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16. Abstract

NHTSA has previously published research using the Test Device for Human Occupant Restraint 50th male (THOR-50M) anthropomorphic test device (ATD) as a driver in 56 km/h flat, full-frontal rigid barrier tests. NHTSA subsequently conducted six additional rigid barrier tests as part of a larger program to evaluate the use of a newer generation of test dummies in existing crash tests. Three additional rigid barrier tests were conducted with an updated seating procedure after minor changes were made to the THOR-50M test dummies. This report will extend the previous study to include the results from all 15 rigid barrier tests using a wider range of vehicle types. These tests also included a Hybrid III 5th percentile adult female (HIII-5F) ATD seated in the right front seat located in the mid track position. A second HIII-5F was seated in the right rear seat position. The RibEye Multi-Point Deflection Measurement System was installed into front and rear seated HIII-5Fs to provide additional measurements of the rib deflection.

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Background

The National Highway Traffic Safety Administration has previously published research using the Test Device for Human Occupant Restraint 50th male (THOR-50M) anthropomorphic test device (ATD) as a driver in 56 km/h flat, full frontal rigid barrier tests (Keon, 2016). NHTSA subsequently conducted six additional rigid barrier tests as part of a larger program to evaluate the use of a newer generation of test dummies in existing crash tests. Three additional rigid barrier tests were conducted with an updated seating procedure and after minor changes were made to the THOR-50M test dummies. The updates were to the foot and the neck of the THOR-50M to match the August 2016 drawing package (NHTSA, 2016). The foot design was updated by replacing the separate molded foot and MIL-spec shoe components with a single molded shoe. The neck design was updated by correcting the front and rear neck cable length to allow proper zeroing of the head/neck platform while preventing contact with the skull in qualification tests. This report will extend the previous study to include the results from all 15 rigid barrier tests using a wider range of vehicle types.

The initial six tests demonstrated that the THOR-50M had similar kinematics to the Hybrid III 50th (HIII-50M) ATD, but predicted a larger risk of chest and femur injury. The last three tests used a THOR-50M modified to match the 2016 drawing package. These tests also included a Hybrid III 5th percentile adult female (HIII-5F) ATD seated in the right front seat located in the mid track position. A second HIII-5F was seated in the right rear seat position. The RibEye Multi-Point Deflection Measurement System (Boxboro Systems, 2015) was installed into front and rear seated HIII-5Fs to provide additional measurements of the rib deflection. The RibEye system can record chest deflections at up to twelve locations in the local x- and y-axes. The standard chest potentiometer was retained in the HIII-5F ATDs for comparison. Angular rate sensors were installed in the head of the right front HIII-5F to allow calculation of the brain injury criterion (BrIC). The final three tests in this series did not use the RibEye system; instead, each HIII-5F was equipped with a harmonized chest jacket and spine box (ATD Harmonization Task Group, 2012).

Methodology

Frontal Impact Crash Testing

Table 1 shows the list of test vehicles, ordered by test weight (Vehicle Crash Test Database, n.d.). Repeat tests were initially conducted for the Chevrolet Malibu. Subsequent testing also included repeat tests for the Honda Fit and Ford F150 vehicles. A 2016 Chevrolet Malibu Limited was tested for consistency with side Movable Deformable Barrier (MDB) and oblique frontal test programs. The Malibu Limited is not considered a carryover for the full-frontal test but is included with the repeated Malibu tests to examine the significance of the model update. In subsequent data plots, the repeat vehicles are referenced in the order shown in **Table 1**. Thus, Fit1 refers to test 9337, while Fit2 refers to test 9566.

Table 1. Research Frontal Impact Test Vehicles

NHTSA Test Number	Make	Model	Year	Weight (kg)
9964	Toyota	Scion iA	2016	1387
9337	Honda	Fit	2015	1427
9566	Honda	Fit	2016	1436
9336	Mazda	Mazda3	2015	1599
9965	Toyota	Prius	2016	1670
9966	Mazda	CX-5	2016	1797
9567	Chevrolet	Malibu Limited	2016	1826
9333	Chevrolet	Malibu	2015	1867
9332	Chevrolet	Malibu	2015	1870
9569	Nissan	Rogue	2016	1888
9570	Toyota	Sienna	2015	2295
9334	Toyota	Highlander	2015	2335
9335	Ford	F150 Super Crew	2015	2474
9571	Ford	F150 Super Crew	2016	2485
9568	Chevrolet	Tahoe	2016	2762

The closest matching New Car Assessment Program (NCAP) tests are shown in **Table 2**, which includes some tests of earlier model year vehicles that safercar.gov uses as carry-over for the frontal test. No comparable NCAP test data was available for the Toyota Scion iA. Some of NCAP tests had different model configurations. Even where an NCAP test was the same, the additional Anthropometric Test Device (ATD) and data acquisition equipment in the research tests resulted in heavier test weights. Ten of the fourteen research vehicles were heavier than the vehicles in the NCAP tests used for comparison. The Mazda3, Rogue, and 2015/2016 Fit research tests were run with a smaller volume of Stoddard fluid to reduce the test weight disparity.

Table 2. NCAP Frontal Impact Test Vehicles for Comparison

NHTSA Test Number	Make	Model	Year	Weight (kg)
9033	Honda	Fit	2015	1329
8539	Mazda	Mazda3	2014	1470
9649	Toyota	Prius	2016	1573
9136	Mazda	CX-5	2016	1730
7856	Chevrolet	Malibu Eco	2013	1844
8987	Nissan	Rogue	2015	1812
9012	Toyota	Sienna	2015	2251
8531	Toyota	Highlander	2014	2250
9097	Ford	F150 Super Crew	2015	2571
8605	Chevrolet	Tahoe	2015	2846

The longitudinal vehicle axis (x-axis) crash pulse characteristics, filtered using the conventional CFC 60, are shown in **Table 3**. All the characteristics are computed from the time of vehicle-barrier contact to the time when the vehicle achieves zero forward velocity. Therefore, these include only the front-end dynamic crush and not vehicle rebound. For the research tests, the peak G's range from 30 to 54 G's with an average of approximately 40 G's. The duration ranges between 69 and 89 milliseconds and does not show a trend of increasing with vehicle weight. Since the initial test speed is the same, the duration is a surrogate for the average acceleration during vehicle front-end crush. Both values are provided to simplify interpretation. Other than a high peak acceleration for the Mazda 3, the research crash pulse values are not significantly different from the previous NCAP tests (Parent et al., 2017).

Table 3. Vehicle Crash Pulse Characteristics

Vehicle	Peak Acceleration (G)	Duration (sec)	Average Acceleration (G)	NCAP Peak Acceleration (G)	NCAP Duration (sec)	NCAP Average Acceleration (G)
2016 Toyota Scion iA	-38.3	0.076	-21.2	n/a[1]	n/a	n/a
2015 Honda Fit	-37.7	0.075	-21.5	-35.1	0.073	-22.2
2016 Honda Fit	-35.7	0.074	-21.7	-35.1	0.073	-22.2
2015 Mazda3	-53.8	0.079	-20.4	-33.4	0.076	-21.2

[1] The Toyota Scion iA did not have comparable NCAP data. Therefore, the Scion's NCAP data will be coded as n/a for "not available."

Vehicle	Peak Acceleration (G)	Duration (sec)	Average Acceleration (G)	NCAP Peak Acceleration (G)	NCAP Duration (sec)	NCAP Average Acceleration (G)
2016 Toyota Prius	-46.9	0.068	-23.9	-47.0	0.065	-25.0
2016 Mazda CX-5	-42.4	0.076	-21.1	-36.7	0.076	-21.3
2016 Chevrolet Malibu Limited	-39.9	0.078	-20.8	-36.8	0.079	-20.4
2015 Chevrolet Malibu	-37.4	0.079	-20.4			
2015 Chevrolet Malibu	-36.1	0.077	-21.0			
2016 Nissan Rogue	-48.6	0.072	-22.6	-44.1	0.072	-22.4
2015 Toyota Sienna	-35.0	0.076	-21.2	-36.6	0.073	-22.2
2015 Toyota Highlander	-54.1	0.069	-23.4	-49.3	0.068	-23.7
2015 Ford F-150	-36.0	0.078	-20.6	-35.7	0.076	-21.3
2016 Ford F-150	-30.2	0.082	-19.8			
2016 Chevrolet Tahoe	-30.9	0.089	-18.0	-34.2	0.083	-19.3

THOR-50M Driver Seat Positioning

The NCAP test procedure locates the driver's seat at mid-track. The THOR-50M in this study was seated using a new procedure developed to achieve a more reproducible position and posture by accounting for the changes in anthropometry, adjustability, flexibility, and measurement capabilities of the THOR-50M [9]. The THOR-50M was designed to meet the anthropometry of motor vehicle occupants (AMVO) specifications, resulting in a larger hip-to-knee length than the HIII-50M. In all but three vehicles, the THOR-50M was positioned at mid-track. For the two Honda Fit tests and the Nissan Rogue test, the THOR-50M was positioned two detents rearward of the seat track mid-point. This adjustment was made to provide a 5-mm minimum clearance between the THOR-50M knees and the knee bolster, as specified in the THOR-50M seating procedure.

HIII-5F Right Front Passenger Seat Positioning

A review of NASS-CDS frontal crashes from 2000 to 2013 with MAIS 2+ injured occupants indicated that the majority of MAIS 2+ injured occupants sit in a mid- to rear seat track position. The number of right front passengers injured when seated in the full-forward position was the smallest number of occupants seen in this data set. For these research tests, the right front seat was positioned at mid-track instead of conventional NCAP full-forward.

HIII-5F Right Rear Passenger Injury Assessment

For the research tests, a belted HIII-5F was positioned in the right rear seat. Frontal NCAP tests do not place an occupant in the rear seat, so no comparisons to conventional NCAP tests are possible.

Test Results

THOR-50M Driver Injury Assessment

Frontal air bags and seat belt pretensioners deployed for all THOR-50M drivers. Side curtain air bags deployed in 8 of the 15 tests. Two of the 8 corresponding NCAP tests did not have side curtain deployments. These were both from one model year prior than the research vehicle, but were considered as a carryover vehicle for the safercar.gov frontal crash rating. A third vehicle, the Toyota Highlander, had the driver curtain window disabled in the NCAP test. No occupant interaction with a deployed side curtain was observed in any test.

Driver shoulder belt loads are shown in **Figure 1** and lap belt loads are shown in **Figure 2**. Both the shoulder and lap belt forces show considerable variation among the test vehicles. Seat belt forces were available for about half of the NCAP tests. The belt loads were similar to the belt loads measured in the research tests (not shown).

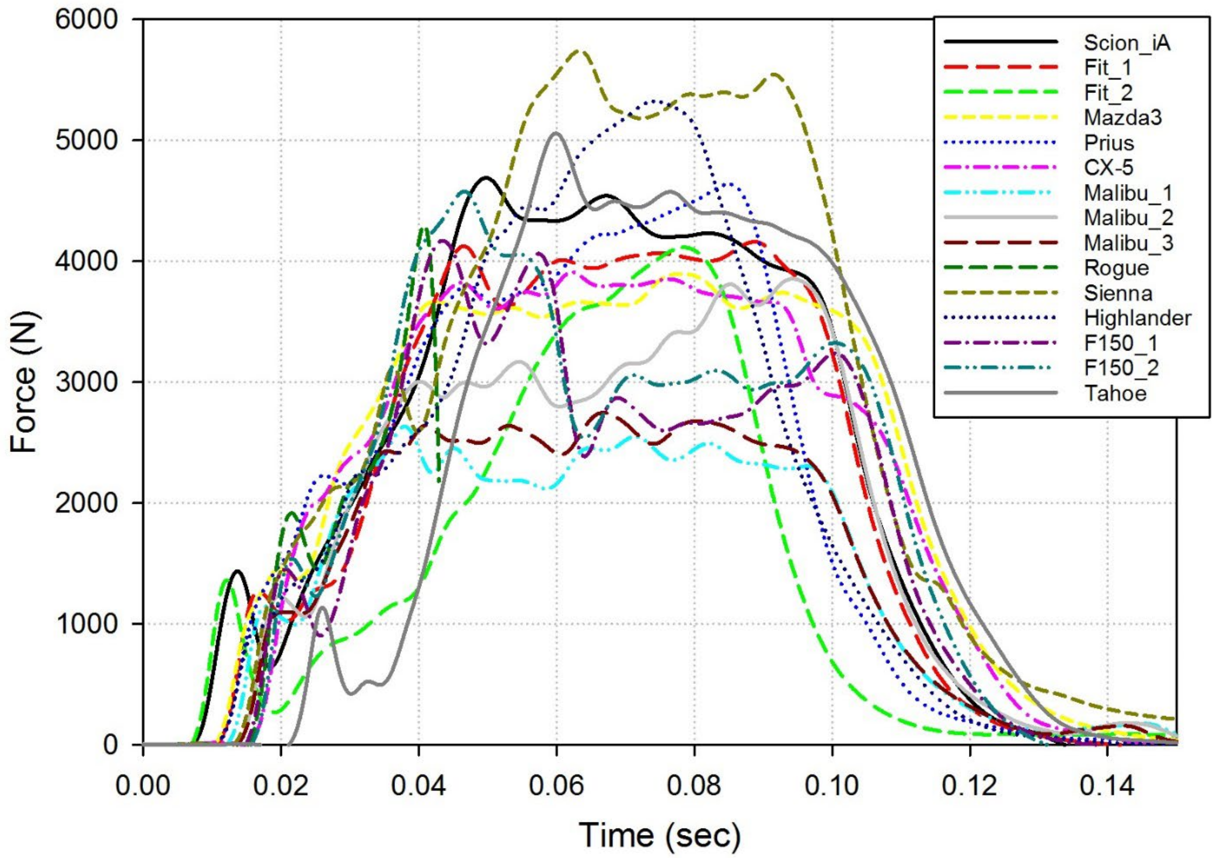


Figure 1. Driver, shoulder belt force.

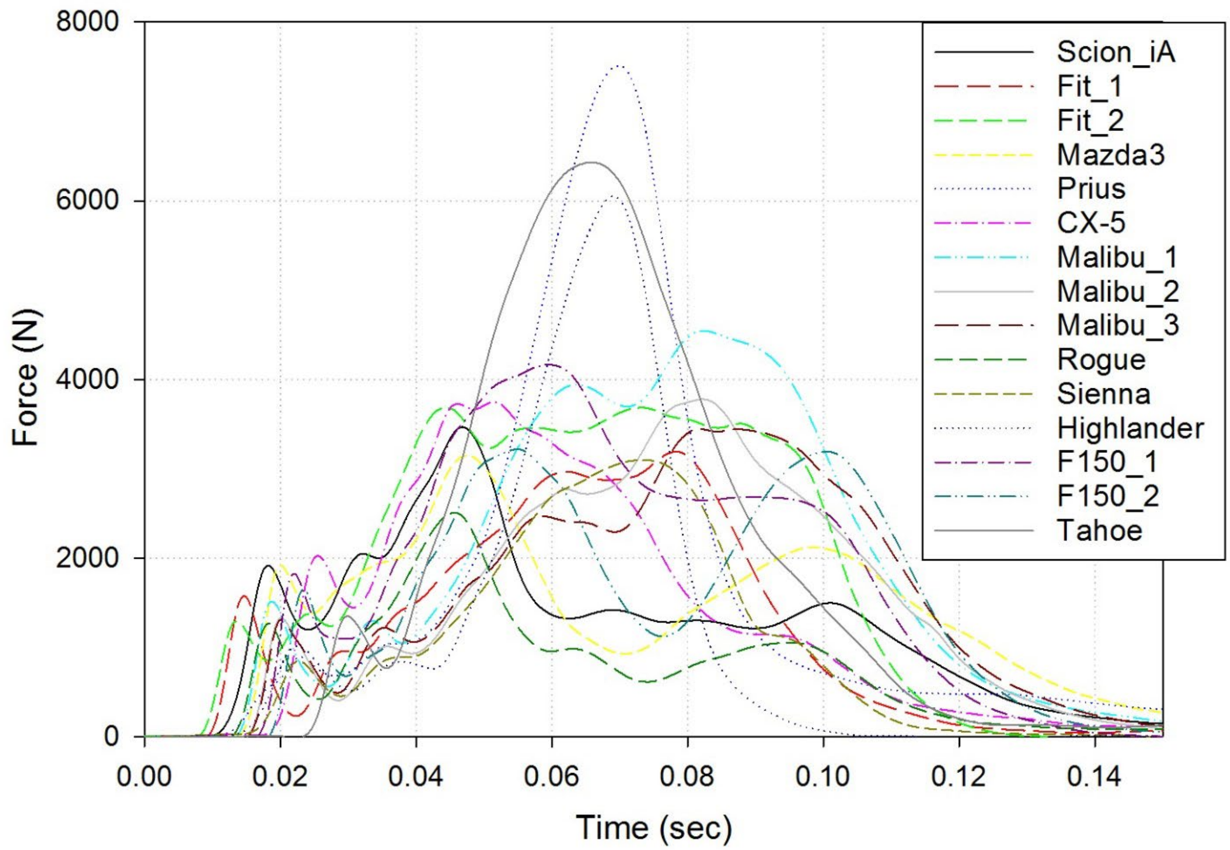


Figure 2. Driver, lap belt force.

As seen in **Table 4**, the THOR-50M HIC15 results exceeded the NCAP HIII-50M HIC15 measurements in all cases, except the 2016 Toyota Prius. However, all HIC15 values were low and represent minimal injury risk. The Rogue had the highest driver HIC15 of 452. The THOR-50M HIC15 values occurred over a slightly later time window for all tests except the three Malibu vehicles.

The BrIC was calculated for each research test. All but one of the tests had the peak rotational velocity occur about the head Y axis. The 2016 Honda Fit had a peak rotational velocity about the head Z axis and resulted in the largest BrIC measured. In that test, the THOR-50M driver's head twisted during contact with the air bag. The repeat Malibu and F150 tests had similar BrIC results, but the repeat Fit tests had significant variation. Head angular velocity was only collected for one NCAP driver.

Table 4. Driver, HIC15, and BrIC Values

Vehicle	Research HIC15	Research HIC15 Time (ms)	NCAP HIC15	NCAP HIC15 Time (ms)	Research BrIC
2016 Toyota Scion iA	216.8	87.8-102.8	n/a	n/a	0.70
2015 Honda Fit	298.3	71.8-86.8	251.4	63.5-78.5	0.60
2016 Honda Fit	321.0	75.7-90.7			0.85
2015 Mazda3	238.3	92.6-107.6	191.7	86.4-101.4	0.56
2016 Toyota Prius	193.7	79.7-94.7	244.0	70.7-85.7	0.70
2016 Mazda CX-5	149.1	92.6-107.6	137.4	87.4-102.4	0.65
2016 Chevrolet Malibu Limited	254.9	72.3-87.3	133.8	79.3-94.3	0.72
2015 Chevrolet Malibu	265.0	76.9-91.9			0.68
2015 Chevrolet Malibu	317.1	75.2-90.2			0.71
2016 Nissan Rogue	452.9	81.5-96.5	294.4	74.6-89.6	0.70
2015 Toyota Sienna	346.0	81.3-96.3	200.5	76.9-91.9	0.80
2015 Toyota Highlander	261.5	68.3-83.3	195.0	64.3-79.3	0.59
2015 Ford F150	350.6	67.8-103.8	199.0	65.4-80.4	0.58
2016 Ford F150	250.2	73.6-88.6			0.53
2016 Chevrolet Tahoe	374.0	81.8-96.8	222.9	79.7-94.6	0.69

The THOR-50M was designed to different anthropometry data than the HIII-50M, causing the THOR-50M to sit further rearward than a comparably seated HIII-50M. **Table 5** shows the increase in relative clearance distances for the THOR-50M driver, using a HIII-50M driver as the baseline. Nose to steering wheel rim distance increased by 64 to 179 mm, and the chest to steering wheel distance increase ranged from 47 to 130 mm.

Table 5. Driver Clearance Distance Comparison Between Research and NCAP Tests

Vehicle	Relative Clearance nose to steering wheel rim, THOR-50M - HIII-50M (mm, x-axis)	Relative Clearance chest to steering hub, THOR-50M - HIII-50M (mm, x-axis)
2016 Toyota Scion iA	n/a	n/a
2015 Honda Fit	76	78
2016 Honda Fit	77	80
2015 Mazda3	64	47
2016 Toyota Prius	97	53
2016 Mazda CX-5	116	74
2016 Chevrolet Malibu Limited	161	107
2015 Chevrolet Malibu	127	99
2015 Chevrolet Malibu	136	90
2016 Nissan Rogue	105	77
2015 Toyota Sienna	119	73
2015 Toyota Highlander	93	70
2015 Ford F150	89	64
2016 Ford F150	109	77
2016 Chevrolet Tahoe	179	130

The THOR-50M Nij measurements are shown in **Table 6** below. The THOR-50M Nij values were generally larger compared to the HIII-50M in NCAP testing. The Sienna was the lone exception. It had a lower Nij value for the THOR-50M driver. The Nij values for the repeat research vehicle tests were consistent. The Nij varied by 0.01, 0.03, and 0.05 for the Fit, Malibu, and F150, respectively.

The peak neck tension values demonstrated more variability between the THOR-50M and HIII-50M results. The THOR-50M drivers in the 2015 and 2016 Fit, Mazda3, Prius, CX-5, Rogue, Highlander, and Tahoe saw a 38 to 1322 N increase in neck tension over the HIII-50M. The 2016 Malibu, both 2015 Malibu vehicles, Sienna, and both F150s saw a decrease of 35 to 722 N. Within the repeated research tests, the Honda Fit and the Ford F150 showed a moderate degree of variation, with ranges of 51 N and 154 N, respectively. The two 2015 Malibu vehicles showed only 55 N variation in the Neck Tension. When comparing the 2015 and 2016 Malibu models, the variation increased significantly to 355 N.

Table 6. Driver, Neck Injury Values

Vehicle	Research Nij	NCAP Nij	Research Tension (N)	NCAP Tension (N)
2016 Toyota Scion iA	0.41	n/a	1584.2	n/a
2015 Honda Fit	0.30	0.28	1166.3	738.6
2016 Honda Fit	0.29		1115.6	
2015 Mazda3	0.41	0.20	1406.7	1031.9
2016 Toyota Prius	0.63	0.30	2346.0	1529.6
2016 Mazda CX-5	0.45	0.18	1671.7	1034.1
2016 Chevrolet Malibu Limited	0.40	0.31	1229.1	1263.9
2015 Chevrolet Malibu	0.38		928.3	
2015 Chevrolet Malibu	0.41		873.7	
2016 Nissan Rogue	0.47	0.29	1792.1	915.9
2015 Toyota Sienna	0.41	0.47	1539.1	2261.6
2015 Toyota Highlander	0.63	0.27	2480.0	1157.6
2015 Ford F150	0.36	0.28	1233.8	1492.4
2016 Ford F150	0.31		1080.0	
2016 Chevrolet Tahoe	0.49	0.33	1690.6	1652.5

The THOR-50M chest deflection measurements use four InfraRed Telescoping Rod for Assessment of Chest Compression (IR-TRACC) sensors. These sensors record three axes of deflection at four locations near the belt path for the driver and passenger seating positions. The HIII-50M uses a single axis potentiometer located at the sternum. The maximum IR-TRACC resultant deflection for the THOR-50M chest is used to evaluate risk of rib fracture. The peak THOR-50M resultant deflections were always greater than the maximum sternum deflections for the HIII-50M in matched NCAP testing (**Table 7**). This finding is not surprising given the multi-axis nature of the measurement and that the THOR-50M thoracic response is more compliant and correspondingly more biofidelic than the HIII-50M in both component and sled test conditions (Parent et al., 2017). The peak resultant chest deflection measured by the THOR-50M occurred at the upper right measurement location for all research tests, which is the location nearest to the initial belt position across the chest. The repeat THOR-50M tests had consistent peak chest deflection measurements.

Abdominal deflections were recorded in the THOR-50M through displacement of IR-TRACC sensors. The range of peak abdomen compression was 46.0 to 66.2 mm. The left and right abdominal deflections are shown in **Table 7**, with the largest abdomen deflection for each test shown in bold. The left abdominal IR-TRACC sensor had several sensor failures in this test series. Out of the seven data anomalies recorded, three were caused by voltage spikes, three were related to bad calibrations, and one was due to abdominal insert interference. The Fit and F150 had over 10 mm of test to test variation, while the Malibu tests varied by less than 2 mm. The 2016 Fit test had a different abdomen displacement time history that was larger and longer duration than the 2015 Fit driver.

Table 7. Driver, Peak Chest and Abdomen Deflection

Vehicle	Research Peak Resultant Chest Deflection (mm)	NCAP Sternum Deflection (mm)	Research Left Peak Abdomen (mm)	Research Right Peak Abdomen (mm)
2016 Toyota Scion iA	47.8	n/a	**58.2**	54.6
2015 Honda Fit	50.4	23.8	**46.5**	46.0
2016 Honda Fit	47.9		58.6	**63.9**
2015 Mazda3	51.1	24.7	Data Anomaly	53.9
2016 Toyota Prius	52.7	25.8	59.1	**61.0**
2016 Mazda CX-5	47.4	20.0	Data Anomaly	53.2
2016 Chevrolet Malibu Limited	38.0	18.2	62.2	**65.0**
2015 Chevrolet Malibu	44.3		Data Anomaly	66.2
2015 Chevrolet Malibu	41.3		Data Anomaly	64.4
2016 Nissan Rogue	49.0	20.6	55.0	**58.4**
2015 Toyota Sienna	53.3	18.7	54.1	**62.3**
2015 Toyota Highlander	65.5	21.4	Data Anomaly	64.4
2015 Ford F-150	39.3	14.9	Data Anomaly	55.3
2016 Ford F-150	39.8		Data Anomaly	63.8
2016 Chevrolet Tahoe	54.1	22.9	56.3	**57.4**

Peak acetabulum loads are shown in **Table 8**. The maximum resultant loading for a test is indicated in bold. The 2015 Malibu tests had relatively consistent peak acetabulum forces, while the Fit and the F150 tests were not as consistent. Both the Fit and F150 repeat test had peak load alternate between the left and right legs.

Table 8. Driver, Resultant Acetabulum Force

Vehicle	Left Peak Acetabulum (N)	Right Peak Acetabulum (N)
2016 Toyota Scion iA	**1970.5**	1894.6
2015 Honda Fit	**1866.5**	1167.3
2016 Honda Fit	1531.3	**1599.0**
2015 Mazda3	**2636.0**	2517.9
2016 Toyota Prius	1919.5	**2524.9**
2016 Mazda CX-5	**1687.6**	1168.4
2016 Chevrolet Malibu Limited	**1147.6**	921.3
2015 Chevrolet Malibu	**1478.9**	1177.2
2015 Chevrolet Malibu	**1356.0**	1109.2
2016 Nissan Rogue	**3383.8**	2937.2
2015 Toyota Sienna	1055.8	**1643.1**
2015 Toyota Highlander	**2269.9**	1596.6
2015 Ford F-150	794.4	**960.9**
2016 Ford F-150	**1475.8**	942.7
2016 Chevrolet Tahoe	1905.1	**2007.4**

Peak femur loads for the THOR-50M are shown in **Table 9**. The maximum femur load for each test is indicated in bold**.** The right femur loads were generally larger than the left femur loads. Peak femur loads in research tests were almost all larger than the corresponding NCAP tests. Only the Malibu tests had larger peak femur load in the NCAP test. The Rogue test had the highest peak femur load, 6727 N. The Rogue also had the largest difference in peak femur force between the THOR-50M and HIII-50M. Knee air bags deployed for 6 each of the research and the corresponding NCAP tests. Knee air bags were present for both research and NCAP tests where indicated in **Table 9**.

Table 9. Driver, Maximum Compressive Femur Force

Vehicle	Research Left Femur (N)	Research Right Femur (N)	NCAP Left Femur (N)	NCAP Right Femur (N)	Knee Air Bag
2016 Toyota Scion iA	**4428.3**	3808.3	n/a	n/a	No
2015 Honda Fit	1938.7	**2933.3**	231.8	**242.0**	No
2016 Honda Fit	1996.3	**2501.7**			No
2015 Mazda3	3743.8	**3890.9**	473.8	**1114.7**	No
2016 Toyota Prius	1593.5	**3265.1**	1288.3	**1569.6**	Driver
2016 Mazda CX-5	**2897.5**	2526.2	**1402.2**	558.7	No
2016 Chevrolet Malibu Limited	1488.7	**3033.3**	**3806.1**	1763.8	Driver, Frt. Pass.
2015 Chevrolet Malibu	1100.1	**1856.8**			Driver, Frt. Pass.
2015 Chevrolet Malibu	1103.5	**2695.8**			Driver, Frt. Pass.
2016 Nissan Rogue	**6727.2**	6244.3	873.1	**1353.1**	No
2015 Toyota Sienna	1787.1	**2908.9**	1819.2	**2299.1**	Driver
2015 Toyota Highlander	2425.0	**3866.9**	**1465.6**	1365.0	Driver
2015 Ford F150	2874.9	**2972.6**	**2011.0**	566.3	No
2016 Ford F150	**3712.0**	3029.9			No
2016 Chevrolet Tahoe	2409.1	**4168.0**	741.4	**1087.0**	No

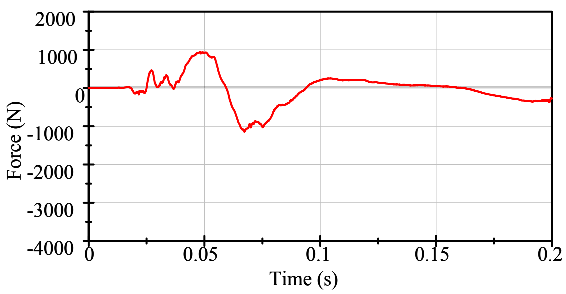
Knee-to-dash clearance is expected to be a factor in the force measured in the femur. **Table 10** shows the difference in knee-to-dash clearance between the THOR-50M and HIII-50M. The table shows the change in knee clearance between the research and the comparable NCAP test. Negative values indicate less clearance for the THOR-50M. The repeat vehicle tests show more consistency in knee clearance distance than was seen for the nose-to-steering-wheel-rim or the chest-to-steering-wheel-hub (**Table 5**). For all the tested vehicles, the knees of the THOR-50M were initially closer to the dash than those of the HIII-50M in matched pair tests. This in part stems from a difference in anthropometry, because the THOR-50M has a larger hip-to-knee length than the HIII-50M. Mazda3 pre-test photos demonstrate the noticeable difference in knee-to-dash clearance between the two ATDs (**Figure 3**).

Table 10. Driver, Knee Clearance Distance, (THOR-50M – HIII-50M)

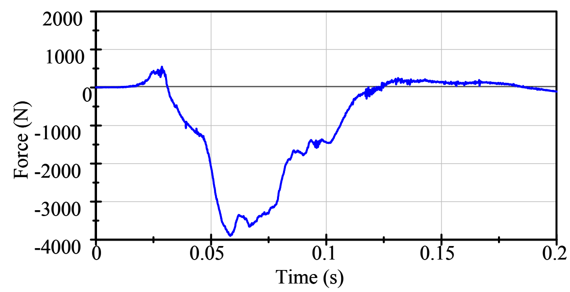
Vehicle	Relative Clearance Left Knee-to-Dash THOR-50M - HIII-50M (mm)	Relative Clearance Right Knee-to-Dash THOR-50M - HIII-50M (mm)
2016 Toyota Scion iA	n/a	n/a
2015 Honda Fit	-29	-36
2016 Honda Fit	-33	-44
2015 Mazda3	-53	-41
2016 Toyota Prius	-37	-30
2016 Mazda CX-5	-20	-40
2016 Chevrolet Malibu Limited	-29	-8
2015 Chevrolet Malibu	-5	-16
2015 Chevrolet Malibu	-7	-15
2016 Nissan Rogue	-44	-51
2015 Toyota Sienna	-23	-16
2015 Toyota Highlander	-26	-24
2015 Ford F150	-41	-34
2016 Ford F150	-31	-37
2016 Chevrolet Tahoe	-16	-9

Mazda3, HIII-50M – pre-test

Mazda3, THOR-50M – pre-test



Mazda3, HIII-50M – right femur force



Mazda3, THOR-50M – right femur force

Figure 3. Mazda3, Driver, Knee Position, Femur Loading.

Compressive forces from the upper and lower tibia load cells were recorded in the THOR-50M to assess lower extremity injury risk. The peak compressive forces are shown for the left and right upper tibia (**Table 11**) and lower tibia (**Table 12**). For each left/right pair, the location of the maximum force is indicated in bold. Both the THOR-50M and the HIII-50M measured more peak loads in the right leg for both the upper and lower tibia forces. The Fit and F150 demonstrated more consistent peak tibia forces than did the Malibu, though all repeat tests were consistent in whether the peak upper and lower tibia forces occurred in the left or right leg.

Table 11. Driver, Upper Tibia Compressive Force

Vehicle	Research Left Upper (N)	Research Right Upper (N)	NCAP Left Upper (N)	NCAP Right Upper (N)
2016 Toyota Scion iA	1472.1	**1846.9**	n/a	n/a
2015 Honda Fit	**1301.3**	1163.9	1081.8	**1989.9**
2016 Honda Fit	**1372.7**	1285.1		
2015 Mazda3	**2048.0**	1435.3	1510.8	**3042.6**
2016 Toyota Prius	**2269.6**	1929.4	**2359.0**	2265.4
2016 Mazda CX-5	1753.0	**2089.9**	1453.5	**1937.3**
2016 Chevrolet Malibu Limited	1853.4	**2555.5**	1293.5	**1753.8**
2015 Chevrolet Malibu	1959.9	**2845.1**		
2015 Chevrolet Malibu	2050.6	**3291.2**		
2016 Nissan Rogue	**1033.7**	769.6	**2778.9**	2085.9
2015 Toyota Sienna	1222.2	**3627.0**	2159.3	**2379.3**
2015 Toyota Highlander	1846.5	**1864.2**	1910.1	**2869.7**
2015 Ford F150	1231.3	**2184.7**	1410.9	**1796.8**
2016 Ford F150	1247.1	**2132.9**		
2016 Chevrolet Tahoe	1058.4	**2736.1**	1270.0	**2301.5**

Table 12. Driver, Lower Tibia Compressive Force

Vehicle	Research Left Lower (N)	Research Right Lower (N)	NCAP Left Lower (N)	NCAP Right Lower (N)
2016 Toyota Scion iA	2526.0	**3112.3**	n/a	n/a
2015 Honda Fit	Data Anomaly	**3686.8**	1201.1	**2466.2**
2016 Honda Fit	2811.4	**4615.9**		
2015 Mazda3	**3100.9**	1862.4	1961.6	**3328.6**
2016 Toyota Prius	**3075.9**	2928.6	**2683.7**	2603.8
2016 Mazda CX-5	2771.0	**3282.9**	1695.1	**2267.1**
2016 Chevrolet Malibu Limited	2577.0	**3423.7**	1720.1	**2044.6**
2015 Chevrolet Malibu	2691.7	**3710.2**		
2015 Chevrolet Malibu	2980.7	**4039.5**		
2016 Nissan Rogue	1670.2	**2176.4**	2004.9	**2533.5**
2015 Toyota Sienna	1960.4	**5076.0**	**3925.0**	2617.6
2015 Toyota Highlander	**2939.0**	2335.6	2079.2	**3649.2**

Vehicle	Research Left Lower (N)	Research Right Lower (N)	NCAP Left Lower (N)	NCAP Right Lower (N)
2015 Ford F150	1794.4	**2440.8**	1772.0	**1879.6**
2016 Ford F150	1890.6	**2636.5**		
2016 Chevrolet Tahoe	1357.4	**4599.7**	1965.9	**3471.6**

The peak resultant tibia moment is calculated from the x-axis and y-axis moment from the THOR-50M to assess potential lower extremity injury. The resultant moments calculated from the upper and lower tibia load cells are shown in **Table 13**.

Table 13. Driver, Tibia Resultant Moment

Vehicle	Research Left Upper (Nm)	Research Right Upper (Nm)	Research Left Lower (Nm)	Research Right Lower (Nm)	NCAP Left Upper (Nm)	NCAP Right Upper (Nm)	NCAP Left Lower (Nm)	NCAP Right Lower (Nm)
2016 Toyota Scion iA	61.8	**111.5**	45.0	**176.7**	n/a	n/a	n/a	n/a
2015 Honda Fit	**89.0**	63.6	**60.4**	52.8	102.2	**114.3**	37.2	**174.0**
2016 Honda Fit	**104.4**	66.7	65.4	**66.4**				
2015 Mazda3	**53.5**	50.6	38.1	**55.8**	94.5	**107.2**	88.6	**122.3**
2016 Toyota Prius	**77.8**	74.3	35.4	Data Anomaly	**82.2**	81.6	28.0	**34.5**
2016 Mazda CX-5	70.9	**76.0**	60.0	**73.1**	**102.7**	50.5	35.4	**108.9**
2016 Chevrolet Malibu Limited	64.2	**67.2**	39.0	**41.7**	31.3	**57.1**	**76.1**	39.9
2015 Chevrolet Malibu	45.8	**47.7**	39.0	**41.3**				
2015 Chevrolet Malibu	46.7	**57.5**	**40.1**	39.5				
2016 Nissan Rogue	**92.8**	87.3	**67.7**	64.6	69.1	**104.9**	**54.9**	50.9
2015 Toyota Sienna	39.8	**58.0**	29.4	**49.9**	74.9	**99.1**	**76.5**	43.9
2015 Toyota Highlander	82.4	**110.8**	55.3	**57.6**	75.2	**100.3**	24.6	**68.2**
2015 Ford F150	52.5	**53.5**	36.5	**59.3**	71.7	**85.2**	30.9	**56.1**
2016 Ford F150	**73.9**	45.8	49.4	**52.7**				
2016 Chevrolet Tahoe	82.4	**93.5**	67.5	**76.4**	72.9	**152.6**	74.9	**145.2**

HIII-5F Right Front Passenger Injury Assessment

For the right front passenger research tests, the HIII-5F was placed at mid-track instead of the conventional NCAP full-forward seating position. The average relative clearance between the HIII-5F chest and the dash increase was 121 mm, with a range of 88 to 153 mm. The nose to windshield clearance increase was also greater. It had a range of 70 to 238 mm with an average of 141 mm. **Table 14** lists the change in the clearance measurements between the research tests and the comparable NCAP tests.

Table 14. Right Front Passenger, Clearance Distances Comparison, (Research Minus NCAP)

Vehicle	Relative Clearance Chest-to-Dash, Mid – Full Fwd (mm, x-axis)	Relative Clearance Nose-to-Windshield, Mid – Full Fwd (mm, x-axis)
2016 Toyota Scion iA	n/a	n/a
2015 Honda Fit	108	149
2016 Honda Fit	96	138
2015 Mazda3	139	107
2016 Toyota Prius	145	225
2016 Mazda CX-5	111	142
2016 Chevrolet Malibu Limited	124	119
2015 Chevrolet Malibu	116	70
2015 Chevrolet Malibu	111	92
2016 Nissan Rogue	122	131
2015 Toyota Sienna	104	138
2015 Toyota Highlander	140	146
2015 Ford F150	153	200
2016 Ford F150	142	238
2016 Chevrolet Tahoe	88	72

In all research tests, the seat belt pretensioners and frontal air bags deployed for the right front passenger. **Figures 4** and **5** display the shoulder and lap belt forces, which show a range of peak loads for the shoulder belt and a large peak force for the Rogue. The lap belt forces are much larger than those of the shoulder belt with the second Fit having the largest peak force.

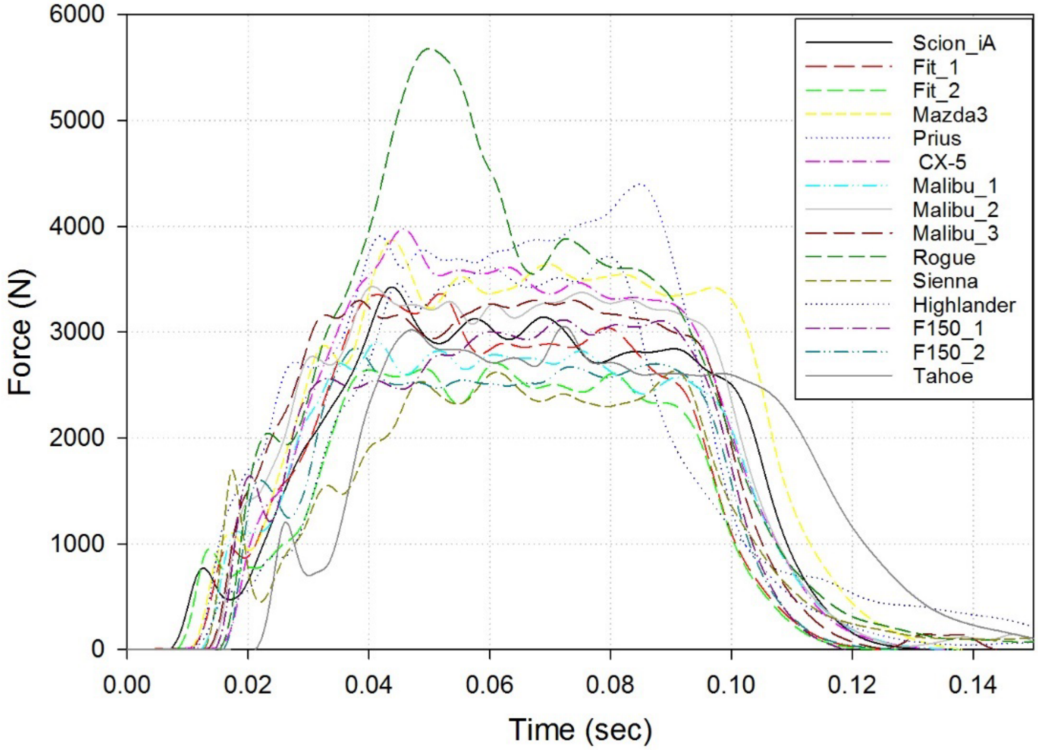


Figure 4. Right Front Passenger, Shoulder Belt Force.

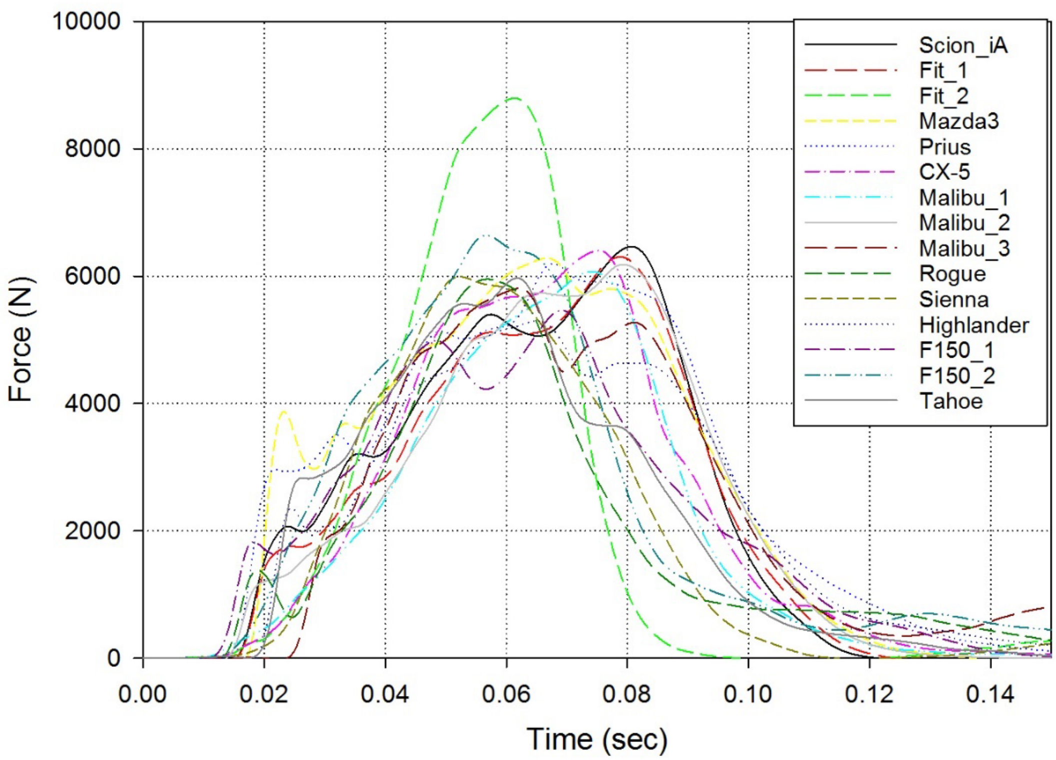


Figure 5. Right Front Passenger, Lap Belt Force.

Still images from test videos showing the right front passenger to air bag clearance are included in **Appendix A.** From NCAP test videos, frame captures were collected at the time when the right front passenger contacts the frontal air bag. A frame capture from the research test at the same event time was paired to demonstrate the change in occupant contact time due to the mid-track seat position. In all tests without side curtain deployment, the NCAP tests show right front passenger contact with the air bag occurring earlier due to the seat's full forward-track position. All right front passenger HIII-5F HIC15 head injury values demonstrated a low risk of injury (**Table 15**).

The research right front passenger HIII-5F was equipped with head angular rate sensors to allow for the calculation of BrIC and are included in **Table 15**. The Tahoe and the 2016 Honda Fit had the highest BrIC values. Comparing repeated research tests, the Ford F150 and Malibu demonstrated good repeatability for BrIC, while the Fit showed variations of around 18 percent. Only three NCAP tests had a right front passenger instrumented to compute BrIC. All Research BrIC measures were lower.

Table 15. Right Front Passenger Head Injury Values, HIC15 and BrIC

<table>
<tr><th>Vehicle</th><th>Research HIC15</th><th>NCAP HIC15</th><th>Research BrIC</th><th>NCAP BrIC</th></tr>
<tr><td>2016 Toyota Scion iA</td><td>186.6</td><td>n/a</td><td>Data Anomaly</td><td>n/a</td></tr>
<tr><td>2015 Honda Fit</td><td>149.3</td><td rowspan="2">266.6</td><td>0.69</td><td rowspan="2">n/a</td></tr>
<tr><td>2016 Honda Fit</td><td>154.9</td><td>0.81</td></tr>
<tr><td>2015 Mazda3</td><td>257.8</td><td>218.4</td><td>0.52</td><td>n/a</td></tr>
<tr><td>2016 Toyota Prius</td><td>182.6</td><td>156.5</td><td>Data Anomaly</td><td>0.71</td></tr>
<tr><td>2016 Mazda CX-5</td><td>259.5</td><td>173.8</td><td>0.56</td><td>0.86</td></tr>
<tr><td>2016 Chevrolet Malibu Limited</td><td>168.8</td><td rowspan="3">297.8</td><td>0.60</td><td rowspan="3">n/a</td></tr>
<tr><td>2015 Chevrolet Malibu</td><td>187.5</td><td>0.48</td></tr>
<tr><td>2015 Chevrolet Malibu</td><td>218.8</td><td>0.48</td></tr>
<tr><td>2016 Nissan Rogue</td><td>283.1</td><td>314.7</td><td>0.69</td><td>n/a</td></tr>
<tr><td>2015 Toyota Sienna</td><td>340.5</td><td>291.0</td><td>0.43</td><td>n/a</td></tr>
<tr><td>2015 Toyota Highlander</td><td>237.8</td><td>412.7</td><td>0.58</td><td>n/a</td></tr>
<tr><td>2015 Ford F-150</td><td>489.8</td><td rowspan="2">202.9</td><td>0.49</td><td rowspan="2">0.78</td></tr>
<tr><td>2016 Ford F-150</td><td>380.3</td><td>0.45</td></tr>
<tr><td>2016 Chevrolet Tahoe</td><td>204.8</td><td>284.5</td><td>0.87</td><td>n/a</td></tr>
</table>

The HIII-5F Nij values did not have a clear trend between the research and NCAP test results. The 2015 Honda Fit had the largest increase from the Nij measured in NCAP and the Mazda CX-5 had the largest decrease. In terms of repeatability, the Fit and Malibu results were reasonably repeatable. There was a large variance for the F150, but the risk of injury remained low. The HIII-5F peak neck tension and compression values also had no trend in comparison to NCAP testing.

Table 16. Right Front Passenger, Neck Injury Values

<table>
<tr><th>Vehicle</th><th>Research Nij</th><th>NCAP Nij</th><th>Research Tension (N)</th><th>NCAP Tension (N)</th><th>Research Compression (N)</th><th>NCAP Compression (N)</th></tr>
<tr><td>2016 Toyota Scion iA</td><td>0.29</td><td>n/a</td><td>551.2</td><td>n/a</td><td>-452.0</td><td>n/a</td></tr>
<tr><td>2015 Honda Fit</td><td>0.62</td><td rowspan="2">0.30</td><td>1322.9</td><td rowspan="2">850.6</td><td>-205.6</td><td rowspan="2">-213.5</td></tr>
<tr><td>2016 Honda Fit</td><td>0.57</td><td>1220.6</td><td>-190.9</td></tr>
<tr><td>2015 Mazda3</td><td>0.45</td><td>0.48</td><td>769.0</td><td>946.6</td><td>-310.6</td><td>-344.9</td></tr>
<tr><td>2016 Toyota Prius</td><td>0.57</td><td>0.53</td><td>1114.2</td><td>765.2</td><td>-405.1</td><td>-202.4</td></tr>
<tr><td>2016 Mazda CX-5</td><td>0.30</td><td>0.77</td><td>649.3</td><td>1154.9</td><td>-734.4</td><td>-286.2</td></tr>
<tr><td>2016 Chevrolet Malibu Limited</td><td>0.52</td><td rowspan="3">0.63</td><td>669.4</td><td rowspan="3">1043.3</td><td>-64.3</td><td rowspan="3">-482.5</td></tr>
<tr><td>2015 Chevrolet Malibu</td><td>0.49</td><td>561.5</td><td>-141.1</td></tr>
<tr><td>2015 Chevrolet Malibu</td><td>0.44</td><td>551.3</td><td>-74.2</td></tr>
<tr><td>2016 Nissan Rogue</td><td>0.54</td><td>0.42</td><td>994.9</td><td>592.9</td><td>-395.4</td><td>-272.5</td></tr>
<tr><td>2015 Toyota Sienna</td><td>0.52</td><td>0.32</td><td>879.1</td><td>972.9</td><td>-368.4</td><td>-244.9</td></tr>
<tr><td>2015 Toyota Highlander</td><td>0.51</td><td>0.35</td><td>1282.7</td><td>968.5</td><td>-277.1</td><td>-355.6</td></tr>
<tr><td>2015 Ford F150</td><td>0.47</td><td rowspan="2">0.32</td><td>935.8</td><td rowspan="2">737.3</td><td>-353.4</td><td rowspan="2">-287.1</td></tr>
<tr><td>2016 Ford F150</td><td>0.29</td><td>853.3</td><td>-304.6</td></tr>
<tr><td>2016 Chevrolet Tahoe</td><td>0.55</td><td>0.34</td><td>989.6</td><td>882.7</td><td>-603.7</td><td>-328.0</td></tr>
</table>

HIII-5F chest deflection is measured by a potentiometer located behind the sternum. The peak deflection measurements are presented in **Table 17** for both the research and NCAP tests. Chest deflection measured in the research tests was generally larger than the corresponding NCAP test. Only one of the 2015 Malibu vehicles and the Malibu Limited had lower peak sternum deflections. All sternum deflections were well below injury levels, so the differences do not reflect a significant change in occupant injury risk.

Twelve of the research tests included the RibEye Deflection Measurement System. The location of the maximum rib deflection for the right front passenger HIII-5F was consistently on the upper left rib. On average, the RibEye measured 2 mm of additional chest deflection as compared to the chest potentiometer. **Appendix B** includes the maximum deflections for each rib of the right front passenger.

Table 17. Right Front Passenger, Chest Deflection Measurements

Vehicle	Research RibEye Deflection	Research Sternum Deflection	NCAP Sternum Deflection
2016 Toyota Scion iA	Not installed[2]	13.2	n/a
2015 Honda Fit	26.1	24.4	14.5
2016 Honda Fit	24.4	22.8	
2015 Mazda3	21.7	17.7	12.2
2016 Toyota Prius	Not installed	17.1	11.0
2016 Mazda CX-5	Not installed	18.3	8.3
2016 Chevrolet Malibu Limited	18.0	16.0	16.5
2015 Chevrolet Malibu	19.5	17.6	
2015 Chevrolet Malibu	16.5	13.9	
2016 Nissan Rogue	34.3	34.3	9.0
2015 Toyota Sienna	17.0	15.7	9.2
2015 Toyota Highlander	25.2	22.6	7.2
2015 Ford F-150	22.2	20.7	7.9
2016 Ford F-150	19.9	18.4	
2016 Chevrolet Tahoe	19.9	18.5	14.8

The seat track position affects the height where the seat belt crosses the ATD's centerline and how it loads the chest. The distance from a reference plate positioned in the seated ATD's lap to the torso belt's upper and lower edge along the ATD's centerline was measured for each test. The average of the two measurements defined the "belt center height." The belt height was plotted against the peak sternum deflection in **Figure 6**. The plot shows a clear separation between the research and NCAP test results. The data points in the circle are the NCAP test results which tended to have lower chest deflection and higher belt height across the chest.

[2] The final three research tests did not include RibEye instrumentation.

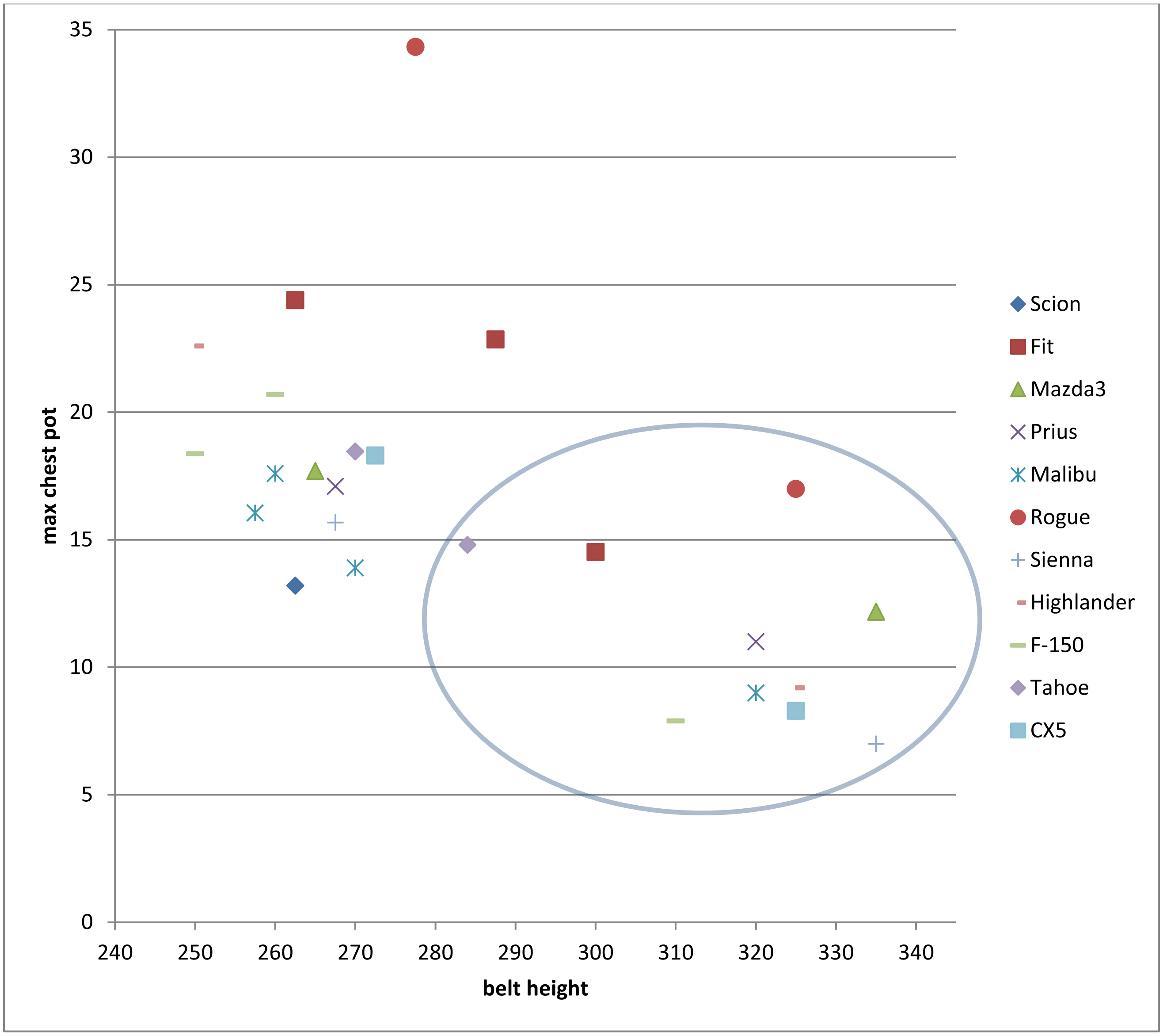


Figure 6. Right Front Passenger, Belt Height and Chest Deflection.

The mid-track seat position increased the knee-to-dash distance as shown in **Table 18**. The compressive femur forces in the research tests were markedly lower than in NCAP tests. In **Table 18**, the largest compressive femur load for each test is shown in bold. The leg with peak loading was not consistent between research and NCAP tests. All peak femur loads indicate a very low risk of femur fracture. For many research tests, the magnitude of the peak femur tension (not shown) exceeded the peak femur compression, due to inertial loading.

Table 18. Right Front Passenger, Femur Compression Force and Knee-to-Dash Distance

<table>
<tr><th>Vehicle</th><th>Research Left Femur Comp. (N)</th><th>NCAP Left Femur Comp. (N)</th><th>Research Right Femur Comp. (N)</th><th>NCAP Right Femur Comp. (N)</th><th>Research Left Knee Dist. (mm)</th><th>NCAP Left Knee Dist. (mm)</th><th>Research Right Knee Dist. (mm)</th><th>NCAP Right Knee Dist. (mm)</th></tr>
<tr><td>2016 Toyota Scion iA</td><td>414.6</td><td>n/a</td><td>137.3</td><td>n/a</td><td>213</td><td>n/a</td><td>220</td><td>n/a</td></tr>
<tr><td>2015 Honda Fit</td><td>63.7</td><td rowspan="2">1449.0</td><td>56.5</td><td rowspan="2">1668.0</td><td>165</td><td rowspan="2">74</td><td>175</td><td rowspan="2">79</td></tr>
<tr><td>2016 Honda Fit</td><td>71.0</td><td>69.6</td><td>165</td><td>175</td></tr>
<tr><td>2015 Mazda3</td><td>167.0</td><td>1582.3</td><td>71.6</td><td>1137.5</td><td>205</td><td>106</td><td>224</td><td>106</td></tr>
<tr><td>2016 Toyota Prius</td><td>631.2</td><td>904.5</td><td>59.2</td><td>794.9</td><td>240</td><td>109</td><td>245</td><td>114</td></tr>
<tr><td>2016 Mazda CX-5</td><td>509.4</td><td>1809.0</td><td>392.8</td><td>1304.1</td><td>166</td><td>55</td><td>180</td><td>72</td></tr>
<tr><td>2016 Chevrolet Malibu Limited</td><td>71.3</td><td rowspan="3">506.8</td><td>108.2</td><td rowspan="3">610.0</td><td>275</td><td rowspan="3">163</td><td>270</td><td rowspan="3">162</td></tr>
<tr><td>2015 Chevrolet Malibu</td><td>93.1</td><td>92.1</td><td>263</td><td>256</td></tr>
<tr><td>2015 Chevrolet Malibu</td><td>109.0</td><td>113.1</td><td>264</td><td>258</td></tr>
<tr><td>2016 Nissan Rogue</td><td>766.2</td><td>1745.7</td><td>69.1</td><td>1786.4</td><td>190</td><td>74</td><td>190</td><td>87</td></tr>
<tr><td>2015 Toyota Sienna</td><td>769.6</td><td>1722.0</td><td>358.1</td><td>1744.7</td><td>190</td><td>80</td><td>195</td><td>93</td></tr>
<tr><td>2015 Toyota Highlander</td><td>625.1</td><td>2687.4</td><td>103.8</td><td>1355.6</td><td>195</td><td>80</td><td>203</td><td>83</td></tr>
<tr><td>2015 Ford F-150</td><td>405.6</td><td rowspan="2">1813.0</td><td>448.5</td><td rowspan="2">1417.9</td><td>205</td><td rowspan="2">74</td><td>214</td><td rowspan="2">79</td></tr>
<tr><td>2016 Ford F-150</td><td>158.9</td><td>149.5</td><td>205</td><td>210</td></tr>
<tr><td>2016 Chevrolet Tahoe</td><td>428.0</td><td>432.1</td><td>181.1</td><td>1483.0</td><td>222</td><td>141</td><td>220</td><td>147</td></tr>
</table>

HIII-5F Right Rear Passenger Injury Assessment

The rear seating positions in the tested vehicles did not contain supplemental or advanced restraint devices (e.g., seat belt pretensioner or seat belt load limiter). Head contact with the front seat back occurred in one test, the 2016 F150. Surprisingly, this test had the second largest nose to seat back clearance distance of 748 mm. Two of the tests, the Mazda3 and Prius, had knee contact with the front seat back. Both tests had lower, but not the lowest, knee to seat back clearance distances at 230 and 258 mm, respectively.

The rear seat shoulder belt forces, shown in **Figure 7**, were significantly larger than forces measured for the right front seating position. The Scion iA had a noticeably high peak shoulder belt force which started earlier and was maintained for a longer duration than the other vehicles.

The rear seat lap belt force, shown in **Figure 8**, demonstrated large variation among the research tests. Again, the Scion belt forces were greater than rear seat lap belt forces measured in the other vehicles. There was significant variation in the peak load, timing and shape for the measured lap belt loads.

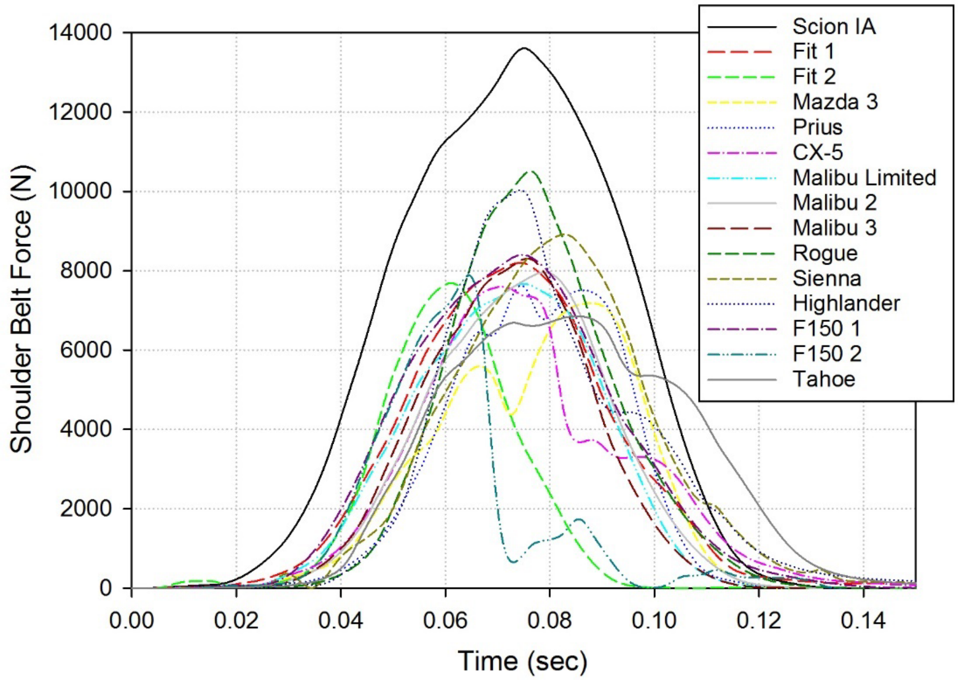


Figure 7. Rear Right Seat Passenger Shoulder Belt Force.

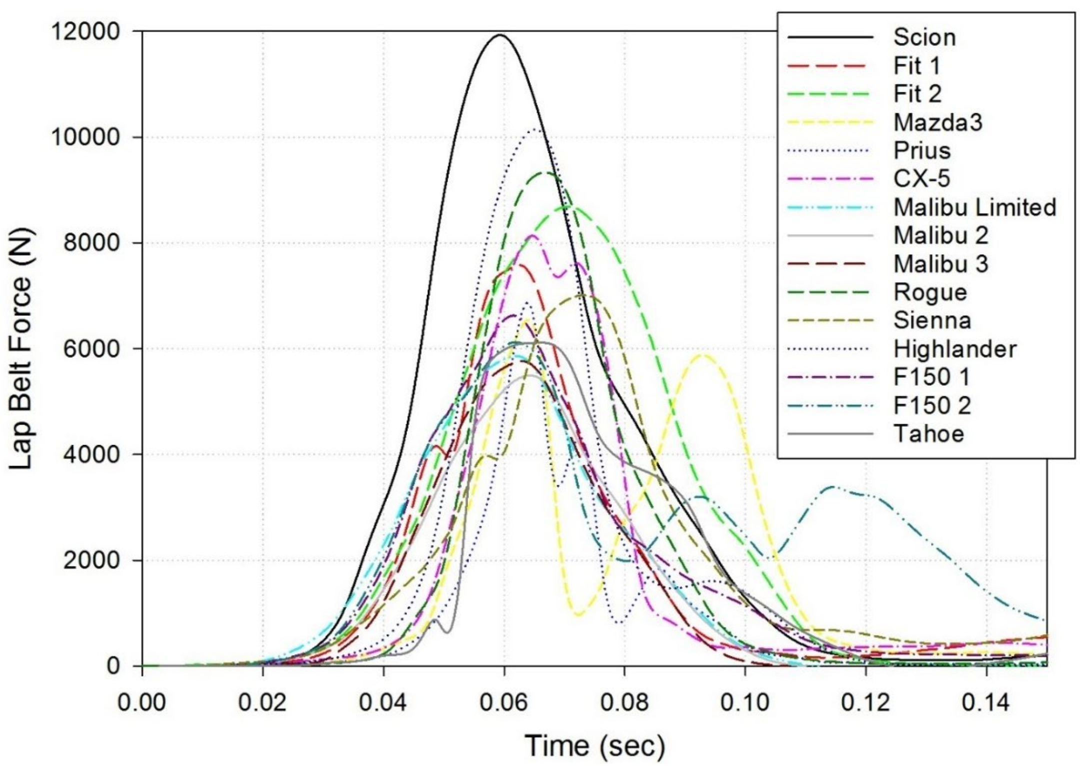


Figure 8. Rear Right Seat Lap Belt Force.

For research purposes, HIC15 was calculated for all crash events that had available data (**Table 19**). Surprisingly, the 2016 F150 was the only test where head contact occurred and had the lowest HIC15. The 2015 F150 had a failure in the X-axis head accelerometer which prevented the HIC15 computation.

Table 19. Right Rear Passenger, HIC15

Vehicle	HIC15	HIC15 Duration (ms)
2016 Toyota Scion iA	482.0	82.75 - 97.75
2015 Honda Fit	737.9	82.45 - 97.45
2016 Honda Fit	915.5	80.4 - 95.4
2015 Mazda3	1098.9	79.65 - 94.65
2016 Toyota Prius	972.1	78.1 - 93.1
2016 Mazda CX-5	570.8	91.5 - 106.5
2016 Chevrolet Malibu Limited	811.3	77.5 - 92.5
2015 Chevrolet Malibu	939.4	76.5 - 91.5
2015 Chevrolet Malibu	844.5	72.25 - 87.25
2016 Nissan Rogue	1155.3	80.25 - 95.25
2015 Toyota Sienna	788.9	85.8 - 100.8
2015 Toyota Highlander	1509.6	82.9 - 97.9
2015 Ford F150	Data Anomaly	Data Anomaly
2016 Ford F150	151.1	55.6 - 69.8
2016 Chevrolet Tahoe	578.6	92.15 - 107.15

The low HIC15 in the 2016 Ford F150 testing is accompanied by a sudden drop in shoulder belt force at 0.066 seconds. This test also had significant rotation of the ATD's torso. These forces are isolated in **Figure 9** below. The rapid drop in shoulder belt force suggests that the head contact with the seat back, although not resulting in a high HIC15 value, was more significant than it appeared visually. It may be desirable to monitor neck loads for rear seat occupants.

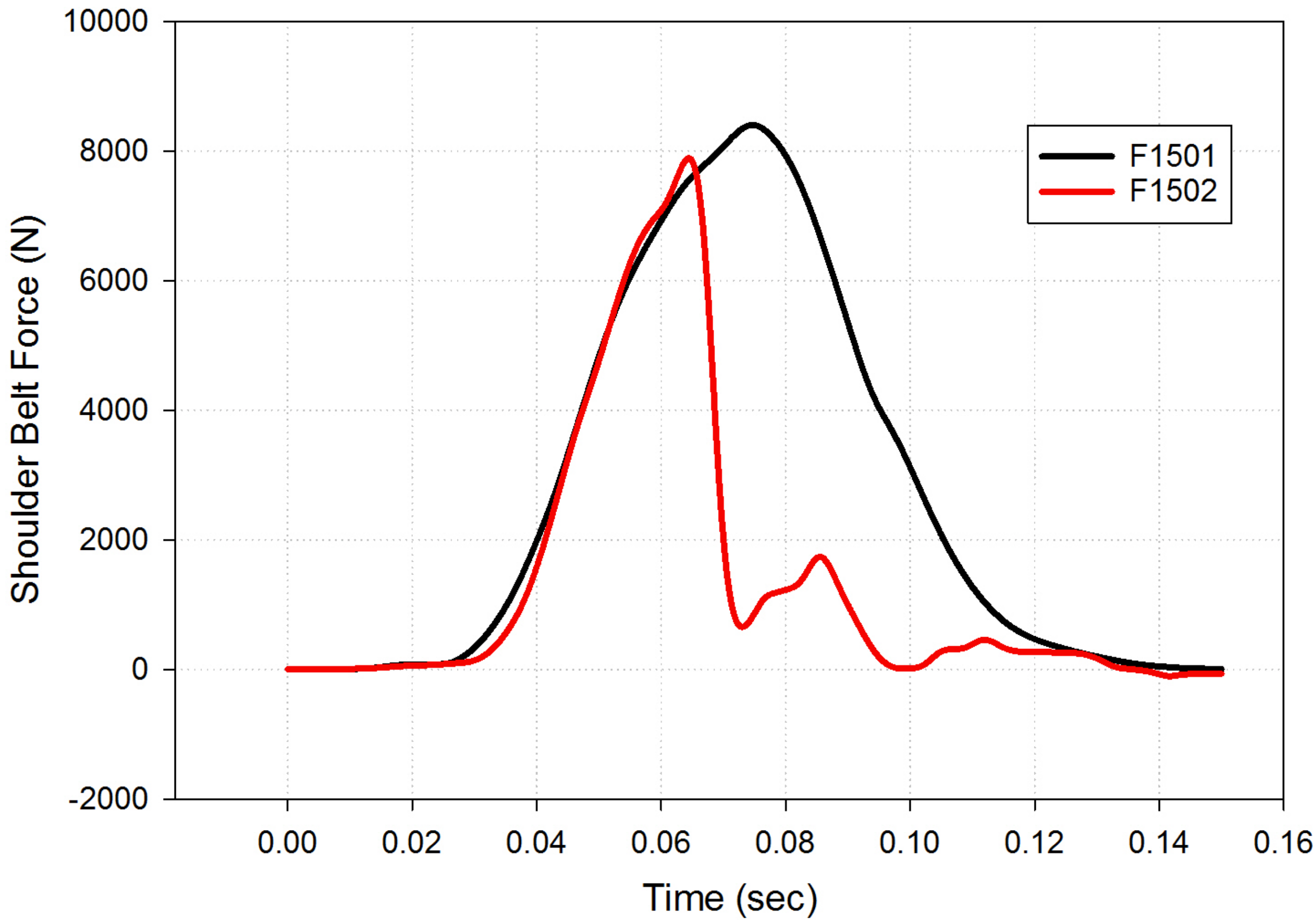


Figure 9. Right Rear Passenger Shoulder Belt Force in Ford F150 Research Tests.

Chest deflection measurements are shown in **Table 20**. The Toyota Highlander's sternum deflection potentiometer measurement appeared to truncate near the near the top of the qualification corridor but within the measurement range of the potentiometer. This anomalous measurement is not reported in **Table 20**. Similar to the right front passenger HIII-5F, the right rear passenger HIII-5F had the RibEye system installed for all but three of the research tests. In two tests, the Toyota Highlander and the 2015 Ford F150, the RibEye system did not collect data due to equipment issues. The maximum x-axis deformation is shown in **Table 20**. The peak deflection measured using the RibEye system was always larger than that measured by the sternum potentiometer and was always observed on the HIII-5F's left side. The rib that had the maximum deflection was not consistent or repeatable. On average, the rear seat HIII-5F had an additional 23 mm of chest deflection as compared to the research testing of the right front HIII-5F passenger at mid-track and an additional 31 mm of chest deflection as compared to the right front NCAP tests.

Table 20. Right Rear Passenger, Chest Deflection Measurements

Vehicle	Sternum Deflection (mm)	RibEye Deflection (mm)
2016 Toyota Scion iA	35.2	Not Installed[3]
2015 Honda Fit	48.0	55.8
2016 Honda Fit	47.8	53.8
2015 Mazda3	39.1	54.1
2016 Toyota Prius	31.4	Not Installed
2016 Mazda CX-5	37.5	Not Installed
2016 Chevrolet Malibu Limited	40.8	48.5
2015 Chevrolet Malibu	42.7	46.8
2015 Chevrolet Malibu	41.1	49.3
2016 Nissan Rogue	50.7	56.0
2015 Toyota Sienna	44.8	58.4
2015 Toyota Highlander	Data Anomaly	Data Anomaly
2015 Ford F150	51.6	Data Anomaly
2016 Ford F150	40.6	50.5
2016 Chevrolet Tahoe	39.4	45.0

Appendix C displays the peak displacements for each of the tests with data collected from the RibEye system. As mentioned previously, rib #1 is at the top of the chest, and rib #6 is at the bottom. The rear seat occupant had more frequent signal drop-outs than the right front passenger. Most drop-outs occurred at the left upper rib (#1) and at the right lower ribs (#5 & #6). The signal drop-outs seem to occur due to obscuring the light emitting diode unit. Drop-outs for right ribs #5 and #6 may be related to interference by the abdominal insert. There is also the potential that the left rib #1 drop-outs come from interference from the chest potentiometer structure, but these potential interference sources were not confirmed in this test series.

Four of the rear seat occupants demonstrated submarining behavior. In these tests, the lap belt of the right rear passenger was observed to slide up into the abdomen area. Submarining was observed in the Mazda3, Tahoe, Prius, and CX-5 research tests. To verify these observations, the ASIS load cell measurements were reviewed using the process described by Keon (2016). A decreasing rate of force of 1,000,000 N/second is used to support the visual observations. The right and left ASIS load cell forces for each of these vehicles are shown in **Figures 10-13**. These plots also include the derivative of the force time-history to show the rate of ASIS force decrease.

[3] The final three research tests did not include RibEye instrumentation.

A horizontal line is included on the plots to show when the rate of force decrease exceeds the reference level.

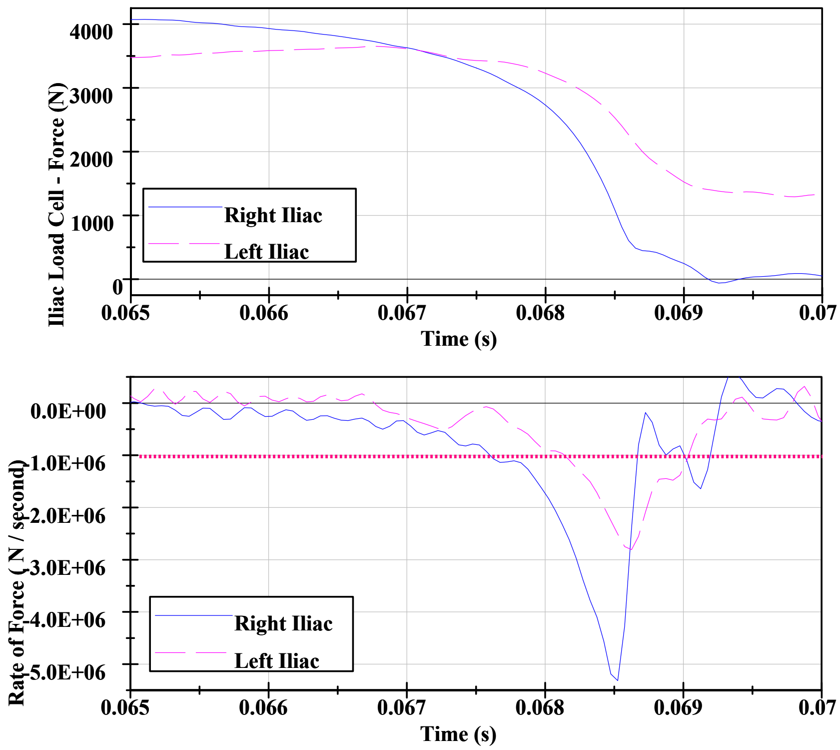


Figure 10. Mazda3, Right Rear Passenger, Iliac Load Cells.

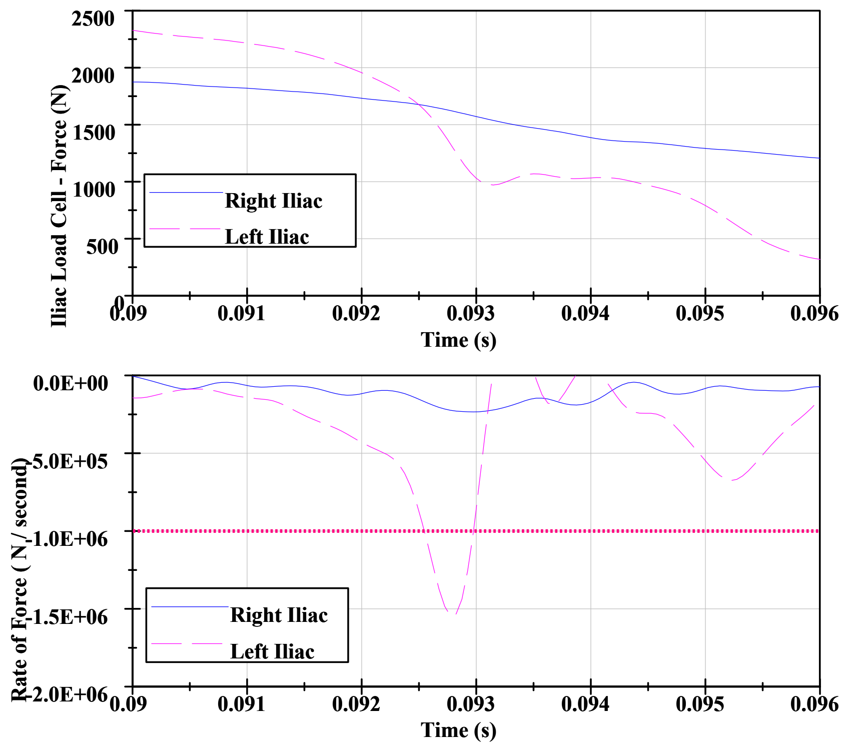


Figure 11. Chevrolet Tahoe, Right Rear Passenger, Iliac Load Cells.

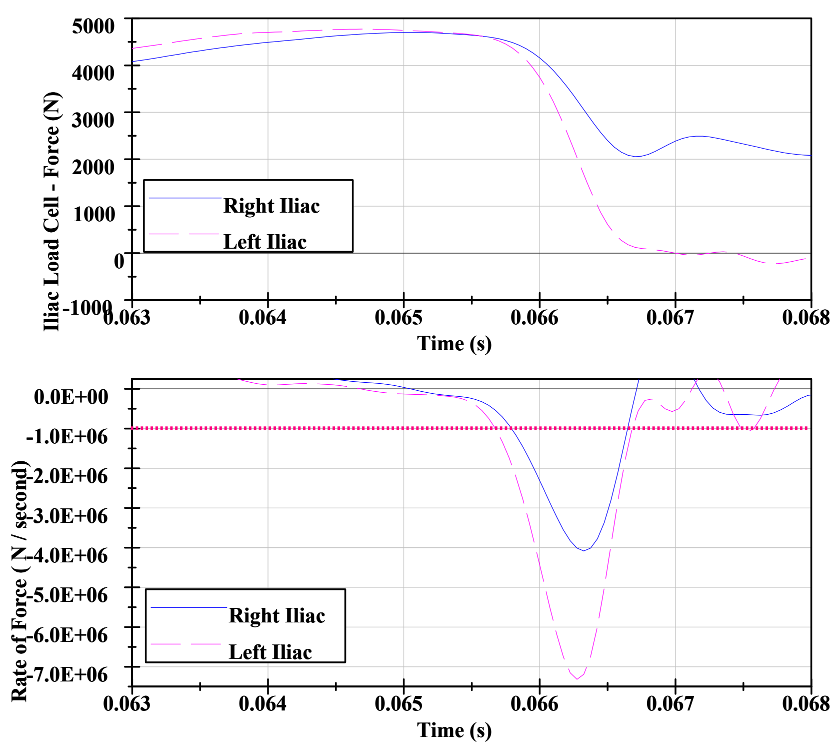


Figure 12. Toyota Prius, Right Rear Passenger, Iliac Load Cells.

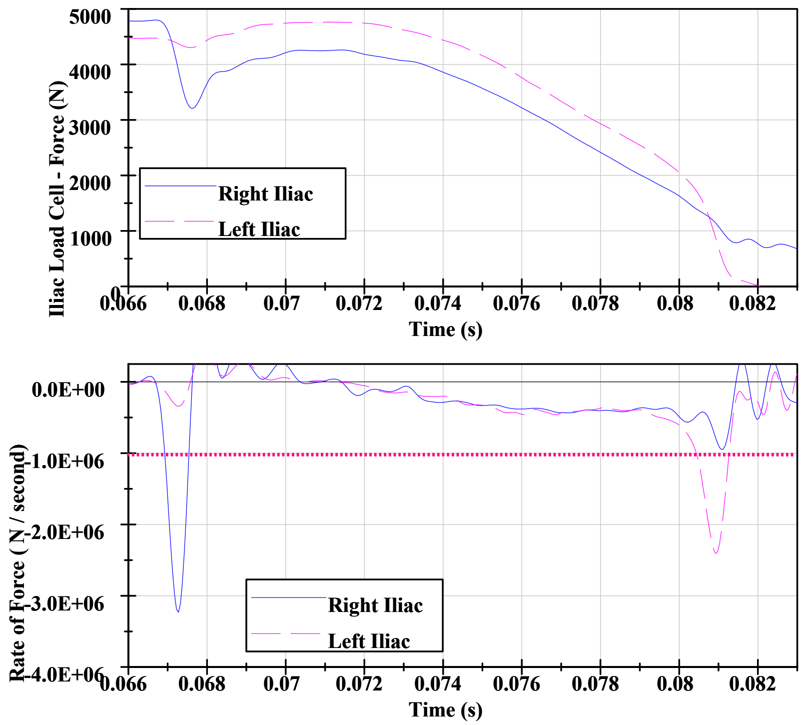


Figure 13. Mazda CX-5, Right Rear Passenger, Iliac Load Cells.

Summary

Fifteen frontal rigid barrier tests were conducted at 56 kph using the THOR-50M in the driver seat. The test results were compared to previously conducted NCAP tests. The THOR-50M driver had low but greater HIC15 values, relative to HIII-50M, in all tests except for the Prius. The THOR-50M tests had consistently larger Nij values than the HIII-50M, except for the Sienna. Neck peak tension results varied considerably between the THOR-50M and the HIII-50M. In all tests, the THOR-50M measured greater chest deflections than the HIII-50M. The THOR-50M peak resultant chest deflections occurred at the right upper measurement location for all tests, which was nearest measurement to the belt's initial position. The abdominal IR-TRACC measurements were not repeatable and had multiple sensor failures. The peak acetabulum force also demonstrated variability between repeat tests. The THOR-50M peak femur loads were greater than HIII-50M in matching tests for all vehicles except the Malibu tests. There was considerable variation comparing upper and lower tibia forces between the two 50th percentile male ATDs.

For the right front passenger HIII-5F, the revised mid-track seating position increased the chest-to-dash distance by 88 to 153 mm. Despite this increased clearance distance, HIC15 measurements remained low and did not display any trend in comparison against NCAP tests conducted with a full forward seating position. The BrIC ranged from 0.43 to 0.87 with an average of 0.59. The Nij, peak tension, and peak compression did not demonstrate a consistent trend of increasing or decreasing based on the change in seat track position. Maximum deflection of the sternum potentiometer was consistently larger for the mid-track seating position. The RibEye system measured an average of 2 mm more deflection than the sternum potentiometer. Peak femur compressive forces were low for all tests in the mid-track seating position.

For the right rear HIII-5F passenger, one of the 15 tests had head contact with the front seatback and two tests had knee contact with the front seat. The test with head-seat contact recorded the lowest HIC15 value but experienced a sharp drop in shoulder belt force suggesting that significant force may have been transmitted during the head contact. The rear seat sternum deflections averaged 23 mm and 31 mm larger than for the right front passenger at mid-track and conventional full forward track positions, respectively. Unlike the right front passenger, the rear seat RibEye deflection measurements were significantly greater than sternum deflections. There were frequent RibEye signal drop-outs for the rear seat HIII-5F's. Peak shoulder belt loads for the right rear passenger were nearly double than the loads for the right front passenger. In four tests, submarining behavior was observed and supported by evaluation of the iliac force measurements.

References

ATD Harmonization Task Group. (2012, July 27). *The brand harmonization of the Hybrid III 5th small female crash test dummy.* Humanetics Innovative Solutions, Inc. Retrieved from https://humanetics.humaneticsgroup.com/sites/default/files/2020-06/hiii_5th_sf_harmonization_white_paper.pdf.

Boxboro Systems. (2015, December 31). RibEye multi-point deflection measurement system [Webpage]. Author. www.boxborosystems.com/ribeye.html.

Keon, T. (2016, April). Alternative approaches to occupant response evaluation in frontal impact. *Journal of Transportation Safety 4*(1):202-217.

National Highway Traffic Safety Administration. (2016, August). *THOR-50M drawing package*. Retrieved from www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/thor-50m_drawing_package-august_2016.pdf.

Parent, D., Craig, M., & Moorhouse, K. (2017). Biofidelity evaluation of the THOR and Hybrid III 50th percentile male frontal impact anthropomorphic test devices. *Stapp Car Crash Journal, 61*: pp. 227-76.

Vehicle Crash Test Database. (n.d.). Retrieved from www-nrd.nhtsa.dot.gov/database/VSR/veh/QueryTest.aspx

Wiacek, N. R. (2015). *Evaluation of frontal crash stiffness measures from the U.S. New Car Assessment Program*. Gothenberg, Sweden: ESV Conference.

APPENDIX A: NCAP Front Passenger Air Bag Contact Time Match With Research Tests

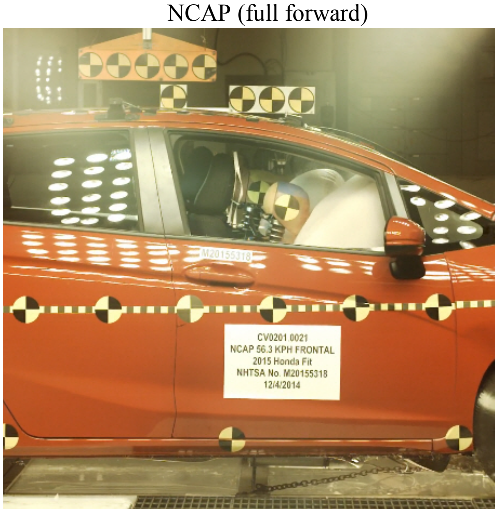
The paired photos below were captured at the same time after impact. The NCAP test was captured at the time of first observed contact between the passenger air bag and the HII-5F ATD. A matching photo from the research test is shown to illustrate the change in air bag interaction for the mid-track seating position. Only the six tests that did not deploy the side curtain are shown below.

NCAP (full forward)

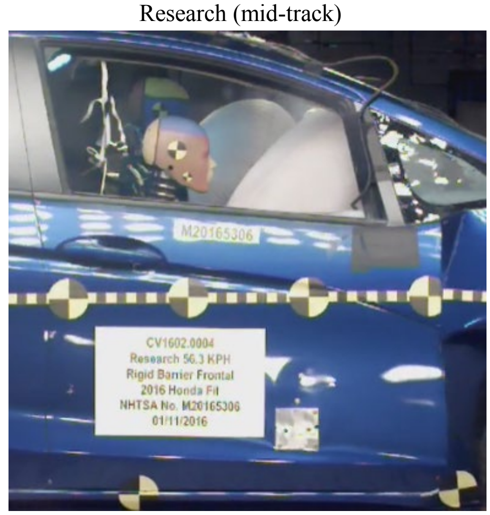
Research (mid-track)

Honda Fit, tests 9033 and 9337 at NCAP air bag contact - 0.046 seconds.

NCAP (full forward)

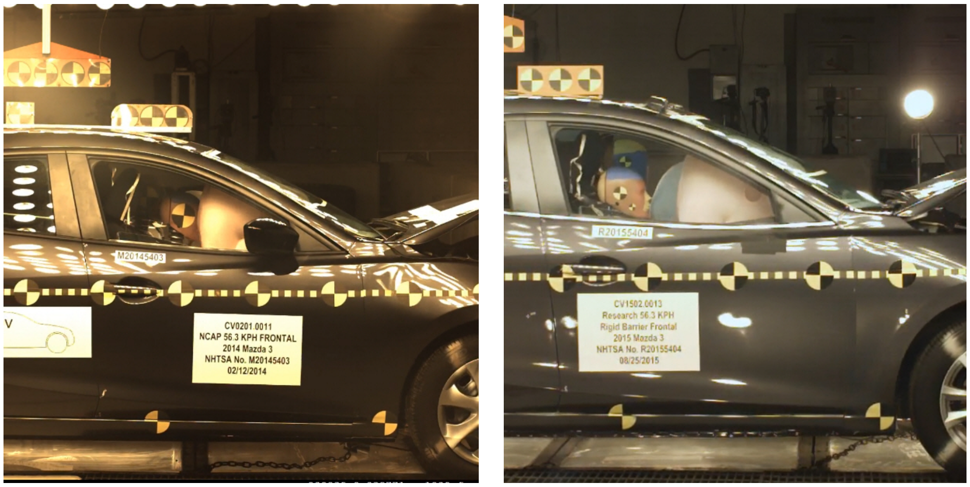


Research (mid-track)



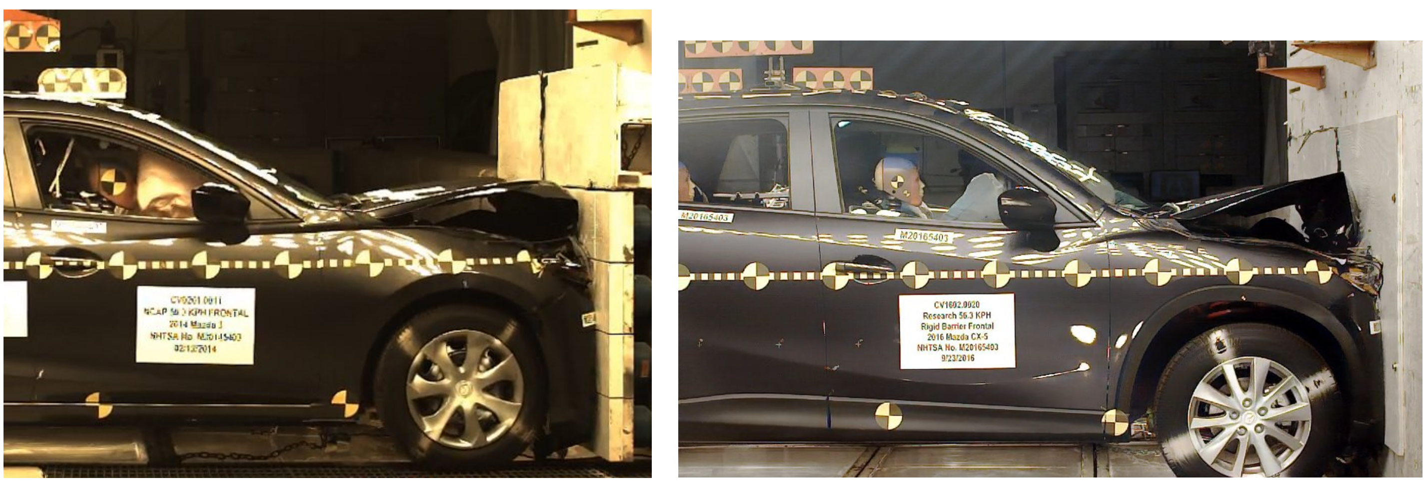
Honda Fit, tests 9033 and 9556 at NCAP air bag contact - 0.046 seconds.

NCAP (full forward) Research (mid-track)



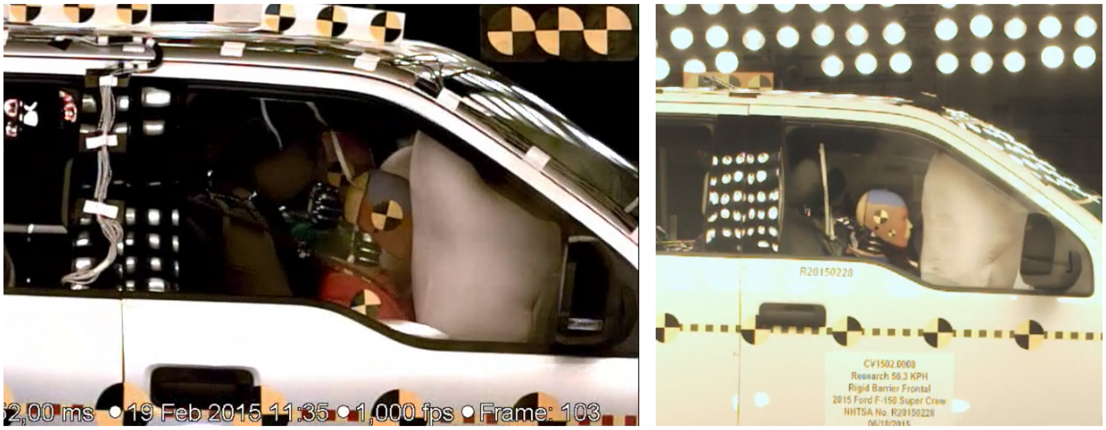
Mazda3 tests 8539 and 9336 at NCAP air bag contact - 0.039 seconds.

NCAP (full forward) Research (mid-track)



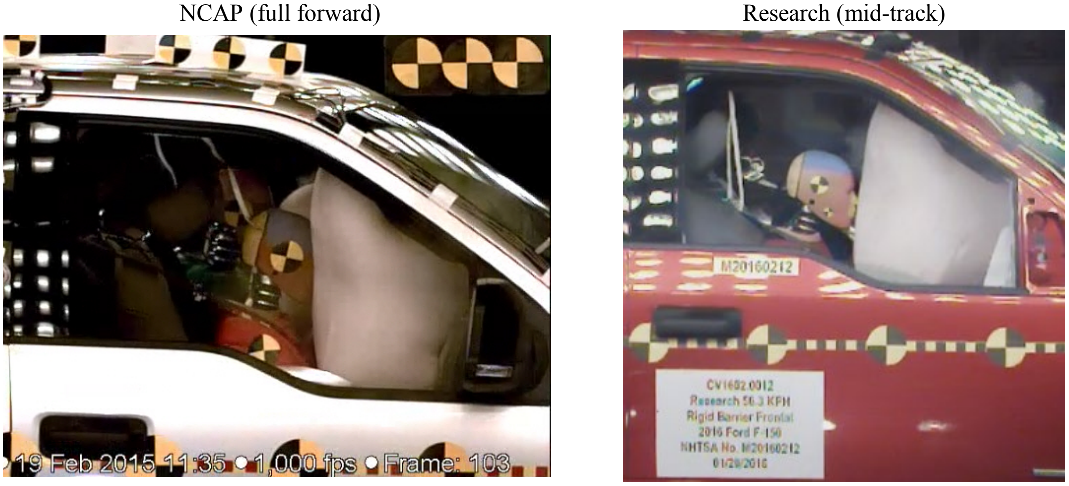
Mazda Cx5 tests 9136 and 9966 at NCAP air bag contact - 0.30 seconds.

NCAP (full forward) | Research (mid-track)



Ford F150 tests 9097 and 9335 at NCAP air bag contact - 0.052 seconds.

NCAP (full forward) | Research (mid-track)



Ford F150 tests 9571 and 9571 at NCAP air bag contact - 0.052 seconds.

APPENDIX B: Peak Ribeye Deflection, Right Front Passenger

Note: Maximum rib eye deflection measurement is **bolded**.

Drop-out signals are noted with an asterisk and the rib deflection prior to signal loss is provided.

Fit 9337	rib deflection (mm)	
rib #	Left	Right
1	**-26.1**	-16.9
2	-25.5	-14.8
3	-25.1	-13.7
4	-24.5	-12.4
5	-23.9	-11.8
6	-22.5	-5*

maximum chest pot deflection: 24.4 mm

Fit 9566	rib deflection (mm)	
rib #	Left	Right
1	**-24.4**	-17.1
2	-23.9	-14.6
3	-23.5	-13.4
4	-22.8	-12.4
5	-21.9	-11.7
6	-20.6	-10.9*

maximum chest pot deflection: 22.9 mm

Mazda3 9336	rib deflection (mm)	
rib #	Left	Right
1	**-21.7**	-12.5
2	-20.4	-10.6
3	-19.5	-9.4
4	-18.3	-8.3
5	-17.2	-7.5
6	-16.2	-3.0*

maximum chest pot deflection: 17.7 mm

Malibu 9567	rib deflection (mm)	
rib #	Left	Right
1	**-18.0**	-12.9
2	-17.0	-11.1
3	-15.8	-9.7
4	-14.8	-8.3
5	-13.8	-7.2
6	-12.2	-6.0

maximum chest pot deflection: 16.1 mm

Malibu 9333	rib deflection (mm)	
rib #	Left	Right
1	**-19.5**	-13.3
2	-18.4	-11.3
3	-17.5	-10.3
4	-16.1	-8.7
5	-15.1	-7.6
6	-13.9	-3*

maximum chest pot deflection: 17.6 mm

Malibu 9332	rib deflection (mm)	
rib #	Left	Right
1	**-16.5**	-11.2
2	-15.2	-9.3
3	-14.2	-8.2
4	-12.9	-6.8
5	-11.8	-5.8
6	-10.4	-3*

maximum chest pot deflection: 13.9 mm

Rogue 9569	rib deflection (mm)	
rib #	Left	Right
1	**-34.3**	-24.2*
2	-33.8	-21.2
3	-33.4	-19.6
4	-33.3	-18.0
5	-33.3	-17.0
6	-32.6	*

maximum chest pot deflection: 34.3 mm

Sienna 9570	rib deflection (mm)	
rib #	Left	Right
1	**-17.0**	-12.7
2	-16.4	-10.5
3	-15.4	-9.4
4	-14.6	-7.9
5	-13.6	-7.0
6	-12.5	-4*

maximum chest pot deflection: 15.7 mm

Highlander 9334	rib deflection (mm)	
rib #	Left	Right
1	**-25.2**	-16.4
2	-24.0	-13.9
3	-23.1	-12.3
4	-22.0	-10.7
5	-21.4	-9.4
6	-19.9	-3*

maximum chest pot deflection: 22.6 mm

F150 9335.	rib deflection (mm)	
rib #	Left	Right
1	**-22.2**	-16.2
2	-20.7	-13.6
3	-19.8	-12.4
4	-18.4	-10.7
5	-17.4	-9.7
6	-15.6	-6*

maximum chest pot deflection: 20.7 mm

F150 9571	rib deflection (mm)	
rib #	Left	Right
1	**-19.9**	-14.7
2	-19.0	-12.4
3	-18.1	-11.6
4	-17.2	-9.7
5	-16.0	-8.6
6	-14.8	-7*

maximum chest pot deflection: 18.4 mm

Tahoe 9568	rib deflection (mm)	
rib #	Left	Right
1	**-19.9**	-16.4
2	-18.8	-13.9
3	-17.4	-12.2
4	-16.3	-10.5
5	-15.5	-8.8
6	-13.9	-6*

maximum chest pot deflection: 18.5 mm

APPENDIX C: Peak Ribeye Deflection, Right Rear Passenger

Note: Maximum rib eye deflection measurement is **bolded**.

Drop-out signals are noted with an asterisk and the rib deflection prior to signal loss is provided.

Data acquisition errors occurred for two tests, Highlander 9334, and F150 9335.

Fit 9337		rib deflection (mm)	
	rib #	Left	Right
	1	-43*	-29.2
	2	-49.3	-29.4
	3	-52.8	-28.3
	4	**-55.8**	-19*
	5	-58*	-12*
	6	-58*	-2*

maximum chest pot deflection: -40.8

Fit 9566		rib deflection (mm)	
	rib #	Left	Right
	1	-42*	-31.4
	2	-47.7	-31.6
	3	-50.7	-30.3
	4	**-53.8**	-21*
	5	-54*	-11*
	6	-54*	0*

maximum chest pot deflection: -48.0

Mazda3 9336		rib deflection (mm)	
	rib #	Left	Right
	1	-46*	-22.1
	2	-52.8	-20.7
	3	**-54.1**	-17.8
	4	-52.5	-15*
	5	-51	-14*
	6	-48	-3*

maximum chest pot deflection: -39.1

Malibu 9567		rib deflection (mm)	
	rib #	Left	Right
	1	-43*	-30.1
	2	-43.6	-28.2
	3	-45.0	-25.9
	4	**-46.9**	-23
	5	-49	-13*
	6	-48	0*

maximum chest pot deflection: -47.8

Malibu 9332		rib deflection (mm)	
	rib #	Left	Right
	1	-44*	-28.4
	2	-45.5	-26.1
	3	-47.3	-24.6
	4	**-47.9**	-22
	5	-49	-13*
	6	-48	-4*

maximum chest pot deflection: -42.7

Malibu 9333		rib deflection (mm)	
	rib #	Left	Right
	1	-44*	-26.7
	2	-43.7	-24.4
	3	-45.4	-23.1
	4	**-45.7**	-20
	5	-47	-13*
	6	-45	-13*

maximum chest pot deflection: -41.1

Rogue 9569		rib deflection (mm)	
	rib #	Left	Right
	1	-39*	-33.3
	2	-49.5	-32.9
	3	-52.7	-27*
	4	**-56.0**	-22*
	5	-50*	-15*
	6	-50*	0*

maximum chest pot deflection: -50.7

Sienna 9570		rib deflection (mm)	
	rib #	Left	Right
	1	-41*	-30.6
	2	-48.1	-29.4
	3	-51.1	-27.3
	4	**-52.1**	-18
	5	-57	-12
	6	-58*	0

maximum chest pot deflection: -44.8

F150 9571		rib deflection (mm)	
	rib #	Left	Right
	1	-43*	-25.6
	2	-44.6	-24.3
	3	-47.2	-21.9
	4	**-48.2**	-17*
	5	-51	-10*
	6	-50	0*

maximum chest pot deflection: -40.6

Tahoe 9568		rib deflection (mm)	
	rib #	Left	Right
	1	-40*	-29.0
	2	-42.5	-27.1
	3	-43.7	-24.5
	4	**-43.8**	-22
	5	-45	-13*
	6	-44	0*

maximum chest pot deflection: -39.4

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