

A REVIEW OF TRUCK FIRE CAUSATION

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Abstract

This paper reports on common causes of fires on heavy trucks, buses and trailers. The author is professionally engaged in forensic engineering investigations, including fires. The paper gives the author's experience of nearly twenty years of heavy-vehicle fire investigations.

The likelihood that a particular heavy vehicle will catch fire during its lifetime is very low. However, the population of heavy vehicles is large enough, and the operating conditions of the vehicles severe enough, to result in a noticeable number of fires; at least in Australia. Heavy-vehicle fires (unrelated to road crashes) apparently occur every day in Australia. There is evidence that heavy-vehicle fires in Australia initiate about 8% of heavy-vehicle insurance claims. Whilst the operating conditions of heavy vehicles might differ in different countries, the causes are likely to be the same.

The common causes of fires are presented here to inform both vehicle owners and vehicle manufacturers about the common causes of fires in Australia. There is some potential for improvements to vehicle designs and to maintenance and inspection practices, which might reduce fire risk.

The paper also describes the forensic process. A competently conducted forensic assessment of fire causation is important so that avoidance countermeasures can be taken on other vulnerable vehicles and so that expensive legal action can be avoided.

Keywords: Truck fires, trailer fires, forensic fire examination, fire causation.



1. Overview

The research is based upon Australian experience, and it has not been determined to what extent geographical factors are important. High ambient operating temperatures, vibration-level and the length of the service-life of vehicles are certainly factors in the rate of vehicle fires and these might differ from country to country. It is noted however, that heavy vehicle technology is similar the world-over.

A leading Australian insurer publishes a regular review of its claims history applicable to the heavy vehicle industry. Figure 1 shows that the attribution to vehicle fires is about 8% of total fault attribution. It exceeds mechanical failure and theft as causal factors.

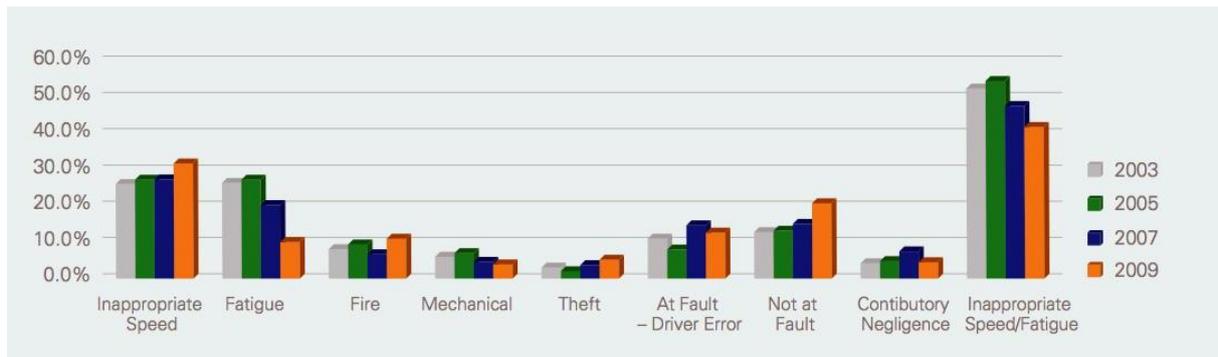


Figure 1 Incident cause-attribution for heavy-vehicle insurance claims (source National Transport Insurers – Australia, 2011). Note: multiple factors can apply so the totals add to greater than 100%.

Serious vehicle fires are usually investigated by a fire-scene examiner and maybe by a forensic engineer. The obvious motivation is to determine a cause so as to prevent other instances. Often insurance companies fund the investigation and occasionally litigation occurs in consequence of the findings.

This paper is mainly concerned with providing a reference to known vulnerabilities. Examples will be given in the following categories:

1. Insulation failure on electrically-unprotected cables.
2. Insulation faults on electrically-protected cables.
3. Overheating at electrical terminals.
4. Battery explosions.
5. Turbocharger failures.
6. Exhaust pipe fires.
7. Fuel and oil line failures.
8. Dragging brakes.
9. Extreme brake imbalance.
10. Wheel bearing fires.
11. Tyre rubs.
12. Static electricity on fuel- and grain-discharging vehicles.
13. Combustible materials lodging in hotspots or in electrical junctions.
14. Heating of combustible loads.
15. Clashes with fixed overhead electricity lines.

Examples in all these categories are presented. The design factors that exacerbate vulnerabilities in each category are also discussed. Recommendations for design improvements are directed to vehicle manufacturers; and for periodic inspections, to vehicle operators.

2 The Forensic-Investigation Process

Fire causation assessment should be based on a scientific approach. A plausible and likely cause can be identified in about 90 % of cases if the forensic examination is thorough and competently conducted. The cause of the other 10% is speculative because the level of fire damage is so great that the physical evidence is destroyed. In reality investigations are often poorly conducted and this promotes uncertainty that often results in court arbitration.

The essential aspects of a thorough investigation are:

- Careful observations recorded as notes and drawings;
- Records of details at the fire scene, including the taking of a large number of high quality photographs;
- Identification of fire markers;
- Identification of energy-source locations;
- Evacuation of burnt parts of particular interest;
- Thorough witness statements and in-particular a detailed driver statement;
- Assessments that are informed by known vulnerabilities or experience;
- Identification of possible scenarios followed by sorting into *included*, *possible but unlikely* and *excluded* scenarios.
- A ranking of likely cause scenarios justified by reference to the evidence, witness statements, physical evidence and known vulnerabilities.

The information flow of a forensic assessment is illustrated in Figure 1.

3. Electrical Causes

3.1 Electrically-Unprotected Faults

Usual practice is to not provide circuit-breaker or fuse-link protection on the battery-to-starter motor positive cable(s). This practice results from the difficulty in providing a circuit breaker that can provide useful electrical protection, whilst tolerating infrequent starter-motor-level current. Manufacturers typically rely upon double insulation and split plastic conduit. That is; manufacturers rely upon on mechanical protection. The risk is that a rub will occur on the starter motor cables, which destroys the insulation. Furthermore, plastic conduits and PVC insulation might deteriorate over time due to UV (sunlight exposure), mechanical trauma and ageing.

Some manufacturers take a further expedient step of running the alternator cables and the cabin power cables from the starter motor power terminals. This results in an unwise and unnecessary extension of the extent of the electrically unprotected circuits.

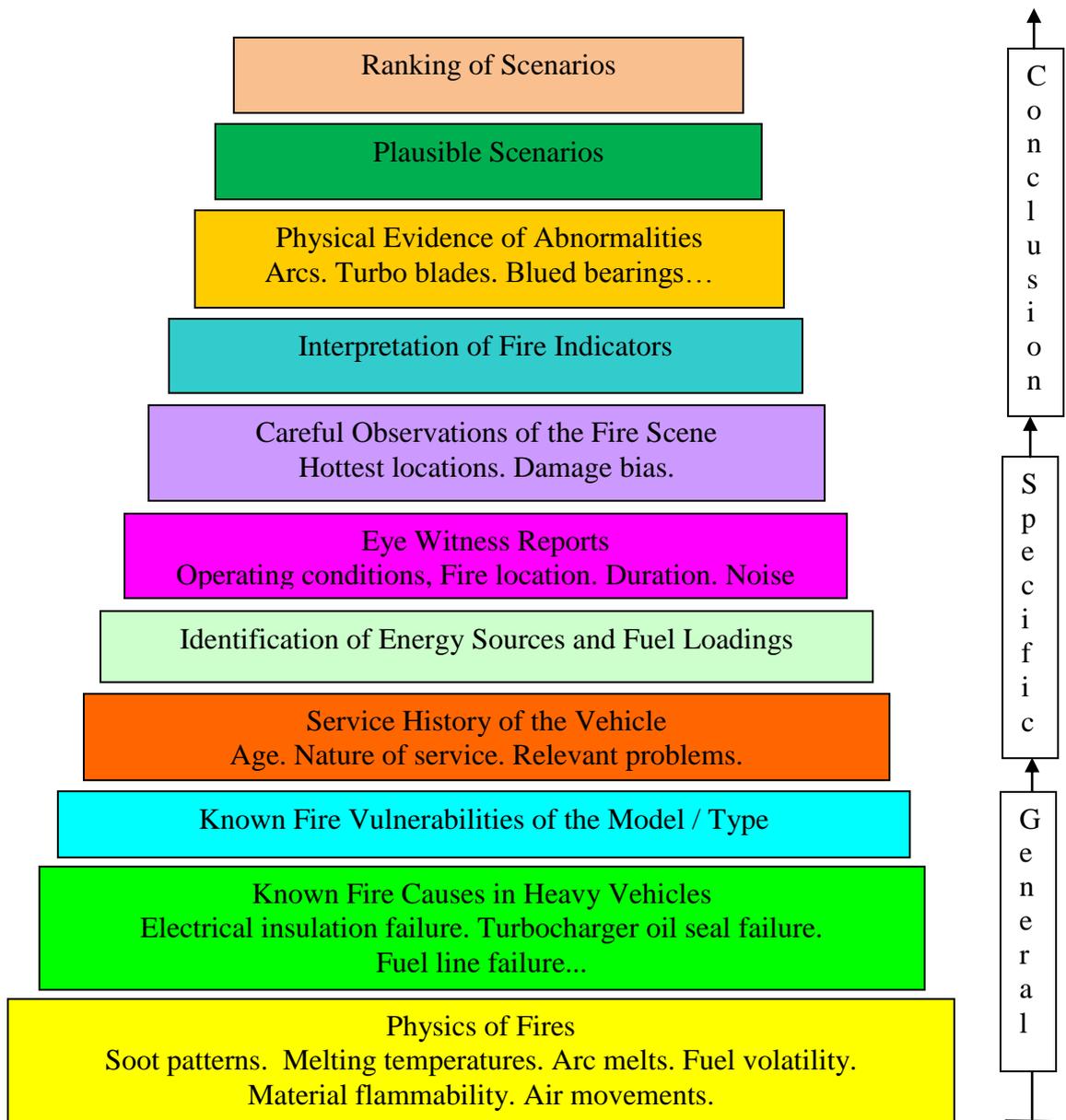


Figure 2 Information-Map for Forensic Fire Assessment.

In the future, battery isolation switches will be available that include circuit breaker protection that is in-circuit except during engine cranking. Abnormal current conditions might also be indicated by building in a Hall-Effect current sensor and some peak detection electronic circuits. In the meantime, manufacturers are encouraged to provide a main (automatically-) resettable circuit breaker for the non-starter battery connections.

Most vehicles now have a cable return (earth) rather than a chassis return, although the engine, transmission and batteries are often also chassis connected. Very occasionally a poor connection in a cable return forces the return current to go via the chassis and the chassis connections are found wanting.

In the author's experience about 33% of heavy-vehicle (and passenger-car) fires occur because of insulation failure on electrically unprotected circuits. All of these could be avoided if electrical protection were provided. Most of them could also be avoided if a thorough, regular examination of cable condition were made in the workshop.

3.2 Faults On Electrically-Protected Circuits

Insulation failure on electrically protected circuits should not cause fire if the protection level is appropriately chosen. That is, well designed circuit protection should always prevent electrical faults causing fire. In practice, the circuit-breaker or fuse protection is often incorrectly chosen. A common problem is that a light-gauge cable is connected into a heavier-gauge circuit. This might be done for example, to connect an instrument (e.g. voltmeter) or warning light onto an ignition circuit that supplies a load. The circuit protection is chosen based on the load current and the light-gauge branch is effectively unprotected. An insulation fault on the light-gauge wire will result in wire fusion rather than circuit-protection action.

The quality of the protection depends critically on the choices made by the designer. One approach is to use earth switched circuits so that most of the exposed circuits are downstream of the load and an insulation fault only causes the load to operate rather than to fault.

A contributing factor in all insulation rubs is the quality of the installation. Insulated clamps should be used that provide a broad clamping surface. Cable runs should be chosen to avoid sharp metal edges. Frequent clamping is needed to prevent cables moving and drooping. UV stabilized wire insulation and conduit should be used.

Figure 3 shows a recommended scheme with separate circuit breakers in the alternator cable and the truck supply cable. Surprisingly, many trucks do not have these circuit breakers. In time, isolation switches that include circuit breaker protection that can be disabled during cranking will be available. They are under development at present. Intelligent circuit protection will also be available. This will identify unusual or unacceptable current waveforms and turn the circuit off before the fault becomes dangerous. The trip conditions will be programmable. The issues will be inappropriate settings and reliability of the electronic circuitry that will be required in this protection scheme.

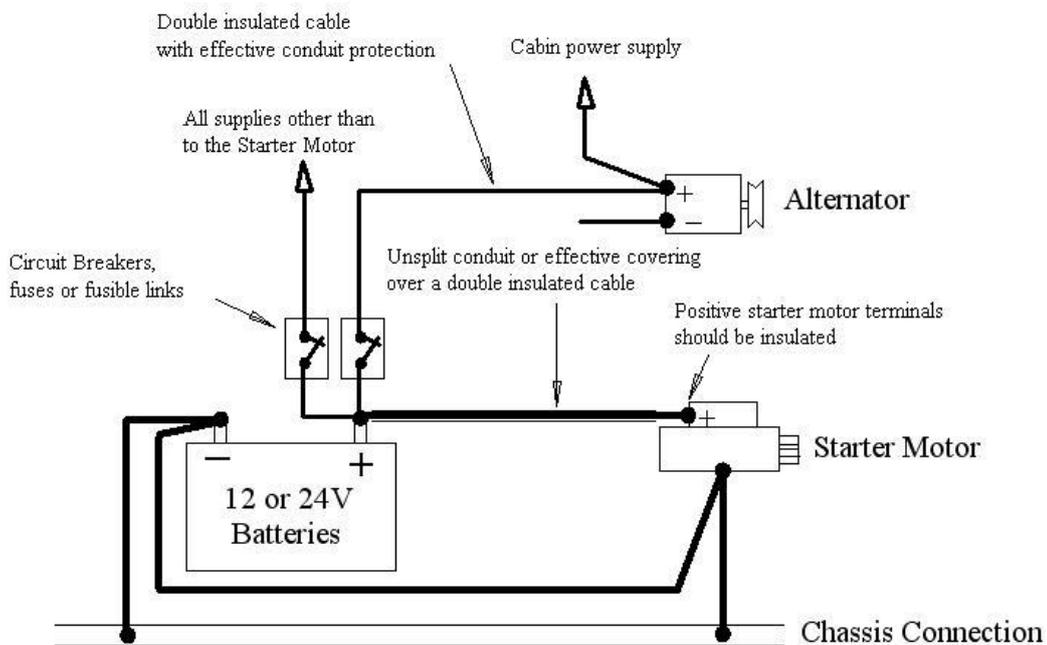


Figure 3 Elements of electrical design



Figure 4 The result of a rub between an alternator cable and an engine stud. The alternator cable (Figure 4) was double-insulated with a split-conduit covering but the split worked its way around to the stud position. There was no circuit breaker protection at the battery end.

3.3 Overheating at Electrical Terminals

Overheating sometimes occurs at a connection point in the electrical circuit. For example, the connection might be a push-on 6.3 mm receptacle-spade terminal at an electrical relay / hard shell connector or a slip-fit fuse connector. Occasionally bolted terminals overheat because a heat-shrink sleeve prevents a flat contact. Terminals will heat on a heavily loaded circuit after hours of operation, particularly when ambient temperatures are high. Terminal heating can cause the plastic insulation on connected wiring or plastic dividers to melt and catch fire. Figure 4 shows a distressed plastic case on a relay. The heating of the plastic is due to heat transmission along the spade terminal metal.



Figure 5 The result of tucking a conduited battery cable on top of an exposed threaded bolt shank inside a battery box.

The contributing factors to terminal heating are:

- Small wire gauge such that the copper wire struggles to absorb and transmit terminal heat.
- Road vibration combined with thermal cycling results in loose slip connections.
- Dirt getting into slip connections.
- Added loads (such as additional driving lights) that are connected to an existing heavily loaded circuit.
- Looseness.
- Contamination between mating faces (e.g. heat shrink ingress).
- Inadequate safety margin in the design.

The latter point needs further clarification. Equipment manufacturers sometimes give a current rating for terminals. For example, a 6.3mm spade terminal is often rated at 30A. Whilst this might be acceptable on a passenger car, it is unacceptable on a heavy vehicle because the conditions are more severe. As a guide the electrical-equipment manufacturer's current ratings should be halved for truck service!



Figure 6 Overheating of a cube relay has resulted from a hot terminal. The plastic case is distressed.

3.4 Battery Explosions

Battery explosions are quite rare. They are even rarer as a fire cause because the explosion is usually heard and the consequences can be responded to.

Lead-acid batteries produce hydrogen. Sealed batteries retain the hydrogen whilst vented batteries loose it. Battery explosions occur when the heavy current path has a broken or inconsistent contact and sparking occurs inside the battery (or very close by). A poor connection at the battery terminals (say due to corrosion or looseness) might cause heating and sparking. Heating at the battery terminals occasionally causes degradation of the plastic case with potential to cause explosion. Battery terminal condition should be inspected in the workshop.

3.5 Electrical Faults Due To Combustible Dust

Organic dust (such as agricultural dust) is flammable and mildly conductive if it is wet. If organic dust settles onto live electrical parts, a 'high-impedance' electrical fault can occur. The fire mechanism is current flow through the dust that causes heating and eventually results in carbonization. Once carbon is present, the current level increases as does the heating potential. If the electrical circuit is battery powered, the fault can occur when the vehicle is parked.

Alternators are vulnerable to this fire cause because they have live internal circuits and air-cooling grills that allow dust in. Electrical equipment that is open to atmosphere so as to provide cooling, should be regularly blown out with compressed air.



Figure 7 Fire resulting from a shorting through agricultural gain dust inside an alternator (on a trailer blower motor).

4. Turbocharger Fires

Turbochargers occasionally suffer mechanical failure. Usually the bearings are badly worn and this allows either the impeller, or the exhaust turbine wheel to contact the housing. Because the blades are turning exceptionally fast, catastrophic mechanical failure is likely to occur. A fractured turbocharger blade might throw a fragment through the flexible stainless steel pipe that connects to the exhaust side or through the aluminum tube that typically connects to the air-intake side. Whilst a hole in the exhaust pipe could cause surrounding material to catch fire by allowing hot gases out, this is extremely rare.

In the author's experience fires occasionally result from turbocharger failure because the rotor oil seals on the air intake side are damaged by the blade failure and an oil-fed fire occurs on the air-intake side of the turbocharger. Truck turbocharger bearings are invariably lubricated and cooled by forced engine-oil flow. If the oil seals fail on the exhaust side, a fire will occur in the exhaust pipe. However, the exhaust pipe is designed to withstand high temperatures so an external fire is unlikely to occur. If however, the oil seals on the air-intake side fail, oil might be pumped into the air intake side. Should this oil catch fire, the internal fire will probably get out by burning through a rubber elbow, or maybe through an aluminum tube.

High temperature is needed for diesel to ignite. The source of high temperature is heat transfer from the exhaust side to the air boost side. For this to occur the cooling effect of the forced oil

supply to the bearing compartment, that is in the centre of the turbocharger, must have failed. Either the oil supply is cut off or the oil in the bearing compartment is on fire.

The factors that could lead to turbocharger fires are:

- Restricted oil flow to the bearing compartment.
- Excessive bearing wear.
- Oil backing that blocks the oil ducts.
- High exhaust-gas temperature due to over-fueling.

The last factor can occur if the exhaust or air intake restrictions are excessive, or if the boost pressure is abnormally low, because the engine controller will usually compensate for restricted air supply by increasing the fueling level. Sometimes the restriction of a single exhaust pipe rather than a dual exhaust is sufficient to produce a high exhaust restriction level that results in over fueling. In another example a leaking charge-air cooler caused low boost that led to over-fueling.

Long-term abnormally high exhaust temperature is likely to lead to backing of oil inside the bearing enclosure and premature turbocharger failure and occasionally to external fire. A useful indicator of excessive backpressure is 'bluing' of the exhaust pipe (although truck fire can confound this assessment). The driver will probably report hearing a bang when the turbocharger fails, and immediate loss of power.

Figure 8 shows a demonstration turbocharger. With the air-boost side oil seal indicated. This is the vulnerable oil seal. Should a fire occur in the exhaust side as a result of seal failure, which is possible, the fire might spread to the air intake side if the bearings and oil seals are damaged. Drivers should be instructed to not drive a vehicle that has a failed turbocharger because subsequent destructive failure of the bearing assembly could result in a vehicle fire.

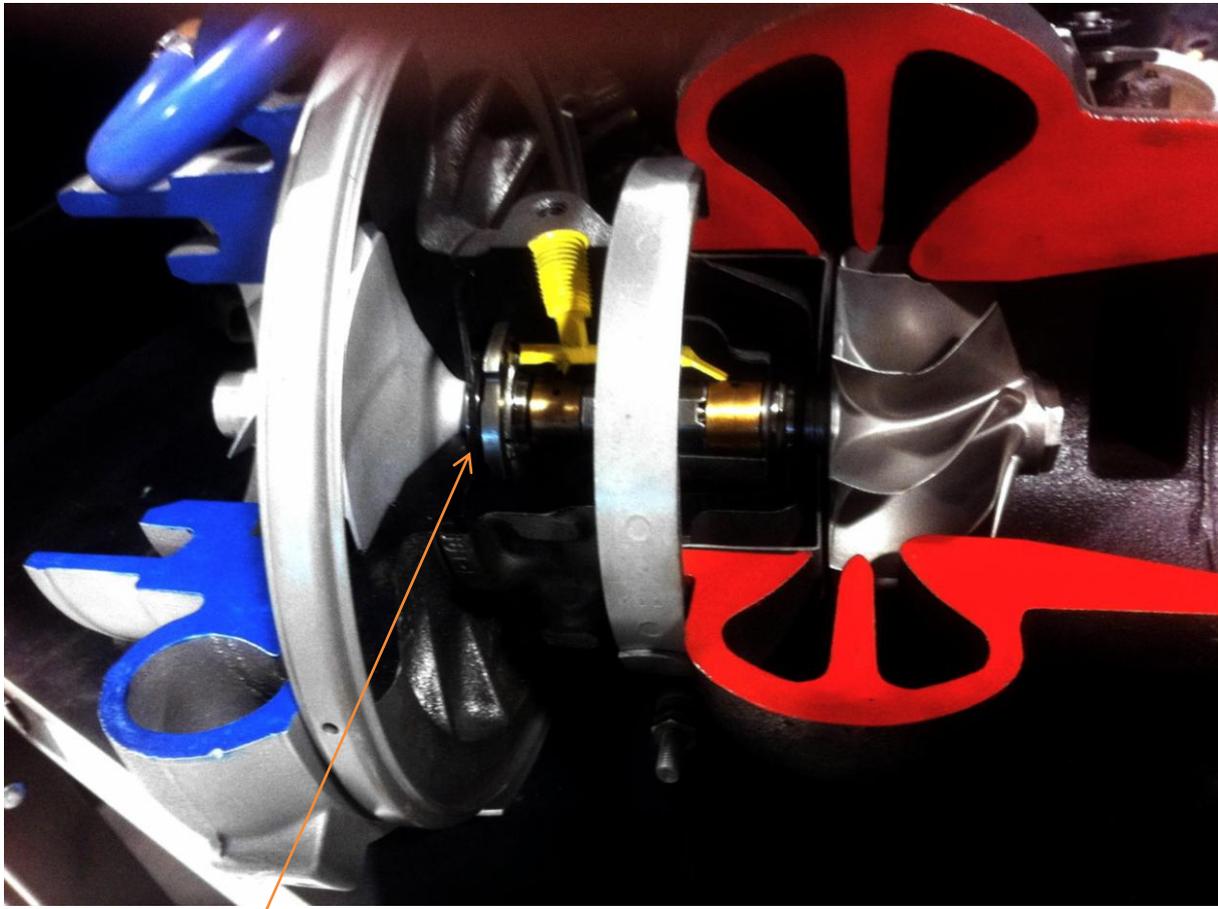
5. Exhaust Pipe Fires

The auto-ignition temperature of diesel fuel is about 260°C. The external temperature on the turbocharger exhaust casing might be 450°C and on the exhaust pipe 500mm from the turbocharger, 350°C. Diesel fuel vapour will explode if it contacts the exhaust pipes near the turbocharger. Usually the fuel lines are kept well away from the exhaust pipe to minimize the risk from fuel leakage, but the exhaust pipes of a dual-exhaust system will probably run behind the engine and may come close to the return fuel lines.

Fuel spray from a leaking or failed (high-pressure) injector tube might reach the turbocharger region under adverse circumstances. A leaking supply or return fuel line can produce a substantial quantity of fuel inside the engine compartment and some of this might be swirled around by air blowing through the compartment. Mechanical failure of exhaust heat shields can expose fuel lines to excessive surface temperatures, potentially resulting in premature aging and failure of flexible rubber or braided fuel-hose. Occasionally it is a lubricating oil line to the turbocharger that fails. In any case, fire resulting from a heavy-hydrocarbon aerosol contacting the exhaust pipe will be preceded by explosion. The driver will probably report that an explosion occurred.

In Australia, hard-working trucks that operate in high-ambient temperatures will often need under-cabin insulation and exhaust heat shields. It is essential that the insulation be

inflammable. Heat shields should be inspected periodically to ensure that they are tightly installed. Loose flammable material that could contact the exhaust pipe is a hazard. Noise absorbing material that is often installed on the cabin floor is a potential hazard if it is flammable. Even fire retardant treatment will have only limited effectiveness against contact with a hot exhaust pipe because the chemicals release the carbon dioxide prematurely.



The oil seal on the air-intake side

Figure 8 The oil seals and lubrication ports are evident in this photo of a sectioned turbo-charger.

6 Brake-Related Fires

Extreme brake temperature can cause the bearing grease or the tyres to catch fire. Heat flows into the wheel hub and the wheel rim from hot disc or drum brakes. In extreme cases the grease runs and ignites as it contacts the hot brake, or the tyre catches fire along the bead.

Extreme brake temperature is caused either by dragging spring brakes or gross brake imbalance on a combination vehicle. Dragging spring brakes are most likely to occur on a trailer due to air leakage from the spring-brake hold-off air lines or very slow spring-brake release. Dragging brakes can also be caused by bearing failure, which produces eccentric brake positioning. In Australia multi-combination vehicles are common. High-powered

engines might pull overcome dragging brakes without the driver being aware of the additional drag.

Very poor brake balance occurs when the brakes on one vehicle in a combination are in poor adjustment or sometimes when one vehicle has disk brakes (with automatic adjustment) and another vehicle has drum brakes (without automatic adjustment).

Brake drums and disc-brake rotors are designed to operate at high temperatures, so signs of excessive temperatures might be difficult to identify after the fire. Occasionally, bluing of the brake shoes in the protected environment of the brake drum, can be identified.

Drivers should walk around the vehicle after it is stopped to check the brake temperatures. Very hot brakes smell. They are easy to identify close-up.



Figure 9 Poor brake balance resulted in hot brakes on one side of a trailer axle. The brake drum became so hot that the tyre caught fire.

7 Wheel Bearing Fires

Excessive wheel bearing temperatures can result from mechanical failure of one of the two wheel bearings. The precursor to this is likely to be poor lubrication. As mentioned previously, dragging brakes may result and this might lead to fire. The fire mechanism is that the brake grease catches fire.

Regular lubrication according to manufacturer's recommendations is essential for satisfactory bearing life. There are some drive-axes for which the bearings are lubricated by oil over-flow from the differential. If the serviceman does not know how to cause the overflow, poor lubrication and fire might result. Regular scheduled maintenance of wheel bearings is

essential to prevent failure and possibly fire. Temperature indicating strips affixed to the axle hub can be useful. Drivers should ‘feel’ for elevated axle temperatures during trip inspections.



Figure 10 Poor lubrication of the outer bearing on a trailer axle resulted in extreme bearing temperature. The steel softened and flowed.

8 Tyre Rubs

Tyres are heated by dragging brakes (as discussed) and as a result of very low inflation pressure. Heating of the sidewall occurs when a tyre is partly deflated. Rubbing between adjacent dual tyres can result in excessive tyre sidewall temperatures on a long journey.

Inspection of tyres at the start of each journey is advisable. It can be difficult to detect when a tyre is partly inflated because the other tyres in a multi-axle group might maintain a near normal chassis level. For this reason drivers often hit the tyres with a stick to sense low inflation pressure. Use of a tyre pressure gauge is advisable. The trend to tyre pressure management might lessen vulnerability to under-inflated tyres becoming hot and catching fire.

It is difficult, if not impossible to put out a tyre fire on the roadside. When the vehicle stops the tyre-fire will spread into the vehicle. Drivers are advised to keep driving to a fire-hose location.

9..Dragging Road Debris

Road debris sometimes lodges in front of the forward differential on a truck. If the debris is flammable, it will possibly catch fire as a result of heating due to dragging friction.. This occurs, for example if a mattress is caught. A mattress has both flammable material and steel springs. The steel generates sparks when dragged on the roadway. Tree branches can also catch fire if dragged.

Drivers are advised to stop and inspect the truck when large pieces of road debris are driven over.

10..References

Hart, P.M., (2008), Why Trucks Catch Fire, short monograph published by ARTSA. National Transport Insurers, Australia, National Transport Research Centre, *Major Accident Investigation Report 2011*



Figure 11 Hot exhausts produce significant risks for petrol tankers.