be between the primary structures of the vehicles (and not between the bumpers since the bumper carry a very small part of the load in collisions at speeds being considered here). One possibility of achieving such increased structural interaction is by aligning the primary structures of the two vehicles. For a high LTV, this may be achieved by requiring that the height of the primary structure be lowered. Alternatively, this may be achieved by adding properly designed secondary structures to the LTV. Both these options are examined here.

Lowered Height of LTVs

A simulation of frontal impact between an LTV and a passenger car was conducted using finite element models of the vehicles. Both the vehicles were moving towards each other at 30 mph prior to the impact (Figure 6).

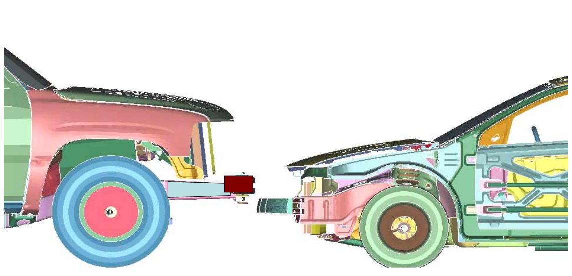

Figure 6: Simulation of LTV-to-Car Frontal impact

For this study, the LTV height was varied to obtain the following four cases (shown in Figures 7a and 7b with the bumpers of both vehicles hidden from view):
a) Baseline- No overlap between the frame rails (primary load carrying structures of the LTV and of the car);
b) Full overlap-The LTV was lowered so that its frame rail fully was fully overlapped by the car frame rail (centerlines of the frame rails of the two vehicles were aligned);

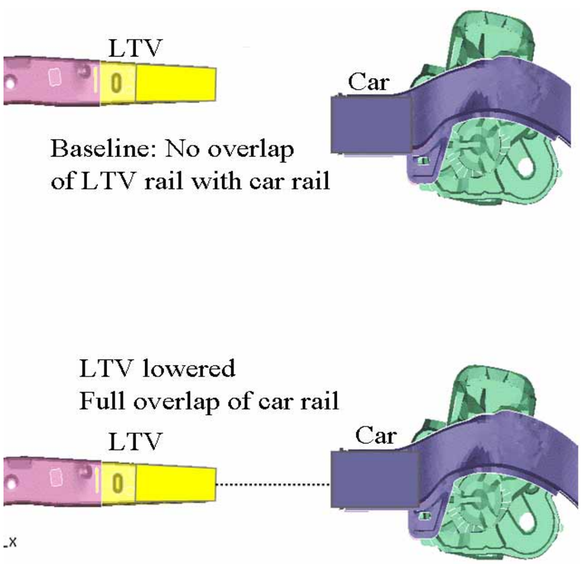

Figure 7a: Baseline and Full overlap cases of LTV rail with Car Rail

c) Large (>50% overlap) - The LTV was lowered so that the car rail overlapped more than 50% of the depth of the LTV rail (bottom of LTV rail was aligned with the centerline of car rail);

d) 50% overlap - The LTV was lowered so that the car rail structure overlapped 50% of the depth of the LTV rail (centerline of the LTV rail was aligned with the top of the car rail).

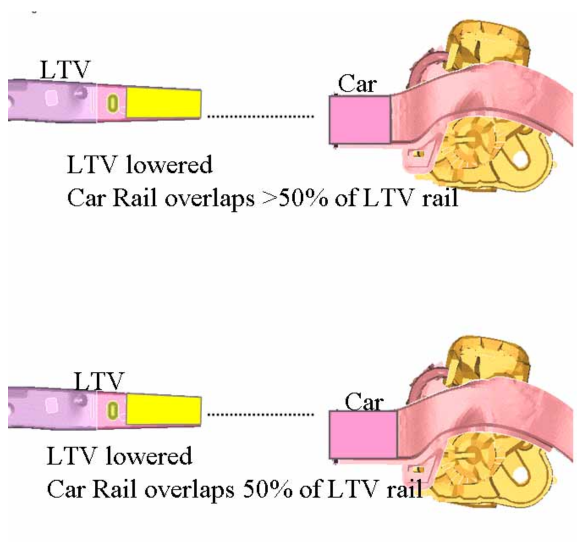

Figure 7b: Partial overlap cases of LTV rail with Car Rail

The calculated intrusions at several points in the struck car are presented in Figure 8 for this simulation of frontal impact.

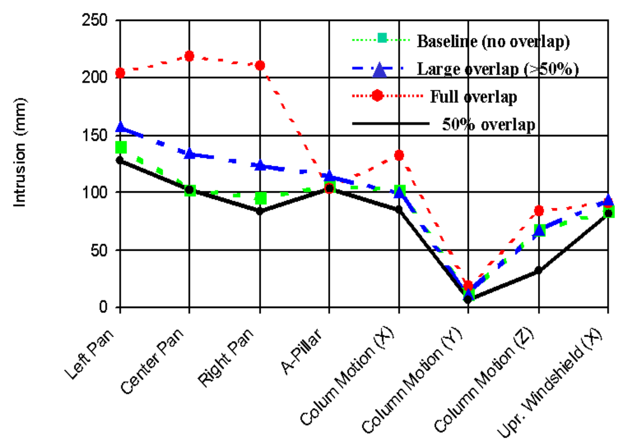

Figure 8: Effect of Increased overlap on Struck Car

It is observed that lowering the LTV to obtain larger structural overlap between the vehicles generally increases the intrusions in the passenger car. The full overlap of the structures of the two vehicles produces the highest amounts of intrusion in the struck car in the present study. It is only in the case of the 50%

overlap that a slight reduction in intrusion in the car is obtained.

Similar conclusions are drawn from an examination of the energy distribution between the two vehicles. The total energy just prior to the impact equals the sum of kinetic energies of the two vehicles. This energy is translated during the impact into the following components-
a) energy dissipated in the structural deformations in the car (shown as 'car energy') and the truck (shown as 'truck energy') ,
b) energy dissipated in the motion of the vehicles during the impact (shown as final 'kinetic energy'); and
c) energy dissipated in other forms (non mechanical, etc).

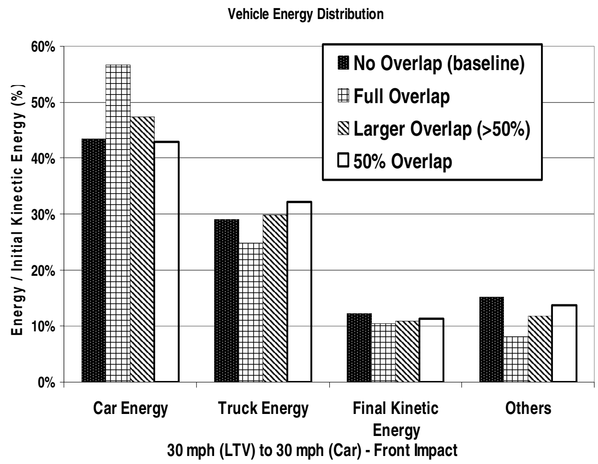

Figure 9: Effect of Structural overlap on energy sharing between two vehicles

Figure 9 show that larger structural overlaps between the two vehicle results in more energy being transferred into the structural deformation of the car (as compared to the baseline case of no vertical overlap). Again, a small reduction in the energy share of the car is observed only for the case of the 50% overlap of the LTV primary structure.

The above conclusion that increasing the vertical overlap between two vehicles of dissimilar mass may not improve the collision compatibility between the vehicles is generally supported by the published[8] test data in the literature.

SECONDARY STRUCTURES ADDED TO LTV

Addition of a 'secondary structure' to the frame rail of a higher vehicle is a possible solution for increasing the structural interaction[6] of such vehicle with a lower vehicle. One of the possible mechanisms by which such added secondary structures improve the interaction between the two vehicles is that, when impacted by the frame rail of the passenger car, these secondary structures generate a bending moment on

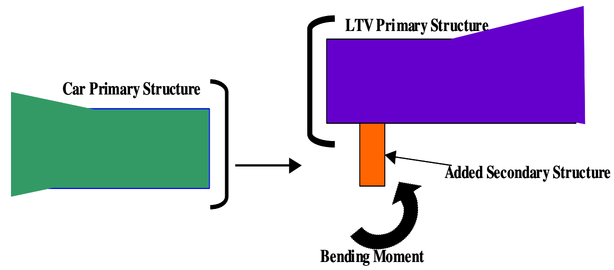

Figure 10: Secondary Structures Added to LTV

the frame rail of the LTV. This of course requires that the secondary structure be of sufficient strength so as to not fail prior to the bending of LTV rail. There may also be other structural interactions. Since the loads required to initiate bending of hollow-sectioned structures are generally lower than the axial crush strength, the effect of secondary structures is to cause higher deformation in the LTV rail in an impact with a lighter car. This has been studied here for impacts between two vehicles. The 'base LTV' was selected to represent a 'mid size Sports Utility Vehicle' in the US. A properly designed secondary structure was added to the LTV (Figure 11) to increase the structural engagement between the primary structures of the LTV and the passenger car.

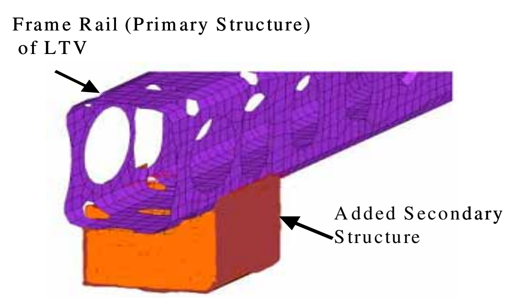

Figure 11: Secondary Structure added to LTV for Increased structural engagement

The impact conditions investigated in the present case (Figure 12) were (a) full frontal crash between the two vehicles, and (b) a 50% offset impact between the vehicles. The LTV and the passenger car

Results from this investigation are shown in Figure 13 for the calculated intrusions at several points in the struck car. For the full frontal impact between the

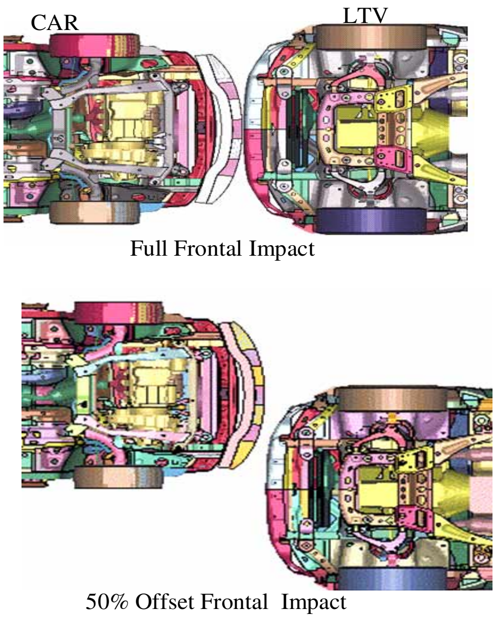

Figure 12: Frontal Impacts between two vehicles

two vehicles, the addition of the secondary structure to LTV leads to reduced intrusion levels in the struck car. Similar conclusions regarding the effect of the added secondary structure are also observed for the

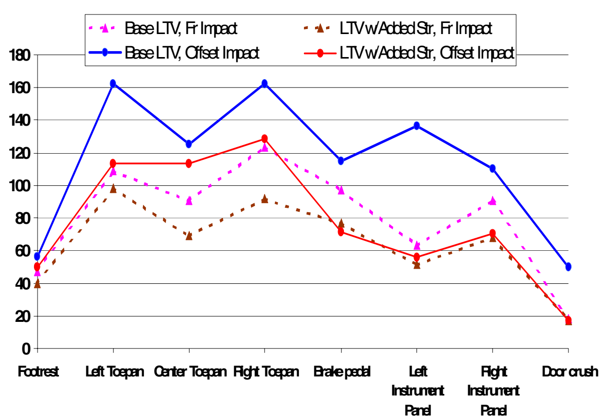

Figure 13: Effect of Added Structure to LTV on passenger car intrusions

the case of offset frontal impact between the two vehicles.

In contrast to the effect observed from lowering LTVs, the effect of adding secondary structure to the LTV is thus found to be preferable in that the intrusion levels in the lighter vehicle are lowered by the added secondary structure.

CONCLUSIONS

This paper discusses the approaches to enhancing geometrical interaction in frontal collision between vehicles. The main points are the following:

1. Evaluation conditions have been identified from. NASS-CDS statistics and these may be considered to be 'field representative' for evaluation of frontal collision compatibility.

2. Forces generated by a vehicle in a barrier test are proportional to the mass of the vehicle and are determined by the various barrier test requirements. These forces and the associated parameters as measured by load cells on a fixed barrier are unlikely to be representative of vehicle-to-vehicle collision compatibility.

3. Lowering the height of larger vehicles to increase their structural interaction with smaller vehicles may not produce desirable results in many cases.

4. The addition of appropriately designed secondary structures to larger vehicles has been shown to increase the structural interaction while reducing the calculated intrusions in the smaller vehicle. This approach needs to be explored further as a possible solution to improving collision compatibility between vehicles.

Further studies are required to assure that the approaches mentioned here improve 'partner protection' without any significant degradation of self-protection in automobiles and thus help achieve the goal of automotive safety of reducing the overall number of injuries and fatalities.

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