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# FIRE, CAUSE AND ORIGIN OF HEAVY VEHICLES (MECHANICAL AND FORENSIC METHODS)

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## ABSTRACT

The occurrence of large scale fires involving heavy vehicles and equipment remains a problem. Methods need to be developed in order to determine the cause and origin of these fires. A method combining mechanical engineering, basic mechanics along with forensic techniques and investigation standards has been developed, in a single source format, to assist in determining the cause of large scale fires. Techniques used in the overall method are; the machines' mechanical and electrical function, the scenario of facts, operational profile, prior maintenance, the construction of the machine and reconstruction of the accident. This paper will use individual case study examples to illustrate the techniques to be used in the analysis.

## INTRODUCTION

Heavy trucks and equipment are expensive and perform valuable work tasks. A fire can occur on a heavy truck or piece of equipment for numerous reasons. Unlike automobiles, they are sophisticated vehicles with many sub-systems. The Author has investigated fires for more than 20 years. During the Author's experiences with fire investigation a consistent pattern of data has been collected. If the vehicle is in motion (driving or idling) certain items are valid as possible causes. Likewise, if the vehicle is stationary, (engine on or off) other items become potential causes. In either case, the situation is dangerous and costly in both human life and property (Photos 1A and 1B).

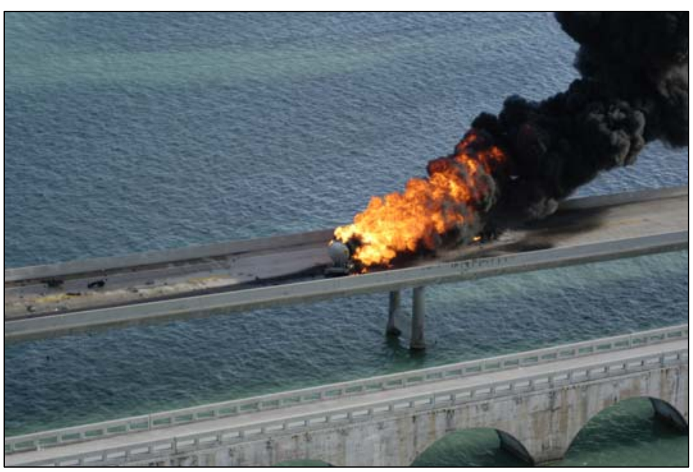


Photo 1A: Fuel Tanker, Bridge to Florida Keys

Photo 1B: 1,000,000 lb G.V.W.R Mining Truck

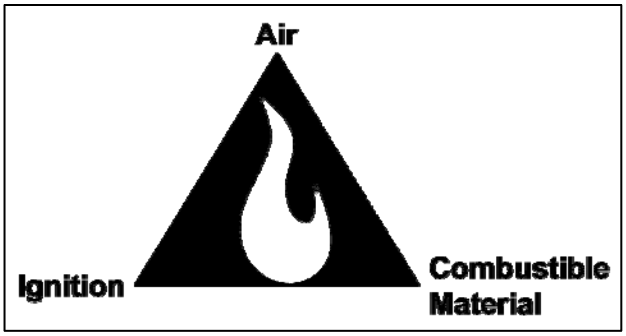


Fig. 1: Fire Triangle

## COMMON CAUSES

The common causes discussed in this paper are not ranked in order of likelihood. Vehicle operational profile, maintenance care, vehicle history and reconstruction help to determine which could be the origin of the fire. Some of the common causes (not exhaustive) that will be discussed are:

- Alternator
- Starter
- Fuel/Combustible Materials
- Hubs/Bearings
- Brakes (Disc/Drum)
- Tires
- Turbocharger
- Sensors/Transducers
- Auxiliary Power Units (A.P.U.)'s
- 2007 Emission Schemes
- Batteries/Cables/Distribution/Electrical System
- Chassis/Vocation Related Components

## WHAT IS REQUIRED FOR A FIRE

Three elements are needed to create a fire: air, a combustible material and an ignition source. These three items form what is known as the Fire Triangle (Fig. 1); if any one of the three elements of the triangle is not present a fire cannot occur despite the presence of the other two. Air is all around us; making for an abundant supply of the first element. A combustible material, the second element, is anything that may be present on the truck such as diesel fuel, power steering fluid, engine oil, transmission fluid, gear/hub oil, grease, tires and wire/cable insulation to name a few. The third element, the ignition source, can come in many forms. An open flame, a sustained duration spark and auto-ignition[†] are the most common ignition sources. Therefore, separating the ignition source(s) from the combustible materials, to the extent that it can be, is good design practice. Along with the completion of the fire triangle, atomization of the liquid must occur in order to satisfy the stoichiometric requirements (14:1) to burn. Absent this proper air-to-fuel ratio, the substance is deemed too rich to burn and will not ignite.

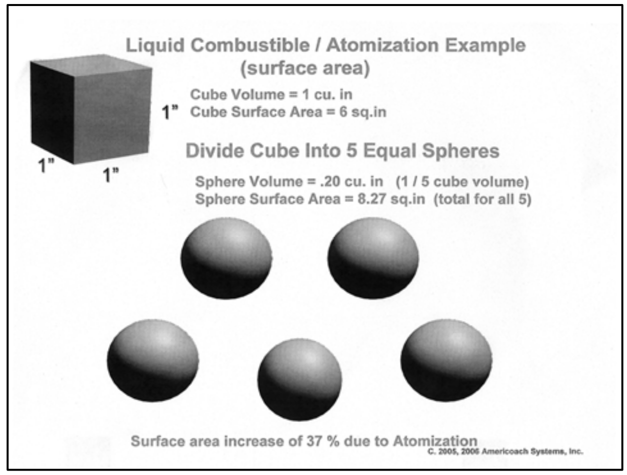


Fig. 2: Atomization

The atomization increases the surface area of the liquid by creating small spheres or droplets. By taking a cube of one cubic inch in volume and simply dividing it up into five equal spheres, each 1/5 of 1 cubic inch, the total surface area of the five spheres is 37% more than the surface area of the original same volume of one cubic inch (Fig. 2).This increase in surface area is what allows the air to properly mix with the liquid for the stoichiometric ratio to be satisfied. As an example, this atomization usually comes from a spraying of the liquid from a pressurized pinhole leak in a hose or component housing or even a breached fuel tank or line. Once this ratio has been met a fire can occur.

## TEMPERATURE MAPPING

Temperature Mapping is a technique used to determine the surface temperature of various components on the truck or equipment. The temperature mapping can be done by taking component temperatures immediately after the vehicle has been operating under load, during loaded operation or on a chassis dynamometer. By using a non-contact laser thermometer, a map of component surface temperatures can be established for any particular vehicle within the engine compartment.

The purpose of this study is to verify individual component surface temperatures to assist in the cause and origin analysis, as well as fire prevention through design. Certain components are normally at the auto-ignition temperature of the on-board fluids and some are not. What can be taken from the temperature map is that if the "cooler" components are functioning normally, they cannot be an auto-ignition source. If a fire was to be traced back to a "cooler" component, such as a drive axle hub, that would indicate that this component experienced some type of mechanical failure which preceded

[†] Auto-ignition is defined as the ability to ignite a flammable substance in the absence of an open flame or sustained duration spark. This phenomenon is created solely by the surface temperature of an object.

Photo 2A: Burn Pattern

Photo 2B: Reassembling components

the fire and became the triggering element – the ignition source. In summary the "cool" components cannot become an ignition source without experiencing a localized failure due to the fact that their normal operating (surface temperature) is less than the average (on board fluid/combustible) auto-ignition temperature.

## DAMAGE PATTERN ANALYSIS

This analysis involves the observation of flame/heat damage patterns leading to the origin of the fire (Photo 2A). The technique is generally comprised of the elements shown in the flow chart (Appendix A) and come from N.F.P.A. 921. This method is further facilitated by reassembling the truck (as much as possible) to show configuration and component placement (Photo 2B).

By following this basic process, investigators can begin to focus in on elements which may have led to the beginning of the fire. However, throughout this process a high level

Photo 3A: Turbocharger, Impact Damage

Photo 3B: Turbocharger,
Impact Damage,
Rough Edges

understanding of the components and systems functional behavior must be known to the investigator.

## PROCESS OF ELIMINATION

In many fires, the origin evidence is burned. This leaves the investigator with a difficult task. A competent method of analysis, if left with this situation, is to systematically eliminate ignition and combustible sources one by one using observations, mechanical function, system logic and reconstruction. Each of the components listed in the common causes section should be evaluated. For example, Photograph 3A shows the truck engine, at the accident scene, with the dual turbochargers off the engine. Photograph 3B shows rough edges on the turbocharger connection indicating a traumatic impact failure. Therefore, since these turbochargers were knocked off the engine in the accident phase and reside on the non-fuel side of the engine, they are not likely a candidate as an ignition source.

## FIRES WITH ENGINE OFF

As discussed earlier, fires can start with the engine off and after an extended period since the shut-down. When these facts are present, the investigator should focus on ignition sources that are (B+) with the ignition in the off position. Specifically, items which are (B+) energized all the time, regardless of ignition position. These are, but not limited to:

- Battery cables
- Batteries
- Brake booster motors
- Alternator
- Starter
- Master power distribution to cab
- Anything wired (B+)

Items which are energized by the vehicles ignition circuit are (normally) not an ignition source with the ignition in the off position. Therefore, they can be eliminated during the analysis.

## ALTERNATOR

For most applications, the charging system for the truck/tractor produces 160 amperes or more. With this, the alternator (and system) carries great potential as an ignition source. During normal operation the alternator is producing anywhere from 12-18 volts (12 volt system) and 24-32 volts (24 volt system). As stated earlier, this is accompanied by amperage ratings from 160-300 amps. Positive (B+) and negative cable connection condition is vital for safe operation.

In some instances a fire has begun with the vehicles' engine off and after some period of time since the most recent engine shut-down. This can be attributed to an internal alternator failure; in some instances a diode failure. Diodes act as a one-way check valve for current. Typically, if a diode fails in this scenario, positive (B+) battery voltage/current goes to ground and has been known to start a fire (Photos 4A and Appendix B).

Photograph 4A shows an alternator that was determined to be the cause of this fire. Photograph 4B shows the alternator of a truck, parked next to the truck in Photograph 4A, however, completely different appearances, despite being involved in the same fire only a few feet apart.

The alternator in Photograph 4A was found on the ground next to the truck, when it was picked up, it had created an unburned area on the floor. This indicates that it fell to the ground prior to anything else falling on that spot and covering the floor in that area. The solution to this potential fire scenario is to park the truck with the main battery switch off. This will disconnect the batteries from the alternator eliminating this potential.

Photo 4A: Causal Alternator

Photo 4B: Non-Causal Alternator

Photo 5A: Remote Jump Posts

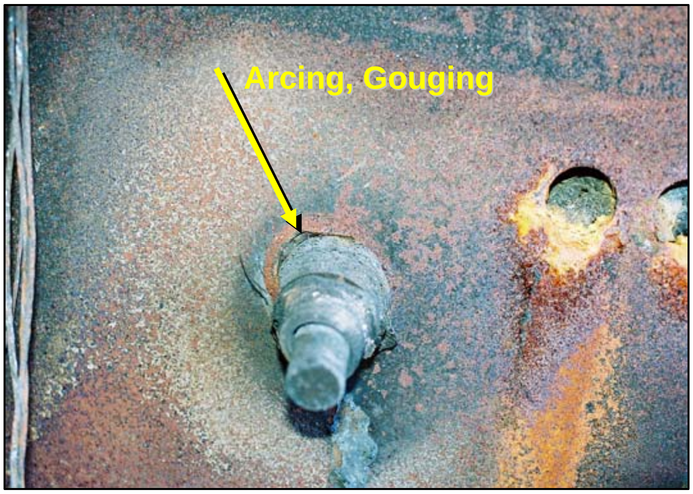



Photo 5B: B+ Jump Post, Battery Box

Photo 6: Hub Failure/Tire Fire

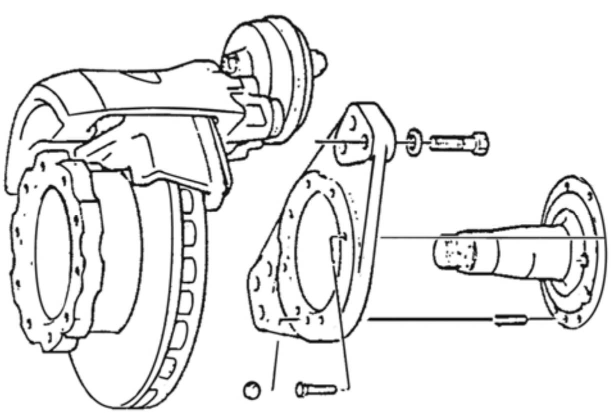


Fig. 3: Disc Brake/Spindle End

**REMOTE JUMP POST**

With some applications a convenience feature is provided in the engine compartment, mounted to the frame rail or battery box for "jumping" a disabled vehicle. This is typically a positive (+) cable running from the starter or battery to an exposed stud. These connections must be inspected and maintained to provide integrity. Additionally, this stud is covered with a flexible rubber boot (Photo 5A).

This boot must be in good condition and over the positive (+) stud at all times. A loose jumping stud/cable, or if it is contacted during a collision, can create a sustained duration high energy spark (Photo 5B).

**STARTER**

Heavy trucks use a variety of starters, Delco, Mitsubishi, Prestolite and Leece-Neville to name a few. Under normal circumstances the starter draws 800 to 1000 amps while cranking the engine. When it is not cranking the engine (no current flow) it is simply exposed to battery voltage. As with the alternator, the starter is connected to the batteries via a B+ (direct battery feed) cable. It too is routed to a stud on the starter motor. Care must be given to the cable condition, cable to starter connections, as well as its' routing so that this B+ cable is not making unwanted contact and potentially coming in contact with ground as a result of an insulation breach.

The starter should be treated and cared for in the same manner as the alternator since it resides on the fuel side of the engine in some applications.

**COMBUSTIBLE MATERIALS**

In some cases, the onboard fuel supply can be a causal element in a fire. In order for the fuel to ignite, the surface temperature of the engine and related components must be at least at the auto-ignition temperature of diesel fuel, a high energy sustained duration spark or open flame must be present. All of the liquids; fuel, power steering fluid, engine oil and hub/gear oil, found on a heavy truck or piece of heavy equipment have an auto-ignition temperature (see Appendix C).

If one or more of these fluids/combustibles were to come in contact with a sufficiently hot surface at auto-ignition temperature; that fluid/combustible would ignite in the absence of an open flame. To minimize fluid fires, all hoses, housings, couplings, fittings and filters must be inspected diligently to reduce or eliminate leaks which could lead to a fire. Practically speaking, the first step is to regularly clean the engine, transmission and interior surfaces of the engine compartment. This has a triple advantage to the operator. First, oil and road dirt covering the engine will act to insulate it holding in engine heat. Second, when the engine is clean it is easier to locate a fluid leak. Lastly, with a clean engine, you reduce the risk of fire and it spreading by virtue of not having any combustible materials on the engine itself. Investigators should observe

Photo 7A: Deformed Bearing Rollers

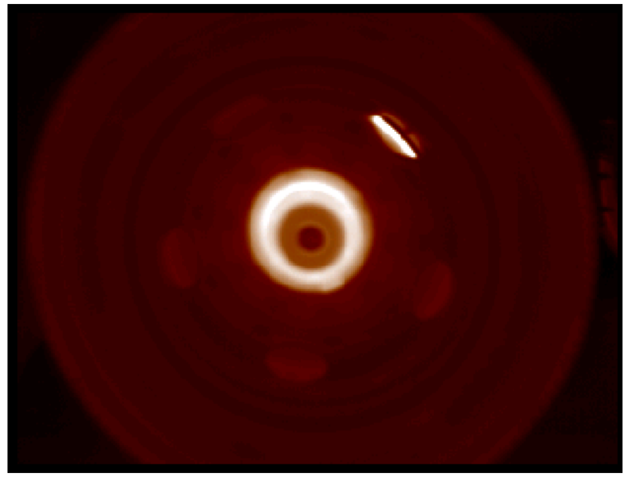


Photo 7B: Thermal Scan; Overheated Wheel Bearing

flame/heat patterns in the engine compartment/room as a further cause and origin method.

**HUB FAILURE**

Wheel hubs low on oil can have an elevated operating temperature high enough to ignite the surrounding combustible materials (hub oil and tires) by auto-ignition. Coincident to this, in some cases, is a wheel end failure resulting in a "wheel-off" situation. Typically, the outer wheel bearings' lowest point is above the lowest point of the hub seal. Therefore, since the outer bearing is at that elevation, it starves for oil first. The inner bearing is at a lower point in the hub and is usually bathed in oil for a longer period of time. There are two common failure modes for the hub (non-driving) to be low on oil; hubcap failure and seal failure. The hubcap can have at least four failure modes; the plastic site glass, o-ring, the rubber plug and the mounting gasket. For any of these reasons the hub can become low on oil. As for a drive hub, the axle flange gasket or seal can be a leak point allowing the hub to become low on oil. It is noteworthy to mention that when the seal wiper becomes worn (grooved) it may create a leak point despite the integrity of the seal itself. The wiper should be inspected each time the hub is removed and changed if it appears to be excessively worn. In some cases, *during a wheel bearing failure, the vehicles' A.B.S. dash light may become illuminated as a result of the sensor-to-hub gap becoming greater due to the hub beginning to come off of the spindle or axle tube, a skidding or locked tire/wheel, or a unitized wheel end failure.* The A.B.S. control module can, in some cases, be downloaded after the incident in order to determine whether or not the A.B.S. system detected a failure prior to the fire—such as a skidding tire due to a bearing failure. This information can be assistive in the cause and origin determination.

Photograph 6 shows a burned trailer which experienced a hub failure. This failure was caused by low hub oil level. This condition ultimately led to the fire which started at the tire. This is indicated by the deformed (melted) bearing rollers (Photo 7A). Bearing rollers, with this appearance, can only occur when

Photo 8: Causal Disc Brake/Wheel End Failure

Photo 9: Non-Causal Disc Brake/Wheel End

the hub oil level is low. This deformation can not occur due to the fire. Low hub oil levels create extremely high heat (Photo 7B). The weight of the load, that the bearing supports, creates pressure on each bearing roller. This pressure coupled with the extreme heat creates the rollers deformation. Once this occurs, the tire(s) near this area can ignite.

An additional hub failure risk exists, with disc brake applications, during a wheel bearing/hub failure. That is, as the outer bearing begins to fail, the hub load is transferred from the outer bearing to the brake caliper, brake pads and rotor. Once the outer bearing has failed completely, no longer able to support the hub load, the caliper, brake pads and rotor are then supporting that particular wheel end (Photos 8, 9). This is due to the fact that the caliper rides in the caliper carrier which is attached to the spider (torque plate) which is mounted to the axle tube/spindle (Fig. 3).

Once the brake caliper begins carrying the load, at that particular wheel end, the surface temperature of the brake pads and rotor (or drum) rise well above the auto-ignition temperature of the surrounding combustibles (due to friction) eventually igniting them. The combustible material typically ignited by this failure mode is the tire(s). This concept of brake caliper/pad/rotor supporting the hub load can typically be seen by non-parallel brake pad contact surfaces. As a result of this temporary load support from the caliper, the operator may continue to drive the vehicle without any indication of a problem until it is too late.

## DISC BRAKES

A “frozen” disc brake caliper can generate enough heat to ignite the surrounding combustible materials and sustain a fire. Proper inspection and lubrication intervals (if applicable) should be adhered to along with a periodic activation and release sequence confirming that the caliper is releasing and allowing the rotor to turn freely. This scenario applies to both air and hydraulic disc brakes. A simple method to determine the proper action of the caliper is to insert a feeler gauge (.002” - .004”) between the brake pad and rotor. By applying the service brakes a technician can feel if the gauge goes into this space, remains there upon brake application and is then released upon release of the service brakes.

## DRUM BRAKES

Drum brakes can create a fire hazard similar to disc brakes by supporting the hub load, during a bearing failure or by a partial application (stuck) brake. Specifically, if the brakes are applied during vehicle motion, through either the service or parking system, they can create enough friction, leading to extreme heat, that they can cause a tire fire or ignite some other combustible material (Photo 10). Over the last 20 years, engine manufacturers have continually produced engines with high

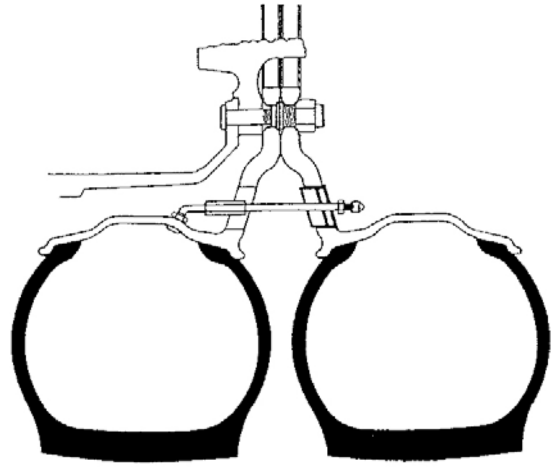


Fig. 4: Sectional View of Dual Tire

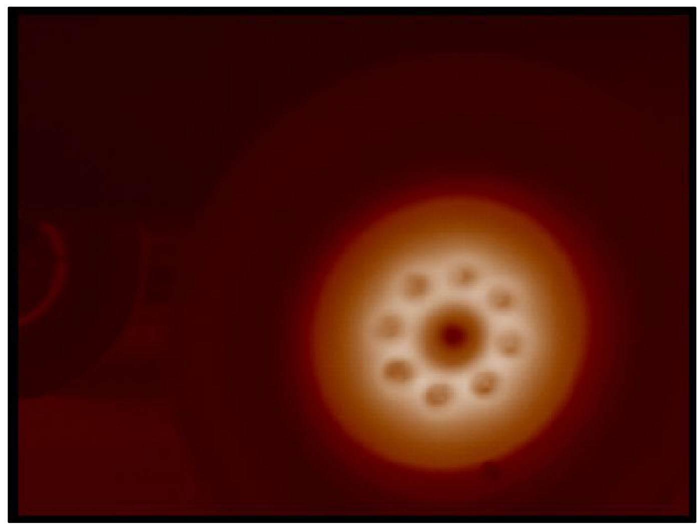


Photo 10: Thermal Scan: Over-Heated Brake Drum

Photo 11: Tire Fire Started by Dragging Parking Brake

Photo 12A: Brake Drum Rouging Caused by Overheating

Photo 12B: Drum Brake; Brake Blocks Overheated

Photo 13: Fused Brake Block

horsepower and torque ratings. These high output engines are capable of driving through a partially applied service brake or fully applied parking brake. If this was to occur at highway speeds, enough frictional heat can be developed to start a fire (Photo 11).

Various pneumatic and mechanical issues can prompt a brake failure which can lead to a fire. Generally speaking, when drum brakes approach this scenario, they leave signatures. Brake drums may show signs of rouging (Photo 12A) and the matching brake blocks may show a burn pattern if not damaged by the fire (Photo 12B). In the extreme case the brake blocks can become fused to the drum as a result of the bonding agent (resin) of the brake blocks actually beginning to melt and burn (Photo 13).

## TIRES

A flat or under-inflated dual tire, or single tire, can have an elevated temperature and in some cases go undetected. Dual tires are spaced apart to provide a gap to prevent contact between the tires (Fig. 4).

If the adjacent tire is under-inflated the gap closes and the tires begin to "kiss". Since an under-inflated tire only bulges at the road surface, a cyclical contact event occurs between the inflated tire and the under-inflated tire. Over time this cyclical contact may generate heat increasing the tires temperature.
Therefore, operators should always ensure that all tires, especially dual tires, are inflated and not in contact with one another. In general, operating temperatures for radial tires can be anywhere between ambient plus 60$^{O}$F (150$^{O}$-180$^{O}$F). Under severe conditions the operating temperatures will range in the 200$^{O}$F area[1] (Photo 14). Tires generally revert (melt) at approximately 250$^{O}$F and catch fire over the 600$^{O}$F mark. It is common, although not mandatory, for the tire fire to occur when the vehicle comes to a stop. This is the condition with the least amount of air flow circulating around the brake rotors,

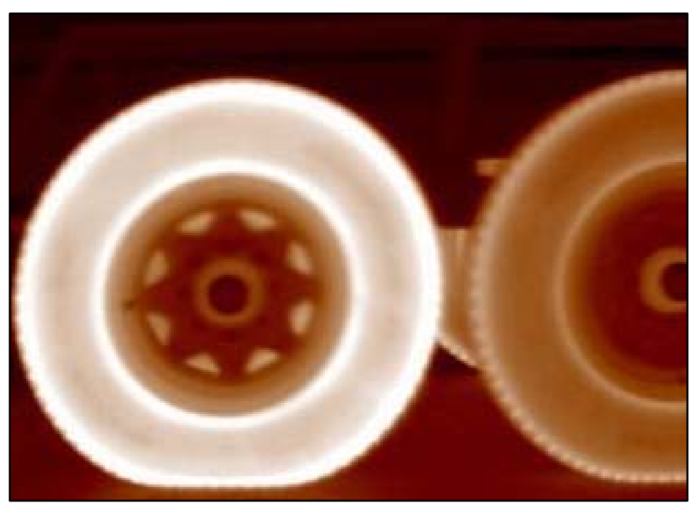


Photo 14: Thermal Scan: Overheated Tire, Due to Low Inflation Pressure

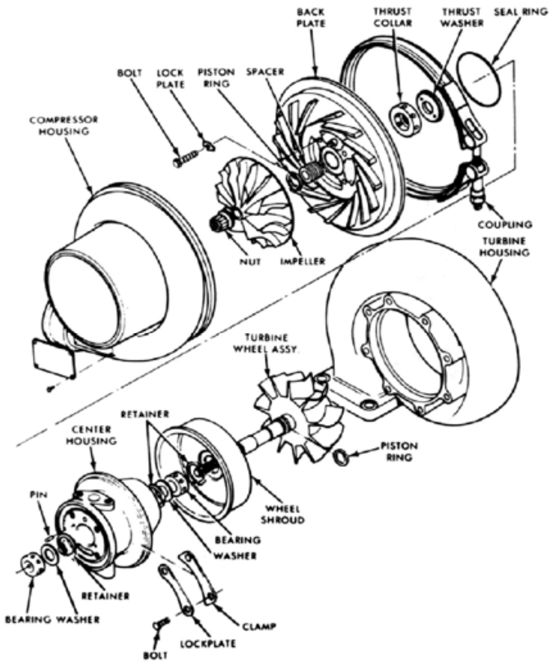



Fig. 5: Turbocharger, Exploded View

brake drums and tires. Without air flow around these items, their temperature rises rapidly and is transmitted to the tire—subsequently igniting it.

Tires which have ignited during (rotation) travel can be indicated by the disturbance or twisting of the tire reinforcing cords. Tires that have ignited while stationary (no rotation), have tire cords which remain largely undisturbed (Photo 15). In general, tires do not become a fire hazard on their own. In most cases it takes a localized failure of an adjacent component to ignite the tire(s).

## TURBOCHARGER

Turbochargers are a dual threat as an ignition source. First, since they are typically very hot, on the surface, they can act as an auto-ignition source. Second, upon their own internal failure, they can become an ignition source by virtue of their own internal lubrication oil. The typical turbocharger supports the shaft of the compressor and turbine with a non-conventional bearing. This is unlike the typical roller bearing. Instead the shaft is supported by two bearing collars which are supported by the boundary lubrication layer (Fig. 5).

Upon a failure of this bearing system or an imbalance of either the turbine or compressor wheels contact is made within the turbocharger housing, causing a rapid deterioration of the compressor and turbine (Photo 16). Once the shaft has been reoriented, as a result of any one of the aforementioned failure modes, the shaft seal(s), which controls the lubrication oil within the bearing cavity, subsequently fails allowing oil to enter directly into the hot side (turbine) of the housing and then directly into the exhaust system (Fig. 6). This can create an

Photo 15: Straight Tire Cords Indicating No Rotation at Time of Fire

Photo 16: Failed Turbocharger

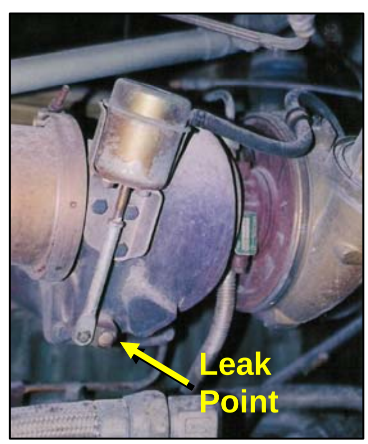



Photo 17: Turbocharger/Waste Gate

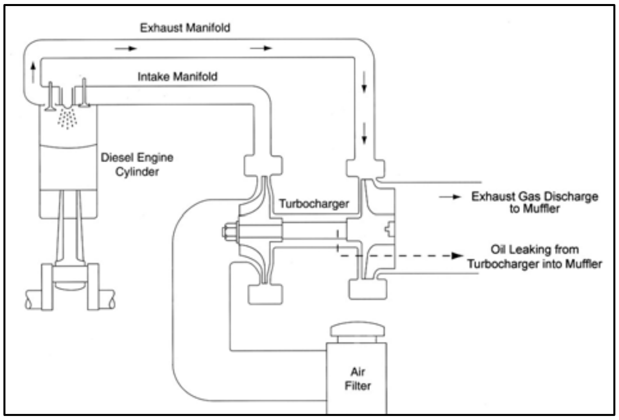



Fig. 6: Air Intake Schematic

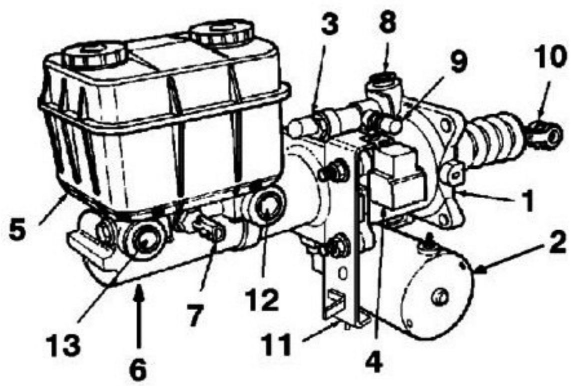



Fig. 7: Electric Backup Brake Booster (Motor is Item #2)

auto-ignition fire within the turbocharger itself or exhaust system.

Some engine manufacturers have reprogrammed engine management software to detect the symptom of this failure[2]. The engine's Electronic Control Module (E.C.M.) monitors turbocharger boost pressure for performance and engine management control purposes. With the change in software, the E.C.M. now sets a fault code for low boost pressure which could indicate an internally failed turbocharger. However, if the engine in question precedes any recent software change, two other simple methods can be used to detect the onset of an internal turbocharger failure. If the turbocharger has experienced an internal failure the performance of the engine is compromised. Specifically, blue smoke, due to oil consumption along with reduced engine torque will be noticed. Also a specific oil leak, from the waste gate pivot point, can be observed (Photo 17). Once oil has begun to leak from this point on the turbocharger it should be removed from service and the exhaust system should be thoroughly cleaned. To assist in preventing this failure mode; the turbocharger waste gate or variable geometry function (V.G.T.) must be confirmed.

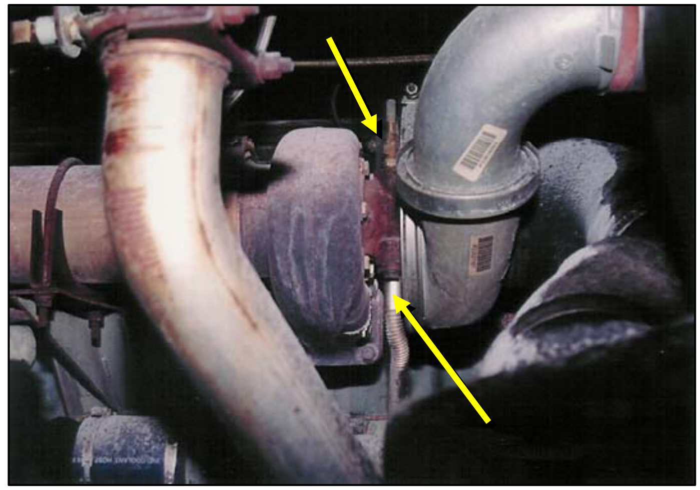


Photo 18: Typical Turbocharger Oil Inlet/Outlet Lines

Photo 19: Auxiliary Power Unit

These two systems regulate turbocharger boost pressure. If they were to fail to regulate this pressure, it may lead to an internal failure, as a result of over pressurization and/or over-speed, thus leading to a fire. Additionally, the shaft free play, both axially and radially, must be inspected by a mechanic.

## EXTERNAL TURBOCHARGER OIL LINES

With most 4-stroke cycle inline engine applications, the turbocharger has two oil lines which need to be periodically inspected (Photo 18). These turbochargers have an external supply and return oil line. In either case, a leaking oil line must be repaired to prevent an auto-ignition fire.

## SENSORS/TRANSDUCERS

In most applications there are sensors which are exposed to either: fuel, engine oil, transmission fluid and hydraulic oil to name a few. These sensors are typically diaphragm type; that is to say, an internal diaphragm is moved by the fluid pressure inside the sensor/transducers/switches. Since pressurized fluid enters these sensors/switches it is vital that they be periodically inspected for leaks. Based on their position on the engine/transmission/component they may become a source for a combustible fluid leak point which may come in contact with an ignition source and initiate a fire.

## AUXILIARY POWER UNITS (A.P.U.)

Some heavy trucks utilize an auxiliary power unit to provide air conditioning, heat or electrical power while the engine is off (Photo 19). These need to be inspected and analyzed to determine if they are related to the fire. The A.P.U. is similar to the trucks engine in that it has its own starter, alternator, fuel system, lubrication and electrical distribution system. Each of these items needs to be analyzed to determine if any were related to the fire. Additionally, the A.P.U. can also be an auto-ignition concern and must be evaluated in that regard.

## 2007 EMISSIONS SCHEMES

At the time of this publication a growing number of 2007 engines with regeneration capability are entering the stream of commerce. The design suggests regenerating (cleaning) the particulate trap by elevating its temperature to burn off the material trapped inside[3]. The regeneration process converts ash and soot, which is trapped in the diesel particulate filter (DPF) and converts it to carbon dioxide. In order to do this the engine must create exhaust gases with high enough temperatures to complete this process. In some designs, during regeneration, raw fuel is injected near the turbocharger, via a doser, increasing the temperature of the exhaust gases to 1200-1500°F. As with any other component, with a high (>430° F) surface temperature, leaks in the immediate area must be repaired to avoid contact with this system while it is regenerating the DPF. Lastly, this systems' interlocks, which dictate when it can function, must be confirmed to be working to avoid a cycle of regeneration at a time or location which is undesirable.

## BATTERIES/CABLES/DISTRIBUTION/ ELECTRICAL SYSTEM

These elements of the electrical system carry and distribute the electrical power throughout the vehicle. Battery location, cable routing and securement, along with control elements, all have the potential to become ignition sources.

*Battery location* is an important design element within any vehicle. The placement of the batteries, in some cases, can be impacted in the collision phase of an accident. This can lead to becoming an ignition source of a fire. This is explained in greater detail in Reference 4.

*Cable routing and securement* is usually a packaging and "house-keeping" item with respect to vehicle design. Cable routing and securement goes hand-in-hand. Loose, pinched,

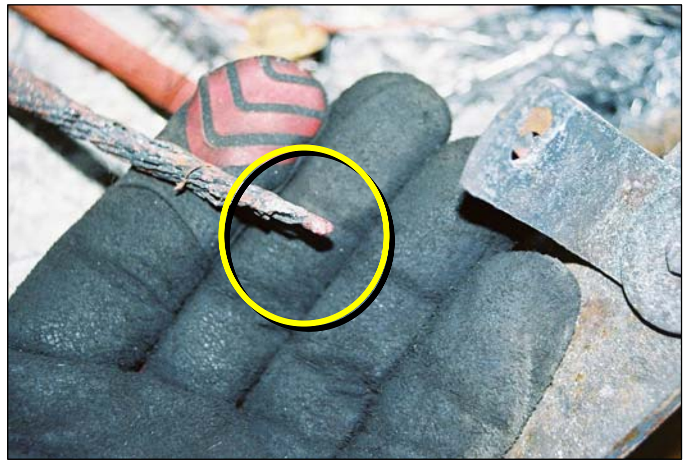


Photo 20: Example of "Balling" Phenomenon

Photo 21: B+ Cable Contacting Structural Gusset Creating B+ to Ground

Photo 22: B+ Cable with "Vee" Cut from Arcing (same cable as in Photo 21)


Photo 23: Full Scale Testing of Fuel Breach

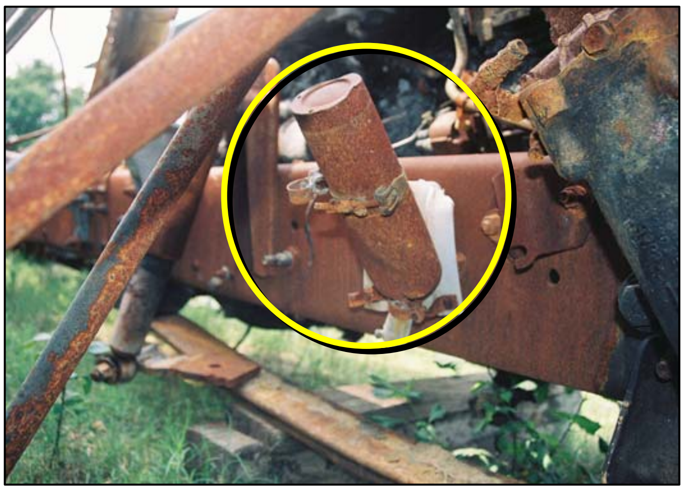


Photo 24A: Starting Fluid Canister-Impact Damage

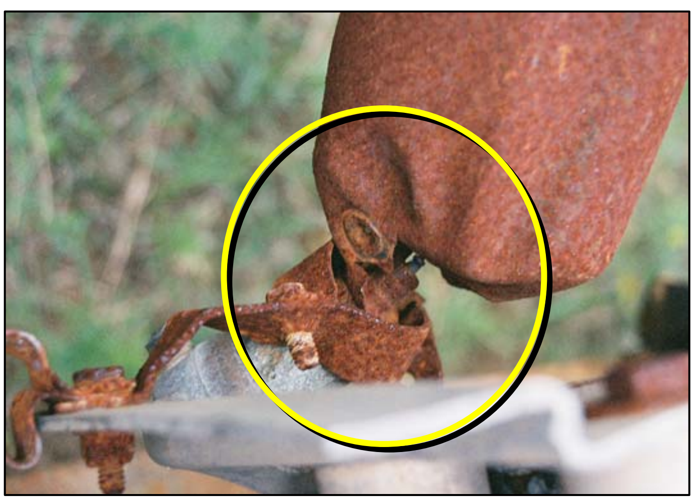


Photo 24B: Starting Fluid Canister (Breached)

excessive length or breached B+ cables(s) can lead to a high energy sustained duration spark which can become an ignition source. For example, "balling", a term used to describe the physical appearance of a cable which has experienced a separation under power is shown in Photograph 20.

Cables which can be contacted during the collision phase of an accident can become an ignition source. The securement of the cable(s), once routing is established, is vital to prevent the breaching of the insulation or the mechanical failure of a cable connector. In some cases, over time, a B+ cable can move cyclically enough that it will eventually make contact with chassis ground creating a sustained duration, high energy spark (Photo 21). In this case a simple clamp (p-clamp) was omitted during assembly which allowed the B+ cable to dangle enough so it contacted a structural gusset creating arcing (Photo 22).

## CHASSIS COMPONENTS

Some trucks with hydraulic brakes, utilize an emergency brake booster which is powered by an electrical motor (Fig. 7). This system is intended to provide boost assistance to the brakes during an engine stall. Without this system, the operator would not be able to provide enough force, by his/her foot, to stop the truck. This system is wired to battery power. That is to say, it is powered all the time regardless of the position of the ignition switch. Consequently, this can become an ignition source even when the engine is off and has been parked for some time.

## VOCATIONAL COMPONENTS

Vocational components and systems are utilized to perform the intended task of the vehicle. For example, a fuel truck may need to pump fuel, from its tank, to the intended storage tank of the customer. Numerous failure modes of the overall system can create either an ignition source or provide the release of the combustible materials. Photograph 23 shows the failure of a fuel delivery elbow, mounted to the tractor, used to distribute gasoline by a chassis mounted pump. Post accident forensic test methods[‡] were utilized to recreate the release of fuel. This group of facts developed into an airborne combustible particulate ingestion and "back fire" fire. This concept is further explained in Reference 5.

[‡] The general methods used for this study were; locate artifact elbow, recreate failure breach pattern on an exemplar elbow, pump water through the exemplar elbow to demonstrate fuel release.

## ADDITIONAL IGNITION SOURCES

Additional body related ignition sources are:

- Evaporator motor(s)
- Condenser motor(s)
- Defroster motor(s)
- A/C compressor clutch coil/wires
- Radio
- G.P.S. systems
- Dash board wiring
- Air dryer heater wire
- Headlight wiring
- Air conditioning, high/low pressure switch wiring; typically carries a ground signal. This can usually be ruled out as an ignition source.
- A.B.S signal wiring; typically carries an inductive low voltage (mili-volts) signal to the A.B.S. controller. This can usually be ruled out as an ignition source.
- Engine Starting Aids (Starting Fluid Canisters) (Photo 24A, 24B)

These systems must be inspected periodically for proper wire/cable routing and support along with proper (B+) connections and wire insulation. Usually not a leading fire cause they must be as vigilantly inspected as any other component on the vehicle.

## CONCLUDING REMARKS

The purpose of this paper is to assist the investigator in conducting fire cause an origin analysis of heavy truck and equipment fires as well as to show the mechanical fingerprints which are associated with it. Additionally, once the correct cause and origin is established, the manufacturer may elect to change the system/design to prevent future fires.

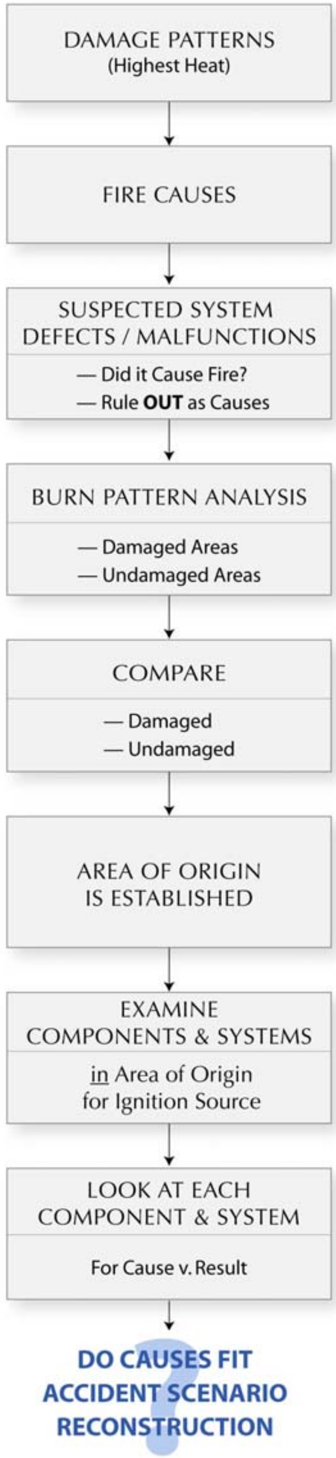
## REFERENCES


1. Bridgestone Commercial Tires (Tire, M.D.)
2. Detroit Diesel Corporation; S-60 Burst Logic Safety Recall, NHSTA-06E-19, DDC:06C-4
3. Detroit Diesel Corporation; *Introducing the New 2007 Series-60*; 6SA2000 (0604), PT3M, 6SA2004 (0603).
4. Ferrone, C.W., Sinkovits, C., “Fire and Explosion Investigations; Why Heavy Trucks May Burn,” A.S.M.E. paper #IMECE 2006-13305, November 2006.
5. Ferrone, C.W., Sinkovits, C., The Runaway Diesel: A Side by Side Mechanical Analysis,” A.S.M.E. paper #IMECE 2005-79034, November 2005.


## AUTHORS NOTE

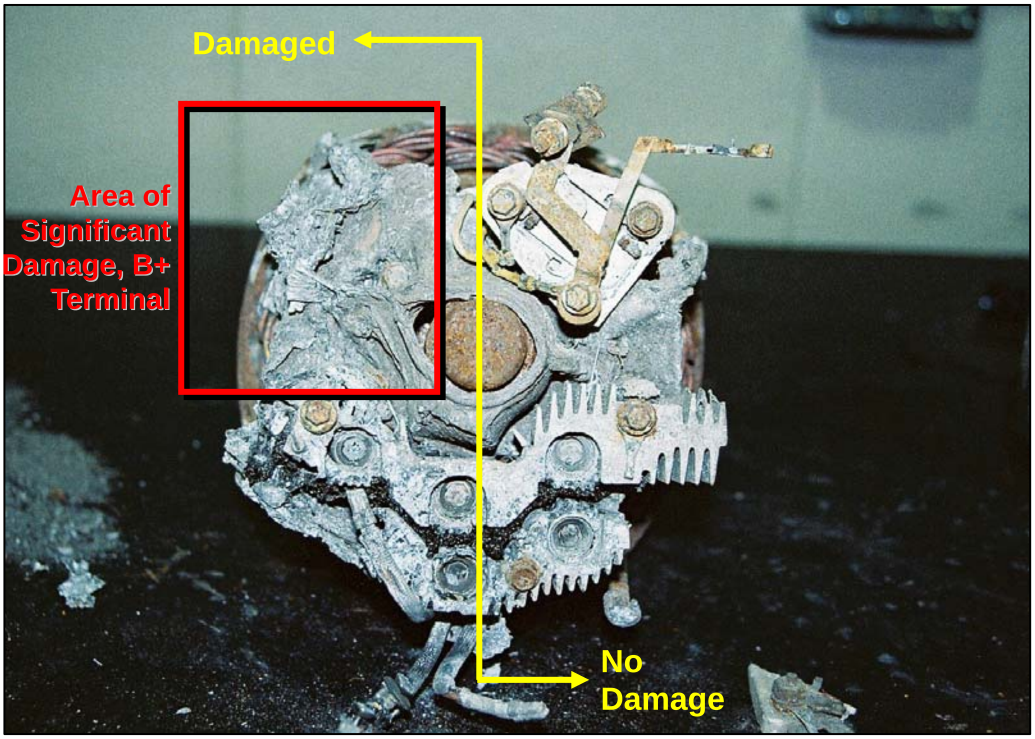
Photograph 7B, 10, 14 were supplied by International Electronic Machines, Corp. These photographs (images) were taken using the SIRIS™ Smart Infrared Inspection System.

**APPENDIX A**

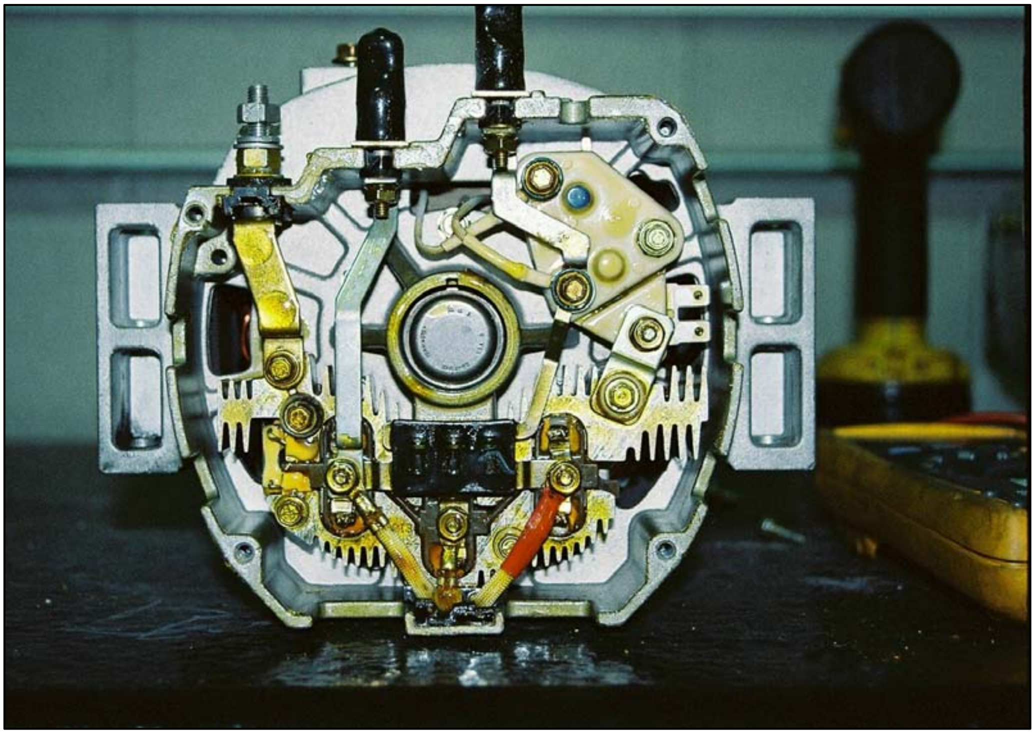



**NOTE: THIS IS A GENERAL SUMMARY OF THE METHODOLOGY DESCRIBED IN N.F.P.A. 921**

**APPENDIX B**




Artifact Alternator



Exemplar Alternator

# APPENDIX C

## AUTO IGNITION TEMPERATURES IN F° / C°

**On Board Fluids**

| | |
|---|---|
| **Diesel Fuel** | **446° / 230°** |
| **Power Steering** | **417° / 213°** |
| **Engine Oil** | **449° / 231°** |
| **Transmission Fluid** | **417° / 213°** |
| **Transmission Gear Oil** | **730° / 387.8°** |
| **Coolants (50/50)** | **903° / 483°** |
| **Hub/Gear Oil** | **428° / 220°** |
| **Tires (smoldering)** | **450°-500° / 232°-260°** |

**Note: These are examples only and do not represent all types and varieties of fluids.**

## FLASH POINTS IN F° / C°

**On Board Fluids**

| | |
|---|---|
| **Diesel Fuel (1-D)** | **100° / 37.8°** |
| **Diesel Fuel (2-D)** | **125° / 51.7°** |
| **Diesel Fuel (3-D)** | **130° / 54.4°** |
| **Gear Oil** | **369°-580° / 187.2°-304.4°** |
| **Engine Oil** | **420°-485° / 215.6° - 251.7°** |
| **Power Steering Fluid** | **365°-450° / 185°-232.2°** |
| **Transmission Fluid** | **399°-453° / 203.9° - 233.9** |
| **Coolants (50/50)** | **230°-270° / None - 110°** |

***Flash points: the lowest temperature at which the vapor of a combustible liquid can be ignited in the air.**

**NOTE: These are examples only and do not represent all types and varieties of fluids.**