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Vehicle Bumper Performance in Part 581 Versus Pedestrian Leg Protection

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16. Abstract

The objective of this study was to determine if it was possible for a single bumper design to perform well with respect to both pedestrian protection and Part 581 bumper damageability requirements. This possibility was investigated by testing various bumper configurations for a "global platform" vehicle following both the European New Car Assessment Programme (EuroNCAP) Pedestrian Testing Protocol and the Code of Federal Regulations 49 Part 581 Bumper Standard. To investigate the bumper damageability side of this question, the test conditions most relevant to pedestrian protection were conducted: the 2.5 mph front center (longitudinal) and 1.5 mph front corner tests. EuroNCAP pedestrian and Part 581 bumper impacts were performed on a U.S. model 2012 Ford Focus and an E.U. model 2012 Ford Focus, which was a U.S. model Ford Focus fitted with European front bumper components.

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Background and Objective

The objective of this study was to determine if it was possible for a single bumper design to perform well with respect to both pedestrian protection and Part 581 bumper damageability requirements. This possibility was investigated by testing various bumper configurations for a "global platform" vehicle following both the European New Car Assessment Programme (EuroNCAP) Pedestrian Testing Protocol and the Code of Federal Regulations (CFR) 49 Part 581 Bumper Standard. To investigate the bumper damageability side of this question, the test conditions most relevant to pedestrian protection were conducted: the 2.5 mph front center (longitudinal) and 1.5 mph front corner tests.

Vehicles and Configurations Tested

EuroNCAP pedestrian and Part 581 bumper impacts were performed on a U.S. model 2012 Ford Focus and an E.U. model 2012 Ford Focus, which was a U.S.-model Ford Focus fitted with European front bumper components. The vehicle configurations and test scenarios are shown in Table 1 below.

Table 1. Ford Focus model years, configurations, and test scenarios

Ford Focus				
Model Year	**Configuration**	**EuroNCAP Lower Legform**	**EuroNCAP Upper Legform**	**Part 581**
2012	U.S.	Yes	Yes	Yes
2012	E.U.	Yes	Yes	Yes

Similarities and Differences Between the U.S. and E.U. 2012 Ford Focus

Externally, the U.S. and E.U. versions of the 2012 Ford Focus are identical (same front bumper fascia for both versions) and both are represented by Figure 1.

Figure 1. 2012 U.S. and E.U. Ford Focus

Internal to the bumper fascia, the 2012 U.S and E.U. Ford Focus are quite different. The bumper beams have similar overall shapes (length, depth, width) but a different configuration of stamped holes as shown in Figure 2.

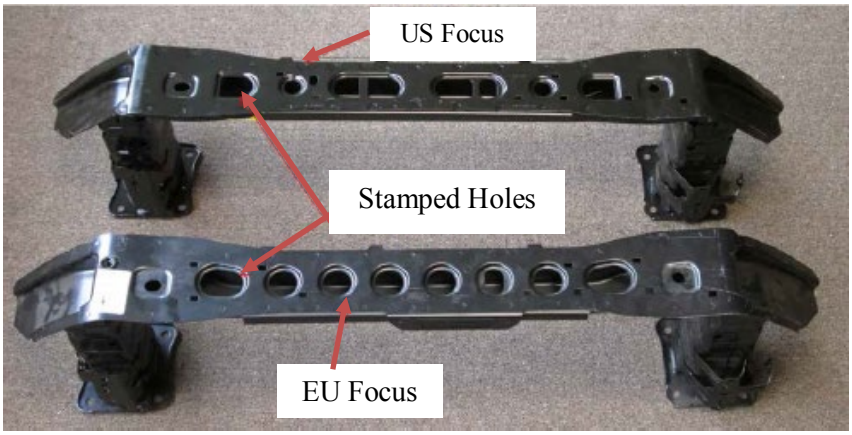

Figure 2. 2012 U.S. (top) and E.U. (bottom) Ford Focus bumper beams

The energy absorbers, which lie in front of the bumper beams mentioned above, are much different between the two models as shown in Figure 3. The U.S. version uses an injection molded plastic energy absorber that is divided into several collapsible compartments and spans the entire length of the bumper beam. The E.U. version uses two pieces of foam that only cover the beam support areas, leaving the center of the beam uncovered.

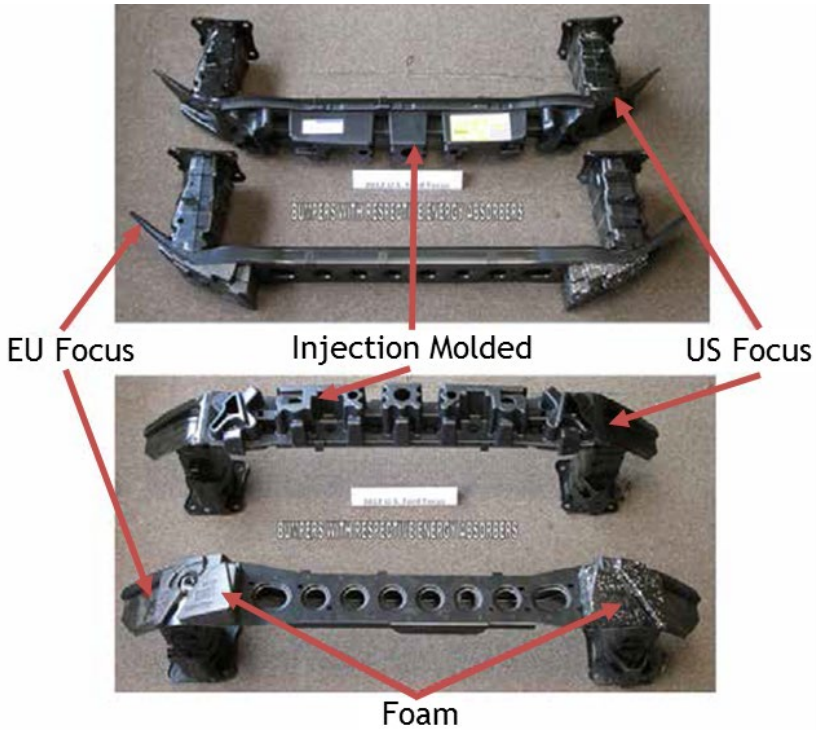

Figure 3. 2012 U.S. and E.U. Ford Focus bumper beams and energy absorbers

Figure 4 and Figure 5 below show the U.S. and E.U. versions of the 2012 Ford Focus, respectively, without the front fascia. The areas circled in red highlight the main differences in the bumper area.

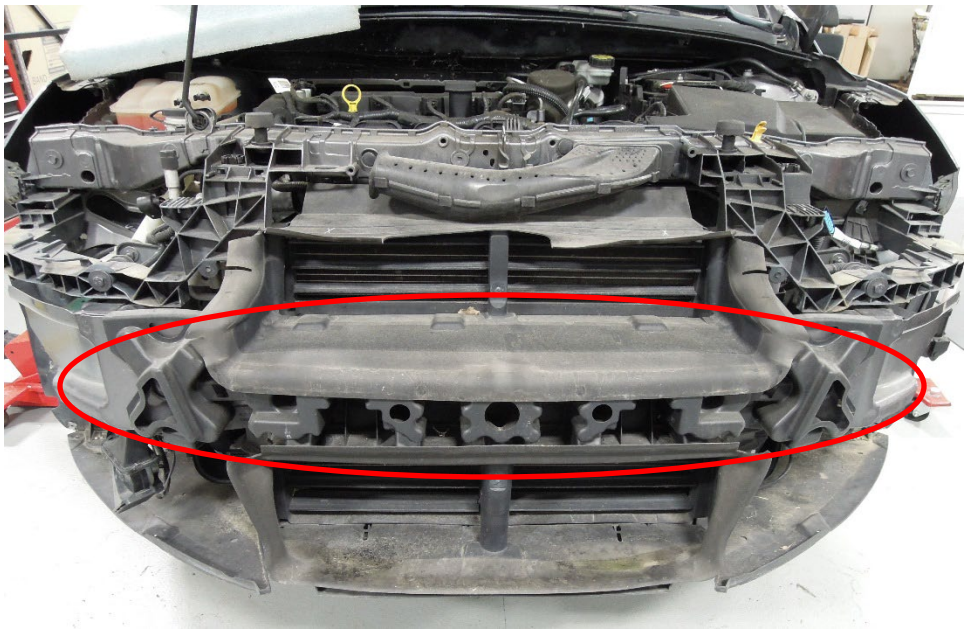

Figure 4. 2012 U.S. Ford Focus front bumper absorber configuration. The bumper absorber (red) spans entire bumper beam width.

Figure 5. 2012 E.U. Ford Focus front bumper absorber configuration. The bumper absorbers (red) only cover the bumper beam support areas with empty space along the middle of the bumper.

Another difference between the two models is in the underbody deflector that is located along the bottom edge of the front bumper and is shown in Figure 6. The U.S. deflector is a thin, flexible sheet of plastic that only acts as an underbody "cover" as it attaches to the underside flap of the front fascia. On the other

hand, the E.U. deflector is much thicker, stiffer, and heavier and contains molded-in ribs. Additionally, the E.U. deflector has additional material in the front, which is highlighted in Figure 6, that extends into and presses against the front fascia, acting as both a support to the lower portion of the front fascia as well as an underbody cover.

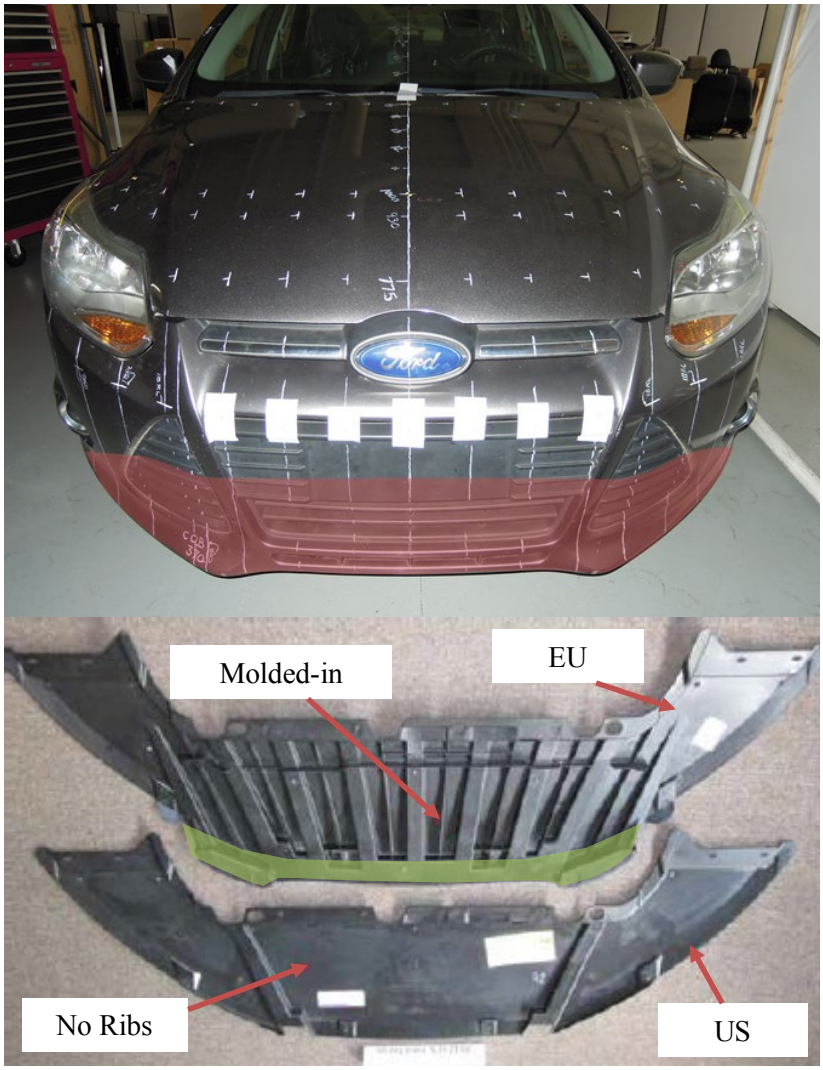

Figure 6. Top image shows the location (highlighted in red) of the underbody deflector panels. Bottom image shows the differences between the 2012 U.S. and E.U. Ford Focus underbody deflector panels. The additional material in the E.U. deflector is highlighted in green

Test Methods

Pedestrian Protection

Lower legform and upper legform testing was performed according to the procedures outlined in the EuroNCAP Pedestrian Testing Protocol (Version 8.3, December 2016) at NHTSA's Vehicle Research and Test Center (VRTC). Certified Flex-PLI lower and TRL upper legforms were used in this study.

Bumper Damageability

The CFR 49 Part 581 Bumper Standard establishes requirements for the impact resistance of vehicles in low-speed front and rear collisions. There are nine protective criteria in the standard that must be met after a series of nine low-speed impact tests (2 front corner, 2 front center, 2 rear corner, 2 rear center, and 1 fixed barrier) are conducted. Seven of these criteria require that the vehicle systems continue to work correctly after the series of nine low-speed tests is completed. The other two criteria are most relevant to pedestrian protection requirements. Those are that (1) the vehicle shall not touch the test device, except on the impact ridge, with a force exceeding 2,000 lbs (8,896 N) on the combined surfaces of Planes A & B, and (2) the exterior surfaces shall have no visible damage on any structure except for the bumper face bar and associated components/fasteners that directly attach the bumper face bar to the chassis frame. Plane forces and surface damage were observed in the four Part 581 test conditions most relevant to pedestrian leg protection: 2.5 mph front center (longitudinal) and 1.5 mph front corner impacts both with and without Upper Plane B. Part 581 test conditions observed in this study are described in Table 2 below. Figure 7 shows the front center test setups with and without Upper Plane B. Figure 8, Figure 9, and Figure 10 show the off-center impact, a corner impact, and the centerline impact, respectively.

Table 2. Descriptions of Part 581 test conditions evaluated in this study.

Test Description				
Speed	**Impact Point**	**Pendulum Height (in)**	**Upper Plane B (Y or N)**	**Notes**
2.5 mph	Front Bumper 12 Inches Right of Centerline	16	N	U.S. & E.U. - Contact with bottom portion of absorbers
1.5 mph	Front Bumper Left Corner	16	N	U.S. & E.U- Contact with bottom portion of absorbers
2.5 mph	Front Bumper Centerline	20	Y	U.S. – Contact with upper portion of absorber E.U. – Contact is between the corner absorbers
1.5 mph	Front Bumper Right Corner	20	Y	U.S. & E.U- Contact with upper portion of absorbers

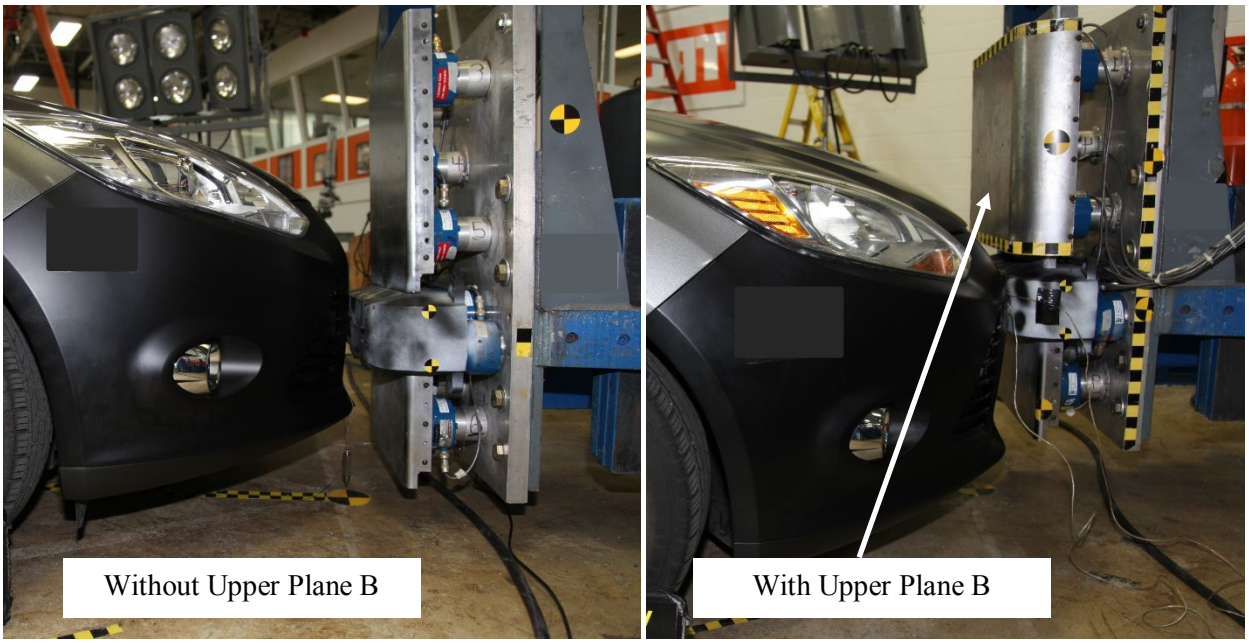

Figure 7. Part 581 front center impacts without (left) and with (right) Upper Plane B. Impacts without the upper plane (left) were performed at a pendulum height of 16 inches. Impacts with the upper plane (right) were performed at a pendulum height of 20 inches. For both impact heights, the fascia lower lip (underbody deflector) is encompassed by the lower plane.

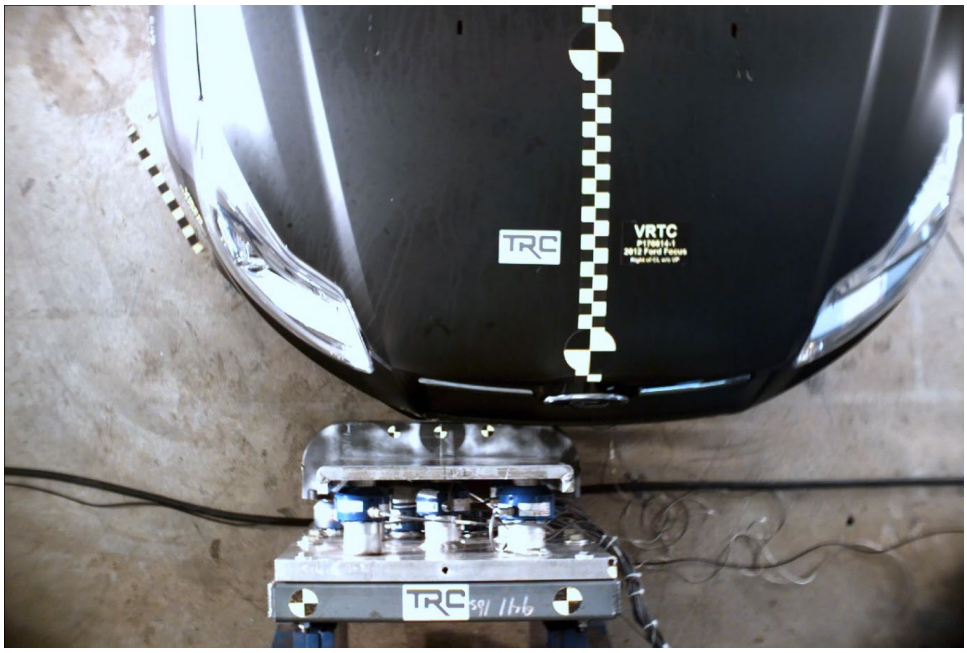

Figure 8. Front bumper impact 12 inches right of centerline. Pendulum contact with the absorbers is present in both the U.S. and E.U. Focus.

Figure 9. Front bumper corner impact. Pendulum contact with the absorbers is present in both the U.S. and E.U. Focus.

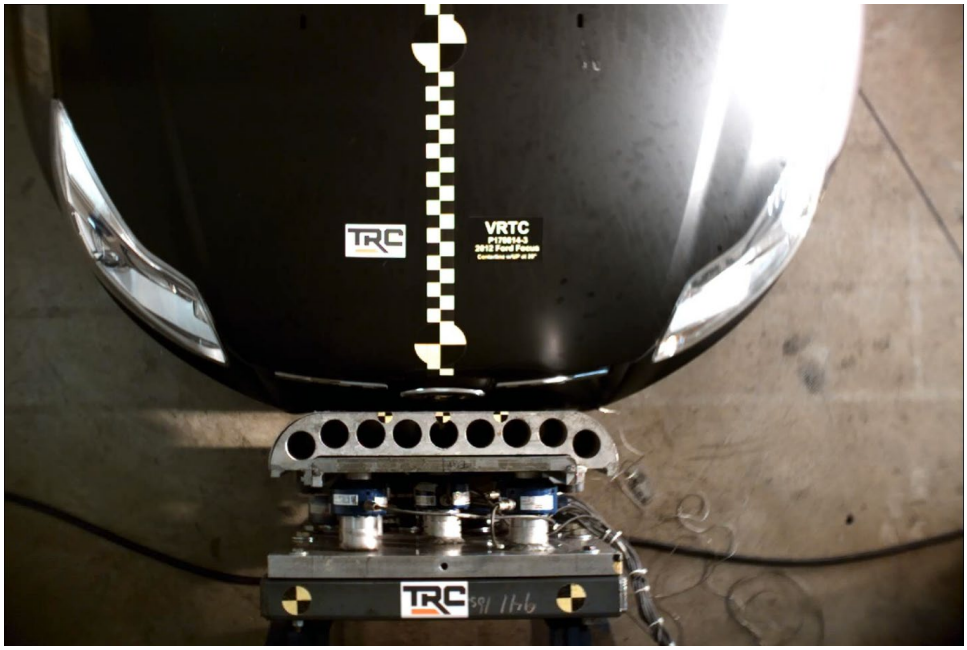

Figure 10. Front bumper impact at centerline. For the E.U. Focus, pendulum contact lies between the absorbers. Pendulum contact is present in the U.S. Focus.

Results

Pedestrian Protection - Lower Legform Results

The lower legform impact points for the 2012 U.S. and E.U. Ford Focus are shown in Figure 11.

Figure 11. Lower legform impact points for the 2012 U.S. and E.U. Ford Focus

Lower legform tibia bending moment and ligament elongation time histories for the 2012 U.S and E.U. Ford Focus are shown in Figure 12 to Figure 14. Tabulated peak bending moment and peak ligament elongation results are presented in Table 3. At the more central, inboard locations (L+1 and L-3), the U.S. Focus produced greater bending moments and ligament elongations than the E.U. Focus. At the outboard location (L+5), the U.S. and E.U. Focus produced similar bending moments and ligament elongations.

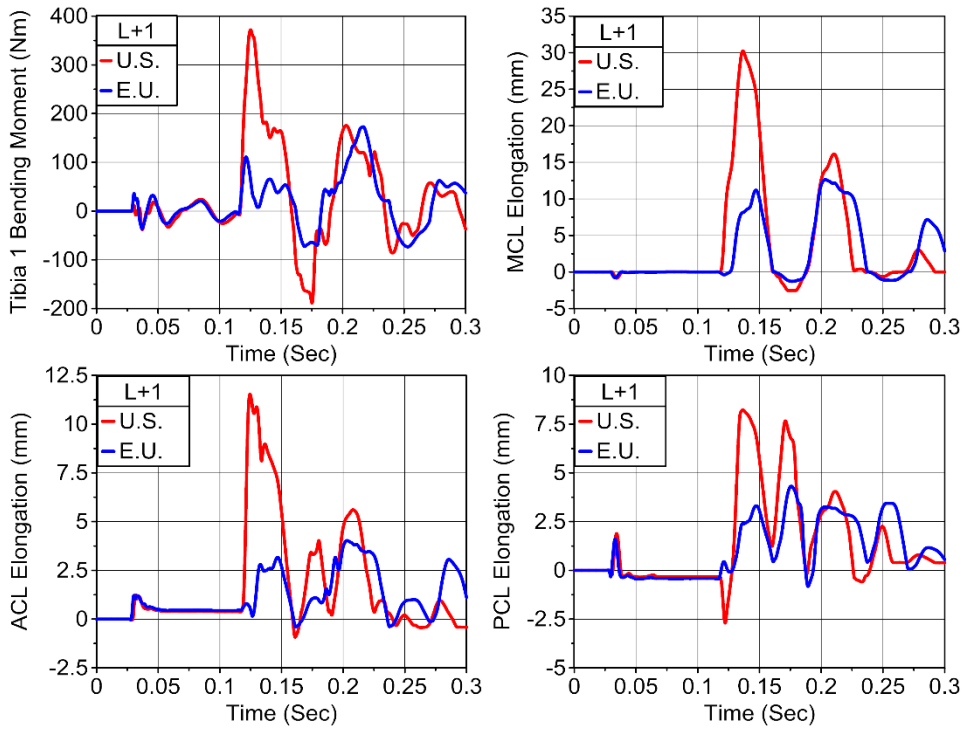

Figure 12. Lower legform tibia bending moment and ligament elongation time histories for the 2012 U.S. and E.U Ford Focus at impact location L+1.

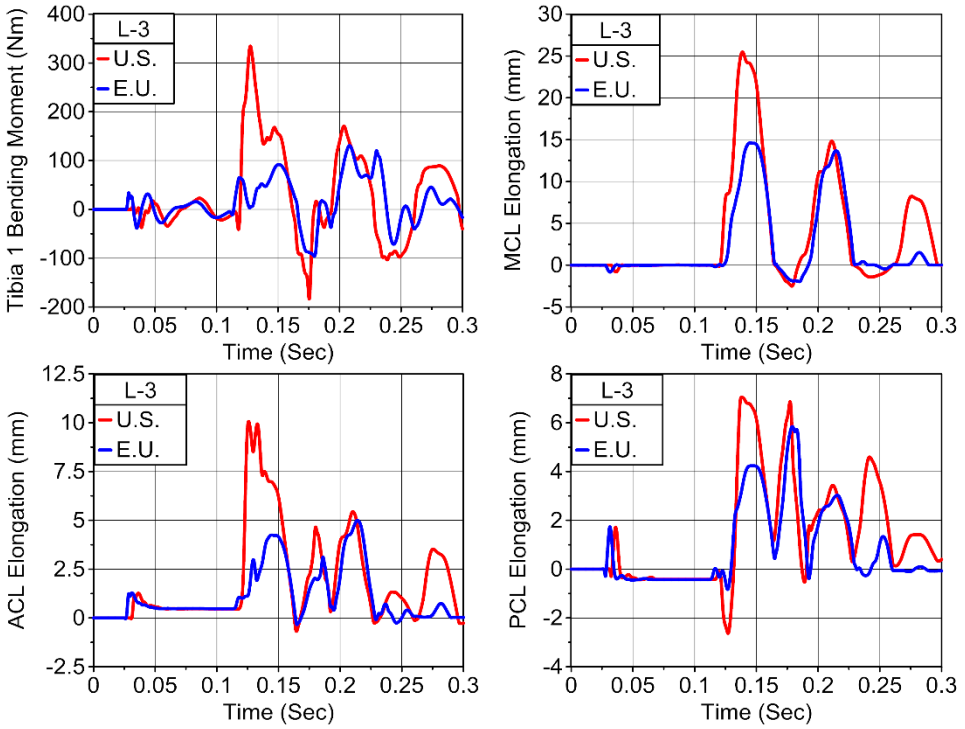

Figure 13. Lower legform tibia bending moment and ligament elongation time histories for the 2012 U.S. and E.U Ford Focus at impact location L-3.

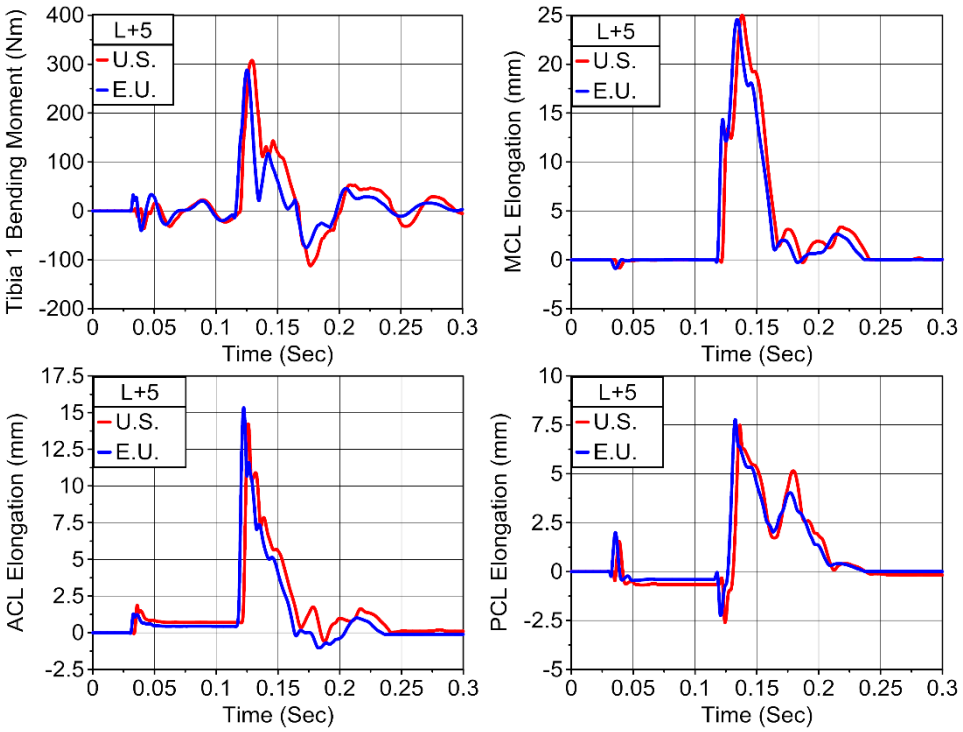

Figure 14. Lower legform tibia bending moment and ligament elongation time histories for the 2012 U.S. and E.U Ford Focus at impact location L+5.

Table 3. Lower legform bending moment and ligament elongation results for the 2012 Ford Focus

Impact Location	**L+1**		**L-3**		**L+5**	
Vehicle Configuration	**U.S.**	**E.U.**	**U.S.**	**E.U.**	**U.S.**	**E.U.**
Tibia 1 (Nm)	372	186	334	162	308	327
Tibia 2 (Nm)	346	173	274	131	289	288
Tibia 3 (Nm)	251	145	188	126	208	207
Tibia 4 (Nm)	116	138	113	130	114	116
MCL (mm)	30.2	12.6	25.5	14.6	25	24.6
ACL (mm)	11.5	4	10.1	5	14.2	15.3
PCL (mm)	8.2	4.3	7	5.8	7.5	7.8

High speed video screen captures of the Flex-PLI at maximum bending are shown for the U.S. and E.U. Ford Focus impacts at the three impact locations in Figure 15 to Figure 17 below. At impact location L+1 (Figure 15), the U.S. Focus produced greater leg bending while the E.U. Focus maintained a straighter leg. At impact location L-3 (Figure 16), the U.S. Focus again produced greater leg bending while the E.U. Focus maintained a straighter leg. At impact location L+5 (Figure 17), the U.S. and E.U Focus produced a similarly bent leg.

Figure 15. High speed video screen capture of the Flex-PLI at maximum bending at impact location L+1 for the 2012 U.S. (left) and E.U. (right) Ford Focus. The U.S. Focus produces greater bending than the E.U. Focus.

Figure 16. High speed video screen capture of the Flex-PLI at maximum bending at impact location L-3 for the 2012 U.S. (left) and E.U. (right) Ford Focus. The U.S. Focus produces greater bending than the E.U. Focus.

Figure 17. High speed video screen capture of the Flex-PLI at maximum bending at impact location L+5 for the 2012 U.S. (left) and E.U. (right) Ford Focus. Both U.S. and E.U. versions of the Focus produce similar bending.

Pedestrian Protection - Upper Legform Results

The upper legform impact points for the 2012 U.S. and E.U. Ford Focus are shown in Figure 18.

Figure 18. Lower legform impact points for the 2012 U.S. and E.U. Ford Focus

Upper legform femur bending moment and femur force time histories for the 2012 U.S and E.U. Ford Focus are shown in Figure *19* to Figure *24*. Peak femur bending moments and peak femur forces are

presented in Table 4 below. At the U+1 impact location, the U.S. Focus produced similar, but slightly higher results than the E.U. Focus. At the U-3 impact location, the E.U. Focus produced similar, but slightly higher results than the U.S. Focus. At impact location U-5, the U.S. and E.U. Ford Focus produced very similar results.

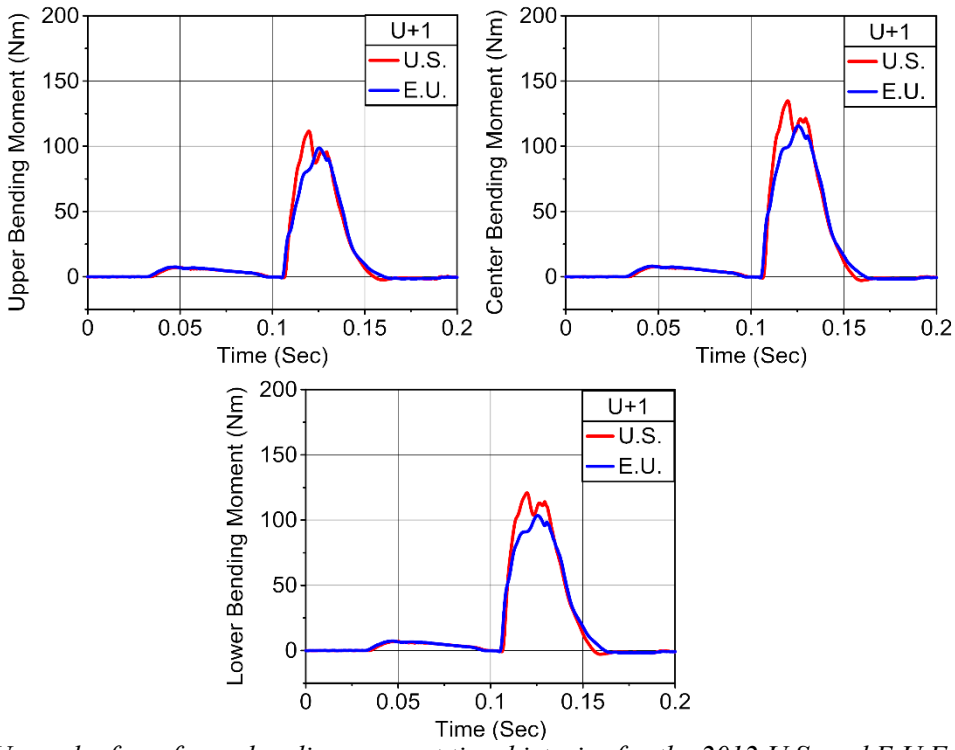

Figure 19. Upper legform femur bending moment time histories for the 2012 U.S. and E.U Ford Focus at impact location U+1.

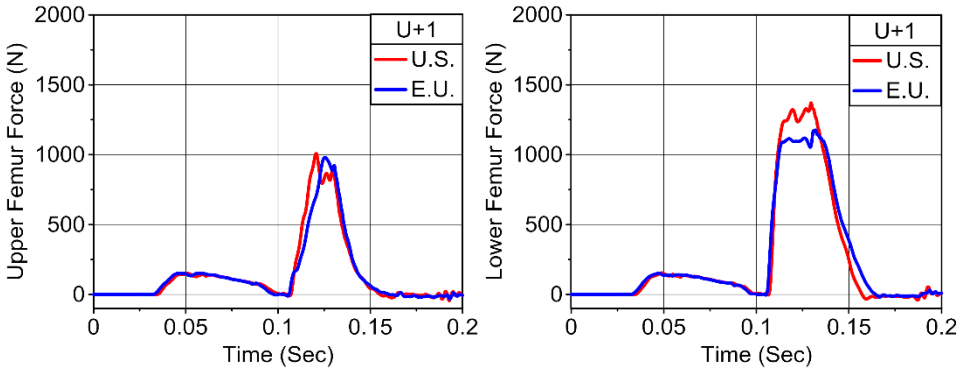

Figure 20. Upper legform femur force time histories for the 2012 U.S. and E.U Ford Focus at impact location U+1.

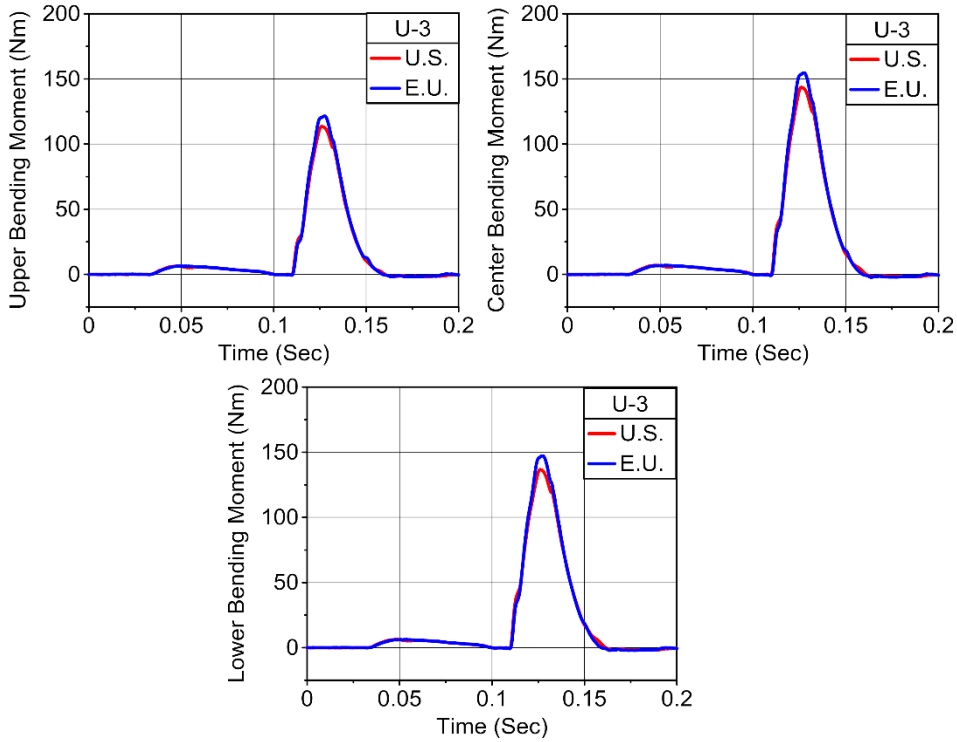

Figure 21. Upper legform femur bending moment time histories for the 2012 U.S. and E.U Ford Focus at impact location U-3.

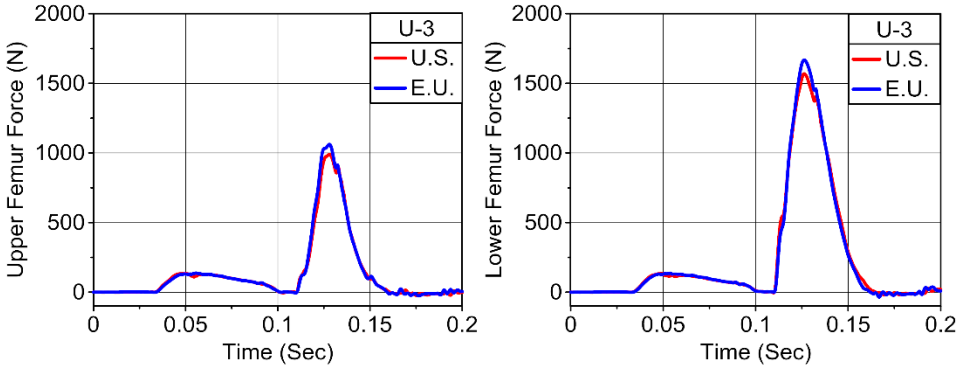

Figure 22. Upper legform femur force time histories for the 2012 U.S. and E.U Ford Focus at impact location U-3.

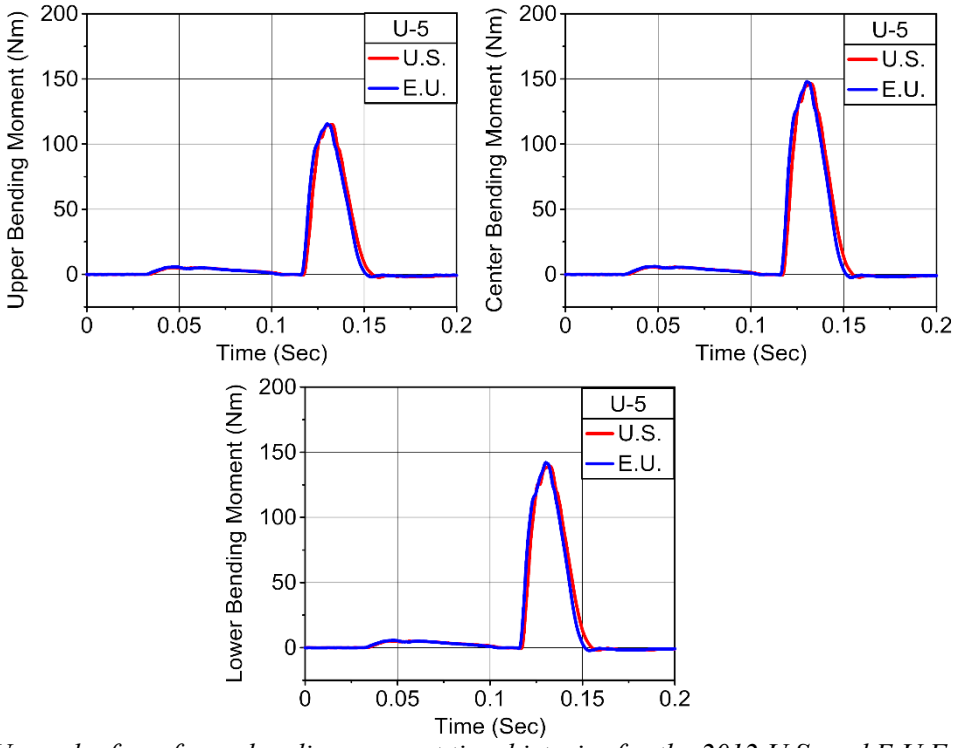

Figure 23. Upper legform femur bending moment time histories for the 2012 U.S. and E.U Ford Focus at impact location U-5.

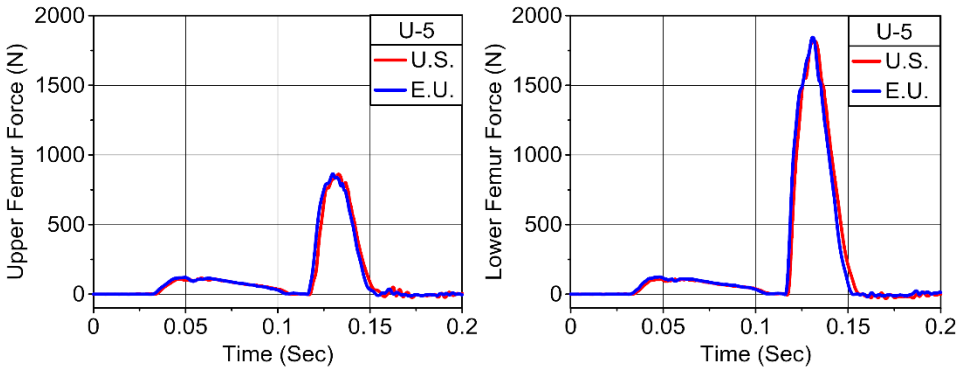

Figure 24. Upper legform femur force time histories for the 2012 U.S. and E.U Ford Focus at impact location U-5.

Table 4. Upper legform bending moment and force results for the Ford Focus

Impact Location	**U+1**		**U-3**		**U-5**	
Vehicle Configuration	**U.S.**	**E.U.**	**U.S.**	**E.U.**	**U.S.**	**E.U.**
Upper Bending Moment (Nm)	112	99	114	121	115	115
Center Bending Moment (Nm)	135	116	144	155	146	148
Lower Bending Moment (Nm)	121	103	137	147	139	142
Upper Force (N)	1,008	981	989	1,061	861	865
Lower Force (N)	1,371	1,176	1,568	1,668	1,820	1,845
Sum of Forces (N)	2,379	2,157	2,557	2,729	2,681	2,710

Bumper Damageability Results

As mentioned earlier, the 2012 U.S. and E.U. versions of the Ford Focus were only tested in the Part 581 test conditions that are most relevant to pedestrian safety. Time histories of the pendulum force sums (forces on the combined surfaces of the upper and lower planes) for the two 2.5 mph front center (longitudinal) and two 1.5 mph front corner impacts are shown in Figure *25* to Figure 28. Peak forces are presented in Table 5 along with the test description and observed vehicle damage. Between the U.S. and E.U. Ford Focus, pendulum forces were observed to be very similar in corner impacts but quite different in the longitudinal impacts. However, for both U.S. and E.U. versions, forces on the combined surfaces of the upper and lower planes were less than 8896 N.

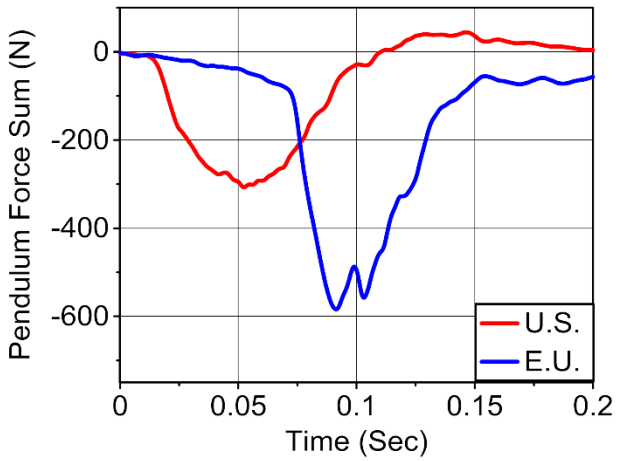

Figure 25. Pendulum force sum results from the 2.5 mph longitudinal impact 12 inches right of the centerline without the upper plane B. The pendulum lower plane extends below the lip of the front fascia in this test. No contact was made with either the upper or lower planes in the U.S. Focus. In the E.U. Focus, the upper part of the bumper made contact with the bottom portion of the upper plane and the lower lip made contact with the top portion of the lower plane.

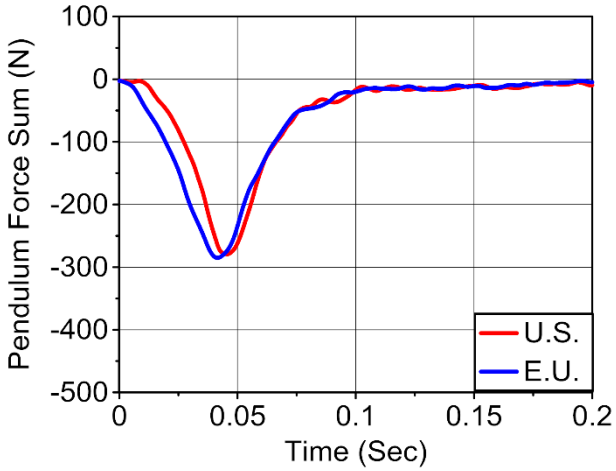

Figure 26. Pendulum force sum results from the 1.5 mph left corner impact without the upper plane B. The pendulum lower plane extends below the lip of the front fascia in this test. No contact was made with either the upper or lower planes in both the U.S. and E.U. Focus.

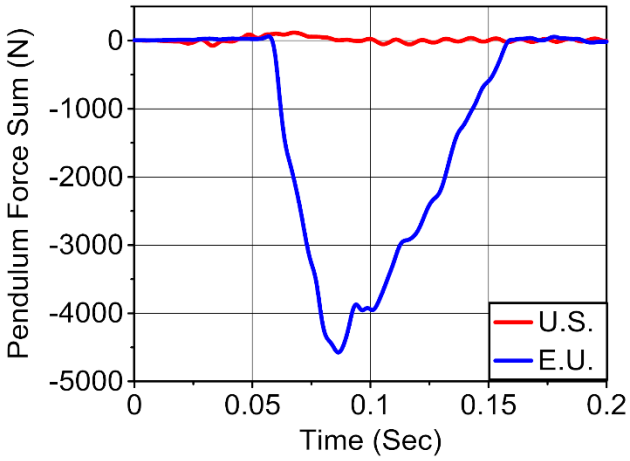

Figure 27. Pendulum force sum results from the 2.5 mph longitudinal impact at the centerline with the upper plane B. The bottom edge of the pendulum lower plane is level with the lower lip of the front fascia in this test. No contact was made with either the upper or lower planes in the U.S. Focus. In the E.U. Focus, there was hood contact with the bottom portion of the upper plane B (level with lower load cells) and lower lip contact with the bottom portion of the lower plane (below load cells).

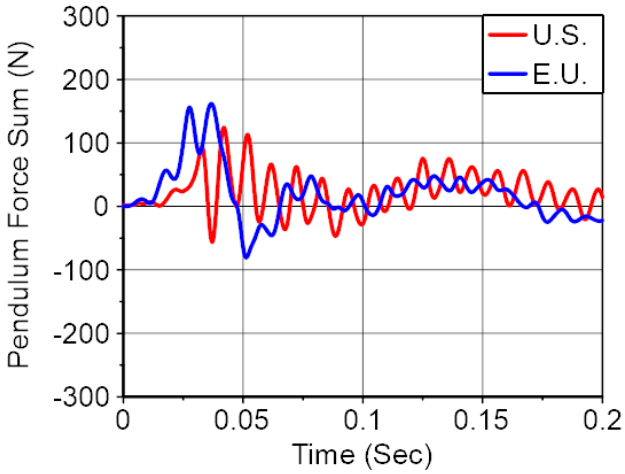

Figure 28. Pendulum force sum results from the 1.5 mph right corner impact with the upper plane B. The bottom edge of the pendulum lower plane is level with the lip of the front fascia in this test. No contact was made with either the upper or lower planes in both the U.S. and E.U. Focus. Noise in the signals likely due to resonance of the impactor plates.

Table 5. Part 581 bumper damageability test results for the 2012 U.S. and E.U. Ford Focus

Test Description			**Pendulum Forces (N)**						**Vehicle Damage**	
			NA			**EU**				
Speed	**Impact Point**	**Note**	**Upper Plane**	**Lower Plane**	**Sum (< 8896 N)**	**Upper Plane**	**Lower Plane**	**Sum (< 8896 N)**	**NA**	**EU**
2.5 mph	Front Bumper 12 Inches Right of Centerline	without Upper Plane	-46	-306	**-307**	-335	-321	**-584**	Minor: scuffs on fascia; no headlight damage	Hood dent; large scuffs on fascia; no headlight damage
1.5 mph	Front Bumper Left Corner	without Upper Plane	59	-319	**-279**	34	-299	**-285**		
2.5 mph	Front Bumper Centerline	with Upper Plane	505	-407	**118**	-4472	529	**-4575**		
1.5 mph	Front Bumper Right Corner	with Upper Plane	427	-314	**124**	504	-343	**162**		

Additionally, the E.U. Ford Focus displayed more damage than the U.S. version as described in Table 5. The U.S. version only observed minor damage in the form of minor scuffs/scratches where the pendulum contacted the fascia. Like the U.S. version, the E.U. version also observed scuffs/scratches. However, the E.U. version also observed contact and damage to its hood, which is pictured in Figure 29 on the next page.

Figure 29. Hood damage (crumpled/bent hood leading edge) to the E.U. Ford Focus (circled in red) that was not observed in the U.S. Focus.

Discussion

The similarities and differences in the pedestrian and bumper damageability test results can be explained by the internal design and structural differences between the 2012 U.S. and E.U. Ford Focus.

As shown in Figure 2, the U.S. and E.U. Ford Focus bumper beams were observed to have similar overall shapes but a different configuration of stamped holes. These slight differences would not be expected to significantly influence legform impact results since the bumper beam location is deeper than the energy absorber.

The energy absorber, on the other hand, is expected to significantly influence legform impact results since it is directly beneath the bumper fascia. The differences between the U.S and E.U. Ford Focus designs explain the similarities and differences in the pedestrian lower legform results. Figures 3 through 5 show how the U.S. absorber spans the entire length of the bumper beam while the E.U. absorber consists of two pieces of foam that only cover the outboard beam support areas, leaving the center of the beam uncovered. Figure *30* and Figure *31* below show the lower legform tibia bending moment and ligament elongation results, respectively. The outboard impact results (highlighted in green) are very similar between the 2012 U.S. and E.U. Ford Focus due to the presence of an absorber at the outboard areas of the bumper. The center impact results (highlighted in red) are much different between the U.S. and E.U. Focus due to the presence of an energy absorber along the center of the U.S. Focus and the lack of an absorber and presence of empty space in the E.U. Focus. The empty space along the center of the E.U. Focus would allow for the lower legform to intrude into the front bumper more, producing less bending in the legform and lower overall measurements than the U.S Focus. Screen captures of lower legform center tests in Figure 15 and Figure 16 also show how the Flex-PLI intrudes into the center of the softer E.U. Focus bumper while bending around the stiffer U.S. Focus bumper.

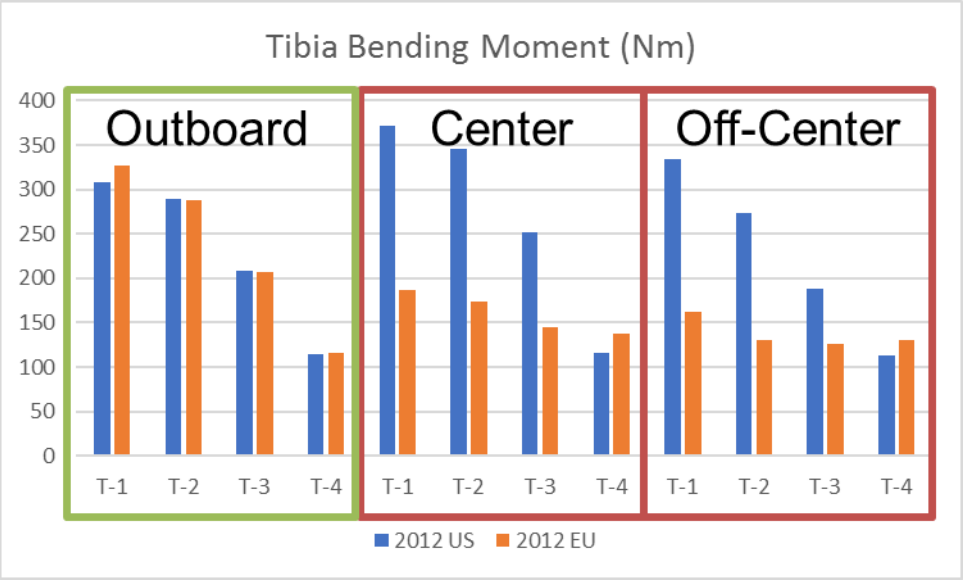

Figure 30. 2012 U.S. and E.U. Ford Focus tibia bending moment results showing similarities at the outboard location and differences at the center locations.

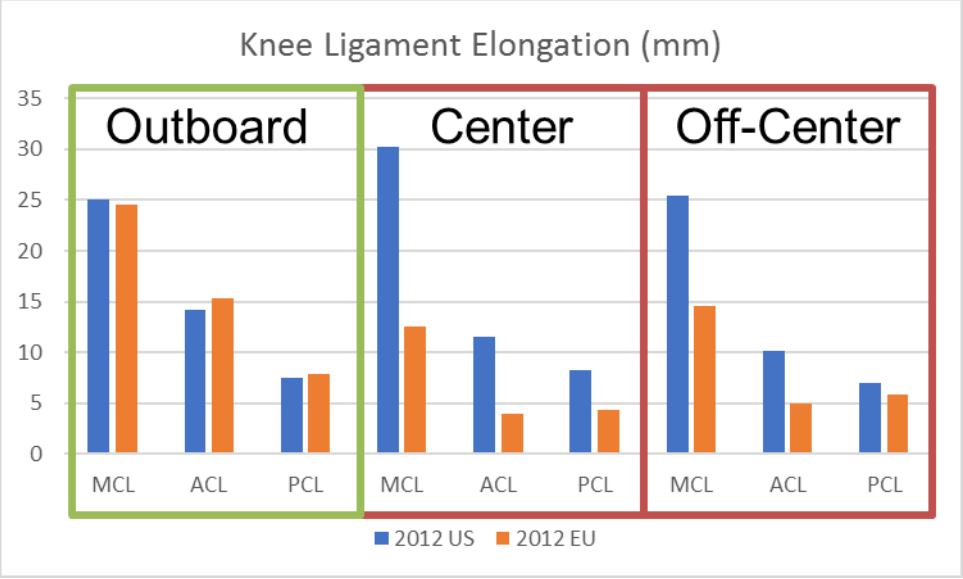

Figure 31. 2012 U.S. and E.U. Ford Focus knee ligament elongation results showing similarities at the outboard location and differences at the center locations.

The underbody deflector, shown in Figure 6, will also significantly affect lower legform impact results. As mentioned earlier, the U.S. deflector is a thin, flexible sheet of plastic while the E.U. deflector is much thicker and stiffer and contains molded-in ribs. The thin deflector on the U.S. Focus does not add any structural support to the lower part of the bumper fascia and during a lower legform impact, the Flex-PLI will bend around the bumper beam. On the other hand, in the E.U. Focus, the stiffer underbody deflector adds support and stiffens the lower part of the bumper fascia preventing bending of the legform below the

bumper beam. In the Part 581 tests, the deflector was encompassed by both pendulum impact heights and no damage was observed as a result of the tests.

These internal differences also explain the increased pendulum forces and greater damage in the 2012 E.U. Ford Focus in the Part 581 bumper damageability tests. The lack of structures in the center of the E.U. Focus allowed for intrusion of the pendulum into the bumper, allowing the Upper Plane B to make contact with the hood of the E.U. version of the Focus that was not observed in the U.S version as shown in Figure *32*. The hood intrusion in the E.U. version resulted in higher forces due to contact with the Upper Plane B and additional damage to areas other than just the bumper. The Part 581 test procedure also allows for varying test heights from 16 to 20 inches. Since the middle bumper of the pendulum impactor makes contact with the absorber area of the Ford Focus throughout this range, it is hypothesized that similar plane forces and damage would be observed at the varying heights.

Figure 32. 2.5 mph Part 581 front bumper centerline impacts with the Upper Plane B showing no hood contact with the 2012 U.S. Ford Focus (left) and hood contact with the 2012 E.U. Ford Focus (right).

Since the internal design and part differences were located around the bumper area and not around the hood leading edge area, upper legform results between the 2012 U.S. and E.U. Ford Focus were found to be very similar. The differences between the U.S. and E.U. Focus in the center impacts are likely due to test setup variances.

Conclusions

2012 U.S. versus E.U. Ford Focus

- The E.U. version performed better in the center locations and similar in the outboard location to the U.S. version in lower legform testing.
- In Part 581 bumper damageability testing, both the U.S. and E.U. versions had pendulum forces below the 8896 N requirement. However, due to the softer central area and intrusion of the bumper pendulum into the hood, the E.U. version sustained much higher forces and consequently more damage than the U.S. version.
- The U.S. and E.U. versions performed similarly in upper legform testing.

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