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

TECHNICAL RECONSTRUCTION GROUP CHAIRMAN'S FACTUAL REPORT

A. CRASH INFORMATION

Location:	Seabreeze Boulevard (State Route A1A) north of Harbor Beach Parkway, Broward County, Florida
Vehicle:	2014 Tesla, Model S, 4-door sedan
Operator:	Private Operator
Date:	May 8, 2018
Time:	Approximately 6:46 p.m. EDT
NTSB #:	**HWY18FH013**

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 Fort Lauderdale Police Department (FLPD), Florida Department of Transportation (FDOT) and NTSB investigators that responded to crash.

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

The collision occurred May 8, 2018, at approximately 6:46 p.m. EDT, during daylight with dry road surface conditions. The crash involved a single vehicle, a 2014 Tesla Model S, four-door sedan, that collided with several roadside fixed objects – specifically masonry/concrete property barrier walls and a luminaire support pole - after it departed the roadway while negotiating a left curve on southbound Seabreeze Boulevard, Florida State Route A1A (SR-A1A) in Ft Lauderdale, FL. The collision events occurred between the intersections of Holiday Drive and Harbor Beach Parkway with the initial collision with a roadside feature having occurred about 590 feet north of the intersection with Harbor Beach Parkway.[1]

The Tesla departed the southbound travel lane as it neared the end of the curve at a high rate of speed. The vehicle ascended a raised curb and sidewalk, then sideswiped a masonry/concrete wall that paralleled the highway and bordered the contiguous residential property. After crossing a driveway, the vehicle sustained a significant impact with the wall on the opposing side of the driveway. The vehicle rotated off the wall and traveled southeastward across SR-A1A where it collided with a luminaire pole on the opposite side of the highway. The vehicle separated from the pole and came to rest further south atop the sidewalk and a post-collision fire ensued.

1.1. Data Sources

Data used by the Technical Reconstruction included material received from FLPD investigators, FDOT, and on-scene NTSB investigators. FLPD investigators provided the NTSB with site documentation that included total station mapping data and photographs. FDOT provided As-built roadway plans from two highway rehabilitation projects covering the crash area. Collision-related event data was also recovered from the vehicle's restraint control module (RCM).

1.2. Site Description

SR-A1A (Seabreeze Boulevard) around the collision site is an urban minor arterial with a posted speed limit of 30 MPH. The area is primarily residential, although hotel land use exists northward of Holiday Drive. The section of SR-A1A on which the crash occurred is a four-lane, undivided roadway with a center two-way left-turn lane. SR-A1A is considered a north-south highway and is generally oriented as such.

Outboard of the right travel lanes in both the north- and southbound direction are bike lanes as designated by pavement striping. Contiguous with the bike lane on both roadways are concrete gutters, estimated to be approximately one foot in width. The curbing is elevated above the roadway and abuts either the concrete sidewalk or a narrow grassy median that offset the curb from the sidewalk. Typical section dimensions exhibited through the area included:

[1] Unless otherwise noted, reference to distances from intersections is based upon the reference station of the approximate center as indicated in the Final "As-Built" Roadway Plans for State Road A1A Resurfacing, Restoration and Rehabilitation "SR A1A east of Mercedes River Small Bridge to Sunrise Boulevard (SR 838). Project ID 430601-1-52-01, June 2017.

- Travel lane widths of about 10 feet.
- Center two-way left turn lane width of about 9 feet.
- Bike lane widths of about 4 feet.
- Sidewalk width ranging from 4.5 to 5.0 feet
- General cross slope superelevation, excluding curves, 0.01-0.04% for the left lane and 0.01-0.06% right lane.

The highway travel lanes are delineated by pavement striping and retroreflective raised roadway markers. The two-way center left turn lane is delineated by parallel normal broken yellow line and a normal solid yellow line at both lane edges. Travel lanes for each roadway are delineated by a normal broken white line with striping segments that are 10 feet in length and placed at 30-foot intervals. White and red (opposing direction) retroreflective roadway markers are installed in line with the striping and placed at 40-foot intervals.

1.3. Highway Alignment and Crash Location

Traveling southbound between the intersections of Holiday Drive and Harbor Beach Parkway intersection, SR-A1A exhibits three horizontal curves. Two of the curves, just south of Holiday Drive, are relatively minor curves. The third curve further south is where the collision events initiated. Overall, this section of SR-A1A is essentially level and exhibits no notable change in vertical alignment.

Southward from Holiday Drive, the first curve begins about 98 feet south of the Holiday Drive intersection (center). This is a left curve exhibiting a radius of 332.11 feet with a length of 47.59 feet. The angular offset between the approach to and departure from the curve (central angle) is 8.2°. A tangent segment of about 61.48 feet in length separates the first curve from the second.

The second curve begins about 207 feet south of the Holiday Drive intersection. This is a right curve exhibiting a radius of 818.83 feet with a length of 199.82 feet. The curve central angle is 13.9°. A tangent segment of about 142 feet in length separates the second curve from the third, where the crash occurred.

The third curve begins about 549 feet south of the Holiday Drive intersection. This is a left curve exhibiting a radius of 488.10 feet over a length of 340.17 feet. The curve central angle is 39.8°. Information from FDOT indicates that the maximum cross slope (superelevation) of the curve is about 3.4% near the intersection of the back and forward tangents of the curve (near the curve midpoint). The superelevation decreases to about 2.0% at the south end of the curve.

Southward from the end of the third curve the highway exhibits a tangent segment for approximately 631 feet to the Harbor Beach Parkway intersection. There is a slight, three-degree, rightward offset in the tangent about 350 feet after the curve (281 feet before the intersection).

1.4. Highway Signage

SR-A1A through the area of the collision has a posted speed limit of 30 MPH with two (2) speed limit signs preceding the curve in the southbound direction. One sign was located approximately 422 feet before (north of) the Holiday Drive intersection. The second speed limit sign was located about 75 feet after (south of) Holiday Drive or 474 feet before (north of) the curve.

Both the north- and southbound directions of travel exhibit horizontal alignment warning signs upon approach to the curve. Both directions of travel exhibit either a curve warning (W1-2) or turn warning (W1-1) sign mounted in conjunction with an amber flashing warning beacon. A (W1-2) Curve Warning sign was installed on the northbound roadway, while a (W1-1) Turn Warning sign was installed on the southbound roadway. The south- and northbound beacon and warning signs were location approximately 171 and 287 feet before the start of the curve respective to the directions of travel.

Installed with the Turn Warning sign on the southbound roadway was a 25 MPH Advisory Speed Plaque (W13-1P). Additionally, the southbound direction of travel through the curve also faced a total of three (3) Chevron Alignment signs (W1-8) that provided additional delineation of the curve. The chevron signs were placed along the right roadside at approximately 114-foot intervals beginning about 84 feet south of (past) the start of the curve according to the highway As-built plans provided by FDOT. The final chevron was located approximately 318 feet from the start of the curve, about 28 feet before the end of the curve.

2. Scene Documentation

The crash site was documented by FLPD investigators who provided the NTSB with photographs and an electronic total station mapping file.[2] The total station data file documented about 550 feet of roadway, curbing, lane lines, sidewalk and wall, tire marks and location of the luminaire pole. The total station data documented a single arced (curvilinear) tire mark that covered a distance of about 238 feet. While the total station site data documented the mark arc as a single arc, photographs revealed a parallel arced mark slightly offset toward the curb or toward the outside of the curve. As depicted in the scene photographs the marks exhibited characteristics consistent with tire scuff marks.[3] The onset of the mark is near the center of the left southbound lane, approximately 136 feet from the start of the curve.[4] Applying a uniform arc to the initial portion of the arced tire mark revealed an approximate radius of 832 feet. As noted, FDOT documents indicate that the highway curve had a radius of 488.1 feet as measured along the center of the highway.

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[2] Generally, all measured or calculated distances being reported have been rounded to the nearest whole foot except were other documentation has provided dimensions in decimal format.

[3] The characteristics exhibited by these marks are consistent with a tire that is rolling and side slipping (attempting to generate cornering force). The offset parallel mark indicates off-tracking of the rear axle that further corroborates the interpreted dynamics of the vehicle. The term “critical speed scuff mark” is also commonly used to define these types of tire marks.

[4] Onset of the mark was about 204 feet from the end of the curve in the southbound direction. The length of the curve was 340.17 feet as indicated by documents provided by FDOT.

The arced mark angled toward the outside of the curve, where it passed through the right travel lane and bike lane. Approximately 213 feet after onset of the documented tire mark, the mark intersected and surmounted the raised curb and sidewalk. Additional tire friction scuff marks were observed on the vertical face of the curb. About 34-35 feet after the tire mark encounters the raised curb, evidence of contact from the vehicle with the concrete wall bordering adjacent property was observed. This evidence consisted of paint and other material transfer.

Material transfer continued along the wall about 10.5 feet to a point where the wall face became rounded and curved away from the roadway to form a driveway entrance. On the opposite side of the driveway, a distance of about 27 feet, additional material transfer and surface damage was observed to the rounded face of an opposing wall that bordered the sidewalk and curved to parallel the driveway. Vehicle parts were deposited at the base of the wall and were further displaced into the roadway.

Tire friction scuff marks and roadway surface metal scars were observed extending southeastward across the highway from this second wall impact. Documentation of the scuff marks began at the curb and extended across the highway over a distance of about 157 feet where a downed luminaire pole had been located. The total distance from wall impact to pole was approximately 182 feet. The separation distance between parallel tire marks and metal scars varied and exhibited a crossover near the middle of the highway indicating the vehicle was in a spin.

Tire friction marks, parallel with the curb, were observed to extend southward of the downed luminaire pole over a distance of about 26 feet. This point was marked as the position of final rest for the Tesla. At rest, the Tesla was atop the sidewalk on the northbound side of the highway with its right axle ends partially in the bike lane.[5]

Figures 1 and 2 depict scaled diagrams that were created with the total station data provided by the FLPD investigators and include a few features derived from FDOT highway plans.

[5] The vehicle wheels and tires had been displaced from the vehicle.

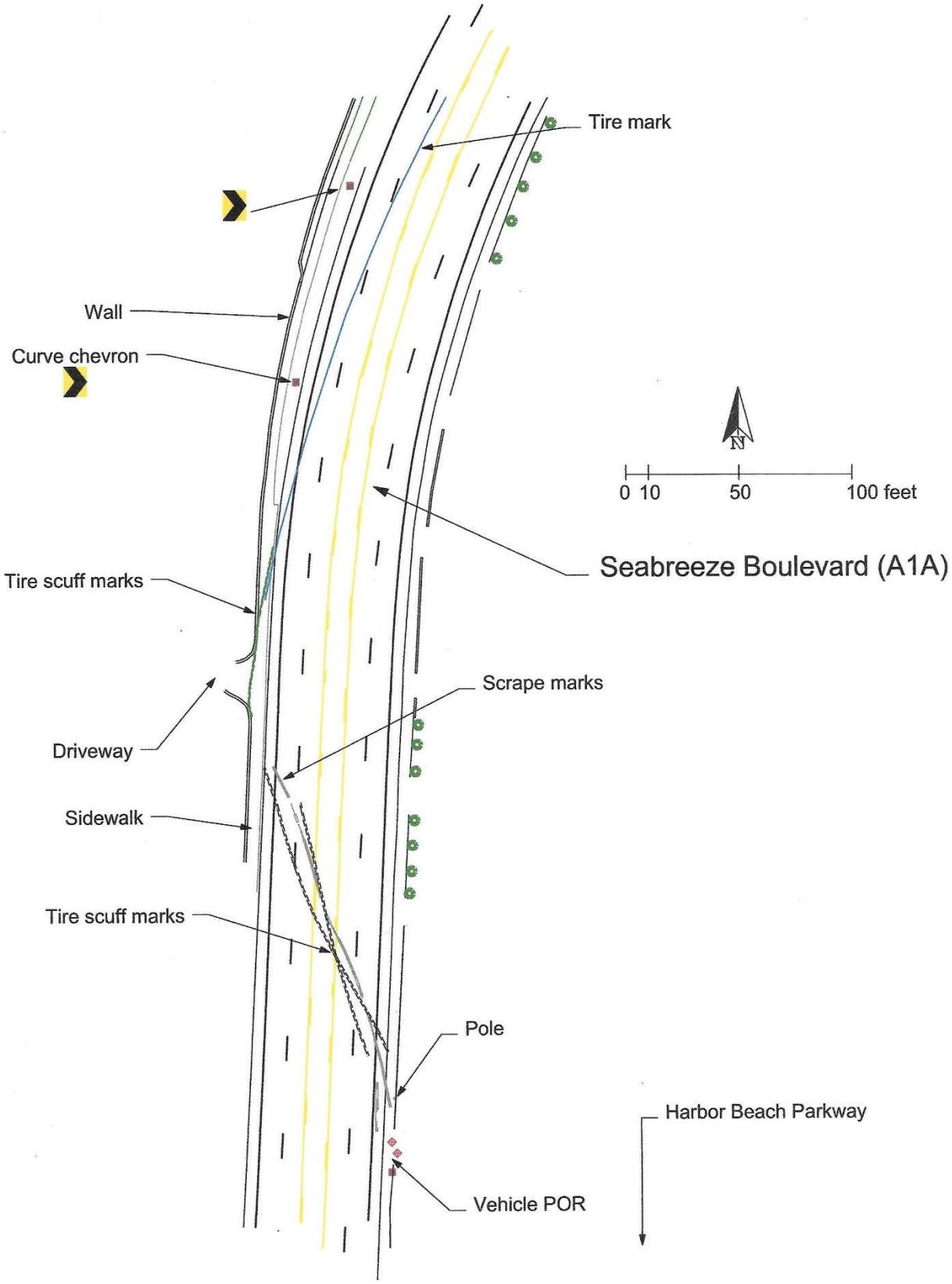

Figure 1: Scaled diagram of collision location depicting total station measurement data provided by FLPD investigators.

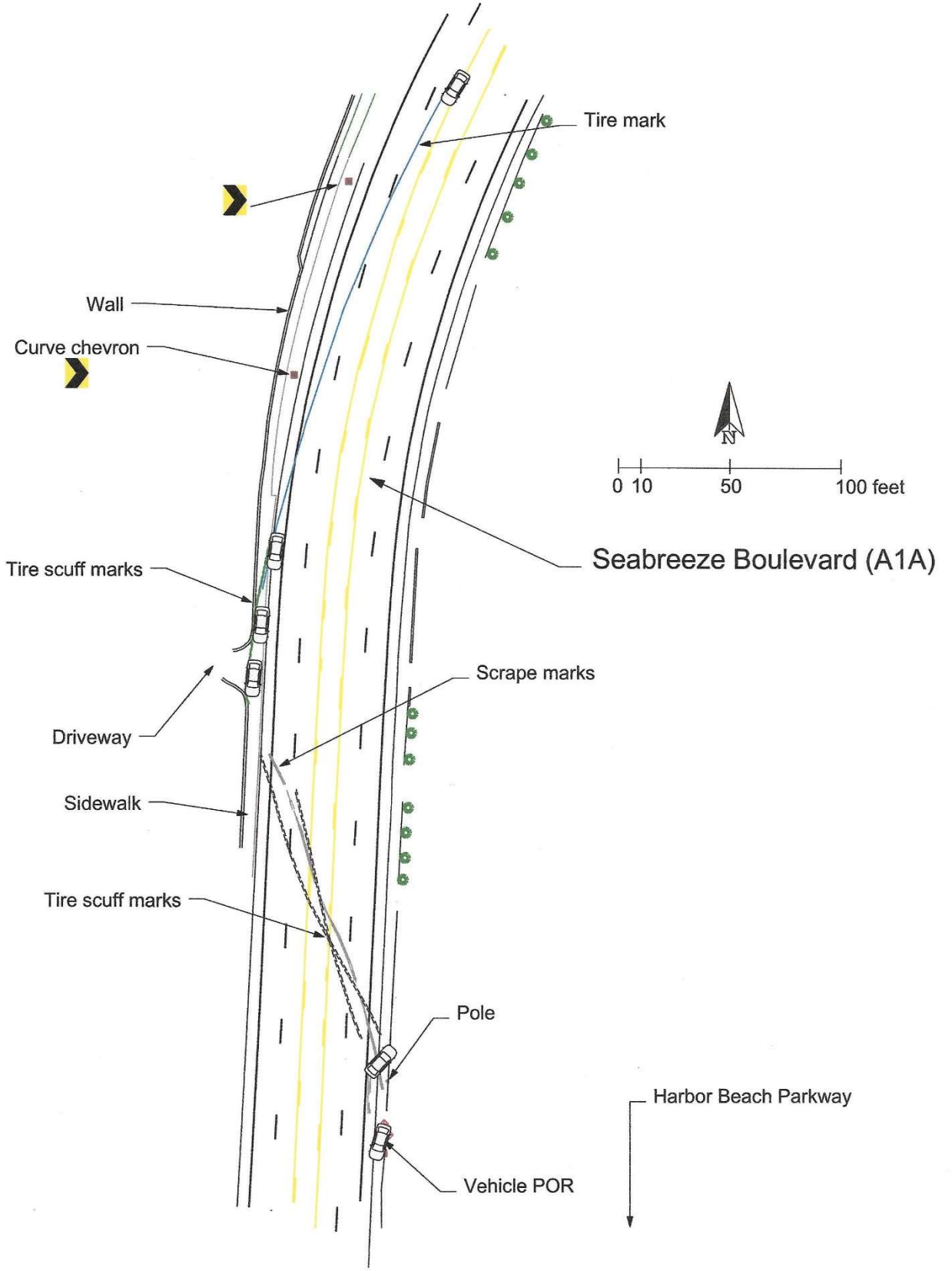

Figure 2: Scaled diagram of collision location depicting vehicle path of travel based upon total station measurement data provided by FLPD investigators.

3. Vehicle Damage Documentation

Documentation of damage to the Tesla was not undertaken by the group, although the following could be summarized from photographs.

- The vehicle interior exhibited extensive fire damage.
- The right (passenger side) front of the vehicle exhibited evidence of impact damage that extended from the front of the vehicle rearward to the firewall.
- The right-side wheels were missing.
- The right-side front passenger door was displaced from the vehicle but exhibited a vertical U-shaped indentation toward the center that extended over the full height of the exterior door panel.
- Scrape marks, paint damage and superficial body damage were observed to the right-side rear wheel fender forward of the tire opening. Similar damage could be seen along the rocker panel below the rear passenger door, however, displacement of the door prevented viewing of any damage to this door panel.
- The left side appeared undamaged in the on-scene police photographs.

4. Electronic Event Data

The Tesla was equipped with pyrotechnically deployed supplemental occupant restraints that included frontal and side airbags and seat belt pretensioners.[6] 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 will be stored. The storing 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.[7]

The RCM installed in the Tesla Model S can store up to two events. The conditions for triggering the recording of an event differ depending on event type. 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 intervals, although the data may be asynchronous.

[6] Supplemental restraints included seat and side curtain airbags. Also included as a pyrotechnic deployed safety device was a high voltage battery disconnect.

[7] 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.

"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 ½-second intervals beginning at a point where the restraint control algorithm is activated. Pre-crash data include certain vehicle performance parameters. In additional to deployment timing, crash data include lateral and longitudinal change in velocity (Δv) as related to time in 10ms intervals resolution to nearest km/h for a total time of 300ms. Also recorded were lateral and longitudinal acceleration as related to time in 2ms intervals with resolution of 0.5g for a total time of 300ms. The remaining data included roll angle that begins recording 1000ms before time zero and may continue up to 5000ms after time zero. Data resolution is to the nearest 10-degrees and is reported at 10ms intervals between 1000ms before and after time zero and at 100ms between 1000 and 5000ms after time zero. The end of an event is typically the moment at which the cumulative delta-V within a 20ms time period does not change by more than 0.8 km/h (0.5 mph) or the moment at which the crash detection algorithm of the RCM resets. Some events may lead to the recording of different duration data as provided for by 49 CFR Part 563.

For this vehicle the RCM data was retrieved by investigators using the Tesla RCM tool with EDR Retrieval Program software v17.32.1. The hexadecimal data imaged from the RCM was then uploaded through a dedicated Tesla web application and interpreted using the Tesla EDR Reporting Service v18.14.1, which was the current version at the time of upload. A data interpretation report was returned electronically in a .pdf format. The data reported a total of 5,631 ignition cycles at the time of data download.

4.1. Crash data

The EDR report conveyed that one event had been recorded with several supplemental systems deployed. The report indicates that driver and passenger side front airbags, knee bolsters and seat belt retractors were issued a deployment command at 55ms from time zero or algorithm enable. The high voltage battery disconnect was also triggered at this time. Preceding the deployment command a lateral acceleration and change in velocity were recorded first with the peak change in velocity reported at 22ms. A longitudinal change in velocity began at 40ms and peaked at 64ms. The maximum change in lateral and longitudinal velocity was reported as 4 km/h, about 2.5 mph. Based on the change in velocity, the calculated principle direction of force (PDOF) initially exhibited a greater lateral component but transitioned to a more longitudinal direction as the collision progressed.[8] At about the time of the deployment command the PDOF was calculated at about 45°, but decreased to less than 20° as the change in velocity leveled off. Roll data indicates a counterclockwise roll (toward driver side) at about time zero.

The data indicate that the RCM algorithm wake-up and subsequent deployment command came as the Tesla first contacted the wall. A deployment command for the second stage of the front driver and passenger airbags occurred 155ms. This command initiated disposal of the second stage propellant that would be used in the event of a more severe impact requiring a faster (or

[8] 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.

firmer) deployment of the airbags.[9] By the time the Tesla impacted the second wall, the supplemental restraints had already deployed except for the driver and passenger side curtains and seat airbags. These devices received deployment commands at 494 and 530ms respectively. At this point the Tesla would have already separated from impact with the second wall.

4.2. Pre-collision data

Pre-crash data reported certain vehicle parameters for up to five seconds before time zero (algorithm active) at ½-seconds intervals. The reported parameters reported included:

- Vehicle speed – A calculated value as 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).
- Service brake - Indicates the status of the brake pedal as reported by the brake pedal switch where the possible values for Service Brake are "On" (pedal applied) and "Off" (pedal not applied).
- Steer angle - The measured rotational angle of the steering wheel with a range between -420 degrees to +420 degrees. The reported resolution is to the nearest degree.
- 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.

As conveyed in the EDR report, the vehicle exhibited an increase in speed over the initial two seconds of pre-crash data. Between the time intervals from -5.0 to -3.0 seconds (before time zero), vehicle speed increased from 109 to 116 MPH. Corresponding with this speed increase the rear motor RPM also exhibited an increase. Accelerator pedal application was initially recorded as 78% although it decreased slightly to 74% at -3.5 seconds.

Initial steer angle data indicated a rightward heading, although at -3.0 seconds the steering transitioned to a leftward heading with the angle steadily increasing. Likewise, at -3.0 seconds the

[9] As reported by Tesla, if deployment of the second is not required for occupant restraint in a more severe impact, the propellant is discharged (disposal) so it will not be a danger to first responders. If a stage two deployment is not commanded due to the collision, disposal is triggered 100ms after stage one deployment.

accelerator pedal application percentage decreased to zero. The accelerator pedal percentage remained at zero until the deployment algorithm was enabled.

At -2.5 seconds service brakes were indicated as "on", and the indicated speed began to decrease as did the rear motor RPM. The service brakes were reported as "on" through the remainder of the pre-crash data.

At -2.0 seconds stability control was reported as "engaged" and the leftward steering angle significantly increased. The calculated rate of deceleration likewise substantially increased. ABS Activity was reported as "off" throughout the entire five seconds of pre-crash data.

The onset of curvilinear tire scuff mark appeared about 247-248 before the initial wall impact and between -2.0 and -1.5 seconds before algorithm enable. This time period corresponds with the substantial increase in a leftward steering angle and the engagement of the vehicle stability control. **Table 1** provides a summary of the EDR pre-crash data.

Table 1: Tesla EDR Report Pre-Crash Data Table

Time (sec)	Vehicle Speed (kph)	Vehicle Speed (mph)	Distance from Time 0	Calculated Acceleration	Accelerator Pedal %	Rear Motor Speed (rpm)	Service Brake	Steering Wheel Angle (deg)	Stability Control	ABS Activity	
-5.0	176	109	794		78	13000	Off	8.4	On	Off	
-4.5	179	111	713	0.170	75	13200	Off	12.6	On	Off	
-4.0	182	113	632	0.170	74	13400	Off	16.8	On	Off	
-3.5	185	115	550	0.170	74	13600	Off	16.8	On	Off	
-3.0	187	116	466	0.113	0	13700	Off	-8.4	On	Off	
-2.5	**184**	**114**	**382**	**-0.170**	**0**	**13600**	**On**	**-16.8**	On	Off	
-2.0	**175**	**109**	**297**	**-0.510**	**0**	**13000**	**On**	**-33.6**	**Engaged**	Off	Onset of mark
-1.5	**166**	**103**	**215**	**-0.510**	**0**	**12300**	**On**	**-42.0**	**Engaged**	Off	
-1.0	**155**	**96**	**138**	**-0.623**	**0**	**11400**	**On**	**-46.2**	**Engaged**	Off	
-0.5	**144**	**89**	**64**	**-0.623**	**0**	**10800**	**On**	**-54.6**	**Engaged**	Off	
0.0	**139**	**86**		**-0.283**	**0**	**10300**	**On**	**-54.6**	**Engaged**	Off	

E. DOCKET MATERIAL

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

LIST OF ATTACHMENTS

- Tesla EDR report

END OF REPORT

Robert J. Squire
Highway Accident Investigator