# INVESTIGATING POTENTIAL CHANGES TO THE IIHS SIDE IMPACT CRASHWORTHINESS EVALUATION PROGRAM

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Paper Number 17-0083

## ABSTRACT

Ninety-seven percent of 2016 model year vehicles evaluated in the Insurance Institute for Highway Safety (IIHS) side impact test received good ratings. Good-rated vehicles have lower side impact fatality rates than other vehicles, but additional crashworthiness improvements may be possible. In a previous analysis of real-world cases, most serious injuries in good-rated vehicles resulted from crashes with impacts centered farther forward than the IIHS configuration and/or crashes that produced greater intrusion at the occupant location. The current study examines whether the occurrence of real-world injury in a different crash configuration can be identified in the laboratory, how injury risk in such a configuration compares to the current IIHS test, and whether current vehicle designs already offer improvements over the vehicles in the real-world cases (median model year was 2007).

A NASS-CDS crash of a 2007 Honda Fit struck by a 1999 Toyota Camry was chosen for laboratory replication. The nearside impact location was centered forward of the front axle and the 75-year-old driver occupant sustained fatal thoracic injuries. A WorldSID-50$^{th}$ percentile male ATD with a RibEye deflection measurement system was used to record injury measures, and these were compared to measures from four additional tests. In the first, the case vehicle was struck by the IIHS MDB at the standard test location and speed (50 km/h). In the second, the reconstruction test was repeated using a 2015 Honda Fit as the struck vehicle. The third and fourth tests involved the IIHS MDB impacting the 2015 Fit at the standard location at 50 km/h and 60 km/h, respectively.

The reconstruction test of the 2007 Fit produced structural damage comparable to the real-world case. Compared to the standard IIHS test, the torso airbag deployment time was similar, the ATD loading was later due to the longer crash pulse, and there was less intrusion at the occupant position. Despite these differences, the injury measures recorded by the ATD were broadly similar and indicated elevated injury risks consistent with the observed real-world injuries. Compared to the 2007 model, the 2015 Fit produced much lower intrusion and injury measures in the reconstruction and standard IIHS tests. The greatest injury risks in all five tests were recorded when the 2015 Fit was impacted by the IIHS MDB at 60 km/h.

The loading and intrusion patterns in the real-world reconstruction differed from the standard IIHS test, but did not translate to large differences in predicted injury risks. Furthermore, tests of the newest generation Fit suggest some of the risk factors observed in the real-world crash have been mitigated by more recent crashworthiness improvements. However, the benefit of these improvements was more than offset by the increased severity of a 60 km/h test.

Simply increasing the severity of the current IIHS test may be more effective at producing additional real-world improvements than a test configuration that has a different impact location but does not result in increased intrusion. However, more research would be needed to ensure that a higher severity test does not promote countermeasures with reduced protection in less severe crashes.

## INTRODUCTION

The Insurance Institute for Highway Safety (IIHS) began its side impact crashworthiness evaluation (SICE) program in 2003. In the SICE test, the stationary tested vehicle is struck on the left side by a 1,500 kg moving deformable barrier (MDB) at 50 km/h. One of four ratings is assigned based on a combination of structural performance, injury measures recorded on dummies in the driver and left rear passenger seat, and observations of the restraint system and kinematics of the anthropometric test device (ATD). Of the 2004-06 models tested in the program, 27 percent received the highest rating of good, while 41 percent received the lowest rating of poor. For 2014-17 models, these proportions had changed to 93 and 1 percent, respectively (Figure 1). Based on analysis of real-world side impacts, Teoh and Lund [1] found that when a left-side crash occurred, drivers of good-rated vehicles were 70 percent less likely to die than drivers of poor-rated vehicles. When combined with other changes in the fleet, driver behavior, and environmental factors, improved crashworthiness has helped contribute to a decline in side-impact driver fatality rates in 1-3 year old vehicles from 22 per million in 2005 to 5 per million in 2015 [2].

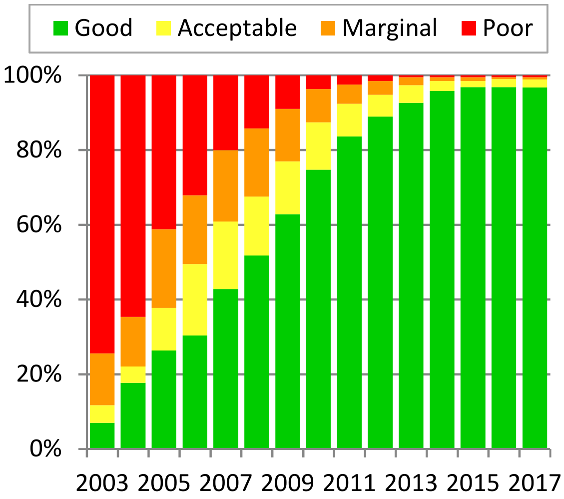


***Figure 1. IIHS side impact ratings by vehicle model year***

Despite these improvements, side impact crashes accounted for 5,593 passenger vehicle occupant fatalities in 2015. These fatalities occurred in vehicles with a median model year of 2003, meaning that most were not rated in the IIHS program. This suggests that side impact fatality rates will continue to fall as the fleet continues to turn over, given the relationship between good test performance and real-world experience. At the same time, however, 49 percent of the rated vehicles with 2015 side impact fatalities were rated good. It is possible that the existing IIHS test configuration could be modified or supplemented in order to encourage additional countermeasures that improve the real-world crashworthiness of the passenger vehicle fleet.

In order to identify changes to the IIHS test that have the potential to provide additional benefit, a previous study focused on crashes that produced serious or fatal injuries to occupants in vehicles with good ratings [3]. Queries of the National Automotive Sampling System Crashworthiness Data System (NASS-CDS) and Crash Injury Research and Engineering Network (CIREN) identified 109 occupants in crashes from 2005-2012. Differences between the real-world crashes and the IIHS test were categorized through in-depth analysis of each case. Table 1 shows the potential for various changes to the IIHS test configuration to affect the injury outcome for the study population. No single change to the current test configuration would have been relevant to more than around one-quarter of the occupants. When considering combinations of two changes, a more severe test with an impact centered farther forward on the vehicle had the greatest potential relevance. This assumes such a test would encourage countermeasures that benefit occupants in crashes that differ from the current configuration in either or both of these ways.

While the NASS-CDS/CIREN study was restricted to good-rated vehicles, it still is possible that the sample does not represent the current fleet. The median model year for vehicles in the sample was 2007, and 91 percent of the occupants were in vehicles built before 2010. Countermeasures introduced since then may have reduced the risk of injury in some of the specific crash scenarios identified in the study.

For example, even among good-rated vehicles, manufacturers have continued to make structural improvements. Figure 2 shows the average B-pillar crush measurements in the IIHS test by model year. Injury risks also may have been reduced due to the oblique pole tests introduced by the National Highway Traffic Safety Administration (NHTSA) in Federal Motor Vehicle Safety Standard 214 and the New Car Assessment Program. Even improvements in other modes such as the IIHS small overlap test or the roof strength test may carry over to provide benefit in side impacts.

| Change or combination of changes | Case occupants affected |
|---|---|
| Forward impact location | 28% |
| Increase severity | 17% |
| Adjust injury criteria | 9% |
| Include far-side occupant | 9% |
| Increase severity and forward impact location | 62% |
| Increase severity and include far-side occupant | 37% |

**Table 1.**
**Potential relevance of test changes to NASS-CDS and CIREN occupants with serious injury in good-rated vehicles**

Even if the relevance of potential test changes shown in Table 1 holds for the current fleet, it does not necessarily follow that a modified side-impact test could predict the real-world injuries that were observed. This is a particular concern for oblique impacts or for perpendicular impacts that are off-centered from the occupant compartment and produce oblique ATD loading or kinematics. Existing side impact dummies have been designed for and validated against perpendicular lateral impacts. Some work has been done to document the response of specific body regions under oblique loading (e.g. [4]) but injury reference values have not been established, nor has the kinematic response of the dummies been validated in oblique conditions. In addition to possible limitations of the ATDs, there may be additional challenges to replicating the vehicle loading conditions observed in real-world cases in a laboratory setting.

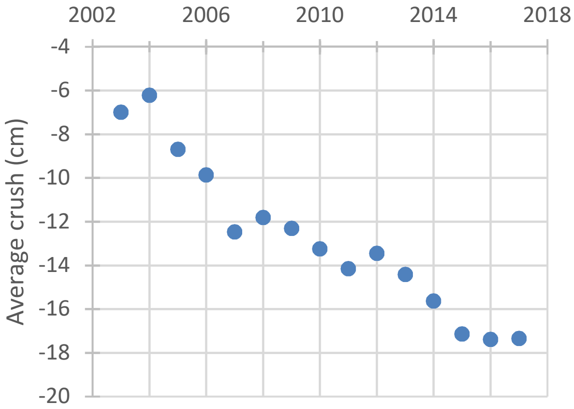


***Figure 2. Average B-pillar crush in SICE tests of good-rated vehicles by model year. Crush is measured relative to the precrash centerline of the driver's seat, with negative values indicating crush does not reach the centerline.***

The current study was conducted to explore the potential for modified crash tests to predict injury outcomes observed in the real-world that may be different from the risks identified in the existing SICE test. In addition, tests of a current vehicle design were used to investigate whether some of the risks associated with a modified configuration have been mitigated by more recent vehicle redesigns.

## METHODS

The NASS-CDS and CIREN cases previously analyzed [3] were filtered to select a case for laboratory replication. The inclusion criteria were a near-side vehicle-to-vehicle crash centered farther forward than the existing SICE test. In addition, a case occupant sustaining thoracic injuries with a level of 3 or higher on the Abbreviated Injury Scale (AIS) was required due to the prevalence of injuries to that body region in the overall analysis. Finally, photographic documentation and measures of structural deformation for the striking vehicle were necessary in order to facilitate and assess the agreement between the test configuration and the real-world case.

Based on the inclusion criteria, NASS-CDS case 2007-02-107 was selected for replication. Details of this case are shown in Table 2. The initial impact was the primary event, with the front of the 1999 Toyota

Camry striking the left side of the 2007 Honda Fit close to the front axle. The coded direction of force for the Fit was 290° (20° oblique towards the rear). The coded case information was used to reconstruct the crash using the PC-Crash software [5]. This resulted in calculated impact speeds of 88 km/h and 33 km/h for the Camry and Fit, respectively.

| | |
|---|---|
| Struck vehicle | 2007 Honda Fit |
| Striking vehicle | 1999 Toyota Camry |
| Case occupant | 75-year-old male, 185 cm, 104 kg, belted, fatally injured |
| AIS≥2 injuries | AIS 5 Bilateral flail chest<br>AIS 4 Trachea perforation<br>AIS 3 Pulmonary artery laceration<br>AIS 3 Left lung contusion, laceration, hemothorax<br>AIS 2 Spleen laceration |

**Table 2.**
**Details of NASS-CDS case 2007-02-107**

The striking and struck vehicles in the replication test were the same generation as those in the NASS-CDS case. Due to the technical challenges of conducting an oblique test with both vehicles moving, two alternative tests were conducted. In the first test, the Fit was stationary but rotated 20° to represent the assumed direction of force in the real-world crash. In the second test, both vehicles were moving but aligned perpendicularly at impact. Based on the damage patterns to both vehicles, the second configuration was selected as the best match to the real-world crash. Another limitation of the IIHS crash propulsion system required the Camry's speed to be reduced from the 88 km/h estimated in the NASS-CDS case to a test speed of 80 km/h. The test speed for the Fit was 32 km/h. Figure 3 shows the orientation of both vehicles at impact. The horizontal centerline of the Camry was aligned 19 cm forward of the Fit's left front axle.

A WorldSID 50th percentile male ATD was used to assess the injury risks for the driver occupant. The ATD was positioned according to the IIHS SICE protocol while following the seat positioning procedure for a 50th percentile male [6],[7]. The ATD was equipped with a RibEye Multi-Point Deflection Measurement System [8]. The RibEye system reports the three-dimensional displacements for each of three LEDs installed on each rib. Figure 4 shows the installation of the LEDs on a rib.

*Figure 3. Impact orientation in replication test*

*Figure 4. RibEye LEDs installed on WorldSID rib [8]*

The three-dimensional displacement measurements were converted to a resultant deflection for each of the three LED locations on each rib. The resultant deflection was defined relative to the centerline of each rib horizontally and vertically and to the centerline of the dummy laterally. In other words, the calculated deflection would match the reading from a potentiometer or IR-TRACC that was attached between the location of the LED and the center of the ATD at the x-coordinate of the rib centerline. In addition to the resultant deflection measurements, the peak lateral displacement was calculated. Figure 5 illustrates the deflection and displacement measurements.

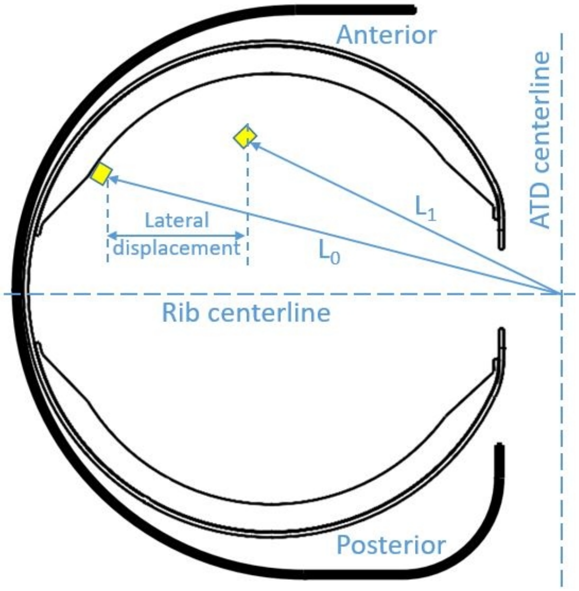


***Figure 5. Definition of the deflection and displacement measurements for one of the RibEye LEDs. Deflection is defined as the difference between $L_0$ and $L_1$.***

Readings from the ATD were compared to the injury risk curves published by the International Organization for Standardization [9]. For the thoracic and abdominal risks, the greatest deflection was used from all measurement locations, even though the standard IR-TRACC would not record deflection at the anterior or posterior locations. Adjusted risks were calculated for a 75-year-old, since this was the age of the occupant in the NASS-CDS case being replicated, as well as for a 45-year-old. Because no injury risk curve has been published for the head, risks were assessed using the HIC-15 curve published for the Hybrid III 50th percentile male ATD in frontal crashes [10].

Injury risks from the replication test cannot directly be compared to the original SICE test with a 5th percentile female SID-IIs ATD. In order to isolate differences introduced by modifying the test configuration, a second 2007 Fit was tested according to the SICE procedure (50 km/h MDB test) but with the WorldSID ATD in the driver position.

To explore the effect of the latest crashworthiness improvements that may not have been captured in the NASS-CDS/CIREN analysis, the replication and SICE tests of the 2007-08 Fit were repeated using the 2015-17 Fit design. Finally, the new Fit was evaluated in a SICE test with the impact speed increased to 60 km/h. This allowed a comparison of injury risks between two crash modes that differed from the SICE test in the ways most commonly identified in the analysis of real-world crashes. The complete test matrix is shown in Table 3.

| ID | Struck vehicle | Impact configuration |
|---|---|---|
| A | 2007 Fit, 33 km/h | 1999 Camry centered 24 cm forward of front axle, 88 km/h |
| B | 2007 Fit, stationary | MDB centered 145 cm rearward of front axle, 50 km/h |
| C | 2015 Fit, 33 km/h | 1999 Camry centered 24 cm forward of front axle, 88 km/h |
| D | 2015 Fit, stationary | MDB centered 145 cm rearward of front axle, 50 km/h |
| E | 2015 Fit, stationary | MDB centered 145 cm rearward of front axle, 60 km/h |

**Table 3.**
**Test matrix**

## RESULTS

Figure 6 shows a comparison of crush measurements from the real-world NASS-CDS case and from the reconstruction test. The bumper bar of the striking Toyota Camry had more deformation in the real-world crash than in the test. The lateral crush measurements on the struck Honda Fit were similar.

Figure 7 shows a comparison of lateral crush measurements for all 5 crash tests. Almost all the intrusion in Tests A and C occurred forward of the pre-test ATD H-point position, while the tests in the SICE configuration had intrusion profiles centered between the H-point and the B-pillar. The tests of the 2015-17 Fit had less crush than the paired tests with the earlier design. In fact, for the tests in the SICE configuration, the B-pillar intrusion for the current design in the 60 km/h test (Test E) was less than the intrusion for the old design in the 50 km/h test.

Several of the RibEye readings had data drop-outs, potentially caused when the line of sight between an LED and a sensor was obstructed. Usually these drop-outs occurred after peak loading, or were of short enough duration that linear interpolation still allowed the data to be used. However, at times the drop outs were longer and none of the output from a given sensor was usable. Table 4 lists these sensors.

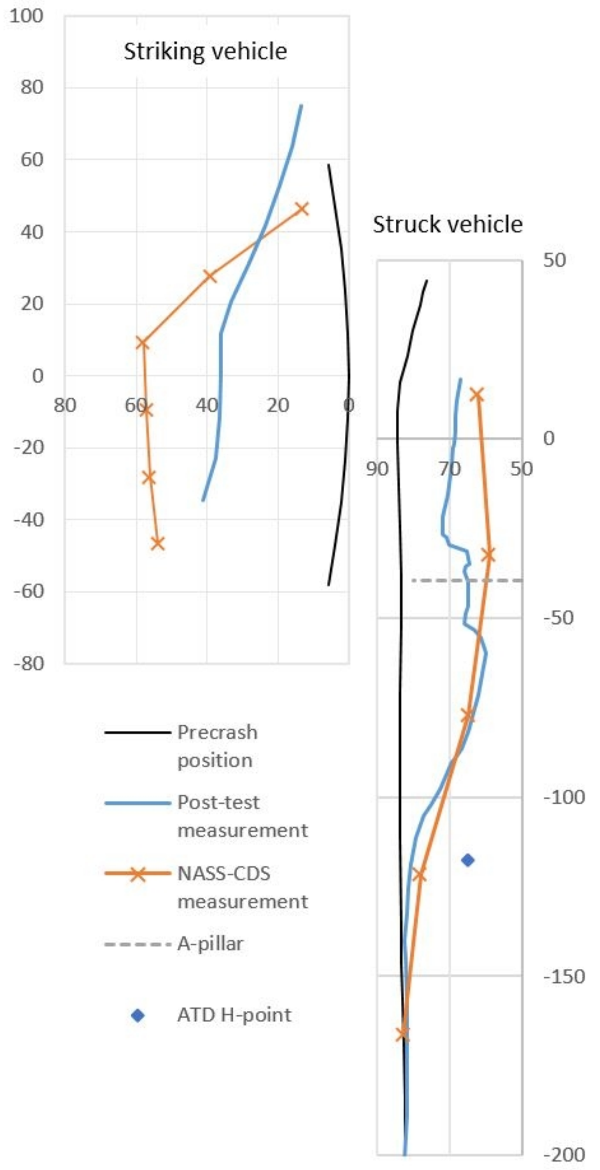


***Figure 6. Vehicle crush measurements (cm) from the reconstruction test (Test A) and from the NASS-CDS case, shown at the test impact point. Measurements of the striking vehicle were taken on the front bumper bar and the origin is the front center of the bumper. Measurements of the struck vehicle were taken near the frame rail height and the origin is the intersection of the front axle and vehicle centerline.***

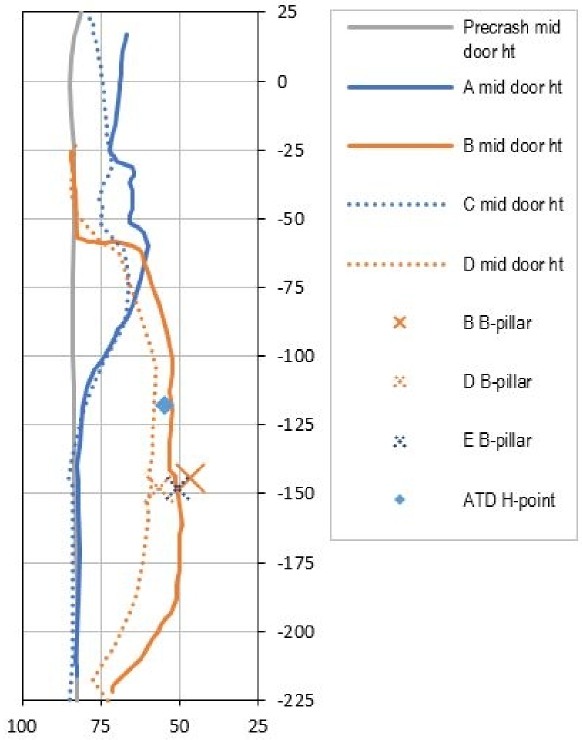


***Figure 7. Vehicle lateral crush profiles taken at the mid-door height (cm). The origin is the intersection of the front axle and vehicle centerline. The crush profile is not shown for Test E because the driver door opened and affected the measurement. The B-pillar deformation is reported at the mid-door height. There was no B-pillar deformation in Tests A or C.***

| Test ID | Rib | Sensor position(s) |
|---|---|---|
| B | Shoulder | Anterior |
| C | Shoulder | Anterior |
| D | Shoulder | All three |
| E | Shoulder | Anterior |
| E | 1st thoracic | Anterior |
| E | 2nd thoracic | Anterior |

***Table 4.***
***RibEye sensor locations where data loss prevented valid measurements***

Peak injury measures for all 5 tests are shown in Table 5. Figure 8 shows the injury risks for a 45-year-old and for a 75-year-old calculated using published risk curves. With the exception of the abdominal body region, the highest injury values were recorded in Test E. Among the other four tests, tests A and B tended to have higher injury risk than the paired tests with the newer Fit. One exception was the higher shoulder force recorded in the SICE test in the newer vehicle.

|  | A | B | C | D | E |
|---|---|---|---|---|---|
| HIC-15 | 135 | 334 | 102 | 224 | 759 |
| Shoulder force (kN) | 2.3 | 1.5 | 1.8 | 2.0 | 3.3 |
| Shoulder deflection (mm) | 47-m | 41-p | 33-m | * | 59-p |
| Shoulder lateral displacement (mm) | 51-m | 51-m | 36-m | * | 65*-m |
| Max thoracic deflection (mm) | 38-m | 43-p | 25-p | 33-p | 57-p |
| Max thoracic lateral displacement (mm) | 42-a | 44-m | 29-a | 32-m | 59-m |
| Max abdominal deflection (mm) | 36-p | 46-p | 26-p | 31-p | 44-p |
| Max abdominal lateral displacement (mm) | 34-p | 45-m | 26-m | 31-a | 42-p |
| Pubic force (kN) | 1.3 | 1.6 | 1.5 | 1.2 | 1.6 |
| Airbag deployment (ms) | 24 | 20 | 20 | 6 | 8 |
| Max thoracic deflection time (ms) | 71 | 23 | 68 | 44 | 36 |

**Table 5.**
**Summary injury measures and timing by test ID. The RibEye sensor locations recording the peak rib deflections and displacements are indicated by: "a" (anterior), "m" (middle) or "p" (posterior). The * indicates either a complete loss of data or a partial loss where the peak value may have been higher.**

Figures 9-11 show the two-dimensional X-Y displacement of the RibEye LEDs at all three measurement locations on the rib. Only the thoracic and abdominal ribs with the highest deflection are shown. While some of the ribs in Tests A and C showed anterior-to-posterior oblique loading initially, the overall peak displacements were oblique from the posterior-to-anterior direction. Among the three measurement locations on each rib, peak three-dimensional deflections were always recorded at the posterior or middle locations (Table 5). But peak lateral displacements were recorded at each of the three locations, and often at a different location than the peak three-dimensional deflection on the same rib.

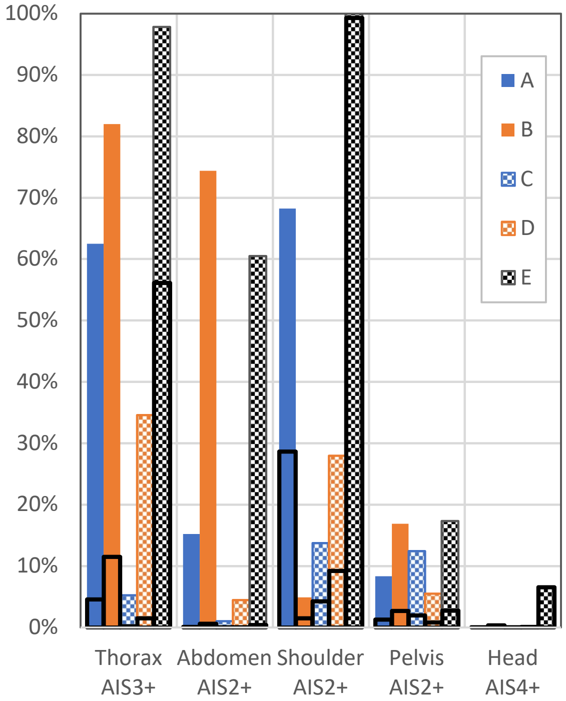


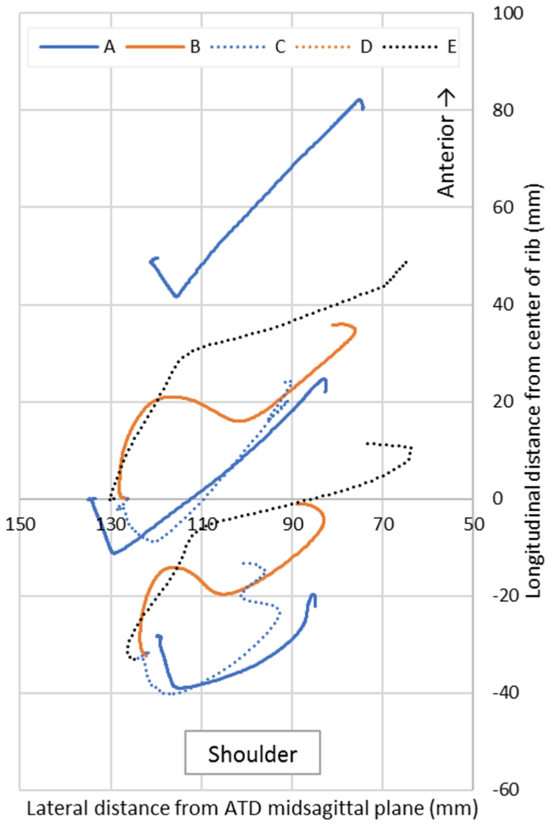
***Figure 8. Injury risks predicted by the WorldSID ATD in each test. The background bars show the risk for a 75-year-old. The thicker foreground bars show the risk for a 45-year-old. (Head injury risks are based on the Hybrid III injury curve and are not adjusted for age.)***

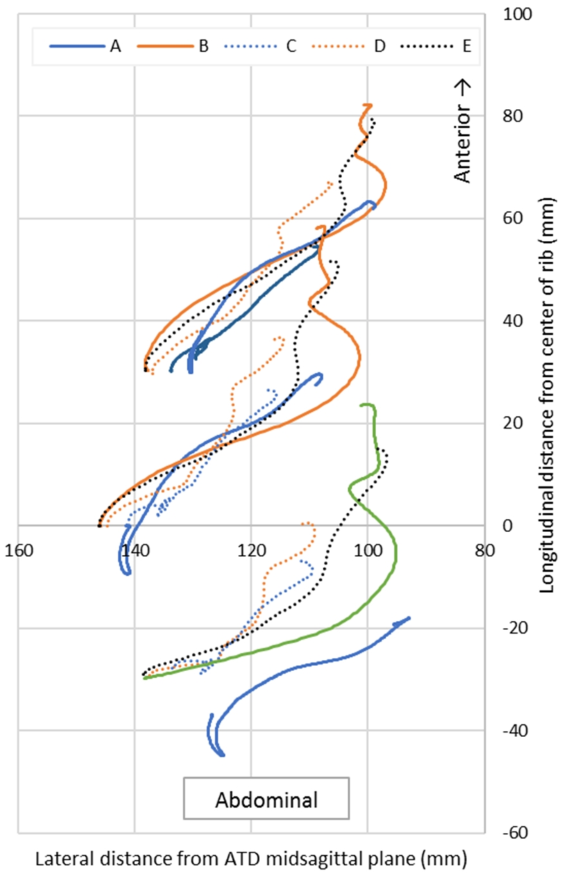
## DISCUSSION

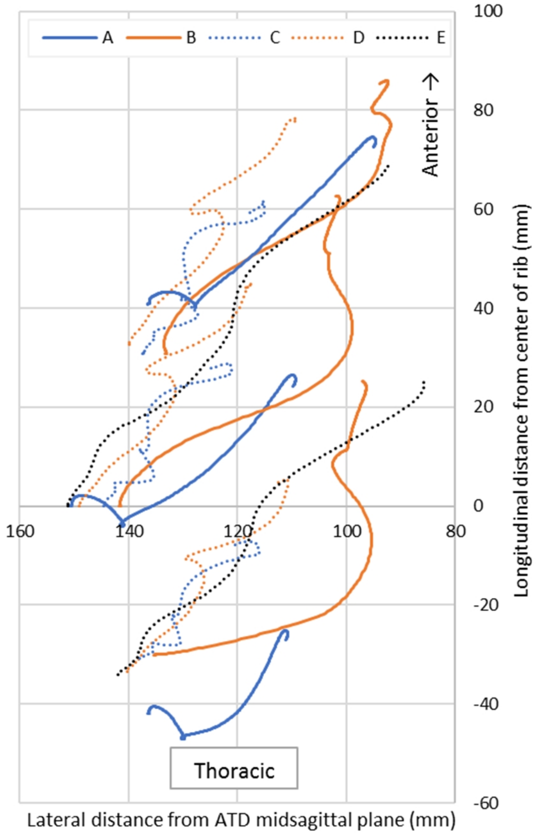
### Reconstruction vs. Current SICE Configuration

The reconstruction of the NASS-CDS case produced generally similar damage patterns to the struck Fit. The measured crush for the striking Camry was less than that measured in the real-world crash, likely due to the required constraint on the test speed. In the real-world crash, the driver sustained fatal thoracic injuries, and in the reconstruction test the thoracic deflections measured with the ATD correlated to a 62 percent risk of AIS≥3 injury. In addition, an elevated shoulder force suggests the possibility of other load paths that may have contributed to the injuries observed in the crash.

Despite the general agreement between the outcomes in the NASS-CDS case and the test, there were no unique crashworthiness deficiencies identified in the reconstruction test. With the exception of the shoulder, injury metrics to all body







***Figures 9-11. Displacement of RibEye LEDs in the rib X-Y plane for the shoulder, thoracic, and abdominal ribs, respectively. Only the thoracic and abdominal ribs with the greatest calculated deflection in each test are displayed. Figure 5 illustrates the coordinate system used.***

regions were lower in this configuration than in the standard SICE configuration for the older Fit design (Tests A and B). The main difference between the two crash modes was the longer crash pulse in the reconstruction test and the later peak loading times. Because the airbag deployed at a similar time, it may have had reduced capacity for energy absorption by the time of peak loading.

Furthermore, the forward impact location did not produce a reversal in the predominant direction of the obliquity of rib loading. While there was some movement in the anterior-to-posterior direction early in the crash, the direction had reversed by the time of intrusion and peak deflection. This may at least partially be due to the design of the WorldSID ATD ribs. Yoganandan et al. observed displacements in the posterior-to-anterior direction during pure lateral load wall tests of the ATD, but they did see movement in the opposite direction during anterior oblique wall tests [4]. In the current study, video from Test A also suggested that the ATD rotated around the pre-tensioned seat belt and it is possible that this could produce twisting of the ATD spine about its vertical axis. If the ribs were partially constrained by loading from the airbag and door, such spinal rotation would be equivalent to moving the RibEye LEDs anteriorly relative to the RibEye sensors. Regardless of the explanation, the ATD was not able to identify a potential injury mechanism unique to this alternative crash configuration.

A comparison of the reconstruction and SICE tests for the new Fit design (Tests C and D) yields similar conclusions. With the exception of the pubic force, injury measures in the SICE configuration were greater than those in the more forward impact. In the forward impact, the thoracic and abdominal rib deflections lacked even the initial indication of anterior oblique loading that was visible in the test with the old Fit.

### New Fit vs. Old Fit

While the 2007 Fit in the NASS-CDS case was a good-rated design, the paired tests of this design and the 2015-17 design illustrate how crashworthiness improvements have continued beyond the level required to obtain a good rating. This suggests that if there were sufficient cases to replicate the NASS-CDS/CIREN study [3] with only the newest vehicle designs, the relevance of specific changes to the SICE test would differ. Specifically, the injury risks that may have been relevant to the occupant in the replicated NASS-CDS case were much lower in the new Fit design, with the risk for a 75-year-old falling from 62 to 5 percent for an AIS3+ thoracic injury and from 68 to 14 percent for an AIS2+ shoulder injury. While limited to a single vehicle design, if this trend held for the rest of the fleet, it is likely that occupants continuing to sustain serious injuries in newer vehicles would be involved in proportionally fewer crashes with forward impact locations and more higher severity impacts to the occupant compartment.

### Potential SICE Changes

As stated above, the test results for these two vehicle designs do not indicate potential value for a crashworthiness evaluation in the more forward impact at 80 km/h. In fact, justifying such an evaluation would have required injury risks that were substantially greater than those observed in the current SICE configuration. This is because there is no indication in the field data that side impacts are more frequently centered forward of the occupant compartment than near the B-pillar. Therefore, a test with an increased speed is most likely to drive meaningful improvements at whatever location currently produces the highest injury risk. Without exception, the 60 km/h impact of the new Fit at the current SICE configuration produced greater injury measures than the 80 km/h more forward impact (Tests E and C).

The 60 km/h impact speed in Test E represents a 44 percent increase in impact energy over the SICE test. The published risk curves for a 45-year-old indicated that the increased speed results in a 90 percent greater risk of AIS2+ shoulder injury and a 55 percent greater risk of AIS3+ thoracic injury. Injury risk to the head, abdomen, and pelvis increased by 6 percent or less. Maximum intrusion at the B-pillar increased from 16.9 cm to 23.1 cm. However, this was still less than the intrusion in the 50 km/h SICE test of the older Fit model, and when compared to the precrash centerline of the seat only would have been 1 cm away from a good structural rating. This suggests that a 60 km/h SICE test would encourage more changes to vehicle restraint systems than to structure. While restraint changes may benefit occupants in higher severity crashes, they have a greater potential to induce injuries in lower severity side impacts. Any potential tradeoff would need to be evaluated prior to introducing a higher severity test.

The most suitable impact speed for a higher severity test also would require further study. In the NASS-CDS/CIREN study, the maximum crush of the occupant compartment in each real-world case was compared to the maximum produced in the SICE test of the same vehicle. The cases with greater crush were categorized as being more severe than the test. For cases in this category, the median crush was 56 cm compared with a median of 31 cm in SICE tests of good-rated vehicles [3]. On its own, this would suggest that the 60 km/h test speed used in the current study is still too low to match the majority of real-world crashes producing serious injury. However, the median crush values are another metric that likely would change if the real-world study could be replicated with only the newest generation of vehicles. A different severity metric, such as door intrusion velocity, may be a better predictor of injury, but establishing a real-world baseline would require a large number of case reconstructions through simulated or physical testing.

## CONCLUSIONS

Side impact crashworthiness, as measured in the IIHS SICE test, continues to improve beyond the level required for a good rating. While real-world crashes of different configurations can produce serious injury in good-rated vehicles, the tests conducted for the current study have not demonstrated that a test with a more forward impact configuration would identify unique injury risks. Increasing the impact speed of the current test is more likely to drive continued crashworthiness improvements that are relevant in real-world crashes. However, potential tradeoffs of more aggressive or complex restraint systems would need to be evaluated to minimize any disbenefit in low and moderate severity side impacts.

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