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The Extinction of Fires in Aircraft Jet Engines — Part IV, Extinction of Fires by Sprays of Bromochlorodifluoromethane

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The extinction of a liquid surface diffusion flame of kerosine burning in air has been studied using sprays of bromochlorodifluoromethane produced by swirl-type nozzles.

PREVIOUS work[1] using full-scale fire tests showed that the quantity of agent required to extinguish the fire varied with the way in which it was applied. In the practical situation, which was simulated in these tests, the agent was discharged as a spray. Hence, a more controlled study was made in which a pool of kerosine burning in an airflow was extinguished by a spray discharge of bromochlorodifluoromethane (BCF, Halon 1211). This type of fire was chosen since it not only gives the most stable type of flame, but also the most favorable conditions for this type of combustion are well established.[2] BCF was chosen as the extinguishing agent (rather than bromochloromethane, which was used in the earlier full-scale fire tests[1]), because its boiling point is more representative of the agents in use at the present in aircraft installations. Spray nozzles with known characteristics were used, and the concentration of BCF required to extinguish the fire was examined over the range of airflows from 3 to 30 fps (0.9 to 9 $m\,s^{-1}$). In addition, the effect of ambient temperature on the efficiency of the agent was examined by making measurements with the agent at both room temperature and − 30° C.

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EXPERIMENTAL

The fire model, wind tunnel configuration, and system of flow measurement were essentially the same as those used earlier.[3] The extinguishing agent was sprayed into the air stream from a nozzle positioned on the center line of the wind tunnel, approximately 2 ft (0.6 m) upstream of the flame holder. This nozzle was connected by a 0.25-in.-diameter (6-mm) pipe to the dip tube of a pressurized reservoir positioned outside the wind tunnel. The duration of the discharge was usually 2 s, controlled by a timer solenoid valve in the feed pipe between the reservoir and the nozzle. The flow of BCF was controlled by nitrogen pressure in the reservoir. For the tests with the extinguishing agent at − 30° C, the reservoir and its contents were cooled to − 30° C in a commercial freezer, and all the pipe work was lagged to minimize heat transfer from the surroundings.

The concentration of BCF in the fire zone was monitored using two thermal conductivity detectors, which had been calibrated against known flows of BCF and air. As before,[3] the calibration was checked at the beginning of each day. The two probes were positioned 0.25 in. (6 mm) each side of the center line of the wind tunnel and 2 in. (5 cm) upstream of the flame holder. This was considered the nearest that the probes could be positioned to the flame without soot affecting detector response. One probe was positioned axially toward the flow so that the total concentration of BCF (both vapor and droplets) could be obtained, while the other opened transversely to the flow to minimize the collection of droplets and to give an estimate of the concentration of BCF vapor.

In each fire test, the concentrations were monitored, and whether the fire was extinguished or not was noted. Nitrogen pressure in the reservoir was adjusted until the boundary between extinction of the fire and continued combustion was clearly defined. In this way, the minimum concentration for the extinction of the flame was obtained.

RESULTS

It had been anticipated that several nozzles would be required to cover the whole range of airflow (3 to 30 fps); therefore, several sizes and types of spray nozzles were selected for the preliminary experiments on the basis of their known discharge characteristics for water. Both hollow and solid cone sprays were included. The latter were found to be unsuitable because the center of the flame was attacked first, indicating that the agent was not being distributed uniformly across the tunnel with this type of spray. Uniform distribution was considered essential if meaningful results were to be obtained. In practice, it was found that one hollow cone spray could be used over the whole range of airflows when the agent was at room temperature. This was a 0.25-in. (6-mm) nozzle with a bore of 0.062 in. (1.575 mm) and a cone of 65° to 75°. Reservoir pressure of approximately 1,000 psig (6.894 MPa) gave a sufficiently high flow of BCF to extinguish the flame at an airflow of 3 fps (0.9 m s^{-1}), while a pressure of about 200 (1.38 kPa) psig enabled the fire to be extinguished when the airflow was 30 fps (9 m s^{-1}). A second, larger nozzle was also required at the higher airflows when the extinguishant was initially − 30° C; namely, a 0.25-in. (6-mm) nozzle with a bore of 0.093 in. (2.362 mm) and a cone angle of 80° to 85°.

Concentration measurements showed that, during a typical discharge, the concentration of BCF rapidly built up to a peak and then decayed, as is the case during the discharge of an extinguishant into an engine nacelle. It was decided, therefore, to use this peak concentration for the purposes of the present study, both in the fire tests and to check the distribution of the agent across the wind tunnel. The latter was checked at an air velocity of 10 fps (3 m s^{-1}), using just sufficient agent to extinguish the flame. The results are shown in Figure 1. These were obtained by placing one probe at the center of the wind tunnel 0.5 in. (1.27 cm) above the top of the flame holder. The position of the other was adjusted so that concentration measurements were obtained at 1-in. (2.54-cm) intervals across the tunnel in a horizontal direction. In each discharge, just one pair of concentrations was obtained. Since those concentrations were not exactly reproducible from experiment to experiment, Figure 1 shows all the concentrations relative to that at the center of the tunnel. Note that the maximum variation across the width of the flame was only ± 15 percent, which was considered acceptable for the purposes of the present work. The maximum concentration occurred between 1 in. and 2 in. (2.54 cm and 5.08 cm) from the center of the tunnel. Since a hollow cone spray was being used, the latter result is not unreasonable.

Some typical results from the fire tests are shown in Table 1, from which it will be seen that, at a given airflow, there was a concentration above which the flame was always extinguished. In some cases, the flame could also be extinguished with a lower concentration, but this was not a reproducible condition. Hence, the former criterion was adopted for the concentration required to extinguish the flame.

Figure 2 shows this quantity as a function of the air velocity when the BCF was initially at room temperature. The total concentration required passed through a maximum value of 6.4 percent at an airflow of 10 fps (3 m s^{-1}). When the air velocity was greater than 20 fps (6 m s^{-1}), the concentration required increased. Figure 2 also gives the results obtained earlier[3] for BCF vapor. It is significant that the maxima in the two curves are in such good agreement, both in terms of the actual maximum concentration of BCF and the air velocity at which the maximum occurred. It is also very striking that the concentrations from the transverse probe were in such good agreement with the results for BCF vapor when the air velocity was greater than 15 fps, although the former rose above the vapor values when the air velocity exceeded 25 fps. At lower airflows, the concentration from the transverse probe passed through a shallow maximum of 5.3 percent BCF (again in the region of 10 fps or 3 m s^{-1}), and a comparison

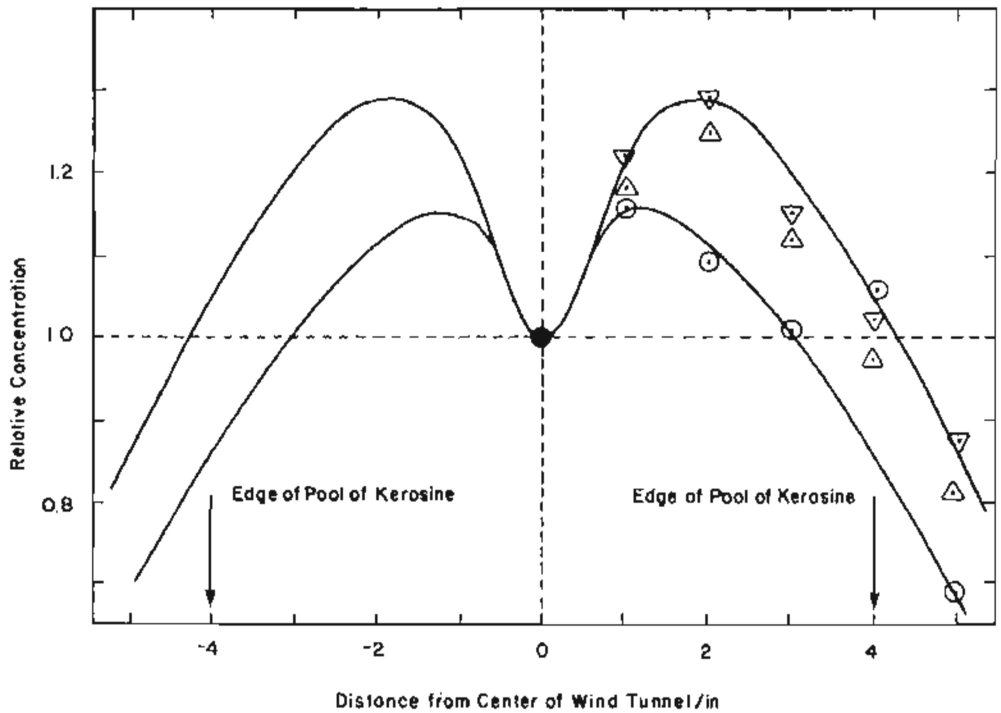

Figure 1. Distribution of BCF across the wind tunnel along a horizontal line 0.5 in. above and 2 in. upstream of the flame holder. The two lines represent the extremes that can be drawn through the three sets of experimental values (⊙, △, and ▽), and the figure assumes that the distribution is symmetrical about the center of the tunnel. • is reference position for measurements.

TABLE 1. *Typical Results from Fire Tests*

Air velocity (fps)	*Reservoir pressure (psig)*	*BCF concentration* (%)*	*Result*
3.0	140	5.76	Fire out
	99	5.59	Fire out
	89	5.45	Not out
	89	4.88	Fire out
	79	4.50	Not out
	79	4.30	Fire out
	58	3.97	Not out
16	192	6.01	Fire out
	130	5.92	Fire out
	151	5.71	Fire out
	99	5.69	Not out
	99	5.36	Fire out
	89	5.21	Not out
23	192	5.92	Fire out
	192	5.34	Fire out
	172	5.05	Not out
	151	4.95	Not out

*Peak concentration from axial probe.

of the results for the two probes implies that approximately 80 percent of the BCF was in the vapor state just in front of the flame holder at this airflow. In contrast, a smaller proportion (67 percent) was in the vapor state when the air velocity was 30 fps or 9 m s^{-1}.

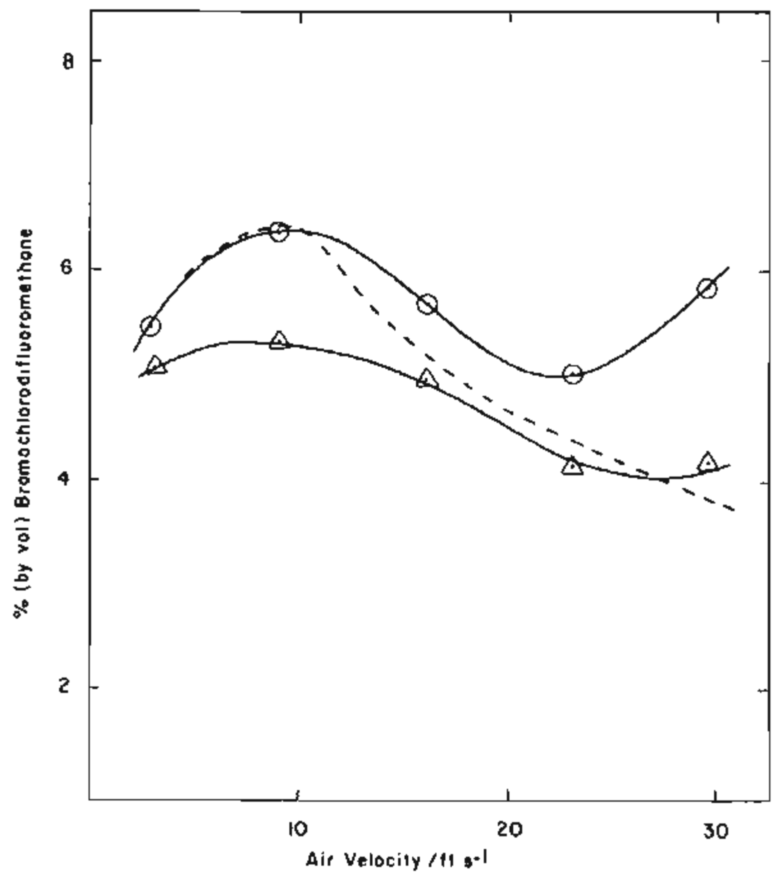

Figure 2. Variation with air velocity of the concentration of BCF required to extinguish the flame. Ambient temperature, ⊙ total spray concentration, △ estimated vapor concentration 2 in. upstream of the flame holder, — — — concentration of vapor known to be required.[3]

With the extinguishing agent initially at − 30° C, the smaller spray nozzle (0.062-in. or 1.575-mm bore) only enabled results to be obtained for air velocities up to 13 fps (3.96 m s^{-1}). The higher airflows were covered using the larger nozzle (0.093-in. or 2.362-mm bore), and the results obtained are shown in Figure 3. The maximum values for the total concentration were the same (5.5 percent) for both nozzles, although these maxima occurred at slightly different air velocities. Similarly, the concentrations from the transverse probe for the two nozzles also passed through the same maximum value of 4.9 percent BCF. The two maximum values are somewhat lower than the corresponding maxima for the extinguishant at room temperature, which seems to imply that the agent is more effective when its initial temperature is below room temperature. The other notable feature of these results is the increased concentration required at the higher airflows.

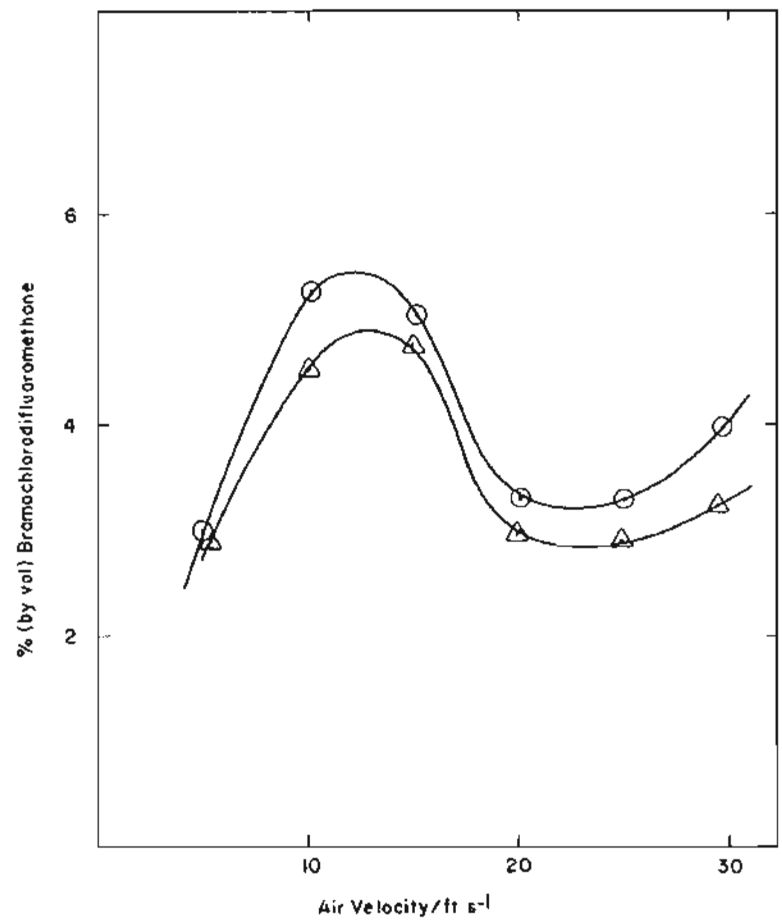

Figure 3. Variation with air velocity of the concentration of BCF required to extinguish the flame. Temperature of extinguishing agent, − 30°C; ⊖ total spray concentration; △ estimated vapor concentration 2 in. upstream of the flame holder.

DISCUSSION

The stability of a diffusion flame is governed by the burning velocity of the small pocket of premixed gas at the base of the flame. In the present arrangement, this will be immediately behind the top of the flame holder, the air and the BCF vapor mixing with the fuel vapor by diffusion. Thus, the flame is "blown out" when a sufficient amount of extinguishing agent is present to reduce the burning velocity below the local gas velocity. It is particularly striking, therefore, that, at the lower air velocities, there is such good agreement between the total concentration of BCF needed to extinguish the flame in the present study and that required with BCF vapor.[3] It implies that, under these conditions, there is sufficient time for the droplets of BCF to vaporize and mix with the air before reaching the flame. This is reasonable since comparison of the concentrations from the two probes suggests that 80 percent of the BCF was already in the vapor state 2 in. (5.08 cm) in front of the flame holder.

It is equally striking that, at the higher air velocities (greater than 15 fps), there is such good agreement between the concentration of BCF vapor known to be required to extinguish the flame[3] and that estimated as present just in front of the flame holder in this work, while the total concentration was somewhat higher. This implies that some of the BCF discharged into the airflow was lost from the point of view of the extinction of the flame. The sharp rise in the total concentration when the air velocity exceeded 20 fps (6 m s^{-1}) shows that this loss increased as the airflow increased. The most likely explanation is that the larger droplets were carried through the fire zone before they had time to vaporize, with an added complication being that the much higher pressure in the reservoir at these higher flows had also changed the distribution of the agent within the wind tunnel. This is particularly marked at an air velocity of 30 fps (9 m s^{-1}) in that, for over half the width of the flame, the concentration of BCF was less than half that at the center. Under such conditions, the concentration of BCF required to extinguish the flame would be expected to rise. This explains why the concentration from the transverse probe rose above the concentration of vapor known to be required. The rise in the total concentration, however, was much more marked, which must imply that, at these airflows, the vaporization of BCF droplets became a major factor in the efficiency of the discharge.

A comparison of the results with the extinguishant at room temperature and at − 30° C shows that the agent was slightly more effective at the lower temperature, in that a lower total concentration was required to extinguish the flame. It had been expected that reducing the temperature of the BCF to well below its boiling point might reduce its efficiency in that it would be more difficult to vaporize. For example, much larger quantities of chlorobromomethane are required to extinguish a fire when it is applied as a spray than when the vapor is used.[1] This has been attributed to the relatively high boiling point of the agent. The proportion of BCF that had already vaporized just in front of the flame holder when the BCF was originally at − 30° C did not differ significantly from the proportion that vaporized when the BCF was originally at room temperature. Therefore, it seems most unlikely that the extinguishant can have any major cooling effect on the flame. The sprays used in the present work were undoubtedly finer than those used in practical installations, so that there may be a reduced efficiency with the coarser sprays (compared with that at room temperature), particularly if the discharge is made into a relatively high velocity airflow.

An essential feature of a well-designed installation is an even distribution of the extinguishing agent through the fire zone. In some installations, this is achieved by discharging the agent through a spray ring at the front of the nacelle and using the airflow to distribute the agent, while in high-rate discharge systems, open-ended pipes are used to produce a swirling distribution around the engine. Both types of installation, however, will almost certainly produce a much coarser spray than the nozzles used in the present work. The present results suggest that, at the higher airflows, the larger droplets did not have sufficient time to vaporize before reaching the flame, so that they passed through the fire zone without having any effect. There is a danger that such effects will be more marked in an engine. The magnitude of this effect can only be determined by further work under conditions that are more representative of the engine situation.

CONCLUSIONS

At low airflows, there was excellent agreement between the total concentration of BCF required to extinguish the flame and that required for BCF vapor. Under these conditions, the extinguishant vaporized and mixed with the air before reaching the flame. In contrast, the spray was significantly less effective than the vapor at air velocities greater than 20 fps (6 m s^{-1}). It is suggested that the larger droplets passed through the fire zone before they had time to vaporize, so that they were effectively lost to the system.

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NOTE: This work was carried out with the support of the Procurement Executive, Ministry of Defence.

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