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Fire Research Report Number 82

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December 2003

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An Experimental Investigation of Backdraught

Experimental investigations of backdraught have been carried out in a compartment representing a room at half-scale which has been constructed and developed at the Fire Experimental Unit (FEU). Limited trials in a full size backdraught demonstration container at the Fire Service College were also carried out. This report describes the investigations and discusses the results.

INTRODUCTION

Backdraughts can occur when oxygen-starved fires are suddenly ventilated, often as a result of firefighting operations. The result is an explosive growth in the intensity of the fire in the form of a fireball, or backdraught. This has caused firefighter fatalities. In firefighting operations, backdraughts seem to be happening more frequently, possibly because buildings are now better sealed against draughts to improve energy efficiency.

The current Fire Research and Development Group (FRDG)[1] interest in backdraught resulted from a study requested by the Joint Committee on Fire Brigade Operations to identify ways in which fire losses could be reduced in large fires. This study identified over thirty areas where research might prove beneficial, and these were refined to eight detailed proposals which were presented to the committee. The committee requested FRDG to pursue a number of these projects, one of which was to look at the application of venting as a firefighting tactic.

As there is a risk of backdraught whenever ventilation takes place, it is important to understand this phenomenon, so a project on backdraught was initiated in parallel with the project on ventilation.

A study was commissioned by FRDG to survey current knowledge of backdraught. The study was carried out by the Fire Research Station (FRS) and concluded that, whilst there was a number of areas where more research would be of benefit, a significant problem was the lack of communication between fire scientists and firefighters. In particular, relevant information had not been presented to the fire service in terms which would be of practical use on the fireground.

To bridge this gap, a volume of the Fire Service Manual has been published which attempts to address what firefighters need to know about fires and ventilation. This has been followed by a series of video training films which have been produced by FRDG. In support of these, it was necessary to develop a backdraught simulator to give the opportunity to produce video on backdraughts and enable further research on the phenomenon.

THE BACKDRAUGHT SCENARIO

In general, if there is an adequate air supply, a fire will continue to burn and grow as long as there is fuel available. In a closed compartment with limited ventilation, the oxygen in the air will be used up and, as the oxygen concentration reduces, the flames will start to die down. As the process continues, the flames will continue to die down and may go out. The fuel will still be hot and produce hot gases containing significant proportions of flammable partial combustion products. These can accumulate in a compartment and, when air is introduced by making an opening, this mixes with the unburnt gases and the resulting flammable mixture can be ignited by any source that may be present. For example there may be a single glowing ember. The heat created by combustion causes expansion which then expels unburnt and burning gases out of the opening as a fireball. This is a backdraught and the definition used in the Fire Service Manual is given below.

> *Limited ventilation can lead to a fire in a compartment producing fire gases containing*

[1] Now the Fire Research Division (FRD) of the Office of the Deputy Prime Minister (ODPM)

significant proportions of partial combustion products and unburnt pyrolysis products. If these accumulate then the admission of air when an opening is made to the compartment can lead to a sudden deflagration. This deflagration moving through the compartment and out of the opening is a ***backdraught****.*

PREVIOUS WORK

In the FRS survey of backdraught, only one group was identified which was conducting direct research into the backdraught phenomena. Fleischmann at the University of California (Berkeley) had conducted backdraught experiments in a half-scale domestic room. These had been supplemented with both salt-water and computational fluid dynamics (CFD) simulations of the mixing processes between fuel and air that may occur on the sudden opening of a vent.

THE COMPARTMENT

An updated copy of this simulator was constructed and installed in a laboratory at the FRDG's Fire Experimental Unit. It consisted of two compartments, a main compartment (2.4m x 1.2m x 1.2m) which represents a room at half-scale and a smaller compartment (1.2m x 1.2m) which could be added to represent a small corridor outside the room.

The compartment frames were constructed using cold formed steel section bolted together and these were lined with non-combustible sheets and insulation blanket.

Both compartments had glass viewing panels which allowed events in the compartment to be observed and recorded on video. A removable panel was provided in the side of the main compartment opposite the viewing panel to allow access. Hinged pressure relief panels were fitted in the roofs of both compartments to control any excessive overpressure in the compartments.

The compartments were installed on a platform to provide a convenient working height and a steel framed enclosure was constructed above the platform and compartments to protect the fabric of the building from the flames produced in the tests (Figure 1).

In order to simulate an opening for air to enter the compartment, the early tests used a hinged panel at one end of the compartment similar to that used by Fleischmann. This when opened, allowed air to enter through a vent.

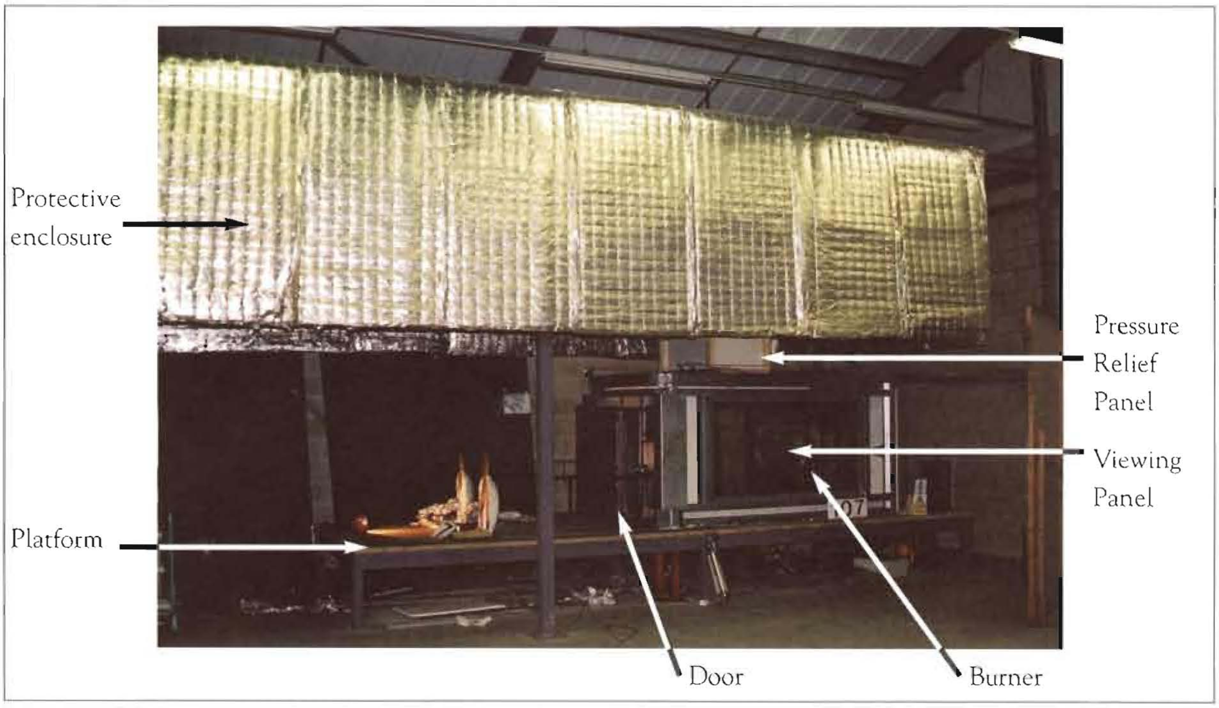


Figure 1: The single compartment installed on the platform under the protective hood

After initial tests using the hinged front panel, a new front panel was fitted with a more conventional door opening (size 1000 mm high by 380 mm wide). In addition four vent openings (each 100mm x 200mm) were fitted into the panel to allow a range of venting options (Figure 2).

Figure 2: Front panel showing door and four vents

To simulate the fire, a gas burner (300mm x 300mm) was positioned near to the rear of the compartment and supplied with methane gas from a bottle located outside the building. The burner was ignited using a small pilot flame mounted above the burner and this in turn was lit with a spark igniter. A control system for the safe operation of the burner, pilot flame and igniters was used.

The source for backdraught ignition was a spark gap made from stainless steel rods which was connected to a high voltage transformer (10kV) of the type used in heating boilers. Initially a single spark was used and then a vertical tree of five spark gaps was introduced.

After the initial tests, metal plates were mounted across the top of the compartment which were pre-heated using the burner, to generate a temperature gradient. This was found to produce more consistent results.

The compartment was used to simulate backdraught by following the procedure below:

- the compartment was pre-heated;
- all openings into the compartment were closed;
- a 70 kW methane flame was ignited using a pilot light and a safety control system;
- this diffusion flame was allowed to burn. It died down as it became oxygen starved and self extinguished after about two minutes;
- after the flame had extinguished, the gas was allowed to flow into the compartment so that the unburnt fuel fraction increased;
- after a set time from the burner ignition, the gas supply was turned off. A time of 7 minutes 55 seconds was used because experience showed that this produced significant backdraughts;
- at 8 minutes, the door was opened to allow air to flow into the compartment – the short time between turning off the gas supply and opening the door was to prevent too much cooling of the gases within the compartment;
- the spark igniter tree, to simulate an ignition source, was switched on after various pre-determined times and the backdraughts were initiated.

The compartment was instrumented to measure:

- gas temperatures;
- oxygen concentration;
- heat output from the fire;
- heat output from the fireball;
- gas velocities through the door;
- static pressure in the laboratory.

All data was recorded on a datalogger located in an instrumentation trailer and results were then processed to give graphical results.

All the tests were recorded on colour video equipment. A wide angle camera covered the fireball coming out of the compartment and a second camera provided a narrower view which showed detail of the development of the backdraught inside the compartment.

Several methods of assessing the severity of the backdraughts were used:

- the heat output from the fireball flux measured outside the compartment;
- the maximum static pressure recorded in the laboratory from a fast response sensitive pressure transducer;
- the velocity measurements in the doorway;
- a figure of merit that was simply a judgement of the size of the fireball from the video record.

In later tests, wooden pieces profiled in the shape of a kneeling firefighter, were positioned in the path of the fireball. Each piece had three copper discs fitted which were connected to thermocouples. The thermocouples outputs were processed to give an estimate of the energy absorbed.

For most tests, no one was allowed in the laboratory housing the compartment for safety reasons. An instrument trailer was located in an adjacent laboratory and served as the control room for the tests and from here the compartment could be observed using the video cameras. Live data from the instruments was displayed in the trailer. The compartment doors and vents were operated from this area using a system of pulleys and levers.

UNDERSTANDING BACKDRAUGHT

Flame Types – Premixed flame

Premixed flames occur where a fuel is well mixed with an oxidant, normally air. For ignition to occur, energy must normally be supplied to the system as a spark or small flame. Auto-ignition is possible at high temperatures. A self-sustaining flame will then be established around the ignition source and propagate outwards in all directions. A mixture of air and fuel will only burn if the concentration of fuel lies between well defined limits, called flammability limits. In the case of methane, the mixture will only burn if the concentration of methane in air lies between 5% and 15%.

Strictly speaking, the term 'deflagration' in the definition of backdraught used above, refers specifically to the propagation of flame through a premixture of fuel vapour and air.

Flame Types – Diffusion flames

Diffusion flames occur at the interface where fuel vapour and air meet. Unlike premixed flames, the fuel vapour and air are separate prior to burning. The dominant process in the diffusion flame is the mixing process. Because diffusion flames exist only at the fuel-air interface, there is no equivalent of flammability limits.

There are two broad types of diffusion flames. In slow-burning diffusion flames, such as candle flames, the fuel vapour rises slowly from the wick in a smooth laminar flow giving a laminar diffusion flame. If turbulence is induced at the interface where fuel and oxygen mix, this gives it an increased surface area in comparison to the relatively small surface area of the smooth fuel/air interface of the candle flame. In this turbulent case, it is this large surface area which determines the rate at which the fuel and oxygen are consumed. This type of flame is a turbulent diffusion flame and most fires comprise large turbulent diffusion flames. The larger the fire becomes, the greater the turbulence generated by the buoyant movement of the burning gases.

A simplified indicator of the flame type is the colour: for methane, orange/yellow flames are likely to be diffusion flames and blue flames are likely to be premixed.

The phenomenon of backdraught is governed by the principles of fluid dynamics, heat transfer and combustion chemistry. The process is outlined below:

- Before the doorway (or vent) is opened, a physical barrier separates two 'reservoirs' of fluid which possess quite different properties. Inside the compartment there are hot gases which are rich in hydrocarbons but oxygen-poor while the outside air contains 21% oxygen and is at ambient temperature.
- When the doorway is opened, a gravity current is created as the denser fluid (cold air) flows underneath the less dense hot gases within the compartment and the less dense hot gases flow out through the top of the doorway.
- Mixing occurs at the boundary between the cold air and the hot gases providing a region in which there will be a flammable mixture.

The severity of the backdraught (see below) then relates to the amount of premixing that occurs prior to ignition once the gravity current has reached the spark source and given rise to turbulent mixing in that area.

Severity of Backdraughts

The flows into the compartment when the vent is opened have been modelled by using the technique of salt water modelling. This has shown that the entry velocity of the gravity current is strongly dependent on the initial temperature difference between the compartment and the ambient atmosphere. Where a greater temperature difference exists, the entry velocity will be greater and the gravity current will reach the spark source sooner. It will impact on the rear wall with the greater kinetic energy and be reflected upwards and back towards the opening, inducing significant mixing between the hot and cold layers as it does so.

Violent backdraughts are likely to occur when the compartment temperature is high and ignition is delayed until after the fresh air current first meets the rear wall of the compartment: under these conditions in which there is greater mixing of the two layers before ignition, the flame will propagate nearly spherically. Conversely, 'lazy' backdraughts are observed when the ignition coincides with the arrival of the gravity current, preventing significant premixing; in these cases the combustion zone appears to be confined to the interface between the hot and cold zones. However, even these situations may give rise to violent events once the combustion zone reaches the compartment doorway as the expansion of flammable gases into the atmosphere induces very efficient mixing. Importantly, however, the backdraught may be reduced to some extent if the fuel gases have burnt at the doorway or vented before a backdraught generated deeper in the compartment arrives at the doorway.

RESULTS

Typical Backdraught Results

Figure 3 shows a sequence of photographs of a backdraught with the spark source, at the rear of the compartment, switched on 5 seconds after opening the door.

0.1s after ignition

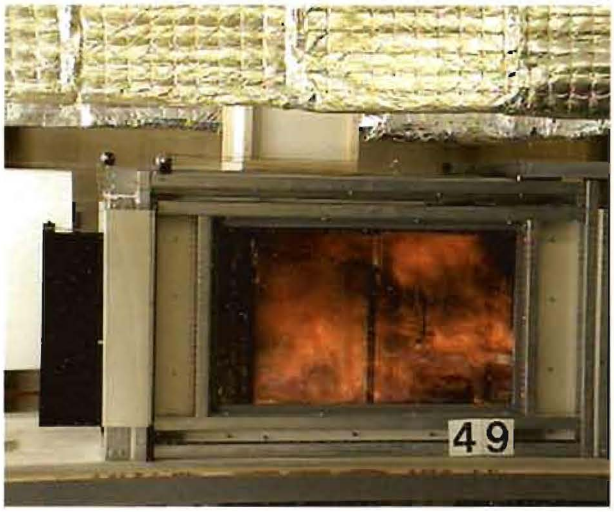
The cool air enters the lower part of the door and ignition occurs when there is flammable mixture in the region of one of the spark sources in the spark tree.

Initially the flame is premixed and expands spherically.

0.4s after ignition

The flames travel along the interface between the gas and air and as it progresses and expands, further mixing takes place. Flow past any objects in the compartment causes further mixing. Turbulent diffusion flames (orange) can be seen in the upper half of the compartment and premixed flames (blue) in the lower region.

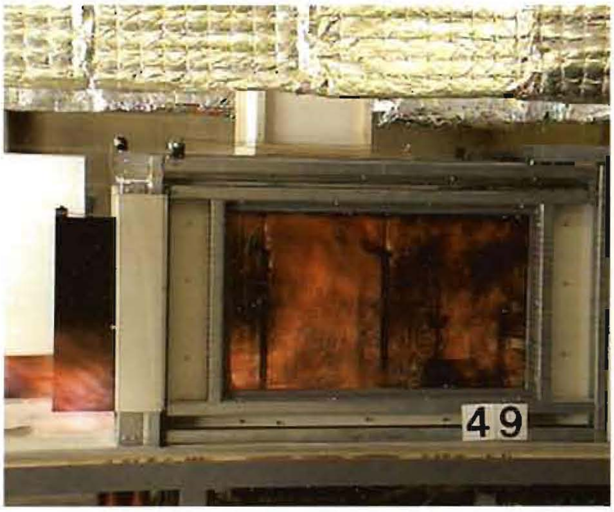
Figure 3: Typical backdraught



0.6s after ignition

The backdraught travels through the compartment involving the whole compartment.

Unburnt flammable gases are driven out of the compartment by the expansion of the gases after combustion.



0.9s after ignition

Flame is driven out of the lower part of the door which ignites the flammable mixture outside.

1.2s after ignition

A massive fireball fills the space outside the compartment.

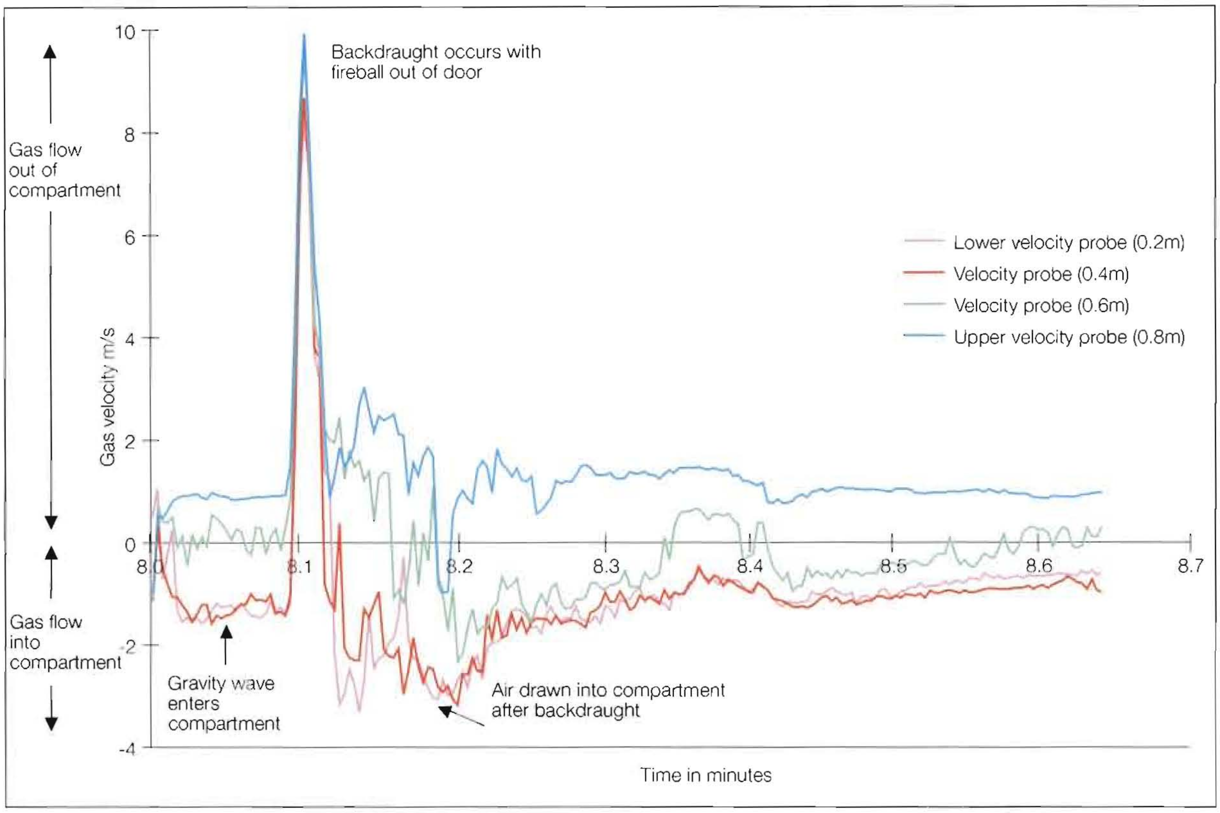


Figure 4: Typical results of gas velocities in the compartment doorway

Large files of data have been collected during the trials which are available on spreadsheets at FEU. As an example which shows the gravity wave, graphical results of the velocities in the doorway are shown in Figure 4 above.

The figure shows the gravity current entering the lower half of the compartment at a velocity of about 1.5 metres per second. Hot gases are leaving the compartment at a lower velocity from the upper half. When the fireball passes out of the door the flow at all heights is out of the compartment at velocities of 8 to 10 metres per second. After the backdraught, as a result of cooling, air is drawn into the compartment at all levels apart from that measured by the top probe, before a steadier flow is established.

It should be noted that the velocities recorded are those of the gases and do not necessarily relate to the observed movement of the fireball.

Effect of delaying ignition with a single compartment

Figure 5 opposite shows the effect of varying the time from opening the door to switching on the spark igniters. The spark tree is located at the rear of the compartment and ignition occurs at a height where there is a flammable mixture in the region of the spark source.

The results from the various methods of assessing the severity of the backdraught show a similar profile as illustrated in Figure 6 on page 10. In the compartment being used, when the time delay is increased the severity reaches a peak at about 5 seconds and then reduces for the longer delays.

Figure 5: Still frame sequences showing the effect of ignition delay on the backdraught

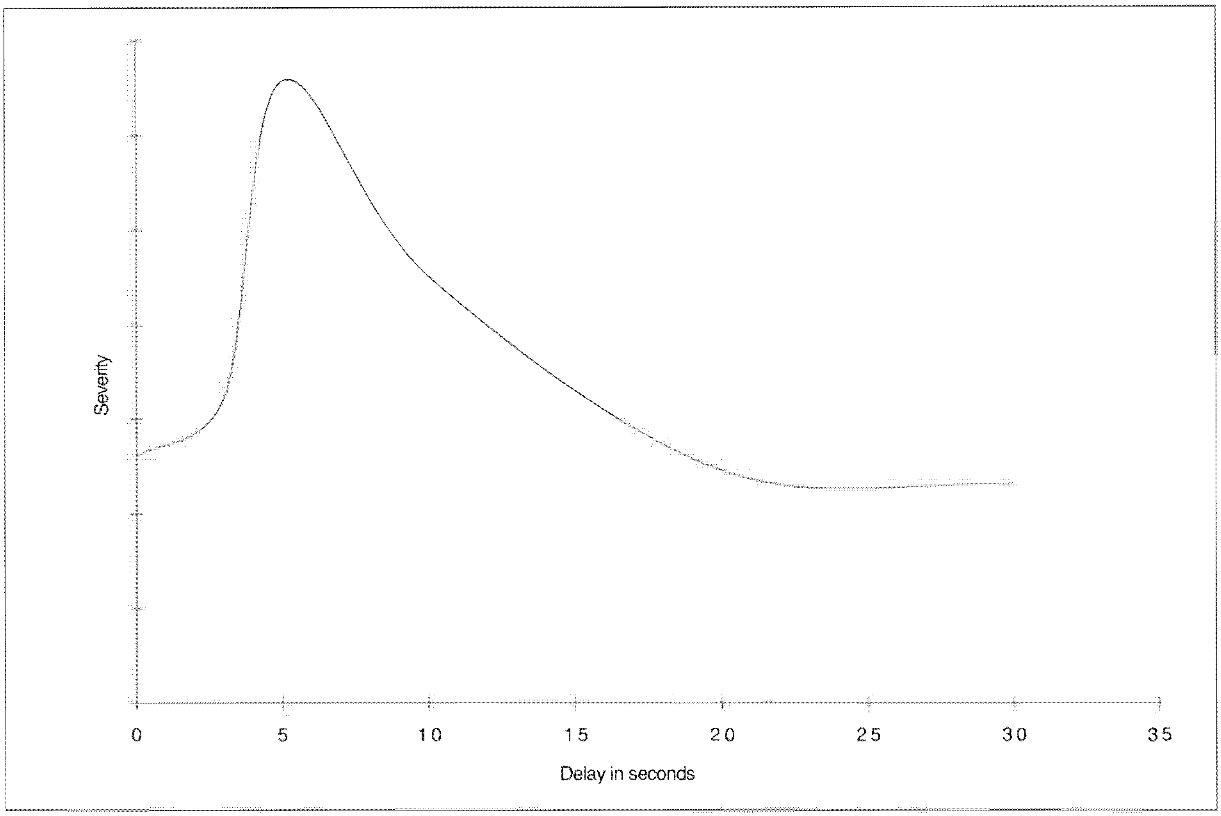


Figure 6: An indication of the effect of ignition delays on the severity of a backdraught
Note: these figures apply to this size compartment only, and do not provide a guide for other sized compartments.

The explanation for this is given below.

For short delays of less than 5 seconds
As the gravity current of air reaches the spark source, ignition takes place and flames appear at the rear of the compartment. The gravity current has not had time to reflect from the rear wall and cause any significant mixing before ignition. The diffusion flames burn lazily in the rear section of the compartment and then slowly spread to the door, mainly in the lower half of the compartment. No backdraught is produced although there is some burning of flammable gas outside the compartment.

At a delay of about 5 seconds
By the time ignition occurs, the gravity wave has reflected off the rear wall and caused a significant amount of mixing. Ignition starts as a premixed spherical flame front and then premixed flames progress along an interface as the flame front moves rapidly towards the door. (This is better illustrated in the sequence for the longer delay of 19 seconds). The whole compartment fills with luminous orange flames (indicating diffusive burning). Once ignition has taken place the gases expand rapidly driving unburnt gases out of the compartment and these are ignited as the fireball progresses.

For longer delays
For delays longer than 5 seconds the gravity wave will have reflected off the rear wall and even returned to the front of the compartment. Cool air continues to enter from the bottom of the door and the hot flammable gases exit from the top without igniting. The longer the delay then the higher the interface between air and gas will be and the higher will be the point of ignition when the spark tree is switched on.

After ignition a flame front propagates towards the door initially along the interface, burning with blue lower edges which are typical of a premixed flame. As the flame front propagates, it causes mixing and yellow diffusion flames fill the rest of compartment.

In this test rig, the backdraught is less severe. After a longer delay, there is less flammable gas in the compartment and that which has escaped will have dispersed so that it does not contribute to the fireball. In a real fire, generation of flammable vapours continues after the compartment is opened up. Whilst the principles are the same, *a delay of 5 seconds should not be taken as representative of what might happen in a real fire*.

Effect of delay with a single compartment with a vertical doorway and the spark tree at the centre

When the spark gap was positioned in the centre of the compartment similar results to those above were obtained. The severity reached a peak at about 5 seconds and then reduced for the longer delays.

Similar explanations to those given above for the spark tree at the rear, can be given; the main difference is that flame propagation takes place in two directions and the overall backdraught is less severe since all the flammable gas is not driven out of the compartment at the same time.

Effect of delay with a single compartment with a vertical doorway and the spark tree at the front

Only two tests were carried out with a single compartment and a spark tree in the front of the compartment.

In these two tests there were no backdraughts. After ignition the flames spread slowly outside the door and also spread towards the rear of the compartment.

Effect of delay with a single compartment with a corridor section and the spark tree at the rear of the main compartment

Tests were carried out with the corridor section attached to the main compartment and a spark tree in the rear of the main compartment.

The results from the various methods of assessing the severity of the backdraught show a similar profile to Figure 6. In some tests, gas was leaked into the outer compartment before the doors were opened. With the corridor section, severe backdraughts were produced with flames involving the whole corridor section (Figure 7).

Figure 7: Backdraught with corridor section showing total flame engulfment in corridor (Spark tree at rear of main compartment, switched on 6s after doors opened. Figure shows 1.8s after ignition).

Effect of reduced vent opening with a single compartment and spark tree at the rear

A number of tests was carried out by opening the four vents after eight minutes (see Figure 2) and leaving the door closed. This reduced the venting area by a factor of five.

Initially tests with this configuration were carried out with no preheating of the upper layer and no backdraughts were produced. When preheating was carried out then fireballs were produced which were the most energetic of all the tests.

Without pre-heating, the gravity current did not have enough energy to cause sufficient premixing at the rear of the compartment and only lazy flames were produced. However with pre-heating, a more energetic gravity wave was produced and the backdraught developed quickly in the whole of the compartment (see Figure 8 overleaf). The reduced ventilation resulted in the compartment gases being forced through a smaller opening and with a higher velocity.

Figure 8: Backdraught from reduced ventilation opening showing a very energetic backdraught (Spark tree at rear of main compartment, switched on 6s after vents opened).

Effect of a door for shielding a firefighter from a backdraught

Avoiding the likely flame path through a vent or door is the priority should a backdraught be likely to occur. The effect of a door for shielding a firefighter from a backdraught was assessed from temperature measurements on wooden pieces, profiled in the shape of a kneeling firefighter. The results are illustrated in Figure 9 in which the cutout representing firefighter A was positioned behind the door and that representing firefighter B in an equivalent position on the opposite side of the opening but not protected by the door. The results show that the cutout behind the door gave significantly lower readings, and thus this position gave greater protection to the firefighter.

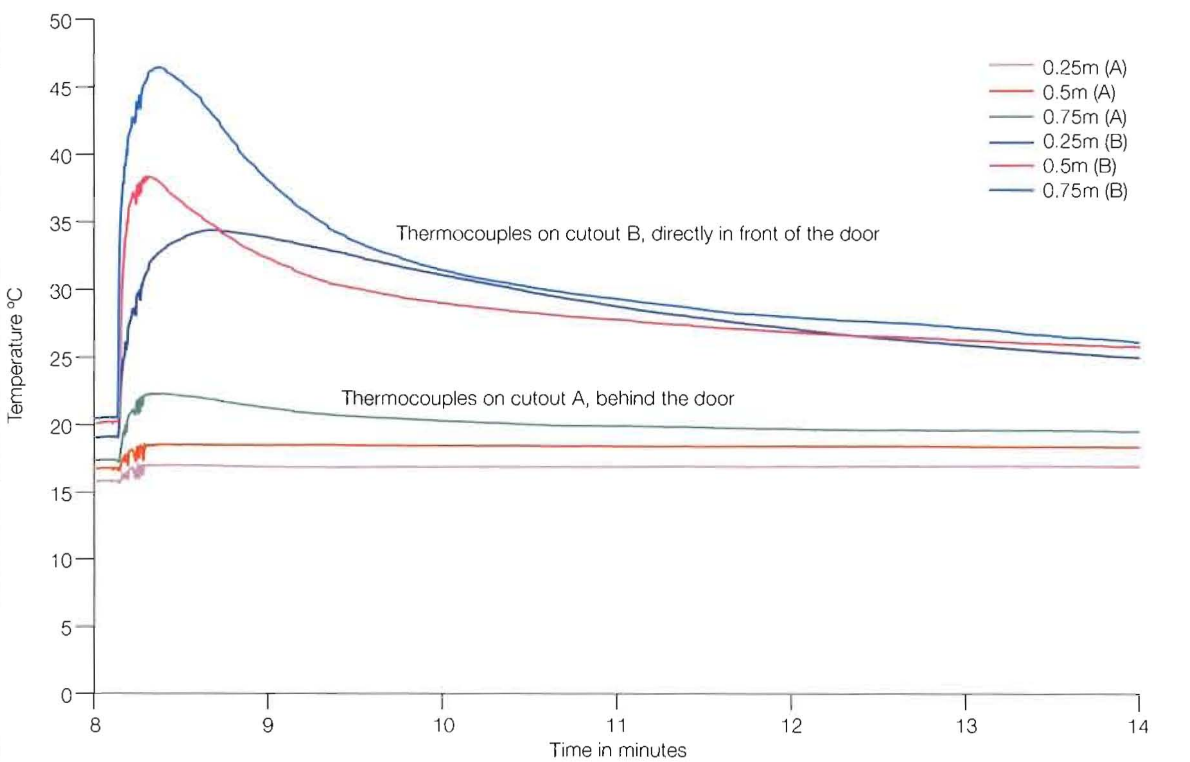


Figure 9: Results of temperature measurements on firefighter cutouts.

The pressure effect outside the compartment from a backdraught

It is important to have an awareness of the energy from a backdraught even with the relatively small compartment used. In one of the early tests when the roller shutter door in the laboratory was closed, the effect of pressure was demonstrated dramatically as the roller shutter door was blown out of its tracks and damaged. The pressure rise in the laboratory housing the compartment was measured during the tests. The maximum pressure recorded was 350 pascals (which was with the roller shutter door half open) and this did give cause for concern about possible damage to the fabric of the building. Following an inspection from a consultant, no significant damage was found.

Introduction of smoke into the compartment

The simulator uses methane gas which produces almost no smoke on burning, unlike the contents in a typical house fire. This has the advantage that the events inside the compartment can be observed through the viewing panel. However, practitioners may have doubts about whether the compartment simulated real life events. To give the fire service more confidence in the compartment and to produce a more realistic effect, smoke was introduced into the compartment using a smoke canister and a backdraught produced. Figure 10 shows a comparison between a backdraught in the Fire Service College (FSC) backdraught demonstration container, a backdraught in the FEU compartment with smoke and a backdraught in the FEU compartment with no smoke.

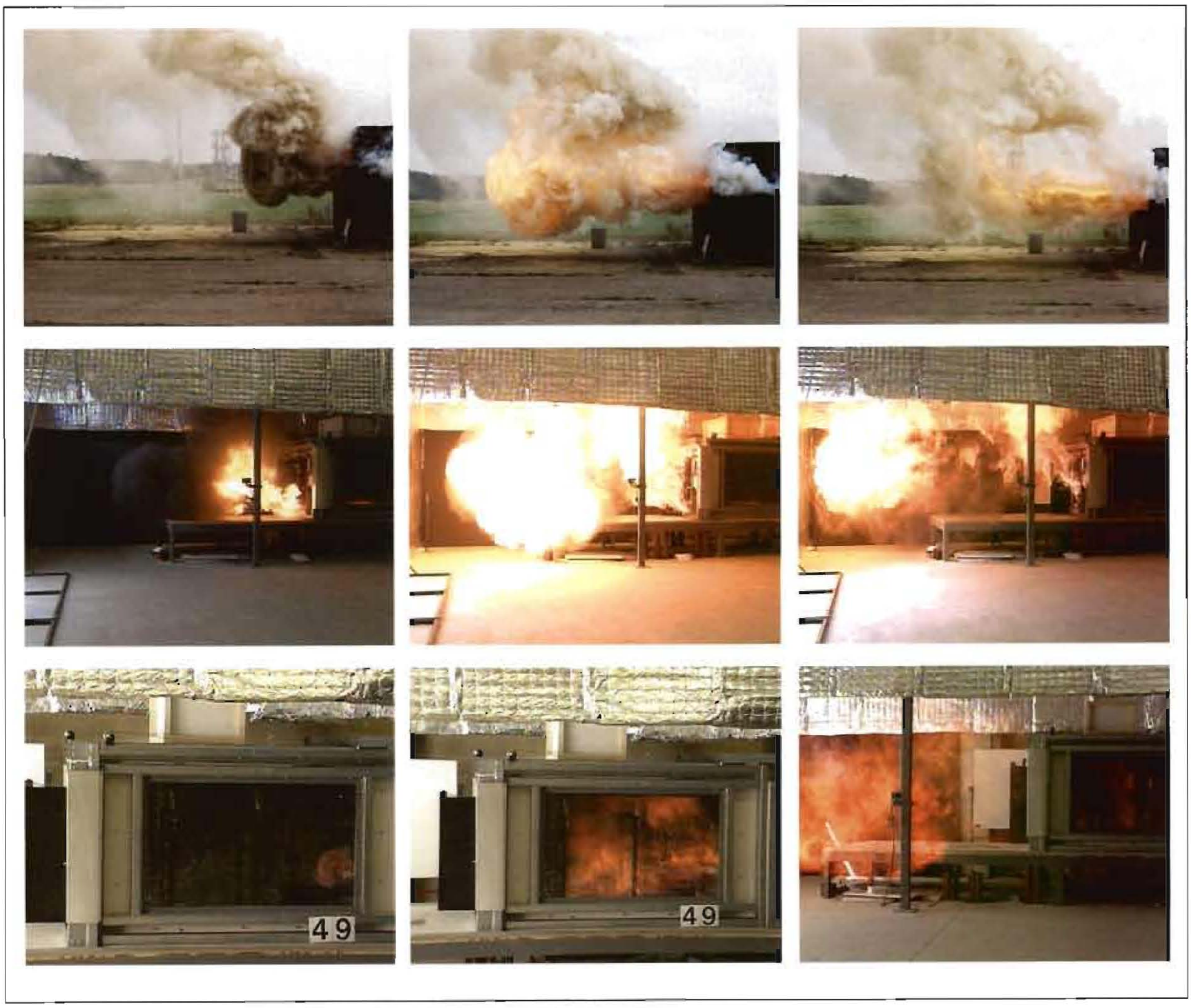


Figure 10: Comparisons of a backdraught in the Fire Service College (FSC) backdraught demonstration container (top), a backdraught in the compartment with smoke (centre) and a backdraught in the compartment with no smoke (bottom),

The upper picture shows the sequence of events from a chipboard fire in the FSC container (see further details below). A quantity of smoke/flammable vapour is pushed out of the compartment and the flame then spreads through this to produce the fireball.

The centre picture shows a similar sequence using smoke introduced into the methane in the compartment simulator. There is a clear similarity between the pictures from the simulator and those from the demonstrator using a more realistic fire.

The lower sequence from the compartment using methane alone allows the development of the backdraught to be observed because this is not obscured by smoke. The timing of this sequence does not correspond with the others because it includes a view of the development inside the compartment which is not possible in the other two cases.

TESTS USING THE FIRE SERVICE COLLEGE BACKDRAUGHT DEMONSTRATION CONTAINERS

Once the basic studies had been completed, it was decided that there would be benefit in using one of the backdraught demonstration containers at the FSC to obtain results from a more realistic fuel. This also gave the opportunity to explore the use of various tactics for use in potential backdraught situations.

The Fire Service Manual addresses actions by firefighters, considers the signs and symptoms of a backdraught and lists the indicators as:

- Dense smoke with no obvious sign of flame;
- Smoke blackened windows;
- Smoke pulsing from doors and windows;
- Signs of heat around the door.

The container (6.1m x 2.4m x 2.4m), with stable doors at the front and on one side, was used to produce backdraughts by following the procedure:

1. Pairs of new sheets of chipboard each 18mm thick were mounted at one end of the container on the end wall, on the side walls and on the roof (Figure 11);

Figure 11: Chipboard arrangement in the container.

2. The chipboard sheets were ignited using kindling timber and paper placed on the floor in the rear corner of the container;

3. When the fire had become established all the doors were closed. An upper section of one of the stable doors was opened when a potential backdraught situation had been judged (by the FSC Instructors) to exist inside the container. The judgement was based on previous experience using a combination of timing and appearance of smoke from around the door. The choice of door to be opened was determined by the wind direction.

There was no backdraught the first time the procedure above was followed and so the doors were opened to allow the fire to re-establish and step 3 above was repeated until a backdraught resulted.

The vertical gas temperature profile in the container was measured at one position (towards the front of the container) by a thermocouple tree with 6 thermocouples. Colour video recordings were also produced which were subsequently analysed to record the timing of the events.

The plan was to be able to produce two similar backdraughts, one after the other, so that the effect of changes in tactics could be compared.

Although the procedures above were generally followed, it was found that the time before backdraughts were obtained was variable and changes had to be made during the tests afte consultation between FEU staff and FSC instructors. The major variable was the wind conditions.

Two short series of tests were carried out in September 1998 and December 1998 and the tests and results are summarised in the Table below.

Aim	Method	Results
To produce repeatable backdraughts.	A range of times was explored for which all the doors were closed before a stable door was opened after a period.	Allowing the fire to re-establish for 90 seconds and then closing all doors for 90 seconds appeared the best approach. Variations were inevitable depending on the wind, weather and state of the burning chipboard.
.To apply water spray to see if this action prevented a backdraught after a door was opened.	The upper front door was opened and water spray applied in bursts from a hosereel (5 bursts of 2 seconds each with intervals of 20 seconds between application). The spray was a tight cone swept around the compartment. The upper door was then closed for one minute before re-opening.nted a backdraught after a door was opened.	The test showed that the water spray reduced the temperatures in the container but, as expected, the temperatures increased after the application. The spray did necessitate the firefighters being exposed to steam being pushed out of the compartment when the door was closed. After re-opening the door there was no backdraught.
To see the effect of closing the door after opening it in a potential backdraught situation. This may be a tactic to be explored during firefighting.	When potential backdraught conditions had been produced in the compartment, the upper door was opened and after a period closed again. The open period was half the time for which a backdraught had occurred in earlier tests.	No signs of a backdraught were observed during this closed period. This single test suggests that the advice to close a vent is likely to prevent a backdraught.
To assess the effect of water spray to protect firefighters from a backdraught.	A spray was produced from a hosereel branch (at 125 lpm and 70° cone angle) and a main line branch (400 lpm and 70° cone angle) mounted on a stand 7 metres in front of the door. Radiometers were positioned behind the spray and in front of the spray to measure the heat output from the backdraught.	Some reduction of heat radiation was shown. The results of these tests were not conclusive because it was not possible to produce repeatable backdraughts for a valid comparison to be made.

OBSERVATIONS FROM THE DEMONSTRATION CONTAINERS

The limited number of tests were not conclusive but gave data not previously available to FEU on the temperatures in the backdraught demonstration containers. The opportunity to witness and analyse the tests gave further insight into the processes of backdraught and the tactics to deal with these.

There were two observations relevant for firefighting operations:

- the severity and time of backdraughts was variable;
- there were several instances when there were no indications of the accepted signs and symptoms of a backdraught, only seconds before a backdraught occurred. This does prompt further advice being given to warn firefighters that a backdraught can occur even when a vent has been opened for some time. This may be particularly relevant when arriving at an incident and not knowing exactly how long a vent has been opened.

USE OF THE FEU COMPARTMENT FIRE SIMULATOR AS A TRAINING AID

The use of this simulator for practical demonstrations of backdraughts was considered in the early stages of the project. In the development stages of the compartment no one was allowed to remain in the compartment laboratory during a test for safety reasons. The major safety concern with direct viewing was that if the viewing panel was to fracture under pressure, then flying fragments of glass might present a hazard. To give protection against this, a protective shelter with polycarbonate glass viewing windows was installed in the laboratory. Representatives of the Safe Concept Working Group and several instructors from the Fire Service College were allowed to watch a test from the shelter.

The consensus of opinion from those taking part was that there was little benefit from seeing the tests directly for the following reasons:

- The backdraught event took place too quickly for it to be appreciated in real time and reviewing the test on video at slow speed was required for the backdraught development to be appreciated.
- There was a minority view of those present that witnessing the event live ensured a more lasting memory of the phenomena. However the logistics of operating the compartment safely would not justify its use when other more simple demonstration devices are available and these can be supported by the video on backdraught.

PRACTICAL SIGNIFICANCE OF RESULTS FOR THE FIRE SERVICE

The main lesson for the fire service, which has been demonstrated from the tests in the compartment and in the demonstration container, is the severity and unpredictability of a backdraught. Large backdraughts with fireballs 5 metres in horizontal extent were produced in the tests and the significant pressure rise that can be generated within a building was demonstrated.

The fireball will engulf anything in its path. The use of the corridor section with the compartment showed that there was total involvement of the corridor as the backdraught passed through. This occurred whether gases had been allowed to leak from the main compartment or not. The recommendation in the Fire Service Manual is to cool and ventilate the outer compartment, but while this is sound advice it should be noted that whenever a fireball passes through a compartment there are obvious dangers to those in its path.

The unpredictability must be stressed. The test conditions in the compartment were closely controlled and have shown the varying severity that can be achieved with different ignition delays, compartment temperatures and venting conditions. In the demonstration containers, this level of control was not possible. Although the procedures were standardised, it was found that the time before backdraughts were obtained was variable and the main variable was the wind conditions. The real life situation is even less controlled than in the demonstration containers.

It is important to appreciate the differences between backdraughts produced in a real fire, in the simulator and even in the demonstration container. Important differences are given below:

- The situation in a real fire environment is uncontrolled. The layout of the building, location of flammable vapour, sources of ignition and positions of vents may not be known and may be changing. Backdraughts can occur a long time after a vent has opened, particularly where there may be the possibility that flammable vapours have been trapped at high level. If there is an open vent into the fire compartment at the time of the arrival of the fire service, it still cannot be assumed that the compartment is safe.
- The tests showed that the longer the compartment is vented before initiating a backdraught, the less severe the backdraught. This cannot be relied on in a real fire since pyrolysis will continue to take place from the fuel after the door is opened. In the compartment simulator there is always a net loss of gas after the door is opened. In a real fire, the size of any vents, the fuel load and combustion state will determine whether there is a net loss or gain of flammable vapour in the compartment.
- The spark igniter tree in the compartment produces a series of sparks at different heights which have sufficient energy for ignition of a flammable mixture. The conditions for a backdraught of an ignition source near the interface layer will generally be met. In the real fire compartment and the demonstration compartment, it may be some time after fresh air is introduced before there is an ignition source of sufficient energy near the interface layer to initiate a backdraught. There may only be smouldering material when fresh air is introduced and this must develop to produce flames for ignition. These flames must be in a region where there is a flammable vapour air mixture or there must be a path for any flame from the ignition source to the flammable mixture layer for a backdraught to result.
- In the limited tests carried out, the fireball from the simulator generally came out of the lower half of the door, across the platform and licked over the edges. In a real fire situation the path would be difficult to predict, but current advice to stay low and to the side of the door or opening is as good as can be given. Avoiding the likely flame path through a vent or door is the priority should a backdraught be likely to occur.
- It was not possible to heat the compartment until the gases in the compartment were above the auto-ignition temperature. In a real fire situation, when the door is opened spontaneous ignition of flammable vapour/air mixture close to the smouldering surface may occur and the flame would then spread out of the door. This would not necessarily result in a backdraught but there would be rapid spread of flame.

CONCLUSIONS

The main lesson for the fire service which has been demonstrated from the investigations is the severity and unpredictability of a backdraught. The test conditions in the compartment were closely controlled and have shown the varying severity that can be achieved with different delays, compartment temperatures and venting conditions.

The situation in a real fire environment is uncontrolled. The location of flammable gas, sources of ignition and positions of vents may not be known and may be changing. Backdraughts can occur a long time after a vent has opened, particularly where there may be the possibility for gases to be trapped at high level. If there is an open vent into the compartment at the time of the arrival of the fire service, it still cannot be assumed that the compartment is safe. There were several instances in the demonstration containers when there were no indications of the accepted signs and symptoms of a backdraught, only seconds before a backdraught occurred.

The investigations have shown that the compartment was a useful tool for demonstrating backdraught and gaining a better understanding of the phenomena. Without the compartment, it would not have been possible to produce the training videos to demonstrate the development of a backdraught. The compartment allows the development of a backdraught in different controlled scenarios to be observed in the absence of smoke. The development of a backdraught in a real fire cannot be observed because of the obscuration from the smoke produced.

Firefighters need to be aware of potential backdraught situations at all times. Guidance is given in the Fire Service Manual and these investigations support this advice. For example, very energetic backdraughts were produced with fireballs 5 metres long. In a real fire situation the path would be difficult to predict but the current advice to stay low and to the side of a door is as good as can be given.

FURTHER INFORMATION

FRDG Publication 5/94, A Survey of Backdraught, R Chitty (Fire Research Station), 1994.

Fire Service Manual, Volume 2, Fire Service Operations, 1997.

NIST-GCR-94-646, Backdraft Phenomena, Charles M Fleischman, 1994.

Fire Engineers Journal July 1997, Flames in Fires and Explosions, Dr J R Brenton and Dr D D Drysdale.

This report describes experimental investigations into the phenomenon of backdraught in fires. These tests were carried out under closely controlled conditions, and have shown the varying severity that can result with different delays, compartment temperatures and venting conditions. The main lesson for the fire service is the potential severity and unpredictability of a backdraught.

Firefighters need to be aware of potential backdraught situations at all times. Guidance is given in the Fire Service Manual and these investigations support this advice.

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