When Two Automobiles Collide – Vehicle Occupants' Safety in Side Impacts

In a crash between two vehicles, injuries may occur to the occupants of one or of both vehicles if the speeds are sufficiently high. It is an engineering challenge to design automobiles that provide maximum possible level of occupant protection in all such crashes since the automobiles involved in any crash may be of the many different types and masses. Also, each crash is a unique combination of parameters such as vehicles’ speeds, their direction at the instant of crash as well as the location of points of impact on each vehicle. In addition, the likelihood and the severities of injuries depend on the occupant(s) and the restraint systems used by them. When the task involves analyzing a crash that has already happened between two (or more) automobiles in order to assess the performance of various systems in the vehicles, all of the relevant parameters must be taken into account in reaching any conclusion. Such analyses are therefore highly complex. This report discusses vehicle-to-vehicle crashes with focus on those cases where side impact to the passenger compartment of one of the automobiles is listed as ‘the most harmful event’ in databases such as the National Automotive Sampling System and the Fatality Analysis Reporting System. The dynamics of vehicles and their occupants are examined and the requirements governing automobile designs for safety in such crashes are described.

The term 'collision compatibility' is often used to describe the issue of the safety of automobiles' occupants in vehicle-to-vehicle crashes. Generally, it is assumed that when two vehicles collide, the lighter vehicle will suffer more damage and its occupants will have higher severity of impact. However, crash-related injuries depend not only on the vehicles’ designs but also on other specifics of the crash. Thus, when examining a vehicle design, it cannot be always assumed that strengthening a part of one or the other automobile would have improved the safety of the occupants. This is due to the fact that crashes involve many different combinations of automobile properties and of crash parameters and detailed analyses are essential before deciding on changes to vehicle designs in order to assure that there are no unintended negative consequences.

Magnitude of the problem: For the year 2009, NHTSA data (“Traffic Safety Facts 2009”) state that of the 33,808 traffic-related fatalities and 2,217,000 injuries on the US roadways, automobile occupants accounted for 24,474 fatalities and 2,011,000 injuries. Further analysis shows that more than 77 percent of these injuries to automobile occupants occurred in collisions involving fixed objects or non-fixed objects.
occupants may be attributed to collision with another motor vehicle in transport (being the 'most harmful event' as noted in NHTSA database). As a comparison, crashes with other objects accounted for less than 16 percent of the total number of such injuries. Similar trends are observed when fatality data for occupants of motor vehicles are examined for the 2009 year. The largest fraction (>40 percent) of these fatalities is due to crashes with another moving vehicle whereas a relatively smaller number (~30 percent) are due to impacting objects other than moving vehicles. The overall conclusion is that vehicle-to-vehicle crashes are major contributors to the overall injuries and fatalities to automobiles' occupants.

The principal modes and the directions of impact can also be evaluated from the above-mentioned traffic safety data. Shown in the chart below is the distributions of fatalities for occupants of passenger cars (excluding light-truck-vehicles such as SUVs, pickup trucks and vans). The numbers in these charts include all crashes for passenger cars and not just the vehicle-to-vehicle impacts and side impacts are seen to account for more than 24% of all fatalities in passenger cars during the year 2009.

**Vehicle Design Factors in Side Impacts:**

In side impacts between two vehicles, the impact severity is dependent on the properties of both vehicles as well as on details of the impact configuration – the parts of the impacted vehicle and those in the striking vehicle that contact each other during a crash are the major factors to be considered in any analysis. In this case, the incoming vehicle’s impact is on the structural components such as the

![Vehicle Damage Image]
rocker, the A- and B-pillars and the door of the struck car. Relatively small differences in the impact configuration (such as higher bumper and front structure on the striking car with respect to the struck vehicle) would have led to an entirely different sequence of events.

**Role of Vehicle Structure:** The space available between the door and the vehicle occupant (the driver in case of the impact shown here) is small and therefore only a very small fraction of the crash energy can be dissipated in structural deformation. Therefore, the more significant requirement of the struck vehicle’s structure is to provide force to reduce the impact velocity of the door against the driver.

A graphical representation of the dynamics of the two vehicles is shown in the figure below. For illustrative purposes, it is assumed that the impact is lateral i.e. the two vehicles are moving at 90 degrees with respect to each other at the instant of impact. The striking vehicle has a forward speed V at the instant of impact whereas the struck vehicle has zero velocity in the direction of impact. Due to the impact, the struck vehicle will gradually accelerate in the direction of impact whereas the striking vehicle will decelerate until the two vehicles reach a common velocity. In general, the door of the struck vehicle will deform and, with respect to an observer on board the struck vehicle, it will appear to intrude inwards into the vehicle. The total intrusion of the door (with respect to the struck vehicle cg) equals the area between the curves shown as ‘Struck Door Velocity’ and ‘Struck vehicle CG velocity’ in the above figure. An example of the deformation of the struck vehicles is shown below. The impacting vehicle’s initial contact was with the rocker, the doors and the B-pillar and these show significant amounts of deformation. The contacts of the driver and of the rear passenger were with the interior surface of the front door and the rear door, respectively, as discussed below for the driver.
The impact of the deforming door with the driver’s torso occurs after the initial gap between the driver and the door is eliminated with progressive loading by the impacting automobile. The specific sequence of impacts between the door and the driver’s body (pelvis, chest, shoulders, etc) and the respective impact velocities will depend on the deformed shape of the door at the instant of impact and on the structural properties of the components packaged inside the door. In the present example, the impact with the driver’s pelvis occurs at time ‘pc’ with the relative impact velocity \( V_p \). Impacts of other segments (torso, shoulder, head, etc) also occur with the intruding parts of the vehicle or with airbags when present. An example is shown below from a crash test between two vehicles where the driver’s head strikes the hood of the oncoming vehicle in this crash.

**Airbags for Side Impact Protection:** Presently, the airbags in use for occupant protection in side impacts fall into two categories:

1. Pelvis & Thorax airbags which are mounted in the seat or in the door and when deployed, provide protection for the pelvis and thorax areas during impact from parts of the nearest door. These airbags are generally vented (i.e. they deflate as impact progresses) and their principal functions are to distribute the impact load over a larger area and as well as to reduce the rate of the
occupant's acceleration and impact severity.

2. Curtain airbags are mounted in the roof rail area of the automobile and when deployed, they cover the window openings and keep occupants' heads from impacting objects outside the windows' plane. Since they function in tension to reduce the outboard excursion of the head, they need to be tethered (i.e. anchored) to the pillars (A-, B- and C-pillars) to function properly. The tempered glass in the side windows usually breaks away during the initial part of the impact and the remaining opening then presents the risk of the occupant’s head striking the oncoming vehicle’s hood or other parts unless a restraint such as the curtain airbag is in place.

**Side Impact Sensors for Airbag Deployment:** Both these types of airbag systems must be deployed between the occupant and the impacting object. Therefore, the properties of the airbags and sensors need to be engineered such that the airbags are in place at or before the moment of the occupant impact with the intruding object. The available time for sensing and deploying airbags in lateral impacts is generally much shorter than in frontal crashes due to the fact that the distance between the vehicle’s exterior (outer surface of the door) and the occupant is quite small. In the example shown of a crash at 38 mph, the door strikes the pelvis in less than 15 milliseconds. Therefore, the combined sensing and inflation time available for pelvis airbag must be less than this value. Similar requirements exist for protecting other parts of the occupant's body.

Several essential requirements determine the location and the properties of the sensors for deployment of side airbags (pelvis/thorax and curtain). The sensors should be able to detect crashes reliably and within the available time span. They also must provide sufficient discrimination between deployment conditions and non-deployment crashes. In many vehicles, such sensors are located in a location close to likely impact (such as in the door, or in the B-pillar) as well as in the vehicle interior (near the driver's seat). In the example cited here, the side impact sensors are located in two places – in the B-pillar bottom and
Requirements and Regulations for Occupants’ Safety in Vehicle-to-Vehicle Crashes:
There are no regulatory requirements that specifically govern occupant safety in vehicle-to-vehicle crashes. However, some procedures have been developed for frontal collision compatibility between passenger cars and LTVs and these have been adopted as ‘voluntary standards’ by vehicle manufacturers (see Verma, “Enhanced Vehicle Collision Compatibility - Progress Report of US Technical Workgroup for Front-to-Front Compatibility”, paper 07-0291, Enhanced Safety of Vehicles Conference, 2007). No data from any evaluations of vehicles are available publicly, however (see US Department of Transportation Report DOT HS 811 621, May 2012, “Evaluation of the Enhancing Vehicle-to-Vehicle Crash Compatibility Agreement: Effectiveness of the Primary and Secondary Energy-absorbing Structures on Pickup Trucks and SUVs”).

For side impacts between two vehicles, there are no regulations or voluntary standards and it is assumed that improvements caused by manufacturers competing for better ratings of their vehicle's side impact safety in the two published ratings will also improve occupant safety in vehicle-to-vehicle crashes. These two rating systems for side impact safety are described below. Both of these contain crash tests in which the subject vehicle is impacted by moving deformable barrier (MDB) in specified configurations.

1. Side Impact NCAP Test (NHTSA): This is part of New Car Assessment program run by NHTSA and consists of two tests whose scores are combined to calculate the ‘star’ rating for the vehicle. The first test represents an ‘intersection’ type collision with a deformable barrier of approximately 1367 kg moving at 62.2 km/h and impacting a stationary test vehicle. The barrier is crabbed (i.e. the wheels on the barrier are turned) to
simulate a relative motion between two vehicles. The driver is a fiftieth percentile male anthropomorphic test device (ATD) and the rear passenger is a fifth percentile female ATD. Since the MDB has a crushable face and may perhaps be assumed to simulate the front end of an ‘average’ US car, this test may be considered one approximation of a vehicle-to-vehicle crash test.

The second part of Side NCAP program is a pole test - a 32.2 km/h, 75 degrees oblique impact of the test vehicle into a fixed pole with a fifth percentile female ATD in the front seat.

Measurements in these NCAP tests are taken on the occupants (ATDs) in the vehicle and are combined into estimates of 'relative risk' of injury for each seating position. Vehicle

![Post-crash - Driver - NCAP MDB Test](image1)

![Post-crash- Driver -NCAP Side Pole Test](image2)

safety ratings (ranging from 1 star to 5 stars) for the front and the rear seat are assigned based on the 'relative risk' calculations according to NHTSA formulae. An overall rating of side impact safety for the vehicle is also calculated and published.

2. IIHS Side Impact Ratings Test: This consists of a 1500 kg MDB impacting a stationary test vehicle perpendicularly at 50 km/h. Measurements are taken of the vehicle deformations inside the passenger compartments as well of the dynamic responses of the front driver and the rear passenger ATD. As will be noted, the IIHS MDB test mass, its impact speed, location of impact and the properties of the deformable barrier face are different than those of the NCAP tests by NHTSA. The mass (heavier than NCAP MDB) and the impact height of the IIHS MDB may be thought of as an impact by a light-truck vehicle (LTV) into the test vehicle.
The ratings of the vehicle’s side impact safety are calculated differently by IIHS than the NCAP ratings. For each of the four categories (Good-Acceptable-Marginal-Poor), there are 'corridors of performance' established by IIHS. The measured vehicle deformation is compared to the pre-established corridors of structural performance and the vehicle's structure is assigned one of the above-mentioned ratings. Similarly, the measured responses of the driver and the rear passenger (ATDs) are compared to the respective corridors of performance and ratings are published in terms of protection of Head/Neck, Torso and Pelvis/Leg in the vehicle. In addition, a 'Head Protection' rating is published based on the observed performance of curtain airbags in these tests.

In summary, vehicle-to-vehicle side impacts are a significant part of the traffic safety equation and a large number of injuries and fatalities to automobile occupants are caused by such crashes. An observation may be made from the first two photographs on the first page of this report: the post-crash identification of the most harmful event during an accident involving two (or more) vehicles and the subsequent evaluation of the effectiveness of vehicle structure and airbags requires that the dynamics of side impacts be comprehended and be included in examining the complete sequence of impacts both external and internal to the vehicles.