

Passenger Vehicle Response to Low-Speed Impacts Involving a Tractor-Semitrailer

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ABSTRACT

Low-speed sideswipe collisions between tractor-semitrailers and passenger vehicles can result in large movements and extensive areas of visible damage to the passenger vehicle. However, depending on the specifics of the collision, the resulting crash pulse may be extended, and the vehicle accelerations correspondingly low. Research regarding the impact environment and resulting injury potential of the occupants during these types of impacts is limited. Five full-scale crash tests utilizing a tractor-semitrailer and a passenger car were conducted to explore vehicle responses during these types of collisions for both the passenger car and the tractor-trailer. The test vehicles included a loaded van semitrailer pulled by a tractor and three identical mid-sized sedans. Instrumentation on the sedans included accelerometers and rotational rate sensors, and the vehicle and occupant kinematics were recorded using onboard and off-board real-time and high-speed video cameras. The test series included four sideswipe impacts, involving extended contact between the semitrailer bottom rail (lower longitudinal structure of the trailer box) and dual wheels and the side of the sedans. A single perpendicular collision involving the semitrailer dual wheels and the right front corner of the sedan was also conducted.

The extended duration crash pulses in the sideswipe tests resulted in relatively low magnitude vehicle accelerations. Specific vehicle component interactions were studied for their effect on the vehicle response. The matrix of test conditions was designed to allow comparison and assessment of vehicle and occupant response under a variety of circumstances, including a comparison of near-side and far-side occupant responses, a comparison of vehicle and occupant responses based upon the initial impact location on the sedan, and a comparison of vehicle and occupant

responses with the sedan brakes applied against the responses with the brakes released. The 90-degree impact test provided a shorter duration impact to be compared against the sideswipe test.

INTRODUCTION

Heavy truck-to-passenger vehicle sideswipe collisions can occur under a variety of scenarios including lane changes, merging roads, and during low-speed heavy truck turning maneuvers, where inboard off-tracking of the trailer tires may be significant. Due to the disparity in the stiffness of the interacting vehicle components ([Figure 1](#)), typically the semitrailer rails and tires will exhibit minimal damage while the damage that is produced on the passenger vehicle is more visibly substantial and can include deformation of the outer body panels, extensive tire transfer marks, and shattered glass. In addition, presumptions about the response of the smaller vehicle are sometimes made based on the large mass differences between the vehicles. Large movement of the passenger vehicle may also occur as a result of these types of impact. However, as these collisions produce an extended-duration impulse with multiple peaks as the various vehicle components interact, velocity change may not be the most pertinent measure of the vehicle response and potential for occupant injury.



Figure 1. Interacting vehicle components.

There has been minimal data published on vehicle and occupants responses to sideswipe impacts from commercial vehicles. In 2001, Tanner, et al [1] published results of sideswipe impact testing involving a crane truck and a passenger vehicle. The impact involved minimal vehicle interaction that resulted in longitudinal scrapes on the surface of the body panel. The resulting vehicle accelerations were less than 1 g. In order to assess the response of sideswipe collisions with more significant body panel interaction, a series of turning maneuver sideswipe collisions were conducted. Additionally, a single 90-degree collision test was also conducted to produce contrasting results with a shorter duration impact. This paper describes the test series conducted by Exponent to document and analyze the response of passenger vehicles to sideswipe collisions involving loaded semitrailers. A full analysis and discussion of the occupant ATD responses for this series of tests is contained in the companion paper by Allen Rodowicz, et al. [2].

FULL-SCALE TESTING

TEST MATRIX

The test series utilized a loaded tractor-semitrailer and three (3) identical sedans. A total of five (5) tests were conducted, including sideswipe impacts along both sides of Vehicles 1 and 2 (Tests 1A, 1B, 2A, 2B) and a single 90-degree collision between the left front dual wheels of the semitrailer and the right front corner of Vehicle 3 (Test 3). The matrix of test conditions was designed to allow a comparison and assessment of vehicle and occupant responses under a variety of impact configurations. Tests 1A and 2A mirrored each other, which allowed for a comparison of near and far side passenger car occupant responses in sideswipe collisions. Tests 1B and 2A allowed for a comparison of vehicle and occupant responses based upon the initial impact location on the sedan. Tests 1A and 2B allowed for a comparison of vehicle and occupant responses with the sedan brakes applied against the responses with the brakes not applied. Test 3 provided a comparison for all the sideswipe tests to an impact with a more typical duration.

The vehicles used in this testing were as follows:

Tractor:	1993 International 9700 cabover with sleeper berth
Semitrailer:	1999 Fruehauf 53-foot van trailer (with 29,300 lbs of ballast)
Sedans:	1993 Ford Taurus (Tests 1A, 1B) 1994 Ford Taurus (Tests 2A, 2B) 1993 Ford Taurus (Test 3)

For all tests, both the tractor and the sedans were instrumented, and the sedans contained two anthropomorphic test devices (ATD) or “test dummies”. A 50th-percentile Hybrid III ATD was positioned and restrained using the available 3-point seat belt in the driver seat position and a 5th-percentile Hybrid III ATD was positioned, unrestrained, in the left rear seat position. A 50th-percentile Hybrid III ATD configured with a pedestrian pelvis was placed, in a prone position, on a mattress in the sleeper section of the tractor cab. The vehicle and ATD movements were recorded using onboard and off-board real-time and high-speed video cameras.

Sideswipe Tests

For the sideswipe tests (1A, 1B, 2A, 2B), the tractor-semitrailer was accelerated by a driver to its maximum speed in 2nd gear, approximately 7 mph, and steered to follow a marked path. The path was designed to allow the tractor to clear the sedan, then, due to the inboard off-tracking of the trailer, contact the sedan with the semitrailer. The sedan was

positioned at two different locations along the trailer path, producing different initial contact locations and velocities. [Figure 2](#) depicts the relative starting positions of the vehicles (sedan position for Tests 1A and 2B shown) and the right turn and left turn tractor-semitrailer paths. The configurations of the four (4) sideswipe tests are described in [Table 1](#).

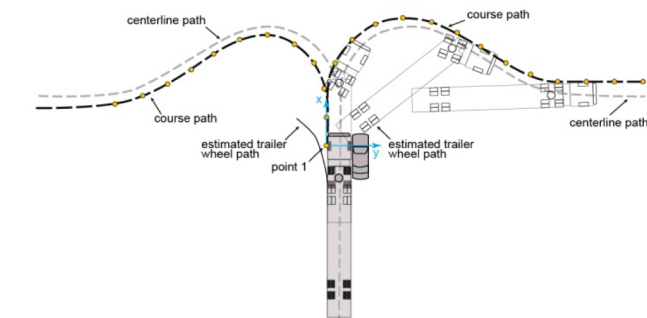


Figure 2. Tractor-semitrailer sideswipe test path.

Table 1. Sideswipe test matrix.

Test	Semitrailer Side	Sedan Side	Trailer Tire First Contact	Sedan Brakes	Sedan Occupants
1A	Right	Left	Rear of LR wheel	Applied	Near Side
1B	Left	Right	Rear of RF wheel	Applied	Far Side
2A	Left	Right	Rear of RR wheel	Applied	Far Side
2B	Right	Left	Rear of LR wheel	Not Applied	Near Side

Test 1A involved the right side of the semitrailer engaging the left side of the sedan. The sedan was positioned laterally such that the leading trailer tire would first contact the sedan in the left quarter panel, behind the left rear wheel. The sedan's brakes were applied during this test. The ATDs, positioned in the front and rear seats on the driver's side of the vehicle for all tests, were near side occupants in this test. [Figure 3](#) depicts the pre-test vehicle configuration for Test 1A. The white curved line depicted in these photographs represents the target path for the front, outer right trailer tire.



Figure 3. Sideswipe Test 1A pre-test configuration.

Test 1B involved the left side of the semitrailer engaging the right side of the sedan. The brakes on the sedan were applied and the ATDs were far-side occupants. The sedan was positioned a greater lateral distance from the tractor than in Test 1A, which resulted in the front, outer left trailer tire impacting the sedan at a steeper angle and at a location forward on the vehicle. [Figure 4](#) depicts the pretest configuration for Test 1B.



Figure 4. Sideswipe Test 1B pre-test configuration.



Figure 5. Sideswipe Test 2A pre-test configuration.

Test 2A was configured to mirror Test 1A, with the left side of the semitrailer engaging the right side of the sedan. As in Test 1A, the sedan was positioned laterally such that the leading trailer tire would first contact the sedan in the left quarter panel, behind the left rear wheel and the sedan's brakes were applied during this test. As the ATDs were positioned on the driver's side during Test 2A, this impact allowed for the evaluation of far-side occupants, differentiating Test 2A from Test 1A. [Figure 5](#) depicts the pre-test vehicle configuration for Test 2A.

Test 2B was set up nearly identically to Test 1A. For this test the right side of the semitrailer engaged the left side of the sedan, and the sedan was positioned laterally such that the leading trailer tire would first contact the sedan in the left quarter panel, behind the left rear wheel. However, for this test the sedan's brakes were not applied. Similar to Test 1A, the ATDs were near-side occupants. [Figure 6](#) depicts the pre-test vehicle configuration for Test 2B.



Figure 6. Sideswipe Test 2B pre-test configuration.

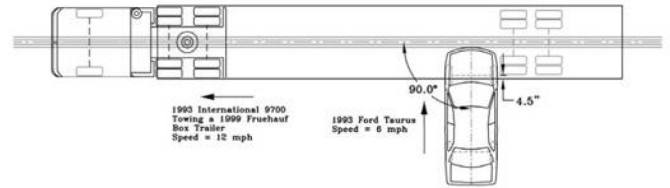


Figure 7. Test 3 impact configuration.

INSTRUMENTATION & DATA ANALYSIS

The driver ATD in each sedan impact was instrumented with a tri-axial accelerometer set mounted at the head center of gravity, as well as load cells to measure forces and moments in the upper neck, lower neck, and lower lumbar spine, and axial forces in the bilateral femurs. The rear ATD was uninstrumented. The human driver of the tractor was instrumented with a headband that positioned a triaxial accelerometer and rate sensor set above the center of mass of the driver's head. The tractor and all sedans were instrumented to measure vehicle responses in the collisions. The instrumentation in each sedan and the tractor are summarized below:

Ford Taurus:

- Triaxial accelerometer set at base of left B-pillar
- Triaxial accelerometer set at base of right B-pillar
- Triaxial rotational rate sensor set at base of right B-pillar
- Driver torso seat belt load cell
- Driver lap seat belt load cell

International 9700:

- Optical velocity sensor on right front bumper
- Triaxial accelerometer set on floor behind driver
- Yaw rate sensor on floor behind driver (Tests 1B, 2A, 2B, and 3)

- GPS velocity sensor on cab roof (Tests 1B, 2A, 2B, and 3)

Each channel of data was recorded at 10,000 samples per second and filtered according to the impact test standard specified in the Society of Automotive Engineers (SAE) recommended practice J211-1. As part of the processing of the data for each sideswipe test, the accelerometers in the sedans were balanced at zero acceleration when the sedans were stationary, and the measured accelerations were corrected for the effects of the acceleration due to gravity in the presence of roll and pitch angles. For the 90-degree collision test, the accelerometers were also balanced when the sedan was stationary and were corrected for the effects of significant yaw rotation rates.

RESULTS

Resultant velocities and accelerations were calculated from the vector sum of the longitudinal, lateral and vertical components measured during the testing. Graphics depicting frames from the crash test video, synchronized with graphs of the vehicle resultant velocity and acceleration were generated to demonstrate acceleration peaks and the corresponding vehicle component interactions. Photographs depicting the vehicle damage produced during each crash test are also presented. Synchronized video-graph figures for Tests 1A, 2B and 3 are found in the body of this paper as representative illustrations of the vehicle response characteristics, while the graphics for Tests 1B and 2A can be found in [Appendix A](#). [Appendix B](#) contains plots of the vehicle component and resultant velocities and accelerations for all tests. Additional photographs depicting the vehicle damage are found in [Appendix C](#).

SIDESWIPE COLLISIONS

The tractor-semitrailer was successfully driven along the intended paths, contacting the sedans with the trailer bottom rail and/or outer front dual tire. As the trailer off-tracked inboard of the tractor's path, the trailer bottom rail contacted the A-pillar of the sedan (in three of four tests). This initial contact caused the sedan chassis to roll on its suspension. Subsequently, the trailer tires contacted the side panels of the sedan, producing black tire transfer marks and accelerating the vehicle laterally and longitudinally. The sedan responses to the collisions of Tests 1A, 1B, 2A, and 2B are most accurately described as extended-duration sideswipe collisions. The extended pulses contained multiple acceleration peaks as the various components of the semitrailer interacted with the sedans.

Test 1A

Vehicle Response

Of all the sideswipe tests, the largest magnitude sedan acceleration (as measured near the center of gravity) and rotational responses occurred during Test 1A. Initial contact

occurred between the trailer bottom rail and the left A-pillar on the sedan, rolling the vehicle chassis to the right ([Figure 8](#)). Peak acceleration of the sedan during the bottom rail contact with the A-pillar was approximately 0.5 g. As the trailer continued to move forward and shift laterally, the outside right tire on the forward trailer axle impacted the sedan's left quarter panel and left rear wheel, displacing the rear of the sedan laterally to the right, and inducing counterclockwise yaw rotation ([Figure 9](#)). Peak acceleration during this portion of the impact was 0.9 g. The combination of the sedan's lateral displacement and the continued yaw rotation of the trailer resulted in an increased impact angle for the subsequent impact of the trailer tire with the driver's door of the sedan ([Figure 10](#)). The maximum acceleration for the entire collision sequence of 1.4 g occurred during this portion of the impact. At this time, the sedan shifted laterally without additional rotation. The trailer tire continued forward, contacting the fender behind the left front wheel of the sedan ([Figure 11](#)). Peak acceleration during this portion of impact was 1.0 g. Finally, the trailer tire snagged the sedan's left front tire, orienting the vehicle nearly parallel with the trailer ([Figure 12](#)) and resulting in an acceleration peak of 0.9 g. The sedan was dragged a short distance until it eventually released from the trailer ([Figure 13](#)), at which time it experienced a second peak acceleration of 1.4 g. [Table 2](#) contains the impact description and corresponding sedan response data from Test 1A.



Figure 8. Test 1A: Trailer bottom rail contacts sedan A-pillar.

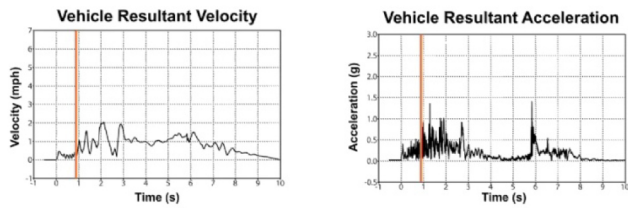


Figure 9. Test 1A: Trailer tire contacts quarter panel.

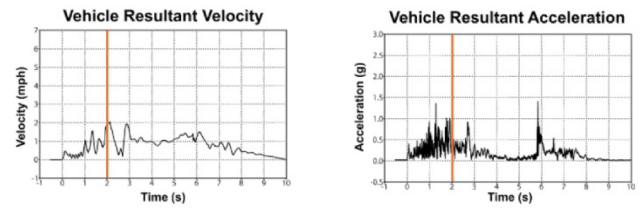


Figure 11. Test 1A: Trailer tire contacts rear fender area.

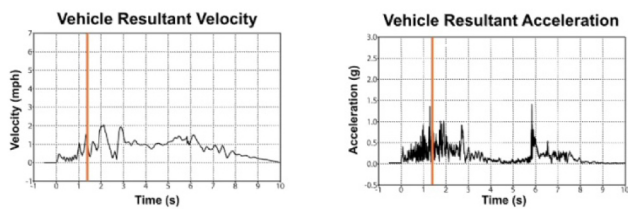


Figure 10. Test 1A: Trailer tire contacts driver's door.

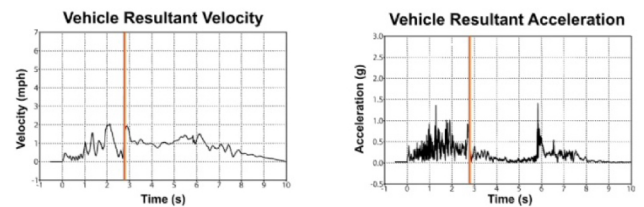
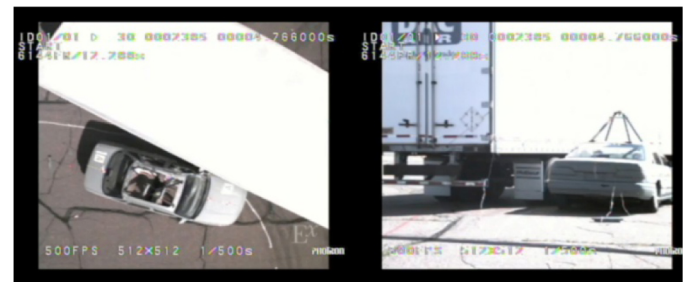


Figure 12. Test 1A: Trailer tire snags left front wheel.

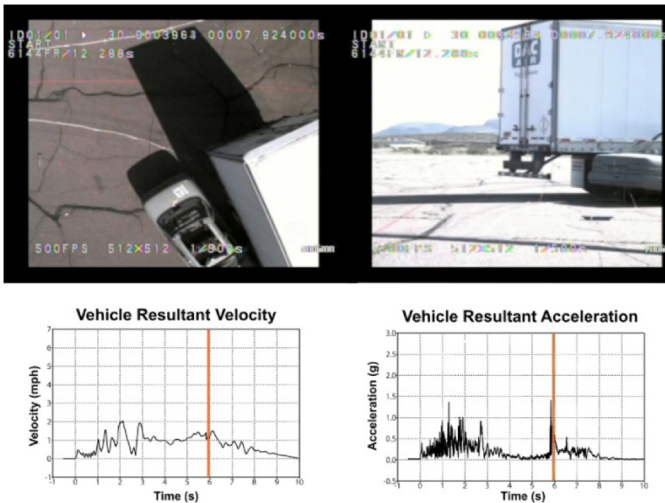


Figure 13. Test 1A: Sedan released from trailer tire.

Table 2. Test 1A: Peak sedan accelerations (at center of gravity) during sideswipe collision.

Test 1A (Trailer Right Side / Sedan Left Side, Brakes Applied)		
Vehicle Contact Description	Sedan Peak Response	
	Acc. (g)	Time (s)
Trailer bottom rail contacts sedan A-pillar	0.5	0.63
Trailer tire contacts sedan LR wheel area	0.9	0.99
Trailer tire contacts driver's door	1.4	1.29
Trailer tire contacts rear of fender	1.0	1.78
Trailer tire snags LF wheel	0.9	2.70
Sedan is released from trailer	1.4	5.83

Vehicle Damage

The sideswipe impact experienced during Test 1A resulted in significant visual damage to the sedan, as depicted in Figure 14. During the initial contact, the trailer bottom rail caused a distinctive horizontal crease in the sedan's A-pillar. The A-pillar deformation also resulted in the fracturing of the tempered glass in the window of the driver's door. The trailer tire contact created black transfer marks beginning on the quarter panel aft of the rear wheel, extending to the corner of the front bumper cover. Transfer was also produced on the wheel covers of the sedan. The sheet metal of the driver's side rear door, front door and fender was deformed inboard, with the greatest penetration at the driver's door. As the trailer tire moved forward on the vehicle, the left front wheel was snagged by the trailer tire and turned to the right. Post-impact, the steering system was not observed to be damaged.

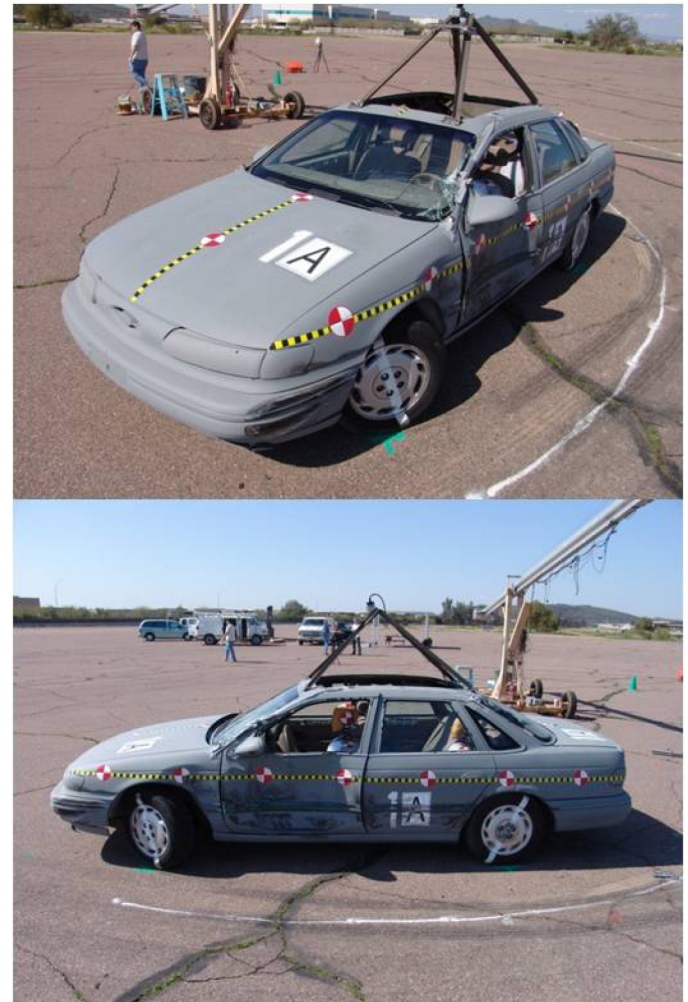


Figure 14. Test 1A post-test damage.

Test 1B

Vehicle Response

In Test 1B, the initial contact occurred between the outside left tire on the forward trailer axle and the sedan's right front door (Figure A-1). This initial impact created a counter-clockwise yaw rotation of the sedan, and the trailer wheel subsequently snagged the sedan's right front wheel (Figure A-2). The trailer dragged the sedan a short distance before it was released (Figure A-3). Peak resultant acceleration during this impact was 1.2 g, occurring as the sedan released from the trailer. Table 3 contains the impact description and corresponding vehicle response data from Test 1B.

Table 3. Test 1B: Peak sedan accelerations (at center of gravity) during sideswipe collision.

Test 1B (Trailer Left Side / Sedan Right Side, Brakes Applied)		
Vehicle Contact Description	Sedan Peak Response	
	Acc. (g)	Time (s)
Trailer tire contacts sedan RF door	0.7	0.38
Trailer tire snags RF wheel	0.9	2.70
Sedan is released from trailer	1.2	1.92

Vehicle Damage



Figure 15. Test 1B post-test sedan damage

In this test, the steering wheel of the sedan was initially turned 360 degrees to the left to facilitate the trailer tire snagging the right front tire on the sedan. Initial contact from the trailer tire occurred approximately three-quarters of the way back on the front passenger's side door as depicted the bottom image of [Figure 15](#). Black tire transfer was evident at the initial contact point on the door and extended forward to

the right corner of the front bumper cover. The front suspension system was not damaged during the collision.

Test 2A

Vehicle Response

The vehicle kinematics in Test 2A were consistent with, but a mirror image of, the kinematics observed in Test 1A ([Figures A-4, A-5, A-6, A-7](#)). Peak resultant acceleration during this impact was 1.2 g, occurring as the lead trailer tire impacted the driver's door. After snagging the right front wheel, the trailer tire momentarily compressed the left front sedan tire, resulting in a 0.8 g peak in the vehicle acceleration. [Table 4](#) presents a summary of the impacts and resulting sedan response data from Test 2A.

Table 4. Test 2A: Peak sedan accelerations (at center of gravity) during sideswipe collision.

Test 2A (Trailer Left Side / Sedan Right Side, Brakes Applied)		
Vehicle Contact Description	Sedan Peak Response	
	Acc. (g)	Time (s)
Trailer bottom rail contacts sedan A-pillar	0.6	0.58
Trailer tire contacts sedan RR wheel area	1.1	0.92
Trailer tire contacts driver's door	1.2	1.42
Trailer tire contacts/snags RF wheel	0.9	2.09
Trailer tire compresses RF tire	0.8	5.17
Sedan is released from trailer	0.9	7.19

Vehicle Damage

The damage exhibited by the sedan in Test 2A, depicted in [Figure 16](#), mirrored the damage produced during Test 1A. The right A-pillar was creased and the window glass in the passenger's side front door was shattered. Black tire transfer began at the right quarter panel aft of the rear wheel, extending forward to the corner of the front bumper cover. The sheet metal of the rear door, front door and fender on the right side were deformed inboard, with the greatest penetration occurring on the forward half of the front door and adjacent fender. As the trailer tire snagged the right front sedan tire, the tire steered to the left. However, no structural damage was observed to the wheel or suspension system. Although during this test the trailer tire compressed the right front tire, the tire remained inflated post-impact.