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UPDATED FUEL TANK PUNCTURE SURVEY: 1995-2020

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ABSTRACT

The Federal Railroad Administration's Office of Research, Development and Technology has been conducting research into passenger fuel tank crashworthiness. The occurrence of a fuel tank puncture during passenger rail collisions and derailments increases the potential of serious injury and fatality for crew and passengers due to the possibility of fire. The purpose of the FRA research is to help support regulatory and standard development with technical data. In the last decade, the research has focused on understanding how fuel tanks are punctured during an impact and how various tank designs respond to common types of loading in collisions, derailments and general operation. Throughout the research, surveys have been conducted to determine the most likely scenarios that are causing fuel tank punctures. A previous FRA survey found that fuel tank punctures occur under two types of loading conditions: a blunt impact or a raking impact. A limited number of accident/incidents were evaluated in this survey. These incidents showed that fuel tanks are punctured on any side that is not protected or shielded.

The purpose of this paper is to report on a recently conducted fuel tank puncture survey updated to include the last decade. This paper identifies and describes accidents and incidents that led to breached fuel tanks in freight and passenger trains traveling on the general railroad system in the U.S. between 2008 and 2020. The results include data from the FRA's Railroad Accident/Incident Reporting System (RAIRS), queried from 1995 to 2020. This data include the number of recorded accidents/incidents and other trends like fuel spillage, operating authority and cause of accident/incident. RAIRS data showed accidents/incidents with fuel tank puncture ranging from 10 to 55 accidents/incidents per year. Additionally, more detailed results are shared from field investigations recently conducted by the FRA or Volpe Center. These more detailed investigations provide additional insight into the types of loading that may lead to a fuel tank puncture. This survey supplements the RAIRS data with more detailed information from field investigations. The paper finally discusses the conditions that lead to fire and the associated hazards.

INTRODUCTION

The FRA has been conducting research into passenger train fuel tanks since the early 2000s. Since about 2007, the research has focused on understanding the performance of fuel tanks under accident conditions to better understand how fuel tanks can be designed efficiently and safely. Research has included conducting testing and analysis to develop technical data that can support regulatory and standard development.

In a previous fuel tank survey conducted from 1995 to 2008, FRA/Volpe investigated and reported on accidents, derailments and general operation incidents that led to fuel tank punctures on the general railroad system in the U.S. [1]. The survey focused on describing examples of both collisions and derailments in which a fuel tank puncture was documented. The survey sought to categorize the accidents and incidents according to the scenarios laid out in the CFR requirements for "loading scenarios" [2]. It was found that some of the seven example incidents fit into more than one scenario. A key conclusion of the 2011 survey is that a fuel tank is punctured according to two specific loading types, either a raking or blunt impact. The collision scenario does not necessarily correlate to what type of loading the fuel tank experiences. Rather, the distinct structure or object that comes into contact with the fuel tank and the direction of the applied load determines the loading type. Figure 1 illustrates the difference between blunt and raking loading, where the blue rectangle represents a side view of the fuel tank with an exposed surface at the top. The red arrow represents the force applied.

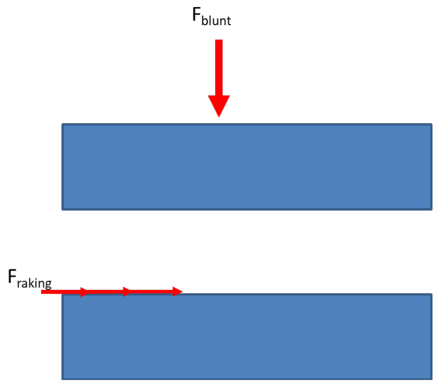

Figure 1. Force Diagrams of Fuel Tank Loading Types: Blunt Impact Load (Top) and Raking Impact Load (Bottom)

This paper seeks to add to and update the FRA/Volpe survey published in 2011 [1]. An additional eleven example fuel tank puncture incidents are described based upon details from FRA and Volpe field investigations conducted between 2008 and 2019. Additionally, FRA's RAIRS was used to extract general data on the numbers of incidents that involve fuel tank punctures and resultant fires.

RAIRS DATA

RAIRS is a publicly accessible database that hosts the data from every incident report filed by an FRA inspector [3]. Each report is filed based upon a standard form, FRA F 6180.39i, which has required data for an incident including location, railroad authorities, accident/incident type, train speed, casualties, equipment type, causal code, and a general synopsis. RAIRS can be searched according to these data categories.

In 2020 a search was conducted to determine the number of accidents and incidents in which a fuel tank was punctured. As fuel tank punctures do not necessarily correlate to a specific collision type, a keyword search was created with the following five words: diesel, spill, fire, fuel and flame. The results were reviewed to isolate incidents that involved a fuel tank puncture. 610 incidents were returned which include both freight and passenger equipment. Figure 2 shows results of incidents involving at least one reported fuel tank puncture over the nearly twenty-five years. According to the RAIRS database there have been on average, about 25 inspected incidents per year with fuel tank punctures. Of these, less than 2% involve passenger equipment. This is not surprising since the vast majority of rail operation in the U.S. is dominated by freight travel. The number of yearly incidents appears to have decreased after about 2008. In 1995 AAR established a series of scenarios and associated static load cases for which all freight fuel tanks must be built [4]. The decline in fuel tank punctures may correlate with the transition from pre-1995 equipment to new locomotive equipment with fuel tanks built to these standards. In 1999 the FRA adopted the AAR fuel tank requirements for passenger locomotives.

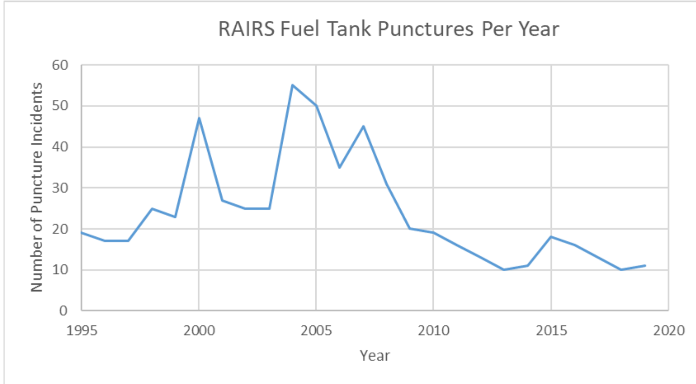

Figure 2. Plot Showing the Incidents Reported in RAIRS with Fuel Tank Puncture

For each incident reported a cause code is identified by the FRA inspector. There are just under 400 specific cause codes categorized into five general cause types. The incidents represented in Figure 2 are categorized according to general cause type in Figure 3. The largest percentage of incidents fall under "Human Factors," which includes train operation errors, such as overspeed incidents, signal or switch errors. The second largest percentage of incidents is attributed to "Miscellaneous," which can include an on-going investigation by FRA or NTSB at the time the report was filed.

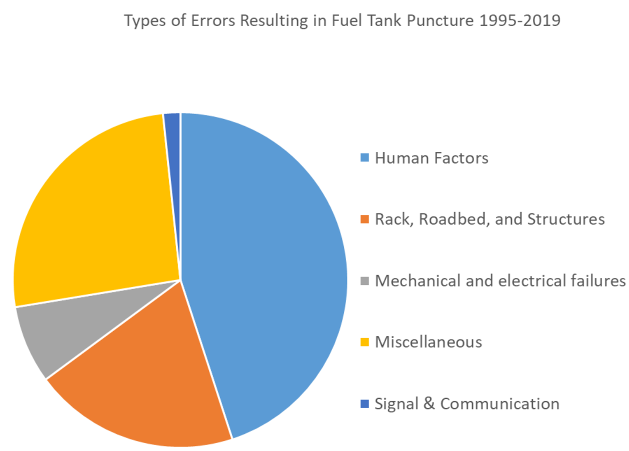

Figure 3. Breakdown of Fuel Tank Punctures According to General Causal Mechanism Categories

Figure 4 plots the average amount of diesel fuel released in the incidents. A freight locomotive fuel tank carries anywhere between 2,600 gallons and 5,500 gallons. On average about 1,400 gallons are spilled in a given incident. It's interesting to note that while the number of incidents each year in Figure 2 decrease after 2008, the average fuel spilled per incident begins to increase around 2010. Of the incidents queried, about 2.5% of them resulted in fire from a diesel fire spill associated with a puncture locomotive fuel tank.

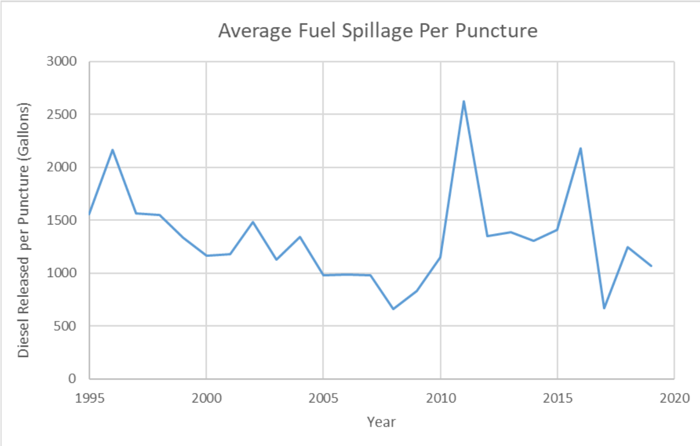

Figure 4. Plot Showing Average Fuel Spillage per Punctured Tank across the Accidents and Incidents Reported in RAIRS with Fuel Tank Puncture

FIELD INVESTIGATIONS

Studying situations in which fuel tanks are punctured is an important step to evaluating how they perform against impacts and understanding what impacts threaten their structural integrity during both usual operation and unusual occurrences. Since the late 1990s, Volpe has been assisting FRA with conducting accident investigations. This section provides descriptions of specific incidents in which fuel tanks were punctured. The following incidents involve a scenario that led to one or multiple fuel tank punctures. The incidents are sequentially organized and not categorized by collision scenario type but by general circumstances, e.g. general operation, operational error, derailment or collision. It has been shown previously that specific collision scenarios are not what lead to fuel tank punctures [1]. Rather, the combination of loading type and impact object are more critical factors in determining whether a fuel tank is breached under a given set of conditions.

Example 1: Chatsworth, California, September 12, 2008

On September 12, 2008, a locomotive-led commuter train collided head-on with a freight train at a closing speed of about 80 mph. The Metrolink passenger train consisted of a four-axle EMD F59PH pulling two Bombardier bi-level coach cars and a Bombardier bi-level cab car. The freight train consisted of two EMD SD-70 six-axle locomotives leading seven loaded freight cars and ten empty freight cars. During the collision the lead passenger locomotive was reduced in length by approximately 15 feet, crushing the locomotive cab along with the operator. As shown in Figure 5, the lead passenger locomotive appears as if encased within the passenger coach car. During the collision, the rear end of the locomotive pushed into the passenger coach, catastrophically failing at the underframe gooseneck and penetrating the occupant volume [4]. All three lead vehicles came off the tracks and rolled to their sides. Approximately two-thirds of the passenger seats in the first coach were destroyed from the locomotive penetration and resultant bulk crushing.

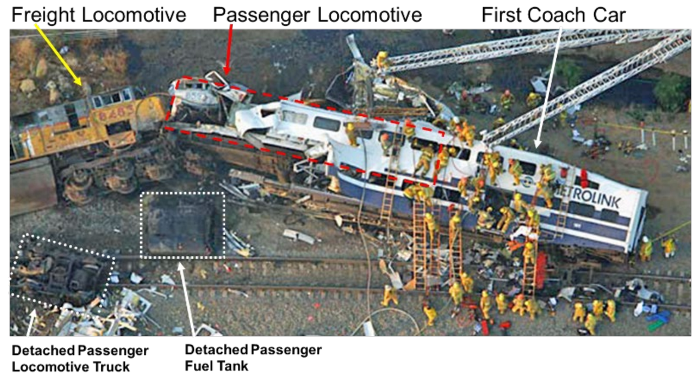

Figure 5. Aerial Photo (from *LA Times* Online News Article) of Two Lead Locomotives and First Coach; Annotations Added to Indicate Position of Detached Fuel Tank and Lead Truck

Damage to the lead freight locomotive was restricted to the front plow, breast plate and draft gear housing; the occupant volume of the cab remained fully intact. The freight locomotive engineer and conductor rode out the collision in the lead cab. Interviews with first responders and the crew revealed that the crew became trapped in the cab [6]. With the locomotive resting on its left side and pressed up against the passenger locomotive, the locomotive conductor and engineer were unable to climb 12 feet up to the ride side exit door nor exit through the nose of the locomotive. A fire broke out due to the spilled diesel from the passenger locomotive fuel tank, which had become detached during the collision. Figure 5 and Figure 6 show that the passenger locomotive fuel tank located adjacent to the toppled lead locomotives post-collision. When the firefighters found the engineer and crew their cab was full of smoke. While part of the firefighter crew worked to suppress the fire, others worked to extricate the locomotive crew. Efforts failed at breaking and cutting a front locomotive window. Firefighters finally succeeded in cutting through the rubber molding of the window encasement and removing the window such that the freight locomotive crew could be extricated.

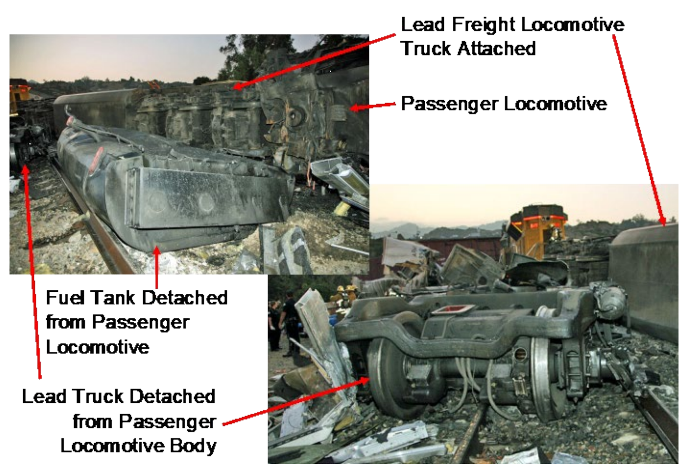

Figure 6. Ground Level Post-collision Photos of Passenger Locomotive Fuel Tank and Truck

Figure 5 and Figure 6 show the final positions of the passenger locomotive fuel tank and lead truck. Both the fuel tank and front truck were separated from the locomotive, and found proximate to the lead freight locomotive after the accident, the fuel tank just next to the tracks and the trucks further ahead straddling one of the rails. It appears that the front truck separated owing to crush of the attachments on the locomotive body bolster, and that the fuel tank then detached as the lead truck struck it once detached. With significant breaches of the fuel tank, a fire ensued near the lead freight locomotive, which threatened the lives of the crew trapped inside the cab of toppled locomotive.

Example 2: Mebane, North Carolina, May 13, 2010
On May 13, 2010, an Amtrak locomotive-led passenger train colliding with a tractor-trailer stuck on the tracks. The truck was pulling a lowboy trailer carrying a CAT excavator. The train was estimated to be traveling at 70 mph. Upon impact with lowboy trailer carrying the excavator, the locomotive and three passenger cars derailed.

Figure 7 shows a post-collision photo of the firefighters working to extinguish the diesel fire. The fire broke out around the fuel tank but extended up to the area around the left side cab window. The locomotive crew was able to exit through the right side door.

Figure 7. Photo Showing Locomotive in Flames as a Result of Its Punctured Diesel Fuel Tank. (Photo Source: *WRAL.com*)

The photo in Figure 8 shows the final positions of the tractor-trailer lowboy and lead vehicles of the passenger train. The lowboy frame is fractured and wedged beneath the passenger locomotive. The lowboy frame had significant structural damage, such that the fractured lateral frame members are exposed along at least half its length. The cab of the tractor-trailer, not visible in the photo, was located near the third coach car.

Figure 8. Photo Showing Locomotive Derailed with Tractor-trailer Lowboy Underneath. (Photo Source: *WRAL.com*)

Example 3: Concord, MA, September 5, 2010
On September 5, 2010, an Amtrak commuter train traveling through Concord, Massachusetts received a warning in the locomotive cab that fuel was being lost. The train was taken out of service. Upon inspection, a puncture was discovered on the bottom surface of the locomotive fuel tank [7]. The locomotive was transported to Massachusetts Bay Transportation Authority's Boston Engine Terminal in Somerville, MA.

The fuel tank involved in the puncture incident is shown in Figure 10. A detailed inspection determined a single puncture in the center lobe of the bottom of the tank; the size, shape and location are shown in the photos of Figure 11. As there had been nothing unusual about the commuter rail operation when the damage occurred, it was presumed that a piece of debris may have been kicked up and struck the bottom of the fuel tank. Striation marks that spanned from front to back of the tank led up to the puncture indicating that an impact object dragged along it until it puncture the bottom surface at the location adjacent to the internal baffles.

Figure 9. Concord, MA, Locomotive Fuel Tank

Figure 10. Puncture on Bottom Sheet (Concord, MA)

From examining the size and the shape of the punctured bottom sheet of the fuel tank, it was determined that the puncture was caused by a joint bar which are sometimes left alongside the tracks. Figure 12 shows an exemplar joint bar. Figure 13 shows that the exemplar joint bar fits perfectly into the contour of the fuel tank puncture. The speed at which the impact occurred is not known.

Figure 11. Identified Impact Object, an Exemplar Joint Bar Section

Figure 12. Identified Impact Object, an Exemplar Joint Bar Section and Joint Bar Inserted into the Fuel Tank Puncture Matches the Exact Contour

Example 4: Red Oak, Iowa, April 17, 2011

On April 17, 2011, a BNSF coal train collided head-on at 23 mph with the rear end of a standing BNSF maintenance of way (MoW) equipment train near Red Oak, Iowa. The coal train consisted of two head-end locomotives, 130 loaded coal cars and one trailing freight locomotive. The MoW train consisted of one freight locomotive pulling 21 loaded cars and 13 empty cars. As shown in Figure 14, the collision resulted in the two lead locomotives derailing, multiple flatcars of the MoW train overriding the lead locomotive, and multiple fuel tank punctures that led to multiple diesel fuel fires. During the collision sequence of events, the modular style cab of the EMD SD 70ACe lead locomotive detached, rotated and significantly crushed. Additionally the entire cab was exposed to fire damage. Both the operator and conductor located in this cab were killed due to loss of occupant volume.

Figure 13. Post-collision Photo of Red Oak, IA Train-to-train Collision. (Photo Courtesy of Red Oak Fire Department)

The lead-end coal train locomotives were an EMD SD70ACe locomotive and a GE ES44AC. The fuel tanks on both locomotives are 5,000 gallon capacity and manufactured to meet S-5506 fuel tank performance standards [4].

Interviews with first responders report fires in three distinct locations of the post-collision wreckage: 1) at the front of the coal train's lead locomotive, 2) at the coal train's second locomotive and 3) at the impact point near the elevated trailing MoW vehicle. An ancillary flash fire was also reported on the highway overpass, which part of the overriding equipment impacted as the collision unfolded [8]. Equipment inspection found that the EMD SF70ACe fuel tank had scrape marks along the left side of the tank but was not ruptured. The GE ES44AC fuel tank had a visible puncture. The fuel tank extends along more than a third of the locomotive underframe, occupying most of the length between front and rear trucks. The fire at the lead end locomotive was attributed to diesel fuel that leaked from the MoW equipment as it overrode the locomotive. It took about two hours to fully extinguish all the fires.

Example 5: Newark, New Jersey, April 28, 2012

On April 28, 2012, two coupled CSX locomotives rolled down a siding and into a switch, sideswiping a freight consist traversing the main line. This incident occurred in the Oak Island Rail Yard in Newark, New Jersey. As illustrated in Figure 15, the impact scenario created an oblique raking impact between the two trains. The main line freight train was traveling at around 7 mph with the fifth to last freight car of the consist on the switch at the moment the runaway two-locomotive consist rolled through the switch at about 4 mph. The impact caused the locomotives of the runway consist to derail and the outside rail of the siding rolled outward. As the freight train continued along the tracks, the right side doortrack of a boxcar (the last freight car) impacted the left side of the lead runaway locomotive fuel tank, dragging along the tank [9] and piercing into it. As can be seen in Figure 16, the fuel tank puncture extends along nearly the entire length of the tank. The end sheet at the lead end of the fuel tank, presumably the primarily impact point, was torn away from the side sheet of the fuel tank at its weld. The door track of the trailing freight car was broken with part of it recovered from inside the fuel tank.

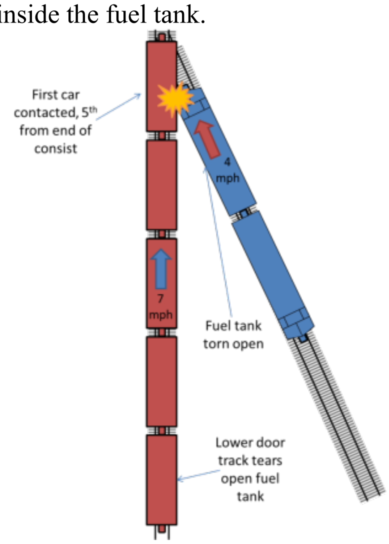

Figure 14. Schematic of Raking Impact in Oak Island Yard in Newark, NJ

Figure 15. Damage to Trailing Locomotive Fuel Tank

The fuel tank released diesel fuel and a small fire broke out, primarily affecting the unoccupied derailed runaway locomotives, as the freight train continued to travel on the main track away from the scene. The fire was extinguished by the fire department and the remaining fuel in the ruptured tank was drained. The runaway locomotive consist was moved to a siding and the damaged boxcars of the freight train were returned to the Conrail yard after being unloaded.

Example 6: Goodwell, Oklahoma, June 24, 2012

On June 24, 2012, two UP freight trains collided head-on in Goodwell, Oklahoma at a closing speed of nearly 100 mph. The eastbound train was traveling at about 65 mph, made up of three locomotives and 80 cars and operated by an engineer and conductor in the lead locomotive cab. The westbound train was traveling at about 38 mph, made up of two locomotives and 108 cars and operated by an engineer and conductor in the lead locomotive cab. During the high speed impact event, the three locomotives leading the eastbound train derailed along with the preceding 24 cars. The two locomotives leading the westbound train derailed along with eight other cars of the westbound train. The post-collision scene consisted of the westbound train in a large pile-up with nearly two dozen cars in large scale lateral buckling, as shown in Figure 17. Not shown in the schematic is the large debris field caused by cargo carried in derailed freight cars. The conductor of the westbound train was able to jump from the train just prior to the collision [10]. The remaining three crew were killed.

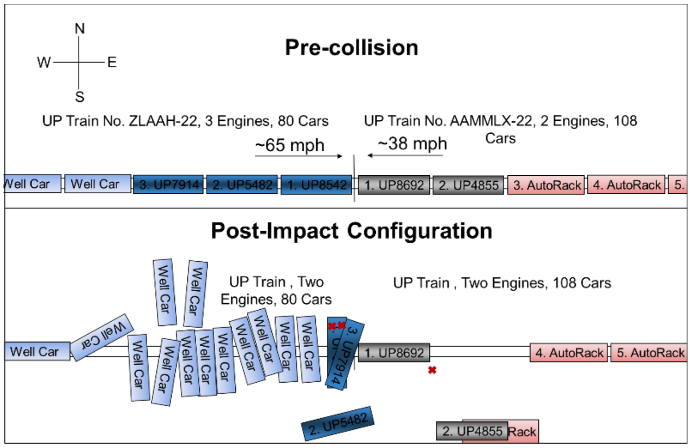

Figure 16. Illustration of Goodwell, OK, Train Accident Pre- and Post- Collision (Positions Estimated and Dimensions Not to Scale)

As is seen in other accidents, fuel tank punctures are common in collisions and derailments where the railcars go into large scale lateral buckling. As cars roll over and begin to pile up, the fuel tank becomes more exposed to impacts from other railcars or debris. The accident in Goodwell, Oklahoma highlights this. Multiple locomotive fuel tanks ruptured, released diesel fuel and lea to a fire that burned for more than 24 hours. Three of the five freight locomotive fuel tanks were punctured as shown in Figures 18, 19, 20 and described below.

The eastbound train's lead locomotive, UP8542 is shown in Figure 18. The bottom of the fuel tank is facing outward and multiple impacts are visible on the bottom of the tank. It is apparent that the fuel tank experienced a series of blunt impacts by an object or structure about 3-6 inches puncturing through the tank's bottom surface.

Figure 17. Post-collision Photos of Lead Locomotive, UP8542 Fuel Tank

The eastbound train's second locomotive is shown post-collision in Figure 19. Like the first locomotive it came to rest on its side. While there was evidence of multiple impacts to the bottom of the fuel tank, none punctured the surface. As is visible from the photo, this tank experienced the most serious impact on the front end of the fuel tank. Further inspection found a broken truck attachment and the measured distance between the two puncture locations match the distance between wheels of the missing truck. It seems likely that during the collision sequence the truck attachment sheared off allowing the truck to push back directly into the fuel tank, puncturing at the locations of the wheels.

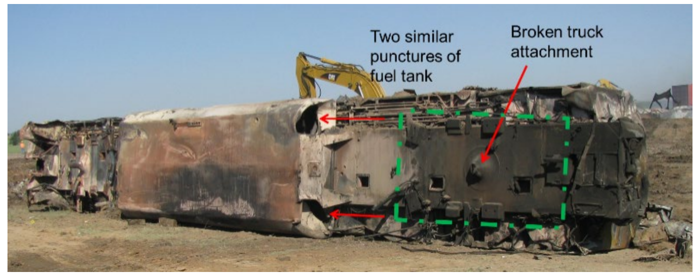

Figure 18. UP5482 Fuel Tank

Figure 20 shows the fuel tank of the westbound train's second locomotive. The bottom of the fuel tank includes clear markings that run the full length of the fuel tank and suggest the tank was moving along the ground for a length of time. At a certain point the fuel tank impacted a rigid object or structure that cut into the tank. The detail of this fuel tank puncture measured two distinct 1-foot long tears. The pause in a continuous 2-foot long tear occurred at the location of where a lateral baffle attached to the bottom surface, thereby strengthening the bottom surface at the location. This correlates to fuel tank deformation behavior modeled and tested in the FRA's fuel tank research program [11].

Figure 19. UP4855 Fuel Tank

Example 7: Cayce, South Carolina, February 4, 2018
On February 4, 2018, Amtrak train No. 91 collided with CSX Train No. F7703 at around 50 mph in Cayce, South Carolina. Amtrak train No. 91 consisted of a locomotive leading seven passenger cars. CSX Train No. F7703 was stationary in a siding with two freight locomotives and 34 autorack cars. Figure 21 shows a photo of the Amtrak lead locomotive, first passenger car and CSX locomotive from the post-collision investigation.

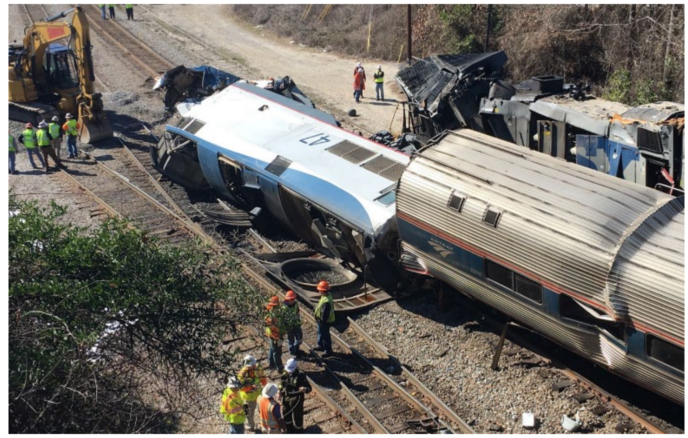

Figure 20. Post-collision Photo of Amtrak Lead Locomotive

The engineer and conductor of the Amtrak train were killed. The engineer of the CSX train was on a hillside at the time of the collision and was unharmed. The CSX conductor tried to exit through the back door of the locomotive and was thrown from the train during the impact. He came to rest pinned between the CSX and Amtrak locomotives and reported being doused in fuel [12]. None of the surviving crew and passengers received serious injuries.

Example 8: Attica, New York, February 15, 2018
On February 15, 2018, Norfolk Southern freight train No. 28N14 derailed. The train consisted of two locomotives and 43 automobile carriers. During the derailment, the two lead locomotives and multiple cars derailed, came over the railbed and down an embankment into a ravine. Figure 22 shows a photograph from the derailment site. The bottom of the second locomotive's fuel tank is shown. The fuel tank displays evidence of large scale bending visible laterally across the center of the tank. Additionally, evidence that it dragged across a more rigid structure or object is clear from the prominent longitudinal striations that span from nearly the center of the bottom fuel tank to the end plate. A distinct section of the end plate is fractured and peeled back exposing a hole in the fuel tank. The lead locomotive did not roll over but the fuel tank was buried in the mud post-incident so photos were not taken.

Figure 21. Trailing Locomotive Fuel Tank 9274

Example 9: Georgetown, Kentucky, March 18, 2018
On March 18, 2018, two Norfolk Southern freight trains collided head-on in Georgetown, Kentucky. The southbound train, 175T817, consisted of five locomotives and 145 cars and was just coming to a stop. The northbound train, M74T817, was travelling at around 32 mph with three locomotives pulling 132 cars. During the incident, the two lead locomotives collided and then the second locomotive of 175T817 overrode the lead locomotive of 175T817. A fire was ignited from spilled diesel fuel causing both locomotives to catch fire. The crew of each freight train survived with minor injuries.

Figure 23 shows the final positions of the two locomotives from two different sides of the tracks. The lead locomotive, NS 8798 of the southbound train was forward facing and the second locomotive, NS 4063, was rear facing during operation. The fuel tanks of both locomotives remained attached to the underframe. As NS 4063 overrode NS 8798, the fuel tank was breached causing the diesel to spill along the length of NS 8798. As such fire broke out around the cab of NS 4063 and just behind the cab of 8798.

Figure 22. Post-accident Photo Showing Override of Second Locomotive on Leading Locomotive of Freight Train 175T817 (on Left) and Lead Locomotive of Freight Train M74T817 (on Right)

The conductor of northbound train M74T817 managed to jump off of the locomotive prior to the impact. The engineer rode out the impact by sitting on the floor and braced his back against the console. The engineer of southbound train 175T817 was able to exit the cab and climb down from the locomotive. The conductor of this train became entangled in the radio handset cord when exiting and laid down on the cab floor to ride out the collision. As the trailing locomotive overrode the lead locomotive the conductor was sprayed with diesel fuel and sand. He was able to free himself from the debris shortly after the collision and climb out of the cab and locomotive while the fire was burning just behind the cab.

Example 10: Caspiana, Louisiana, April 9, 2019
On April 9, 2019, a Union Pacific freight train collided with a tractor-trailer at a grade crossing near Caspiana, Louisiana. The freight train consisted of three locomotives and 106 loaded freight cars. During the impact, the three lead locomotive derailed along with the preceding 20 freight cars. The locomotives plowed through gravel and dirt coming to rest at an angle partially down an embankment with their underframes buries in the gravel and mud. As the locomotives derailed, the preceding freight cars experienced large scale lateral buckling causing at least the eight of them to pile up and spilling their contents, mostly grain and dirt. Figure 24 shows the final position of the lead locomotives. Figure 25 shows a photo looking back along the consist with the second and third locomotives at an angle along the embankment and the trailing freight cars having rotated nearly 90 degrees from their original position of travel. The fuel tank of the lead locomotive was breached, most likely from impacting or dragging across a rigid

structure as it traveling over the tractor trailer. The fuel tank released approximately 500 gallons of diesel.

Figure 23. UP Locomotive 8703

Figure 24 UP Locomotive 5379

Example 11: Speonk, NY – May 25, 2019

On May 25, 2019, a Long Island Railroad (LIRR) Train No 5785 collided with a LIRR Train No 8700 located at a siding. Train No 5785 was traveling westbound at 8 mph. Eastbound Train No. 8700 was carrying no passengers and temporarily pulled into a siding when westbound Train No. 5785 attempted to pass it on the main track. Eastbound Train 8700 consisted of 14 cars with a diesel locomotive at the rear. The siding was long enough for a 13-car train. Consequently, as the westbound train attempted to pass the parked eastbound train, it impacted the overhanging locomotive of Train No. 8700. The left side of the overhanging locomotive was impacted, which punctured the fuel tank and derailed the locomotive. The fuel tank released approximately 365 gallons of diesel and a few small fires ensued [3]. There were no injuries. Figure 26 shows a photograph of the derailed lead locomotive.

Figure 25. Photo Showing Lead Locomotive 511 Post-accident in Speonk, NY. (Photo Source: *Railroad.net*)

OBSERVATIONS AND CONCLUSIONS

The example accidents and incidents described in this paper show both big picture patterns of fuel tank puncture as well as more detailed contributing factors. In at least three highlighted example collisions, a detached truck is specifically identified or surmised to be the object that punctures the fuel tank. It highlights the reality that the surrounding components and equipment near the fuel tank can transform into hazardous impact objects if detached. This was apparent in the Goodwell collision, Chatsworth collision and possibly contributed to the Georgetown collision. By association, the truck attachment requirements are important in influencing the likelihood of fuel tank punctures.

The Chatsworth train-to-train collision also demonstrated that if a fuel tank becomes punctured and detached from a locomotive, fuel may be released along the tank's trajectory. In the Chatsworth accident, the fire started due to fuel spilled from the passenger locomotive fuel tank but due to the position of the detached locomotive, the fire threatened the lives of the crew trapped inside the freight locomotive. Similarly, crew in the Georgetown and Cayce collisions reported being covered in diesel fuel during the incidents. In both incidents the fuel came from a punctured fuel tank on an adjacent locomotive.

The incident in Concord, Massachusetts shows that though unusual, a fuel tank can get punctured in a non-collision or derailment event. In this incident a joint bar was determined to be the impact object that punctured the fuel tank during general operation. Volpe Center analysis of fuel tanks has investigated impact object size on punctures [9]. Small rigid impact objects, such a joint bar, broken rail or boxcar doortrack, apply a focused load to tanks and typically result in localized damage. As seen in the Concord and Red Oak incidents the profile of the impact object is still visible in the puncture or tear mark. With larger impact objects the damage may be leave an imprint or deformation pattern broader than the impact object as the load is resisted by the external and internal structure of the tank.

Consideration of these findings is important if performance-based standards are to be developed in the future.

The Goodwell collision highlighted both loading types that cause fuel tank punctures as well as the importance of truck attachments and fuel tank attachments in protecting fuel tanks. In this collision the fuel tanks showed very clear examples of an impact with a blunt impact object and a raking impact. While neither of the impact objects were identified, the impacts helped to illustrate the different in the two loading types.

The Attica derailment helps highlight the importance of the fuel tank end plate performance during impacts as well as some of nuances of the design effects the performance. In this accident a discrete panel located on the end plate pulled away. Much like observed in fuel tank testing, areas where discrete panels are connected are more likely for a tear or puncture to be initiated.

RAIRS was used for this paper to provide data on the trends of recorded fuel tank punctures. Of the eleven example incidents described in this paper, only one incident was reported in RAIRS with a fuel tank puncture and fire. This indicates that RAIRS lacks sufficient and complete data on fuel tank puncture incidents. The incident reports used to populate RAIRS lack a specific field for indicating a fuel tank puncture. As a result, fuel tank punctures must be reported and described in the synopsis field. If not all incidents with fuel tank punctures are reported in RAIRS, using this data may lead to inaccurate predictions regarding the likelihood of fuel tank punctures and resultant fire.

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