

A Comparison of Various Fire Detection Methodologies in Transit Vehicle Engine Compartment Fire Protection Systems

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ABSTRACT

Distinctly different fire hazards exist within the engine compartment of a transit vehicle and various detection methodologies may be employed to detect fire events arising from these hazards. The engine compartment presents a particularly challenging environment and it is important to select the correct methodology to ensure timely detection response in the early stages of the development of a fire whilst minimizing nuisance alarms. The choice of the correct detection methodology for a specific fire hazard is therefore determined by the suitability of the methodology for the detection of the anticipated fire event within the environment in which it is required to operate. This paper presents experimental data to demonstrate the variation in the response times of different detection methodologies in the presence of common fire events in the form of simulated flaming fuel fires and a simulated electrical fault in the form of an overheated electrical cable. The data presented relates to experiments conducted within a simulated transit vehicle engine compartment and includes the impact of environmental parameters, such as cooling due to high airflow rates, on detection response times. The paper will conclude with the lessons learned from this testing, and provide insight into key aspects for successful detection of the different fire hazards in this demanding application.

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INTRODUCTION

Analysis of the frequency of occurrence and causes of fires within transit vehicles highlights the fact that a large percentage of reported fires originate in or around the engine compartment. One study conducted in Finland suggests that over 64% of fires originate within the engine compartment [1]. Another study conducted by NFPA suggests that over 64% of transit bus fires originate from within the engine area, running gear or wheel area of the vehicle [2]. An FMCSA commissioned study supports these overall conclusions. In this study the origin of the fire is further broken down; 36% of all fires were found to originate within the engine compartment and 34% in or around the wheel well of the vehicle [3].

The reported causes of fires within the engine compartment are many and varied; however they may be broken down into two distinct classes of fire threat. The first class is fast flaming fires resulting from ignition of flammable liquids, for example, the leakage of fuel, cooling fluid and hydraulic fluid, onto hot surfaces such as turbo

chargers and exhaust manifolds. The second class is slow growth fire events arising from overheating of electrical cables, mainly associated with live ignition system cables coming into contact with the grounded chassis of the vehicle. In the previously referenced FMCSA study 83 fire events are directly attributed to specific fire ignition points within the engine compartment. Of these 83 events, 53% were identified as fast flaming fires originating at the turbo charger or fluid lines, and a further 20% may be directly attributed to electrical faults within the engine.

The spread of fires to areas outside the engine compartment poses a risk to passenger safety; in addition this may result in significant damage to, or even loss, of the vehicle. It has been suggested that careful attention to preventive measures, including regular maintenance checks and improvements to vehicle designs, may go some way towards preventing the occurrence of engine fires and reduce the risk of fires spreading outside of the engine compartment [4]. Although these preventive steps help mitigate the risk, some unforeseen risk will always remain and this may be

addressed by a correctly designed and deployed fire protection system.

For on-board fire protection systems, the time taken to detect the fire event is a critical factor in ensuring the expedient evacuation of passengers and minimising damage to the vehicle [5]. Faster detection of a fire allows for the deployment of an extinguishing agent in the early stage of development of the fire. Thus a faster detection response increases the likelihood of successfully extinguishing/suppressing the fire whilst it is still a small event. It has been suggested that the choice of detection methodology may result in a variation in response times from 0.1seconds to 180seconds [6]. The choice of the detection methodology is therefore an important consideration.

An engine compartment is a hot, noisy, dirty environment with high levels of fumes, vibration and high airflow due to the operation of forced air cooling systems and the naturally high air flow associated with a moving vehicle. This is a challenging environment for a fire detection system which must address the need for timely detection of a fire event whilst avoiding the occurrence of nuisance alarms. As a result of the limitations imposed by the operational environment, some commonly employed methods of accidental fire detection within other applications are unsuitable for use in engine compartments. For example smoke detectors are particularly unsuitable due to the high levels of dust, dirt and fumes present in this application, which will cause frequent nuisance alarms and over time degrade the performance of the detector.

Only two basic detection methodologies are recommended for fire detection within transit vehicle applications; thermal detectors, both spot thermal and linear heat detectors, and optical flame detectors [7]. Details of the different types of detectors available in each of these classes and their operating principles are described elsewhere and will not be discussed in detail in this paper, but a brief summary now follows [8].

- Spot thermal detectors

Two main classes of spot thermal detector may be considered for vehicle engine compartment applications, these being fixed temperature heat detectors and rate of rise detectors.

Fixed temperature devices are designed to generate an alarm when the temperature of the surrounding air exceeds the design operating point. These devices are susceptible to thermal lag and as such, during a rapid rise in air temperature, the temperature of the environment at the point of alarm may be significantly higher than the alarm temperature specified for the device. Rate of rise devices detect a fire when the rate of temperature increase exceeds a predetermined value; this may overcome some of the limitations of fixed temperature devices and provide a faster response.

Rate of rise detectors are generally designed to compensate for slow changes in ambient temperature. However, these devices may be susceptible to nuisance

alarms in an environment which experiences rapid changes in ambient temperature. Despite the obvious disadvantage of a relatively slow response associated with fixed temperature devices, they are extremely immune to nuisance alarms. As such they may often prove to be the most suitable choice in a high temperature environment or in environments which experience rapid changes in the ambient air temperature. It may be argued that a transit vehicle engine compartment is such an environment.

- Linear Heat detectors

A linear heat detector, as the name suggests, will detect a heating event at any point upon its length. Several devices have been developed and the operating principles of these may be mechanical, electronic, pneumatic or hydraulic in nature. Linear heat detectors fall broadly into two classes of device; discrete heat detection elements, which respond when the temperature at any point along their length exceeds an alarm threshold, and averaging elements which respond when the average temperature along the whole length of the sensing element exceeds a certain value.

One example of an “averaging type” detector is comprised of a pair of conductors separated by a negative temperature coefficient semiconductor material [9,10]. The impedance between conductors is monitored and an alarm generated when the impedance falls below a certain value. The negative temperature coefficient semiconductor material has an exponential dependence of resistance on temperature and this gives the detector an averaging characteristic biased towards the hottest part of the detector. If only a small length of element is heated a higher temperature is required to generate an alarm; if a greater length of sensing element is heated a lower temperature is required. This feature enables averaging type linear heat detectors to be routed near recognised localised “hot spots”, for example turbo chargers and exhaust manifolds, whilst still providing a lower temperature alarm threshold for monitoring the surrounding ambient environment.

- Optical Flame detectors

Optical flame detectors respond to the radiant energy emitted by a flame. This can be infrared (IR), visible light or ultra violet (UV) light. In order to minimise nuisance alarms from common light sources, in general only IR and UV light are employed in most applications. Further details regarding the operation and recommended installation of infrared flame detectors are available from a variety of sources [8,11,12].

The field of view (FOV) of a flame detector defines the full angle over which the detector will successfully receive radiant energy emitted by a flame. It is imperative that these optical flame detectors are positioned such that any potential accidental fire source is within the field of view of the detector and that the detector has an unobstructed line of sight to the potential accidental fire source. In addition to the FOV, it is common practice to specify the distance at which a flame detector will receive sufficient radiant energy to detect a fire source of a given size. A combination of the field of view and

the minimum detected fire size at a given distance defines the suitability of an optical flame detector for a given application.

Other factors to consider when choosing an optical flame detector are the fuel characteristics and environmental conditions. For example, UV flame detectors are sensitive to nearly all fuel types and are inherently insensitive to visible and solar radiation; however they are particularly susceptible to a reduction in sensitivity due to aerosols, smoke and vapour in the air and oil films on the surface of the detector window. In contrast all IR detectors are best suited to the detection of hydrocarbon fires and are less susceptible to a reduction in sensitivity. The single IR detector does however still suffer from a significant loss in sensitivity due to the presence of water or ice on the detector window.

Dual IR detectors are particular well suited to detecting hydrocarbon fuel fires within the dirty environment of transit vehicle engine compartment. These devices utilise two spectrally filtered infrared detectors to compare the radiant intensity of the peak around $4.4\mu\text{m}$ (arising from the CO_2 emissions present in all hydrocarbon flames) with the radiant intensity within a different spectral region of the infrared spectrum. A second optical channel is used to correct for variations in intensity and is employed to reduce the influence of contamination on the detector window and the presence of aerosols, smoke and vapours in the air.

Triple IR detectors incorporate an additional reference channel which provides improved sensitivity compared to the dual IR detector. However, due to the relative cost of the two devices, the increased cost of a triple IR detector is difficult to justify when detecting events over relatively short distances.

In comparison with many other branches of fire protection, few standard approval tests exist for fire detection systems for commercial vehicles. This results in a lack of clear guidance as to which detection methodology or particular system is best suited to addressing the challenge of fires within the engine compartment of a transit vehicle. This paper describes an attempt to address this question through an experimental investigation that compares the response times of both thermal and optical flame detectors in the presence of the two classes of fire threat commonly encountered within a transit vehicle engine compartment. It is hoped that the results of this experimental work may provide an improved understanding of the relative performance of the commonly employed detection methodologies. From this improved understanding some conclusions can be drawn regarding the appropriate choice of detection methodology for fire detection within a transit vehicle engine compartment.

This paper concentrates on the performance of detection methodologies with respect to the detection times in the presence of common fire threats. In addition to detection times both the initial installation cost and ease and cost of maintenance are also important factors which must be taken into consideration when selecting a fire protection system. To some extent both the initial installation cost and ease and cost

of maintenance are dependent upon both the system supplier and exact details of the integration of the system. As such only the relative cost of individual detectors has been considered. Any further discussion on cost of installation and ownership of an automatic fire detection system is considered to be beyond the scope of this paper.

TEST METHODOLOGY

The aim of the experimental work described in this paper was to provide a side by side comparison of the response times of several fire detectors when subjected to flaming fuel fires and overheating of electrical cables. Two distinct sets of experiments were carried out within the test article. The first set of experiments aimed to provide a comparison of the response of the detectors under test to fast flaming fires arising from the combustion of flammable liquids within the engine compartment. The second set of experiments aimed to provide a comparison of the response of the detectors under test to overheats/fires associated with overheating of electrical cables.

The test article employed for the comparison of the detector response times is based around an enclosed chamber as shown in [Figure 2](#). This has a free volume of 3600litres to which a variable airflow from 0litre/sec up to 1950litre/sec may be applied across the chamber. The free volume of the enclosed test chamber is consistent with reported rear mounted engine compartment volumes of 3000 litres to 4000litres [13]. By extrapolation of published data relating airflow rates to engine running speeds, the maximum airflow rate of 1950 litre/sec is believed to be equivalent to an engine speed of 2200RPM (revolutions per minute) [14]. This represents an average running speed for a transit bus engine. Similarly an airflow rate of 980litre/sec is believed to be equivalent to an engine speed of 1100RPM, which represents a fast idle of the engine.

A summary of the detectors included in these tests and the identification for each alarm temperature threshold are shown below in [Table 1](#). The choice of detectors aimed to encompass three broad categories of common detection methodologies employed on transit vehicles: spot thermal, linear heat and optical flame detectors. The exact choice of fire detectors was driven by the ease of availability of devices at the time of testing. The devices chosen are currently utilised in vehicle applications and are designed to withstand the harsh environment of a transit vehicle engine compartment. Specifically, these devices are specified to operate over an ambient temperature range of -40°C to 125°C , withstand the shock and vibrations encountered within vehicle applications and are rated as NEMA 4X enclosures.

Three relatively low cost spot thermal detectors were evaluated. These were fixed temperature normally open thermostats of a bimetallic snap disc construction. The chosen alarm temperatures for the spot thermal detectors were 140°C , 177°C and 232°C .

Table 1. Summary of detectors employed during flammable liquid fire tests

Detector Identification	Alarm Temperature	Description
Average 1	125°C (257°F)	1700mm length of averaging linear heat detector
Average 2	125°C (257°F)	6000mm length of averaging linear heat detector
Average 3	180°C (356°F)	1700mm length of averaging linear heat detector
Average 4	180°C (356°F)	6000mm length of averaging linear heat detector
Discrete	176°C (349°F)	1500mm length of discrete linear heat detector
Spot 1	140°C (280°F)	Snap disc spot thermal detector
Spot 2	177°C (350°F)	Snap disc spot thermal detector
Spot 3	232°C (450°F)	Snap disc spot thermal detector
Optical	N/A	Dual infrared optical flame detector

A dual infrared optical flame detector was evaluated. The chosen optical flame detector is specified by the manufacturer to be suitable for the detection of liquid fuel fires up to a distance of approximately 1070mm. This specification is based upon the detection of a 300mm×300 mm pan fire within a 100° field of view. The manufacturer also claims that the detector is immune to false alarms from sunlight, flashlights, lightning, vehicle headlights, incandescent lights and welding arcs. In addition, the manufacturer's claims suggest that this device is able to operate even when heavily contaminated by oils and other fluids. The devices used during these tests had been utilized in previous studies and as a result were heavily contaminated by a mixture of oil, dust and fire extinguisher powder as shown in [Figure 1](#).

Two types of linear heat detector were also evaluated. The first type of linear heat detector employed in these tests was a relatively high cost “averaging type” detector comprised of a pair of conductors separated by a negative temperature coefficient semiconductor material. Due to the averaging nature of these linear heat detectors, different length elements will exhibit different response characteristics for a given overheat/fire event. As such the decision was taken to include both a 1700mm length element and a 6000mm length element in the comparative tests. Two alarm temperature thresholds were set for each averaging linear heat detector element, the first at 125°C and the second at 180°C. The alarm temperature threshold corresponds to the impedance of the element when fully immersed at the specified temperature.

The second type of detector employed was a relatively low cost, discrete alarm temperature linear heat detector. The construction of this device is a twisted pair of conductors separated by a polymer insulator. This polymer softens and melts above the alarm temperature causing the conductors to be brought into contact, closing an alarm circuit. This is a single use device which cannot be reset and must be replaced after alarm. The chosen detector is specified with a 176°C alarm temperature.



Figure 1. Example of contamination of dual IR sensor prior to commencement of testing

FLAMMABLE LIQUID FIRES

A comparison has been made of the response time of all detectors to flammable liquid fires by monitoring the time of response of the detectors from the point of ignition of a diesel pan fire. Three fire pan sizes were used for the tests. These were square fire pans with dimensions 200mm×200mm, 300mm×300mm and 400mm×400mm, each approximately 100mm in height. These were filled with water up to approximately 25mm from the top of the pan (the water was replaced before each test). 0.5litres of diesel was added to the 200mm×200mm and 300mm×300mm fire pan and 1.0litres of diesel to the 400mm×400mm fire pan. Fifteen 0.5mm diameter metal sheathed type K thermocouples, labelled T1 to T15, were installed in the test chamber, as shown in [Figure 2](#). [Figure 2](#) also shows the position of the detectors and the pan fire.

The spot thermal detectors were installed approximately 300mm below the ceiling of the test chamber and positioned directly above the centre of the pan fire location.