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FIRE SIZES IN RAILWAY PASSENGER SALOONS

V. P. Dowling and N. White
CSIRO Fire Science and Technology Laboratory
PO Box 56 Highett, Victoria 3190, Australia

ABSTRACT

In designing underground railway systems, fire engineers need to estimate likely fire sizes in the event of a fire involving a train. Traditionally they have done so by taking the complete fire load and dividing by assumed times, and incorporating an assumed efficiency factor. However, fire loads tell nothing about the burning behaviour of materials. Therefore, this approach penalises materials of good fire performance.

With new fire test methods, it is now possible to measure the rate of heat release of all materials used in the saloons of trains. But this still does not enable us to predict what size fire will occur in a train, as the link between flammability of individual materials and likely fire size has not been established. At present, simple summation methods are used in some rail specifications. This approach is at odds with what is known about fire growth in enclosures, and may result in grossly incorrect estimates of fire size.

CSIRO is conducting a research program that is attempting to establish links between flammability of materials and fire size in train saloons. The goals of the research are to develop techniques for estimating fire sizes that can be used as design fires in tunnel design.

So far, the research program has focused on measuring the contribution to fire growth of assemblies of seats and linings. Experiments have been carried out in enclosures designed to have cross-sectional areas the same as train carriages, but of shorter length, and in one actual train carriage. Fire spread and window breakage have been studied. The ISO 9705 room corner test has also been used to study the behaviour of linings.

This paper describes experiments that have been performed, and the data obtained. It discusses current methodologies for estimating fire size and compares predictions with experimental results.

KEYWORDS

Train fires, full-scale fire experiments, tunnel fires

INTRODUCTION

Rail operators have two concerns when considering the flammability of the materials in their cars. One is the fire behaviour of individual materials, and the other is the severity of the fire should all flammable materials become involved, and how this will impact on life safety, and in underground systems, how it will impact on tunnel design.

The traditional approach to these two problems has been:
(i) use one or more fire tests to determine the fire behaviour of individual materials; and
(ii) use fire load data to estimate likely fire sizes.

By and large, the first approach is used in BS 6853 [1] and NFPA 130 [2]. Both of these standards use a suite of fire tests to control aspects of flammability such as flame spread and smoke production. This approach fails to consider geometry and interactions between materials.

Traditionally fire engineers have used the second approach to estimate fire sizes. The method involves taking the complete fire load (in MJ) and dividing it by an assumed time. By doing this, and incorporating an assumed efficiency factor, a figure for fire size (in MW) can be estimated. However, fire loads tell nothing about the burning behaviour of materials. For instance, a particular quantity of material such as wood has a fixed fire load, whether or not fire retardants have been added. Therefore, this approach penalises materials of good fire performance whilst failing to identify particularly hazardous materials. It also ignores the environment in which the fire is occurring.

FIRE SIZE ESTIMATION

The method of estimating fire size by dividing fire load by time is being replaced by methods using measured rates of heat release for all major surface materials. In these methods, total fire size is estimated by adding together rates of heat release for materials. The advantages of this approach, compared to the fire load approach, are that it distinguishes between materials that burn rapidly and those that burn slowly. It also allows for data on complete components to be used. Examples of components that have been tested in the cone calorimeter for rate of heat release are seats, where the cover and padding are assessed together, and floors, where the floor covering is assessed over the floor.

The disadvantages of this approach are that no proven models have been developed to relate individual fire properties to the fire performance of the car as a whole, and there has been no large-scale experimental validation of the approach.

Summation of rates of heat release

NFPA 130 Appendix D contains a non-mandatory method for determining ‘hazard load’ in BTU per ft^3 of saloon volume (MJ per m^3 of saloon volume). This method, based on work by Smith [3], uses heat release rates per unit area (kW/m^2) determined in the OSU calorimeter, and integrates them over the first 3 minutes of the test to obtain 3-minute heat outputs (kJ/m^2). These are multiplied by the area of exposed material in the saloon to obtain 3-minute heat outputs (MJ) for each material. The heat outputs of all surface materials are summed and divided by the internal volume of the saloon to produce the ‘hazard load’ in MJ per m^3 of saloon volume. A maximum value for this summation may be used to control material flammability.

Later, Duggan [4] published a method that summed rates of heat release per unit area of materials. It had two advantages over the NFPA 130 Appendix D method. Firstly it used data from the cone calorimeter, which does not have some of the disadvantages of the OSU calorimeter, for example heat losses. Secondly, it used the entire heat release curve, not just an integration over three minutes. Duggan used this calculation method to assess cars to be used with the Heathrow Express. He found a maximum ‘fire power output’ of 5 MW per car.

Some rail specifications include a requirement that the total nominal heat release rate of all surface materials in a saloon, when summed together, shall not exceed a given heat release (eg 5 MW) at any time. In order to obtain this data, all surface materials must be tested in the cone calorimeter. In meeting this requirement, these rail operators accept calculations based on the method published by Duggan. This approach assumes that there is sufficient ventilation available to allow all surface materials to be involved in combustion at once; that is, the fire is free-burning on all surfaces and is not ventilation controlled either locally or globally. This assumption is at odds with what is known about fire growth in enclosures, and may result in a grossly incorrect estimation of fire size. In this approach, the calculation is usually done for one carriage only, and ignores any contribution from the sub-floor components. Whilst this may be a suitable way to control the flammability of internal surface materials, it does not provide any estimate of likely fire size, even though the results are expressed in megawatts.

A similar method that attempted to allow for fire spread within a saloon was employed to look at fire growth [5]. This method, whilst similar to Duggan’s method, assumed that because of the square cylinder shape of a saloon, fire could not commence on all surfaces at once. It arbitrarily chose a rolling ignition that involved 10% of a saloon each minute. However, there is no experimental verification of this approach either.

Modelling

Modelling can provide the link between material flammability and fire size. Modelling can consider the influence of the environment. Fires can be fuel-controlled (free burning) or ventilation controlled. There are simple relationships in existence that give guidance on likely maximum fire sizes in enclosures such as saloons in rail cars (provided there is sufficient fuel). One of these is Thomas’ flashover criterion. Put simply, for a given sized compartment, the larger the openings, the greater the fire size needed to achieve flashover. Of course, during saloon fires windows break, increasing the ventilation. There is also the issue of saloon geometry. Models developed for typical rooms are not immediately valid for train saloons.

Forced air flow must be considered when modelling the burning of trains in tunnels. Recent tunnel experiments have shown that buoyancy driven flow can occur in essentially horizontal tunnels. All of these factors mean that the modelling of train fires is still far too complex to produce reliable results.

LARGE-SCALE EXPERIMENTS

Large-scale experiments can be used both to obtain data on the performance of whole carriages, sections of saloons, or groups of components. They can also be used to assess mathematical models.

Nine European nations combined to run the EUREKA project between 1990 and 1992 [6]. In this project various vehicles, including railway passenger saloons were burnt in a tunnel to obtain information related to safety and fire size. The railway carriages burnt were stripped of internal fittings and seats so that the influence of linings could be seen. Fire sizes of 15-20 MW were calculated. Whilst the influence of different linings on fire size was noted, it was not an objective of these experiments to estimate fire sizes from the fire properties of particular materials.

The need for large-scale or real-scale experiments has been acknowledged in the European FIRESTARR Project [7], funded by the European Commission. The FIRESTARR Project is part of a program for preparing a seven part European Standard for fire protection on railway vehicles (prEN 45545). One of the main objectives of the FIRESTARR Project is:

> To propose a classification system for a range of railway products and to validate these proposals with real-scale tests on parts of European trains.

Whilst components were tested in an enclosure representing the part of the rail carriage in which they are normally installed, they were tested in isolation.

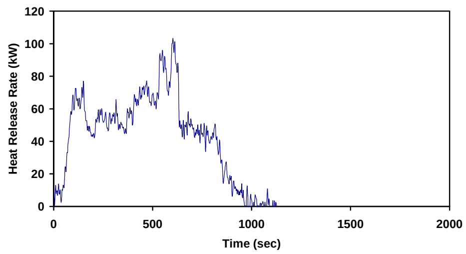
Over the years, at CSIRO, we have conducted many experiments on materials used in train saloons. In one series, we built a replica of one-fifth of the upper deck of a double-decker train (Figure 1).

Figure 1. Mock up of part of an upper deck of a double-deck saloon

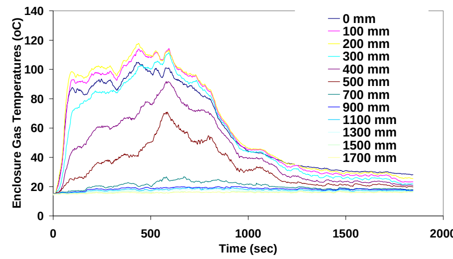
Figure 2. Seat experiment in progress showing hood

The objective of this series of experiments was to study the performance of the seats as arranged in a saloon, and thereby determine what were appropriate performance parameters for seating in trains [8]. In addition, the heat release rate was measured continuously by oxygen consumption using an ISO 9705 hood and flue system (Figure 2).

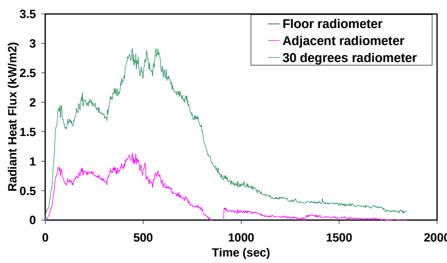
The type of data we were able to collect from these experiments is illustrated in Figure 3.



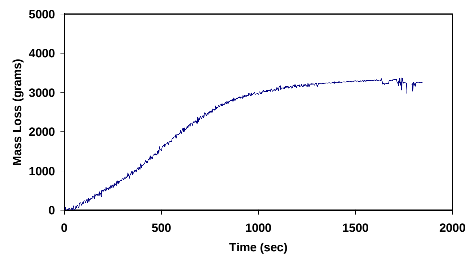
(a) Rate of heat release



(b) Temperatures in saloon



(c) Radiation from source area



(d) Mass loss of seats

Figure 3. Data from burning seats

On this scale the measurement of rate of heat release of complete sets of materials is not only feasible, but relatively simple. In these experiments the fire was confined to the seat first ignited, even with relatively large ignition sources. The next stage in this series needs to address the interactions between seats and linings, especially wall linings.

We have recently conducted a full-scale experiment in which a fire was initiated in a train saloon (Figure 4). In this experiment [9], the sub-floor materials were not included. The objective of this experiment was to look at the interactions between seats and wall linings, and to study aspects such as fire and smoke spread and window breakage.

Figure 4. Full-scale fire test of single carriage (internal only)

On this larger scale, it is not always possible to measure rate of heat release, though the restrictions are more related to the cost of the experiment than to outright technical difficulties.

Comparing models and experiments

It is not necessary to burn a complete rail car to assess models. What is necessary is a facility where the internal components of a saloon can be arranged in the same fashion as in a saloon. For instance, the ISO 9705 room fire test can be adapted to this purpose. Models that attempt to predict fire size in railway carriages should be able to cope with the relatively simple configuration of an ISO 9705 room corner test (Figure 5).

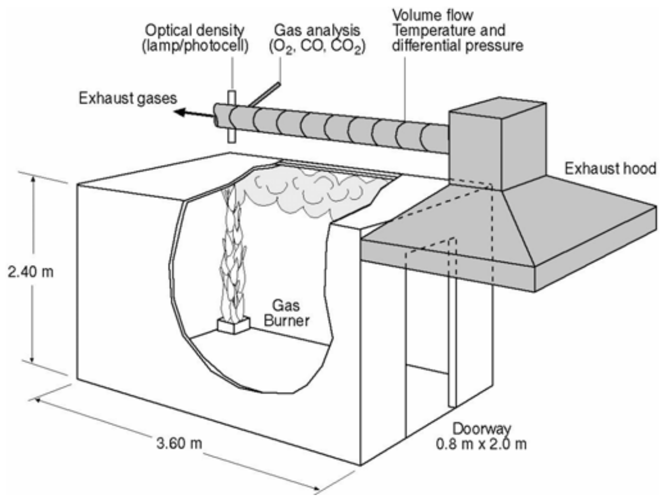


Figure 5. Cut-away view of the ISO 9705 room corner test

We compared results from room corner experiments with predictions of the summation methods for the same materials. In these methods, materials or components are tested in the cone calorimeter at irradiances selected according to their orientation in a rail carriage, according to the scheme in Table 1.

Table 1. Irradiances for cone calorimeter testing in summation methods

Surface	Irradiance kW/m^2
Floor	20
Wall	35
Ceiling	50

These exposure conditions can be related to real fires. Three types of flaming fires have been categorised by the British standards Institution [10]. These are

- developing fires, flaming (pre-flashover);
- fully-developed fires, high ventilation (post-flashover fuel-controlled fires); and
- fully-developed fires, low ventilation (post-flashover ventilation-controlled fires).

According to Peacock and Braun [11], the heat flux levels found in fires are:

- developing fires – 20-50 kW/m^2; and
- fully-developed fires – 50-75 kW/m^2.

Actual exposure levels in passenger train fires can be expected to fall within these ranges. Peak heat flux at floor level, measured in the 1984 Amtrak vehicle interior tests, ranged from 0.5-62 kW/m^2 [12]. A typical exposure for seats in trains is 35 kW/m^2 [11]. Exposure levels for wall and ceiling linings can be expected to range from the floor level values up to the levels found in fully developed fires. Therefore the flux levels proposed by Duggan, and used in these comparisons are reasonable.

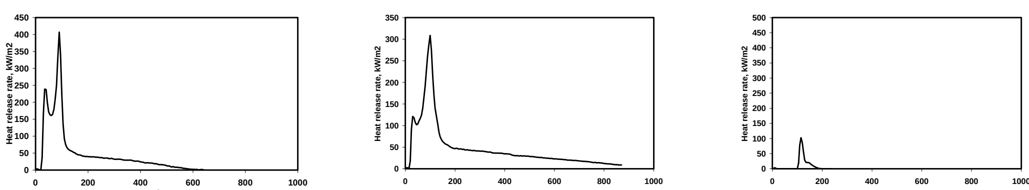
The heat release per unit area curves for each individual component is multiplied by the area of the component in the carriage to obtain that component's contribution to the total fire power output in the carriage. In the punctuated summation method presented in [5], it was assumed that only 10% of the carriage was initially ignited. As the geometry of the ISO 9705 room is different to the square cylinder shape of a rail carriage, and represents about 10% of the length of a rail carriage, the summation method presented in [5] becomes identical to the method presented in [4].

In order to compare the summation methods with experimental data, we took room corner experiments for which we also had appropriate data from the cone calorimeter. Data from the cone calorimeter had been determined at the applied irradiances given in Table 1. The cases studied are given Table 2. A full description of the materials is given in [13].

Table 2. Materials, areas and irradiances used in comparison

	Ceiling	Walls	Floor
Area, m^2	8.64	27.2	8.64
Irradiance kW/m^2	50	35	25
1	Plywood	Plasterboard	Plasterboard
2	FR plywood	Plasterboard	Plasterboard

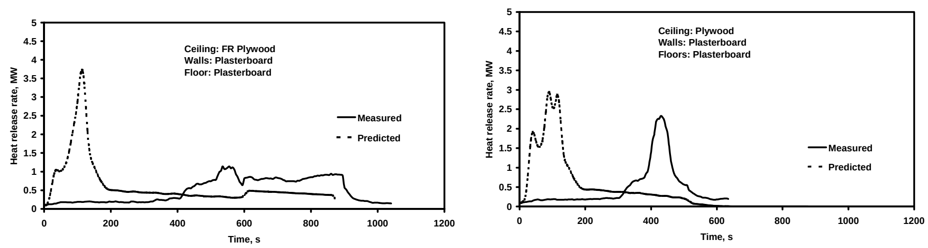
The heat release rate date from the cone calorimeter is given in Figure 6. Plasterboard tested at 25 kW/m^2 did not ignite and there was no measurable heat release rate.



(a) Plywood (50 kW/m^2) (b) FR Plywood (50 kW/m^2) (c) Plasterboard (35 kW/m^2)

Figure 6. Cone calorimeter rates of heat release for linings

In order to do the comparison, it was necessary to consider also the contribution from the gas burner used in the room corner test. Nominally this input is 100 kW for the first 10 minutes, followed by 300 kW for ten minutes if flashover has not occurred. However, the experiments being used for these comparisons were terminated earlier than 1200 s as all combustion of the specimen had ceased. Therefore, the measured heat input of the gas burner for each room corner test was added to the appropriate summation. The summed products of heat release rate and area were smoothed by applying a 20-s rolling average, as proposed in [4]. The resulting comparisons are shown in Figure 7.



(a) FR plywood ceiling (b) Plywood ceiling

Figure 7. Comparison of measured and predicted rates of heat release in room corner test

If the value being used for determining acceptability of materials is peak heat release rate ('fire power output'), the prediction for the summation with the plywood ceiling is not grossly wrong, though the time of the peak is shifted forward in the prediction. However, for the summation with the fire-retarded plywood ceiling, there is an enormous discrepancy, and in fact the system with FR plywood is predicted to have a higher value than the system with the non-FR plywood.

There are a number of reasons for this discrepancy:

- a relatively low level of fire retardant in the plywood, leading to only marginal improvement in the cone calorimeter tests;
- the well-ventilated combustion environment in the cone calorimeter compared to the build up of a low oxygen environment beneath the ceiling in the full-scale test; and
- the coincidence of the peaks for the FR plywood and the plasterboard, whereas for the plywood and plasterboard, the peaks are not quite coincident.

DISCUSSION

In this paper we have explored some of the issues involved in determining how fast fires in rail passenger vehicles will grow, and how big they will become. We have not considered the contribution from external components, such as sub-floor components (which contain large quantities of combustible materials, especially rubbers), cab face masks, and transformer oils. All of these components can make significant contributions to a rail carriage fire. Nor have we considered inter-carriage spread. Given that many passenger trains used in underground systems have little or no barriers to fire spread between carriages, this is an important factor to be considered both in future experiments, and in current modelling exercises.

Even with the limited the work we have done so far, we can see major discrepancies between the way that fires grow in trains, and the assumptions that are made about fire growth on trains, especially when selecting design fires for tunnel design. We believe that there is a strong case for more large-scale experiments so that credible design fires for tunnels can be developed, and so that we link the flammability of the materials used in trains to these design fires.

In at least two train fires in tunnels, including the one in Daegu, fire spread was due in part to winter clothing. Rail authorities cannot control the goods and clothing carried on to a passenger train, but they do need to take this additional fuel into account when specifying the fire safety systems to be installed in rail passenger vehicles.

CONCLUSIONS

The need for full-scale fire experiments of rail passenger vehicles is well recognised, but at this stage there have only been a limited number performed, and the data collected is insufficient for linking material flammability behaviour and design fires for tunnels.

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