The Extinction of Fires in Aircraft Jet Engines — Part II, Full-Scale Fire Tests

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Tests indicate that the degree of vaporization of methyl bromide influences its efficiency as an extinguishing agent.

THE TYPES of fire that can be encountered in aircraft engines have been simulated in a small-scale wind tunnel.[1] It has been shown that a pool of fuel burning behind an obstruction represents the most difficult fire to extinguish. In this work, however, the agent was always in the vapor state; whereas in a practical situation, a large part of the agent will be discharged in the form of droplets. These must vaporize, and the resulting vapor must mix with air before it enters the fire if the most effective use is to be made of the extinguishant. Some of the problems associated with the discharge of an agent have been examined in full-scale tests using a model of the engine and nacelle of a subsonic jet aircraft. An agent with a relatively high boiling point, namely bromochloromethane (CB), Halon 1011, was chosen for this part of the work. The efficiency of a conventional extinguishing system was compared with one in which the extinguishing agent was stored at a higher pressure. A comparison with the effectiveness of CB vapor shows that these practical systems were less effective than the vapor itself, which indicates that all the droplets did not vaporize and mix with air before entering the fire. On the other hand, experiments with methyl bromide (MB), Halon 1001, in the vapor state showed that the concentrations required in these full-scale tests were lower than those required to extinguish the pool of burning fuel in the wind tunnel.[1] It follows that the engine installation used in the present work does not give the most stable type of flame that can be encountered. This supports the view that the wind tunnel results are applicable to practical fire conditions.[1]

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EXPERIMENTAL PROCEDURE

Full-scale fire tests were carried out in a simulated Gyron Junior jet engine. The annular space between the engine and the nacelle accurately represented the position of the fuel lines and the other auxiliary equipment; therefore, it was possible to simulate a realistic fire. A number of quartz windows were situated in the wall of the nacelle to permit visual observation of the fires, while bursting discs were situated along the top of the nacelle to provide venting in case a vapor phase explosion occurred.

Air was fed from a centrifugal fan through a 6-in. (150-mm) venturi flowmeter into a duct that led directly into the annular space between the engine and the nacelle. Airflow in the annulus varied considerably because of irregularities in its cross section. The main flow tended to spiral around the engine. Airflows used covered the range of flows encountered in flight with this aircraft and varied from 0.28 to 0.79 kg s^{-1}.

Kerosine was fed into the fire zone as a fine spray at a pressure of 100 psig (689 kPa). The spray was directed inward, normal to the nacelle wall, from a position 60 cm from the rear fire wall and 45° down from the vertical on the side opposite to the air inlet. This position was used for all tests because preliminary work showed that the resulting fire required the highest concentration of agent for extinction. The ignition source was a high energy Lodge Igniter Unit. The spark produced at the plug ignited a pilot jet, which, in turn, ignited the main spray. Preliminary experiments also showed that the most difficult fire to extinguish, in terms of the concentration of agent required, was obtained when the air:fuel ratio was 14.7, i.e., when the fuel and air were fed into the fire zone in stoichiometric proportions. Thus, throughout this part of the work, the flows of fuel and air were adjusted to maintain this value for the ratio. Every fire test was allowed to burn for 10 s before any extinguishant was applied, as the time normally needed for the detection of an engine fire and the taking of corrective action is probably about 10 s.

The agent was introduced through a spray ring constructed from ⅜-in. (10-mm) outside diameter copper piping, which had thirty spray holes (0.086-in. diameter) equally spaced around the circumference. It was attached to the forward bulkhead, so that the agent was directed downstream into the fire zone. The agent and vapor were metered directly into the air inlet duct through an open ended pipe. The entry point was 18 in. (452 mm) from where the duct fed into the engine, so that some premixing was obtained. In these experiments, the flow of agent was gradually increased until the fire was extinguished.

When an extinguisher system was being evaluated, it was only necessary to use part of the discharge to extinguish the fire; thus, the remainder was discharged to waste. The proportion of the discharge fed into the fire zone was controlled by chokes in the main feed pipe or in the pipe leading to waste, and this proportion was varied until the fire was just extinguished. A calibration curve of choke area against the quantity of agent discharged into the fire zone in conjunction with the known duration of discharge enabled the required concentration to be obtained.

RESULTS

The concentration of vaporized methyl bromide (MB), Halon 1001, required to extinguish the fire is shown in Figure 1 as a function of airflow. As pointed out earlier, the actual flows in the annulus will have varied considerably because of the irregularities in its cross section, but the extremes of airflow used in this part of the work corresponded to average velocities of 2.4 and 6.5 fps (0.732 and 1.98 m s^{-1}). Figure 1 also shows that significantly lower concentrations were required in these full-scale tests than were required to extinguish the liquid surface diffusion flame burning in the wind tunnel.[2]

There is one striking difference in the form of these two sets of results. In the full-scale tests, the concentration required to extinguish the fire increased with increasing airflow; whereas with the liquid surface diffusion flame, the concentration decreased. Unfortunately, it was not possible to examine the concentrations required at higher airflows because the maximum output from the fan was already being used. However, such flows would have substantially exceeded those intended by the designers of the installation.

Methyl bromide has a boiling point of only 4° C. Although it would be expected to vaporize readily in an adequate airflow at room temperature, vaporization may be much more difficult to achieve at subzero temperatures. The rate of vaporization of the extinguishant, as well as its distribution, will influence the efficiency of any practical installation, and these factors obviously can be affected by the nature of the discharge. As a result, a number of full-scale tests were made in which the extinguishant was discharged in different ways. In these tests, CB was used as the extinguishant, since its relatively high boiling point of 68° C should enhance any effects that can arise from any difficulty in the vaporization process.

A conventional discharge was used first in these tests. The weight of extinguishant that had to be discharged into the annulus of the engine to extinguish the fire is shown in Figure 2 as a function of airflow. To obtain the corresponding concentrations, the duration of discharge was measured from a cinerecord of the discharge, and the discharge rate was assumed to be constant over the whole of the discharge time. Concentrations obtained in this way are compared in Figure 3 with the corresponding concentrations of CB vapor that were required to extinguish the fire. It is very striking that discharges in the form of a coarse spray were much less effective than the vapor itself. This presumably reflects the fact that some of the droplets of agent must have passed through the fire zone without being vaporized.

It has been claimed that a high rate discharge system is more effective than a conventional one. Such systems have been simulated using reser-

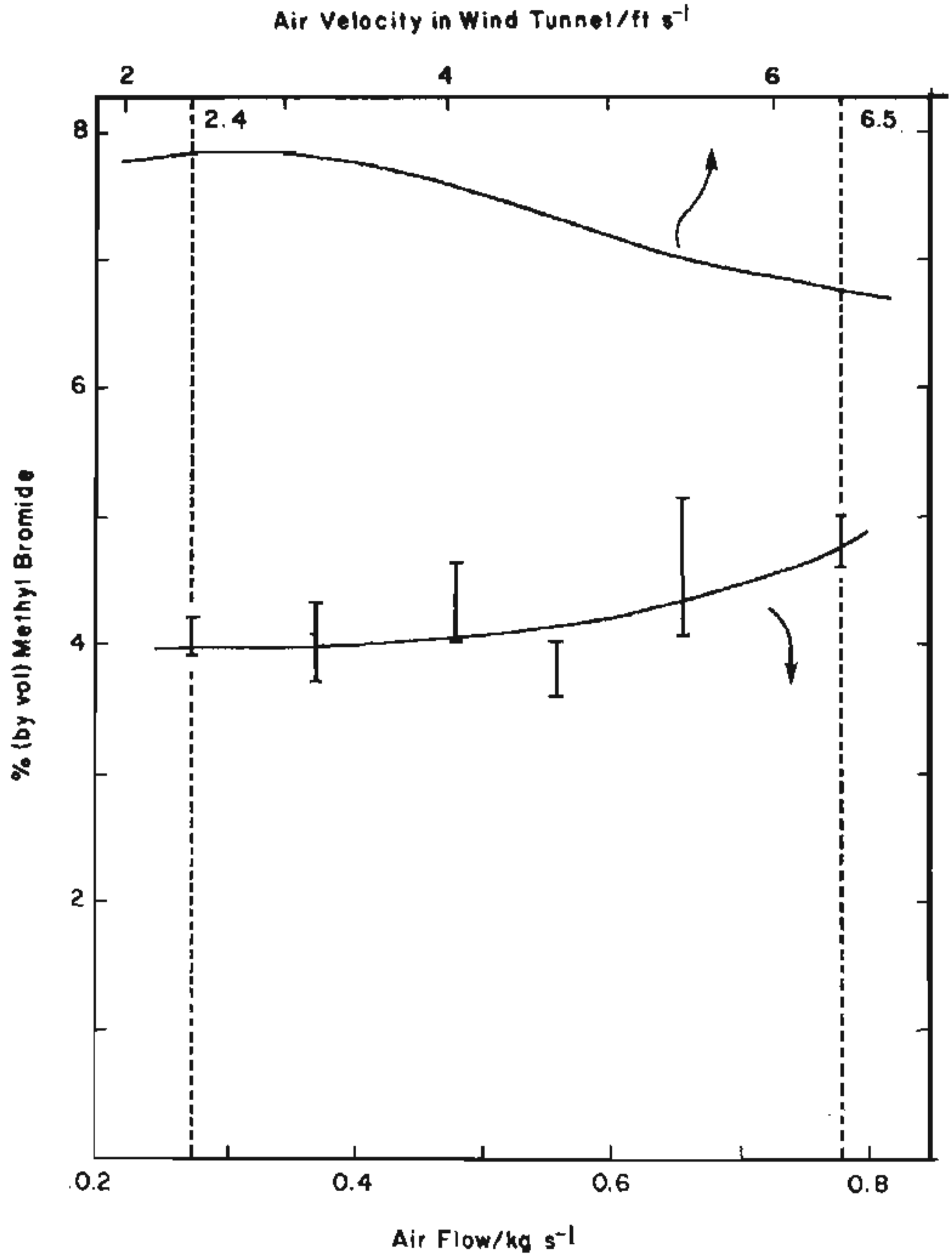

Figure 1. Comparison of the concentrations of methyl bromide required to extinguish full-scale fires and fires in the wind tunnel. Bars on the lower curve represent the scatter in the experimental results.

voir pressures of 1,000 and 2,000 psig (6.89 and 13.78 MPa) instead of the normal pressure of 250 psig (1.72 MPa) employed in the conventional system. At the same time, the design of the bottle was changed in an attempt to obtain more rapid vaporization of the agent. A separate

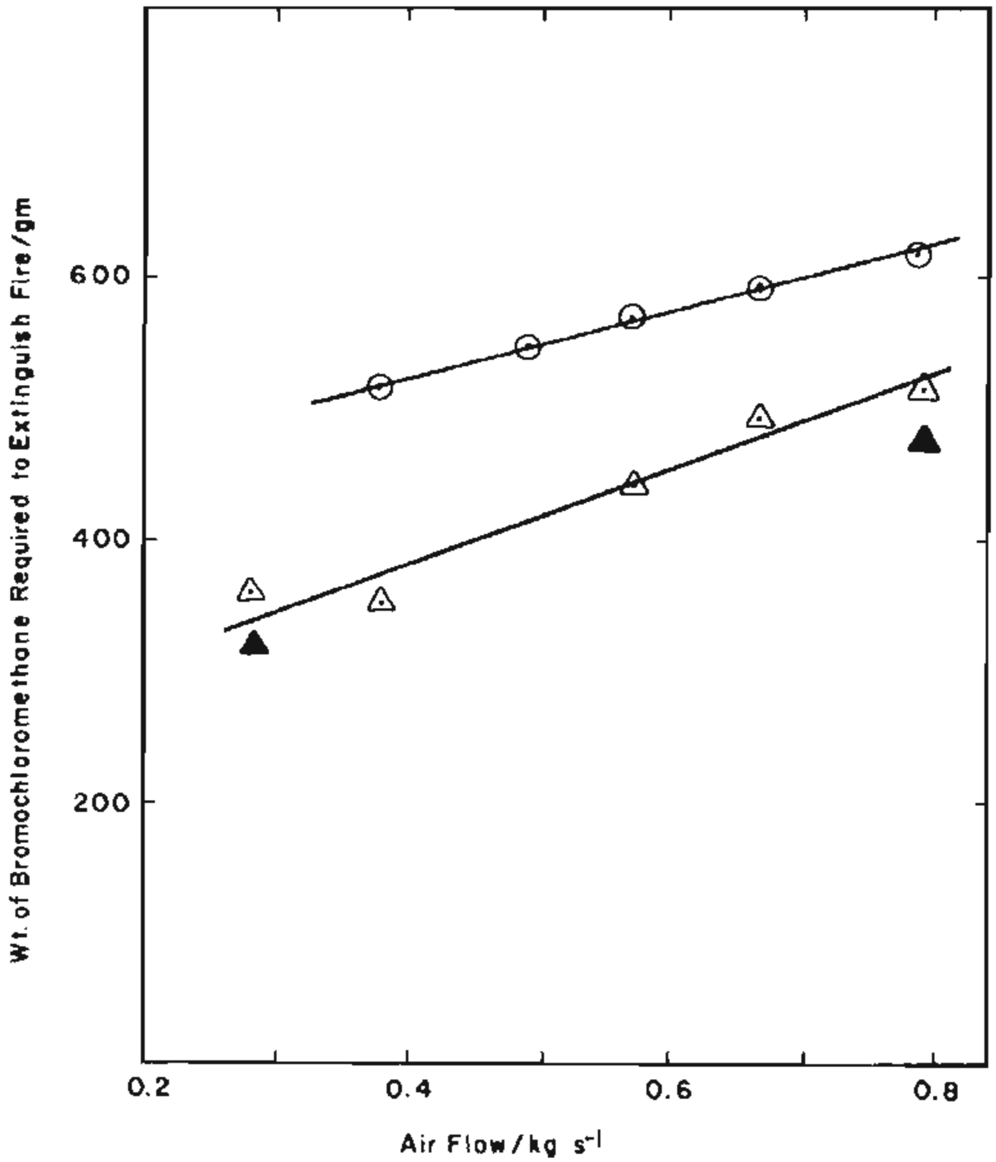

Figure 2. Comparison of weight of bromochloromethane required for different discharges. Conventional system, ⊙ nitrogen pressure 250 psig: High pressure systems, nitrogen pressures △ 1000 psig and ▲ 2000 psig.

storage vessel (4,100 m^3) was used for the nitrogen and was separated from the vessel containing the CB (780 m^3) by a 1-in. (25-mm) hand-operated, quick acting valve. When the valve was opened, nitrogen was fed through a dip tube to a spray ring at the bottom of the liquid CB, so that the agent was not only pressurized, but also partially emulsified. The agent was contained in its vessel by a 0.002-in. (0.05-mm) nickel diaphragm, which was designed to burst when the pressure reached 300 psig (2 MPa). The results obtained with this system are also shown in Figure 2, where it will be seen that the weight of agent required to extinguish the fire was lower than that

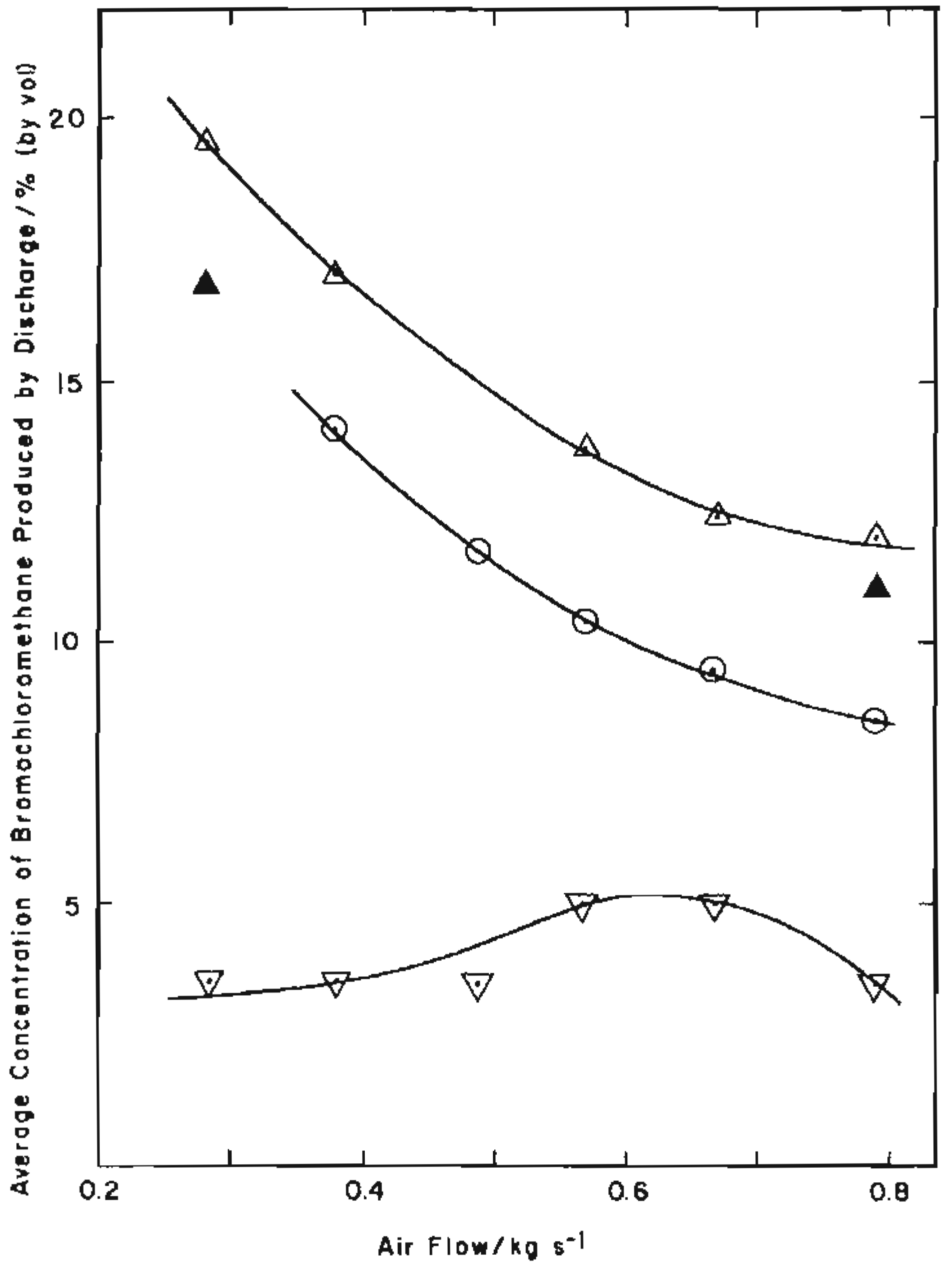

Figure 3. Comparison of efficiency of bromochloromethane with method of discharge. Vapor ▽; conventional system ○; high pressure systems, △ 1000 psig, ▲ 2000 psig.

required with the conventional discharge. In contrast, the corresponding average concentrations (see Figure 3) were higher than with the conventional system. This occurred because the duration of the discharge time was much shorter with the high pressure system (between 0.6 and 1 s) compared with a discharge time of 1.6 s for the conventional system.

These results suggest that there is some advantage in using a high reservoir pressure, but it is clear from Figure 3 that vaporization of the

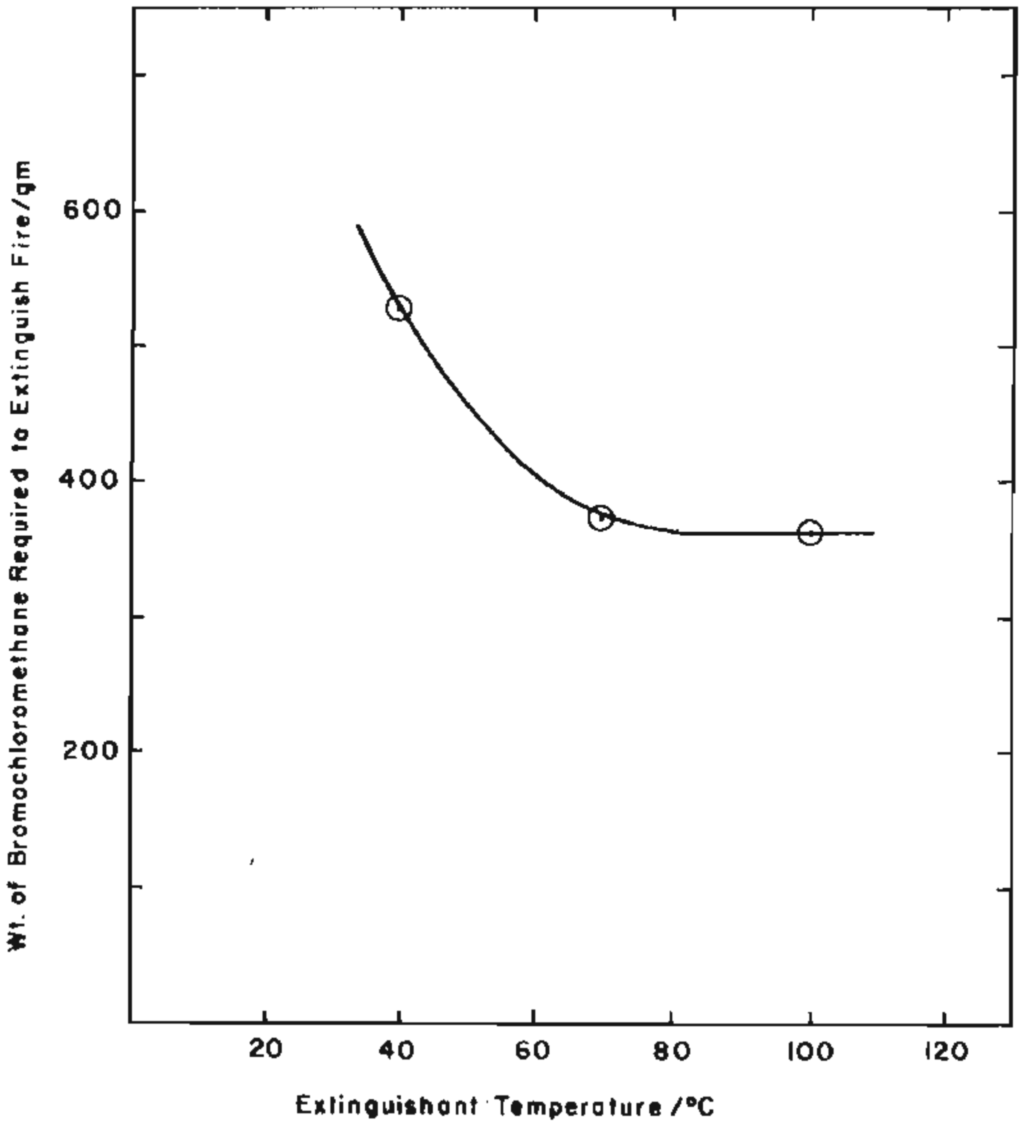

Figure 4. Comparison of extinguishant temperature on the efficiency of bromochloromethane as an extinguishing agent.

agent is one of the limiting factors in the use of this extinguishant. As a result, the effect of temperature on the efficiency of the agent was examined in more detail at one airflow, namely 0.57 kg s^{-1}, with a constant reservoir pressure of 400 psig (2.8 MPa). The results in Figure 4 show that, as the temperature of the agent was increased from 40° C to 100° C, the amount of agent required to extinguish the fire fell from 550 g to 350 g. It is very striking, however, that this quantity had reached an almost constant value by the time the boiling point of the agent had been reached. From the practical point of view, therefore, the agent will be most effective if the discharge consists mainly of vapor and small droplets that can easily vaporize before entering the flame.

DISCUSSION

These full-scale fire tests using CB show that the efficiency of the agent depends on both the temperature of the discharge and the velocity of the droplets. Drop size distribution of the discharge and the ambient temperature will also affect the agent's efficiency. The relative importance of these factors will vary with the geometry of the nacelle and the air velocity. However, the aim of any extinguishing system must be to obtain the optimum usage of the extinguishant, i.e., to vaporize all the agent and distribute the vapor evenly in the airflow before the flame is reached. Any liquid agent that hits the wall of the nacelle in the region of the flame or that passes through the fire zone without being vaporized is largely lost, so that the system will be less effective than it could be. The present results show that the maximum efficiency of the agent is achieved when it is discharged at or above its boiling point and that there is an advantage in building up the concentration rapidly in the fire zone. Under the latter condition, the weight of agent required to extinguish the flame is lower, although the actual average concentration in the discharge must be somewhat higher. These two effects operate in opposite directions, so that in a practical installation, it is necessary to achieve a compromise if the lightest extinguishing system is required.

There is one feature of the results from these tests that is a little surprising, namely that the concentration of vapor required to extinguish the flame increased slightly as the airflow increased, while the concentration decreased quite rapidly when the agent was discharged as a spray. (See Figure 3.) This is probably a consequence of the geometry of the nacelle. The vapor was discharged directly into the air duct 18 in. from where it fed into the engine, and as the velocity profile around this annulus was very uneven, there were a number of low velocity regions where excess fuel was likely to collect. The fuel input was that required for stoichiometric combustion and thus at the very low flows. Where there was very little air entrainment in the fuel rich zones, the main airstream would have been fuel lean. As the airflow increased, air entrainment in these low velocity regions would also have increased, so that the main airstream would have become richer in fuel and the fire more intense. The concentration of agent required to extinguish the fire was probably controlled mainly by the fuel:air ratio of this main airstream. By analogy with limits of flammability diagrams, this concentration should thus increase as the airflow increases. In contrast, the spray discharges were made through a spray ring attached to the forward bulkhead, so that there would have been a uniform distribution of the agent around the annulus. These conditions were much closer to those in the wind tunnel with the burning pool of fuel,[1] where the concentration of extinguishant was found to decrease with increasing airflow. It is also probable that the droplets of extinguishant vaporized more easily as the airflow increased, because the intensity of the fire in the main airstream also increased. Thus, it seems most probable that this difference in behavior was simply a consequence of the different geometries in the two cases.

It was suggested earlier[1] that the maximum concentration of agent required to extinguish a simulated burning pool of fuel should be used as a basis on which design concentrations of extinguishing agents should be decided, and it is instructive to consider the concentrations of MB vapor required in these full-scale tests in these terms. Thus, Figure 1 shows that the concentrations were between 4 percent and 5 percent MB; whereas, the small-scale simulation led to a concentration of 7.8 percent MB. To cover the eventuality that the most stable flame might be encountered in practice, a somewhat higher design concentration should be used.

CONCLUSIONS

These full-scale tests show that the fire was always extinguished with a lower concentration of agent when it was discharged as a vapor than was required for the extinction of a pool of fuel burning under its optimum conditions of stability. This is in accord with the suggestion made earlier that full-scale tests do not necessarily include flame holders with an optimum configuration.[1] The present tests also show that there is a danger of some of the extinguishing agent having insufficient time to vaporize when it is discharged at an ambient temperature that is below its boiling point. There also appears to be an advantage in terms of the weight of extinguishing agent required when it is discharged more rapidly to give a higher average concentration. Any quantitative advantage over maintaining a lower concentration for a longer period of time, however, needs further assessment.

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