CASE STUDY WITH A FIRE ORIGIN AND FIRE CAUSE REMOTELY LOCATED FROM THE ROOT CAUSE OF THE FAILURE IN A COMMERCIAL VEHICLE

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ABSTRACT

Vehicles and equipment typically contain electrical power systems utilizing 6/12/24-volt (or greater) direct current (DC) power systems configured with most of the (metallic/conductive) chassis, cab, and body electrically connected to the negative side of the batteries as a negative common voltage reference. Various electrical failure modes in the DC power circuits are one of the major types of fire causes in these vehicles and equipment and vehicular products.

A case study will be presented that demonstrates the origination of a fire in an area of a vehicle physically separate and remote from the root cause of the fire. Vehicles or equipment, in this and similar fires, have revealed electrical positive power cables that short/weld to components of the vehicle or equipment that are (normally) electrically part of the common negative, connected to the battery(s) negative. The initial short/weld failure does not originate any fire (or the primary fire) at the failure location (or even in the immediate area) of the short/weld – yet is the root cause of a fire in a separate, remote location in the vehicle or equipment. Unintended electrical circuit paths created from these root cause failures have been determined to cause fires originating at components that are normally part of the electrical system but are included in the electrically negative common reference of the cab/chassis/body, as they are electrically connected to the battery negative. Such components as wire reinforced pressure hoses, mechanical control cables, etc. have been determined to be involved in the origination of such fires.

There are three significant issues relevant to fires involving such phenomena that should be considered (and will be analyzed in planned future publications):

- A fire may initiate at a location on the vehicle/equipment *where there is no defect, abnormality, or any other condition that would directly cause a fire* - prior to the occurrence of another (root cause) which is completely remote and separated from the root cause failure location, yet part of the fire sequence.
- The short/weld evidence that is the root cause in such a fire is not located at, or surrounding, the origin of the fire, completely contrary to the (unfounded and empirically disproven) theory of arc mapping as a means of fire origin determination - for vehicles and equipment utilizing DC power circuits and a common negative.
- Retained fire evidence may need to include potentially pertinent critical root cause evidence that is remote and separate from a properly determined area of fire origin.

SCOPE

The scope of this paper is to provide a case study of a commercial truck engineering failure analysis fire investigation determining the fire origin and cause, and further determining the failure root cause that led to the fire. Potential implications of a failure physically located separate and remote from the fire originated will also be briefly discussed.

BACKGROUND

This case study stems from an engineering failure analysis assignment involving the investigation and determination of the root cause of a fire that occurred in a commercial tractor-trailer vehicle. The fire was reported as an "engine compartment fire" with fire damage restricted to the truck-tractor with no involvement of the semi-trailer that was attached to the tractor at the time of the fire. The truck-tractor was manufactured in October of 2012, put into service in January of 2013, with the fire occurring in May of 2013, after approximately 35 months and 336,000 miles of service.

Circumstances

Prior to the fire, the tractor-trailer had pulled into an interstate highway public service plaza around noon and was parked with the engine not running. The driver had reported an operational issue of a leak of power steering fluid to his dispatcher and had gone into the plaza building, leaving the tractor hood open, while waiting for a service truck to arrive to fix the leak. Upon his return to the tractor, the driver discovered a fire in progress on the left side of the engine compartment (always as oriented from the operator position). The details of the driver's discovery of the fluid leak and fire, including the timing of events relative to the fire were not available. After the fire, the truck-tractor was separated from the semi-trailer and towed to a company service location where the fire investigation inspection was later performed.

Product

The truck tractor was of a standard general configuration (Photo 1) similar to most other contemporary "semis" used in commercial highway and regional-haul tractor applications. It was configured as a diesel-powered, conventional, 6x4, day-cab, truck-tractor (*conventional* indicting the engine was located in an engine compartment in front of the cab, *6x4* indicating 6 wheel ends [i.e. 3 axles] with 4 powered wheel ends, and a *day-cab* indicating a standard size non-sleeper cab configuration.) The apparent nonstandard components were the wide-base drive axle tires and full height cab fairing. The engine compartment contained a 13L six-cylinder diesel engine meeting 2010 emission levels, and typical auxiliary systems for electrical power and controls, steering, braking, etc.

Photo 1 – Subject Truck-Tractor

Involved Systems

Further details of the electrical power and power steering systems are provided here due to their involvement in the fire investigation. The electrical power system of the tractor (with the engine off) provided electrical power potential from the three 12-volt batteries (wired in parallel) located in the battery box mounted to the left side frame rail behind the cab. The electrical power potential from the batteries was available via pairs of positive and negative battery cables running to the starter located at the bottom left rear of the engine. Positive and negative electrical connections are made at the starter to other points on the engine, cab, and chassis. Hydraulically assisted power steering is provided by means of a pump located on the left rear of the engine above the starter (and behind the frame rail) with a wire-braided pressure hose running under the frame rail to the steering gear mounted at the front outside of the left frame rail. Output from the steering gear runs through hose to the power steering reservoir and then back to the pump.

FIRE ORIGIN DETERMINATION

The area of the fire origin was determined through the witness account of the driver as the left/driver's side of the engine compartment (often referred to as the *cold* side of an in-line internal combustion engine, as the *hot* exhaust system components are typically grouped on the right side of the engine.) This witness account is consistent with the evidence on the inspected tractor showing the only fire damage present on the vehicle was located on the left side of the engine area, mostly inside the frame rail (Photo 2). With the hood open during the fire, there was little fire damage visible to the right side of the engine (Photo 3).

Photo 2 - Left Side Engine Compartment

Photo 3 - Right Side Engine Compartment

FIRE CAUSE DETERMINATION

The area of the fire origin (Photos 4, 5) was examined for evidence relating to the cause of the fire. As NFPA 921 notes[1] fire cause determination is the process of identifying the first fuel ignited, the ignition source, the oxidizing agent, and the circumstances that resulted in the fire. The oxidizing agent is available air oxygen. There was a known prior leak of combustible power steering fluid potentially available as a first fuel, but an ignition source was initially lacking as there are normally no sources of sufficient temperature and heat for autoignition or competent sparks or arcs[2] for piloted ignition available on the left/driver's/cold side of the engine.

Photo 4 - Left Side Front Engine Compartment

Photo 5 – Left Side Engine Compartment Underside Between Frame Rail and Engine

Inspection of the area of fire origin revealed no pertinent evidence indicating a possible cause except a power steering pressure hose with an anomaly that was removed for further examination (Photo 6). Further inspection showed a typical wire braid pressure hose that had lost integrity at a point, with the wire braid severed and failure of the inner liner, allowing the reported leak of the power steering fluid. This anomaly (Photos 7, 8) was located at the point of the rearward support clip for the hose with the clip attached to the engine (Photo/Schematic 9). Beads present at the severed braids on the hose wire braiding were magnetically confirmed to be steel (Photo 10). A mechanical failure of the hose and clip protective coverings would only potentially result after a long period of wear, eventually resulting in a hose leak, (if not noticed during periodic service inspections) but would not display the beading of the wire braiding present in the subject hose failure.

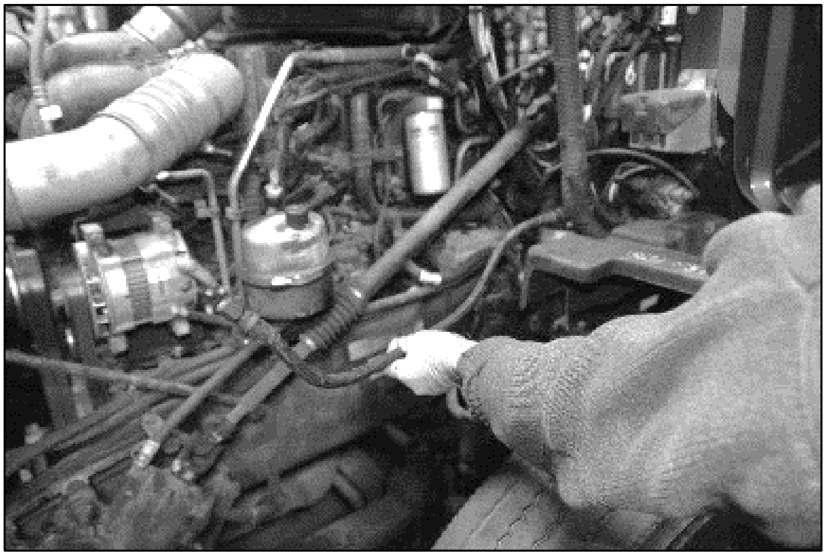


Photo 6 - Power Steering Hose Removed from Under and Inside Frame Rail – shown with Routing Displaced Upward and Outward

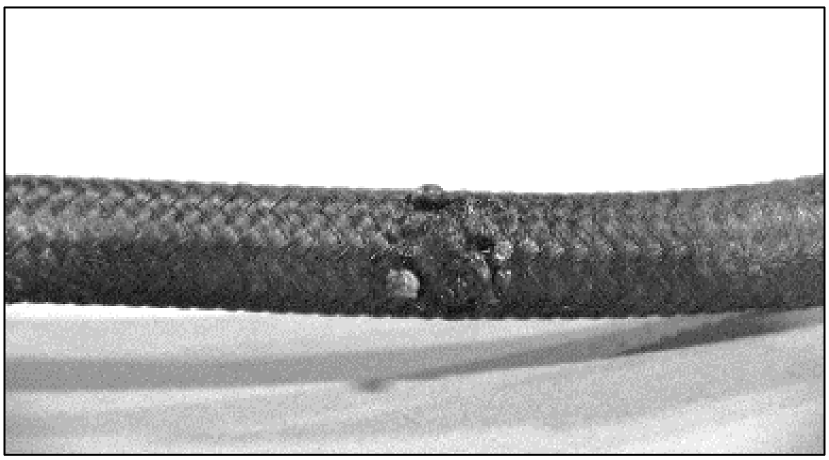


Photo 7 - Power Steering Hose Failure of Steel Ire Braiding with Beading

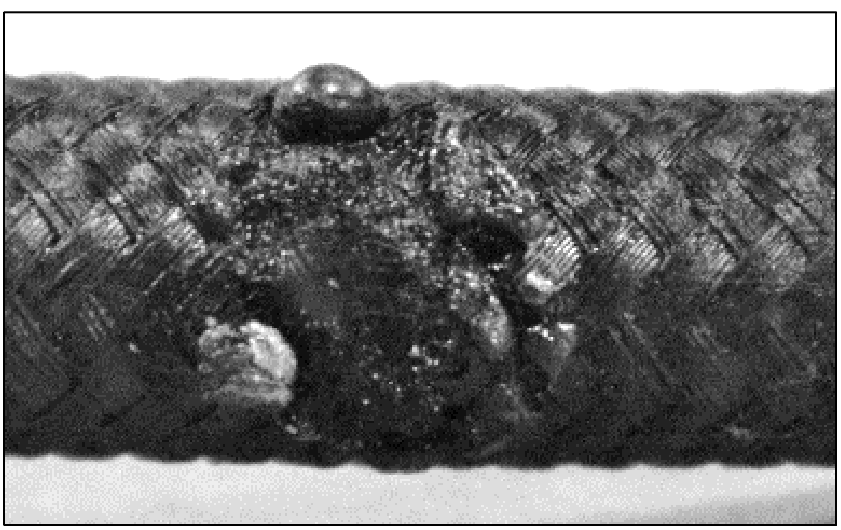
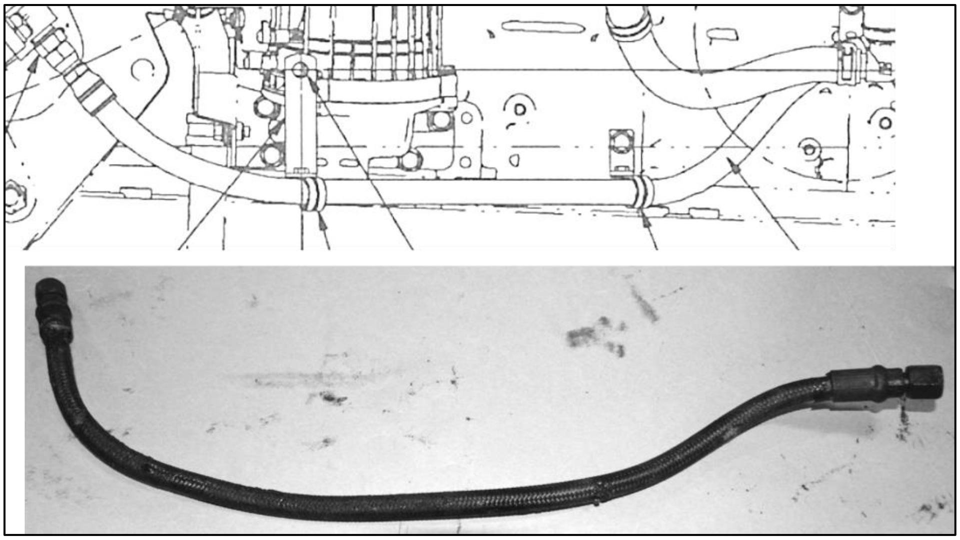


Photo 8 - Closeup of Power Steering Hose Failure of Steel Wire Braiding with Beading



Photo/Schematic 9 - Power Steering Hose with Failure Location at Rear Support Clip

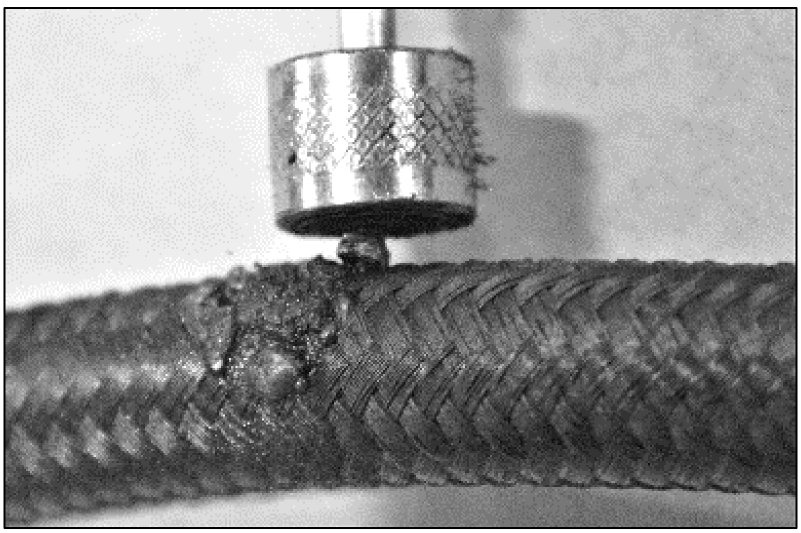


Photo 10 - Power Steering Hose Failure of Steel Wire Braiding with Beading and Magnet

The only possible highly localized source of heat available to heat and sever the wire braid and create the beading of the steel wire braid would be an electrical potential between the hose support clip and the wire braid of the pressure hose. The electrical shorting occurred at that point when the outer covering of both the hose and clip had softened/melted sufficiently to allow the contact and subsequent shorting between the metallic clip and wire braid of the hose. This shorting between the clip and hose braiding was apparently present for some time prior to the fire, resulting in the leak of power steering fluid for which the tractor-trailer was stopped awaiting repair. No anomalies were found in any of the electrical wiring in the area of fire origin outside of normal fire/heat damage.

While the *complete* circumstances that resulted in the fire are not reported at this point, all of the elements of the immediate fire cause determination have been determined within the area of fire origin.

FAILURE ROOT CAUSE DETERMINATION

Further examination of the electrical system, outside of the area of fire origin (or fire damage), was performed and evidence was found in the battery box of shorting of the positive battery cables to the hold-down post securing the batteries (PHOTOS 11,12) - though exhibiting limited thermal damage without evidence of any fire. The battery hold-down post, which is normally part of the electrically common negative side of the truck, once shorted to the positive battery cable then creates an electric potential to other components, creating unintended electrical circuits eventually resulting in the unintended electrical activity between the power steering hose support clip and the wire braiding of the hose. The limited thermal damage evident in the battery box cannot be an effect of the fire in the engine compartment, but the engine compartment fire can be an effect of the shorting in the battery box.

Photo 11 - Battery Box – mounted left side frame rail behind cab

Photo 12 - Battery Cable at Hold-down Post

Details of the electrical interactions (shorting/welding) of the power steering hose braiding with the hose support clip and also the battery cables with the battery hold post were not further explored and documented due to the desire of the insurance fire investigator to involve, or turn his investigation over to, an associated electrical engineer in a follow-up inspection, which was never scheduled.

POTENTIAL LIABILITY ANALYSIS

Supplied maintenance records indicated that all batteries had been replaced at least once in the tractor. Comparison of the battery cables' routing, clipping, and sheathing in the battery box show significant changes from the new/as-manufactured configuration of the cables at the time of the fire. The battery cables were no longer grouped and separated by polarity and secured and protectively sheathed as in the as-manufactured condition. Changes in the battery cable protection during service operations were determined to be responsible for the failure to protect the electrical power system in the battery box and directly led to the subsequent power steering leak and fire.

OTHER EXAMPLES OF FIRE ORIGIN AND FIRE CAUSE REMOTELY LOCATED FROM THE ROOT CAUSE OF THE FAILURE

The authors have investigated numerous fires in a wide variety of vehicles and equipment which were determined to have a root cause remotely located from the area of fire origin and immediate fire cause. Such fires usually involved shorting of the battery cables or other electrical power cables to an electrically negative component of the cab/chassis/body as the root cause. The fires then originated in an area remotely located from the root cause in unintended electrical circuits involving wire mesh pressure hoses, mechanical control cables, or other components not designed to carry electrical currents.

POTENTIAL FIRE INVESTIGATION IMPLICATIONS OF SIMILAR FAILURE PHENOMENA

There are three significant issues relevant to fires involving such phenomena that should be considered and will be analyzed in planned future publication(s):

- A fire may initiate at a location on the vehicle or equipment where there is *previously no defect, abnormality, or any other condition that would directly cause a fire* - which is completely remote and separated from the root cause electrical short/weld.
- The short/weld evidence that is the root cause in such a fire is not located at the origin of the fire, completely contrary to the scientifically unfounded[3,4] and empirically disproven[5] theory of arc mapping as a means of fire origin determination - in vehicles and equipment utilizing DC power circuits.
- Fire evidence collected from only the area of the fire origin and immediate fire cause may not contain evidence of the root failure cause.

SUMMARY AND CONCLUSIONS

1. A case study of a tractor-trailer fire with limited fire damage is presented showing;
    a. The area of fire origin was determined to be the left (driver's/cold) side of the engine compartment as reported by the driver and consistent with fire damage patterns and limited area of fire damage.
    b. The immediate fire cause was determined to be the shorting between the power steering hose braided steel wire and the hose support clip attached to the engine, located within the area of the fire origin.
    c. The root cause of the failure that resulted in the fire was the shorting of a positive battery cable to a battery hold-down post within the battery box, with no fire damage and limited thermal damage in that area.

2. There are several potential implications to providing an accurate and complete fire failure analysis investigation in light of the occurrence of similar local fire origin & cause with remote, separate root-cause phenomena as determined in the case study:
    a. The subject fire originated in an area of the vehicle that contained no defective condition prior to the initiation of the remote failure. The root cause failure was in a separated, remote area of the vehicle that was not within the fire region, in this fire.

b. Arc mapping is defined in NFPA 921[6] as "identification of electrical arc sites to assist in the identification of the area of origin…" is (again) demonstrated to not be directly applicable in vehicles and equipment with direct current (DC) power circuits. This is due to the creation of failures producing unintended electrical circuits in common negative direct current electrical system designs. This does not in any way negate or minimize the need to inspect for all signs of electrical activity – rather conversely demonstrating the need to fully survey electrical power cables (especially) for electrical activity evidence.
c. An accurate and complete failure analysis investigation may not be able to be conducted unless all pertinent *root cause* evidence is retained and available for consideration, including potentially critical evidence remote from a properly determined area of fire origin.

ABOUT THE AUTHORS

Doug Stahl is a forensic engineer focused on engineering failure analysis investigations of vehicles and equipment including fire origin and cause, product liability, accident investigations, and design analysis in private practice and for a major truck and bus OEM for over twenty-five years. He is a Professional Engineer and earned a BS in Materials Science and Metallurgical Engineering from the University of Cincinnati and a MS in Metallurgy with a minor in Mechanical Engineering from Georgia Tech. Doug holds CFEI/CVFI certifications, serves as a member of the SAE Task Group of the NFPA 921 Technical Committee, and holds several patents.

Kerry Parrott is a senior engineer and fire analyst focused on vehicle and equipment fire investigation failure analysis including fire origin and cause and product liability analyses in private practice and for a major truck and bus OEM for nearly twenty years. He earned a BS in Mechanical Engineering from the University of Kentucky. Kerry holds CFEI/CVFI-NAFI certifications and CFI-IAAI certification. He is a principal member of the NFPA 1192 Technical Committee on Recreational Vehicles and also serves as member of the SAE Task Group of the NFPA 921 Technical Committee.

ENDNOTES

[1] Guide for Fire and Explosion Investigations, NFPA 921, 19.1, NFPA (2017).

[2] Parrott, Kerry D. and Stahl, Douglas R., "Electrical Arcs and Sparks: A Literature Review of Definitions and Their Implications in the Analysis of 12 Volt Direct Current Electrical System Fires" Proceedings. International Symposium on Fire Investigation Science and Technology, College Park, MD. Sarasota, FL: NAFI, 2014.

[3] Stahl, Douglas R. and Parrott, Kerry D., "Applicability and Limitations or Arc Mapping in Vehicle and Equipment Fires Investigation." Proceedings. International Symposium on Fire Investigation Science and Technology, College Park, MD. Sarasota, FL: NAFI, 2012.

[4] Babrauskas, V. (2017). Arc Mapping: New Science or New Myth? Fire and Materials, San Francisco, CA.

[5] DeMarois, P.H., Ballard, W., Engle, J., West, G. et al., "Full Scale Burn Demonstration of Two 2013 Ford Fusions - Arc Mapping Analysis," SAE Technical Paper 2018-01-1439, 2018, doi:10.4271/2018-01-1439.

[6] Guide for Fire and Explosion Investigations, NFPA 921, 3.3.9, NFPA (2017).