FIRE-EXTINGUISHMENT STUDIES OF THE CONVAIR-340 POWER PLANT

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SUMMARY

Fire tests were conducted in the accessory section of a full-scale operable CV-340 nacelle in order to evaluate the extinguishing system used in this power plant. A study was made of the recommended emergency procedure in which the exit air-vent door at the top of Zone 2 is closed during extinguishment. Comparative studies were made of emergency procedures in which the vent door was left open and in which both the vent door and the air-inlet duct to the zone were closed.

The tests indicated that the presently used quantity of bromochloromethane (CB), 22.5 pounds, is ample for fire extinguishment in flight at cruising speed with the vent door either open or closed. As long as the fire remained confined, extinguishment was assisted by closing the vent door. The minimum quantity of agent required is smaller if the inlet and the vent door are both closed at the time of extinguishment.

A study was also made of the procedures and techniques involved in extinguishing fires resulting from unsuccessful attempts at starting the engine while the airplane is on the ground.

INTRODUCTION

United Air Lines, Consolidated Vultee Aircraft Corporation, and the Technical Development and Evaluation Center of the Civil Aeronautics Administration collaborated in a program to evaluate the fire safety of the Convair CV-340 power plant. United Air Lines supplied an airplane engine, a propeller, and replacement parts. Convair supplied the test nacelle and technical assistance in preparing the nacelle for operation. TDEC provided the test facilities, instrumentation, and personnel to conduct the tests. Testing started in November 1952.

The fire-extinguishing tests under simulated flight conditions were confined to Zone 2, the accessory section, because Zone 1, the power section, was not protected by an extinguishing system and because Zone 3 was simply enclosed with sheet metal (for purposes of these tests) and was not representative of Zone 3 in operational aircraft. However, the Zone 3 extinguishing system was intact.

DESCRIPTION OF TEST EQUIPMENT

The fire-extinguishing evaluation tests were conducted in a Convair CV-340 left-hand nacelle, which differs from the right-hand nacelle principally in that the accessory section of the latter contains the cabin supercharger. Although all of the usual accessories required for the left-hand nacelle were in position, only the engine-driven fuel pump, the starter, and the tachometer generator were functioning. Such other accessories as the water-injection regulator, the hydraulic pump, and the generator were inoperable. The propeller, a Hamilton Standard hydromatic, Model 43E60-3, was driven by a Pratt & Whitney R-2800-CB16 engine. Normally, the engine used in the CV-340 has a single-stage, two-speed supercharger; but the test engine was not equipped with the supercharger selector valve or the clutch assembly. Low blower operation was simulated by the use of a gear train instead of the supercharger clutch.

The test facilities shown in Fig. 1 have been described in an earlier report.[1] A mobile air-blast unit provided cooling air for the test engine to simulate flight conditions. Since the mobile unit by itself was not capable of simulating flight at cruising speed in Zone 2, the air flow and the static pressure in the zone were increased by means of a centrifugal blower. The blower, rated at 40 hp, was connected to the intake scoop by an 8-inch-diameter metal duct. See Fig. 2.

The conventional Walter Kidde Company extinguishing system in the CV-340 airplane includes lines, valves, and other items of equipment to protect two nacelles, plus two spherical extinguishing-agent containers intended to provide two separate discharges. Such a system is shown in Fig. 3. The test extinguishing system was similar to that portion of the conventional system required to protect a single nacelle. It comprised two spheres for two separate discharges, sufficient feed line to simulate line distance to the more remote nacelle, and the

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*Manuscript submitted for publication February 1955.

[1] L. A. Asadourian, "Fire-Detection Studies in the Convair-340 Power Plant," CAA Technical Development Report No. 250, November 1954.

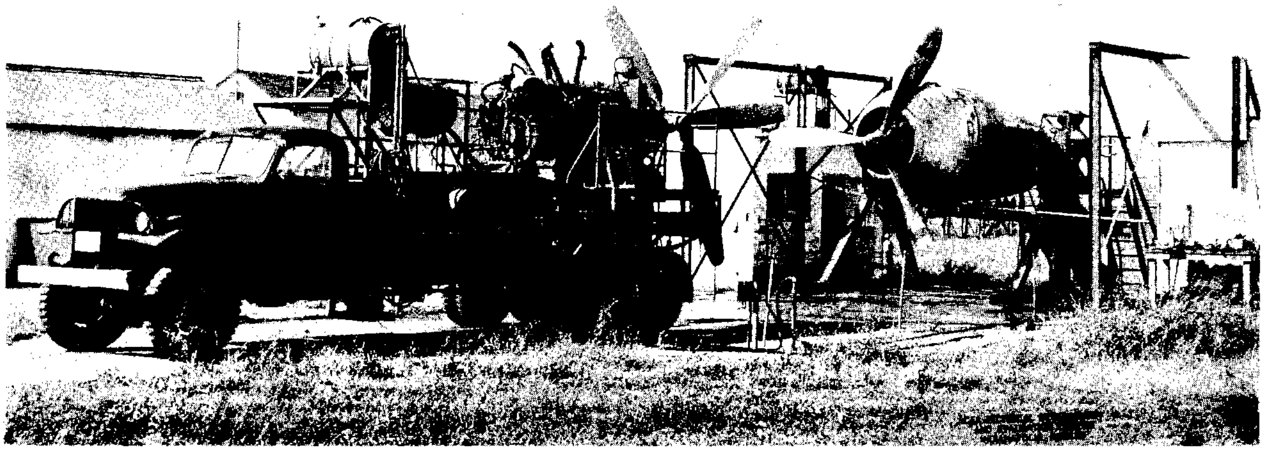

Fig. 1 General View of Test Facilities

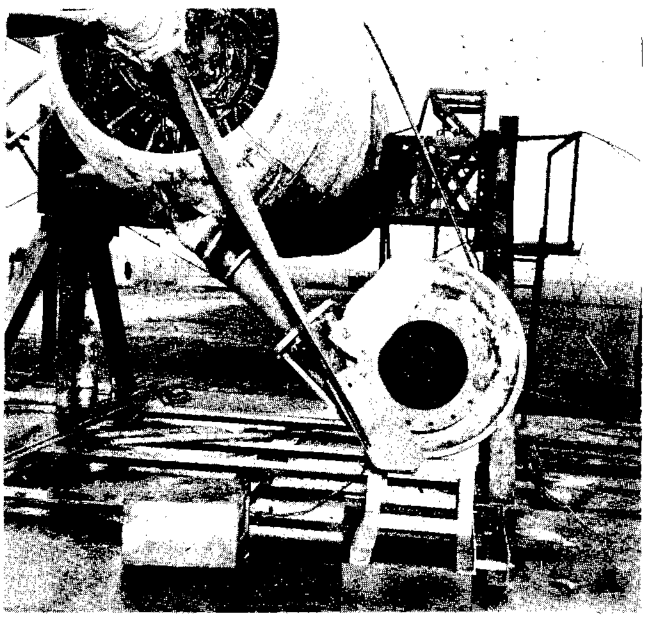

Fig. 2 Centrifugal Blower Used to Increase Static Pressure in Zone 2

distribution system within the nacelle. The spheres used in this airplane have a volume of 630 cubic inches and contain 22.5 pounds of bromochloromethane pressurized with nitrogen to 400 psi. This size sphere as well as other sizes and other quantities of bromochloromethane were used in the test program. Discharge of the fluid was accomplished electrically by the usual cartridge-and-frangible-disk assembly with which these spheres are equipped.

For accessibility during the tests, the spheres were mounted outside the nacelle. See Fig. 4. The feed line, extending from the sphere to the Zone 3 distribution fitting, consisted of 331 inches of 1-inch-OD stainless steel tubing having a wall thickness of 0.028 inch. Beyond the distribution fitting were three smaller lines. One of these was 5/8-inch-OD stainless steel tubing having an 0.020-inch wall thickness and a length of 222 inches, bent in the form of a loop, and perforated with 134 holes of 0.063-inch diameter. This loop was entirely within Zone 3. Another 5/8-inch-OD (0.020-inch) line 269 inches long extended from the distribution fitting to the fire wall where it continued as 1/2-inch-OD stainless steel tubing. It also was bent into a loop and perforated with 64 holes of 0.063-inch diameter. The third line, 1/4-inch OD by 48 inches long, was used for pressure actuation of the Zone 2 air-exit vent door.

After the extinguishing agent was discharged the first few times, the vent door (shown in Fig. 5) failed to close properly. Examination of the door-triggering assembly revealed that bromochloromethane had caused corrosion of some of the parts. The trigger-assembly cylinder was replaced with a new unit (supplied by Convair) which was more resistant to corrosion. Standard practices in airline operation specify that the system be flushed with water after discharge. However, in order to conserve valuable test time which would otherwise be expended in the repeated cleaning of parts, actuation of the vent door was accomplished for the remainder of the program by compressed air instead of by pressurized bromochloromethane.

The airplane extinguishing system was modified slightly during the latter part of the program to effect the extinguishment of fires which came overboard in the vicinity of the oil cooler. A 3/8-inch-OD line having a wall thickness of 0.035 inch was connected to the Zone 2 supply line and was formed into a loop aft of the oil cooler. It was 52 inches long and was perforated with 12 holes of 0.076-inch diameter. This is illustrated in Fig. 6.

Two standby systems were maintained to extinguish fires which for any reason could not be extinguished by the system just described. One of these, a methyl bromide system, was arranged to distribute a 25-pound charge of methyl bromide into all three zones through 1/2-inch-OD copper tubing. The other, a carbon dioxide system, was arranged to distribute as much as 400 pounds of carbon dioxide as needed into all three zones through 1-inch copper tubing.

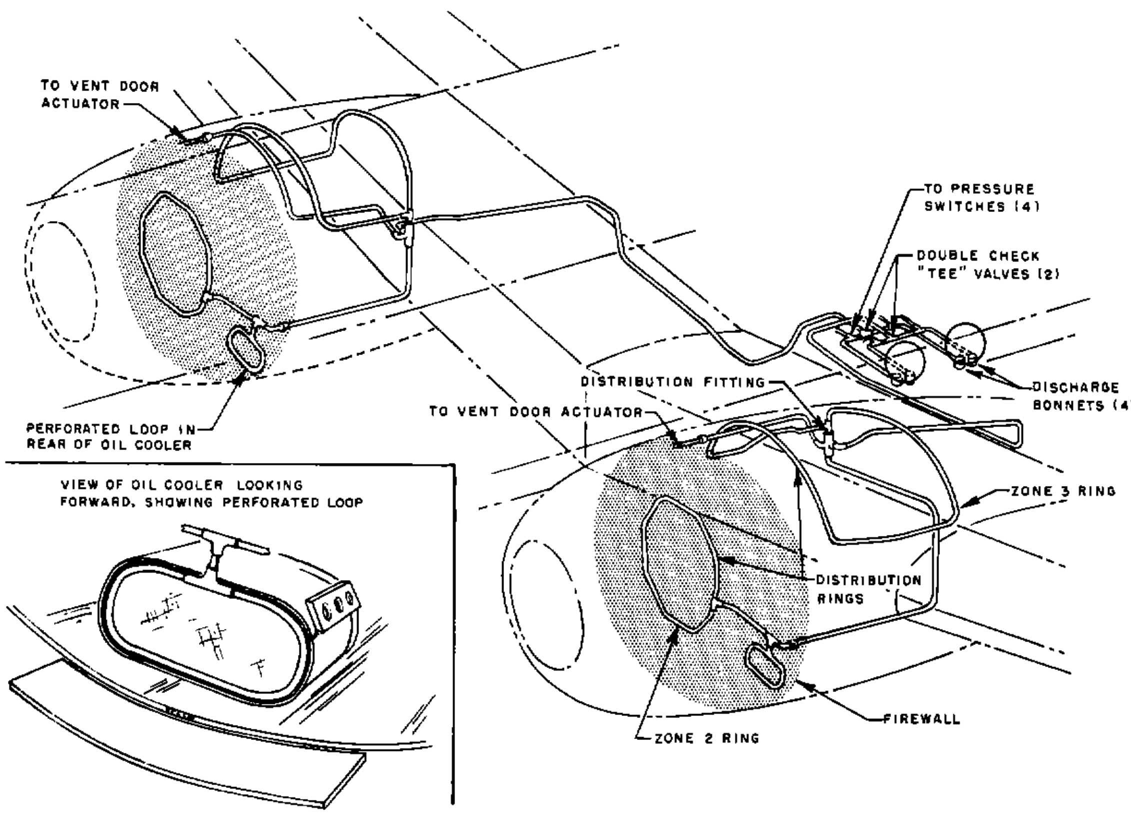

Fig. 3 Bromochloromethane-Container Installation and Tube-Routing

Extinguishing-agent concentrations inside Zone 2 were measured by means of a Statham Model GA-2A gas analyzer. The analyzer consists of sampling tubes, a vacuum pump, three analyzer units, a control unit, and a recorder. Nine sampling tubes were installed in Zone 2; and, during a test, continuous samples of the Zone 2 atmosphere were withdrawn by means of the vacuum pump. As the samples of agent-air mixture passed through the analyzer units, the percentage concentrations of extinguishing agent were measured. These measurements were recorded by an oscillograph.

The ground-fire extinguishing tests were conducted with the aid of two 15-pound carbon dioxide containers fitted with those and horn assemblies. These were sufficiently long for agent to be discharged into the upper extremities of the engine even though the containers remained on the ground.

The fires used in the simulated-flight-fire tests were established by burning either gasoline supplied at a rate of 1 1/2 gpm or a mixture of gasoline at 1 1/2 gpm and hot oil and hydraulic fluid at 2 gpm. Gasoline only, at 1/3 gpm, was used in the ground-fire extinguishing tests. In all cases the fluids were ignited by a spark ignitor. Prior to the initiation of the fire-extinguishing tests, all of the engine-fuel and oil hose lines (MIL-H-5511) were removed and replaced with flexible metal hose lines supplied by Flexonics Corporation of Maywood, Illinois

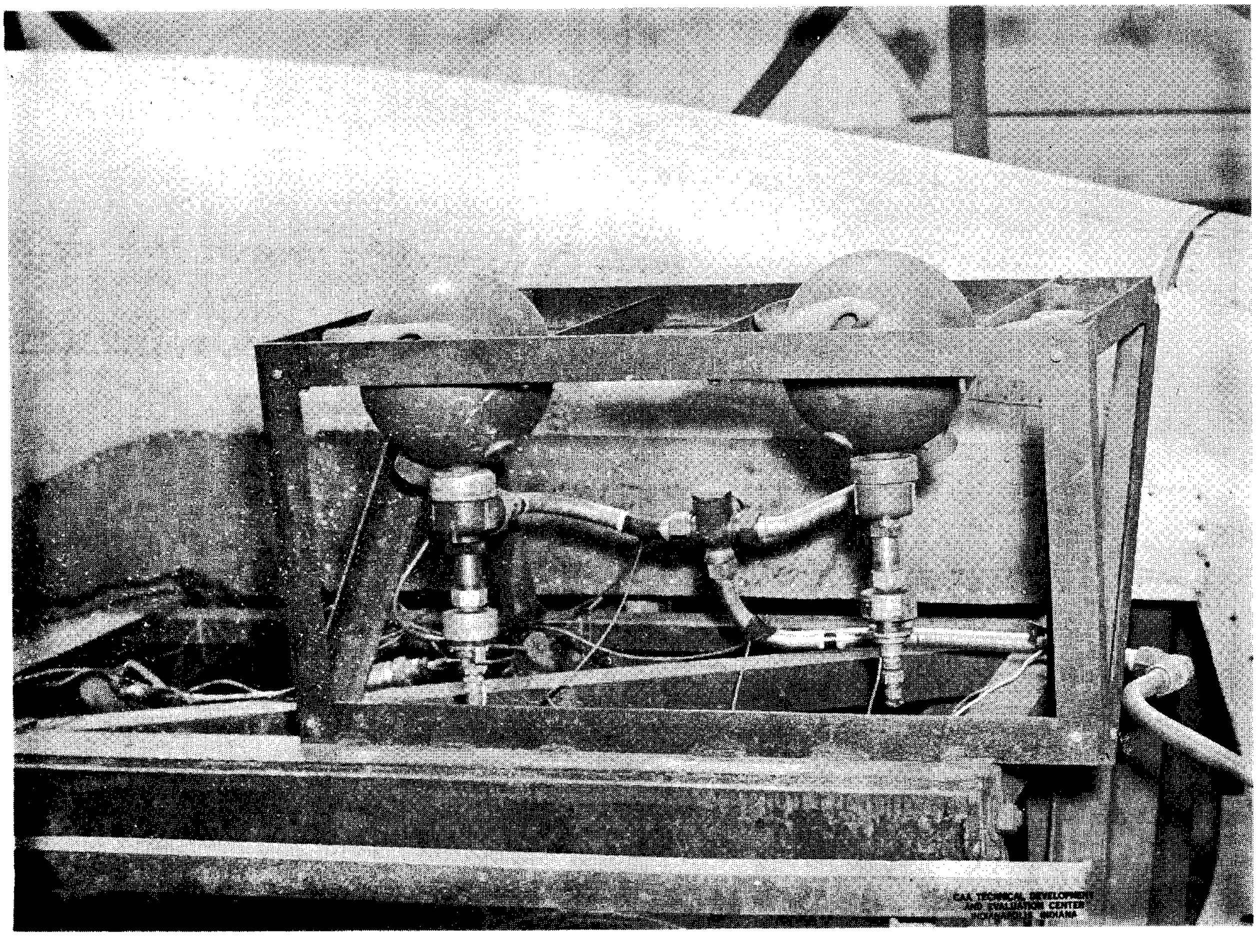

Fig. 4 Extinguishing-System Sphere Located Outside the Test Nacelle

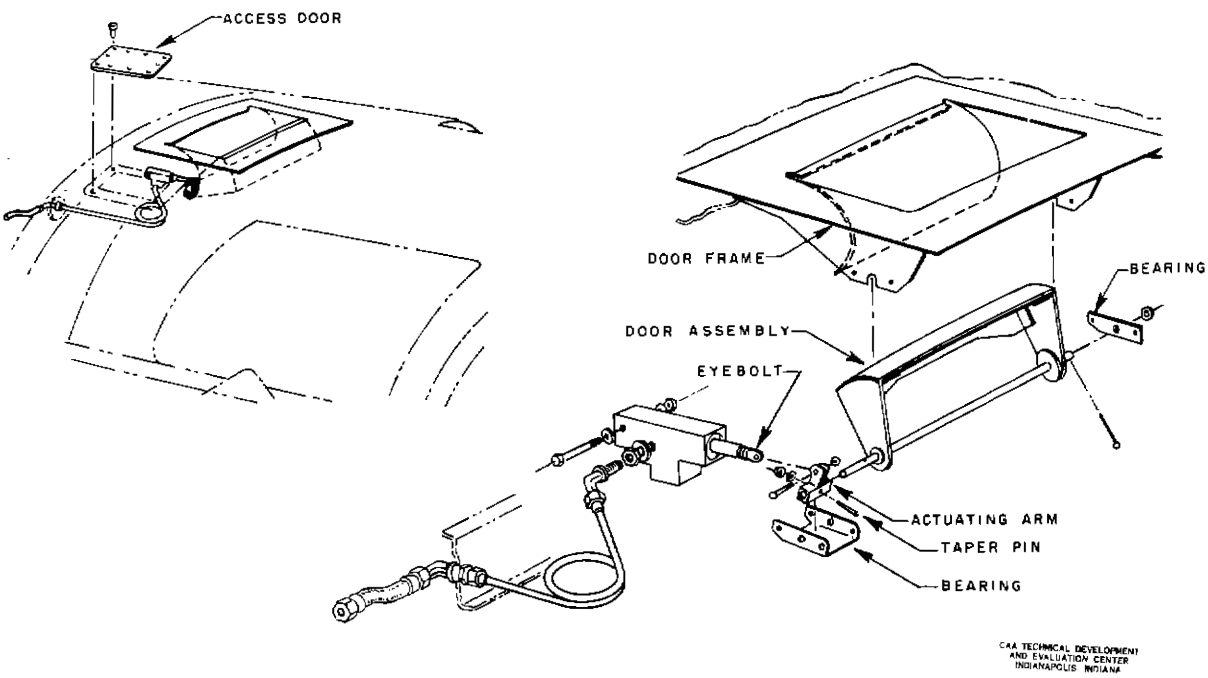

Fig. 5 Accessory-Section Vent Door

TEST PROCEDURE

Before any fire tests were conducted, the extinguishing system was removed from the nacelle and supported on framework in its normal attitude. This was done to facilitate the work of determining what percentage of the 22.5 pounds of bromochloromethane fluid goes into each zone when the system is discharged. Each of the perforated loops was loosely covered with a sleeve of plastic tubing to prevent escape of the fluid to the atmosphere. When the system was discharged, all of the fluid was conveyed by the sleeves to containers. The fluid collected in the containers was then weighed, and the relation of the weight from each loop to the total weight collected was computed. At the conclusion of this test,the system was reinstalled in the nacelle for conducting fire tests.

The following steps constituted the typical procedure used in conducting simulated-flight-fire extinguishing tests:

1. The CV-340 engine and mobile air-blast engine were warmed up.
2. The desired simulated-flight condition was established by proper adjustment of the CV-340 controls, the mobile equipment, and the centrifugal blower.
3. A fire was started within Zone 2.
4. After the lapse of a predetermined period of time following detection of the fire, the emergency shut-down procedure was initiated. The fuel ignitor was turned off with fuel still flowing.
5. While the air blast from the mobile unit and the centrifugal blower continued, the extinguishing agent was discharged.
6. When the detection system indicated that the fire was out, the flow of fire fuel was stopped and the mobile unit and compressor were shut down. If extinguishment was unsuccessful, the flow of fire fuel was stopped, the mobile unit and compressor were shut down, and the fire was extinguished by the use of standby equipment.

After each test, compressed air was released into the extinguishing-system lines near the spheres to purge the lines of any residual extinguishing agent.

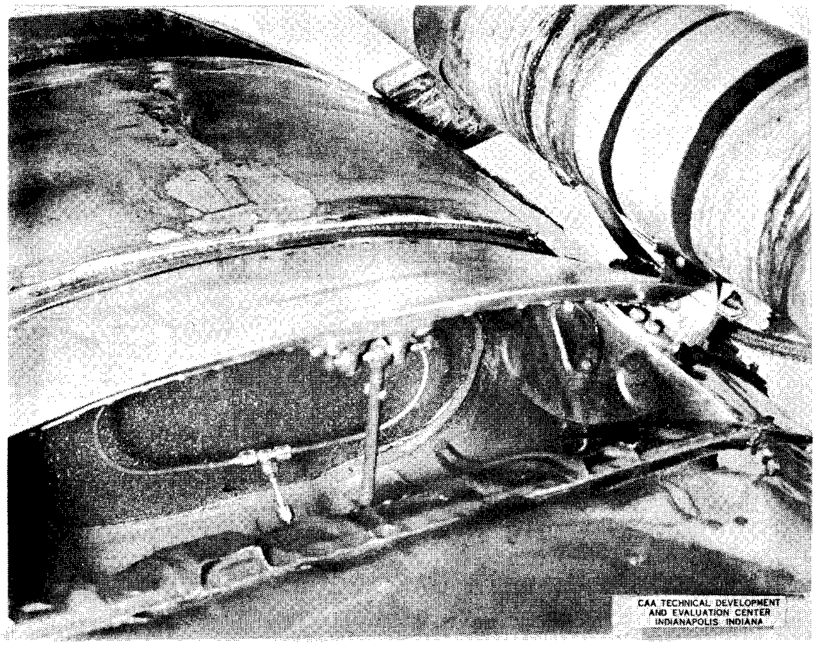

Fig. 6 Perforated Loop Mounted Aft of the Oil Cooler

In conducting tests to extinguish fires existing under a selected set of conditions, the quantities of extinguishing agent were increased or decreased as dictated by test results in order to determine the minimum weight of agent required. From time to time the location of the fire nozzle was changed to simulate fires originating at different points within the zone. Also, from time to time other changes were made and their effects on extinguishment were investigated. For example, the effects produced by having the vent door open or closed at the time of agent discharge were investigated.

The investigation covered three possible variations of procedure with respect to the closure of the vent door: (1) the normal procedure currently used in which the vent door is closed as extinguishment takes place; (2) the normal procedure except that the vent door remained open; and (3) a new procedure in which the vent door and the Zone 2 air-inlet scoop were both closed. In the tests, closure of the inlet port was simulated by closing the inlet to the centrifugal blower, which was connected by a duct to the air-intake scoop.

The first few fires which burned inside Zone 2 were totally confined. However, such fires were very damaging, especially to the seals. After the seals were burned out, fire emerged to the outside of the nacelle. The seals around the oil cooler were repeatedly burned out and replaced. Eventually, the oil cooler itself was damaged as shown in Fig. 7. Because there was no oil cooler available for replacement, it became necessary to seal off both ends of the core and to use it only as a mock-up. Actual oil-cooling was accomplished by connecting the oil system to an auxiliary cooler remotely located. It was at this time that the regular extinguishing system was extended to include a perforated loop mounted aft of the oil cooler. If the core had been functioning, the loop would have been mounted forward (upstream) of the oil cooler.

The procedure used in determining the percentage concentrations of bromochloromethane inside Zone 2 during discharge of the extinguishing system was as follows:

The desired flight condition was established with such variations as necessary to serve the purposes of the test. Without creating a fire, an emergency situation was presumed and the same procedure was followed as if a fire were present. This included the discharge of the extinguishing agent. A continuous record of the concentrations at nine different points was obtained with the Statham analyzer.

Although the investigations mainly involved fires which ordinarily would occur in flight, some consideration was given to the handling of fires which can occur while the airplane is on the ground. A study was made to determine the most effective procedure to follow in the event a fire ignites while the airplane engine is being started. Overpriming and backfiring are generally the causes of such fires. However, attempts to cause fires within the nacelle by simulating an overprime condition during engine start-up were unsuccessful. The simulation was accomplished by discharging gasoline at 1/3 gpm through a spray nozzle near the ends of the engine exhaust pipes. The fires had to be ignited by a spark ignitor.

The most effective methods for extinguishing such fires with hand extinguishers operated from the ground were investigated. Fires were attacked by discharging carbon dioxide up the augmenter tubes which are readily accessible from the ground. Fires were also attacked by introducing the carbon dioxide through and around the engine cylinders at the propeller end and through the cowl-flap ports.

RESULTS AND DISCUSSION

The indicated air speed for a CV-340 airplane cruising at an altitude of 10,000 feet is 220 mph. The measured static pressures in Zone 2 at this speed are 4.3 inches of water with the vent door open and 10.8 inches with the vent door closed. The combined effects of the mobile unit and the centrifugal blower produced the maximum static pressures given in Table I.

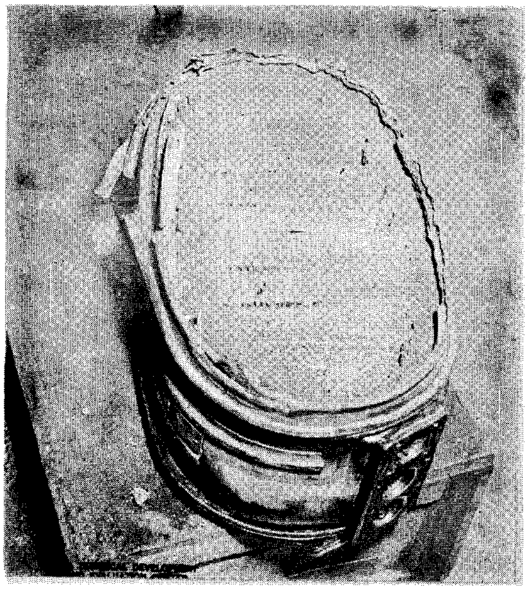

Fig. 7 Oil Cooler Damaged by Repeated Fires

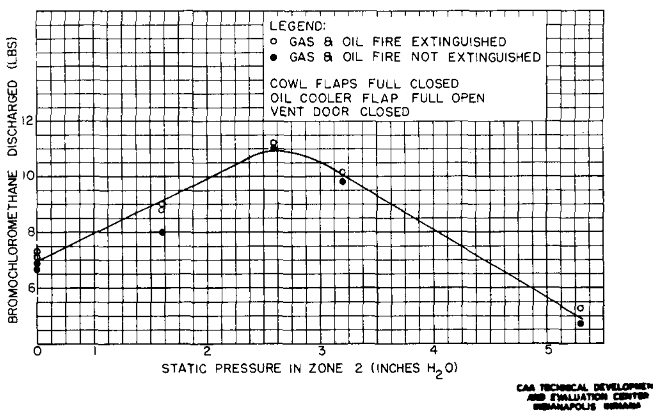

Fig. 8 Agent Requirements Versus Zone 2 Static Pressure

TABLE I

MAXIMUM STATIC PRESSURES PRODUCED IN ZONE 2
BY COMBINED OPERATION OF CENTRIFUGAL AND MOBILE BLOWERS

Zone 2 Ventilation	Static Pressure in Zone 2 (Inches H_2O)
Vent door open	4.2
Vent door closed	5.6
Inlet and vent door closed	0.0

The static pressure obtained with the vent door open was comparable to that obtained in flight with the vent door open. However, the pressure obtained when the vent door was closed was much lower than the corresponding pressure during flight. The reasons for this may be that the compartment (at the time the pressures were measured) was badly warped and that all seals were in poor condition. The weight of air pumped into Zone 2 was approximately 3 pounds per second regardless of whether the vent door was open or closed.

The reason for closing the vent door or both the vent and inlet doors was to assist in retaining the extinguishing agent within the compartment. With both doors closed the zone would be completely sealed except for leakage, and the air flow through the zone would become negligible.

One adverse effect noted in connection with the closing of the inlet port was that the heat-actuated fire-detection system required a longer period to reset after a fire had been extinguished. If closure of the inlet port is adopted as standard procedure, pilots should be informed of this fact. The period between the discharge of the extinguishing agent and a fire-out indication under such conditions varied between 20 and 40 seconds.

The extinguishing tests were mainly directed toward the evaluation of the extinguishing system with the vent door either open or closed. In either case, the air flow was a critical factor. Since air flow is a very difficult quantity to measure, extinguishing requirements were determined for various static pressures.

The plotting of the required agent quantities against the static pressures measured within the Zone 2 compartment established the minimum agent weight that can be used. This relation is shown in Fig. 8 for a closed vent door. The curve for the open vent door is similar to that shown

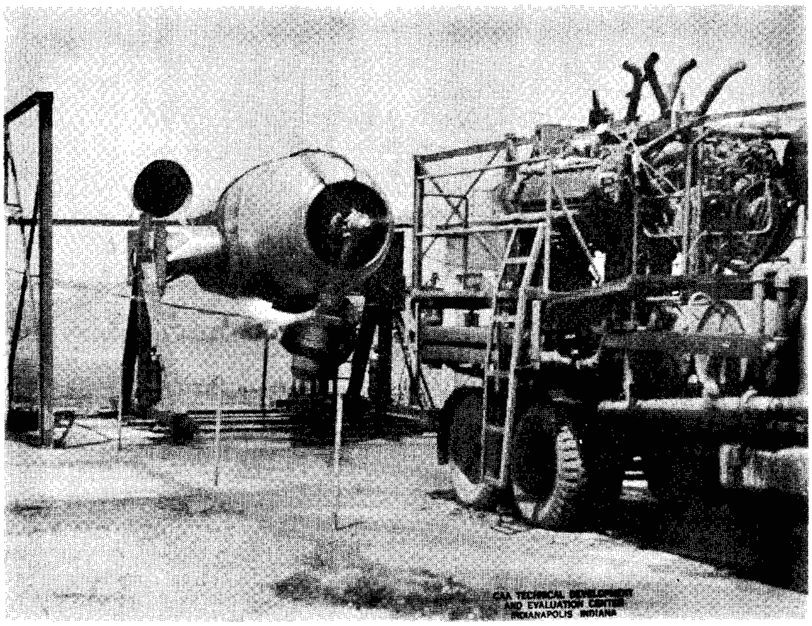

Fig. 9 Overboard Fire Lodged Aft of the Oil-Cooler Flap

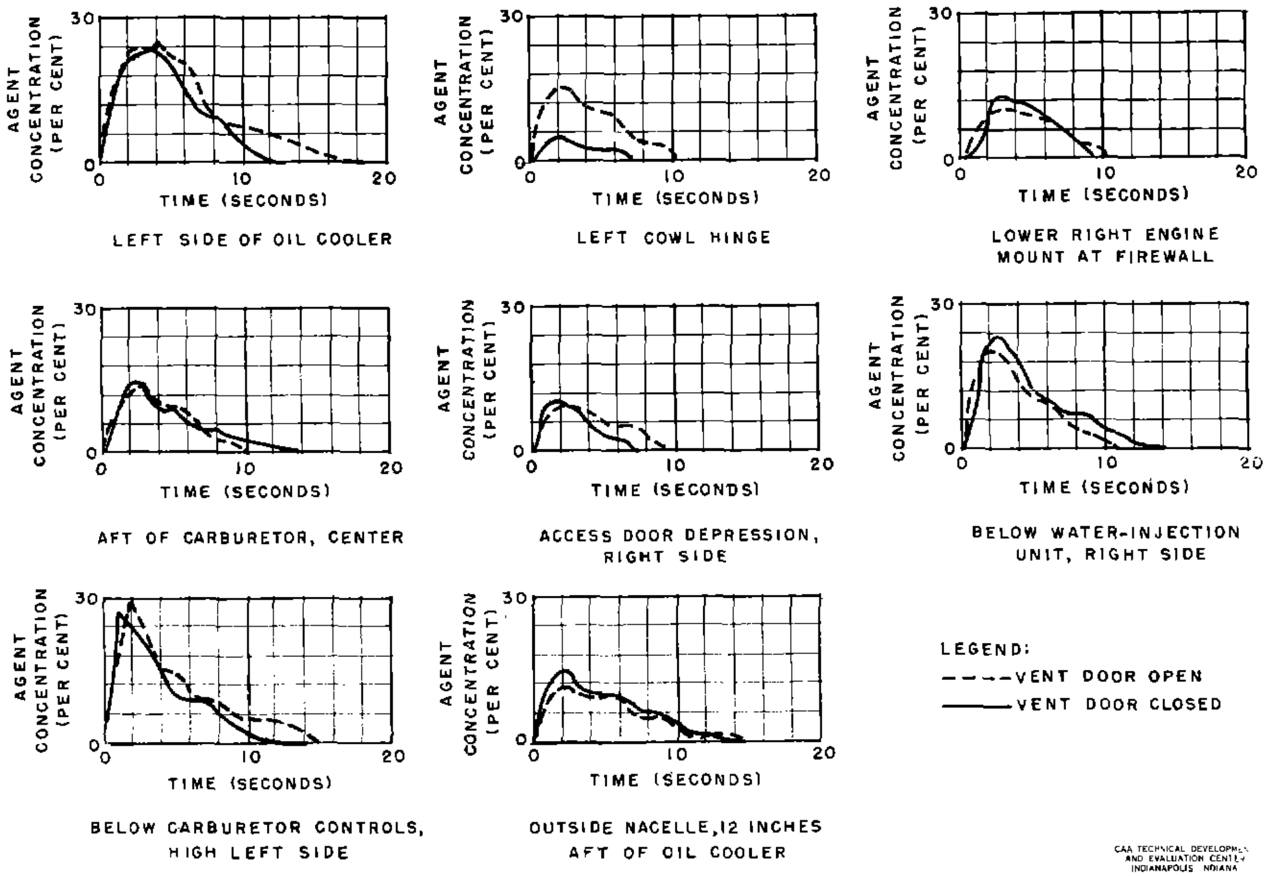

Fig. 10 Concentrations Produced at Various Points by Discharge of 22.5 Pounds of Bromochloromethane

in Fig. 8 except that the peak requirement is 3 pounds higher. Closure of the vent door assisted extinguishment.

At the beginning of the extinguishing-test program, gasoline discharged at a rate of 1 1/2 gpm was used as the fuel for the test fires. After the first ten of these fires (each of approximately 20 seconds duration), which were totally confined within the Zone 2 compartment, the seals around the oil cooler burned through and permitted the flammable fluids and fire to escape to the outside. After the oil-cooler seals were replaced, the fire fuel was changed to a mixture of gasoline and hot oil supplied at a rate of 3 1/2 gpm. This resulted in more severe fires. In the first test following replacement of the seals, the fire remained inside the zone; but in the second test, the fire extended outside of the nacelle aft of the oil cooler. Such a fire is illustrated in Fig. 9.

The closing of the Zone 2 vent door at the time of discharge of the agent may have increased the tendency for fire to extend overboard, but overboard fires did not become a problem until the oil-cooler seals had burned through. The fires that extended overboard usually did so before the vent door was closed.

The oil-cooler flap prevented fires from being wiped off by the air stream past the nacelle. Attempts were made to determine the feasibility of closing the flap as part of the emergency shut-down procedure, but the process was found to be too slow to be effective.

Since the integrity of the oil-cooler seals appears to be the key to overboard fires and since external fires complicate the extinguishing problem, it is highly desirable that the most fire-resistant material available be used for the seals and that the seals be carefully installed. Because the hazard of overboard fires is very real with the presently used oil-cooler seals, protection against such fires is advocated.

As previously described, a loop of 3/8-inch-OD copper tubing was installed aft of the cooler. During discharge of the regular 22.5 pounds of bromochloromethane, approximately

0.5 pound came out of the holes in this loop. This quantity was effective in wiping off the external fires which lodged behind the oil-cooler flap.

To supplement the data obtained by conducting actual fire tests, a number of measurements were made of the agent concentrations inside Zone 2 for various operating conditions. Tests of this kind, in which a known weight of agent is discharged into a zone where no fire exists, are not only harmless to the zone but are more informative than fire-test results in many respects. The curves in Figs. 10, 11, and 12 show how concentrations vary with time for each set of conditions. The curves shown in Fig. 10 were produced when 22.5 pounds of bromochloromethane was discharged with the vent open and with the vent closed during simulated emergency operation at cruise conditions. The average peak concentration produced with the vent open was 18 per cent; and,with the vent closed, the concentration was 17 per cent. An average concentration of 15 per cent existed for 1.8 seconds in both cases.

For comparison, 12.5 pounds of bromochloromethane was discharged under similar conditions. The resulting curves from these tests are shown in Fig. 11. The average peak concentrations were 15 per cent with the vent open and 14 per cent with the vent closed. In the first instance the duration of a 15 per cent concentration was 0.5 second, and in the latter only 0.37 second. Many of the confined fires could be extinguished with 12.5 pounds of bromochloromethane.

For further comparison, a third series of tests was conducted with the static pressure in Zone 2 at approximately 2.5 inches of water. See Fig. 12. Under this reduced pressure, the peak concentration for a 12.2-pound discharge was 17 per cent with the vent open and 20 per cent with the vent closed. Also, the average durations of a 15 per cent concentration were 1.2 and 3.5 seconds, respectively. The relatively high concentrations shown in Fig. 12, as compared to those shown in Fig. 11, are understandable because there is less dilution of the fluid at the lower air flow.

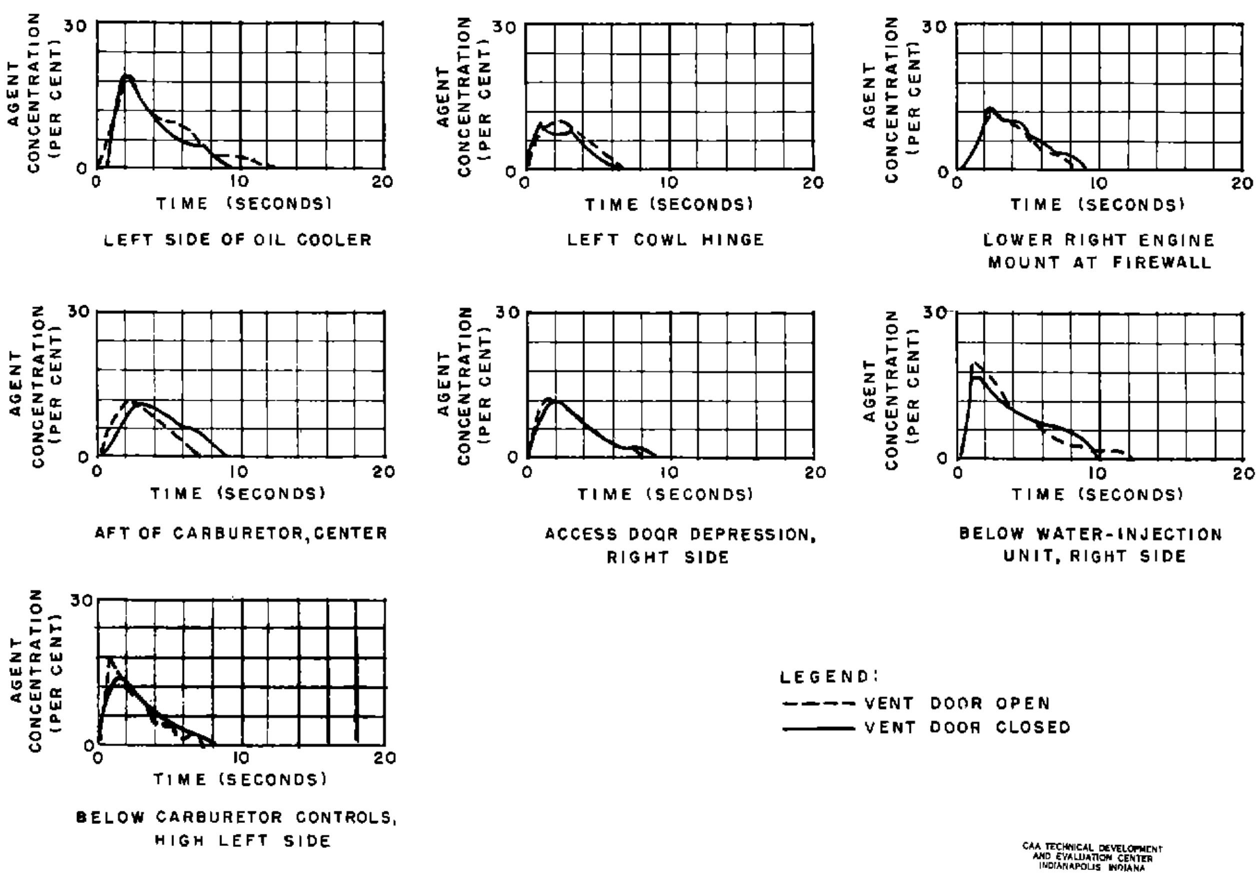

Fig. 11 Concentrations Produced at Various Points by Discharge of 12.5 Pounds of Bromochloromethane

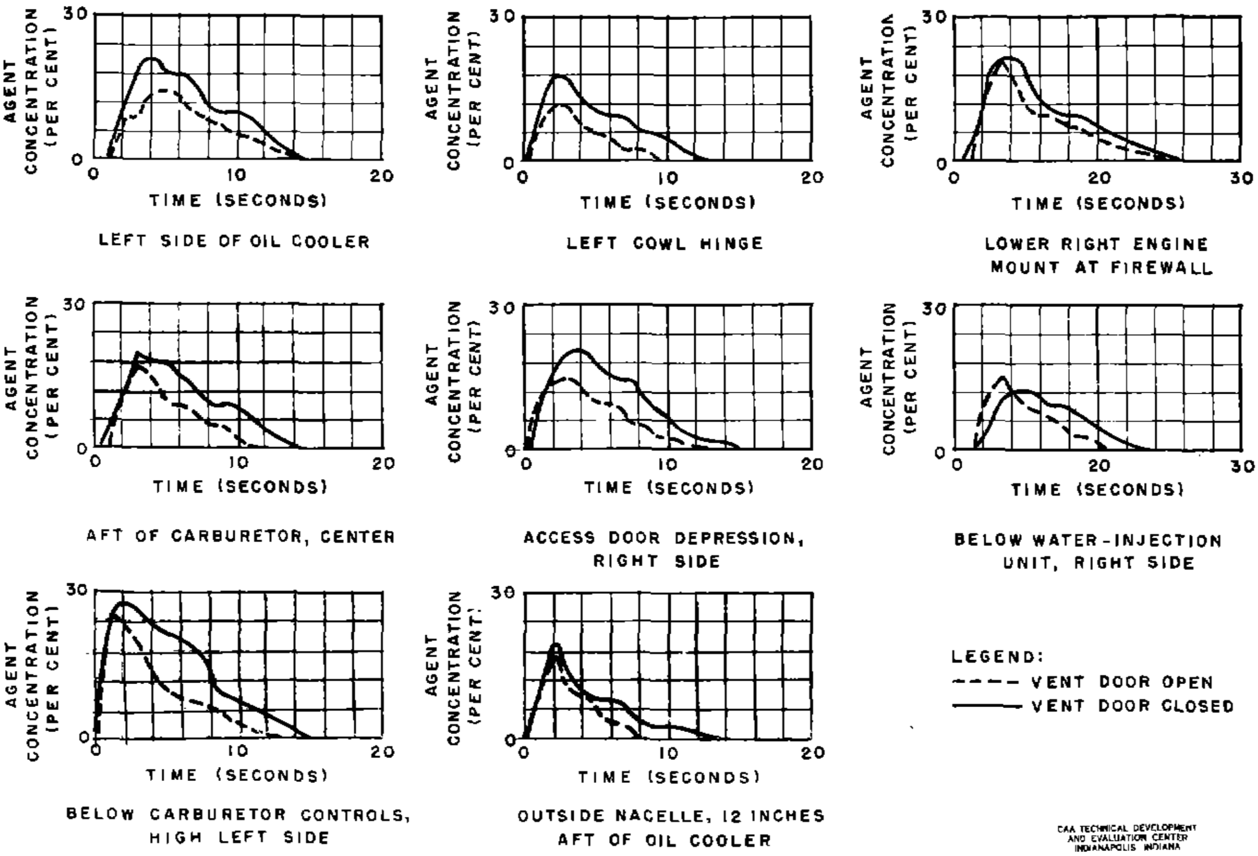

Fig. 12 Concentrations Produced at Various Points by Discharge of 12.2 Pounds of Bromochloromethane at Reduced Static Pressure in Zone

The quantities of flammable fluids supplied to the fires remained constant during the tests even though the air flows in the zone varied. Therefore, the fire size varied. It is probable that a less stable fire existed at the higher air flows. Moreover, the higher air flow and higher static pressure may have been effective in dislodging or suppressing the fires. Consequently, a smaller peak agent concentration and a shorter retention time were effective at cruise conditions.

Figs. 10 and 12 are curves showing the agent concentrations measured outside of the nacelle and 12 inches downstream from the oil cooler. Concentrations of these or greater magnitudes should be provided by the oil-cooler extinguishing ring. Since no air was passing through the oil cooler at the time the measurements were made, it is possible that a larger capacity tube and more perforations would be required in conventional aircraft systems. A loop fabricated in accordance with the rest of the system to provide a suitable concentration of bromochloromethane at the oil cooler might be described as follows: 52 inches of 3/8-inch-OD stainless steel tubing, having an 0.020-inch wall thickness, perforated with 21 holes of 0.076-inch diameter, and located forward of the oil cooler. During flight tests, the concentration should be checked at a point 12 inches downstream, as in the simulated tests, for purposes of comparison.

The discussion up to this point has dealt with the problems associated with fires in flight. The remainder deals with the special problem created by fires that start while the airplane is still on the ground. In the air, successful control of a nacelle fire depends on the installed extinguishing system and on the proper procedure. On the ground, the situation is entirely different but not necessarily any easier to control. Although the installed system is still available for use, there is a question of whether it should be used. If used, would it be effective? Would hand extinguishers be more effective? Should both be used? What is the technique of using hand extinguishers? These are some of the questions which prompted an investigation of ground-fire problems.

When an airplane, loaded and ready to depart, suffers a nacelle fire, there is a natural reluctance to discharge the installed extinguishing system because: (1) the fire is frequently in the engine section, which the extinguishing system does not protect; (2) the fire may be more successfully attacked by a ground crew; (3) if the ground crew is successful, a long delay brought about by the necessity of recharging the system and washing down the nacelle will be avoided; and (4) if the ground crew is unsuccessful, the installed system can be used as a last resort.

Fires in the engine section may be attacked through the cowl-flap ports, the aft end of the augmenter tubes, and the front opening in the cowling. Discharging the extinguishing agent into the cowl-flap ports was not very effective because it was difficult to direct the fluid into the region near the augmenter tubes where the fire was concentrated. A more successful attack could be made by aiming the horn into the exit of the augmenter tubes, provided that the wind was blowing from the rear to assist the agent up the tubes and into Zone 1. It was almost mandatory, however, to discharge the agent up both tubes simultaneously. The best results were obtained by directing the agent into the engine section through the front above the propeller and approximately in the same plane as the bell mouths of the augmenter tubes. If a single horn is used, it should be aimed alternately and rapidly to the right and to the left. This method is particularly effective when the airplane is headed into the wind. Fires in the accessory section cannot be reached by hand extinguishers and, therefore, must be extinguished by discharge of the installed system.

CONCLUSIONS

1. The 22 1/2 pounds of bromochloromethane currently used in a single discharge through the conventional CV-340 extinguishing system is ample to extinguish a fire in Zone 2.
2. The minimum quantity of bromochloromethane found capable of extinguishing an established test fire with the vent closed was 11 pounds, provided that the fire remained confined within the zone.
3. The minimum quantity of bromochloromethane required to extinguish an established test fire with the vent open was 14 pounds, provided the fire remained confined within the zone.
4. Closure of the vent door assists extinguishment.
5. If both the inlet duct to the accessory section and the vent door are closed prior to the discharge of the extinguishing agent, less than 11 pounds of agent are required to extinguish a fire, provided the fire remains confined within the zone.
6. A heat-actuated detector system mounted in a zone where both the inlet and the vent door are closed as part of the emergency procedure is slower to indicate when a fire has been extinguished than a system mounted where the vent door only is shut.
7. Fires originating in Zone 2 will remain in that zone only as long as the oil-cooler seals remain intact.
8. Zone 2 fires which extend aft of the oil-cooler flap greatly complicate the extinguishment problem.
9. The oil-cooler flap closes too slowly to assist extinguishment of fires extending overboard.
10. An addition to the extinguishing system to provide protection at the oil cooler makes it possible to extinguish fires which extend overboard.
11. Fires occurring in Zone 1 while the airplane is on the ground may be attacked by hand extinguishers through the front cowl opening if the airplane is facing into the wind or through the augmenter tubes if the airplane is facing in the opposite direction.
12. Fires in Zone 1, while the airplane is on the ground, cannot be effectively attacked through the cowl-flap ports.

RECOMMENDATIONS

1. The extinguishing system should be modified by adding a loop of perforated tubing or nozzles forward of the oil cooler to extinguish overboard fires.
2. The complete system should be tested in flight both with the vent door open and with it closed to ascertain agent concentrations and the agent quantity required to produce them.
3. For effective extinguishment, a concentration of at least 15 per cent for one second duration should be obtained.

4. The vent door should be closed as part of the emergency procedure.

5. No attempt should be made to change the oil-cooler-flap position during an emergency procedure.

6. Cowl seals and oil-cooler seals should be made of highly fire-resistant materials.

7. Fires occurring in Zone 1 while the airplane is on the ground should be attacked by hand extinguishers through the front cowl opening if the airplane is facing into the wind or from the rear through the augmenter tubes if the airplane is facing in the opposite direction.

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