IIHS Side Impact Parametric Study using LS-DYNA®

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Abstract

Side impact crashes are the second most common reason for vehicle passenger deaths after frontal crashes. In 2003, the Insurance Institute for Highway Safety (IIHS) introduced its side impact crash test using a Moving Deformable Barrier (MDB) to encourage manufacturers to implement safety improvements, including side airbag coverage and stronger side structures, in most vehicle models. While many vehicles were rated poor in the beginning of testing in 2005, most of the vehicles were rated good in 2015. Improved IIHS ratings are associated with a more than 30% reduction in passenger deaths in multiple-vehicle side impact crashes. Of the remaining fatal side impact crashes, the majority are occurring at a more forward impact location and higher severity compared to the IIHS test. For this reason, the IIHS is planning a series of full-scale tests to evaluate the effect of different impacting vehicles and test setups with respect to today's test protocol. For reducing costly, time-consuming, and complex full-scale testing, finite element (FE) simulations play an important role and are successfully used in vehicle safety research and development. Therefore, the aim of this study was to complement the ongoing IIHS full-scale side impact crash test study with FE simulations. This study features a validated FE model of a 2015 midsize sedan as the target vehicle in the IIHS test configuration. The parametric study varied bullet vehicle characteristics: bullet vehicle velocity (50 km/h vs. 60 km/h), bullet vehicle mass, and impact location relative to the target vehicle's occupant compartment. Available bullet vehicle models represent small and midsize passenger cars, sport utility vehicles (SUVs), and pickups in addition to a model of the standard IIHS MDB. Impact severity of the target vehicle was assessed from measures of maximum lateral B-pillar intrusion relative to the driver-seat centerline, used for calculating IIHS structural ratings, B-pillar peak lateral velocity, and maximum crush of the door at chest and pelvic height. In the standard IIHS configuration, the MDB was more severe than the small and midsize cars, but less severe than the midsize SUV or pickup. Aspects of the MDB's geometry make its impact pattern more SUV-like, but a lower mass decreases the severity. Increasing the MDB mass to 2,000 kg resulted in structural intrusions more similar to the midsize SUV. At the higher velocity of 60 km/h, the bullet vehicles produced structural intrusions ranging from good to poor ratings. Either a higher mass striking vehicle or greater impact speed can be used to create a more severe impact configuration, with the higher impact speed having a greater effect. An evaluation of more forward impact locations indicated that the most structurally challenging impact location was at the current IIHS configuration, not farther forward. This parametric study provided insights into the types of crash configuration changes IIHS may consider when conducting full-scale research tests developing a higher severity side impact test to address real-world injured occupants in good-rated vehicles.

Introduction

Side impact crashes are the second most common reason for vehicle passenger deaths after frontal crashes. In 2015, 6,598 occupants died in frontal multiple-vehicle crashes in the US compared to 3,800 in side impacts [1]. Most passenger cars have substantial crumble zones in the front and rear of the car, but relatively less space to absorb impact forces on the side, making it a vulnerable area for occupants [2, 3]. To reduce the number of passenger deaths occurring in accidents, several crash tests have been established to ensure safety standards of cars and encourage automobile manufacturers to make safety improvements. The Federal Motor Vehicle Safety Standard (FMVSS) 214 Side Impact Protection was enhanced in 1990. In 1997, the National Highway Traffic Safety Administration (NHTSA) introduced a side impact crash test with a Moving Deformable Barrier (MDB), representing the front end of a car from the early 1980s, within the New Car Assessment Program (NCAP) [5, 8]. In this test, a MDB with a mass of 1,368 kg hits a stationary vehicle at a 90° angle with a crabbed wheel angle of 27°. The velocity of the MDB is 61 km/h and simulates a bullet vehicle moving at 55km/h hitting the target vehicle moving at 27 km/h. The deformable part of the barrier is 838 mm high, measured from the ground.

Since the development of the NHTSA MDB side impact crash test, the vehicle fleet has changed dramatically, especially due to the increasing number of sport utility vehicles (SUVs) and pickups, as shown in Figure 1. While about 80% of vehicles were sedans in 1980, about 50% of vehicles were a SUVs or pickups in 2003 and 2015. [9].

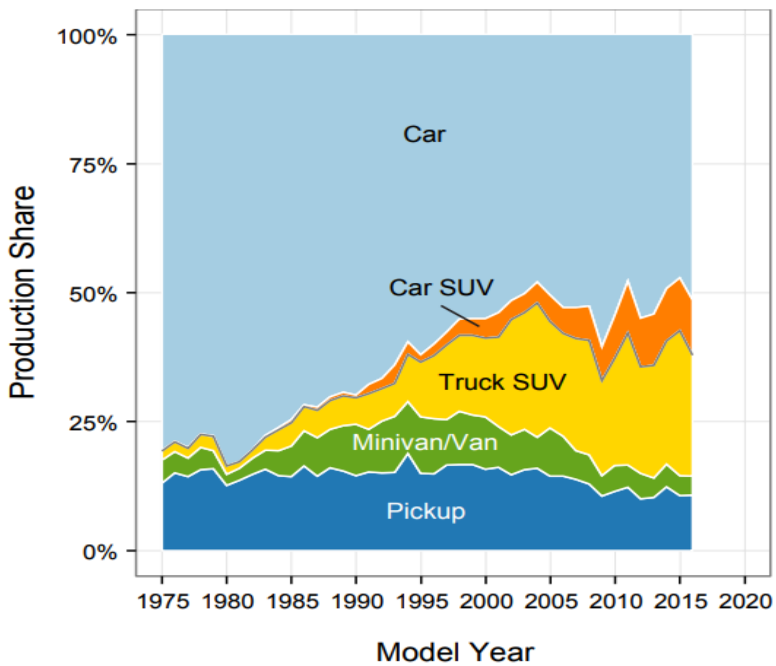


Figure 1. Light vehicle market share in the US [9]

As there is a much greater risk of head injuries from impacts with taller bullet vehicles, the Insurance Institute for Highway Safety (IIHS) decided to start its own side impact crash test in 2003 with a modified MDB [10]. In the IIHS side impact crash test, the modified MDB hits the driver side of a stationary target vehicle at 50 km/h [11, 12]. The IIHS MDB has the geometry, shape, and height of a typical midsize SUV [4, 5]. The mass of the IIHS MDB (1,500 kg) is comparable to a small SUV or midsize car [4]. The deformable part of the barrier is 1,138 mm high, measured from the ground. The IIHS side impact rating is based on different aspects, including injury risk assessment, restraint system, and structural performance [5].

The introduction of the side impact crash test by IIHS resulted in improved curtain airbags, side airbags, and stronger side structures in most vehicle models. While nearly all tested vehicles were rated poor in the beginning of the testing, 97% of the vehicle models were rated good in 2016 [6]. The number of passenger deaths in multiple-vehicle side impact crashes was reduced from 6,097 in 2005 to 3,800 in 2015 according to data from the U.S. Department of Transportation's Fatality Analysis Reporting System (FARS) and The Polk Company's National Vehicle Population Profile [1, 7], as shown in Figure 2. This significant reduction of fatalities in side crashes can be attributed to the countermeasures triggered by the IIHS test. The number of fatalities for occupants travelling in a sedan is significantly higher than the number of fatalities for occupants travelling in a SUV or pickup due to the lower seating position.

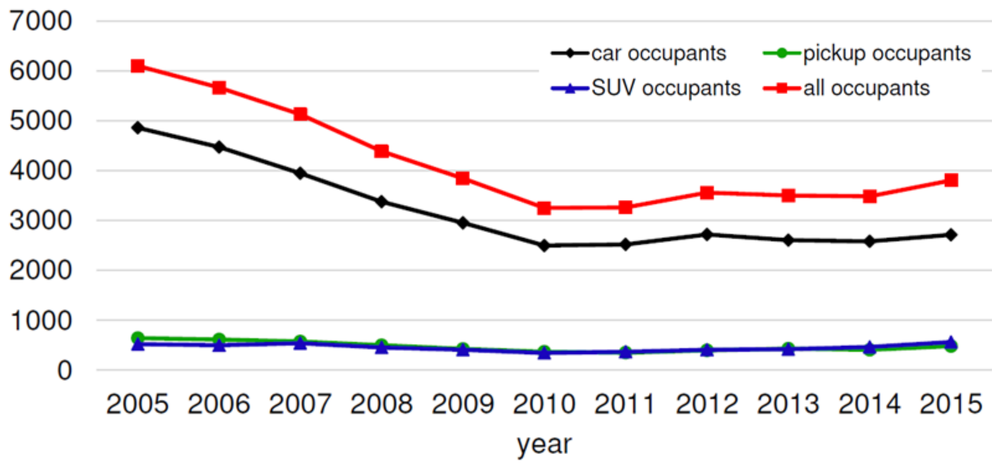


Figure 2. Passenger deaths in multiple-vehicle side impact crashes, 2005–2015

Although the number of passenger deaths has been reduced in recent years, many of the current accidents with fatal injuries occur under different circumstances than those in the IIHS test. A more forward impact location and increased velocity compared to the IIHS test are the most common reasons for side impact crash deaths [4]. This shows the possible need to change the setup of the actual test to obtain further improvement in side crash safety. Additionally, since the development of the barrier in 2003, the proportions of the vehicles and the composition of the vehicle fleet have been changing. In respect to the changing size and mass of current models, the following questions arise: how representative is the MDB for today's vehicle fleet, and would modifications to the MDB improve vehicle safety? For this reason, since 2015, the IIHS has been planning different full-scale tests to evaluate the effect of different impacting vehicles and test setups with respect to today's test protocol [4].

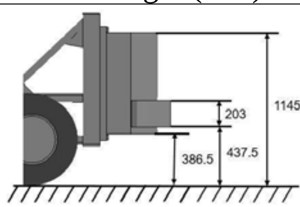
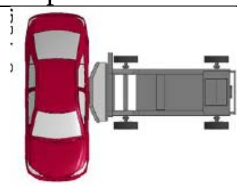
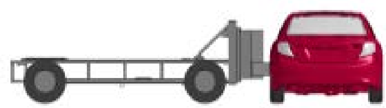
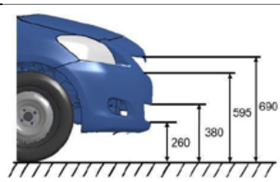
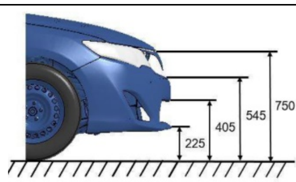
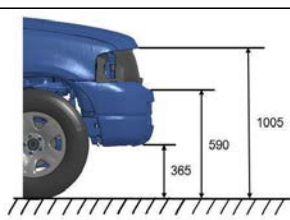
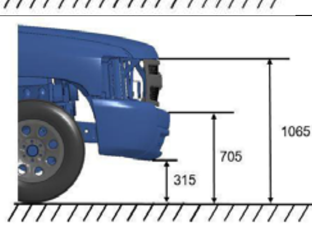
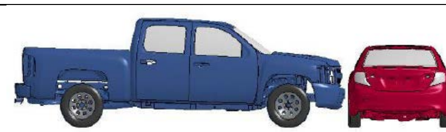
For examining the effect of an increased severity and different impact locations, the IIHS conducted tests with the MDB striking a 2015 Honda Fit using impact velocities of 50 km/h and 60 km/h [4]. It was found that a more severe test using a higher impact velocity may have a greater effect on improving the test configuration with respect to real-world conditions than changing the impact location, which did not result in a higher intrusion. It was discussed that potential changes in the vehicle restraint system due to a more severe impact configuration may reduce injury potential for more severe crashes, but may also affect the injury risk for lower speed impact.

For reducing costly, time-consuming, and complex full-scale testing, finite element (FE) simulations play an important role and are successfully used in vehicle safety research and development. Therefore, the aim of this study was to complement the ongoing full-scale studies by the IIHS with a computational parametric study. A previously validated model of a 2015 Toyota Camry sedan was chosen as the target vehicle. Different striking vehicles and barriers, such as small and midsize passenger cars, SUVs, and pickups, were used as bullet vehicles. First, the effects of an increased severity with higher velocities were examined. Second, increased masses of the striking vehicles were evaluated. Third, the effects of different, more forward impact locations were analyzed.

Methods

For the numerical calculations of the side impact behavior with different barriers, vehicles, velocities, masses, and impact locations, the FE analysis software LS-DYNA was used. The FE vehicle models were developed and validated by a team from the Center for Collision Safety and Analysis (CCSA) at George Mason University. In Table 1, the vehicle models used for the parametric study are shown and described with their respective vehicle height and mass. In addition to the 1,500 kg IIHS MDB, the following vehicles were evaluated: a 1,250 kg, 2010 Toyota Yaris sedan; a 2,250 kg, 2003 Ford Explorer SUV; and a 2,250 kg, 2007 Chevrolet Silverado pickup truck. For the post-processing, the analysis of the binary files, and the evaluation of the calculated data and the visualization, the post-processors Animator, LS-PrePost®, and HyperView were used. A FE model of a 2015 Toyota Camry was previously validated for a variety of impact configurations [13]. It correlates well with full-scale crash test results for different impact conditions. For example, the distance between the B-pillar and the seat centerline in the IIHS side impact test was 13.2 cm in the simulation compared to 12.5 cm in the full-scale test, both representing a good structural rating.

Table 1. Finite element models

Model	Mass (kg)	Vehicle height (mm)	Top view	Side View
MDB	1,500			
2010 Toyota Yaris	1,250			
2015 Toyota Camry*	1,530			
2003 Ford Explorer	2,250			
2007 Chevrolet Silverado	2,250			

*Also used as the target vehicle for all parametric studies
kg=kilograms
mm=millimeters

The IIHS side impact test setup is shown in Figure 3. The MDB, used by the IIHS since 2003, has a deformable, honeycomb, aluminum face. It has the geometry, shape, and height of a typical midsize SUV [5]. Its mass of 1500 kg, however, is more comparable to a small SUV or midsize car [4]. The overall rating for the IIHS side impact test is based on two aspects: vehicle structural deformation and dummy occupant performance from two Side Impact Dummies (SID-IIs). These dummies represent a 5th percentile female occupant installed in both the driver and left rear passenger seats [5]. Sensor measures from the head, neck, chest, abdomen, pelvis, and legs were recorded and related to real-world injury risks, and dummy kinematics and resulting contact points assessed head and chest protection for occupants. This study focused on the structural performance of the target vehicle.

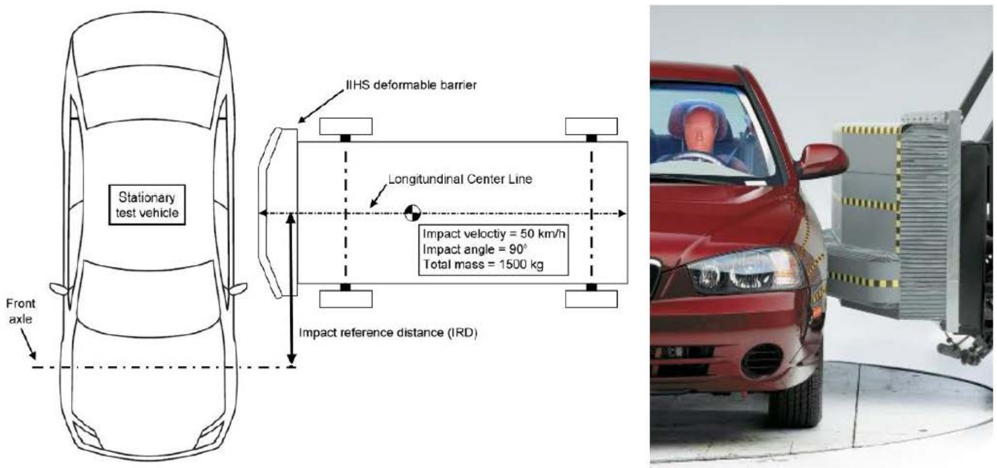


Figure 3. IIHS side impact configuration

Vehicle structural performance is primarily based on resistance of the B-pillar against intrusion into the occupant compartment. This study calculates B-pillar intrusion relative to the vehicle's seat centerline as stated in the IIHS rating protocol [11]. Measures of B-pillar intrusion are then applied to the official structural rating system shown in Figure 4, with categories of good, acceptable, marginal, and poor [5, 10, 11].

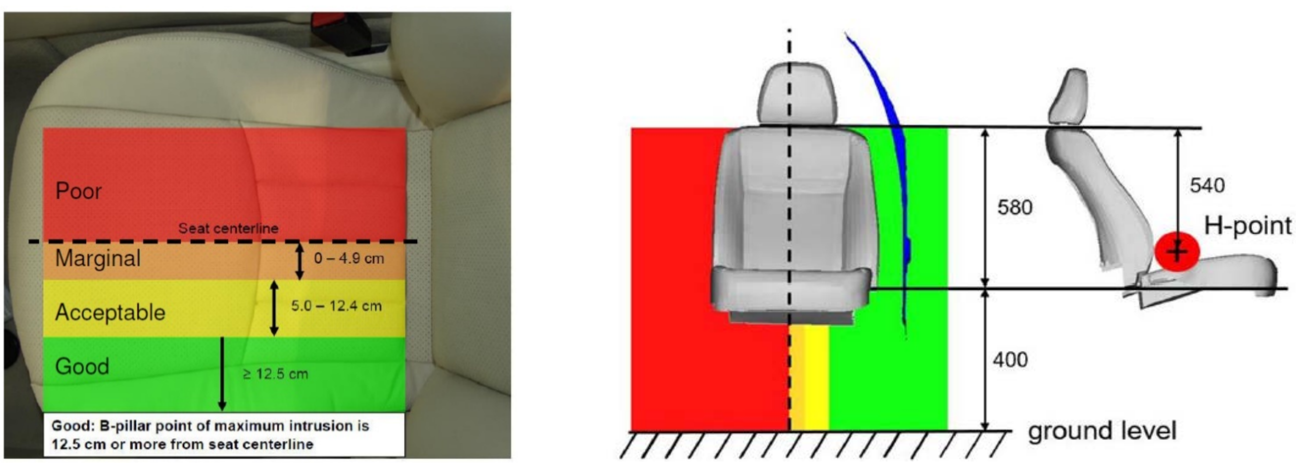


Figure 4. IIHS structural performance criteria, measured at the B-pillar

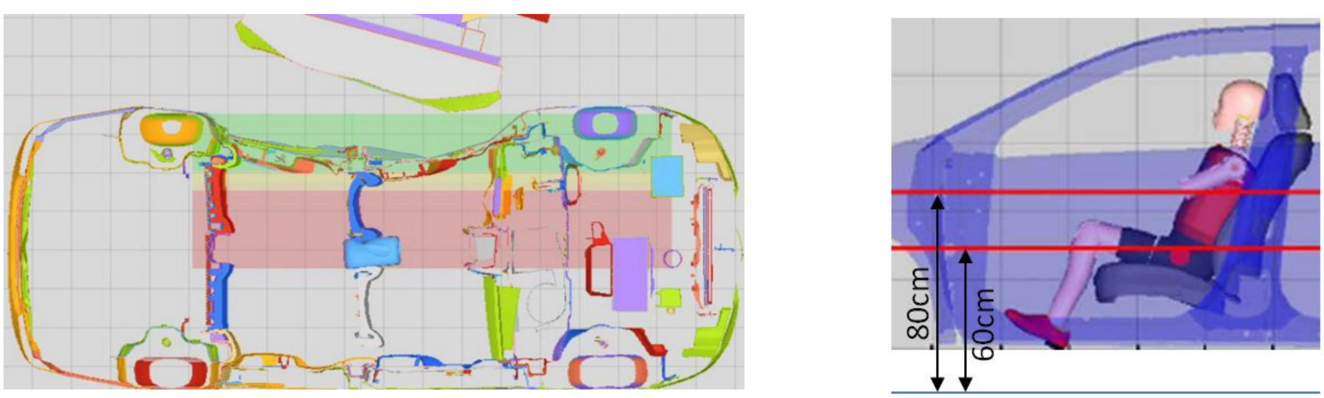
The absolute velocity of the B-pillar was also measured. High B-pillar structural velocity is associated with higher injury risk, as there is less space for torso airbag deployment early in the crash. The location at chest height was chosen because it is a more representative and comparable component of the whole vehicle performance compared to door structures.

Simulations also examined the role of impact location on occupant compartment intrusions, based on research from IIHS suggesting that higher severity and forward impact locations were the most common injury-causing side crash configuration [4]. Four different impact locations were simulated as shown in Figure 5. The baseline simulation, where the MDB or bullet vehicle hits the stationary target vehicle at the B-pillar (i.e., a distance of 159 cm behind the front axle), was used as the most rearward impact location (Figure 5a). Positioning the MDB centerline 24 cm forward of the front axle of the Toyota Camry was used as the most forward impact location, as shown in Figure 5d. This case was derived from a crash reconstruction study conducted by IIHS [14] and represents a side impact crash into the front end of a vehicle. In addition, an impact location 31 cm rearward to the front axle, representing a side impact crash into the A-pillar (Figure 5c) and an impact location 95 cm rearward of the front axle, representing an impact into the front door (Figure 5b), were evaluated.

(a) B-pillar (b) Front door (c) A-pillar (d) Front axle

Figure 5. Evaluation of different impact locations

Additional intrusion measurements were taken along a horizontal line of the struck side of the car at pelvis and chest height, as shown in Figure 6a. Values at mid-door heights of 60 cm and 80 cm above the ground were compared for each crash configuration. Sixty centimeters above ground represents the height of the front-seat passenger's pelvis and 80 cm is around the chest height, as shown in Figure 6b.



(a) Top cross section view (b) Reference lines at chest and pelvis height

Figure 6. Example of structural intrusions measured horizontally at door outer

Results

Bullet vehicles and impact velocity

Simulation results for B-pillar intrusion relative to seat centerline of the target 2015 Toyota Camry using different bullet vehicles at both 50 km/h and 60 km/h striking velocities are shown in Table 2. IIHS structural rating categories based on the maximum B-pillar intrusions are also included in Table 2, as colored cells.

Table 2. IIHS B-pillar distance to seat centerline for different bullet vehicles and impact velocities

Bullet vehicle impact velocity (km/h)	B-pillar distance to seat centerline for each bullet vehicle striking the Camry (cm)				
	MDB	2010 Toyota Yaris (small sedan)	2015 Toyota Camry (midsize sedan)	2003 Ford Explorer (SUV)	2007 Chevrolet Silverado (pickup)
50	13.2	23.0	21.3	11.0	7.5
60	7.2	16.5	15.3	2.6	-1.0

Legend for IIHS structural ratings: Good Acceptable Marginal Poor
cm=centimeters
km/h=kilometers per hour

The baseline configuration, a 1,500 kg MDB striking the Camry at 50 km/h, had a good structural rating with a 13.2 cm remaining distance between the B-pillar to seat centerline. Different bullet vehicles at the standard 50 km/h impact velocity produced a range of structural performance for the target Camry. Replacing the MDB with a 2010 Toyota Yaris small sedan (1250 kg) and a 2015 Toyota Camry midsize sedan (1530 kg) as the bullet vehicle showed a good structural rating, with an increased occupant survival space of 23 cm and 21.3 cm remaining distance between the B-pillar and the seat centerline, respectively. Replacing the MDB with a 2003 Explorer SUV (2250 kg) and a 2007 Silverado pickup (2250 kg) as the bullet vehicle resulted in less survival space than the MDB configuration and an acceptable structural rating, with 11 cm and 7.5 cm remaining distance between the B-pillar and the seat centerline, respectively.

Increasing the impact speed from 50 km/h to 60 km/h reduced the occupant survival space in all bullet vehicle configurations, with structural ratings ranging from good to poor. The Yaris and Camry bullet vehicle configurations still had good structural ratings, but more intruded B-pillars, measuring 16.5 cm and 15.3 cm, respectively. The MDB configuration had a lower structural rating from good to acceptable, with 13.2 cm and 7.2 cm, respectively. The Explorer bullet vehicle’s occupant compartment space decreased from 11 cm to 2.6 cm, which represents a marginal structural rating. The worst Camry performance was with the Silverado pickup bullet vehicle, receiving a poor structural rating from a B-pillar to centerline measurement of -1 cm. The negative number indicates that the B-pillar, as measured postcrash, intruded further than the seat center line.

The absolute velocity of the B-pillar, measured at chest height (about 80 cm above ground) are shown in Table 3. The baseline simulation showed a maximum B-pillar velocity of 9.5 m/s. B-pillar velocities were lower for the Yaris and Camry bullet vehicles and higher for the Explorer and Silverado vehicles. In the higher impact speed scenarios, the B-pillar velocity increased by about 2 m/s for all vehicles.

Table 3. Maximum B-pillar velocity for different bullet vehicles and impact velocities

Bullet vehicle impact velocity		Maximum B-pillar velocity for bullet vehicles striking the Camry (m/s)				
km/h	m/s	MDB	2010 Toyota Yaris (small sedan)	2015 Toyota Camry (midsize sedan)	2003 Ford Explorer (SUV)	2007 Chevrolet Silverado (pickup)
50	13.9	9.5	8.4	9.1	10.8	10.2
60	16.7	11.9	10.1	10.8	12.4	12.3

km/h=kilometers per hour
m/s=meters per second

Bullet vehicle mass

The effect of increasing the MDB mass by 500 kg compared to the baseline configuration is shown in Table 4. The target Camry distance to seat centerline was reduced by 2.1 cm to 11.1 cm, which is an acceptable structural rating, compared to the baseline good rating.

Table 4. IIHS B-pillar distance to seat centerline for different mass MDB tests

Mass of MDB (kg)	Distance to seat centerline (cm)
1,500	13.2
2,000	11.1

Legend for IIHS structural ratings: Good Acceptable
cm=centimeters
kg=kilograms

Simulations were run varying the mass of the Silverado pickup from 2050–2550 kg in 100 kg increments at the standard 50 km/h configuration. B-pillar structural measures are shown in Table 5. All B-pillar to seat centerline measurements would result in acceptable ratings for the target Camry, but B-pillar to centerline distance varied from 8.5–6.2 cm, with the 500 kg increase associated with a 2.3 cm reduction in survival space.

Table 5. IIHS B-pillar distance to seat centerline for different mass Silverado tests

Mass of Silverado (kg)	Distance to seat centerline (cm)
2,050	8.5
2,250	7.6
2,350	7.1
2,450	6.7
2,550	6.2

Legend for IIHS structural ratings: Acceptable
cm=centimeters
kg=kilograms

Impact locations

Simulations with the baseline MDB conducted with four different impact locations, shown in Table 6, indicated that more forward impacts were less intrusive into the driver's occupant compartment than the baseline standard IIHS test, which is based on the B-pillar and door intrusion relative to the seat centerline. The greatest decrease in intrusion is between the standard B-pillar location and the front door, while A-pillar and front axle locations are very similar in measured occupant compartment intrusion.

Table 6. Distance to seat centerline using the MDB as bullet vehicle at different impact locations

	Intrusion measurement locations		
Impact location on Toyota Camry	B-Pillar inner (cm)	Door outer at pelvis height (cm)	Door outer at thorax height (cm)
B-Pillar (IIHS standard)	13	21	23
Front door	22	26	27
A-pillar	36	32	31
Front axle	36	36	32

cm=centimeters

Simulations examining the role of impact location were also conducted with the Silverado bullet vehicle at the standard 50 km/h impact velocity. Measures of occupant survival space at the B-pillar and intruding door are shown in Table 7. This is similar to the trend in MDB location variations, where the standard IIHS impact location measured the highest occupant compartment intrusion, while the A-pillar and front axle locations indicated low intrusions at the occupant compartment.

Table 7. Distance to seat centerline using the Silverado as bullet vehicle at different impact locations

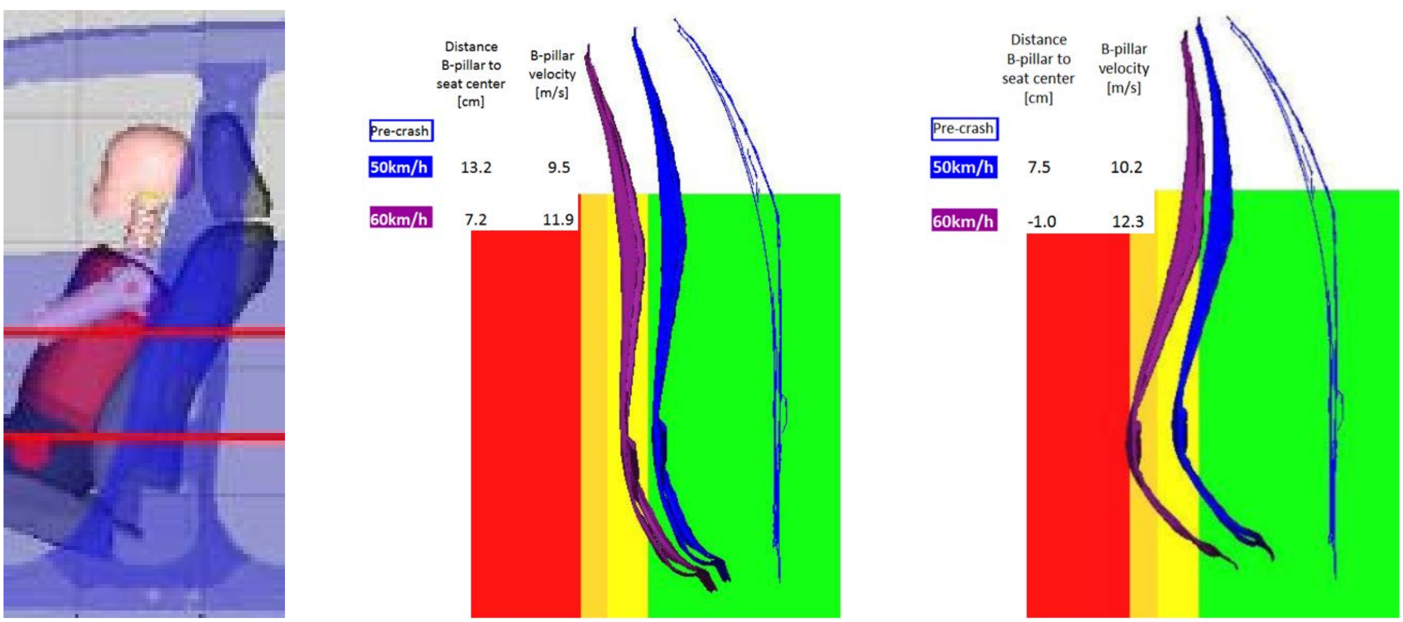
Impact location on Toyota Camry	Intrusion measurement locations		
	B-Pillar inner (cm)	Door outer at pelvis height (cm)	Door outer at thorax height (cm)
B-Pillar (IIHS standard)	8	12	15
Front door	13	18	24
A-pillar	35	26	27
Front axle	36	35	34

cm=centimeters

Discussion

Compared to the different sizes and classes of vehicles used in this study, the IIHS MDB produced a more severe impact than the two sedans, but a less severe impact than the SUV and pickup. The MDB produced higher intrusions than the small and midsize sedans, 9.8 cm and 8.1 cm additional B-pillar intrusion, respectively, because the contour, height, and ground clearance of the MDB is more representative of SUVs and pickups. The MDB produced less intrusion than the SUV and pickup, 2.2 cm and 5.7 cm less, respectively, because its 1,500 kg mass is more comparable to the evaluated sedans (1250 kg for the small sedan and 1530 kg for the midsize sedan) than the 2,250 kg SUV and pickup. The comparison of B-pillar velocity confirmed these same trends. When the MDB was simulated with 2,000 kg, which more closely represents a SUV mass, the B-pillar to seat centerline value approached the Explorer, 11.1 cm and 11.0 cm, respectively. From these simulations, the recommended method for changing the IIHS test configuration to be more representative of SUV-to-car crashes would be to increase the MDB mass.

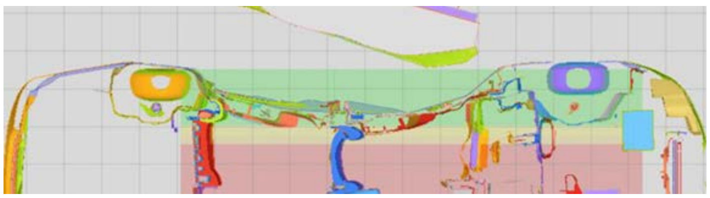
Either a higher mass bullet vehicle or greater impact speed can be used to create a more severe impact configuration. Increasing impact velocity from 50 km/h to 60 km/h had a more significant effect on the structural deformation than increasing the bullet vehicle mass, since the kinetic energy is proportional to the square of the impact velocity while only proportional to the mass. An impact velocity increase of 20% from 50km/h to 60km/h with the IIHS MDB produced a 6 cm additional intrusion, while a 33% increase in MDB mass from 1500 kg to 2000 kg resulted in only a 2 cm greater intrusion. This observation was also true for full vehicle models, where the Silverado at the higher impact speed produced 8.5 cm greater intrusion to the Camry, while the 500 kg variation in mass only resulted in a range of 2.3 cm difference in intrusion. Additionally, higher impact velocities produced greater B-pillar velocities measured at chest height, which may contribute to higher chest injury risks, as torso airbags may not have adequate time and space to provide protection. Despite similar B-pillar to seat centerline measurements between the 50 km/h Silverado pickup and the standard MDB at a higher velocity of 60 km/h, 7.5 cm and 7.2 cm, respectively, the higher velocity MDB test produces a higher B-pillar velocity, 11.9m/s versus 10.2m/s (Figure 7). These simulations indicate that increasing both MDB impact velocity and MDB mass in the IIHS test would produce the greatest severity test, but of the two factors, the more significant one is impact velocity.



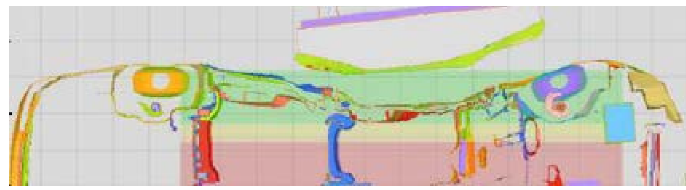
(a) Reference lines (b) MDB into Camry (c) Silverado into Camry

Figure 7. B-pillar deformation and velocity using different bullet vehicles and impact speeds

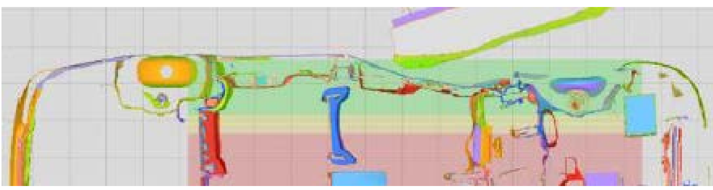
Evaluation of more forward impact locations showed that the most structurally challenging configuration, with the highest intrusions into the occupant compartment, is the current IIHS configuration (Figure 8a). The barrier primarily loads the B-pillar and doors, mostly avoiding contact with the A- and C-pillars. This concentrates energy absorption on the B-pillar and lower sill structures and for most sedans, the MDB impacts above the vehicle side sill, requiring all energy to be absorbed by the B-pillar and door structures. The second most severe impact location is where the barrier is centered at the front door, as shown in Figure 8b. The barrier still loads the B-pillar but also engages the stiffer rocker-pillar area of the A-pillar and frontal cross beam members. While this configuration produces less intrusion at the occupant's seat, it may produce challenges for airbag deployment and occupant interaction may be affected by localized intrusion of the front door. For the two more forward impact locations of the A-pillar (Figure 8c) and front axle (Figure 8d) impact locations, the barrier primarily loads the stiffer areas around the rocker with cross members and firewall, with little intrusion in the occupant compartment. These findings are considered applicable to variation in impact locations farther rearward than the standard IIHS. Locations that interact with the stiff areas at the C-pillar, rear-seat cross member, and rear axle are expected to indicate lower occupant compartment intrusions than the standard IIHS location. These simulations show that keeping the impact location at the standard IIHS location will result in the most severe occupant compartment intrusions for the driver compared to shifting the impact farther forward or rearward.



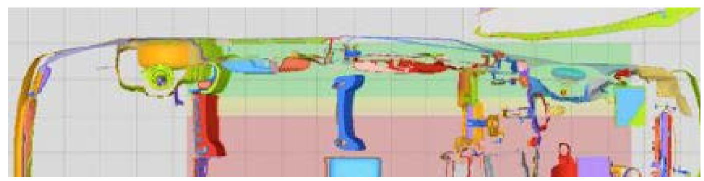
(a) B-Pillar (current IIHS position)



(b) Door



(c) A-Pillar



(d) Front Axle

Figure 8. Cross section views for different MDB impact locations

This study simulated a large range of parameters to evaluate for increasing the severity of the IIHS side impact crash test to address real-world injuries in side impact crashes of good-rated vehicles. One limitation of the study is the available vehicle models. Both the struck vehicle, a 2015 Toyota Camry, and the range of bullet vehicles were chosen based on the availability of validated full vehicle FE models at CCSA at George Mason University. Additional desired work includes simulating a small SUV into the Camry. This will show how the MDB relates to a SUV with similar geometry and a mass closer to the MDB than the heavier midsize Ford Explorer. Also, another study would be useful that focuses on an SUV or a pickup as the struck vehicle to add to the understanding of how different sized and shaped vehicles are affected by the same test parameters. Another aspect of the IIHS side impact test rating that was not addressed in this research is integrated occupant simulations, evaluating the effect of different crash configurations on dummy injury risk and restraint system performance. Future research may also include full-scale testing before a new higher severity crash configuration can be recommended.

Conclusion

Since the introduction of the IIHS side impact configuration in 2003, side impact fatalities and severe injuries have been reduced due to improved side structures and restraint systems. Serious and fatal injuries are still occurring in vehicles with good IIHS side impact ratings. The most important factors in injury-causing crashes were impacts with a higher speed than in the IIHS configuration and with a more forward impact point.

In this study, validated FE models were used to evaluate the effect of different parameters on the structural performance in a side impact configuration, indicating what types of IIHS test modifications will address the remaining real-world injuries. A 2015 Toyota Camry midsize sedan was used as a target vehicle, since most injuries occur in cars with a lower and more vulnerable seating position, especially when struck by a SUV.

Models of the MDB, small and midsize sedans, a SUV, and a pickup truck with different velocities and masses were used as bullet vehicles. The resulting intrusions measured at the B-pillar of the target vehicle were compared using the IIHS structural rating scheme. Additionally, more forward impact locations were analyzed using the MDB and the model of the pickup truck as bullet vehicles. Increasing the velocity from 50 km/h to 60 km/h would have a more significant effect with respect to impact severity than increasing the mass. MDB and other bullet vehicles showed about 6 cm higher intrusions and about 2 m/s higher B-pillar velocities when the impact speed was increased by 20%. Structural intrusion, measured at the B-pillar and door, showed the highest severity for the current impact location at the B-pillar. More forward impact locations resulted in lower occupant compartment intrusion due to the bullet vehicle loading the stiffer structures around the front axle, A-pillar, and frontal cross beam. Additional research, including full-scale testing and integrated occupant vehicle simulations, will be needed to evaluate the effect of a side impact test with an increased severity on injury risk and restraint system performance, and to develop a test procedure that would potentially contribute to further reductions of serious injuries and fatalities in side crashes.

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