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TESLA EDR CASE STUDIES
AND RECONSTRUCTION TECHNIQUES

INFOTAINMENT SYSTEMS
USE IN ACCIDENT RECONSTRUCTION

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TESLA EDR CASE STUDIES & RECONSTRUCTION TECHNIQUES

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Abstract

Tesla is currently the newest addition to the nearly comprehensive family of EDR/CDR supported vehicles. Aspects of the technology that are unique to this manufacturer will be covered through comprehensive review of case studies of crashes involving Tesla vehicles. Besides the mechanics of obtaining a download and telematics information, the discussion will include how data from the vehicle telematics obtained through Tesla compares and differs from the data retrieved from the airbag control module, as well as traditional reconstruction methods as well as video evidence evaluation.

Introduction

In today's ever more technological world, we are increasingly offered different avenues to arrive at vehicle speeds. In 16 short years Tesla has made a significant impact on the automotive industry. According to Forbes, Tesla Model S and X made up 45% of the sales of electric vehicles in the United States and according to Statista by December of 2018 Tesla held 2.08% of the U.S. market share of cars and light trucks. They are a leader in new technology in vehicles and beginning with the Model S look at diagnostic data directly from the vehicle on a regular basis. This diagnostic data was generally only available to law enforcement on presentation of proper authority, i.e. a search warrant. In 2018 Tesla released its Event Data Retrieval Tool during the 2018 EDR Summit in Houston, Texas. This tool allowed for private consultants to retrieve information relevant to a crash and complied with 49CFR563. This initial rollout of the Tesla EDR tool included legacy coverage of: Model S, 2012 to present; Model X, 2016 to present; and Model 3, 2017 to present. The only model not included in coverage was the Roadster, produced from 2002 to 2012 prior to the effective date of 49CFR563.

Tool Overview

The Tesla EDR retrieval tool continues Tesla's innovation by utilizing automated in-house data translation. The software is free and available from Tesla's EDR Reporting Service Portal. The retrieval equipment can be purchased through Crash Data Group and includes the following components:

- Hard-Shell protective carrying case with padded dividers, plus
- TPCAN: PCAN-USB adapter
- Power: AC power supply unit
- TIV-144: Model S and Model X
- TIV-145: Model S older than Sept. 2016
- TIV-996: Model 3
- TD2M-139: Model S
- TD2M-601: Model X and 3
- TD2M-602: Model S older than mid-2019

The Tesla EDR retrieval tool currently includes the PCAN interface, which is analogous to the Bosch CDR Tool's CAN Plus or CDR 900 interfaces, and the Tesla In-Vehicle (TIV) cables and the Tesla Direct-to-Module (TD2M) cables, are analogous to the Bosch CDR Tool's DLC, and direct-to-module cables.

Figure 1: Tesla EDR Kit

The process for retrieving the raw data is similar to the Bosch CDR Tool (Figure 2). The software must be obtained and installed on a windows computer. Once the PCAN drivers are properly installed, the raw *.edr file is obtained via either an in-vehicle connection or direct to module connection, whichever is appropriate for the vehicle's condition.

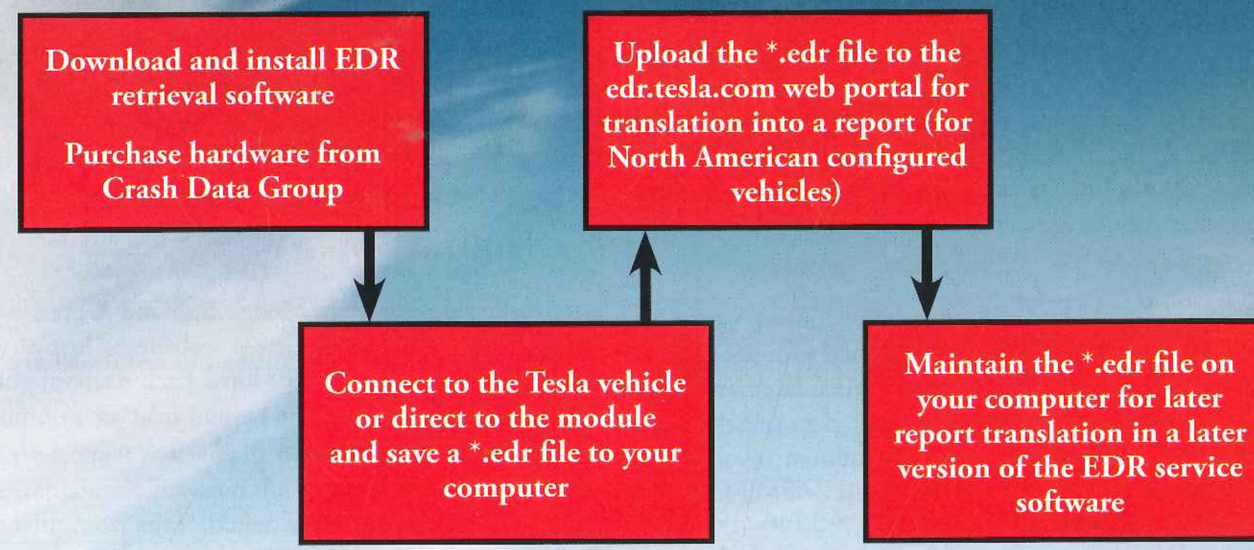

Figure 2: Process for obtaining a Tesla EDR report

Unlike the Bosch CDR Tool software, which translates the data and creates the report on your computer, the Tesla *.edr file is uploaded to Tesla via the Online EDR Reporting Service Portal (https://edr.tesla.com/) and is automatically processed with the most recent translation. An EDR report is generated in an Adobe (pdf) file to be downloaded to your computer. This process typically takes about half a minute, depending on your connection speed. Like the *.CDRx file in the Bosch CDR Tool, the original Tesla *.edr file should be saved so that it can be retranslated to verify that the translation has not changed prior to testimony, etc.

When initially released there was some concern expressed that the data sent to Tesla could be altered to create translations that were skewed in favor of the manufacturer. However, it is important to recognize that data translation is automated so that there is not any human involvement before the file is delivered via a secure download from the Tesla EDR Reporting Service Portal.

Worldwide Tesla EDR Access

When the Tesla EDR Tool was rolled out in March of 2018, EDR reports could be obtained by uploading *.EDR files from Tesla vehicles worldwide to the Tesla EDR Reporting Service Portal. For vehicles configured for sale in North America, every data element recorded in the EDR report had been verified as correctly recorded and translated. This was not true for vehicles with other configurations, such as right-hand drive vehicles for the UK, or those configured for sale in china.

During this same time frame the General Data Protection Regulation (GDPR) was passed into legislation in the European Union in an effort by the European Commission and the EU to ensure that citizens' personal data is handled in the appropriate manner by organizations who hold their data. Because crash data is associated with a specific VIN, it was considered by some to be personal data.

Because Tesla EDR reported data had not been verified for vehicles configured for sale outside of North America, by August 2018 Tesla updated their Online EDR Reporting Service Portal so that only *.EDR files obtained from vehicles intended for distribution in North America can be translated into an EDR report. Uploading a *.EDR file from a vehicle intended for distribution outside North America generates the message shown in Figure 3. This does not violate 49CFR563 since it does not apply outside the U.S. and nowhere else in the world is there another regulation requiring the same data access as that found in 49CFR563. The ability of the EDR tool to obtain a *.EDR file from Tesla vehicles remains unaffected. By contacting Tesla Legal staff, law enforcement with an appropriate court order can still obtain an EDR report from *.EDR files collected from non-North American sales vehicles.

Tesla EDR Data Retrieval

Retrieval guides for Tesla Models S, 3 and X are available through the Crash Data Group website at https://www.crashdatagroup.com/tesla-edr-kit/. Each retrieval guide is updated periodically and the version or release number or can be found at the bottom of the first page as show in Figure 4.

Retrieval Method	Required Cable
In-vehicle connection	Tesla In-Vehicle EDR Retrieval Cable. Tesla part number 1131144-00-A or later.

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Figure 4: Example of the version or release number of the EDR Retrieval Guide

In-Vehicle Connection

Analogous to a DLC/OBD II connection, the CAN bus access point can be used to establish an in-vehicle connection in order to perform a crash data retrieval via one of the vehicle's three CAN bus networks without physically accessing the RCM. As shown in Figure 5, the Model S and Model X, the CAN bus receptacles are located behind the storage pocket under the touch screen and the Model 3's CAN bus receptacle is located beneath the passenger door sill cover strip by the base of the B-pillar. For the Model 3, the receptacle must be released from the wiring harness before the in-vehicle cable can be plugged in, and then replaced before the vehicle can be driven again.

Once the vehicle communication harness is located, the *.edr data is retrieved by attaching the appropriate cable to the PCAN adapter and retrieving data through the Tesla EDR software.

At this time, we are unable to provide an EDR report for the uploaded file. The Tesla EDR Reporting Service has only been validated for use with vehicles manufactured for distribution in North America. ×

Figure 3: Message for vehicles not manufactured for North American distribution

Figure 5: In vehicle connector locations for Tesla Models S and X (left) and Tesla Model 3 (right)

Direct to Module Connection

The ACM or RCM is located inside the center console under the center stack for Tesla Models S and X, and inside the center console between the front seats for Tesla Model 3. As with most automobiles, a direct-to-module connection requires more disassembly and requires the appropriate direct-to-module cable to be used with the PCAN to establish communication with the RCM to perform a crash data retrieval.

Tesla Diagnostic Logs

In addition to crash related data, starting with the Model S, Tesla collects vehicle parameter data from the vehicles' CAN buses in order to monitor vehicle systems to improve functionality, quality and reliability. The information related to vehicle operation and performance is recorded at 1Hz and include parameters such as: date and time stamps, VIN, alerts, full charge complete, brake on/off, gear selection, motor RPM, accelerator pedal position, stability control status, driver and passenger seat belt status, crash severity and direction, and warning indicators. These diagnostic logs are uploaded to the cloud via cellular connection in data packets when the vehicle is not in use. Tesla makes this information available to law enforcement upon appropriate authority, i.e. search warrant.

Tesla EDR Tool Report and Case Study #1

The Tesla EDR report follows the general layout logic found in most EDR translations from most OE and/or the Bosch CDR Tool. As shown in Figure 6 the report has a "File Information" table and takes advantage of the Adobe Acrobat "book marks" functionality. There is also data limitations, the required Table I and many of the Table II elements laid out in 49CFR563.

The File Information table identifies the version of the software used to retrieve data and used to generate the report (Figure 6). The data limitations are specific to the Model S, 3 and X, and they are similar to that obtained from newer vehicles although perhaps with additional detail including information regarding the data element ranges and resolution. The data tables are comparable to and ordered much the same way as other commonly encountered EDR reports, and the data element names are consistent with those widely used in EDR reports and/or specified in 49CFR563.

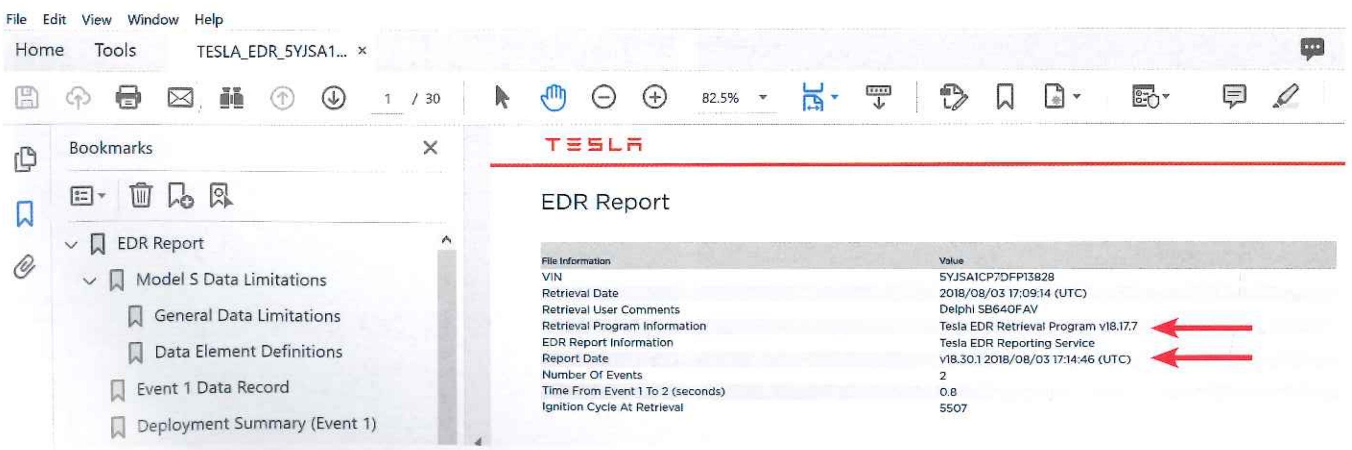

Figure 6: Tesla EDR Tool Report, Example File Information table

Figure 7: 2013 Model S – Case Study #1

In the first case study, data was retrieved direct-to-module from a 2013 Model S involved in a crash where it sustained damage to the right front and the left rear side (Figure 7). There were two events recorded that were 2.6 seconds apart (Figure 8).

In Event 1, a -21 km/h ΔV_x and a +6 km/h ΔV_y was recorded and all reported devices were deployed (Figure 9). In Event 2, a -5 km/h ΔV_x and -2 km/h ΔV_y was recorded and there were not any deployments commanded.

The pre-crash data for the 1st and 2nd events further demonstrate the impact order and fit with the reported 2.6 seconds between events (Figure 10).

As demonstrated above, the data retrieved from a Tesla is comparable to that seen in other 49CFR563 compliant vehicles. The data is laid out in an easy to read manner with data limitations and data tables that are similar to that seen in other EDR reports. In addition, EDR data concepts such as data timing and overlapping pre-crash are similar to that seen in other EDR data sets.

File Information	Value
VIN	5YJSA1CPXDFP05822
Retrieval Date	2018/08/06 23:12:51 (UTC)
Retrieval User Comments	Model S - 073M
Retrieval Program Information	Tesla EDR Retrieval Program v18.17.7
EDR Report Information	Tesla EDR Reporting Service v18.47.1
Report Date	2019/02/04 02:33:46 (UTC)
Number Of Events	2
Time From Event 1 To 2 (seconds)	2.6
Ignition Cycle At Retrieval	8709

Figure 8: File Information table for Case Study #1

Deployment Summary (Event 1)

Device	Status	Deployment Command
Driver Front Airbag Stage 1	Deployment Commanded	57
Driver Front Airbag Stage 2	Deployment Commanded	157
Driver Knee Airbag	Deployment Commanded	57
Driver Retractor Pretensioner	Deployment Commanded	2
Driver Lap Pretensioner	Deployment Commanded	2
Driver Side Seat Airbag	Deployment Commanded	2
Passenger Front Airbag Stage 1	Deployment Commanded	57
Passenger Front Airbag Stage 2	Deployment Commanded	157
Passenger Knee Airbag	Deployment Commanded	57
Front Right Passenger Retractor Pretensioner	Deployment Commanded	2
Front Right Passenger Lap Pretensioner	Deployment Commanded	2
Passenger Side Seat Airbag	Deployment Commanded	2
Left Side Curtain Airbag	Deployment Commanded	2
Right Side Curtain Airbag	Deployment Commanded	2
HV Battery Disconnect	Deployment Commanded	2

Event 1 Data Record

Data Element	Value
Maximum Delta-V, Longitudinal (km/h)	-21
Time To Maximum Delta-V, Longitudinal (ms)	300.0
Maximum Delta-V, Lateral (km/h)	6
Time To Maximum Delta-V, Lateral (ms)	61.0
Time To Maximum Delta-V, Resultant (ms)	300.0
Ignition Cycle At Event	8705
Airbag Warning Lamp Status	Off
Driver Safety Belt status	Buckled
Passenger Safety Belt status	Buckled
Occupant Classification Status In Front Passenger Seat	Adult
Driver Seat Position	Rearward
Complete File Recorded	Yes

Figure 9: Event 1 Data Record and Deployment Summary for Case Study #1

Event Data (Event 1)

Time (sec)	Vehicle Speed (kph)	Accelerator Pedal %	Rear Motor Speed (rpm)	Service Brake	Steering Wheel Angle (deg)	Stability Control
-5.0	73	20	5400	Off	4	On
-4.5	73	23	5400	Off	4	On
-4.0	75	24	5500	Off	0	On
-3.5	76	24	5600	Off	0	On
-3.0	77	24	5700	Off	0	On
-2.5	78	24	5700	Off	0	On
-2.0	78	24	5800	Off	0	On
-1.5	79	24	5900	Off	0	On
-1.0	80	24	5900	Off	-4	On
-0.5	81	24	6000	Off	4	On
0.0	83	89	6400	Off	76	On

← Event #1 – deployment →

Event Data (Event 2)

Time (sec)	Vehicle Speed (kph)	Accelerator Pedal %	Rear Motor Speed (rpm)	Service Brake	Steering Wheel Angle (deg)	Stability Control
-5.0	78	24	5700	Off	0	On
-4.5	78	24	5800	Off	0	On
-4.0	79	24	5900	Off	0	On
-3.5	80	24	5900	Off	-4	On
-3.0	81	24	6000	Off	4	On
-2.5	73	95	3400	Off	8	Engaged
-2.0	23	24	3100	Off	46	Not Available
-1.5	49	2	3000	On	34	Not Available
-1.0	8	0	3000	On	25	Not Available
-0.5	42	0	2900	On	21	Not Available
0.0	35	0	2900	On	50	Not Available

Event #2 – non-deployment →

Figure 10: Pre-crash data for Event 1 and Event 2 for Case Study #1

Case Study #2 –speed from video and Tesla Diagnostic Logs and EDR in accident reconstruction

In August 2017 a 2014 Tesla Model S rear-ended a 2016 Zero SR motorcycle stopped for a red traffic light in Scottsdale, Arizona. The scene was long, spanning 357 feet. The motorcyclist was projected a total of 262 feet from impact to rest and sustained fatal injuries. The motorcycle itself was projected 226 feet from impact to rest, 121 feet of which was spent tumbling, before becoming entangled in a barb wire fence on the west side of the roadway. The overall size of the scene gives an impression that the Tesla was traveling at a very high speed, substantially above the 45 mph speed limit, at the time of the collision.

The Tesla Model S had significant damage to the front end, focused primarily to the right side of the vehicle (Figure 11). None of the wheels were locked due to damage. Based on damage to the windshield it is evident the motorcycle rider left the motorcycle and rode up onto the windshield and roof of the Tesla where he then departed the vehicle. The motorcycle rear wheel assembly was removed from the motorcycle as it departed the crash and remained wedged under the front of the Tesla.

There was no roadway evidence of post-impact braking for the Tesla and the motorcycle was entangled in a barb wire fence before coming to rest. The uncertainty of ascertaining the vehicles' post-impact speeds limits the usefulness of conventional collision reconstruction methods, such as conservation of momentum.

Searle offers a method to bracket the minimum and maximum speed of the rider based on the rider's post impact trajectory. As shown in Figure 12, using a 0.66 g deceleration for an asphalt surface, the minimum Searle speed is calculated to be 60 mph. A similar calculation for the maximum Searle speed yields 78 mph. With an 18 mph range, as illustrated in Figure 13, there is potential for a significant over-estimate or under-estimate, depending on what speed within the range is considered.

In addition, it is important to recognize that Searle's speed represents the speed of the rider exiting the collision, and not necessarily the striking vehicle's impact speed. Particu-

Figure 11: The 2014 Model S and an exemplar 2016 Zero SR

$$S = \sqrt{\frac{30df}{1+f^2}}$$

$$S = \sqrt{\frac{30(262)(0.66)}{1+(0.66)^2}}$$

$$S = \sqrt{\frac{4474.8}{1.4356}}$$

$$S = \sqrt{3613.5}$$

Figure 12: Searle Minimum Speed Calculations

larly for a roof vault where the vehicle passes beneath the rider, the vehicle's impact speed is faster than the rider's post-collision speed. Under these circumstances, the Searle min and max speed range would be biased towards lower speeds, which would give the benefit of the doubt to the suspect.

The collision in this example pre-dated the Tesla EDR Tool. The only known available electronic evidence was the Diagnostic Logs. A search warrant was delivered electronically to Tesla for typical 49CFR563 Table One information: Vehicle Speed, Brake Switch position, Accelerator Pedal position, steering wheel angle, and (not 563 related) forward looking brake assist over a time period between 1148 until 1200 hours on the date of the collision. Tesla satisfied the request within a week by providing an Adobe (pdf) file with the requested information spanning the time period requested.

As seen in Figure 14 the information organized in a spreadsheet form with data titles along the top and VIN and UTC time columns to the left. From the data, the apparent resolutions are 0.1 mph for speed, 0.2% for accelerator pedal position, 0.1 degrees for steering wheel angle. Brake pedal is reported as on/off and steering polarity follows the right hand rule and SAE J211 with a right steer as positive. Values of 179.8 mph and +/- 819.1 degrees are recorded when the vehicle is off.

Other than the column headers, Tesla offers no data limitations or further explanation of the diagnostic log data. As seen in Figure 14, the VIN identifies the vehicle involved in the crash, and the time of the crash is indicated by the row containing the word "CRASH" in the frontal crash detection column. It is noteworthy that data is generally recorded at even seconds, but a row with a fractional second time step is created for the beginning of brake applications, and crash detected. After crash detection, data continues to be recorded in fractional second increments for several samples as also shown in Figure 14. Using the fact that the crash occurred in the one second time interval with the 11:52:16 time stamp yields another impact speed range of 75 to 84 mph, as illustrated graphically n Figure 15.

In response to the search warrant, Tesla also indicated, "You may find it relevant to refer to the attached page from the Tesla Model S Owner's Manual which explains, 'Automatic Emergency Braking operates only when driving between 5 mph (8kph) and 85 mph (140 kph).'" Since the recorded speeds did not drop down into the range until after the collision, this fatal crash was not the result of an AEB system failure.

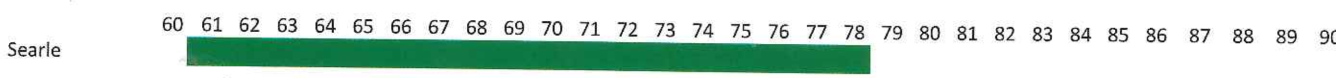

Figure 13: Impact speed range using Searle

VIN	DATE (US/Pacific)	VEHICLE SPEED (mph) (179.8 mph is recorded when vehicle is off)	ACCELERATOR PEDAL POSITION (%) (102 is recorded when vehicle is off)	STEERING ANGLE SENSOR (degrees) (positive indicates right turn, +/-819.1 is recorded when signal not available)	BRAKE APPLICATION	FRONT CRASH DETECTION
5YJSA1H1XEFP61345	Aug-13,2017 11:52:12.0 AM	99.4	70.8	-1.0		
5YJSA1H1XEFP61345	Aug-13,2017 11:52:13.0 AM	103.4	70.4	-3.0		
5YJSA1H1XEFP61345	Aug-13,2017 11:52:14.0 AM	106.9	0.0	-3.4		
5YJSA1H1XEFP61345	Aug-13,2017 11:52:14.9 AM				ON	
5YJSA1H1XEFP61345	Aug-13,2017 11:52:15.0 AM	105.7	0.0	-3.7		
5YJSA1H1XEFP61345	Aug-13,2017 11:52:16.0 AM	97.1	0.0	-7.7		
5YJSA1H1XEFP61345	Aug-13,2017 11:52:16.6 AM					CRASH
5YJSA1H1XEFP61345	Aug-13,2017 11:52:16.6 AM	84.5	0.0	-13.9		
5YJSA1H1XEFP61345	Aug-13,2017 11:52:16.9 AM	78.3	0.0	-15.1		
5YJSA1H1XEFP61345	Aug-13,2017 11:52:17.0 AM	75.5	0.0	-13.3		
5YJSA1H1XEFP61345	Aug-13,2017 11:52:17.1 AM	73.4	0.0	7.1		

Figure 14: Tesla Diagnostic Log for Case Study #2

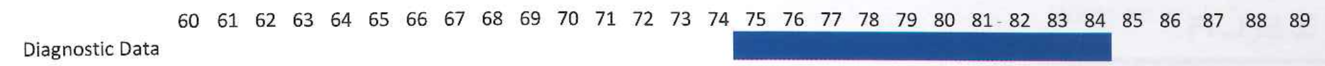

Figure 15: Impact speed range from Tesla Diagnostic Logs

A search of NHTSA's vehicle recall database indicated that there were 3 recalls for the 2014 Model S, but searching by the VIN confirmed that only 1 recall applied to the subject vehicle. That recall was related to a loss of power steering assist due to corrosion. Clearly, corrosion is not a problem normally encountered in the Arizona desert and increased steering effort was not described, nor would it be a cause for this fatal crash. Therefore, this recall is not relevant.

According to news stories, other Tesla crashes have been attributed to problems with Tesla's Autopilot. All Tesla vehicles manufactured since October 2014 are equipped with Autopilot 1. However, a firmware update removed some of the self-driving features. All Tesla vehicles manufactured after October 2016 are equipped with Autopilot 2, which is capable of full self-driving. The speed limit for Autopilot was raised from 80 to 90 mph in a 2017 update. The subject vehicle was not being driven in Autopilot mode, since it did not have Autopilot 2, having been manufactured in December 2014 as indicated on its VIN plate, and its speed was above the Autopilot speed limit. In addition, because the vehicle will slow via regenerative braking when the accelerator pedal is released, the pre-crash speeds, which do not exhibit a steady speed with no accelerator pedal application also confirms that the Tesla was not being driven in Autopilot mode. In fact, as shown in Figure 14 and Figure 18, the pre-crash data shows the typical pattern of accelerator pedal release followed by brake application a short time later. As such, it can only be concluded that the driver, and not the Autopilot, was in control of the Tesla and responsible for this fatal crash.

TESLA

EDR Report

File Information	Value
VIN	5YJSA1H1XEFP61345
Retrieval Date	2018/06/04 17:49:25 (UTC)
Retrieval User Comments	Direct to Module in vehicle Per Search Warrant SW2018-005814
Retrieval Program Information	Tesla EDR Retrieval Program v17.32.1
EDR Report Information	Tesla EDR Reporting Service v18.14.1
Report Requested By	
Report Date	2018/06/04 18:00:25 (UTC)
Number Of Events	1
Time From Event 1 To 2 (seconds)	N/A
Ignition Cycle At Retrieval	6289

Figure 16: EDR Report File Information for case study #2

TESLA

Event 1 Data Record

Data Element	Value
Maximum Delta-V, Longitudinal (km/h)	-17
Time To Maximum Delta-V, Longitudinal (ms)	153.0
Maximum Delta-V, Lateral (km/h)	-2
Time To Maximum Delta-V, Lateral (ms)	33.0
Time To Maximum Delta-V, Resultant (ms)	157.0
Ignition Cycle At Event	6288
Airbag Warning Lamp Status	Off
Driver Safety Belt status	Not Buckled
Passenger Safety Belt status	Not Buckled
Occupant Classification Status In Front Passenger Seat	Empty
Driver Seat Position	Rearward
Complete File Recorded	Yes

Figure 17: Event Data for Case Study #2

Tesla EDR Data

When the Tesla EDR tool was released, the suspect vehicle had been stored for seven months at a secure police impound lot, at the Scottsdale Police Department's property and evidence facility. A second search warrant was written and granted on the suspect vehicle and on June 4, 2018 the data was imaged using a direct-to-module cable.

The file information table shown in Figure 16 includes identification, event and user entered information, such as user comments. The VIN is read from the module. Space for the name of the requestor was available in this first version of the Tesla EDR Service, but was not included in the later version, as demonstrated in the Case Study #1 File Information shown in Figure 8.

Figure 17 shows that the Tesla EDR reported maximum longitudinal ΔV was -17 kph (-10.5 mph) at 153 msec and the maximum lateral ΔV was -2 kph (-1.2 mph) at 33 msec. A time to maximum resultant ΔV is reported, although the maximum resultant ΔV is not provided. The ignition cycles at event, 6288, is one less than the ignition cycles at retrieval shown in Figure 16. The Airbag MIL was off and both front seat belts were unbuckled, and the front passenger seat occupant classification was "empty."

TESLA

Event Data (Event 1)

Time (sec)	Vehicle Speed (kph)	Accelerator Pedal %	Rear Motor Speed (rpm)	Service Brake	Steering Wheel Angle (deg)	Stability Control	ABS Activity
-5.0	157	70	11800	Off	4.2	On	Off
-4.5	160	70	12000	Off	0.0	On	Off
-4.0	164	70	12300	Off	0.0	On	Off
-3.5	167	69	12500	Off	0.0	On	Off
-3.0	169	0	12600	Off	0.0	On	Off
-2.5	169	0	12500	Off	0.0	On	Off
-2.0	167	0	12400	On	0.0	On	Off
-1.5	163	0	12100	On	-4.2	On	Off
-1.0	149	0	11200	On	-4.2	On	Off
-0.5	135	0	9800	On	-8.4	On	On
0.0	132	0	9700	On	-8.4	Engaged	On

Figure 18, Precrash Data for Case Study #2

The deployment summary indicates which safety equipment was commanded to deploy and deployment times. Comparison with the deployed safety equipment observed within the vehicle further supported the premise that this EDR file was a record from this fatal crash.

The data from case study #2 is shown in Figure 18. From the pre-crash data, it is evident that vehicle speed is reported in 1 kph resolution, which according to data limitations is rounded to the nearest kph. The accelerator pedal position has 1% resolution, the motor RPM has 100 RPM resolution, and the steering wheel angle's resolution is 4.2 degrees.

The suspect vehicle speed at T = 0 was reported to have been 132 kph, or 82 mph. The highest reported speed was 169 kph, or 105 mph before braking at T = -2 secs and the ABS became active at T = -0.5 secs.

Accounting for allowable speedometer error, the underreporting of speed due to ABS slowing wheel speeds, and the maximum amount of slowing due to braking after the last reported sample before impact results in a range of 74 mph to 89 mph as demonstrated in Figure 19 and shown graphically in Figure 20. This latter assumes that the last reported speed could have been as old as half a second, as has been observed in older designs from other manufacturers in order to give maximum benefit of the doubt to the suspect.

Utilizing ΔV to arrive at an impact speed is a common and acceptable means of analysis. When using this approach, one must consider a number of factors, including the following:

	Low	High
Last Speed	82	82
Braking	-8.50	0.00
Wheel Slip	+4.10	+4.10
Speedo	-3.28	+3.28
	74mph	89mph

Figure 19: Impact Speed Calculations

1. Was the entire crash recorded?
2. Did the recorder miss any ΔV prior to wake up?
3. Was there any data clipping?
4. Does an adjustment for offset need to be made, (effective mass ratio)?
5. Did the recorder capture too much, (before or after the crash)?
6. Are ground forces effecting the calculation?

Fortunately, the Tesla EDR report contains information that is useful for this type of analysis. In addition to the ΔV graph, the Tesla EDR report provides a graph of the vehicle's impact acceleration, as shown in Figure 21. This is useful for determining when the crash pulse ends in order to evaluate if the entire crash pulse was recorded.

Figure 20: Impact speed range from pre-crash speeds

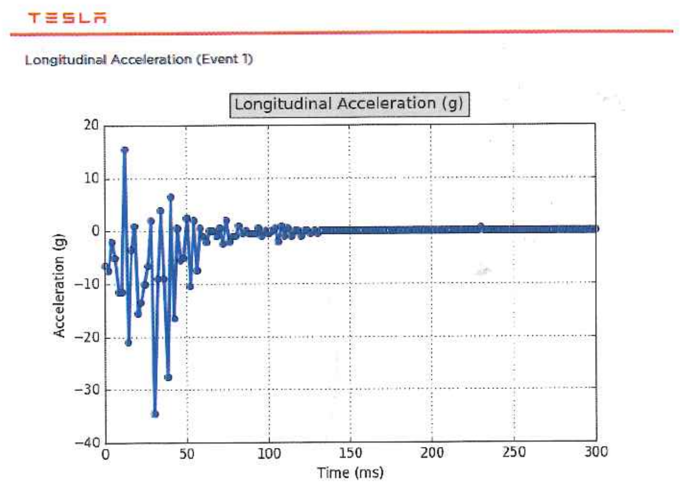

Figure 21: Telsa EDR vehicle acceleration

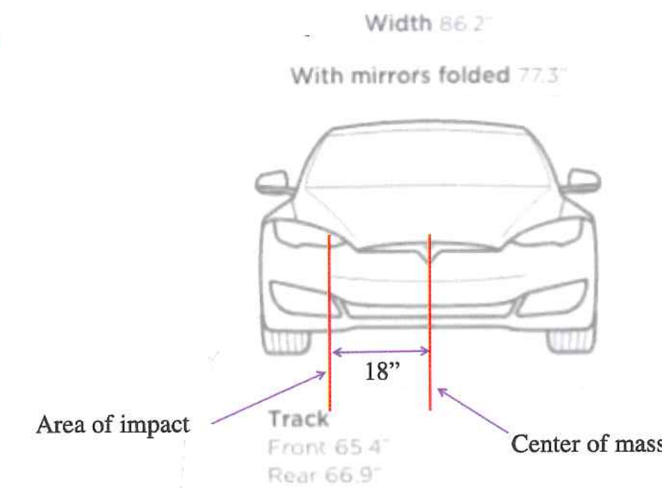

Figure 22: Impact eccentricity

Any additional ΔV that was measured after the crash pulse ended can be removed after the crash pulse end evident in the acceleration graph. As with any threshold activated recorder, it is possible to miss a small amount of ΔV due to the sub-threshold acceleration preceding module wake-up, but this is generally small, or even negligible for impacts outside the realm of low speed. The presence or absence of the clipping flag indicates if data clipping occurred.

Adjustment can be made for the impact's eccentricity or offset between the line of action of the collision force and the vehicle's airbag control module/center of mass. Figure 22 shows that the area of the centroid of damage was approximately 18 inches to the right the vehicle's centerline.

As shown in the pre-crash data, the driver was braking sufficiently hard to engage the ABS during the last 0.5 to 1.0 seconds. Because a frontal impact would only cause the driver to apply the brakes harder, it is fair to assume that the vehicle brakes would be active during the crash. Because the accelerometer within the vehicle's airbag control module cannot distinguish between deceleration from the crash, and that from continued braking, the measured ΔV is the combination of ΔV due to impact and slowing due to braking. Removing the possible additional ΔV due to ground forces results in a lower impact speed calculation, which again lends benefit of the doubt to the suspect.

Once the effect of ground forces on the automobile's ΔV has been properly accounted for, the ΔV of the motorcycle can be calculated by applying the principal that the ΔV's are inversely proportional to the ratio of vehicle masses as shown in Figure 23.

The impact's restitution affects the closing speed of impact. This parameter must be estimated since it cannot be measured. The restitution of normal large collisions, including the 35 mph barrier crashes for the New Car Assessment Program, generally run about 0.1 or 10%. As a collision becomes more inelastic, the vehicles' tendency to stick together increases and the restitution approaches zero. As shown in Figure 11, the motorcycle's rear wheel assembly was detached and remained with the Tesla, indicating a lower restitution. Based upon this information, a lower restitution of 5% was chosen to be used with effective mass ratio in the closing speed calculations, shown in Figure 24. The motorcycle was stopped according to witnesses, as well as what was shown on a surveillance video. Therefore, the closing speed will also be the Tesla's impact speed, which was calculated to be 81 mph. Accounting for the potential

$$\Delta v_{gf} = (17.56 mph/s)(0.06s)$$
$$\Delta v_{gf} = 1.05 mph$$
$$\Delta v_1 = (-9.32) + (1.05)$$
$$\Delta v_1 = -8.27 mph$$

$$\Delta v_2 = -\Delta v_1 \left(\frac{w_1}{w_2}\right)$$
$$\Delta v_2 = -(-8.27)\left(\frac{4852}{523}\right)$$
$$\Delta v_2 = (8.27)(9.27)$$
$$\Delta v_2 = 76.66 mph$$

Figure 23: Calculation of automobile and motorcycle ΔV's

$$S_{close} = \left(\frac{1}{1+e}\right)\left(\frac{|\Delta v_1|}{\gamma_1} + \frac{|\Delta v_2|}{\gamma_2}\right)$$
$$S_{close} = \left(\frac{1}{1+0.05}\right)\left(\frac{|-8.27|}{0.9429} + \frac{|76.66|}{1}\right)$$
$$S_{close} = (0.9524)(85.43)$$
$$S_{close} = 81 mph$$

Figure 24: Closing speed calulation

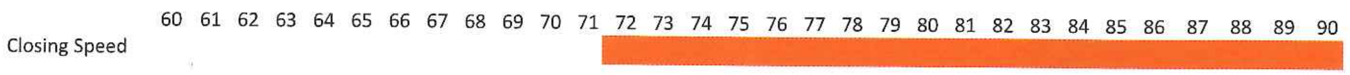

Figure 25: Impact speed range from EDR reported Delta V

for error allowed in Part 563, or +/- 10%, results in an impact speed range of 72 to 90 mph and depicted graphically in Figure 25.

Video Evidence

Every investigation includes a search of the area for potential surveillance camera footage. This led to a video recording of the event obtained from a dealership bordering the roadway where the collision occurred. Figure 26 shows video frames depicting the appearance of the motorcycle and the Tesla. The video shows the motorcycle come to a stop at the intersection and then moments later, the red Tesla approached the intersection at high speed and collided with the motorcycle and rider.

Roadway evidence was used to determine the point of impact and a frame by frame review of the video was utilized to determine a specific location for the Tesla from which a distance to the area of impact could be used for a time distance speed calculation. This was accomplished by placing a patrol vehicle in a location comparable to that of the Tesla captured in a frame of the surveillance camera video. Figure 27 shows two video frames, representing the patrol vehicle at the same location as the Tesla.

The distance measured from the patrol vehicle to the area of impact was 357 feet. The frame rate of the raw video data was determined to be 5 frames per second. The video evidence was then again reviewed frame by frame to determine the frame nearest the collision. This was determined to be frame 813 and can be seen in Figure 28. Once this was accomplished, Input Ace, Video specific software, was utilized to verify the exact time between frames as well as the time from frame 800 to frame 813. This was determined to be 2.6 seconds. This allowed a simple time distance calculation. Accounting for possible errors in time associated with one frame, and +/- 5 feet for impact location results in an average speed within the range of 86 to 103 mph over the 2.4 to 2.8 seconds preceding the collision.

The Diagnostic Logs, EDR pre-crash speed and EDR ΔV, all indicated an impact speed for the Tesla within the approximate 75 to 84 mph range, and the Diagnostic Logs and EDR pre-crash data recorded top speeds within the 105 to 107 mph range. The impact speed compared favorably with the more conservative pedestrian throw analysis and the top speed compared favorably with the video analysis. As demonstrated in this case study, the electronic data from the Tesla, greatly enhanced the speed analysis of this fatal automobile to motorcycle collision.

Summary and Conclusions

As outlined through two case studies, the Tesla EDR report is detailed and organized in a familiar manner. Like other EDR information, the Tesla EDR data is a valuable addition to a situationally complete reconstruction.

The Tesla Diagnostic Logs provide additional information which may be slightly different, due to parameters being sampled at different times and consistent with its different intended purpose.

Figure 26: Surveillance video frames showing the apparance of the motorcycle and Tesla

Figure 27: Surveilance video frames shown the Telsa and patrol vehicle at a comparable location

Figure 28: Collision depicted in surveillance video frames

In the second case study, impact speeds obtained from data from the EDR and Diagnostic Logs, traditional momentum analysis, as well as video analysis demonstrated a consistent speed range, which was substantially above the speed limit.

In addition to impact speed in the second case study, by confirming the Diagnostic Log data was related to this fatal crash through date and time, and the EDR Report data was related through ignition cycles and reported parameters that matched seat belt use and deployed devices for example, both electronic data, as well as video analysis, confirm that pre-crash the suspect was driving the Tesla at about 100 mph, which is nearly twice the speed limit.

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