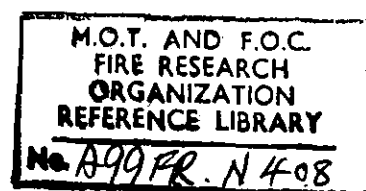


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F.R. Note No. 408/1959.
Research Programme
Objective

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICERS' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

FIRE RESEARCH AND THE AIRCRAFT CRASH FIRE PROBLEM

LECTURE TO M.T.C.A. FIRE OFFICERS TRAINING COURSE JULY 1st, 1959

by

D. Hird.

July, 1959.
File No.

Fire Research Station,
Boreham Wood,
Herts.

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INTRODUCTION

The risk of flammable liquid fires is today spread throughout most branches of industry and even the home, and the work at the Joint Fire Research Organization is intended to cover many of these risks. Flammable liquid fires can occur under many widely different conditions from a large petrol storage tank with a free liquid surface to a spill fire and the appropriate types of extinguishing agent and methods of application will obviously depend on the type of fire expected. The way in which the fire is tackled will also depend on the risks associated with the fire; thus a large storage tank fire which is extinguished satisfactorily in 2 hours might be considered to be a highly successful operation. As you all know, the same does not apply to an aircraft crash fire. It has been estimated that the life of the occupants of an aircraft would be seriously endangered within 3 minutes of a major crash-fire starting. This overriding importance of gaining a rapid control of the fire must colour all ones thoughts and discussions of the crash fire-fighting problem and makes the aircraft crash fire a very particular example of the flammable liquid fire.

GENERAL CONSIDERATIONS

Although you will be mostly concerned with low flash point fuels it is worth very briefly going over the way in which the extinction of a fire can depend on the properties of the flammable liquids.

1. High boiling point liquids - gas oil, transformer oil.

These can be extinguished by cooling the liquid to below its fire point and this can be achieved easily and economically with water sprays. However, as the fire point gets nearer to ambient temperature, extinction becomes more difficult and for liquids with fire points below that of kerosene the use of water is operationally unattractive.

2. Liquids with low flash points

These cannot be extinguished by cooling the liquids and must be extinguished in one of the following ways -

- (a) Covered by a layer through which the fuel vapour cannot permeate - FOAM.
- (b) By extinguishing the flame. Under ideal conditions this can be achieved by a water spray which cools the flame. Normally done by inerting the combustion zone with CO₂, vaporizing liquids or dry powder.

If the fire is extinguished by extinguishing the flame, (b), then any source of ignition can reignite the vapours and give a 'flash back'. On this important point we can classify all extinguishing agents for flammable liquid fires into two groups.

- (1) FOAM - giving protection against reignition.
- (2) All other agents giving no such protection.

1. FOAM

In discussing foam we will confine ourselves to foams produced from protein

compounds, which are the only ones used in this country. Differences in the type of protein compound can produce some differences in foam properties when used with given equipment but these differences are of little practical importance.

The properties which may affect the fire fighting capabilities of a foam are -

- (1) EXPANSION - inversely proportional to the density of the foam.
- (2) FLUIDITY - the ease with which a foam will flow over surfaces and around obstacles is an important property. Fluid foams in general produce a thinner foam layer than stiff ones.

This property can be measured by a torsional vane viscometer giving the critical shear stress of the foam. Normal branch pipe foam has a critical shear stress of 100-200 dyne/cm² whereas equipment such as the foam pump can give very stiff foams of about 1,000 dyne/cm².

- (3) DRAINAGE CHARACTERISTICS -

Liquid will of course drain from all aqueous foams due to drainage down the channels between the bubble walls and rupture of some of the bubbles. The rate at which liquid drains from the foam can affect the usefulness of the foam. A measure of this is given by the time taken for a given percentage of the liquid content (generally 25%), to drain under standard conditions. For a given foam compound the drainage characteristics and fluidity have a fixed relation, and it is not possible to vary one independently of the other. A fluid foam will always drain more rapidly than a stiff one. These properties can be varied (though not independently) by varying the concentration used (pick-up) and the method of making the foam.

This is illustrated by test results using different foam compound concentrations through a No.2. foam making branchpipe.

Table 1. Variation of foam properties with concentration.

Compound concentration per cent	Foam Expansion	Critical shear stress dyne/cm ²	25 per cent drainage time (mins)
1	4	95	2
3	6	170	3
5	7	215	3½
10	11	410	10

Now that we have some idea of the range of foam properties we are likely to be dealing with, let us look at the effect of these properties on the fire fighting capabilities of the foams.

Here we must remember that there are two other things which will affect this - the type of fire and the method of application. Most of the experimental work has been done by applying foam gently to the surface of petrol fires in trays and although all the conclusions from these tests may not be applicable to the aircraft crash fire it is worth examining the general conclusions.

There are three criteria on which one can judge the fire fighting capabilities of a foam -

1. The critical rate of application

When foam is applied to fire some liquid is lost by evaporation and some by drainage and unless the foam is applied faster than it is being destroyed the fire will never be extinguished. This rate is called the critical rate and can be thought of as - rate of drainage from foam per square foot of foam blanket + rate of evaporation per square foot of foam blanket.

For a foam produced from a 3% concentration and having a critical shear stress of 100 dynes/cm² these losses are about .006 gall/ft²/min. by drainage and .102 gall/ft²/min. by evaporation. Thus the foam must be applied at a rate greater than .108 gall/ft²/min. to extinguish the fire.

Let us then look at the effect of varying the concentration of foam compound in a branch pipe on the critical rate of application.

Table 2. Variation of critical rate with concentration.

Compound concentration %	Critical rate of application gall/ft ² /min
1	.022
3	.015
5	.013
10	.012

These figures for the critical rate of application were obtained on small fires with the foam applied very gently and are therefore probably rather lower than might be obtained under operational conditions. However the effects of varying foam properties are likely to be similar.

It can be seen that the biggest improvement is obtained by increasing the pick up from 1% to 3% and that only marginal improvements are gained thereafter.

The reduction in the critical rate is gained by reducing the loss by drainage as the evaporation loss is sensibly constant for all foams.

2. Time taken to control the fire

When foam is applied gently to a fire on a free petrol surface the time taken to control the fire is about the same as the time the foam would take to cover the surface if there were no fire. This time is governed by the rate of application, and the fluidity of the foam. The higher the rate of application and the more fluid the foam the more rapidly the surface is covered. The fluidity of the foam is important merely because it controls the weight per unit area of the foam blanket or the amount of water per unit area. The lower the fluidity the lower the weight per unit area and thus the more rapid the control. Because the fluidity controls the weight of the foam blanket and not its volume the expansion, which is proportional to the volume of the foam, does not affect the control time under these conditions.

Since, at rates above the critical rate, control of the fire is largely a matter of covering the surface of the fuel with a layer of foam which will act as a vapour barrier, the control time is likely to depend on the way in which the foam is applied. For instance, one might expect different rates of cover of the liquid surface if the foam is applied to a spill fire by a branch pipe, compared with foam applied gently at one point to a free surface fire.

To investigate these differences and to obtain information relating more precisely to the aircraft crash fire case, two series of larger scale tests have been planned by a Committee representing those particularly interested in the crash fire-fighting problem. The first of these series of tests were made on a 100 sq.ft. fire containing some obstructions and having partly a free petrol surface and partly petrol soaked sand. Foams of different properties were applied at three rates of application both as a jet and a spray, and the time taken to control the fires measured.

In these tests the only factors which affected the control time were the rate of application and, at the two lower rates of application, the fluidity.

The second series of tests was made on a much larger fire of 900 ft² containing obstructions and a largely free petrol surface. Again foams of varying expansion and fluidity were applied to the fire as a jet at two rates of application. Results of large fire tests are always very variable and these were no exception, but the results seemed to be at variance with those on the 100 ft² fire. In these tests if any factor other than the rate of application was important it was the expansion of the foam rather than its fluidity.

As you can see this problem of the effect of foam properties and method of application on the control time of large spill fires is still largely unresolved. Laboratory investigations are now going on to determine the effect of foam properties on the minimum weight per unit area of foam blanket required to act as an adequate vapour seal. This work should provide some of the basic information which will help in interpreting the results of the large scale fire tests.

3. FOAM STABILITY AFTER EXTINCTION

Once the main fire has been extinguished it is important that the foam blanket should continue to act as a vapour seal until rescue operations and salvage are complete, although the main criterion must still be to control the fire as rapidly as possible.

The stability of the foam after the fire has been extinguished depends only on the rate at which liquid drains from the foam which in turn is related to the fluidity of the foam. Fluid foams drain more rapidly than stiff ones.

Turning again to our branch-pipe foam in which the foam properties are varied by varying the pick-up we can get some idea of the stability from the percentage of liquid likely to be left in the foam 10 minutes after extinction.

Table 3. Variation of stability with concentration.

Compound concentration	Critical shear stress dynes/cm ²	Approximate proportion of liquid remaining in foam blanket 10 mins after extinction. Per cent.
1	95	25
3	170	45
5	215	50
10	410	65

FOAM - CONCLUSIONS

Foam properties can be varied by varying the design of foam producing equipment and by varying the foam compound concentration. With a branch pipe the benefits to be gained by increasing the pick-up beyond 3 - 5% are small.

We have discussed the effect of foam properties on its fire fighting capabilities. The most important property, that of rapid fire control, is still unresolved although one common factor emerges from all the test results, namely that whatever the foam properties, the foam should be applied as rapidly as possible to achieve control quickly.

2. OTHER AGENTS

Agents other than foam which can be used for flammable liquid fires are carbon dioxide, dry powder and vaporizing liquids. All three types of agent are active in the vapour phase and they neither cool the high fire point liquids nor provide any permanent protection against reignition of the low fire point liquids. Being active in the vapour phase it is only necessary to get the required concentration for extinction of the flames and with this proviso extinction is rapid. The size of fire which can be tackled will depend on the critical rate of application which can be affected by a number of factors.

The method of application of the agents to a fire is more important than with foam. They must be well dispersed above the liquid surface. Carbon dioxide being a gas is naturally dispersed and dry powder is also dispersed with the expanding gas stream at the nozzle although a reasonably wide cone angle spray will require less manipulation than a narrow one. Vaporizing liquids however need to be discharged as a well distributed fine spray to realise their full efficiency; any agent which reaches the flammable liquid being largely wasted. Nozzle design is likely to affect the capabilities of vaporizing liquids much more than dry powder or CO₂.

If there are a number of obstructions in the fire area the rate of application needed to extinguish the fire may well be increased due to the possibility of flames being stabilised behind the obstructions.

These are factors common to all these agents and we will now discuss the properties of the agents separately.

(a) DRY POWDER

Most of the commercial powders in use at present consist largely of sodium bicarbonate with small amounts of such chemicals as talc and zinc or magnesium stearate to improve their flow and water-proofing properties.

Tests on free surface petrol fires in trays 3ft x 3ft have shown that the specific surface of the powder is an important property. Fine powders can extinguish the fire more rapidly and use a smaller weight than coarse powders. The present M.O.W. specification calls for a minimum specific surface of 2,500 cm²/gm, almost twice that commonly used before the specification was issued.

To extinguish a fire in a low flash point fuel by hand, a given concentration of powder must be maintained across the whole fire front. Thus in extinguishing fires of different sizes the controlling factor might be expected to be the rate of application per foot of fire front rather than the rate per unit area of fire as with foam. If the results for fires of different sizes are examined it can be seen that this is in fact the best way of expressing the critical rate of application. This means that any fire is best tackled on its narrowest front as this will give a larger safety margin.

Powders based on chemicals other than sodium bicarbonate have been investigated. Inert materials such as pulverised fuel ash can be used to extinguish fires but they are only about 1/6th as effective as sodium bicarbonate. There are a number of chemicals which have been shown to be as effective as sodium bicarbonate but none very much better. Some idea of the comparative efficiencies of

different powders is given in Table 4. where the criterion of efficiency is taken as the critical rate of application.

Table 4. Performance of different types of powder on petrol fires.

Powder	Efficiency Index.
Sodium bicarbonate	100
Potassium bicarbonate	120
Sodium chloride	100
Borax	100
Cement	25
Pulverised fuel ash	15

An important problem concerning the use of dry powder for aircraft crash fires is the question of its compatibility with foam. The combined use of powder and foam has been advocated in two fields. Firstly the use of up to 200 lbs on light rescue vehicles, in which case foam would be applied from the major vehicles after the powder, and secondly, the use of powder to extinguish small fires remaining after the foam blanket has been formed. Standard powders can have serious effects under both these conditions.

It is well known that the water proofing agents used in standard powders (metallic stearates) can break down protein foams rapidly. These stearates are slightly soluble in petrol and presumably they are dispersed in the foam with the petrol which inevitably contaminates the foam when it is applied to a large spill fire. Sodium bicarbonate with no additives also tends to break down foam although not to any serious extent.

Laboratory investigations have been going on for some time to examine the effects of different additives and a number of chemicals other than sodium bicarbonate are being tested. It appears that even when the metallic stearate content of a sodium bicarbonate based powder is reduced to one tenth of that normally used, the powder still accelerates the breakdown of the foam considerably. A complementary part of this research programme is concerned with the development of tests to assess the caking properties of powders on storage.

(b) Vaporizing liquids

Vaporizing liquids such as carbon tetrachloride and methyl bromide have been in use for many years but there has been considerable development of new types of vaporizing liquid recently.

The combustion products of all the vaporising liquids are toxic although the toxicity of the vapours themselves varies considerably from that of methyl bromide, which is toxic in very small concentrations, to trifluoro-bromo-methane which is stated to be less toxic than carbon dioxide.

The question of toxicity is obviously one which will affect its use on aircraft crash fires.

The limitations of vaporising liquids as extinguishing agents are similar to those of dry powder in that no permanent protection against

reignition is afforded and this is particularly important when dealing with fires containing obstructions.

Tests have shown that the most efficient use can be made of vaporising liquids if they are applied as a wide angle flat spray, fires being much more easily extinguished if the whole fire front can be covered. Most fire tests in this Country have been confined to carbon tetrochloride (CTC) and chloro-bromo-methane (CB) and have shown CB to be 4 or 5 times as effective as CTC. Trifluoro bromo methane which is gaseous at normal temperatures and pressures has only just become available in this Country but American test results indicate that it is considerably superior to CB.

(c) Carbon Dioxide.

As the last of the 'other agents', carbon dioxide has been used as an extinguishing agent for many years and weight for weight can be considered about as effective as CTC against flammable liquid fires. Being a gas and leaving no deposit, it obviously has advantages over some of the other agents where delicate equipment is concerned. As an agent for inserting aircraft wing spaces, it is many times more efficient than dry powder or CB, although trifluorobromomethane, also a gas, would be even more effective.

OTHER AGENTS - CONCLUSIONS

The main advantage of the three types of agent we have discussed over foam is that under the right conditions they can extinguish a flammable liquid fire more rapidly than with foam and much less weight of agent is required.

For instance about 1 to 2 lbs of foam per square foot of fire area are required to extinguish a petrol fire. Using dry powder or chlorobromomethane only about a tenth of this weight, 0.1 to 0.3 lb/ft², need be used. Thus where only a small amount of agent must be carried quickly to the fire, as with a light rescue vehicle, these agents are obviously more attractive than foam. They are also more useful for such incidences as engine fires where foam would be difficult to apply.

As we have emphasised earlier, the main disadvantage common to all other agents but foam is that they afford no protection against reignition of the fuel.

3. MAGNESIUM FIRES

The increasing use of magnesium alloys in modern aircraft for wheel castings and heavy structural members presents a special fire hazard in the event of a crash since most of the common agents will react with burning magnesium and intensify and possibly scatter the fire.

There are two distinct problems likely to arise. The first is the danger of a wheel fire following cases of overheating of brakes, which with increased landing speeds are becoming more frequent. In these instances although the magnesium wheel castings may be considerably heated by the burning brake linings, a heavy casting is very difficult to ignite, because of its high conductivity, and the problem is to extinguish the brake and possibly tyre fire before it can ignite the magnesium. Some experience has shown that considerable care must be taken in this cooling process, as a too rapid cooling of the casting can lead to an explosive disintegration. Since the magnesium itself is not burning there is no problem of the cooling agents reacting with it.

The second problem, more likely to occur in an aircraft crash fire is that of extinguishing a magnesium fire which may have occurred in a casting. Such a fire is likely to have a high nuisance value as it can act as a source of reignition of the flammable vapours. Water, foam, and carbon dioxide all react with burning magnesium.

There are a number of agents which might be used but one of the most attractive

appears to be trimethoxyboroxine (TMB). TMB, which is a colourless liquid, is an anhydrous compound of boron with a specific gravity of 1.2. When it is applied to burning magnesium it rapidly extinguishes the white fire characteristic of magnesium and forms a skin of boric oxide over the metal. In decomposing the TMB produces methanol and methyl borate which burn with a greenish flame to give a fairly small secondary fire. The most important fact which has been demonstrated is that once the white magnesium fire has been extinguished water can be applied quite safely to cool the magnesium. The water must however be applied as a spray, fairly gently, so as not to expose fresh surfaces of magnesium which will react with the water.

Fairly small amounts of TMB are needed to control a magnesium fire. On tests with a 15 lb wheel casting about half a gallon of TMB was required before water could be applied.

TMB has certain properties which would mean it would have to be handled with special care. It decomposes readily with water and water vapour to form methanol and orthoboric acid. Its viscosity is very dependent on temperature, for instance at 70°F it has a viscosity of 12 centistokes (about the same as foam compound) but at 32°F its viscosity is 108 centistokes.

These properties would mean it would have to be stored carefully and used in special extinguishers, but this would not preclude its use operationally.