HEAVY TRUCK FRONTAL IMPACTS AND FIRES

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ABSTRACT
Industry and government studies have noted the dangers of heavy truck frontal and underrun crashes, suggesting various measures to improve safety in these types of accidents including strengthening front suspension components and adding protective structures. In 1986, The USDOT found post-crash fires were involved in 16% of heavy truck fatalities compared to only 4% for cars. The report identified several mechanisms of fuel tank rupture including frontal impacts resulting in front axle contact with fuel tanks. The hazards of exposed side saddle fuel tanks have been known for decades, yet heavy trucks still use this vulnerable outboard location for fuel tanks.

In 1994, the United Nations ECE published a standard for heavy truck front underrun protective structures (FUPS); however, the United States still has no requirements regarding front underrun protection of heavy trucks. A FUPS prevents underrun and engages the energy absorbing structures of smaller impacting vehicles, provides protection of the trucks steering components, and helps prevent the truck's front axle from being displaced into the fuel tank which can cause rupture and fire.

Three real-world crashes are presented wherein heavy trucks experienced a frontal impact, resulting in fire and serious injury. In each of these cases, testing was conducted on a production truck front structural assembly and compared to a similar FUPS equipped assembly. The effectiveness of FUPS in mitigating damage in these frontal crashes was assessed.

INTRODUCTION
Fuel tanks in heavy trucks have traditionally been placed outside the frame rails in a side-saddle arrangement. This fuel tank arrangement was abandoned decades ago in passenger cars, light trucks, and vans due to the vulnerability of the fuel tanks. The photo below shows the side saddle fuel tank location that Consolidated Freightways, the precursor to Freightliner, was using at least as early as the 1940s (see Figure 1).

Figure 1. Consolidated Freightways Truck (Precursor to Freightliner) Fuel Tank Placement

In 1983, the University of Michigan studied fires and fatalities in heavy truck accidents.[1] This study found the rate of fire-associated fatalities in diesel fueled road tractors was 15 times as high as the corresponding fatality rate among passenger car occupants. The study noted “Yet some improvement might result from strengthened front axle mountings, from moving the fuel tanks in from the absolute edge of the vehicle side boundary, etc.”

The United States Department of Transportation (DOT) published Truck Occupant Protection in 1986.[2] This study found that post-crash fires were involved in 16% of heavy truck fatalities compared to only 4% for passenger cars. The report identified several mechanisms that could rupture the fuel tank including the following:

- Frontal impact with low object: Front axles, battery boxes, etc. contacting tanks
- Side impact, vehicle into truck: Direct impact into tank
- Rollover: Scraping along ground, contact with object, fuel cap leakage
- Collision with fixed objects: Mounting guardrails/barriers, direct contact

In 1986, the DOT also published the Heavy Truck Safety Study.[3] This study identified post-crash non cargo related fires as a vehicle related safety issue. This study notes the American Trucking Association (ATA) recommended exploring the concept of cab fireworthiness and developing a cab capable of protecting an occupant in a fire for a specific period of time. This study also suggested that truck front end structures could be designed for energy absorption and deflection in order to manage full frontal and offset frontal impacts.

In 1994, the United Nations ECE published a standard for the design of a front underrun protective device, also known as a FUPD. The FUPD is required to resist loads of 80 kN and 160 kN at different locations (see Figure 2). In addition, the displacement during the test is limited to 400 mm. A FUPD resists underride and engages the energy absorbing structures of passenger cars and LTVs, providing a significant improvement protection to the occupants of these vehicles. By 2003, European trucks were required to comply with ECE R93.

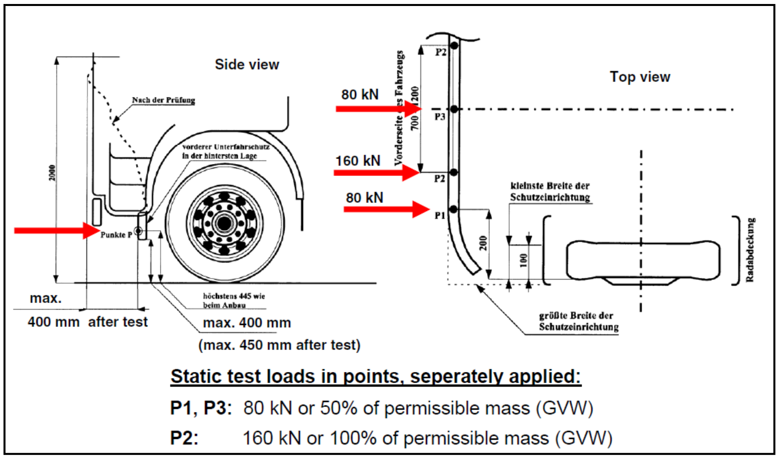


Figure 2. ECE R93 Test

In a study commissioned by the Australian government, Lambert and Rechnitzer of Monash University noted that head on crashes are more severe than other crash modes, and the performance of FUPS devices must be at a significantly higher standard of at least double that of a rear underride barrier. They recommended strength levels at the load points specified in ECE93 as follows. [4]

P1: 400kN (~90,000 lbs)
P2: 300kN (~67,000 lbs)
P3: 200kN (~45,000 lbs)

Despite these findings, Australia adopted the requirements of ECE R93 in 2009 as Australian Design Rule 84/002.

CASE STUDIES

Three real-world crashes are presented wherein a heavy truck experienced a frontal impact, resulting in fire and serious injury. In each of these cases, sled testing was conducted on a production truck front structural assembly and compared to a similar FUPS equipped assembly. The effectiveness of FUPS in mitigating damage in these frontal crashes was assessed.

Case Study 1

A tractor/trailer was travelling east in the number two lane when it side swiped a parked tow truck on the side of the road, resulting in a flash fire. A separate fire source and origin analysis determined that diesel fuel vapor was released from the right fuel tank of the truck and the ignition of these vapors resulted in a flash fire or a "fireball." The fireball engulfed the driver of the tractor/trailer, resulting in burn injuries (See Figure 3).

Figure 3. Scene Photographs

A production heavy truck frame including bumper assembly and front axle was subjected to a sled impact on the right side of the front bumper to evaluate the structure's resistance to impact forces. The assembly was rigidly supported by an impact barrier at the rear of the frame and to the floor at several locations along the assembly at approximately zero degrees of yaw, pitch and roll, so that the striking sled's vertical face would initially contact the vehicle's right front side of the bumper outboard of the interior frame supports (see Figure 4).

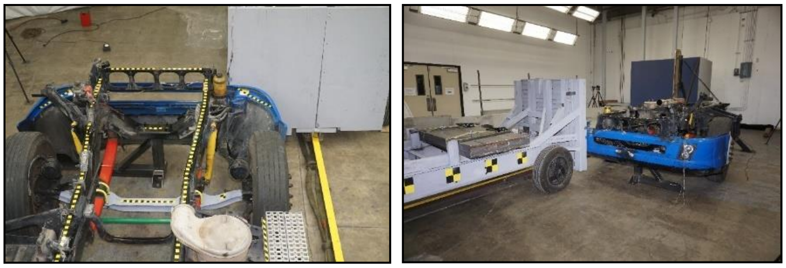


Figure 4. Production Sled Test

The sled impacted the front of the heavy truck frame assembly at 27.4 mph and decelerated at a peak rate of approximately 11.3 g's displacing 76.0 inches towards the rear of the frame. Prior to impact, the kinetic energy of the sled was approximately 132,000 ft-lb. Utilizing the sled mounted accelerometers filtered at 10 Hz, the peak load was calculated to be approximately 52,600 lb. at a displacement of 66.3 inches.

The test progressed as planned with the striking sled's vertical face impacting the right front side of the bumper assembly. The first contact was to the external plastic fascia of the bumper. The impact tore the fascia and bent the corner support inward towards the frame. The sled continued to move forward striking the right front tire. The leaf spring/axle clamping fixture broke free of positioning pin allowing the axle to move rearwards. As this motion continued, an axle U-bolt failed on both the passenger and driver side of the vehicle. The tire continued to move rearward striking the Diesel Particulate Filter (DPF) and the attached steps. The steps were driven into the Selective Catalytic Reduction (SCR) assembly, which was driven rearward (see Figure 5).

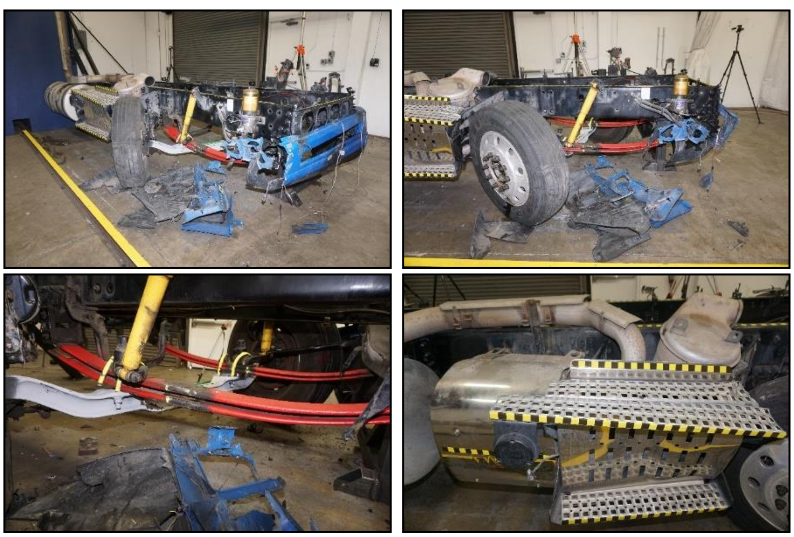


Figure 5. Production Sled Post-Test Photographs

Additionally, a FUPS system was constructed and attached to a production heavy truck frame, front axle and bumper assembly and was subjected to a similar sled test impact. The main FUPS beam was composed of ASTM A500 six inches by six inches square tube with a thickness of 0.25 inches with a four inches by four inches square tube with a thickness of 0.120 inches welded on top, aligned along the front. The four by four was attached with the production attachment points to the bumper center bumper beam location and the production bumper assembly was placed over the completed FUPS (see Figure 6).

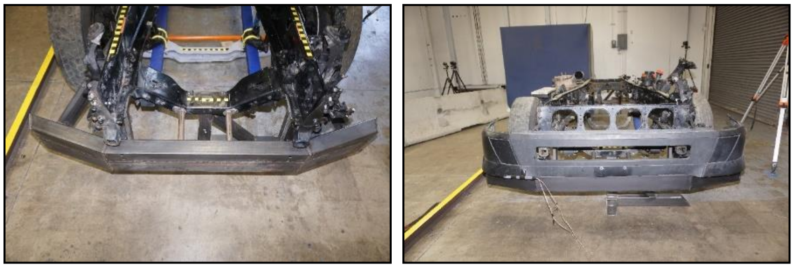


Figure 6. FUPS Sled Test

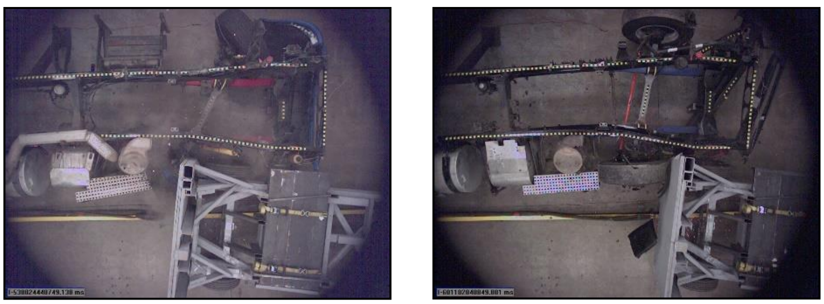
The sled impacted the front of the heavy truck frame assembly at 27.1 mph and decelerated at a peak rate of approximately 16.9 g's displacing approximately 47.0 inches towards the rear of the frame before rotating to rest. Prior to impact, the kinetic energy of the sled was approximately 130,000 ft-lb. The striking sled's vertical face impacting the right front side of the bumper assembly. The first contact was to the external plastic fascia of the bumper. The impact tore the fascia and began loading the FUPS. The sled continued to move forward bending the FUPS attachments to the frame. The sled continued to move rearward striking the right front tire driving it rearward. The leaf spring/axle clamping fixture broke free of its positioning pin allowing the axle to move rearwards. The tire continued to move rearward contacting the DPF and the attached steps (see Figure 7).

Figure 7. FUPS Sled Post-Test Photographs

SAFE's sled testing of a heavy truck production design showed the susceptibility of the front axle under foreseeable crash conditions. SAFE's sled testing shows that a FUPS significantly reduces penetration and results in reduced depth of damage into the truck's structure. A comparison between the production and FUPS tests indicated a displacement reduction for the FUPS test by approximately 40%. Additionally, a FUPS increases the initial stiffness and energy absorption characteristics of the front structure. This increased initial stiffness allows for earlier and faster separation of the sled and reduced probability of interaction with the fuel tank (see Figure 8 and Figure 9).

Production Sled Test FUPS Sled Test

Figure 8. Post-Test Photographs



Production Sled Test FUPS Sled Test

Figure 9. Point of Maximum Penetration

Case Study 2

A heavy truck impacted a bear in the roadway with the left front bumper of the tractor. The impact caused the tractor trailer to be directed towards the southerly edge of the roadway ultimately leading to the vehicle interaction with the roadside culverts, catching fire, and tipping over. A separate fire source and origin analysis found that the first fuel ignited was diesel fuel vapors released from the passenger side’s fuel tank (see Figure 10).

Figure 10. Scene Photographs

A production frame, front axle and bumper assembly were subjected to an impact on the left front bumper in order to evaluate the structure’s resistance to impact forces. The frame assembly was rigidly supported by an impact barrier at the rear of the frame assembly and positioned such that a 255 lb impactor designed to approximate the subject bear would initially contact the left front side of the bumper outboard of the frame rails (see Figure 11).

Figure 11. Production Sled Test

The impactor struck the bumper at 58.0 mph. Prior to impact, the kinetic energy of the impactor was approximately 29,000 ft-lb. The test progressed as planned with the rubber face of the impactor striking the left front side of the bumper. The impact bent the metallic bumper and supporting rods inwards towards the frame and steering box. The impactor began to rotate and then struck the left front wheel assembly. The rotation of the impactor continued as its forward motion stopped. The wheel assembly rotated outward, and the impactor moved away from the chassis in a lateral direction before striking the surrounding test containment barriers and coming to rest. The left front tire continued to rotate outward until the impactor disengaged from it. At that point, the rotation of the tire reversed and the leading edge of the tire moved towards the frame. This causes the steering wheel to forcefully spin and would impact the ability to steer or control the truck (see Figure 12).

Figure 12. Production Sled Post-Test Photographs

A FUPS system was constructed and attached to a production frame, front axle and bumper assembly, and was subjected to a similar sled test impact. The main FUPS beam was composed of ASTM A500 six inch by six inch square tube with a thickness of 0.25 inches (see Figure 13).

Figure 13. FUPS Sled Test

The impactor struck the bumper at 59.6 mph. Prior to impact, the kinetic energy of the impactor was approximately 30,000 ft-lb. The rubber face of the impactor struck the left front side of the FUPS. The impact caused the impactor to go into a counterclockwise rotation (as seen from above). At approximately 90 degrees of rotation, the impactor came into very light contact with the front tire. The impactor continued to rotate, moving away from the chassis before striking the surrounding test containment barriers and coming to rest (see Figure 14).

Figure 14. FUPS Sled Post-Test Photographs

This sled testing shows that the production design allows for significant engagement and rotation of the steer wheel during a collision with a foreseeable roadway object, like an animal, which would affect the driver's ability to control the directionality of the truck. The testing also showed that a FUPS virtually eliminates wheel assembly engagement, preserving steering control (see Figure 15).

Production Sled Test FUPS Sled Test

Figure 15. Post-Test Photographs

Case Study 3

An SUV crossed the roadway centerline and impacted a heavy truck (both travelling at approximately 50-55 mph) in an offset orientation and outside of the heavy truck frame rail, causing major damage to the left front of both vehicles. The impact compromised the truck's side saddle fuel tank, leading to a large fire (see Figure 16).

Figure 16. Scene and Vehicle Photographs

In order to investigate if a FUPS could protect the heavy truck steering and fuel tank from significant damage, a full scale crash test was conducted with a FUPS equipped chassis. The main FUPS beam was composed of as ASTM A500 rectangular tube six inches by eight inches with a thickness of 0.25 inches. The truck chassis was rigidly mounted at the rear in a level orientation parallel to the direction of travel of the impacting SUV. The front of the FUPS equipped chassis was supported by the front axle assembly and was ballasted with approximately 7,000 lbs of concrete blocks in order to represent a typical front axle load. The SUV struck the driver's side of the FUPS equipped chassis with 35% overlap (on the SUV) and a 0° PDoF at 55 mph (see Figure 17).

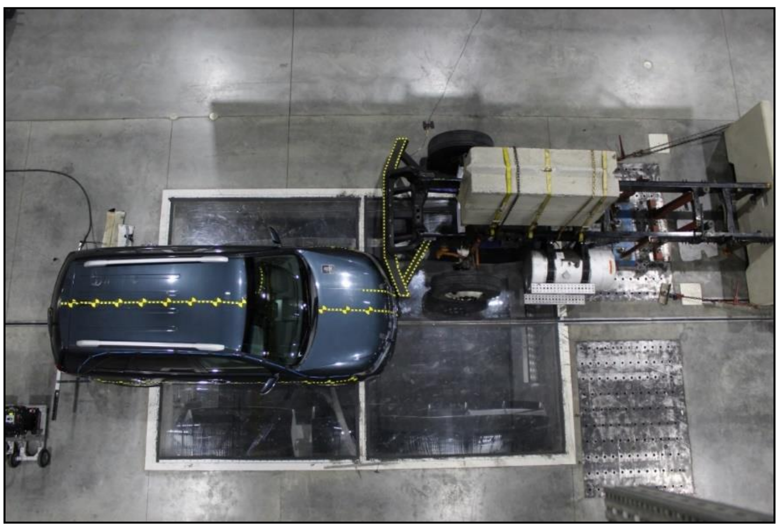


Figure 17. FUPS Full Scale Crash Test

The SUV impacted the FUPS, distorted it, overloaded many of the bolted attachments, and contacted the left steer tire. Ultimately the SUV was deflected away from the truck and ran into the test containment barriers. The steer tire rebounded and the axle remained attached to the truck suspension, although the entire side had been shifted rearward. The front suspension and front axle assembly remained intact, and the rearward displacement of the front wheel assembly was limited such that the front tire did not make contact with the fuel tank during the test. In addition, all steering linkages remained intact, and the steering mechanism was observed to be functional after the test, indicating steering control would have been maintained after the impact. Full scale testing showed that a properly constructed FUPS was able to effectively deflect a mid-sized SUV at 55 mph, while protecting the front axle and fuel tank (see Figure 18).

Figure 18. Post-Test Photographs

CONCLUSIONS

Common heavy truck construction in the United States lacks structural components outboard of the frame rails and below the frame rails. This lack of structure creates a major crash compatibility mismatch that puts occupants of smaller impacting vehicles at risk from intrusion and can make it difficult for deployable restraints to respond appropriately. In addition, heavy trucks are vulnerable to damage to their steering components, displacement of their axles, and rupture of their fuel tanks. The resulting risk of loss of control and fire, places the occupants of the heavy truck and other road users at risk in the event of secondary impacts and fires. Sled impact testing was an effective methodology for evaluating the frontal impact mode and demonstrated front axle, steering component, and fuel tank damage consistent with that seen in real world accidents. The testing has also shown that front underrun protective structures are effective in mitigating the damage caused in these frontal impact crashes, improving safety for heavy truck occupants and other road users alike.

REFERENCES

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[4] Review of Truck Safety: Stage 1: Frontal, Side and Rear Underrun Protection, Lambert and Rechnitzer, 2002