APPLICATION OF HALON 1301 TO AIRCRAFT CABIN AND CARGO FIRES

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INTRODUCTION:

Over the past 20 years the aviation industry has had considerable experience in the development and use of halogenated extinguishing systems for the protection of aircraft against fires occurring within the engine nacelle. The reason for this concern over fire safety was that this type of fire was considered as perhaps the most severe likely to occur in flight. However, this experience with the extinguishing systems utilizing Halon 1301 agent (Bromotrifluoromethane - CF_3Br) until recent years has been mostly confined to the control of fires involving the ignition and burning of flammable fluids rather than solid combustible materials as is the case with Class A fires.

Indeed Federal Regulations have required for the past 10 to 15 years or since about the beginning of the jet age in air transport that Halon 1301 systems be installed in commercial transport to control engine fires. In contrast, the application of Halon 1301 as an extinguishing agent for Class A fires in aviation involving fires in cabin materials and cargo has evolved slowly in spite of numerous studies and tests conducted to appraise the effectiveness and hazards of this chemical as demonstrated by the scope and attendance of this symposium. The reasons for this lag in the introduction of Halon 1301 in aviation are numerous and varied. First, the extent and seriousness of the experience with Class A fires in aircraft, especially in flight have been so rare as to contribute only slightly to the overall safety hazards in aviation. Based on this low estimation of fire risks balanced against costs of the system and especially the severe penalty of its weight, fire extinguishment was considered impractical. Instead, to improve cabin fire protection much emphasis during the past 5 years was placed on raising the flammability requirements of the cabin materials to limit the spread of fire. Regulations since 1947 have restricted the use of interior materials to those designated as "flame resistant" showing a slow burn rate of 4 inches per minute or less. Since 1967 new standards have been adopted so that at present nearly all materials being used in the latest air transport are required to be self-extinguishing within a 6- or 8-inch burn length as determined by a prescribed test method according to the use of the particular material in the cabin. The risk of rapid and extensive spread of flames, especially from a small ignition should be greatly diminished with the use of new materials, capable of meeting the latest requirements of FAA Notice for Proposed Rule Making - NPRM 69-33.

However, as the size of the latest transport airplanes and the number of passengers carried aboard continues to increase, it becomes necessary to consider new concepts for reducing still further, possible fire hazards.

In this respect, aviation has long been considered the leader and innovator in fire technology and safety. Also, aviation is in a favorable position to benefit from the increasing interest in the fire problem that has become a national issue since the enactment and recent extension of the Flammable Fabrics Act Amend PL 90-189 of 1967 and Fire Research and Safety Act, PL 90-259 of 1968. This as well as other activities by government agencies and technical groups should greatly accelerate the progress toward greater fire safety in all areas.

The main stumbling block to the use of Halon 1301 to protect habitable areas from fire has been the fear of exposing passengers to the breathing of both the gaseous agent and in particular its very toxic decomposition gaseous byproducts. Numerous investigations have been conducted to minimize this hazard by determining the conditions for its safe use in combating fire.

Portable Halon 1301 units designed for the fire protection of cabins while the airplane is undergoing maintenance in the hangar have been available for several years. The Aviation Committee of the National Fire Protection Association (NFPA) has recently drafted a document of recommended practices for the use of such systems which specify minimum concentrations of Halon 1301 (3 to 6 percent) to extinguish the fire, maximum concentrations (10 percent) for safe breathing and maximum preburn times (10 seconds) to limit pyrolysis of the agent by fire.

At present, FAA at its test facility in Atlantic City is preparing a completely furnished DC-7 airplane cabin for tests utilizing a prototype permanently installed Halon 1301 system designed for in-flight operation. The test program to be completed over a period of two years or more will consider optimum design systems to provide uniform distribution of Halon 1301 gas at any point inside the cabin. The effect of ventilation, exit and door openings on distribution and losses of the agent from the cabin will be measured simultaneously at 12 sampling points by a special fast response porous-plug type gas analyzer. Other effects pertaining to the compatibility of a rapid discharge Halon 1301 system with the safety of passengers will also be studied in finalizing the design for aircraft.

Work involving protection against fires in non-inhabited areas, such as cargo compartments, dates back to the mid 1940's. This was carried out at the Civil Aeronautics Authority (CAA) test facilities located in Indianapolis, Indiana, and concerned itself primarily with detection. Reasons for this were first, because extinguishing agents eliminated only the visible flames and had little effect on the smoldering fires and secondly, because the history of fires in cargo compartments indicated that incidents of fire were very infrequent. Furthermore, during these early years the compartments were relatively small and since fires in such compartments, when ventilation was limited, were not considered a serious threat to safety, the added weight of any extinguishing system was not considered practical.

In recent years after it was realized that Halon 1301 was effective in combating fires in very low concentrations (i. e. 5% by volume) and cargo compartment volumes were increased many fold, it was considered worthwhile to resume the work on cargo compartment fire extinguishment. Hence, the project conducted in the Lockheed C-130 fuselage at the FAA facilities in Atlantic City, N. J. was initiated.

PART I - CABIN MOCKUP FIRES

Test Procedures

Fire extinguishing tests utilizing Halon 1301 were conducted on urethane seat foam and wool drapery ignited inside a closed 640-ft^3 insulated enclosure simulating the airplane cabin mockup. A description of tests and results of the findings are contained with other fire studies in FAA Report No. FAA-RD-70-81, titled, Air Transport Cabin Mockup Fire Experiments.

A plan drawing of the mockup with the locations of the Halon 1301 aspirator discharge nozzle, fire load consisting of two 3-foot square and 4-inch thick flexible urethane pads weighing about 10 pounds, thermocouples, smoke and gas sampling points, etc. is presented in Figure 1.

Temperatures were measured at 24 different points in the air and on surfaces throughout the interior of the cabin. Smoke density in percent obscuration of a beam of light through an optical path of one foot was measured at two locations. Concentrations of oxygen, carbon monoxide and carbon dioxide were measured continuously at two locations, one near the ceiling and the other at a lower height near the exit sign. A total heat flux transducer was used to measure radiant and convective heat on the opposite far side of the cabin wall. Colormetric tubes placed inside the trailer at mid height above the floor and 6 inches from the wall near the exit sign were used to measure the concentrations of HF, HBr, Br_2/Cl_2, HCl, HCN and $COCl_2$.

The foam pads (10 pounds fuel load) were in most cases ignited from below by a propane-fed Bunsen burner flame of about 3 inches in height. In a few tests, an incandescent hot body (i.e. barbecue calrod) and chemicals consisting of about 3 ounces of hexamethylenamine and potassium chlorate and primed with gun powder were used in an attempt to ignite the foam.

Summary of Test Results

The effectiveness of Halon 1301 as a safe means for securing fire control within an enclosure is shown by the test results presented in Table 1. In these tests the extinguishing agent was employed in different ways and amounts; namely, (1) low and high concentrations of about 3.5 to 7.0 percent by volume in air; (2) low- and high-rate discharges, and (3) discharge before, during and after the fire to check for possible reignition of fire. The usefulness of the agent was also evaluated for different types of ignition sources; namely, (1) propane/air mixture; (2) incandescent heat; and (3) chemicals containing their own oxygen supply. Also, extinguishing tests were conducted on both smoldering and open flaming urethane fires.

For Tests Nos. 5 through 8, Halon 1301 agent was discharged by opening the valve of a standard compressed cylinder. The discharge was relatively slow and occurred at a diminishing rate requiring about 2 minutes to be completed.

In Test No. 5, Halon 1301 at a concentration in air calculated at 4.1 percent by volume was discharged 1 minute after ignition of the foam pad when flaming became self-sustaining. Flaming of the foam was extinguished within 1.5 minutes after the discharge of the agent. Although the propane/air mixture used by the burner was still flammable although erratic when ignited by electrical, the foam could not be made to burn with an open flame. Foam consumed in this test was less than 1 pound.

In Test No. 6, Halon 1301 at 3.6 percent concentration was again discharged from a standard cylinder but at a later time when the ceiling temperature had approached 150°F and a flash fire appeared imminent from past experience as shown by the steep rise in the temperature curve and sharp drop in the oxygen content of the air as plotted in Figure 2. Although the ceiling temperature increased to 300°F following the slow discharge of the agent, a flash fire did not develop. The effectiveness of Halon 1301 is shown by a comparison of the curves presented in Figures 2 and 3. The same fire conditions were present in both Tests Nos. 4 and 6 except that no agent was used in Test No. 4. In the latter test, burning of the foam continued until a flash fire occurred. The fire parameters for Test No. 6, related to time and to each other, are presented in Figure 3 for comparison with Test No. 4. The same conditions were present in both tests except for the use of Halon 1301 to extinguish the fire.

In Test No. 7 Halon 1301 was discharged from two cylinders one during the fire as in the previous test and the other after the fire was extinguished. Total Halon 1301 discharged into the cabin was calculated at 7.1 percent concentration. At this higher concentration the propane/air mixture of the burner could not be ignited by electrical sparking as before. However, the chemicals were readily ignited and burst into flames which reached almost to the ceiling. Although of only short duration a high heat source developed, from the burning chemicals on top of pads, which failed to ignite the foam to a flame. An electrically-heated element (i.e. barbecue grill) with an output of 500 watts heat placed in direct contact with the foam also failed to cause flaming combustion. Considerable smoke was generated by the smoldering combustion.

In Test No. 8 a folded wool curtain 2 1/2 feet wide and 5 feet in height was suspended from the ceiling near the center of the mockup. The curtain from below was subjected to a propane/air flame, chemical fire as in the previous test and contact with the 500 watt incandescent element. A 3.9 percent Halon 1301 agent concentration was discharged into the mockup before attempts were made to ignite the fabric. No flaming combustion could be obtained with the 3 types of heat sources although considerable charring of the fabric resulted.

In Test No. 9 an aircraft type extinguishing system for engine fires was used for the rapid discharge of 14.1 pounds of Halon 1301 equivalent to a 5.8 percent concentration of the agent inside the mockup. Rapid discharge was effected by pressurizing the bottle with nitrogen to 600 psi and releasing the contents of the bottle by an explosive rupture of a disk to provide a large outlet. The fire parameters for this test related to time and each other are presented in Figure 4. Halon 1301 was discharged when the ceiling temperature approached 150°F and at a time when a flash fire was a threat. From visual observations and the curves, it was shown that the flames were extinguished within a few seconds. Neither the chemical fire as in the previous test or the incandescent element with a heat output of 2,000 watts could reignite the foam to a flaming combustion. Considerable smoke emission was produced by smoldering combustion as shown in Figure 4.

Data on toxic gases, other than carbon monoxide resulting from the pyrolysis of Halon 1301 subjected to fire is meager and inconclusive. Only a few general observations on the toxic hazards are possible from the available test data herein. This subject has been investigated much more thoroughly by the Bureau of Mines for the Air Force. In the tests, concentrations of HBr and HF, highly toxic gases resulting from the dissociation of Halon 1301 were measured as a function of preburn time of a cotton sheeting fuel load. Results of these tests are contained in Air Force Technical Report AFAPL-TR-70-39, titled, "Fire Suppression For Aerospace Vehicles," dated July 1970.

Concentrations of toxic gases in parts per million (ppm) in air obtained with colorimetric tubes are given in Table 1. HF and Br_2 concentrations exceeding 15 and 50 ppm are reported. Also, very obnoxious fumes with a bromide odor were experienced when the mockup door was opened after extinguishment of the foam fire. This was especially noticeable for tests during which considerable pyrolysis of Halon 1301 was evident from the prolonged exposure of this agent to a large fire (i.e. long preburn time).

CONCLUSIONS

Based on an analysis of the results of a limited number of tests, it was determined that:

1. A high-rate discharge system utilizing Halon 1301 at a concentration of 5.8 percent in air is effective in rapidly extinguishing a Class A fire in urethane seat padding.

2. Prolonged exposure in a cabin fire to flames and heat from incandescent hot bodies can cause pyrolysis of Halon 1301 into extremely toxic gases in concentrations that may be harmful.

3. Although Halon 1301 concentrations as low as 3 to 4 percent in air were sufficient to extinguish Class A fires, the propane-gas burner could still be ignited to flame by electrical sparking. However, when the concentration was doubled the propane/air mixture at the burner was no longer flammable.

4. Halon 1301 may not be effective in the recommended range of 5 to 10 percent concentrations when used on chemicals containing their own supply of oxygen such as the chlorates.

PART II - CARGO COMPARTMENT FIRES

Test Procedure

The effectiveness of combating Class A fires using Halon 1301 as an extinguishing agent was demonstrated by conducting full-scale fire tests in a Lockheed C-130 fuselage section; that, which lies between station 245 and 737. Aluminum bulkheads were fabricated and attached to the ends of the fuselage section. This provided a compartment with a volume of 5,000 cubic feet.

Two observation windows, each 1 foot square, were provided in each of the bulkheads. These were located just above the floor line. An air inlet, 14 inches in diameter, was located in the forward bulkhead 5 feet above the floor and a baffle was provided to reduce inlet air velocities and localized effects such as dead air spaces within the compartment. The 14-inch-diameter duct attached to the inlet contained an axial flow fan which was capable of moving air at the desired 2,000 cubic feet per minute, a set of straightener vanes, and a calibrated orifice for measuring the airflow. An air outlet was provided in the aft bulkhead. This outlet was 14 inches in diameter, fitted with a check damper for controlling airflow and located 1 1/2 feet from the top of the bulkhead. An aluminum flap was fabricated, to be interchangeable with the observation windows, to provide an outlet near the floor.

Throughout this program standard pieces of cargo were used both for the fire load and for the cargo load. This standard parcel consisted of a corrugated cardboard carton measuring 28 x 24 x 20 inches, weighing 4 pounds and filled with 16 pounds of excelsior. Thus each parcel weighed a total of 20 pounds. Figure 4 shows a stack of 144 cargo-parcels and one open parcel on the scale showing its contents. This stack represents about one-half of the load used in the C-130 fuselage compartment when the 50-percent-load test was conducted.

Tests were conducted in the 5,000-cubic-foot C-130 fuselage compartment using a loading of 10 percent by volume and a loading of 50 percent (for all practical purposes, nearly full). Two methods of extinguishment or fire control were used: (1) airflow shutoff; and (2) airflow shutoff plus bromotrifluoromethane (Halon 1301).

Four tests were run using airflow shutoff as a means of fire control. In these tests, as in all tests in this program, ignition was achieved by placing an electric barbecue lighter in the bottom center standard parcel of the fire load. Ignition (visible flames external to the cardboard container) usually occurred about 3 minutes after voltage was applied to the lighter. Twenty seconds after ignition, application of the voltage to the igniter was discontinued. During the ignition period and until detection occurred airflow through the compartment was maintained at 2,000 cubic-feet-per-minute or about one air change every 2.5 minutes. At the time of detection (when 300°F was recorded by any one of the thermocouples), the airflow was reduced to 75 cubic feet per hour.

Although temperatures at nine different locations were recorded, only the highest temperature trace was used in evaluating the data, because the lower temperatures were of less significance. The convection currents due to the heat generated by the fires had more effect on temperature distribution than the airflow through the compartment so the highest temperature, even before detection and airflow shutoff, invariably occurred at the thermocouples located above the fire location rather than downstream or at the air outlet. Therefore, only the highest temperature recorded was used to determine detection, fire severity, and for plotting the time-temperature curves.

In every cargo-fire extinguishing test conducted in this program, data were taken for 2 hours after the start of the tests. This permitted a determination to be made of the effectiveness of the control or extinguishing method employed in each particular test. At the end of this 2-hour test period, since visual flames were extinguished but smoldering continued in every case, the fire was extinguished completely by introducing approximately 1,200 pounds of CO_2 from a Cardox system. The compartment was kept closed with zero airflow until the next day. With the possible exception of two occasions, the fire was out by then and after airing out the compartment for an additional day it could be emptied and cleaned in preparation for loading for the next test.

SUMMARY OF TEST RESULTS

In general the results of the tests conducted indicate that the relocating of the compartment outlet from the top to the bottom location had no noticeable effect on the control afforded by either the airflow shutoff or the Freon 1301 extinguishant method for combating the compartment fire.

The results of a typical cargo-compartment fire test, 10-percent-load configuration, in which airflow shutoff was used to effect control are shown in Figure 6. In this test detection was assumed when a temperature of 300°F was indicated at which time the airflow was shut off. Shortly thereafter a flash fire occurred as evidenced by the rapid rise in pressure and temperature followed by a reduction in the percent oxygen reading which usually dropped to near zero percent and remained there for several minutes. During the flash fire a maximum temperature of 1,800°F and a pressure of 0.10 pound per square inch were recorded. In other similar tests temperatures of over 2,000°F and pressures up to 0.175 pound per square inch were recorded.

Results of the tests conducted using bromotrifluoromethane in addition to airflow shutoff (with simulated leakage) are shown in Figure 7. These results show that in all cases where an extinguishant is used in addition to airflow shutoff the flash fire was eliminated. They also indicated that both 100 pounds of agent (5 percent by volume) and 60 pounds of agent (3 percent by volume) were effective in extinguishing the flames and controlling the continuing smoldering condition for a 2-hour period. The only noticeable difference between the 3- and 5-percent agent tests was that the compartment temperature, due to the smoldering cargo, remained between 50° and 100°F higher throughout the 2-hour period when the lower agent concentration was used.

CONCLUSIONS

Based on the results of the tests conducted, it is concluded that in compartments with a volume of up to 10,000 cubic feet:

1. The use of bromotrifluoromethane extinguishing agent released at the time of detection of a cargo fire can prevent the occurrence of flash fire, greatly reduce the maximum temperatures, and provide effective fire control for periods of at least 2 hours.

2. The use of as little as 3 percent by volume of bromotrifluoromethane can effectively control cargo fires in a compartment with a 10-percent and a 50-percent load configuration.