TESLA INSPECTION FACTUAL REPORT

Mountain View, CA

HWY18FH011

(24 pages)

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

TESLA INSPECTION FACTUAL REPORT

A. CRASH INFORMATION

Location: Southbound US Highway 101 (US-101) south of North Shoreline Boulevard at the exit ramp transition to State Route 85 (SR-85), milepost 43.38, Mountain View, Santa Clara County, California

Vehicle #1: 2017 Tesla Model X

Vehicle #2: 2010 Mazda 3

Vehicle #3: 2017 Audi A4

Date: March 23, 2018

Time: Approximately 9:27 a.m. PDST

NTSB #: **HWY18FH011**

B. INVESTIGATIVE GROUP:

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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 INVESTIGATION:

On April 6, a group was convened at Atlas Towing Services, 24 S. Amphlett Blvd., San Mateo, California. The group consisted of the NTSB investigator, five people from Tesla, a representative of the California Highway Patrol, and support from San Mateo Fire Department and Atlas Towing Company.

The crash ruptured the front of the battery case and exposed battery modules, two of which were separated from the vehicle. At the scene, loose cells were placed in a bucket half full of water. At the tow yard, the bucket was placed against the front of the vehicle with a tarp covering the wreckage. On March 28 and while the car was unattended, the San Mateo Fire Department responded to a call from the tow yard that the wreckage had begun to smoke. This event was captured on a security camera, and was documented.[1] The wreckage was uncovered and flames of up to 12 inches high were seen at the front edge of the open front passenger foot well area. Flames were also seen above the water in the bucket.

1.0 VEHICLE DAMAGE:

The 2017 Tesla Model X had Vehicle Identification Number (VIN) 5YJXCAE28HFXXXXXX.[2] The Tesla struck an attenuating barrier at the highway off ramp, separating the car forward of the passenger compartment, damaging the primary battery, which ignited and caused a vehicle fire. The vehicle structure had been split in pieces during the crash, to the extent that nothing from ahead of the front door pillars was present for examination. This included the 12 VDC battery, front drive motor, body parts, and complete front suspension. The front left (driver) door was laying loosely on the ground next to the vehicle and a bucket (tub) of water containing loose battery debris was found at the front of the vehicle, as shown in Figures 1 and 2.

Figure 1. Overall view of vehicle, as found at tow yard. Blue bucket has been pulled forward from contact with the vehicle.

[1] Attachment 1 – Fire Response at Tow Yard March 28, 2018.
[2] The last 6 digits of the VIN were replaced with X.

Figure 2. Frontal view of the vehicle, showing crush to front of battery casing at bottom.

In areas without evidence of impact or thermal damage, the battery was relatively undamaged. Opening a discharge port plug at the rear revealed that water and debris had accessed the auxiliary compartment holding the battery management system (BMS). Figure 3 illustrates the undamaged structure of the Tesla with he front of the battery case identified.

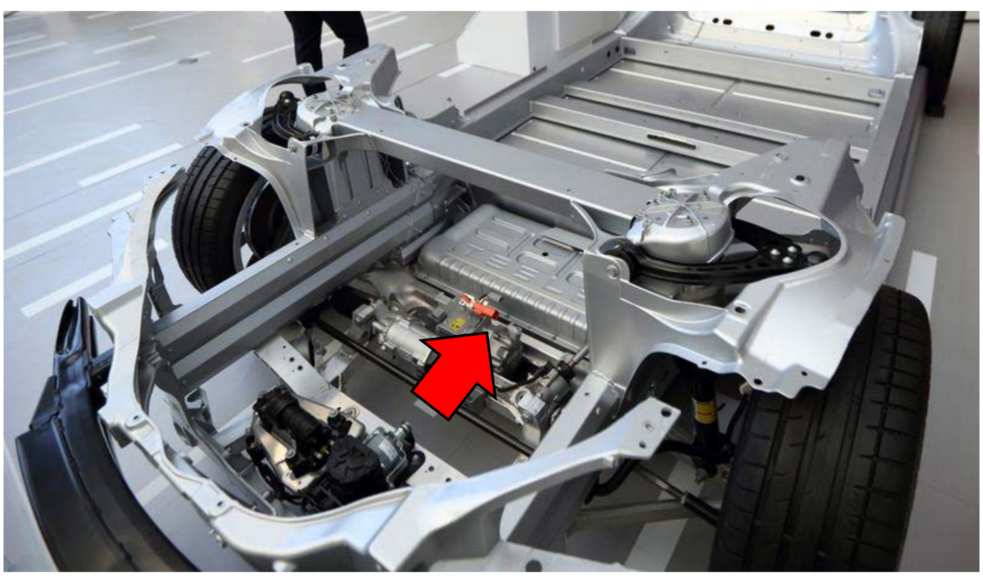

Figure 3. Photo of partial exemplar vehicle with arrow added to depict the leading edge of the battery visible in Figures 1 and 2. Parts of the missing forward structure, drive motor (concealed by arrow), and suspension are shown.

Fire damage in the passenger compartment was limited to forward of the front seats and roughly above window height to the rear of the front seats. The seat materials, interior plastics, and carpet aft of the front seats and below window height were largely intact, other than being extensively soot covered. The rear doors were found shut and latched. The Tesla does not have internal door handles at the rear passenger doors. Each was opened by prying off the speaker grill to locate a cable which needed to be pulled. A tool was used to pry off the left grill. Both cables had a swaged ball on the end, used to grip the cable and pull, as shown in Figure 4. A second person lifted the doors open.

Figure 4. Cable in rear door speaker which needed to be pulled to manually open a rear door after removal of a speaker grill.

In the cabin, the side airbags were found deployed and the front airbags were missing, consistent with video and images from the scene of the accident posted on the internet, as shown in Figure 5 and 6. All seats were in place and had burned cover materials, except for the two stowed small aft seats in the cargo compartment. Missing cover material exposed the forward foam surfaces of the two front seats.

Figure 5. Still image from internet showing deployed side air bags at the scene of the accident with initial fire in front right of battery, prior to fire burning the seats and plastic interior materials.

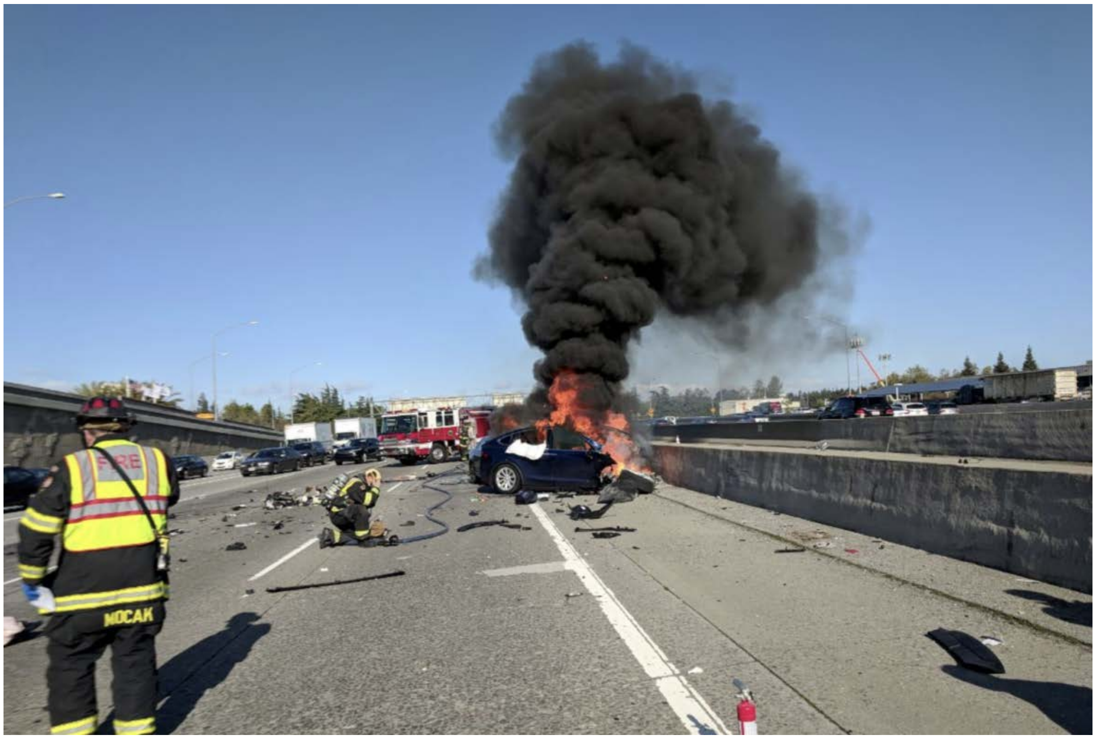

Figure 6. Internet photo showing fire burning the seats and other interior materials.

Two child seats remained attached to the mid bench seat. The rear seats were folded down and miscellaneous personal items were found on the cargo floor behind the mid seats. Three windows remained intact at the left rear door and as small side windows behind each of the rear doors.

2.0 VEHICLE FLOOR AND BATTERY CASE DAMAGE:

The exposed forward features of the cabin and battery exhibited heat damage from the exposed battery. As viewed from the front, looking aft, and from top to bottom were the following layers of debris, as shown in Figure 7, 8, and 9.

- Laying on the carpet were strands of copper wiring in the center tunnel area which had extended to the front instrument panel.
- The interior carpet rests on a layer of thick carpet padding. Ahead of the seats, the carpet and padding had scorched features and collected plastic which had melted and solidified.
- The forward edge of the carpet hung down over a layer or egg crate shaped foam beneath.

A thick closed-cell foam egg-crate layer beneath the carpet pad raised the interior floor above the bottom of the aluminum vehicle body. The egg-crate had melted back about two inches farther on the driver side than the passenger side. In the passenger footwell was an additional triangular portion melted away from the front right corner with a slightly smoother and blacker different appearance.

Figure 7. Fire damaged wiring in lower left. The driver seat is at top left of driver footwell. The lower yellow arrow shows the remaining forward edge of the vapor barrier. The step-like appearance at the upper blue arrow is the edge of the egg crate foam beneath the carpet.

Figure 8. Passenger footwell with passenger seat at top.

Figure 9. Cut back carpet and pad in driver footwell, lifted from the egg crate foam, which is referenced by the arrow.

A layer of rubber-like black layer existed between the bottom of the vehicle body and a clear sheet of plastic vapor barrier which covered the battery. While an air gap of less than a centimeter existed between the battery and bottom of the vehicle, it was filled with compressible materials. This hindered water from flowing along the top surface of the battery. The layers found are shown in Figure 10. The plastic sheet was found melted to about the mid-distance between the front and rear of modules 13 and 14.

Figure 10. Layering of materials prevents ability of cooling water to flow in space between the vehicle body and steel top of battery. Green points to edge of aluminum vehicle floor pan, black to rubber-like material, white to compressible material, purple to vapor barrier, yellow to the steel top of the battery case.

Beneath the top steel cover is a layer of insulation similar to mica, plastics, and flexible silicone-like materials. These included the top plastic tray of the battery cells. Once soot and other debris were cleaned away, these materials appeared not to have heat damage aft of the walls between modules 15/16 and mules 13 and 14. The mid bench seat was removed to access a wire harness for the battery communication bus. Removal required cutting a strap for the right rear child seat, removing the child seats, then cutting the supporting legs for the mid bench seat. The seats and minor cargo were loosely returned to the rear of the vehicle when work was completed. The sharp-edged remaining fragment of the front left "A" door pillar was loose and removed to eliminate a hazard. It was placed on the driver's seat.

3.0 BATTERY GENERAL DESCRIPTION:

The Tesla Model X P100D automobile is powered by a 400 VDC lithium ion battery of 100 kWh, located beneath the passenger cabin of the vehicle. The battery is comprised of approximately 8,500 vertically-mounted and tightly packed cells which are divided into 16 modules, as shown in Figure 11.[3]

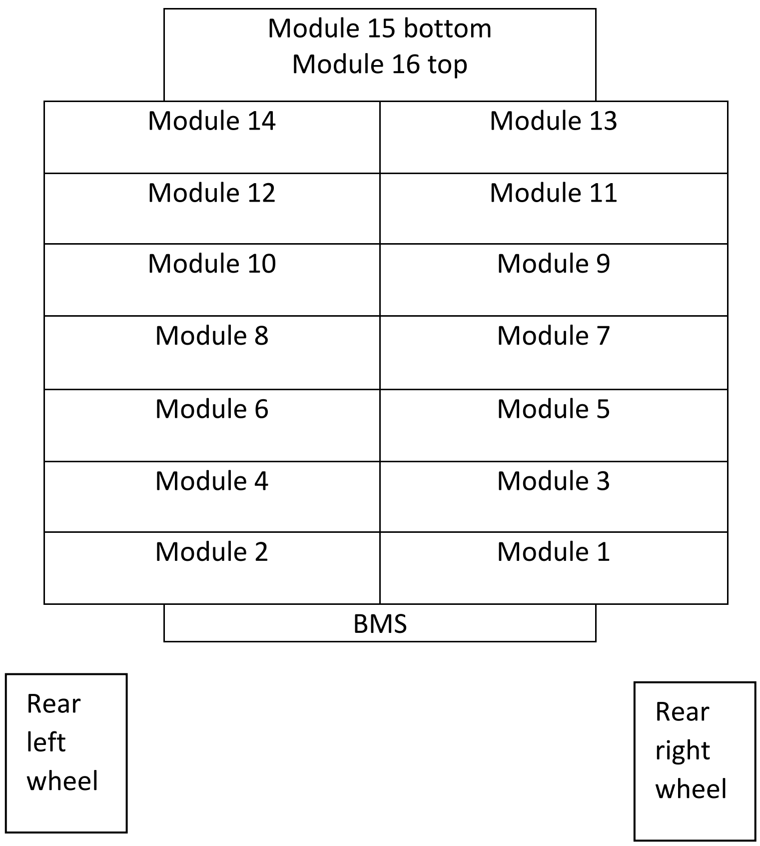

Figure 11. Module numbering in the Tesla High Voltage Numbering Scheme. This view looks down on an assembled battery, with the front at the top of the illustration.

[3] The cells are of the lithium-ion type known as 18650 and the chemistry is a proprietary combination of cobalt oxide with nickel. The 18650 is approximately 18 mm (.71 inches) in diameter and 65mm (2.6 inches) in length. The dimensions and protective features of 18650 cells can vary slightly between manufacturers.

An additional module at the rear of the assembly contains electronics for the battery management system (BMS).[4] The shape of the battery extends from side to side of the car and from between the front wheels to between the rear wheels. Most of the battery is flat and about four inches in height, with the height almost doubling in the front, where module 16 is stacked vertically above module 15. The BMS module at the rear contains the electronics pertaining to the general battery. The features in this section include monitoring and data collection from each of the modules, over-voltage charge protection, power distribution, under-voltage protection which includes an electronic fuse and two lithium primary cells, and contribution to the temperature regulation system.

Within each of the modules is a Battery Monitoring Board (BMB), which monitors the temperature and voltage for each of the cells within that module. The BMB also is an essential part of the charge balancing for each of the cells within an individual module. Each of the approximately 8,500 cells is attached electrically through a small diameter current collector wire. When beyond certain electrical parameters, the individual cells are capable of separating from the grouped cells within a module. The overall battery is essentially unaffected by the loss of individual cells or small numbers. The BMS system samples voltage and temperature data from the cells and modules but does not retain that data.

Woven between groups of cells in each of the modules are a proprietary material and a series of flattened aluminum tubes which contain glycol-based fluid for heating and cooling. The heating/cooling system is to keep each of the individual cells at a uniform temperature to prolong battery life. A radiator is located beneath the front of the car, aft of the front bumper, and a coolant heater are incorporated into the system.

The car and the battery have extensive protective features, in addition to the summarized BMS arrangement noted above. Each of the modules are nearly self-contained and separated from the other modules by metal walls. The heat from venting cells is discharged overboard through a row of “umbrella” poppet valves. The umbrella valves are nominally a flexible translucent silicone type of material. Modules 1-14 each have six umbrella poppets along the outboard edges of the battery, and the poppets face downward into a steel baffle tray. Modules 15 and 16 have a different design for venting, which places the poppets above a grill, inboard of the front wheels. The umbrella valves also provide a means for balancing atmospheric pressure. The steel baffle and umbrella valves provide protection from the entrance of splashing water and other environmental contaminants. In addition to heat removal by venting and since the modules are separated by metal walls which are the height of the 18650 cells, the overall battery design facilitates discharge of heat from a module in thermal runaway through radiation from the larger areas of the top and bottom module surfaces, rather than through the narrow wall to adjacent modules.

Tesla utilizes a similar battery pack construction for the Tesla Powerpack System and Tesla Powerwall. The li-ion battery emergency response guide for these systems provides more detail about the material content, construction, and hazards given various scenarios.[5]

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[4] The module containing the BMS is also called the auxiliary module.

[5] Attachment 2 – Tesla Lithium-Ion Battery Emergency Response Guide, Tesla Powerpack System, Powerwall, and Subassemblies, All Sizes, Released October 22, 2018, Document Number TS-0004027, Revision 05.

The automobile also has a 12V automotive battery which is located in the front luggage "trunk" compartment. This battery provides minor functions, such as powering some controls when the vehicle is parked and heating the main battery when the exterior temperature is cold. The 12V system also provides power for a communications bus used by the BMS and BMB circuits.

The Model X involved in the accident had two 400V electrical drive motors, with one located between the front wheels and one between the rear wheels. The 400V electrical system normally is almost entirely contained within the battery case or other structure and any high power wiring is colored bright orange. An electrical "cut loop" for the 100 KW battery is located next to the 12V battery, so that both are co-located in a location where first responders would disconnect the battery in most ICE vehicles.

To protect against physical damage, the cells are contained within layers of thick aluminum and the walls between modules are bolted into place. Along the front of the battery assembly is an aluminum guard of about 0.25 inch thickness. Along the bottom of the battery pack assembly are smooth raised rails, referred to as ski ribs, for the battery to slide over objects. The steel baffles covering the umbrella valves also provided a smooth sliding surface. To the left and right outboard edges of the battery are extensive castings, providing about five inches of crushable layers.

4.0 BATTERY INSPECTION:

The 400 VDC 100 kWh battery was found with the front edge crushed aft and up. Due to concerns of potential re-ignition of the battery from excessive movement of the vehicle, an unobstructed view of complete underside was not possible. Although the rear tires were resting on three layers of wood, which raised the rear end about 5.25 inches, the air suspension had deflated to leave a minimal gap between the bottom of the battery and the ground. The area of the battery case visible (bottom surface aft of modules 13 and 14), was smooth and unbuckled, aft of modules 13 and 14, as shown in Figure 12.

Figure12 . Smooth bottom surface of battery and limited amount of clearance to ground. Note that wood elevates the front and rear of the vehicle. The discharge port is located to the left of this photo.

The front left of the vehicle battery had a sticker with the following identification, as shown in Figure 13.

- 100 kWh, 400 VDC
- Tesla P/N   1086755-00-D
- Tesla S/N   T17H0160977

Figure 13. Battery identification sticker.

Battery modules 13-16 were extensively damaged. Module 16 was nearly separated from the vehicle, and the top steel surface had been folded back over modules 13 and 14. Video from the scene of the accident showed module 16 being scooped into a large blue bucket. The bucket was with the vehicle when the car was examined in the tow yard, as shown in Figures 14 and 15.

Figure 14. Still image from YouTube video showing remnants of module 16 being lifted to place in blue bucket.

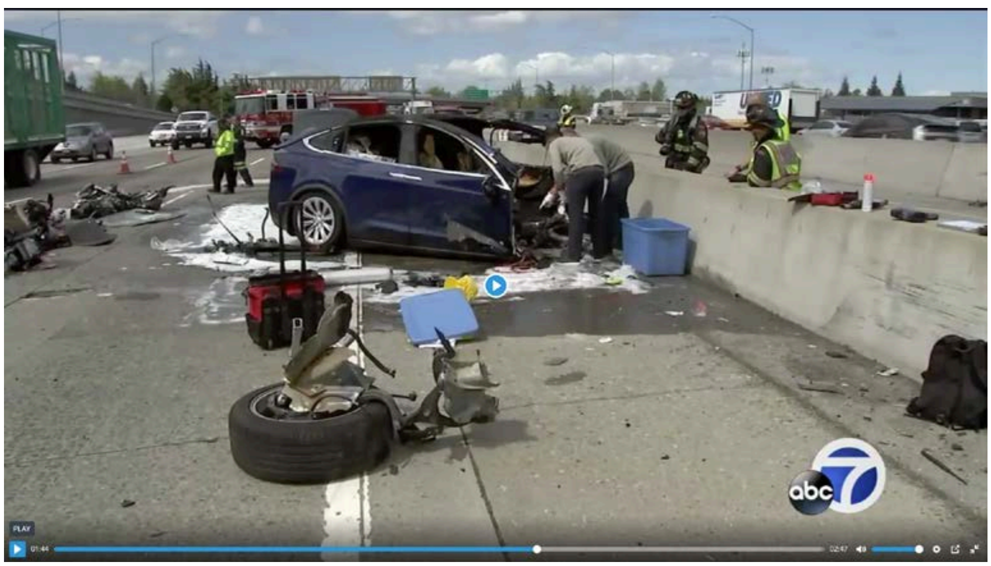

Figure 15. Still image from news video showing blue bucket during removal of module 16 at the scene of the accident.

Evidence of power was found in module 14. Other than obvious damage to the forward two modules (15/16), the extent of remaining electrical or chemical energy for the other 13 modules could not be determined.

Electrical potential of 25.39 VDC was initially found from an exposed bus bar which hung roughly above the right end of module 15 to the aluminum battery case, see Figure16. The bus bar was connected to module 14 on the left and was referred to as the "14 positive bar."

Figure 16. Multimeter display of voltage on the 14 positive bus bar.

A layer of insulating material was placed between the 14 positive bar and a second bus bar behind it to enhance isolation and prevent a short circuit. The second bus bar was referred to as the “spine return” bar and it had no electrical resistance to the battery case. A short laminated bus bar was found at the front right of the remaining module 15/16 case and 3.4 VDC was found from it to the battery case. A value of 3.4 VDC was measured between random cells at the diagonally opposite corners of the remnants of module 15 (front right to aft left corners). Two large orange electrical cables extended from the frame rail beneath the right A pillar. Neither was found to have electrical potential to the battery chassis. Between the cables was a measurement of 520 k-ohms. No electrical measurements could be obtained for modules 1 through 13 and their state of charge could not be determined.

Because power was found, the vehicle battery was relatively intact, and it had already begun to burn twice, the group did not move the vehicle and took care not to reposition, stress, or place weight on the damaged battery. The group also occasionally examined the exposed features of the battery with thermal imaging cameras to assure that a new discharge event had not initiated as work progressed. The 14 positive bus bar material was too thick to cut with available tools (in order to reduce risk of HV exposure). An insulating rubber glove was put back on and a mica box was taped over the area after the inspection was completed, as shown in Figure 17.

Figure 17. View of front of the 400 VDC 100 kWh battery, as found, looking down and aft. The black and red rubber gloves are on the 14 positive bus bar. The exposed cells are the tops of module 15 and the buckle through the middle of module 15 is visible.

An indication of a fluid level was observed from black residue evident in module 15 and on the wall between modules 13 and 15, as shown in Figure 18. (The residue was typical of deposits burning above fluid.) This was consistent with firefighter descriptions of aiming water stream into open and burning area.

Figure 18. This captioned tag is on the 14 positive bus bar. The added blue arrows point to a fluid level, typical of burning above a fluid depth.

Cells and other loose fragments of module 16 were found in the bucket of water and within the fore-aft tunnel which existed between the driver and passenger foot wells. The steel of the top surface of the battery case had post-fire rust with no remaining paint.

While module 16 was essentially missing and only remained as fragments in the water bucket, the exposed top of module 15 was largely intact, with the tops of module 15 cells visible, some displaced upward. Many of the module 15 cells had fire damage and evidence of open tops. The copper materials at the top of module 15 had fused and the plastic features of both modules 15 and 16 had largely been consumed. The module 15 BMB was in place with blackened and fire-damaged features. Figure 19 shows a view of Module 15.

Figure 19. Top of module 15 after cleaning off debris from the fire. The forward edge is along the bottom of the photo. The arrow points to the edge of the top plastic tray. The oval indicates the partially open cover at the front of module 14. At the lower left is the module 15/16 bus bar.

The aft displacement of the battery case cover from module 16 had exposed areas of modules 13 and 14. A gap also existed below the bolted wall which separated modules 13 and 14 from modules 15 and 16, as shown in Figure 20.

Figure 20. Oval around module 15 BMB. Base plastic of the pyrotechnic fuse remained beneath the BMB. The arrows point from the area of modules 15/16 to module 13 and partially covers a fragment of the pyrotechnic fuse.

The majority of the pyrotechnic battery fuse which had been in module 15 was found in the bucket of water. Electrically, the fuse was found in the open configuration. The body of the fuse had fractured into multiple parts which were held together by the internal metal features, such as wiring. The contrast between burned surfaces and clean fracture surfaces indicated that the fuse had fractured after an initial intense fire exposure, as shown in Figure 21.

Figure 21. Pyrotechnic fuse.

The general battery had buckled laterally through the aft portions of modules 13 and 14 and 12, with the battery forward of that slanted slightly upward, as shown in Figure 22. The steel top of module 16 was folded back along with a portion of the aluminum vehicle floor. This prevented removal of the battery.

Figure 22. View of the top of the driver footwell, looking aft after cleaning off the fire debris. The buckle in the top surface of the modules 12 and 14 is visible. The aluminum driver footwell floor is accordion-folded aft.

After cleaning away the fire debris, the mica insulator in module 13 was found fragmented and broken. The steel top of the case could be flexed by hand, so the mica was not disturbed in order to minimize potential contact between the steel and conductive materials beneath the mica, as shown in Figure 23. Module 14 also had exposed mica which appeared to be less damaged, but the same precaution was taken to avoid flexing the steel downward where it might contact exposed conductors.

Figure 23. Top of module 13 after cleaning away fire debris, pointing at broken mica on plastic tray. The mica and plastic were able to be moved to see the cell

tops. The rectangular material above the pointer was added to isolate the powered bus bar.

The exposed top of module 14 had features not containing residue of venting cells or thermal exposure, which included a length of silicone-like translucent material, adhesive exposed by the peeling top of the module, and other exposed plastics, as shown in Figure 24.

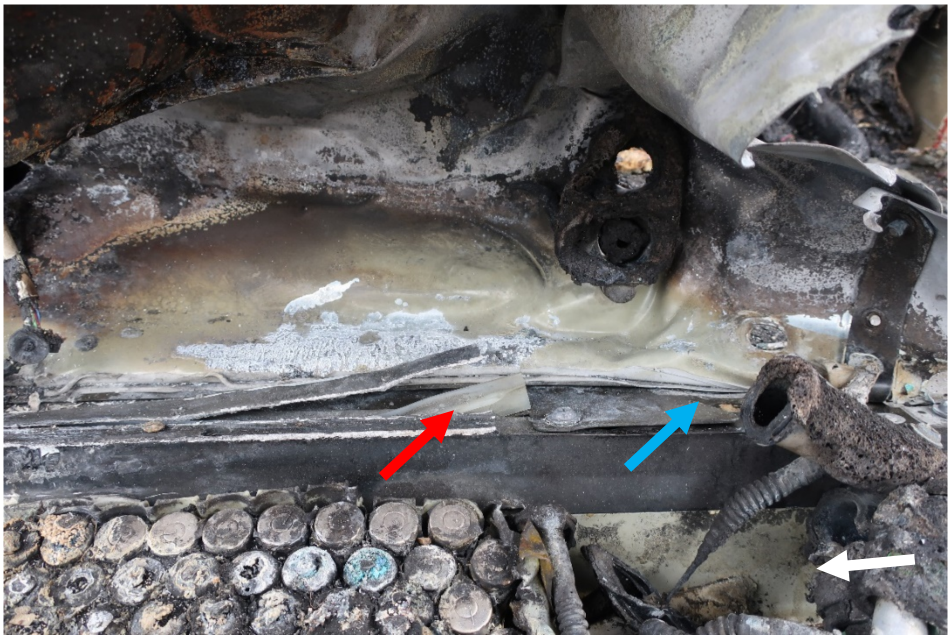

Figure 24. Looking aft into the top of module 14 from 15/16. Left red arrow points at unburned silicone-like material on aft side of wall between modules. Right blue arrow points to unburned adhesive. A flood level mark is at approximately half the 18650 cell heights as was visible near the BMB and is pointed to by the lower white arrow.

The umbrella poppets were removed from each side of the vehicle to examine for black sticky residue typically associated with venting from cells in thermal runaway. Ten of the fourteen sets did not contain sticky black residue. Figures 25 through 38 provide a view of the poppets for the modules as labeled.

Examining the left set of modules, the features for four (2, 4, 6, 14) of the seven sets of umbrella poppets appeared to retain their translucent normal appearance and no evidence of heat. Module 8 had five clean umbrellas and one separate which was coated with black sticky residue. The poppets for modules 10 and 12 were coated with sticky black residue. Black residue and standing water were found in the baffles beneath the corresponding umbrella poppets.

Examining the right set of modules, five sets (1, 3, 5, 7, 9) of poppets were clear of black residue. The module 13 set had black residue which had a washed appearance. All but one of the module 11 set were clear of black residue but had a similar grey muddy deposit similar to that seen in the BMS auxiliary module. The wetness in the baffle trays dried during the day of examination.

Figure 25. Module 14 poppets and baffle. Note that 25.39 had been measured on the 14 positive bus bar

Figure 26. Module 13 poppets and baffle.

Figure 27. Module 12 poppets and baffle.

Figure 28. Module 11 poppets and baffle.

Figure 29. Module 10 poppets and baffle.

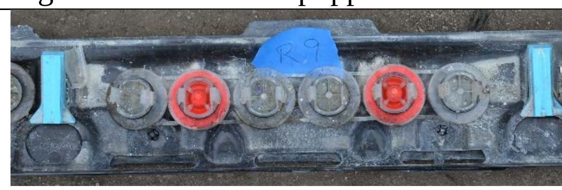

Figure 30. Module 9 poppets and baffle.

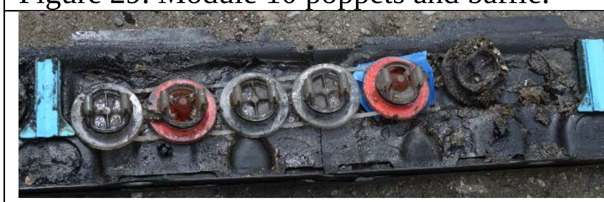

Figure 31. Module 8 poppets and baffle.

Figure 32. Module 7 poppets and baffle.

Figure 33. Module 6 poppets and baffle.

Figure34 . Module 5 poppets and baffle.

Figure 35. Module 4 poppets and baffle.

Figure 36. Module 3 poppets and baffle.

Figure 37. Module 2 poppets and baffle.

Figure 38. Module 1 poppets and baffle.

The 400 VDC battery was not removed from the vehicle to positively establish which cells had vented. Examination for subsequent battery removal found that the top of the battery and forward portion of the vehicle body had become enmeshed in an accordion fold. Lowering the battery for removal would have required cutting of the vehicle body. Further, the left and right edges of the battery had been displaced outward to come into contact with the edges of the vehicle body assembly.

5.0 ATTEMPT TO DISCHARGE BATTERY:

Due to water contamination, the battery could not be discharged and the amount of trapped energy was not determined. A description of the discharge port and attempt to discharge the battery follows. The circular cover for the discharge port was covered by a warning label, which was removed; the circular plug was removed, and water drained from the open hole.

The plug contained a thick layer of residue which dried to a muddy paste, as shown in Figure 39. The group discussed that while the modules were essentially isolated from each other, the isolation was not water-tight. Water entering the front of the battery was able to find paths to reach the rear auxiliary/BMS compartment of the battery.

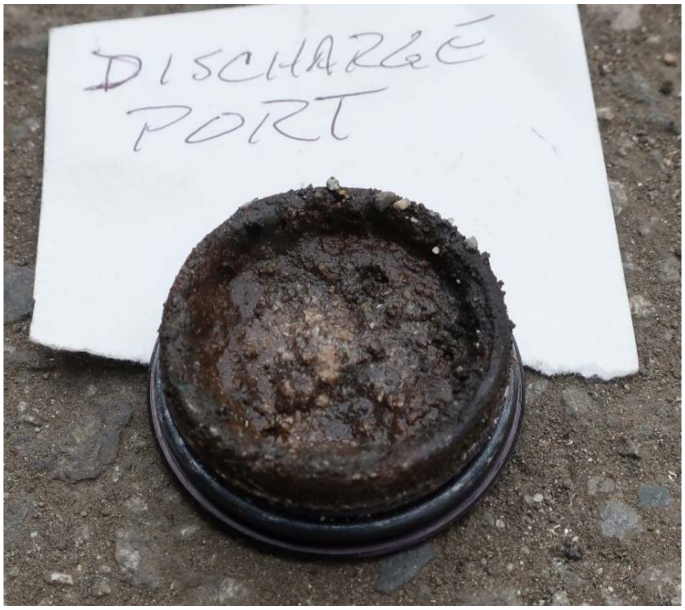

Figure 39. Muddy material drying out in the discharge port cover.

Because the bottom of the car was so close to the ground, the electrical connector within the port could only be seen by taking photographs and examining the images. The images showed that the electrical connector was also filled with the muddy residue, which was cleaned as much as possible in the limited access, as shown in Figure 40. Once the discharger was attached by a cable, the electrical connection was not sufficiently clean for the discharger to function.

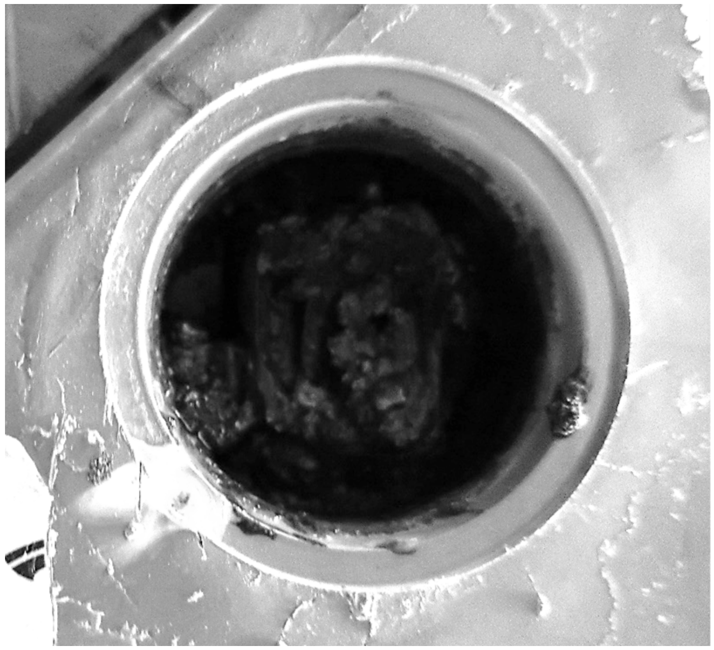

Figure 40. Muddy material in the discharge port beneath vehicle. The bright area at the lower left of the hole is water draining. For best visibility of electrical connection in the black confines, the image is shown in black and white after modifying the sharpness and brightness.

The discharger was then connected to the exposed 14 positive bus bar at the front of the vehicle. When connected, the discharger computer recognized that it was not connected to a functional battery and would not function. Tesla personnel noted that 400 VDC batteries damaged in tests have been discharged by flooding with salt water, and that complete discharge takes approximately two to three days. Flooding with plain water has been effective, but may require more than two weeks.

6.0 COMMUNICATION BUS:

The BMS is a computer which normally communicates with the BMB circuit card in each module, relaying relevant information to the vehicle systems and memory. The BMS is located contained in the vehicle battery auxiliary compartment which holds the discharge port and communicates with the vehicle through a set of digital bus wires which enter the cabin beneath the mid seat. Communication with the BMS normally provides data containing the extent of health or damage in each module and the state of charge in each module. The bus is normally powered by the vehicle's 12 VDC battery.

The rear seat was removed from the vehicle by cutting the supporting legs. The carpet and padding under the seat were pulled from the aft surface to expose a small rubber plug and wire harness. After referring to a wiring diagram, the wires of the harness were cut and connectors were attached to the wires as shown in Figure 41. A small battery was used to place power on the bus. The attempt to communicate with the BMS in the wet auxiliary compartment of the vehicle battery was unsuccessful as shown in Figure 42.

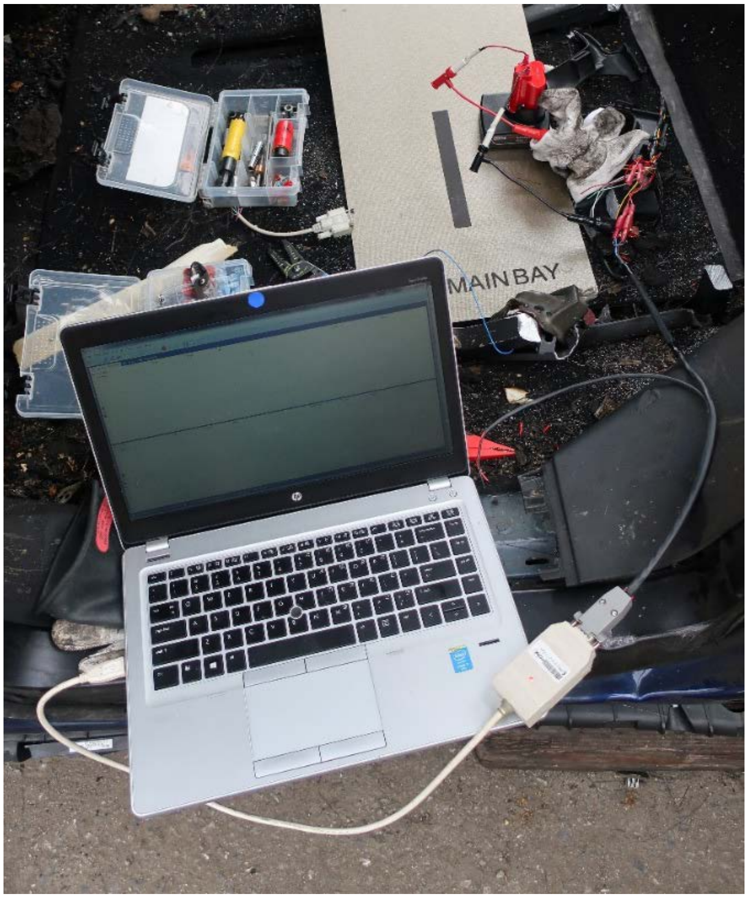

Figure 41. Connections between laptop, battery, and wires of the vehicle battery communication bus. The location is the floor inside of the left rear door, beneath where mid seat had been removed.

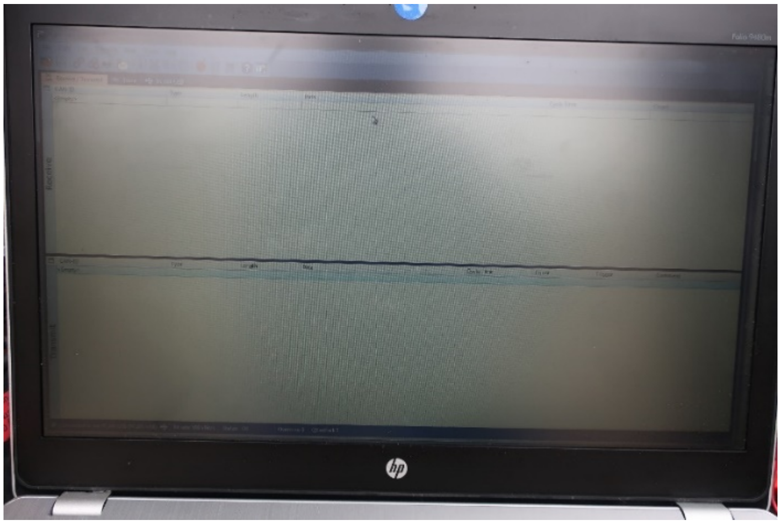

Figure 42. Screen of laptop, shows lack of response on battery communication bus

E. DOCKET MATERIAL:

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

LIST OF ATTACHMENTS

Tesla Inspection Attachment 1 – Fire Response at Tow Yard, March 28, 2018
Tesla Inspection Attachment 2 – Tesla Lithium-ion Battery Emergency Response Guide

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END OF REPORT