EA12-005 Reconstruction Testing for KJ Jeep Liberty and ZJ Grand Cherokee

July 2014

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16. Abstract

This crash reconstruction program was performed to evaluate whether an improvement in performance was evident in the fuel tanks in 2002-07 Jeep Liberties and 1993-98 Jeep Grand Cherokees during low to moderate speed rear impacts when these models were equipped with original equipment tow hitch-receivers. Two real-world scenarios were reconstructed where the struck Jeeps were not equipped with a tow hitch-receiver and in which fuel leakage and fires occurred. In the first scenario, the baseline reconstruction successfully produced a fuel leak (using non-volatile liquids). Subsequently, that same crash was replicated with a tow hitch-receiver installed and no fuel leak occurred, indicating that the addition of an OEM tow hitch-receiver improved rear impact fuel tank performance.

In the second scenario, the baseline reconstruction tests did produce a fuel leak; however, the exact failure mode (the cut on the bottom of the tank) of the real-world crash was not replicated. In the comparative tests, the addition of the hitch-receiver bracket and mounting bolts provided a structural reinforcement and there was no collapse of the moderately rusted rear frame rail. This test also indicated that the addition of an OEM hitch-receiver improved rear impact fuel tank performance.

A third crash reconstruction of a real-world crash was performed to evaluate whether removal of a ball and drawbar from the hitch-receiver improved the performance of the Jeep Liberty in a rear impact crash. In the real-world crash used as the model, an aftermarket drawbar was installed in the hitch-receiver. The rear impact fractured the rear cross-member of the hitch-receiver and forced the broken section into the fuel tank, causing a leak. The reconstruction was conducted with only the manufacturer's hitch-receiver and no aftermarket drawbar. During the reconstruction test, the hitch-receiver cross-member did not fracture and did not pierce the tank. The overfill vent connector and the charcoal vapor connector broke off of the top of the fuel pump assembly. When the vehicle was later rolled on the rollover fixture after the reconstruction test, a fuel leak began. This test indicated that the presence of the ball mount drawbar in the hitch-receiver when the struck vehicle was not being used for towing increases the risk of fuel tank failure in a rear impact.

A total of eight tests were performed.

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1.0 INTRODUCTION

This crash reconstruction program was performed by the National Highway Traffic Safety Administration's (NHTSA) Vehicle Research and Test Center (VRTC) in response to requests from NHTSA's Office of Defects Investigation (ODI) relating to allegations of poor performance of fuel tanks in rear-impact crashes involving 2002-2007 Jeep Liberty and 1993-1998 Jeep Grand Cherokee vehicles. When these models were not equipped with a trailer hitch, also known as a tow hitch receiver (herein "hitch-receiver"), and were involved in rear impact collisions, some fuel leaks and fires occurred due to compromised fuel systems. Chrysler Group, LLC has proposed remedying this safety defect in low to moderate speed crashes by installing a hitch-receiver in the subject vehicles. NHTSA decided to assess the effectiveness of this proposed remedy by undertaking a crash reconstruction program. The program described in this report was designed to first replicate crash damage of real-world rear impacts involving Jeeps that did not have an original equipment (OE) hitch-receiver installed, and then repeat the tests with an OE hitch-receiver installed to document the differences in crash performance.

2.0 BACKGROUND

The 2002-07 KJ Jeep Liberty and the 1993-98 ZJ Jeep Grand Cherokee are vehicles in which the manufacturer placed the fuel tanks behind the rear wheels instead of a mid-ship or above-axle location. These tanks are made of a deformable plastic that exhibits high toughness properties. These vehicles were self-certified by Chrysler as meeting the requirements of the minimum Federal Motor Vehicle Safety Standards (FMVSS) for each model year that they were produced. However, in some cases where a subject Jeep is struck from behind by a smaller, lower profile vehicle, the striking vehicle may not substantially engage the bumper of the Jeep. The Jeep Liberty has a high-mounted, plastic bumper cover and plastic reinforcement. A low striking vehicle may progress directly into the fuel tank since approximately 10 inches of the lower portion of the Liberty tank is exposed below structural sheet metal. In cases where a Jeep Liberty is equipped with an OE hitch-receiver, as shown in Figure 1, the hitch-receiver is mounted several inches below the lowest rigid point on the bumper, creating a structural steel barrier across approximately the midpoint height of the exposed tank (see Figure 2).

Figure 1 – Jeep Liberty hitch-receiver

Figure 2 - Jeep Liberty without hitch-receiver and with hitch-receiver installed

The 1993-1998 Jeep Grand Cherokee is similar, but instead uses a sheet metal bumper reinforcement beneath the plastic bumper cover that can be seen in the digitally measured rendering above the installed hitch-receiver, shown in Figure 3.

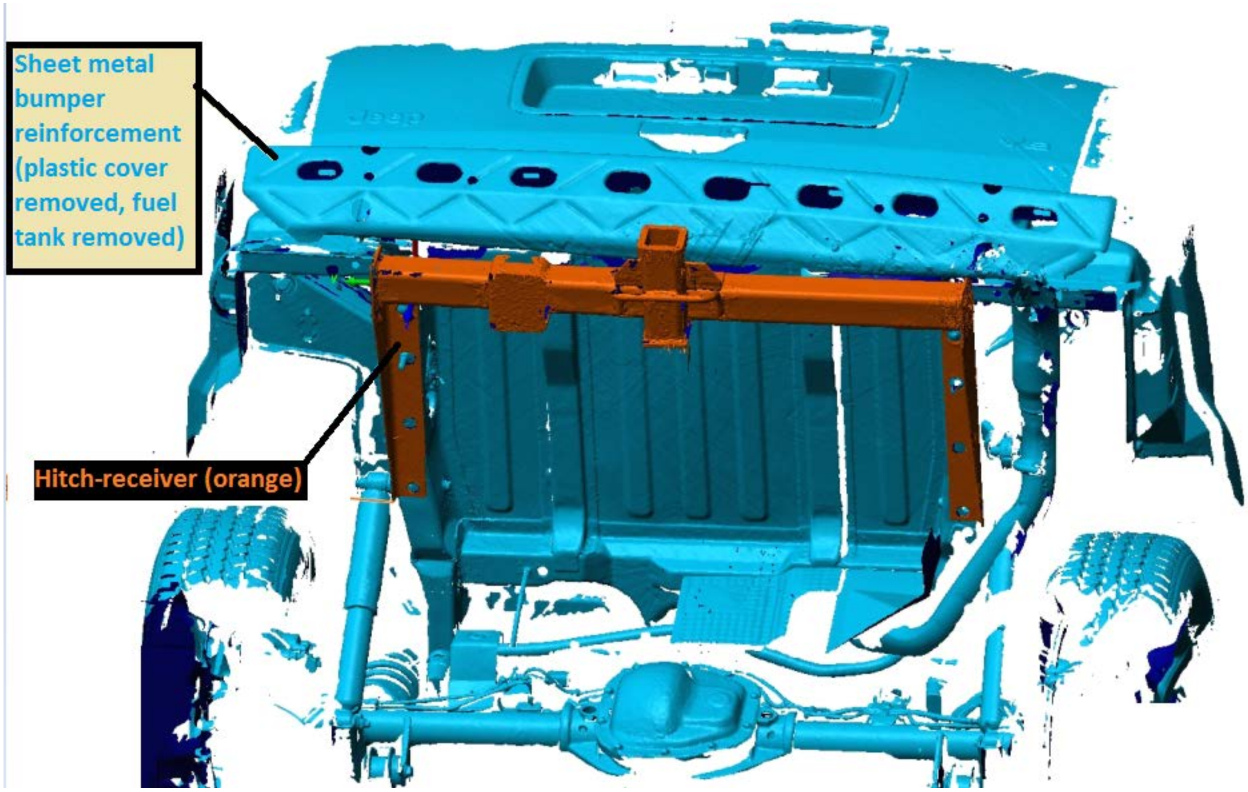


Figure 3 - Grand Cherokee 3D scan, hitch-receiver in orange, fuel tank removed

3.0 OBJECTIVE

The objectives of this effort were to conduct crash tests to reconstruct real-world crashes involving the subject vehicles that resulted in fuel leakage and to evaluate whether improvement was evident when an OEM hitch-receiver is installed. Using the method of reconstruction provided the ability to focus on crash scenarios that had unreasonable outcomes influenced by conditions such as incompatible vehicle bumper heights and the presence of a ball-mount drawbar. The baseline re-creation was established as the control group. Each reconstruction test changed a single relevant variable, such as the presence of a hitch-receiver. Vehicles in the first two scenarios with hitch-receivers installed were the treatment group.

The specific real-world crashes were chosen because there were generally enough facts available about the incidents to allow reconstruction.

Baseline recreations of two original crashes were conducted to adequately reproduce the unsatisfactory outcomes of the real-world scenarios; neither was equipped with a hitch-receiver.

A repeat of the baseline tests with the hitch-receivers installed were then conducted to determine whether the outcomes improved.

An additional reconstruction was conducted to evaluate whether the removal of a ball and drawbar from the hitch-receiver, present in the real-world crash, improved the performance of the Liberty in a replication of the rear impact crash. The absence of the aftermarket tow drawbar and ball became the independent variable. A Jeep Liberty with a hitch-receiver with no aftermarket tow drawbar with ball installed became the treatment group.

4.0 TEST VEHICLES

4.1 Test Vehicles Information

NHTSA ODI identified the selection criteria for the make, model, and model year vehicles to be used in testing as shown in Table 1. For the reconstruction testing, these vehicles were separated into two categories (bullet and target). The term “bullet vehicle” refers to the striking vehicle (vehicle in motion) during a crash test. The bullet vehicles selected for testing were required to be free from collision damage from the vertical support aft of the front door (B-pillar) forward to the front bumper. The term “target vehicle” refers to the struck vehicle (stationary in this program) that is impacted by the bullet vehicle. The target vehicles selected were required to be free from collision damage from the B-pillar rearward to the rear bumper. Any vehicles with modifications to the frame, body, or drivetrain were rejected. Any vehicles with relevant collision damage, either visible or reported, were also rejected. All vehicles were inspected for perforating corrosion (rust) of the frame and body. Only vehicles with visibly non-perforated corrosion of the frame were selected. When possible, exact model years were obtained to minimize variations in model year changes.

MAKE	MODEL	TARGET MODEL YEAR	ACCEPTABLE MODEL YEAR	ENGINE	DRIVETRAIN	Vehicle Category
CADILLAC	DEVILLE	1993	1992 & 1993	4.9 liter V8	NA	BULLET
DODGE/ PLYMOUTH	NEON	1997	1995 - 1999	NA	NA	BULLET
FORD	F-150 SUPER CAB	2008	2006 - 2008	5.4 liter V8	4 Wheel Drive	BULLET
JEEP	GRAND CHEROKEE	1996	1996 & 1998	NA	4 Wheel Drive	TARGET
JEEP	LIBERTY	2004	2004	3.7 liter V6	4 Wheel Drive	TARGET

Table 1 - Vehicle selection criteria

4.2 Test Program, Vehicle Requirements, Inspection, and Procurement

This program explored three crash scenarios:

4.2.1 Scenario 1

The first scenario was the reconstruction of a rear impact incident in which a stationary 2004 KJ Jeep Liberty caught fire after being struck by a 1997 Plymouth Neon, reported to NHTSA via Vehicle Owner Questionnaire (VOQ) #10138726. A police accident report, several pictures, and other various documents were available for reference. The available information indicated that the Neon was traveling at 35-40 mph based on the 40 mph posted speed limit; therefore 40 mph was selected as the test velocity (worst case). There was no documentation of pre-impact braking by the Neon, so it was assumed that there was no pre-impact braking, or vehicle pitch prior to impact.

4.2.2 Scenario 2

The second scenario was the reconstruction of a rear impact incident where a slow moving 1996 ZJ Jeep Grand Cherokee caught fire after it was struck by a 1993 Cadillac Deville, reported to NHTSA via VOQ #869217. According to the police accident report, the Jeep Grand Cherokee was merging onto a highway at low speed when the Cadillac, assumed to be traveling at the posted 55 mph speed limit, struck the rear of the Jeep, with a slight offset to the left. Based on available pictures, it was estimated that the Cadillac struck the Jeep with an offset of 15 inches to the left. The relative difference in velocity between a vehicle traveling at 55 mph and the other assumed to be merging at 20 mph led to a 35 mph difference in velocities. For the reconstruction testing, the 35 mph reference was maintained by using this as the bullet vehicle velocity, while making the target vehicle stationary. This velocity proved to be adequate in creating similar damage and a fuel leak. There was no documentation of pre-impact braking, so it was assumed there was none. However in baseline tests, it was evident that the Cadillac was striking two to three inches too high, so the Cadillac height was modified to simulate front end dive associated with pre-impact braking, as determined by dynamic testing described in Section 6.1.

4.2.3 Scenario 3

The third scenario was the reconstruction of a rear impact incident in which a stationary 2004 KJ Jeep Liberty was struck by a 2008 Ford F-150 Super Cab, reported to NHTSA via VOQ #10512282. Although there was no fire, the fuel tank was punctured, and led to a fuel leak. The concern with this crash regarded the strength of the hitch-receiver, and whether the aftermarket ball-mount drawbar altered the crash dynamics. When it was struck by the F-150, the cross-member of the hitch-receiver fractured into two pieces, and a sharp edge of the hitch-receiver cross-member then cut a gouge in the tank, producing a noticeable fuel leak. NHTSA dispatched its Special Crash Investigations (SCI) group to investigate both vehicles that were involved in this crash (SCI #CR13023). A download of the Ford's powertrain control module (PCM) showed that it had stored the pre-crash event and indicated a striking speed of up to 43 mph with pre-impact braking. Witness marks transferred between vehicles corroborated that the front of the F-150 was diving downward, consistent with pre-impact braking, and had an offset to the left of 11¼ inches. The achievable amount of front end dive was verified with dynamic testing, described in further detail in Section 6.1.

4.2.4 Candidate vehicles and hitch-receivers

The list of the 16 vehicles tested in this program is shown in Table 2. Prior to procurement of each vehicle, a CARFAX report was reviewed and the vehicle was inspected by a technician to ensure that the vehicle met the requirements for testing. All hitch-receivers used in this test program were original equipment units. **Appendix A** shows the as-received photographs of each vehicle.

SCENARIO	MAKE	MODEL	MODEL YEAR	VIN	COLOR	Project Usage	TRC Test File #
Scenario 1	PLYMOUTH	NEON	1997	3P3ES47C5VTxxxxxx	Purple	Test# 1 Bullet Vehicle	130925
	JEEP	LIBERTY	2004	1J4GL48K44Wxxxxxx	Silver	Test# 1 Target Vehicle	130925
	PLYMOUTH	NEON	1997	3P3ES47CXVTxxxxxx	Purple	Test# 2 Bullet Vehicle	131024
	JEEP	LIBERTY	2004	1J4GL48K54Wxxxxxx	Blue	Test# 2 Target Vehicle	131024
Scenario 2	CADILLAC	DEVILLE	1993	1G6CD53B7P4xxxxxx	Grey	Test# 3 Bullet Vehicle	131031
	JEEP	GRAND CHEROKEE	1998	1J4GZ48S1WCxxxxxx	Black	Test# 3 Target Vehicle	131031
	CADILLAC	DEVILLE	1993	1G6CD53B4P4xxxxxx	Black	Test# 4 Bullet Vehicle	131107
	JEEP	GRAND CHEROKEE	1996	1J4GZ58S1TCxxxxxx	Gold	Test# 4 Target Vehicle	131107
	CADILLAC	DEVILLE	1993	1G6CD53B7P4xxxxxx	Blue	Test# 5 Bullet Vehicle	131121
	JEEP	GRAND CHEROKEE	1996	1J4GZ78Y4TCxxxxxx	Purple	Test# 5 Target Vehicle	131121
	CADILLAC	DEVILLE	1993	1G6CD53B5P4xxxxxx	White	Test# 6 Bullet Vehicle	131127
	JEEP	GRAND CHEROKEE	1996	1J4GZ58S0TCxxxxxx	White	Test# 6 Target Vehicle	131127
	CADILLAC	DEVILLE	1993	1G6CD53B9P4xxxxxx	Red	Test# 7 Bullet Vehicle	131204
	JEEP	GRAND CHEROKEE	1996	1J4EZ78S9TCxxxxxx	Green	Test# 7 Target Vehicle	131204
Scenario 3	FORD	F-150	2008	1FTPX14V58Fxxxxxx	Red	Test# 8 Bullet Vehicle	131212
	JEEP	LIBERTY	2004	1J4GL58K94Wxxxxxx	Silver	Test# 8 Target Vehicle	131212

Table 2 – List of vehicles tested

5.0 PREPARATION for TESTING

5.1 Panic Braking Tests

Panic braking tests were required on the Cadillac Deville and Ford F-150 to establish the amount of front end dive. One of each vehicle model was instrumented with a data collection system and the following transducers:

1. GPS Receiver (vehicle speed)
2. 2g Accelerometer (vehicle longitudinal acceleration)
3. Two (2) LASER Distance Measurement Systems (vehicle ride height front/rear)

Vehicles were tested multiple times at their maximum deceleration rate from velocities ranging from 32 to 55 mph in order to find the average of the maximum relative change in front ride height. The ride height time-histories for the Cadillac Deville and Ford F-150 are shown in Figure 4, respectively, and their average results are indicated by the horizontal red lines shown in Table 3.

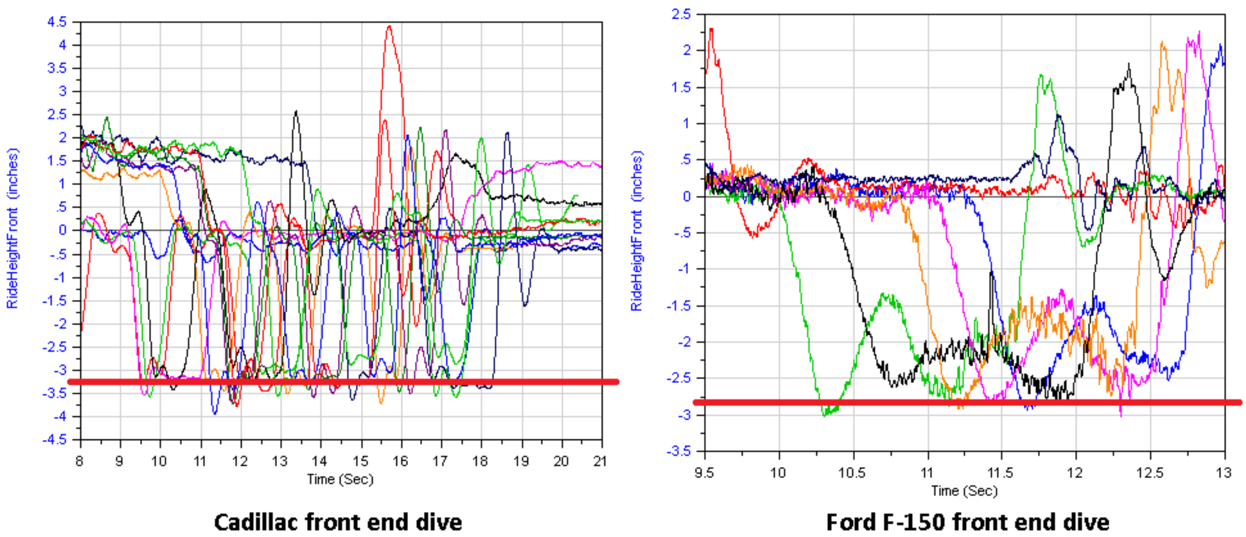


Figure 4 – Cadillac Deville and Ford F-150 front end dive (pitch) under maximum braking

MAKE	MODEL	MODEL YEAR	VIN	AVERAGE MAX DIVE (inches)
CADILLAC	DEVILLE	1993	1G6CD53B4P4xxxxxx	3.25
FORD	F-150 SUPER CAB	2008	1FTPX14V58Fxxxxxx	2.80

Table 3 – Results from panic braking tests

5.2 Test Vehicle Preparation

Each of the bullet vehicles used for testing had the front impact zone painted with three (3) regions of different colors (an example is shown in Figure 5) for the purpose of being able to identify and measure areas of interaction between the target vehicles. The regions are specified in Table 4 and were separated by a one inch stripe of unpainted area (vehicle body color).

Figure 5 - 1997 Plymouth Neon bullet vehicle with painted regions

Region	Height of Painted Area (inches)
1	0 - 16
2	17 - 24
3	25 & Above

Table 4 - Bullet vehicle painted regions

6.0 RECONSTRUCTION TESTING

A series of eight (8) vehicle-to-vehicle crash tests were run for this test program. They covered the three real-world motor vehicle crashes involving vehicles with and without hitch-receivers. The basic test protocol and procedures for conducting a rear impact test were derived from the FMVSS No. 301[1] "Fuel System Integrity" performance test. Per that procedure, fuel tanks are filled to between 92% and 94% capacity with Stoddard liquid, a gasoline-like liquid that is not explosive. For both Scenarios 1 and 2, the real-world fuel levels were unknown, so the vehicles' fuel tanks were filled at 93% capacity. For Scenario 3, a "half-tank" of fuel was documented in the accident reference material, so it was filled with 10 gallons to achieve no less than a one-half tank of Stoddard liquid. The compliance test procedure also includes a procedure that rolls the vehicle over about its longitudinal axis in 90° intervals to detect fluid leakage. While none of the reconstructed scenarios involved a rollover, this aspect of the procedure was retained for informational purposes.

For reconstruction Scenarios 1 and 2, one or more baseline tests were conducted to establish the relevant test parameters of the control group, as similarly to the real-world crash as possible. After the parameters and a fuel leak were confirmed, one or more comparative tests were conducted to the treatment group, where the target vehicle was equipped with the hitch-receiver as the single independent variable. The objective of Scenario 3, to evaluate whether removal of the ball and drawbar from the hitch-receiver improves performance of the Jeep Liberty in a rear impact crash, only required a single test of at least the same severity as the real-world crash, in part because there was a substantial amount of detailed data about the parameters

[1] TP-301-04 U.S. Department of Transportation National Highway Traffic Safety Administration Laboratory Test Procedure for FMVSS 301 Fuel System Integrity"

of the crash. In this high-impact energy reconstruction, the consumer-installed drawbar, or in this case the absence of it, acted as the independent variable. Testing without the drawbar installed demonstrated whether the presence of the owner installed drawbar altered the crash dynamics and contributed to the eventual fractured hitch-receiver cross-member.

In all scenarios, when facts were unknown, variables were assumed to be nominal (i.e. traveling at posted speed unless actual velocity was otherwise known). Several photos of the exact vehicles from the reconstructed crashes are shown in Appendix B. The reconstruction test data can be found in the searchable NHTSA vehicle crash test database at http://www.nhtsa.gov/Research/Databases+and+Software .

6.1 Scenario 1 - Reconstruction of Plymouth Neon and KJ Jeep Liberty Crash

This reconstruction test series consisted of two tests. Table 5 shows the test parameters for each of the tests conducted.

TEST NUMBER	BULLET VEHICLE	TARGET VEHICLE	TOW HITCH RECEIVER EQUIPPED	IMPACT SPEED (mph)	IMPACT ANGLE (degrees)	BULLET VEHICLE IMPACT POINT OFFSET (inches)	RIDE HEIGHT REDUCTION (Simulate Panic Braking)
1	NEON	LIBERTY	NO	40.0	180	0	NONE
2	NEON	LIBERTY	YES	40.0	180	0	NONE

Table 5 - Parameters for first reconstruction test series

6.1.1 KJ Under-ride Baseline Test

This test used a 1997 Plymouth Neon as the bullet vehicle and a 2004 Jeep Liberty without a hitch-receiver as the target vehicle. Post-test observation of the impact damage to the target vehicle was compared to and found to be consistent with the damage of the vehicle in the real-world crash. The fuel tank was directly contacted by the Neon, and most of the 68.5 liters of Stoddard in the tank spilled by the end of 30 minutes. Review of the high-speed video footage revealed the Neon passed under the Jeep and significantly lifted the back end until the front wheels of the Neon contacted the back wheels of the Jeep to move it forward, indicating significant under-ride as shown in Figure 6.

6.1.2 KJ Under-ride Comparative Test

This test used a 1997 Plymouth Neon as the bullet vehicle and a 2004 Jeep Liberty equipped with an OE hitch-receiver as the target vehicle. Model years of both the bullet and target vehicles were the same as the original crash. Post-test observation of the impact damage to the target vehicle showed no rupture of the fuel tank. Review of the high speed video footage revealed the Neon directly impacted the hitch-receiver and reduced upward motion of the Jeep from the baseline test due to reduced under-ride, also shown in Figure 6. Additionally, the front wheels of the Neon did not contact the back wheels of the Liberty. Post-test observations from the baseline and comparative test, as compared to the real-world crash are shown in Figure 6. A comparison between the two front bumper reinforcements of each Neon test vehicle is shown in Figure 7. Pre and post-test photos of the target vehicle fuel tanks are shown in Figure 8, Figure 9, and Figure 10, respectively. Test #1 shows significant scraping of the tank from the under-ride of the bullet vehicle (see Figure 9). Also the orange paint from Region 2 (17 to 24 inches above the ground) can be seen on the vehicle exhaust pipe and rear differential indicating significant interaction between the bullet vehicle, the Jeep fuel tank, and other adjacent components. Figure 10 shows the post-test photo of the comparative test (Test #2) with the hitch-receiver installed. The fuel tank and exhaust pipe do not show signs of under-ride or interaction with the bullet vehicle.

Figure 6 - Difference in dynamic overlap of Neon and Jeep Liberty

	Original Real World Accident	Test 1 25-Sep Little visible rust 0" Dive NO HITCH	Test 2 24-Oct Little visible rust 0" Dive HITCH
Exhaust pipe	Bent outward	Bent outward	Bent outward
Rear gate	Pushed inward	Pushed inward	Pushed inward
Left taillight	Intact but melted	Intact	Intact
Spare Tire	Bent downward	Bent downward	Bent downward
Left rear quarter panel	Minor deformation	Minor deformation	Minor deformation
Right rear quarter panel	Minor deformation	Minor deformation	Minor deformation
Lower rear gate frame	Lower lip bent forward	Lower lip bent forward	Lower lip bent forward
Fuel filler tank connections	Unknown -consumed in fire	Intact	Intact
Fuel filler rubber hoses	Unknown -consumed in fire	Intact and in tension	Intact and not in tension
Left frame rail	Minor damage	Minor damage	Bent
Left frame rail passthrough	Intact	Intact	Intact
Gas tank	Unknown -consumed in fire	LEAK, Deformed, heavily scraped, punctured	Partially deformed, no leak, little scraping

Table 6 – Scenario 1 test comparison to real-world crash

Figure 7 - Neon bumper reinforcement Test 1 vs. Test 2. Arrow at hitch-receiver contact

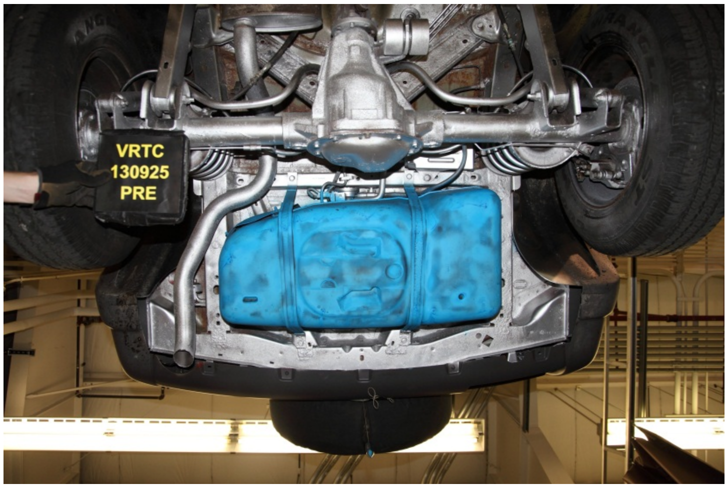


Figure 8 – Test #1 Pre-test target vehicle rear underbody view without hitch-receiver

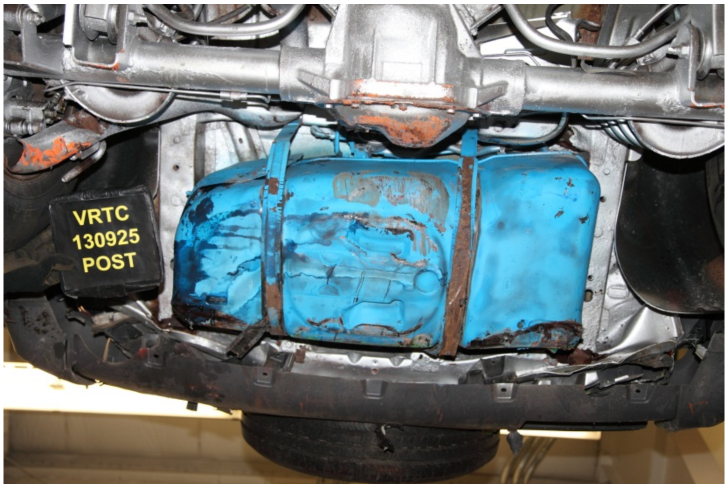


Figure 9 – Test #1 Post-test target vehicle fuel tank close-up view without hitch-receiver

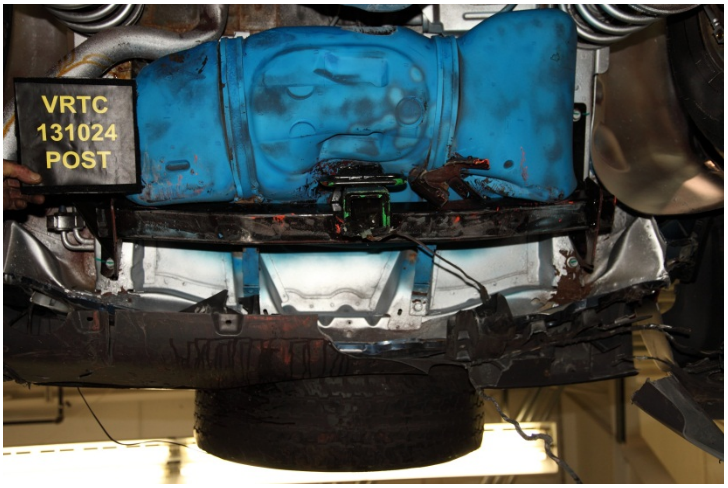


Figure 10 – Test #2 Post-test target vehicle fuel tank close-up view with hitch-receiver

6.2 Scenario 2- Reconstruction of Cadillac Deville and ZJ Jeep Grand Cherokee Crash

This reconstruction test series consisted of five tests. Table 7 shows the test parameters for each test conducted.

TEST NUMBER	BULLET VEHICLE	TARGET VEHICLE	TOW HITCH RECEIVER EQUIPPED	IMPACT SPEED (mph)	IMPACT ANGLE (degrees)	BULLET VEHICLE IMPACT POINT OFFSET (inches)	RIDE HEIGHT REDUCTION (Simulate Panic Braking)
3	DEVILLE	GRAND CHEROKEE	NO	35.1	180	15	NONE
4	DEVILLE	GRAND CHEROKEE	NO	35.0	180	15	2 inch dive +/- 1"
5	DEVILLE	GRAND CHEROKEE	NO	35.1	180	15	2.5 inch dive +/- 1"
6	DEVILLE	GRAND CHEROKEE	YES	35.0	180	15	2 inch dive +/- 1"
7	DEVILLE	GRAND CHEROKEE	YES	35.0	180	15	NONE

Table 7 - Parameters for second reconstruction test series

6.2.1 ZJ Grand Cherokee Baseline Tests

This series consisted of three tests identified as Test #3 through #5. Each test used a 1993 Cadillac Deville, the same model year as the bullet vehicle in the real-world crash. Test #3 used a 1998 ZJ Jeep Grand Cherokee without a hitch-receiver as the target vehicle, while Test #4 and #5 each used a 1996 ZJ Jeep Grand Cherokee without a hitch-receiver as the target vehicle. The real-world crash Jeep was a 1996 model year. The Cadillac used in the first baseline test was prepared at normal ride height because there were no documented facts to support pre-impact braking. At the conclusion of the first test, it was evident that the Cadillac struck the Jeep with an impact point at least two inches higher than in the real-world crash based on intrusion patterns into the rear gate of the Jeep. At least one known source of the fuel leak in the real-world crash was a several inch long cut along the bottom of the tank. It is possible that other leak sources existed, but no other sources were documented. In the baseline crash, a fuel leak was produced; however it originated at the fuel filler hose connections. There is a relief tunnel (hole) through the left frame rail that routes the fuel filler hose along the path to the filler cap shown in Figure 11. The tunnel in the frame rail was crushed due to the force of the crash, combined with significant rust originating from the hollow, inside of the rail, and this resulted in the hoses being captured in the frame rail, shown in Figure 12. As the frame rail bent, it pulled upward on the fuel tank hose connections and broke them at their bases on the plastic tank, resulting in a significant leak, as shown in Figure 13.

Figure 11 - Frame rail relief tunnel for fuel filler hoses

Figure 12 - Test #3 Significant rust causes collapse at relief tunnel in rail where fuel hoses pass through

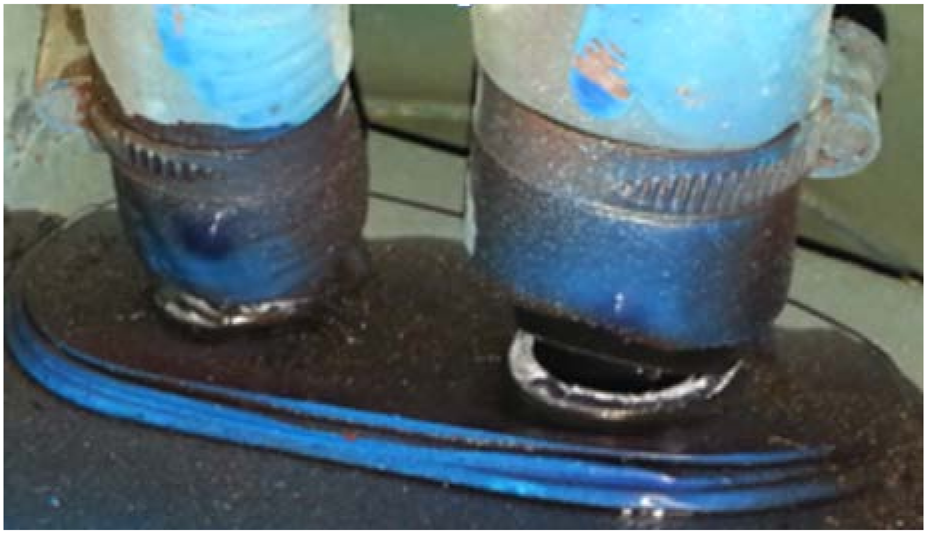


Figure 13 - Test #3 Broken fuel connections on plastic fuel tank

Although the first test produced a fuel leak, it did not recreate the cut along the bottom of the tank. So a second baseline test, Test #4, was conducted assuming moderate pre-impact braking, that correlated to about two inches of front bumper dive. This test produced similar results and the same failure mode as Test #3, with a crushed, rusted relief tunnel in the left frame rail and broken hose connections on the tank. The varied front heights tested on the Cadillac produced the same failure mode; height was therefore not considered a significant variable.

Both of the Jeep Grand Cherokees tested to this point had unseen corrosion (rust) inside of the frame rails that wasn't revealed until after the tests. While this was not surprising given the number of exposure years in salt-belt states, it was reasoned that this could potentially be a variable in crash performance and may reduce the ability of the frame rail relief tunnel to resist crushing. A Jeep Grand Cherokee with limited salt exposure was procured for baseline Test #5. Although height had not been a significant factor in producing the crushed frame rail, the cut on the bottom side of tank in the real-world crash had still not been produced, so a final attempt was made to further lower the front ride height of the Cadillac, but the progressive springs limited static compression to between two and three inches, making the striking height essentially only marginally lower than in Test #4. At the conclusion of this test, there was no fuel leak. The left frame rail had bent outward, but the filler hose relief tunnel was not crushed and allowed the hoses to slide through the tunnel as it was bent by the force of the crash. Despite significant scraping between the Cadillac and the Jeep tank being produced, the cut in the bottom of the tank was not produced. It became apparent that it would be improbable to be able to control the formation and motion of sharp features from the deforming Cadillac, while also predicting whether the metal reinforcement on the Jeep would break away or just deform.

6.2.2 ZJ Grand Cherokee Comparative Tests

This series consisted of two tests identified as Test # 6 and 7. Each used a 1993 Cadillac Deville as the bullet vehicle travelling at 35 mph and a stationary 1996 Jeep Grand Cherokee with an OE hitch-receiver as the target vehicle. The Jeep in Test #6 exhibited minimal rust. The 1993 Cadillac front ride height was set for two inches of dive, which made it most similar to Tests #4 & #5. After the crash, there was no fuel leak. A still photo from the high speed video showed the difference in dynamic overlap, where the Cadillac did not encroach as far into the Grand Cherokee when it was equipped with the hitch-receiver (Figure 14).

Figure 14- Dynamic overlap between Cadillac and Jeep Grand Cherokee without and with a hitch-receiver

The Cadillac bumper engaged directly with the Jeep's hitch-receiver and prevented the frame rails from bending near the tank. The support brackets that attach the hitch-receiver to the body of the Jeep with three bolts on each side provided significant structural support (Figure 15). This also resulted in greatly reduced scraping between the Jeep's tank and the Cadillac.

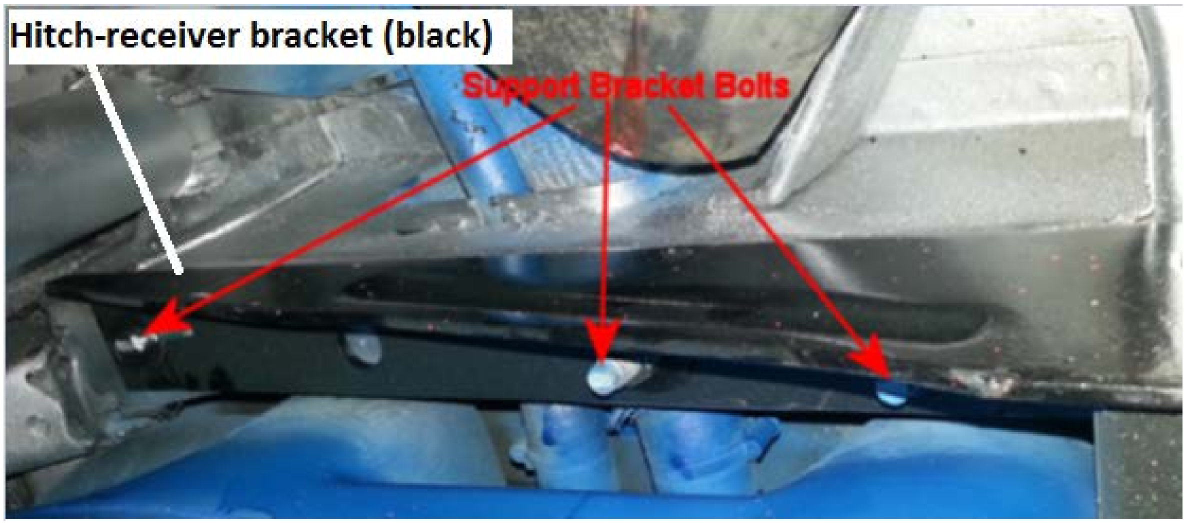


Figure 15 - Test #6 - Hitch-receiver bracket reinforces tunnel, hose not captured - Minimal rust vehicle

The last ZJ Grand Cherokee test was Test #7. This test was conducted to determine whether the frame rail reinforcement properties demonstrated in Test #6 would also sufficiently benefit a rusted frame rail relief tunnel. The Jeep used for Test #7 had up to 18 years of road salt exposure. The Cadillac was set to normal ride height, similar to baseline Test #3. At the conclusion of the crash, there was no fuel leak. The Cadillac again directly struck the hitch-receiver and the frame rails did not bend near the tank. The hitch support bracket bridged the frame rail relief tunnel and transferred the impact force to a forward point on the frame rail away from the tank (Figure 16). Scraping between the Cadillac and fuel tank was minimal.

Figure 16 Test#7 Rail with rust reinforced by hitch-receiver bracket, hose not captured – moderately rusted vehicle

Crash damage for all of the ZJ tests is categorized by either not having pre-impact brake dive, or having it, as shown in Table 8 and Table 9, respectively. A comparison of post-crash damage in the left rear D-pillar area, between the baseline test vehicles and the real-world crash is shown in Figure 17. A comparison of post-crash damage in the rear bumper reinforcement area between the baseline test vehicles and the real-world crash is shown in Figure 18. A comparison of post-crash damage in the rear lift gate area between the baseline test vehicles and the real-world crash is shown in Figure 19. A comparison of post-crash damage in the right rear area between the baseline test vehicles and the real-world crash is shown in Figure 20. A comparison of post-crash damage of the fuel tank area, between Test# 3 (no hitch-receiver) and Test #7 (hitch-receiver) is shown in Figure 21 and Figure 22, respectively.

Pre-test and post-test photos of the target vehicle fuel tank from the baseline test (Test#3) are shown in Figure 23 and Figure 24, respectively. The post-test photo shows the scraping caused by the under-ride. Figure 25 shows the post-test photo of the comparative test (Test #7) with hitch-receiver installed. The fuel tank did not show signs of under-ride, but did show signs of impacting the rear differential of the Jeep.

	NO HITCH	NO HITCH	HITCH
	Original Real World Accident **Rust unknown**	**Test 3** **31-Oct** **Little visible rust** **0" Dive**	**Test 7** **4-Dec** **Little visible rust** **0" Dive**
Left rear wheel	Debeaded	Not debeaded	Not debeaded
Exhaust pipe	Bent	Bent	Bent
Rear gate	Deformed, not gouged	Deformed and gouged	Deformed, not gouged
Left taillight	Broken	Broken	Broken
Right taillight	Intact	Intact	Intact
Bumper reinforcement	Failed	Damaged but in place	Damaged but in place
Left rear quarter panel	Damaged	Excessively damaged	Excessively damaged
Right rear quarter panel	Not damaged	Damaged	Damaged
Lower rear gate frame	Bent/torn	Bent, protected by reinforcement	Bent, protected by reinforcement
Fuel filler tank connections	Unknown	Broken	**Intact**
Fuel filler rubber hoses	Unknown	Pinched in rail	**Intact**
Left frame rail	Unknown	Crushed/Bent up aft rear bolt	**Bent upward forward of tank, rust**
Left frame rail relief tunnel	Unknown	Crushed/rust	**Intact**
Gas tank	**LEAK from cut, significant sliding interaction**	**LEAK at filler connectors, significant sliding interaction**	**Minimal sliding interaction w/bullet, Intact**

Table 8 – Scenario 2 test comparison – Reconstruction with no pre-impact brake dive compared to real-world crash

	NO HITCH Original Real World Accident Rust unknown	NO HITCH Test 4 7-Nov Little visible rust 2" Dive	NO HITCH Test 5 21-Nov No rust ~3" Dive	HITCH Test 6 27-Nov No rust 2" Dive
Left rear wheel	Debeaded	Debeaded	Debeaded	Not debeaded
Exhaust pipe	Bent	Bent	Bent	Bent
Rear gate	Deformed, not gouged	Deformed, gouged lower edge	Deformed, not gouged	Deformed, not gouged
Left taillight	Broken	Broken	Broken	Broken
Right taillight	Intact	Intact	Intact	Intact
Bumper reinforcement	Failed	Failed	Damaged but in place	Damaged but in place
Left rear quarter panel	Damaged	Damaged	Damaged	Damaged
Right rear quarter panel	Not damaged	Damaged	Damaged	Damaged
Lower rear gate frame	Bent/torn	Bent/torn	Bent, protected by reinforcement	Bent, protected by reinforcement
Fuel filler tank connections	Unknown	Broken	Intact	**Intact**
Fuel filler rubber hoses	Unknown	Pinched in rail	Intact	**Intact**
Left frame rail	Unknown	Crushed/bent up/rust	Bent outward	**Bent upward forward of tank**
Left frame rail relief tunnel	Unknown	Crushed/rust	Intact	**Intact**
Gas tank	**LEAK from cut, significant sliding interaction**	Deformed, **LEAK at filler connectors, significant sliding interaction**	Deformed but intact, **significant sliding interaction**	**Minimal sliding interaction w/bullet, Intact**

Table 9 - Scenario 2 test comparison - Reconstruction with pre-impact brake dive compared to real-world crash

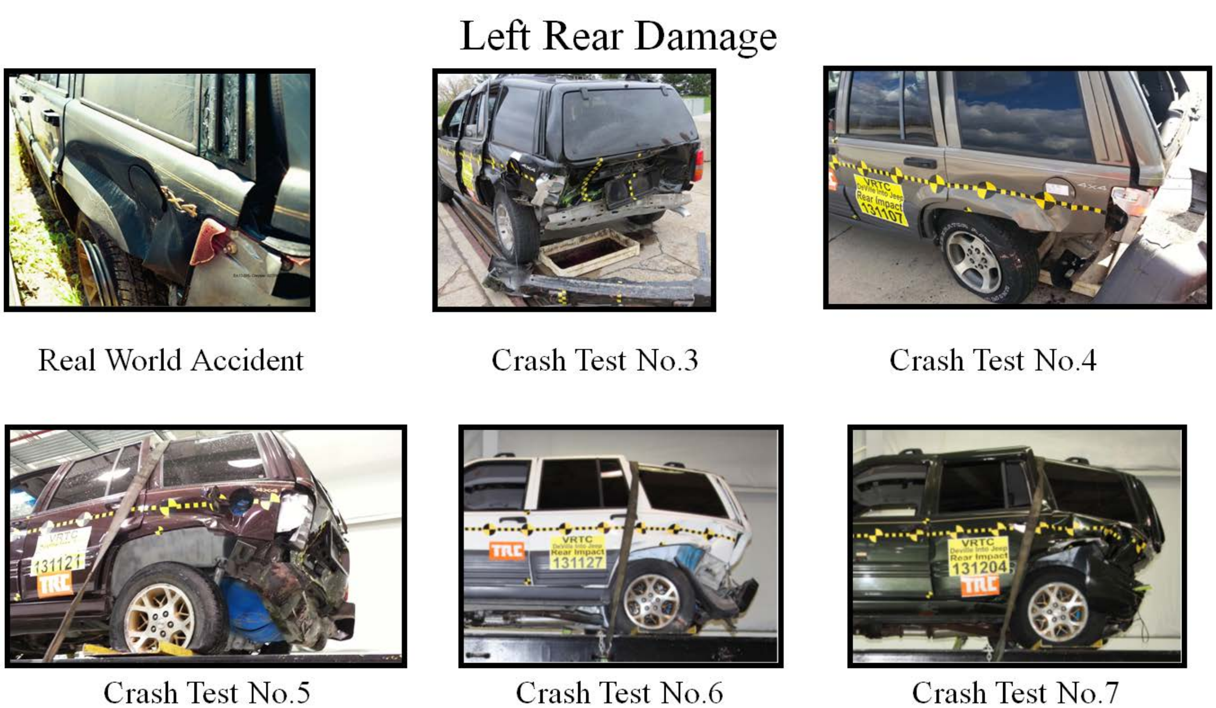


Figure 17 - Comparison of post-crash damage of the left rear D-pillar area between the baseline tests and the real-world crash

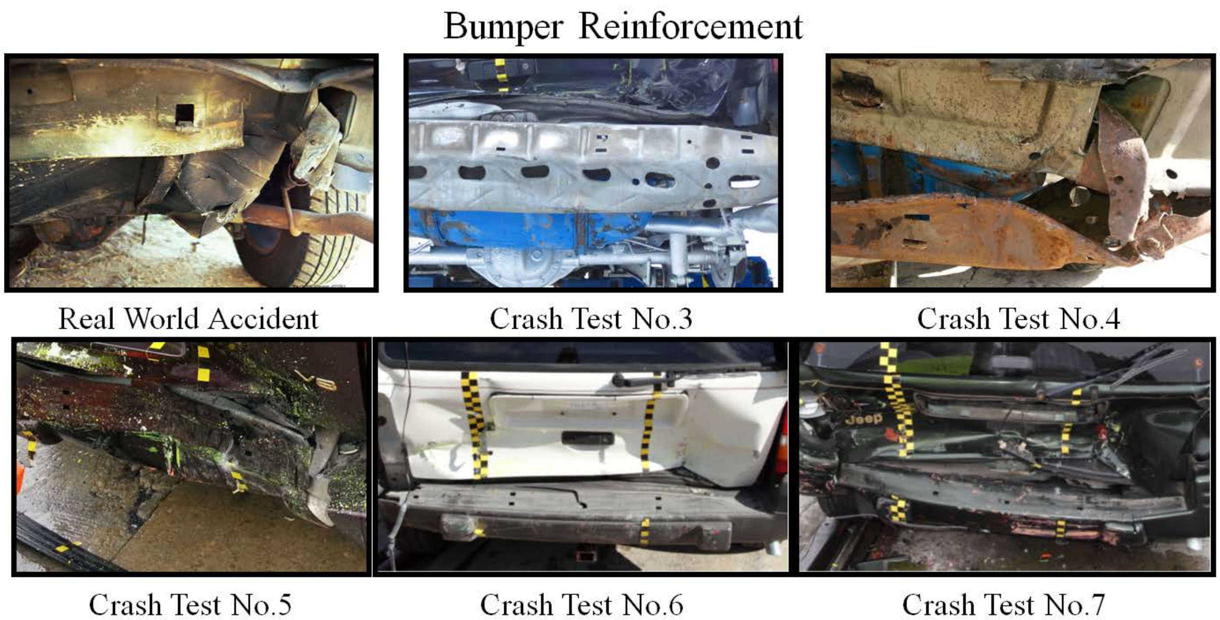


Figure 18 - Comparison of post-crash damage of the rear bumper reinforcement area between the baseline tests and the real-world crash

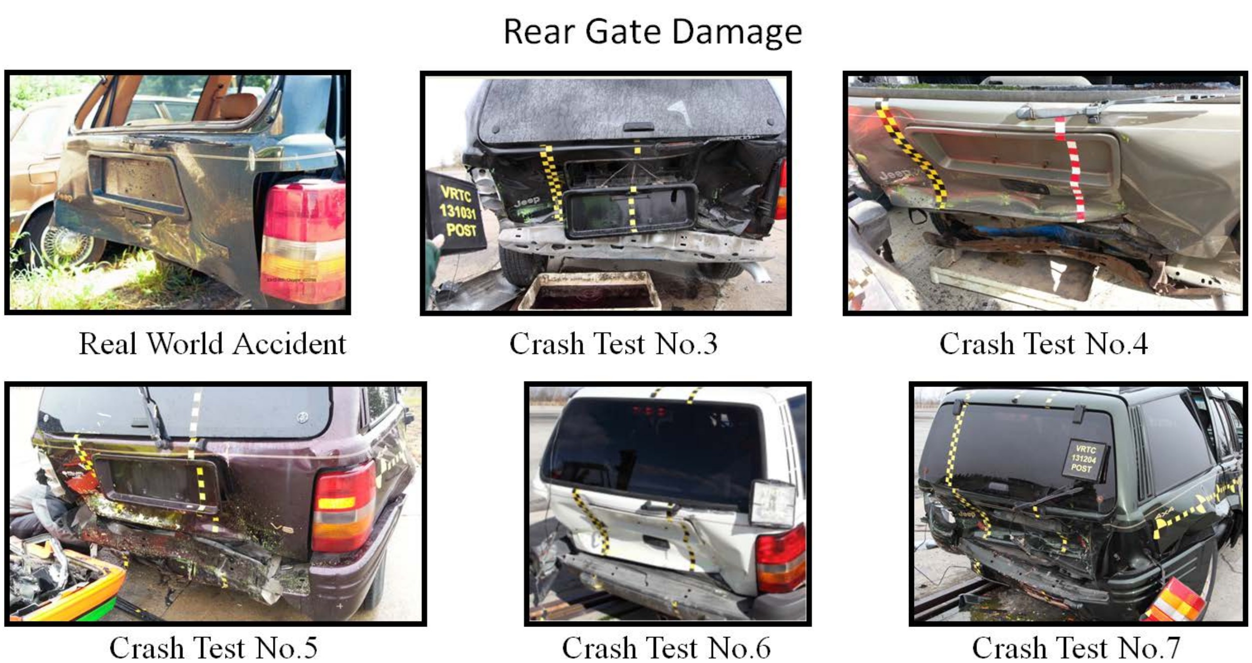


Figure 19 - Comparison of post-crash damage of the rear lift gate area between baseline test and real-world crash

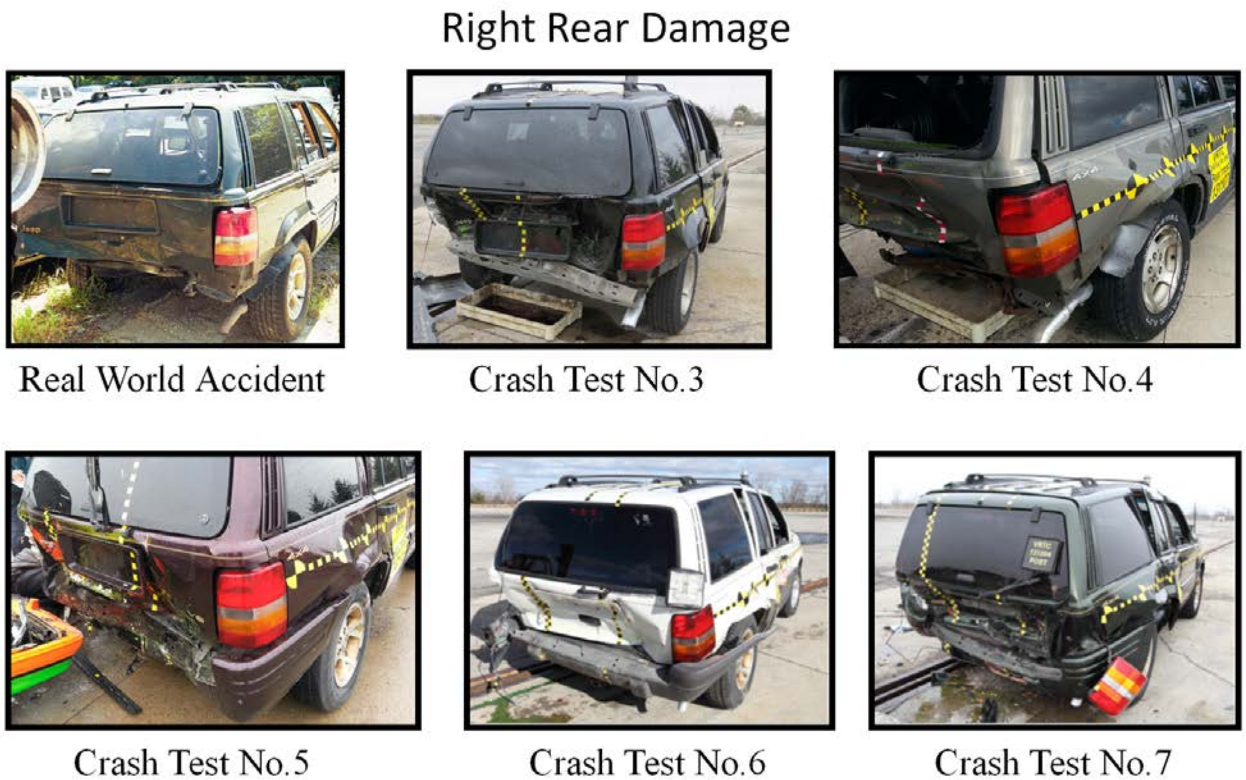


Figure 20 - Comparison of post-crash damage of right rear area between baseline test and real-world crash

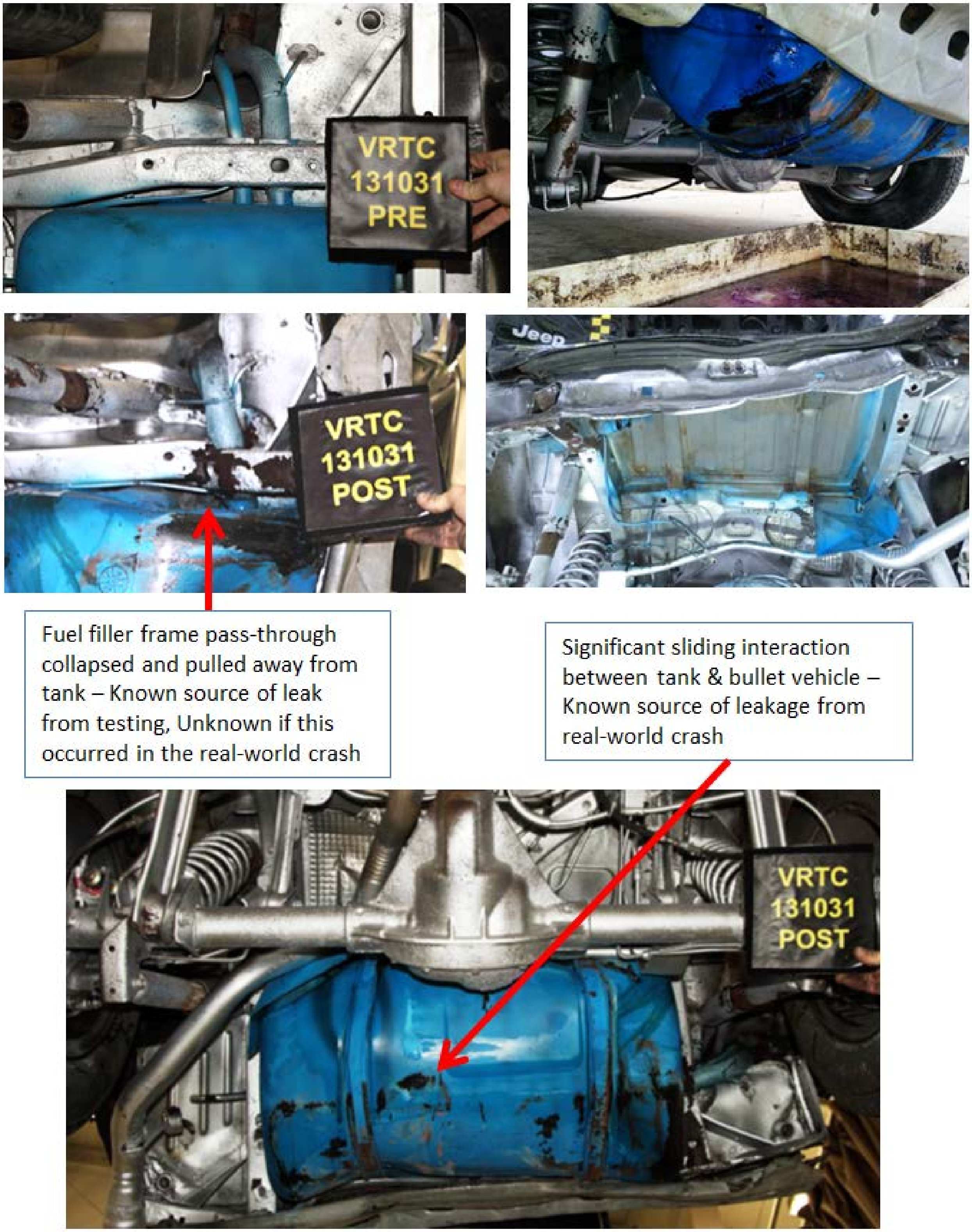


Figure 21 – Post-test damage from Test #3 – No hitch-receiver

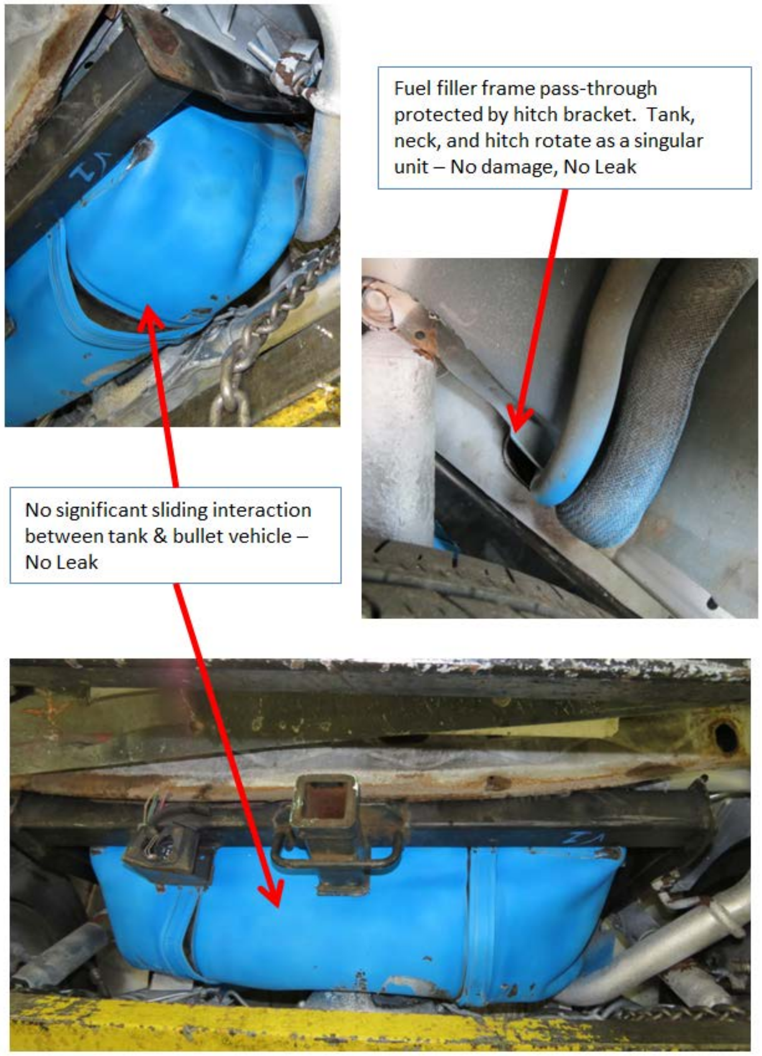


Figure 22 - Post-test damage from Test #7 - With hitch-receiver

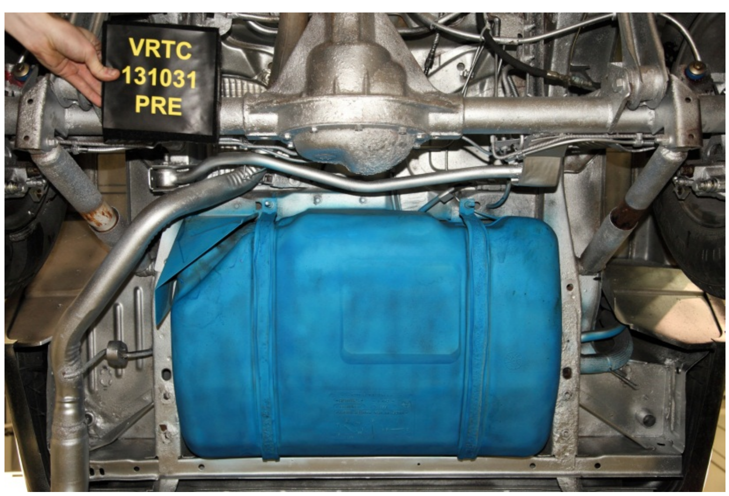


Figure 23 - Test #3 Pre-test target vehicle fuel tank close-up view without hitch-receiver

Figure 24 - Test #3 Post-test target vehicle fuel tank close-up without hitch-receiver

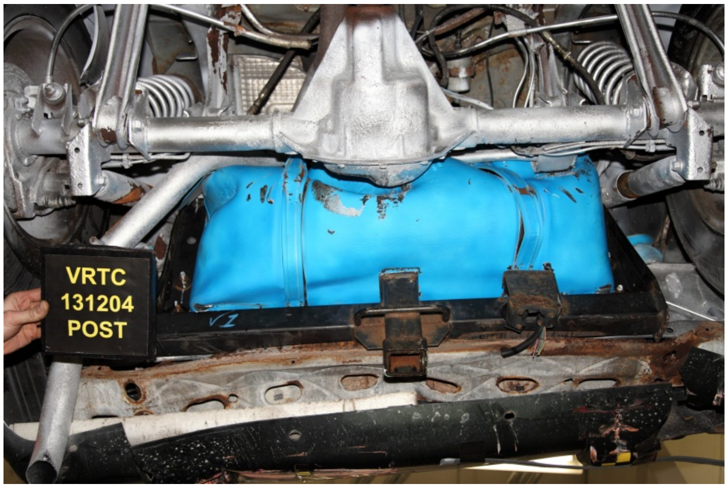


Figure 25 - Test #7 Post-test target vehicle fuel tank close-up with hitch-receiver

6.3 Scenario 3-Reconstruction of Ford F-150 and Jeep Liberty Crash

This reconstruction consisted of one test. Table 10 shows the parameters for this test.

TEST NUMBER	BULLET VEHICLE	TARGET VEHICLE	TOW HITCH RECEIVER EQUIPPED	IMPACT SPEED (mph)	IMPACT ANGLE (degrees)	BULLET VEHICLE IMPACT POINT OFFSET (inches)	RIDE HEIGHT REDUCTION (Simulate Panic Braking)
8	F-150 SUPER CAB	LIBERTY	YES	43.0	180	11.25	2.5 inches

Table 10 - Parameters for third reconstruction test series

6.3.1 KJ Hitch Fracture Test

This crash scenario consisted of one test identified as Test #8 from VOQ #10512282. It used a 2008 Ford F-150 Super Cab travelling at 43 mph as the bullet vehicle and a stationary 2004 Jeep Liberty with a hitch-receiver as the target vehicle. Unlike the real-world crash, the hitch on this test vehicle did not have the consumer installed ball-mount drawbar inserted into the hitch-receiver. Upon impact, the hitch partially collapsed, but the cross-member did not fracture as it did in the real-world crash (see Figure 26 and Figure 27). The cross-member did push into the fuel tank but did not pierce it. Stoddard solvent droplets were observed immediately after the crash but ceased before they could be measured. There were no observable openings in the tank.

Figure 26 - Left: Real-world crash cross-member fracture, Right: Reconstruction deformation, no cross-member fracture

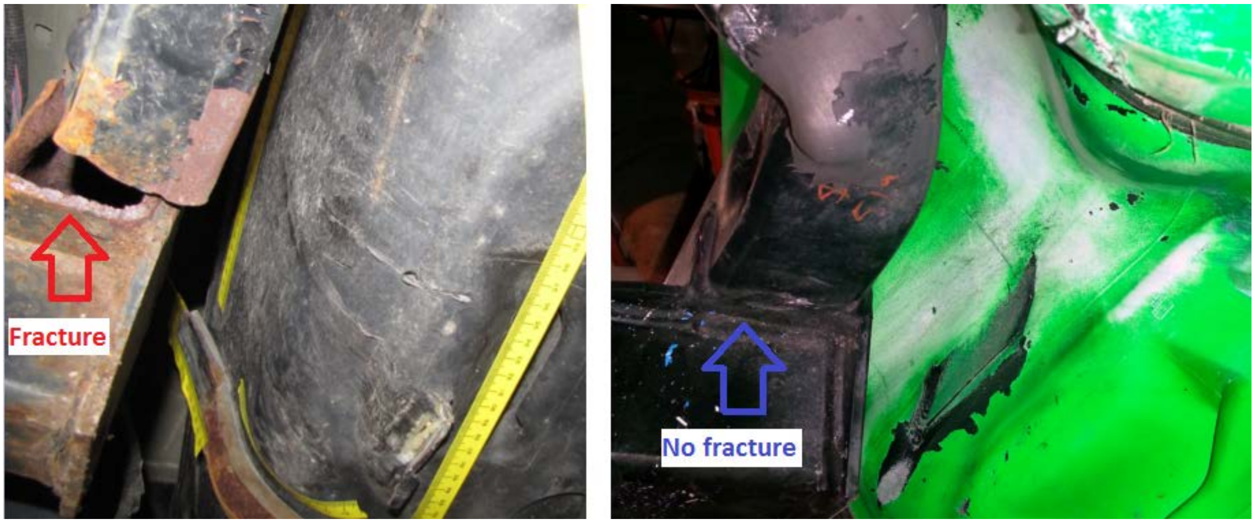


Figure 27 - Left: Real-world crash cross-member fracture (picture taken several months after crash), Right: Reconstruction deformation, no cross-member fracture

Pre-test and post-test photos of the target vehicle fuel tank from the baseline test (Test#8) are shown in Figure 28 and Figure 29, respectively. The post-test photo shows no signs of under-ride from the bullet vehicle. Post-test observations are compared to the real-world crash and shown in Table 11. Damage to the tested Jeep Liberty indicated that the energy levels were consistent with, if not in excess of that achieved in the real-world crash. In post-test observation and during the procedural longitudinal rollover test, leakage occurred when the vehicle was rolled in the rollover fixture. Upon disassembly, the source of the droplets was discovered to be the overfill vent connector and the charcoal vapor connector, which had broken off at the top of the fuel pump assembly (Figure 30). These connectors were made from a nylon material and were formed into the top of the housing. They do not carry fuel during normal operation because they function to vent vapors and prevent overfilling. A third connector of the same material, the high pressure supply connection, which does carry fuel during normal operation, remained intact. Further investigation of the fuel pump inside of the tank revealed that the bottom of the plastic pump housing assembly had been displaced forward, had shattered inside of the fuel tank, and had broken the internal supply tube to the fuel pump. This rendered the pump incapable of pressurizing the external fuel tube.

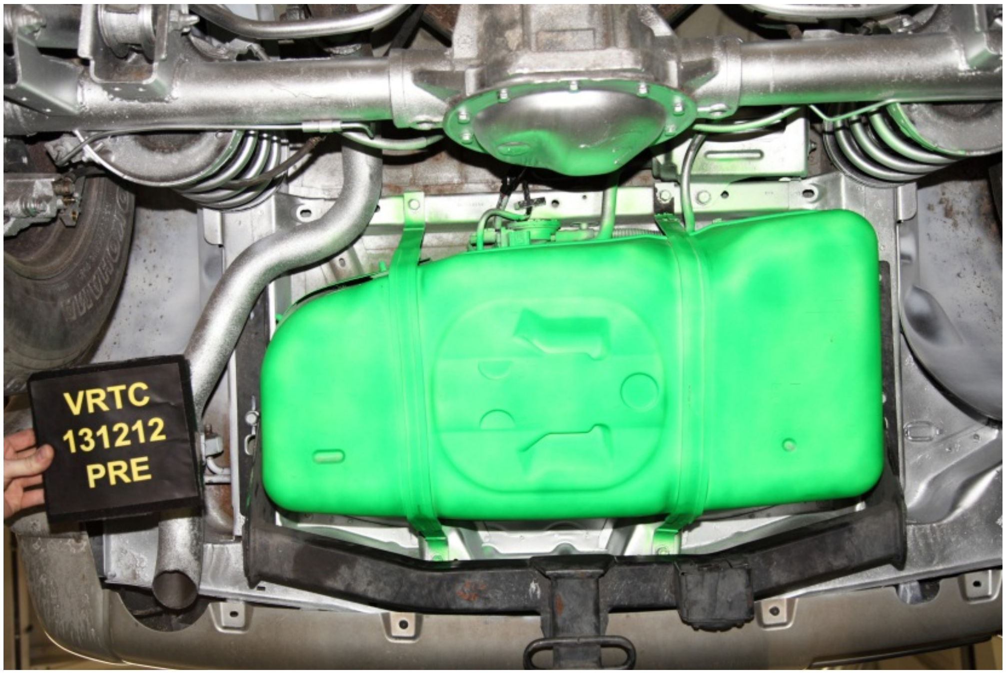


Figure 28 - Test #8 Pre-test target vehicle fuel tank close-up view

Figure 29 - Test #8 Post-test target vehicle fuel tank close-up view

	HITCH w/BALL & DRAWBAR INSTALLED	HITCH, No DRAWBAR, NO BALL
	Original Real World Accident Pre-impact braking = 2.5" dive	Test 8 12-Dec Little visible rust 2.5" Dive
Gas tank	Deformed, cut by edge of hitch, LEAK	Deformed but tank intact
Hitch	Overload fracture to the right of center	Damaged, but intact
Tailgate	Damaged beyond repair	Damaged beyond repair
Spare Tire	Damaged	Damaged
Left Taillight	Intact	Damaged
Right Taillight	Intact	Damaged
Left rear quarter panel	Little to no damage	Damaged
Right rear quarter panel	Little to no damage	Damaged
Lower rear gate frame	Repairable damage	Damaged
Fuel filler tank connections	Intact	Intact
Fuel filler rubber hoses	Intact	Intact
Left frame rail	Minimal damage	Damaged, but intact

Table 11 - Scenario 3 test comparison to real-world crash

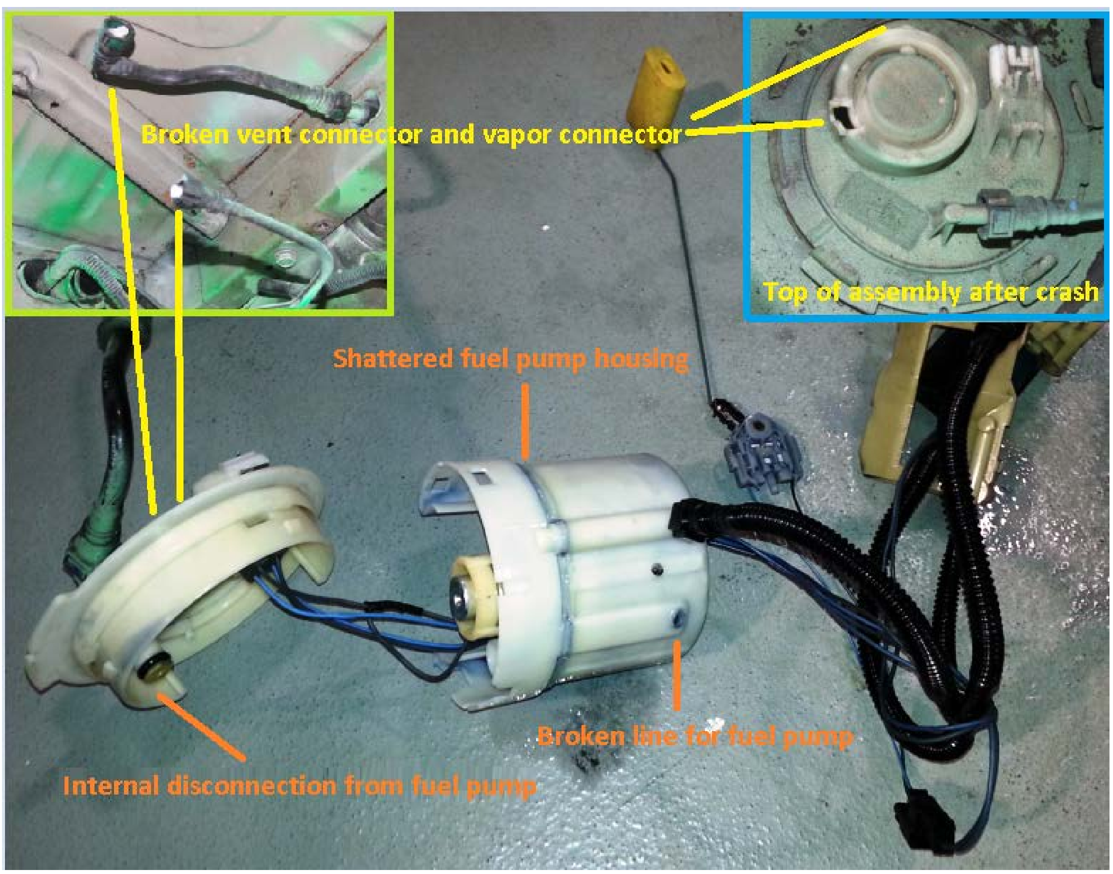


Figure 30 - Additional observation: Fuel pump assembly contained in tank rendered internally non-functional by crash. Vent and vapor tubes broken externally.

7.0 **CONCLUSIONS**

This test program demonstrated that crash reconstruction testing of KJ Jeep Liberty and ZJ Jeep Grand Cherokee could reasonably replicate real-world, rear impact fuel system leakage occurrences. Adding the OEM hitch-receiver to the vehicles places additional structure behind and to the sides of the fuel tank. The added structure appears to reduce tank damage and fuel leaks in certain rear impact crashes.

7.1 Reconstruction Scenario 1

The reconstruction of the Plymouth Neon into the KJ Jeep Liberty demonstrated the consequences of an under-ride situation. Without the hitch-receiver, the Neon progressed under the Liberty until the front wheels of the Neon pushed the rear wheels of the Liberty ahead, and the back of the Liberty was lifted several inches into the air. The fuel tank was directly contacted by the Neon, and a significant fuel leak resulted. When the hitch-receiver was installed, the Neon directly impacted the hitch-receiver, upward motion of the Jeep was reduced, and the front wheels of the Neon did not contact the back wheels of the Liberty. The fuel tank did not show signs of under-ride or interaction with the bullet vehicle, and no fuel leak occurred.

7.2 Reconstruction Scenario 2

The reconstruction of the Cadillac Deville into the ZJ Jeep Grand Cherokee revealed a repeatable failure mode with the crushed and rusted frame rail pulling on the fuel filler hoses until they broke the connections from the plastic tank. It was confirmed that a vehicle with little to no rust could withstand the crash. The hitch-receiver bracket and mounting bolts provided a structural reinforcement that prevented the collapse of the moderately rusted frame rail relief tunnel in testing.

A known failure mode in the real-world crash was a large cut on the bottom of the tank caused by scraping between features on the striking car and the Jeep’s fuel tank. While the reconstruction tests did not result in replicating the large cut on the bottom surface of the tanks, preventing a bullet vehicle from interacting with the fuel tank would be expected to reduce the risk of cutting it.

Varying the height of the bullet vehicle by approximately zero to three inches did not prove to be relevant to the failure mode. The stepped front bumper of the Cadillac caused a partial under-ride and contributed to these vehicles crushing the fuel tank in a crash when the Jeep was not equipped with a hitch-receiver. When the hitch-receiver was installed, a reduced level of rear structure and fuel tank crush occurred.

7.3 Reconstruction Scenario 3

The reconstruction of the F-150 into the KJ Liberty demonstrated the hitch was capable of withstanding a higher energy impact without the hitch-receiver cross-member fracturing and without piercing the tank. Damage to the tested Jeep Liberty indicated that the energy levels were consistent with, if not in excess of that achieved in the real-world crash. The presence of the aftermarket tow drawbar and tow ball inserted into hitch-receiver in the real-world crash seems to have increased the leverage acting upon the cross-member and may have contributed to the overload fracture. The droplets of fuel leakage during and immediately after the test that originated from the vent and vapor tube connectors ceased shortly after the impact. Significant leakage did not occur until the vehicle was rolled in the rollover fixture. The source of the leak was the overfill vent connector and the charcoal vapor connector, which had broken off of the top of the fuel pump assembly.

APPENDIX A
Test Vehicles

1997 Plymouth Neon, VIN: 3P3ES47C5VTxxxxxx
Bullet Vehicle Test# 1

2004 Jeep Liberty, VIN: 1J4GL48K44Wxxxxxx
Target Vehicle Test# 1

1997 Plymouth Neon, VIN: 3P3ES47CXVTxxxxxx
Bullet Vehicle Test# 2

2004 Jeep Liberty, VIN: 1J4GL48K54Wxxxxxx
Target Vehicle Test# 2

1993 Cadillac Deville, VIN: 1G6CD53B7P4xxxxxx
Bullet Vehicle Test# 3

1998 Jeep Grand Cherokee
VIN: 1J4GZ48S1WCxxxxxx
Target Vehicle Test# 3

1993 Cadillac Deville, VIN:1G6CD53B4P4xxxxxx
Bullet Vehicle Test# 4

1996 Jeep Grand Cherokee
VIN: 1J4GZ58S1TCxxxxxx
Target Vehicle Test# 4

1993 Cadillac Deville, VIN: 1G6CD53B7P4xxxxxx
Bullet Vehicle Test# 5

1996 Jeep Grand Cherokee
VIN: 1J4GZ78Y4TCxxxxxx
Target Vehicle Test# 5

1993 Cadillac Deville, VIN: 1G6CD53B5P4xxxxxx
Bullet Vehicle Test# 6

1996 Jeep Grand Cherokee
VIN: 1J4GZ58S0TCxxxxxx
Target Vehicle Test# 6

1993 Cadillac Deville, VIN: 1G6CD53B9P4xxxxxx
Bullet Vehicle Test# 7

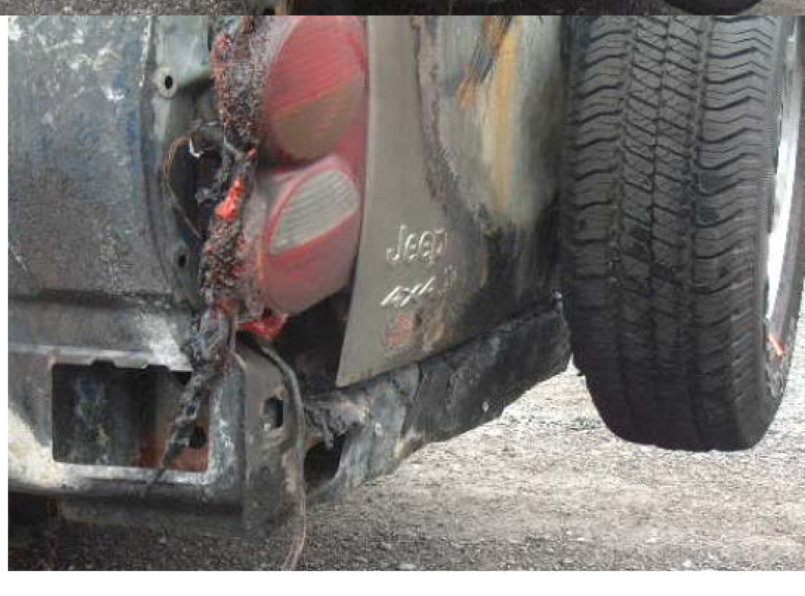
1996 Jeep Grand Cherokee
VIN: 1J4EZ78S9TCxxxxxx
Target Vehicle Test# 7

2008 Ford F-150, VIN: 1FTPX14V58Fxxxxxx
Bullet Vehicle Test# 8

2004 Jeep Liberty, VIN: 1J4GL58K94Wxxxxxx
Target Vehicle Test# 8

APPENDIX B
Real-World Crash Photos

Scenario 1-Jeep Liberty
(Neon pictures were not available)


Jeep

Scenario 2 - Jeep Grand Cherokee
(Cadillac Deville pictures were not available)


4X4

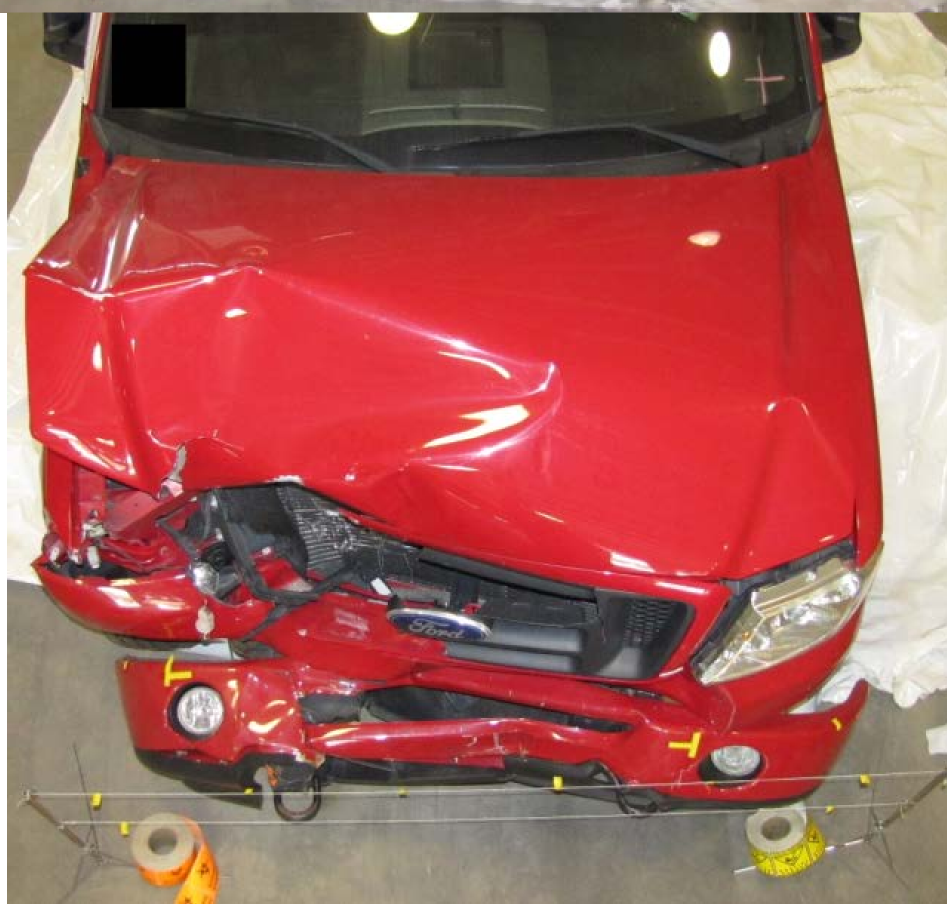
Scenario 3- Jeep Liberty & Ford F-150


STANDARD
LOAD
77
76
75
74


REESE


82
83
84
85
86
87
88
89
90
91
92
93
94


Ford


Ford