NATIONAL TRANSPORTATION SAFETY BOARD
OFFICE OF HIGHWAY SAFETY
WASHINGTON, D.C.

TECHNICAL RECONSTRUCTION GROUP CHAIRMAN'S FACTUAL REPORT

A. CRASH INFORMATION

Location: 14000 block US 441, Delray Beach, Palm Beach County, Florida

Vehicle 1: 2019 International truck-tractor in combination with a 2008 Vanguard semi-trailer

Operator 1: FirstFleet Inc., Murfreesboro, TN

Vehicle 2: 2018 Tesla Model 3

Operator 2: Private Operator

Date: March 1, 2019

Time: Approximately 6:17 a.m. (EST)

NTSB #: **HWY19FH008**

B. TECHNICAL RECONSTRUCTION GROUP

Robert Squire – Highway Crash Investigator, Group Chairman
NTSB Office of Highway Safety
490 L'Enfant Plaza East, S.W., Washington, DC 20594

C. CRASH SUMMARY

For a summary of the crash, refer to the *Crash Summary Report* in the docket for this investigation.

D. DETAILS OF THE TECHNICAL RECONSTRUCTION INVESTIGATION

The Technical Reconstruction Group for this investigation was convened after NTSB Office of Highway Safety investigators initiated a field investigation of this crash and determined that data acquired during the investigation could benefit from additional analysis. The portion of the investigation undertaken by the Technical Reconstruction Group was limited to analyzing data that was received from the Palm Beach County Sheriff's Office (PBSO), Florida Department of Transportation (FDOT) and NTSB investigative groups.

1. Introduction - Data Sources, Collision Site and Highway Description

The collision occurred March 1, 2019, at approximately 6:17 a.m. EST, approximately 27 minutes before sunrise during clear weather and with dry road surface conditions. The crash involved a right-angle collision between two vehicles - 2018 Tesla Model 3, four-door sedan, and a 2019 International truck tractor in combination with a 53-foot van body semitrailer. The Tesla traveling southbound on U.S. Route 441 / Florida State Route 7 impacted the left side of the semitrailer as the combination vehicle, traveling east, exited an agricultural business intending to turn left onto the northbound roadway.

The Tesla was being operated with a partially automated advanced driver assistance system – termed *Autopilot* by the manufacturer – engaged. The combination vehicle entered the southbound roadway from a business driveway after failing to stop for a posted stop sign and yield to the approaching Tesla. Although the Tesla was operating in an automated driving mode, neither the automated system nor the driver responded to truck's incursion into the Tesla's path of travel. The Tesla underrode the semitrailer resulting in the separation of the vehicle's roof structure. After exiting from the far side of the trailer the Tesla entered the grass median and came to a stop approximately 1,680 feet south of the area of impact.

1.1. Data Sources

Data used by the Technical Reconstruction included certain scene photographs and measurements provided by PBSO investigators, FDOT highway plans, and NTSB group investigative data. Data recorded by the event data recorder (EDR) function in the restraint control module (RCM) as well certain vehicle performance parametric data were provided by Tesla, Inc. to NTSB investigators. Data recording the operation of certain advanced driver assistance system and vehicle performance data – referred to as *Carlog* data – are briefly discussed. Additional details on this data is discussed in other NTSB investigate group reports.

1.2. Site Description

As discussed in greater detail in the NTSB Highway Factors Group factual report, US-441, also known as State Route 7, is a north-south divided highway with a posted speed limit of 55 MPH through the area of the collision. The nearest major highway intersections to the collision location were Atlantic Avenue (SR-806), approximately one mile to the south, and Boyton Beach Boulevard (SR-804), approximately four miles to the north. Traffic movement through these intersections is control by automatic signals. Traffic movement entering US-441 from the minor roadways and paved driveways between these intersections were controlled by stop signs.

The two travel lanes of the north- and southbound roadways of US-441 were separated by an earthen (grass-covered) median. The highway was straight with minimal change in elevation.[1] At the location of the crash, a paved driveway for the business intersected US-441 at a right angle on the west side and consisted of an entrance and exit travel lane that were separated by a small median. Eastward traffic movement at the intersection with US-441 was controlled by a posted stop sign and pavement stop line. Site measurement data provided by PBSO (via total station)

[1] Satellite imagery indicates fluctuations in elevation no greater than three feet overt four-mile distance southward from SR-804.

indicated setbacks of approximately 23 and 31 feet for the stop line and stop sign respectively from the right edge of the southbound through lane. The stop sign was offset about 31 feet from the right edge line of the driveway exit.

As noted in the NTSB Highway Factors Group factual report, directly across from the business driveway was a paved median crossover. The crossover facilitated left turning vehicles entering and exiting the business as well as U-turning vehicles - other than trucks - traveling north and south on US-441.[2] Measurement data indicated the median crossover was about 34 feet in width (left edge line to left edge line) with an opening width of about 72 feet. Lateral, east-west, measurements across the southbound roadway indicated a distance of about 59 feet from the driveway stop line to the median edge, which includes a right turn lane, bicycle lane and median left turn lane.

1.3. Highway Sight Line

On-scene investigators reported no physical obstructions to lines of sight for either driver as they approached the intersection. A tree line that parallels the southbound roadway to the west is setback about 60-70 feet from the pavement edge and while the driveway median has several trees, the median terminates at about 80 feet from the pavement edge. The north-south line of sight from the driveway is unobstructed by physical features or terrain between the tree line and intersection.

1.4. Lighting

No supplemental lighting was provided at the intersection or the approach along US-441 or the driveway. Photographs depict high intensity lighting on the business property after passing through the gated entrance. The tree line paralleling the southbound roadway was sufficiently dense to obstruct light such that there was no evidence of stray lighting reaching the highway.

The crash occurred about four minutes before the start of civil twilight, which is generally defined as the period preceding sunrise when the sun is about six degrees below the horizon but during which there is sufficient natural light to engage in typical outdoor activities without artificial lighting. As depicted through video evidence, the sky above the horizon had begun to brighten that contributed to ambient illumination.

2. Roadway Evidence and Area of Impact

PBSO investigators provided the NTSB with crash scene photographs and total station measurement data documenting certain roadway features and evidence. Roadway evidence included a single tire friction mark, shallow pavement gouges and vehicle debris deposited further south of the impact, the latter of which were documented through photographs. The tire friction mark was located in, and parallel with, the southbound right travel lane. The tire mark was located about 2.9 feet from the lane line that separates the right and left through travel lanes and measured about 10.8 feet in length. In photographs, the tire mark appearance was narrow, but dark in intensity. Just to the left of the tire mark, atop the lane dividing line were glass deposits and vehicle structure debris, some exhibiting red color paint. Also within this area – between the tire mark

[2] Trucks are restricted from U-turn maneuvers from US-441 as indicated by posted signs.

and lane dividing line – road surface gouges were identified. The gouges were not easily identified in the photographs. This evidence was sufficient to establish this area as the area of impact. Additionally, this area was about 33 feet directly across from the eastbound exit roadway of the agricultural business.

Extending southward from the area of impact, debris from the Tesla (some components were red in color and others marked with Tesla branding) was observed deposited essentially atop the lane line separating the left and right through lanes. The debris trail extended an estimated distance of about 200 feet. Some vehicle debris was also deposited in the median crossover just past the left turn lane and eastward of the impact area.

PBSO investigators documented the position of final rest for the Tesla in the highway median about 1,680 feet south of the area of impact. Site photographs provided by PBSO investigators depict that the Tesla departed the highway pavement and entered the median an estimated 425-435 feet south of the area of impact. Evidence of the vehicle's southward path of travel through the median consisted of tire impressions through the grass median. The path exhibited serpentine characteristics where the vehicle traveled to the median edges and then steered back, eventually coming to a stop near the center.

Figures 1 and 2 depict scaled diagrams based on the total station data provided by the PBSO investigators and further supplemented by photographs, FDOT highway plans and Google Earth imagery.

3. Vehicle Damage Documentation

Post-collision the combination vehicle and the Tesla were examined and documented by NTSB investigators. Specific data related to those examinations are available in the NTSB Vehicle and Survival Factors Groups factual reports.

Data significant to or acquired by the Technical Reconstruction Group included certain vehicle and damage dimensional data. The overall combination vehicle length was calculated at about 68.4 feet. The initial impact damage was observed on the left (driver's) side of the semitrailer, centered approximately 30.6- and 46-feet rearward of the front of the trailer and tractor respectively. As referenced from the rear of the trailer, the area of contact was centered about 22.4 feet forward. Contact damage on the trailer indicates that the Tesla left A-pillar contacted the lower sidewall rail of the trailer about 20 inches rearward of the trailer mid-point. Contact evidence of the Tesla's right (passenger's) side A-pillar was observed about 59 inches further rearward. NTSB investigators measured the vertical ground clearance of the trailer's lower sidewall rail at about 3.6 feet (43.2 inches).

Dimensional data from the Tesla Model 3 identified the vehicle as having an overall maximum height of 4.75 feet (57 inches). The documented vertical heights at the base of the front windshield and rear window were 3- and 3.7-feet (13- and 44-inches) respectively. Post-collision measurements taken by NTSB investigators depicted the presence A-pillar contact damage evidence at a vertical height of about 3.6 feet, just below the point where the pillar separated.

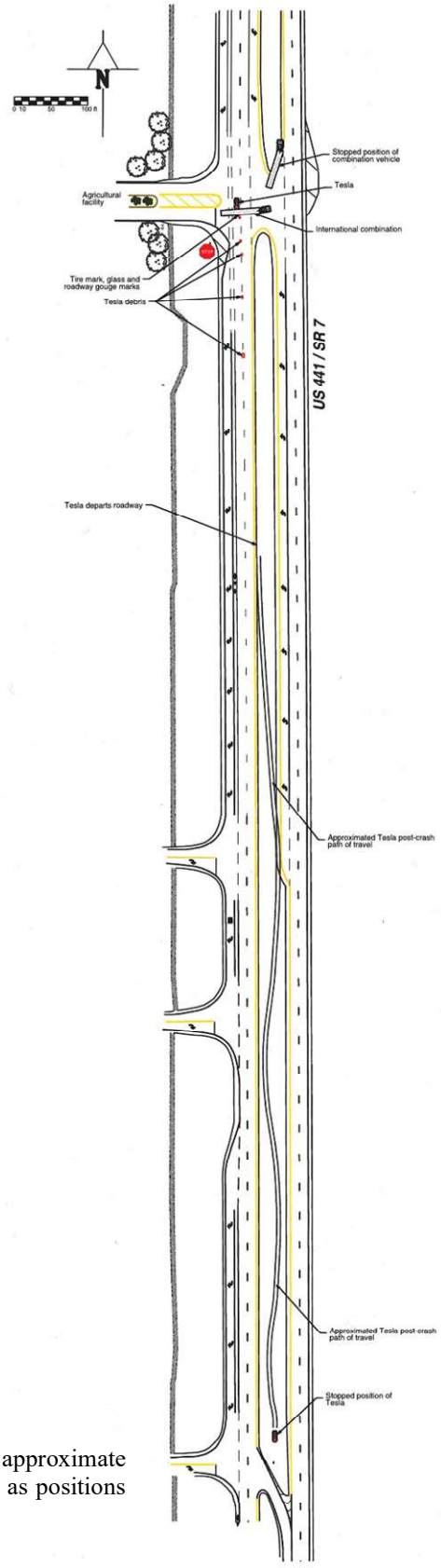

Figure 1: Scaled site diagram depicting approximate area and configuration of impact as well as positions of vehicles at final rest.

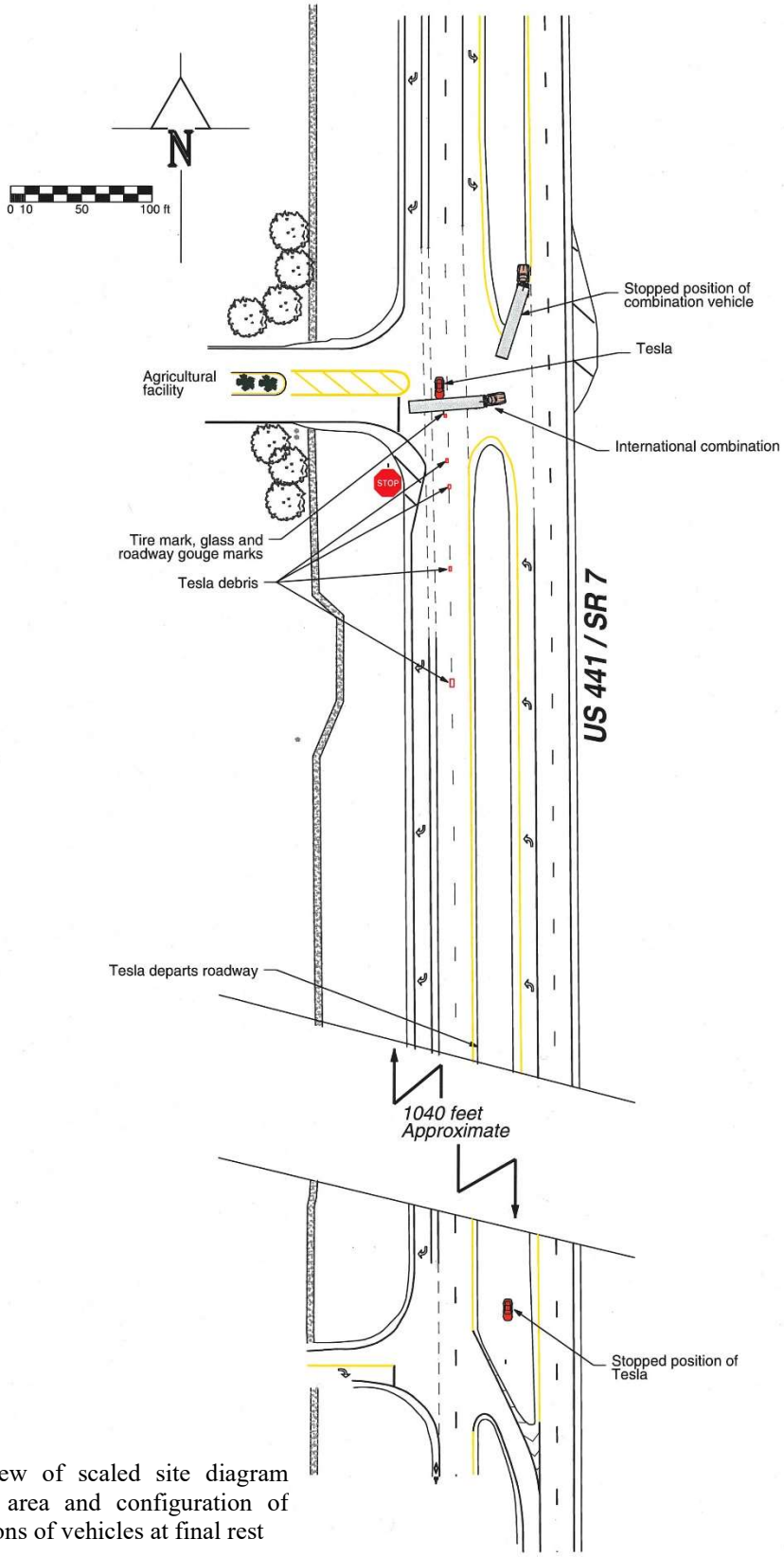

Figure 2: Enlarged view of scaled site diagram depicting approximate area and configuration of impact as well as positions of vehicles at final rest

4. RCM Electronic Event Data

The Tesla was equipped with pyrotechnically deployed supplemental occupant restraints that included airbags, seat belt pretensioners and a high-voltage battery disconnect. Deployment or activation of these supplemental restraints and safety devices is commanded by the airbag or restraint control module (RCM) based on a programmed algorithm. In the event of a deployment command or certain non-deployment events where the command algorithm has enabled, certain data was recorded.[3] The recording of "event" data defines this capability of the RCM as an Event Data Recorder (EDR). The EDR functionality of the Tesla ACM adheres to the requirements of 49 Code of Federal Regulations Part 563.[4]

The RCM installed in the Tesla Model 3 can store up to two events, including non-deployment. Data from non-deployment events are not locked into memory and can be overwritten by a subsequent event. An event record includes crash data related to activation of the supplemental restraint system and pre-deployment vehicle performance data that are recorded in discrete time intervals, although those data may be recorded asynchronously. "Time Zero", as noted throughout an event record, is the point where the restraint control algorithm was activated in any sensing direction.

Pre-deployment, or pre-crash data is reported for five seconds at time intervals between two and 10 hertz depending upon the vehicle parameter being monitored. The data, initially buffered, is chronologically written to the record beginning five seconds before the deployment decision algorithm is triggered or enabled. Crash data includes deployment decision timing, lateral, longitudinal and vertical acceleration as well as lateral and longitudinal change in velocity (Δv). Lateral, longitudinal and vertical time-series acceleration data is reported at ½-millisecond intervals at 0.8g resolution from algorithm enable until the end of the event.[5] Lateral and longitudinal change in velocity (Δv) is a calculated integration value that is reported in 10ms intervals to the nearest kilometer per hour from Time Zero until the end of the end of event. The end of an event is typically the moment at which the cumulative change in velocity within a 20ms time period does not change by more than 0.8 km/h (0.5 mph) or the moment at which the deployment decision algorithm of the RCM resets. Data parameters may have different recording run times as provided for within 49 CFR Part 563.

For this vehicle the RCM data interpretation was retrieved from Tesla as the vehicle's onboard telematics had transmitted this and other data to the manufacturer's data servers following the crash. The report was provided in a .pdf format. The report indicated 302 ignition cycles at the time of both the event and data download. The vehicle odometer mileage was reported as

[3] A non-deployment event occurs and may record data when the RCM senses a triggering event (enabling the decision algorithm) but a deployment command is not given.

[4] In summary, 49 CFR Part 563 defines an Event Data Recorder as a device or function in a vehicle that records the vehicle's dynamic time-series data during the time period just prior to a crash event (e.g., vehicle speed vs. time) or during a crash event (e.g., delta–V vs. time), intended for retrieval after the crash event. This regulation defines the minimum data set that must be collected if a manufacturer decides to voluntarily install an EDR in their vehicle, along with requirements for the range and accuracy of the data. Part 563 is applicable to vehicle manufactured after September 1, 2010 and applies to vehicle with a GVWR of 8,500 pounds or less.

[5] 49 CFR Part 563 requires the recording time of at least 300ms.

3,449.7 kilometers (~2,143.5 miles). The trip distance before the collision was calculated as 9.4 miles.

4.1. Crash data

The EDR report conveyed that one non-deployment event had been recorded with no deployment of any supplemental systems commanded. The reported data indicates the event was triggered by both a longitudinal and lateral acceleration. The trigger event terminated after about 55ms, although the cumulative changes in velocity peaked at 150ms longitudinally and 142.5ms laterally. The maximum change in longitudinal and lateral velocity was reported as 14- and 3-km/h (8.7- and 1.8-mph) respectively. Based on the changes in velocity, the calculated principle direction of force (PDOF) of about 12-degrees exhibited both longitudinal and lateral components that were consistent with the characteristics of the crash.[6]

The data referenced along the longitudinal, lateral and vertical axes followed the SAE J1733 sign convention, which indicated the relative acceleration vectors detected by the RCM accelerometer.[7] As indicated by the data, the accelerations recorded by the RCM were consistent with a frontal crash, right to left lateral impact force (truck movement) and a downward vertical movement (that peaked at about 60-80ms).[8]

The data indicate that the RCM algorithm wake-up occurred when the Tesla contacted and then began to underride the trailer. While accelerations were sensed by the RCM and the deployment algorithm enabled, the SRS deployment threshold had apparently not been satisfied with peak accelerations developing later in the event.

4.2. Pre-collision data

Pre-crash data reported certain vehicle parameters for up to five seconds before Time Zero (algorithm active) at between 100 and 500ms intervals (0.1-0.5 seconds). The reported parameters included:

- Vehicle speed – A calculated value of the average of the speed signals of all four wheels with a resolution to the nearest km/h.
- Percent accelerator pedal - The percent of full application of the accelerator pedal with a resolution to the nearest whole percent.
- Rear motor RPM - The rate of rotation of the rear drive motor with a resolution to the nearest 100 rotations per minute (RPM). Maximum value is 17,900 RPMs.

[6] Principle Direction of Force (PDOF) is calculated as an angle relative to the vehicle (0° at front) along which the collision forces are directed. PDOF is based on the lateral and longitudinal change in velocity at a particular time as reported by the EDR data.
[7] SAE J1733, Sign Convention for Vehicle Crash Testing, specifies a right-handed coordinate system such that positive coordinates directions are forward, right-to-left and upward.
[8] Vertical (normal) acceleration was reported at 20ms intervals during a period of 900ms before Time Zero and 500ms after Time Zero.

- Service brake - Indicates the status of the brake pedal as reported by the brake booster where the possible values are "On" (pedal applied) and "Off" (pedal not applied).

- Steering wheel angle - The measured rotational angle of the steering wheel with a range between -819 degrees to +819 degrees. The reported resolution is to the nearest degree and is reported at 0.1 second intervals.

- Stability control - The status of the Electronic Stability Control system (ESC) where the possible values are "On", meaning the ESC was enabled but not active; "Off" meaning the ESC was turned off; and "Engaged" meaning that the ESC was active.

- ABS activity - The status of the Anti-lock Braking System (ABS) where the possible values are "On" meaning the ABS was active and "Off" meaning the ABS was not active. Active ABS status does not necessarily indicate that the ABS control unit was actively modulating braking at one or more wheels.

- Lateral acceleration – is the measured physical acceleration at the RCM during the five seconds before and including Time Zero.

- Longitudinal acceleration - is the measured physical acceleration at the RCM during the five seconds before and including Time Zero.

- Roll rate – measured angular velocity at the RCM around the longitudinal axis at a resolution to the nearest 0.1 degrees per second and reported at 0.1-second intervals.

- Yaw rate - measured angular velocity at the RCM around the vertical axis at a resolution to the nearest 0.1 degrees per second and reported at 0.1-second intervals.

As conveyed in the EDR report, the vehicle exhibited a steady speed of 69 MPH during the five-second period before the collision. The other data parameters are consistent with the vehicle traveling along a straight and level path (aside from minor corrections for surface cross slope and minor vertical irregularities) with no apparent driver inputs before impact. The data indicate no brake pedal application or steering wheel input before the collision. Additionally, the steady-state data and lack of accelerator pedal percent data indicate the vehicle cruise control was active.

Additional data in the EDR report conveyed that no system warning lights were illuminated; the driver's seat belt was buckled (latch engaged) and the passenger seat was empty.

5. Carlog Data – Crash Event Related

The Carlog consisted of various vehicle and system status values recorded during established time intervals or upon a change in status. Certain data for the from the day of crash was interpreted by Tesla and provided to NTSB investigators. The data is referenced by date and time (Pacific Standard Time for this file). The first indications of the crash appeared at 06:16:55.2 a.m. when an RCM crash algorithm wake-up message was recorded. At the same time stamp, and continuing over the next 0.1 seconds, multiple system fault and warning messages were recorded.

About 0.2 seconds after the RCM crash algorithm wake-up an *active frontal near deployment* message was recorded. Approximately 0.3 seconds after the crash algorithm wake-up leftward steering was detected by the primary steering angle sensor.

The data also indicated a *cruise control enabled state* report 10.2 seconds before the crash detection and an *autosteer active nominal* status 9.9 seconds before the crash. The final cruise control speed setting indicated 69 MPH 12.3 seconds before the crash was detected. Carlog data reported the vehicle speed as 68.3 MPH when the crash was detected. No fault messages or collision mitigation intervention was indicated within the data.

E. DOCKET MATERIAL

The following attachments and photographs are included in the docket for this investigation:

LIST OF ATTACHMENTS

- None

END OF REPORT

Robert J. Squire
Highway Accident Investigator