National Transportation Safety Board

Washington, DC 20594

Highway Accident Brief

Rear-End Collision Between a Car Operating with Advanced Driver Assistance Systems and a Stationary Fire Truck, Culver City, California, January 22, 2018

Accident Number:	HWY18FH004
Accident Type:	Rear-end collision involving partially automated vehicle
Location:	Southbound Interstate 405, Culver City, Los Angeles County, California
Date and Time:	Monday, January 22, 2018, 8:40 a.m., Pacific standard time
Vehicle 1:	2014 Tesla Model S P85 car
Vehicle 2:	2006 Seagrave custom fire truck (pumper)
Fatalities:	0
Injuries:	0

Crash Description

About 8:40 a.m. on Monday, January 22, 2018, a 2014 Tesla Model S P85 car was traveling in the high-occupancy vehicle (HOV) lane of southbound Interstate 405 (I-405) in Culver City, California. The Tesla was behind another vehicle. Because of a collision in the northbound freeway lanes that happened about 25 minutes earlier, a California Highway Patrol (CHP) vehicle was parked on the left shoulder of southbound I-405, and a Culver City Fire Department truck was parked diagonally across the southbound HOV lane. The emergency lights were active on both the CHP vehicle and the fire truck. When the vehicle ahead of the Tesla changed lanes to the right to go around the fire truck, the Tesla remained in the HOV lane, accelerated, and struck the rear of the fire truck at a recorded speed of about 31 mph (figure 1).

At the time of the crash, the fire truck was unoccupied. The Tesla driver did not report any injuries. The car was equipped with advanced driver assistance systems (ADASs), including Autopilot.[1] Based on the driver's statements and on performance data downloaded from the car after the crash, the Autopilot was engaged at the time of the collision.

[1] ADASs are designed to help drivers perform certain driving tasks (such as staying in the lane, parking, avoiding collisions, reducing blind spots, and maintaining a safe headway) and improve safety. Autopilot gives automated longitudinal and lateral control of a vehicle. For a more detailed description, see "Advanced Driver Assistance Systems" section.

Figure 1. View of crash scene showing striking vehicle in HOV lane behind fire truck, southbound I-405, Culver City, California. (Source: CHP)

Highway Information

The crash occurred in the southbound HOV lane of I-405, about 350 feet north of Washington Boulevard in Culver City (figure 2). A concrete barrier divides the northbound and southbound lanes.

The leftmost lane in each direction of I-405 is a dedicated HOV lane. The left edge of the southbound HOV lane is delineated by a solid painted yellow line and bordered by a paved shoulder. The right edge of the HOV lane is delineated by a solid painted white line and two sets of solid, double yellow lines. The southbound lanes at the crash location consist of five through lanes and a right-exit lane for Washington Boulevard. The posted speed limit is 65 mph.

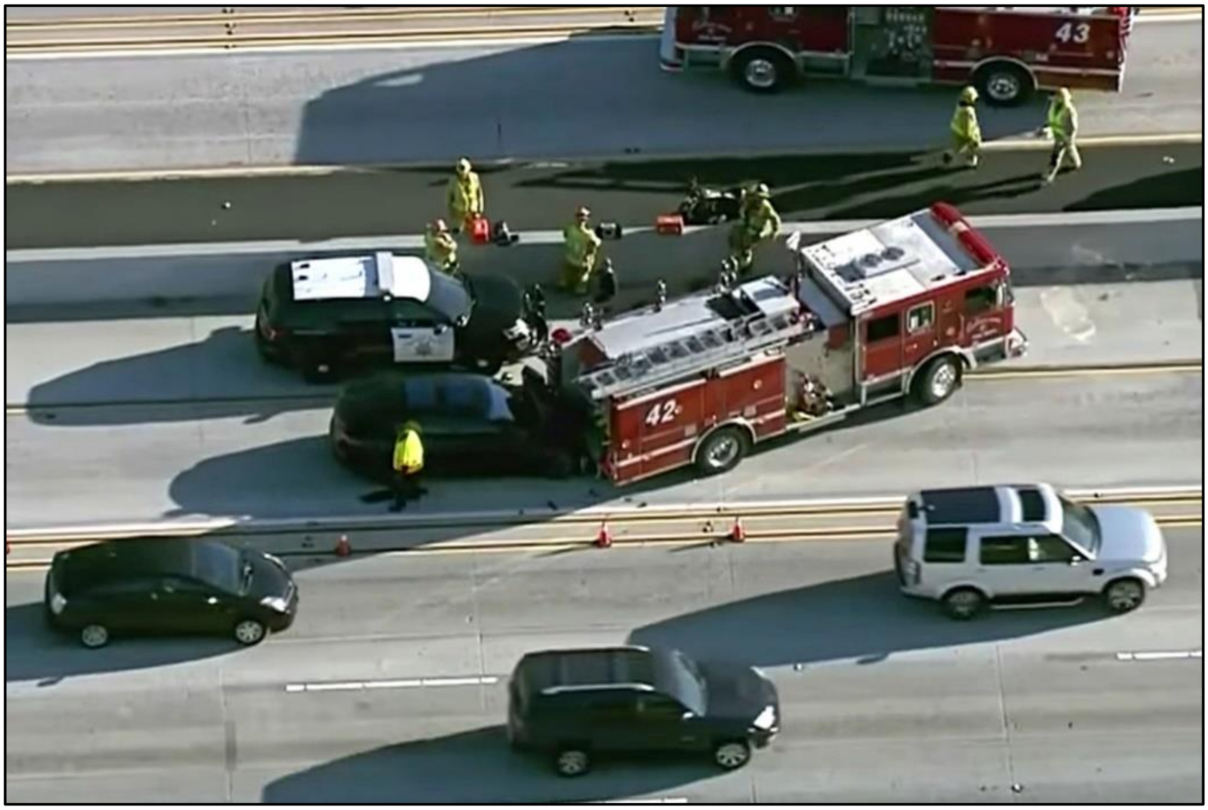

Figure 2. Overhead view of crash scene showing Tesla and fire truck at final rest on southbound I-405. (Source: CHP)

Driver

The Tesla driver was a 47-year-old male. He held a valid California class C driver's license, issued in 1997, and had no history of traffic violations or crashes.

CHP officers observed the driver immediately after the crash. They did not note any signs of impairment, and no toxicological tests were performed.

Precrash Activities

The crash occurred while the driver was traveling from his residence in Woodland Hills to his job in Los Angeles. The driver told National Transportation Safety Board (NTSB) investigators that he usually took I-405 because the HOV lane accommodated electric vehicles, making the trip faster than on alternate routes.[2] About halfway into his 30-mile commute, the driver entered the HOV lane and activated the Autopilot system. The driver said that he was drinking coffee and eating a bagel and maintained touch on the steering wheel while resting his hand on his knee.

[2] In accordance with California Vehicle Code 21655.5, the California Air Resources Board designated the Tesla Model S as an approved vehicle for single-occupant use in HOV lanes.

The driver said that immediately before the crash, he was traveling behind a lead vehicle identified as either a large sport utility vehicle or a pickup truck. He noticed the large vehicle change lanes to the right, out of the HOV lane, but he did not see the stopped fire truck.

The driver told investigators that he was not using his cell phone. A witness who was traveling alongside the Tesla said that before the crash, the Tesla driver "appeared to be looking down at a cell phone or other device he was holding in his left hand." Records confirm that the driver was not using his phone to talk or text in the minutes before the crash, but they do not contain any information about manual manipulation of the phone or using applications installed on it.

The driver said that he was unsure whether he had a coffee mug or a bagel in his hand at the time of impact. He told a CHP officer after the crash that he had been distracted by the car's radio.[3]

Familiarity with Autopilot Technology

The driver had owned the Tesla for about 6 months. It was the first vehicle he had owned that was equipped with ADAS technology offering both longitudinal (braking, acceleration) control and lateral (steering) control. He told investigators that before buying the car, he had researched the technology and selected the Tesla because of its Autopilot feature. He bought the car from a private party, then took it to a Tesla dealership for a comprehensive mechanical inspection. The inspection found the car to be in good condition. The driver said that he received an owner's manual when he bought the car but did not read it. A salesman at the Tesla dealership instructed him on how to use the technology.

The driver described the Autopilot technology as reliable and added that the name "Autopilot" did not accurately describe the technology because the car did not fully drive itself. He said that he would usually activate Autopilot on highways where traffic was stop-and-go, in normally flowing traffic, and in areas where he did not intend to change lanes or exit. His favorite area to activate Autopilot was in carpool lanes, where other cars do not usually change lanes.

The driver stated that when using Autopilot, he would lightly touch the bottom of the steering wheel, and that Autopilot would sometimes disengage when he was holding the steering wheel. Occasionally, when the car could not detect lane markings, a light would come on indicating that he needed to control the car. After he took the wheel, the warning light would go off.

Vehicle Damage

2014 Tesla Model S

The car sustained front-end damage that extended back from the front bumper to the firewall/dashboard area and was concentrated on the left (driver's) side (figure 3). The center of the front bumper was rotated upward about 90 degrees from its original mounting position, and a red transfer mark was visible to the right of the centerline. The lower part of the cowling at the

[3] When interviewed by the NTSB, the Tesla driver said, "Maybe I was changing the radio, maybe not."

front of the car had separated from the vehicle, and the upper part was imprinted with a pattern that matched the fire truck's rear deck. The hood was crushed back and to the left, compromising the windshield and shattering the glass. The left side of the hood displayed red transfer marks. The left side of the firewall was displaced to the rear, which then displaced the dashboard and instrument panel into the passenger compartment. The left side of the dashboard was touching the top of the steering wheel.

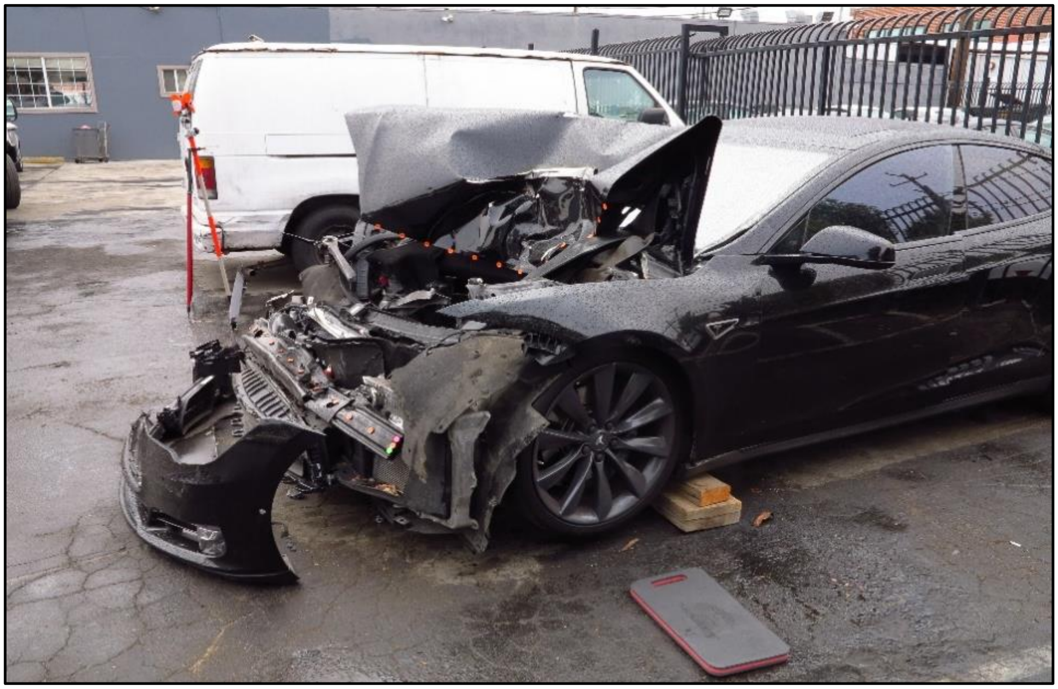

Figure 3. Front-end crash damage to Tesla.

Both the driver's knee bolster air bag and frontal air bag deployed during the crash.[4] The driver's seat was equipped with a lap/shoulder belt that showed signs of being worn at the time of the crash. It was locked in an extended position, and abrasion burn marks were found at the B-pillar belt guide.

Investigators found no anomalies in the car's powertrain, steering, braking, and suspension systems. There were no recalls at the time of the crash in the National Highway Traffic Safety Administration (NHTSA) Office of Defects Investigation database related to the operation of the Tesla.

2006 Seagrave Fire Truck

The fire truck sustained damage to the rear deck and the left rear corner (figure 4). The lower part of the left rear corner had crush damage. Gouges, scrapes, and black transfer marks originating at the left rear corner extended forward about 40 inches along the two equipment

[4] Also called a *knee bar*, a *knee bolster air bag* is an impact-absorbing padded panel under the dashboard that keeps occupants from sliding under the instrument panel during a crash.

compartment doors on that side. The lower part of the compartment door and the left part of the rear deck sustained impact damage. The lens of the lowest red emergency light on the left rear was crushed, but the light was functional.[5] The left side of the rear deck was distorted upward, which prevented the rear compartment doors from opening.

Figure 4. Crash damage to rear deck and left rear corner of fire truck.

Advanced Driver Assistance Systems

The crash car was equipped with the following ADAS technologies:

- Autopilot system: traffic-aware cruise control (TACC), Autosteer, and auto lane change. A forward-facing camera, radar, and multiple ultrasonic sensors collected data on the vehicle's surroundings as input to the Autopilot system.
- Forward collision avoidance: forward collision warning and automatic emergency braking (AEB).
- Lane assist, speed assist, and autopark.

In evaluating the crash, NTSB investigators examined the performance of the Autopilot system and the forward collision avoidance technologies.[6]

[5] The truck had flashing emergency lights on all four rear corners. The lights on the upper corners consisted of a rotating red halogen light above an amber flashing light-emitting diode (LED) lens. The bottom rear assemblies contained two red LED lights. All emergency lights were found to be functional after the crash.

[6] Data from the camera were not available.

Autopilot System

Two components of the car's Autopilot system, TACC and Autosteer, controlled the vehicle's speed and direction by automating the braking, acceleration, and steering functions of driving.

Traffic-Aware Cruise Control. TACC is an adaptive cruise control system that modifies speed based on information from the camera and radar sensors. The system determines if another (lead) vehicle is traveling in front of the Tesla, in the same lane. If the system does not detect a lead vehicle, TACC maintains a cruise speed set by the driver. When a lead vehicle is detected and is traveling slower than the car's set cruise speed, TACC modulates motor torque to maintain a driver-selected, time-based distance from the lead vehicle. The Tesla Model S owner's manual contains numerous warnings about TACC's limitations, including the following:

> Traffic-Aware Cruise Control is designed for your driving comfort and convenience and is not a collision warning or avoidance system. It is your responsibility to stay alert, drive safely, and be in control of the vehicle at all times. Never depend on Traffic-Aware Cruise Control to adequately slow down Model S. Always watch the road in front of you and be prepared to take corrective action at all times. Failure to do so can result in serious injury or death.

Autosteer. Autosteer is a lane-keeping assist system that automatically steers the vehicle to keep it inside lane boundaries. The system can be engaged only after TACC is activated; it cannot operate without TACC. Autosteer, with TACC, relies on the camera, radar, and ultrasonic sensors to detect lane markings and any vehicles directly in front of the car. The system then automatically maintains the car in a center lane position and at a set cruise speed and a set distance from the lead vehicle. The Tesla owner's manual contains several warnings about Autosteer and the importance of a driver keeping his or her hands on the wheel, such as the following:

> (1) Autosteer is a hands-on feature. You must keep your hands on the steering wheel at all times. (2) Autosteer is intended for use only on highways and limited-access roads with a fully attentive driver. When using Autosteer, hold the steering wheel and be mindful of road conditions and surrounding traffic. . . . Never depend on Autosteer to determine an appropriate driving path. Always be prepared to take immediate action. Failure to follow these instructions could cause serious property damage, injury or death.

When Autosteer is engaged, it monitors driver-applied changes to the steering wheel torque (driver's hands on the steering wheel). If drivers keep their hands off the steering wheel for a time, the system produces a series of "hands-off" warnings, starting with a visual alert. The time between the detection of hands-off operation and the display of a visual warning depends on (1) vehicle speed, (2) presence of lead vehicle, (3) lateral acceleration, (4) type of roadway, (5) detection of system errors (which would prompt an immediate warning), (6) driver application of pedals, and (7) miscellaneous factors, such as presence of a construction flag.

Timing of Alerts. The Tesla company outlined the logic behind the timing of Autopilot's hands-off alerts for the crash vehicle.[7] The company considers a divided highway such as I-405 to be an appropriate roadway type for Autopilot operation.[8] When a Tesla equipped with the Autopilot system installed on the crash car travels on a highway at a speed greater than 45 mph and with lateral acceleration below a fixed threshold, one of the following scenarios will apply:[9]

- If a lead vehicle is present ahead of the Tesla, the system will issue a visual warning on the instrument panel after 3 minutes of not detecting driver-applied torque on the steering wheel.
- If a lead vehicle is not in front of the Tesla, the system will issue a visual warning on the instrument panel after 2 minutes of not detecting driver-applied torque on the steering wheel. When the car is traveling on a divided highway at a speed of between 8 mph and 25 mph and with lateral acceleration below a fixed threshold, the Autopilot will not issue a hands-off warning until 10 minutes has elapsed.
- If the system does not detect driver-applied torque on the steering wheel after an initial visual warning, it will sound the first audible hands-off warning 15 seconds after the visual warning.
- If driver-applied torque on the steering wheel is still not detected, the system will sound another audible warning 10 seconds after the first audible warning.
- If, after 5 more seconds, driver-applied torque on the steering wheel is still not detected, the system will sound a third audible warning and begin to decelerate the vehicle to a complete stop.
- If the system detects driver-applied torque on the steering wheel during Autopilot operation, it will cancel any warnings and reset the hands-off count. The count will restart when the system no longer detects driver-applied torque on the steering wheel.

Downloaded Data

Autopilot Activation and Hands-Off Warnings. System performance data were downloaded wirelessly by the vehicle manufacturer and provided on request to NTSB

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[7] The Tesla involved in the crash operated with hardware version 1.0 and firmware version 17.50.97-3bd9f6d082U. The firmware was installed using wireless connectivity on December 28, 2017. The timing of Autopilot's hands-off warnings was based on that version. Newer Tesla vehicles are equipped with hardware version 2.0, 2.5, or 3, which have different sensors and different detection capabilities, and thus different timings for hands-off alerts, than version 1.0. According to Tesla, hardware version 2.0 was introduced in October 2016 on all new vehicles. Hardware version 3 went into production in the first quarter of 2019.

[8] According to instructions distributed by Tesla, Autosteer is intended for use on highways and limited-access roads, not city streets or residential zones.

[9] The timing logic presented here assumes the following: (1) divided roadway, (2) lateral acceleration below fixed threshold, (3) no construction zone (specifically, no flagger), (4) no driver application of accelerator pedal during Autopilot operation, and (5) no system-detected errors.

investigators. The data describe the operation and performance of the ADAS as well as the driver's interactions with the steering wheel.

The crash trip lasted about 66 minutes and covered about 30 miles. During the trip, the Autopilot system was engaged for a total of 29 minutes 4 seconds (figure 5). For most of that time, the system did not detect driver-applied steering wheel torque. Hands were detected on the steering wheel for only 78 seconds.

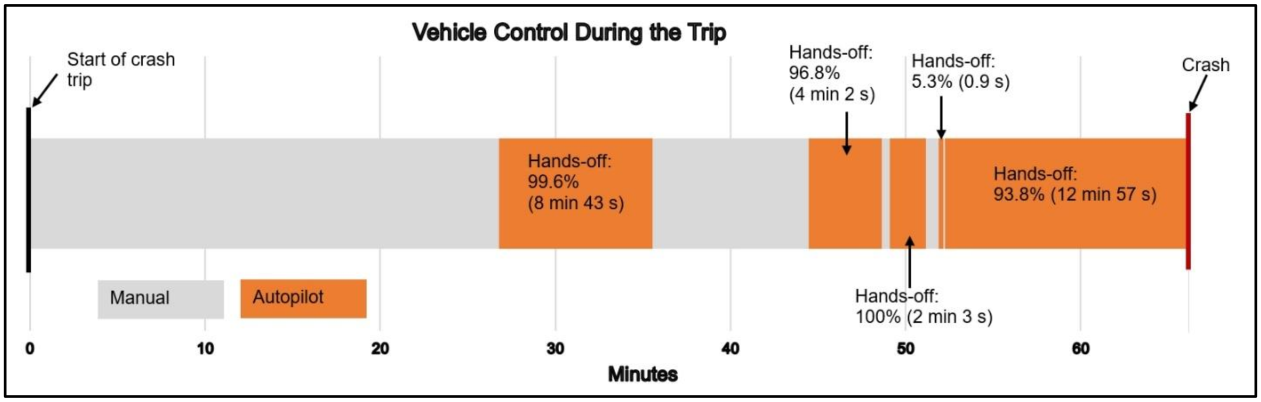

Figure 5. Periods of manual and Autopilot control during crash trip, with callouts showing percentage and duration of time driver had hands off steering wheel while Autopilot was engaged.

The Autopilot system was engaged continuously in the final minutes of the crash trip. During the last segment, the Autopilot system issued several hands-off alerts. As shown in figure 6, in the last 13 minutes 48 seconds before the crash:

- The system detected driver-applied steering wheel torque for a total of 51 seconds.
- The system displayed a visual PLACE HANDS ON THE WHEEL alert four times.
- The system sounded a first-level audible warning once—after the first visual alert.
- In the last 3 minutes 41 seconds before the crash, the system did not detect driver-applied steering wheel torque. During that time, while following a lead vehicle, the Tesla's speed went below 25 mph. According to the logic outlined above, the system would produce a warning after 10 minutes of hands-off operation when the car was traveling at between 8 mph and 25 mph.[10]

[10] The current version of Autopilot would warn of hands-off operation after 2 minutes at speeds below 25 mph.

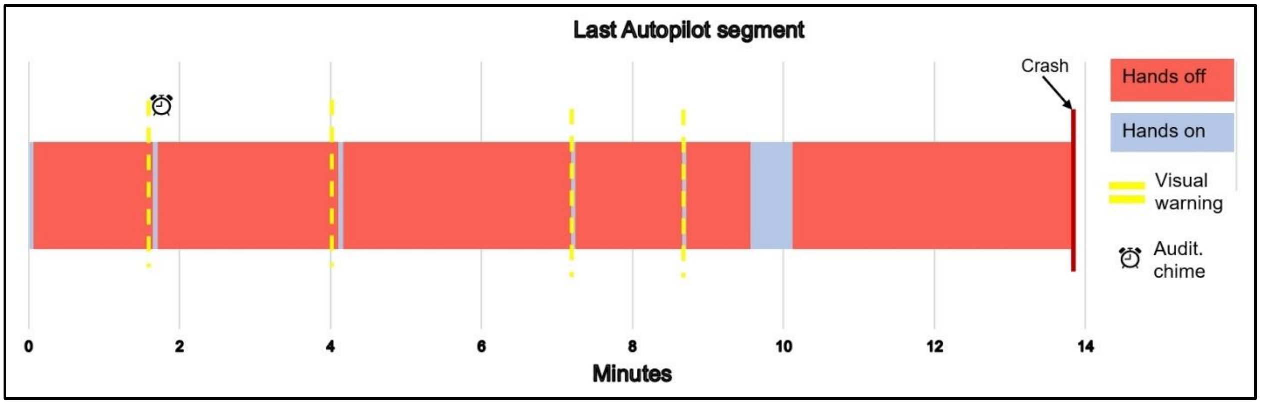

Figure 6. Last Autopilot segment of crash trip, showing hands-off warnings and brief periods when driver's hands were detected on steering wheel.

Following Distance, Speed, and Forward Collision Avoidance. During most of the driver's operation with the Autopilot engaged, the system detected and followed a lead vehicle. In the last 15 seconds before the crash, the Tesla detected and followed two different lead vehicles.

When TACC is engaged, the system adjusts the car's speed to maintain a time-based distance from a lead vehicle immediately ahead. According to the downloaded data, for 4 to 7 seconds before the crash, while the Tesla was traveling about 21 mph, the distance to the lead vehicle (a large sport utility vehicle or pickup truck, according to the driver) was shrinking—that is, the lead vehicle was slowing. Data show that 3 to 4 seconds before the crash, the lead vehicle changed lanes to the right. That movement is referred to as a "cut-out scenario."

When the TACC no longer detected a lead vehicle, the system accelerated the Tesla toward the preset TACC speed of 80 mph, which the driver had set about 5 minutes before the crash.[11] About 0.49 second (490 milliseconds) before the crash, the system detected a stationary object in the Tesla's path. The forward collision warning activated, displaying a visual warning and sounding an auditory warning to the driver. By the moment of impact, the Tesla had accelerated to a speed of 30.9 mph.

Figure 7 depicts the movement of the Tesla and the two lead vehicles in the last 15 seconds before the crash. In the left panel—covering 15 to 8 seconds before impact—the Tesla is accelerating from 9 to 18 mph while following a lead vehicle (red car) at 30 to 46 feet. In the middle panel—covering 7 to 4 seconds before impact—the Tesla is traveling at a constant 21 mph while following a lead vehicle (green car) at a distance decreasing from 148 to 108 feet. In the right panel—covering the last 3 seconds before impact—the Tesla is accelerating from 21 to 31 mph, with no lead vehicle and a forward collision warning half a second before impact.

[11] The driver told investigators that he had set the TACC speed to 65 mph before the crash.

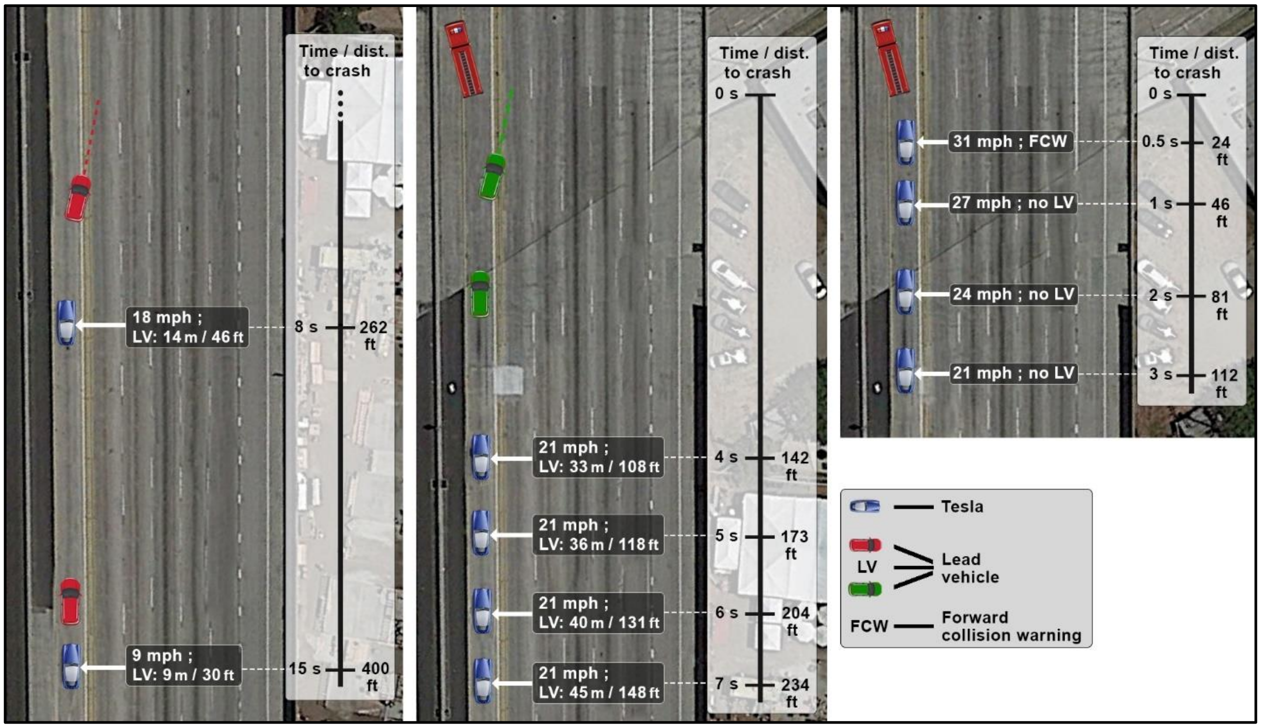

Figure 7. Illustration of movement of Tesla (blue car) and vehicles traveling ahead in same lane (red and green cars). Time before crash is 15 to 8 seconds (left image), 7 to 4 seconds (middle image), and 3 to 0 seconds (right image). Shown are approximate vehicle positions and Tesla's speed and distance to closest lead vehicle (LV). Red fire truck is shown at top of middle and right panels.

AEB did not activate during the event, and data show no driver-applied braking or steering before the crash. Tesla's AEB is a radar/camera fusion system that is designed for front-to-rear collision mitigation or avoidance. According to the company, the system requires agreement from both the radar and the camera to initiate AEB; complex or unusual vehicle shapes can delay or prevent the system from classifying vehicles as targets or threats.

Detection of stationary objects is a challenging scenario for ADAS manufacturers. Cut-out scenarios, in which a lead vehicle rapidly changes a lane to reveal a stationary vehicle, present additional difficulties for ADAS-equipped vehicles. The Tesla Model S owner's manual includes the following warning:

> Traffic-Aware Cruise Control cannot detect all objects and may not brake/decelerate for stationary vehicles, especially in situations when you are driving over 50 mph . . . and a vehicle you are following moves out of your driving path and a stationary vehicle or object is in front of you instead.

The limited time a stationary vehicle is in the car's field of view challenges the system's ability to assess a threat and apply AEB.

NHTSA has established test protocols and performance specifications for forward collision warning and AEB (as part of the New Car Assessment Program, or NCAP). Crash avoidance systems that meet the performance specifications are listed as "Recommended Safety Technologies" in NHTSA's 5-Star Safety Ratings program.[12] Such assessment is conducted globally, including by European NCAP (Euro NCAP).[13] While the two programs use similar scenarios in their test protocols, Euro NCAP uses a variety of targets—such as vehicles, bicyclists and pedestrians—tests at a greater range of velocities, and most important, rates system performance.

As part of an expanded AEB assessment, Euro NCAP conducted a preliminary evaluation of adaptive cruise control that included cut-out scenarios.[14] While cut-out scenarios are not part of validated standard test protocols, Euro NCAP noted that the scenarios are challenging because they require rapid detection of a suddenly revealed stationary vehicle. Other scenarios that involve approaching a stationary vehicle, even without a cut-out component, are also difficult for AEB systems to handle. Several vehicle models performed inadequately in such tests.

Previous NTSB Investigations

The NTSB has previously investigated crashes involving vehicles operating with ADASs (also called automated vehicle control systems). When investigating the collision in May 2016 between a 2015 Tesla Model S 70D car and a tractor-semitrailer truck near Williston, Florida, the NTSB found that the Tesla driver was inattentive to the driving task, and that his pattern of use of the Autopilot system indicated an overreliance on the automation and a lack of understanding of system limitations.[15] The NTSB also concluded that the way the Tesla Autopilot system monitored and responded to the driver's interaction with the steering wheel was not an effective method of ensuring driver engagement. In addition, the NTSB concluded that because driving is an inherently visual task and a driver might touch the steering wheel without assessing the roadway, traffic conditions, or vehicle performance, monitoring steering wheel torque provides a poor surrogate means of determining a driver's degree of engagement with the driving task.

The NTSB issued seven safety recommendations as a result of the Williston investigation, including the following:

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[12] In 2016, NHTSA added AEB to the list of recommended technologies, starting with model year 2018 vehicles (NHTSA website, accessed July 18, 2019). AEB systems engage dynamic brake support or crash-imminent braking to prevent or mitigate the severity of rear-end collisions.

[13] See Euro NCAP website, accessed July 18, 2019.

[14] The Euro NCAP 2018 automated driving tests examined ADAS performance for the following vehicles: Audi A6, BMW 5 Series, DS 7 Crossback, Ford Focus, Hyundai NEXO, Mercedes-Benz C-Class, Nissan Leaf, Tesla Model S, Toyota Corolla, and Volvo V60. (See website for 2018 automated driving tests, accessed July 17, 2019.)

[15] *Collision Between a Car Operating with Automated Vehicle Control Systems and a Tractor-Semitrailer Truck Near Williston, Florida, May 7, 2016*, NTSB/HAR-17/02. Washington, DC: National Transportation Safety Board, 2017.

Develop applications to more effectively sense the driver's level of engagement and alert the driver when engagement is lacking while automated vehicle control systems are in use (H-17-42).

The recommendation was addressed to manufacturers of vehicles equipped with level 2 vehicle automation systems (Volkswagen Group of America, BMW of North America, Nissan Group of North America, Mercedes-Benz USA, Tesla Inc., and Volvo Car USA).[16] Safety Recommendation H-17-42 is classified "Open—Acceptable Response" for all recipients except Tesla, for whom the recommendation is classified "Open—Await Response." All manufacturers except Tesla have responded to the NTSB explaining their current systems and their efforts to reduce misuse and keep drivers engaged, including consideration for improving driver monitoring techniques.

The NTSB is investigating two recent crashes involving vehicles in which Tesla's Autopilot system was engaged at the time—one in Mountain View, California, and another in Delray Beach, Florida.[17]

Discussion

In this crash, the driver's lack of braking and steering in response to the stopped fire truck, his statement that he never saw the fire truck, and his potential in-vehicle distractions (bagel, cup of coffee, radio) all suggest that the driver was not attending to the driving task before the crash. In addition, the fact that the Autopilot did not detect driver-applied steering wheel torque in the last 3 minutes 41 seconds before the crash suggests driver overreliance on vehicle automation.

Performance data show that the Tesla followed various lead vehicles in heavy traffic for minutes before the crash. When the last lead vehicle changed lanes—3 to 4 seconds before the crash—revealing the fire truck on the path of the Tesla, the system was unable to immediately detect the hazard and accelerated the Tesla toward the stationary truck. By the time the system detected the stationary vehicle and gave the driver a collision warning—0.49 second before impact—the collision was imminent and the warning was too late, particularly for an inattentive driver. The AEB system did not activate. Had the driver been attending to the driving task, he could have taken evasive action to avoid or mitigate the collision.

Probable Cause

The National Transportation Safety Board determines that the probable cause of the Culver City, California, rear-end crash was the Tesla driver's lack of response to the stationary fire truck in his travel lane, due to inattention and overreliance on the vehicle's advanced driver assistance system; the Tesla's Autopilot design, which permitted the driver to disengage from the driving task;

[16] In recommended practice SAE J3016, the Society of Automotive Engineers (SAE) defines six levels of driving automation, from no automation (level 0) to full driving automation (level 5).

[17] For further information, see the preliminary reports for NTSB accidents HWY18FH011 (Mountain View) and HWY19FH008 (Delray Beach).

and the driver's use of the system in ways inconsistent with guidance and warnings from the manufacturer.

Report Date: August 22, 2019

For more details about this accident, visit the NTSB public docket and search for NTSB accident ID HWY18FH004. The accident dockets include such information as police reports, photographs, driver and witness statements, data on previous crashes, and highway engineering reports.
