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Evaluation of Means Adopted To Provide Fire Protection in B-36 Aircraft Powerplants

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Evaluation of Means Adopted To Provide Fire Protection in B-36 Aircraft Powerplants

By

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EVALUATION OF MEANS ADOPTED TO PROVIDE FIRE PROTECTION IN B-36 AIRCRAFT POWERPLANTS*

FOREWORD

The investigation covered by this report was conducted at the Civil Aeronautics Administration's Technical Development Center, Indianapolis, Indiana, and was sponsored by the Equipment Laboratory, Wright Air Development Center. Tests were conducted during the period of December 1953 to September 1956.

SUMMARY

A full-scale test program was conducted for the purpose of evaluating the fire-extinguishing system used in B-36 airplane powerplants and to assist in the design of an improved system. Certain design features of the powerplant which affected the control of in-flight fires also were evaluated.

Both laboratory and in-flight tests were made on the original and a number of revised extinguishing systems using an agent concentration recorder to determine the concentration and distribution of agent within the various fire zones. The quantity of agent discharged into each zone was determined from catch tests on a mocked-up system. The effectiveness of all fire control provisions ultimately was determined from laboratory tests in which actual fires were ignited in the powerplant under simulated flight conditions.

Certain firewall improvements and a fire-curtain installation incorporated in B-36 aircraft by the Department of the Air Force were evaluated and found to be effective in preventing powerplant fires from spreading forward into the wing. A revised extinguishing system which included Zone 3 coverage was found to be inadequate. Weaknesses in the fire seal separating Zones 1 and 3 and in the shrouding of hot surfaces in Zone 2 were indicated.

INTRODUCTION

A study made of fire incidents in B-36 aircraft during the year 1949 showed that fire detection was inadequate. It was believed generally that fire extinguishment also should be improved. To overcome these apparent weaknesses a fourfold plan was adopted. The detection problem was met by replacing the Edison unit-type detector system, with which the powerplants were equipped, with the newly developed Edison continuous-type system. This latter system afforded wider coverage and greater simplicity in installation than its predecessor. The control and extinguishment of powerplant fires were approached in three ways: (1) by improving the firewall seals, (2) by installing a new fire curtain, thereby creating a new buffer zone, and (3) by improving the fire-extinguishing system.

The Technical Development Center (TDC) of the Civil Aeronautics Administration (CAA) had a part in the development of each of these modifications. A report[1] published previously deals with the development of the new detector system. This report deals with the fire-control and fire-extinguishment programs.

PROCEDURE

The left outboard nacelle, including a 19-foot section of the wing to which it was attached, was used as a test article for the development of improved fire protection for the

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*Manuscript submitted for publication August 1958.

[1] Lyle E. Tarbell, "Evaluation of the Resetting Continuous Fire-Detection System for the B-36 Aircraft Nacelle," CAA Technical Development Report No. 295, November 1956.

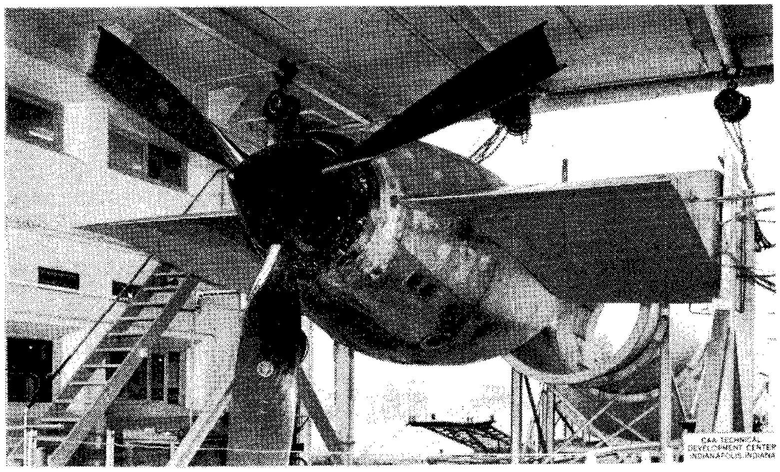

Fig. 1 The B-36 Aircraft Nacelle Mounted in the Test Cell

airplane. The test article was mounted as shown in Fig. 1 in the center of a test cell directly in line with an open wind tunnel which supplied air for cooling the engine and for simulating flight conditions. During part of the program, the wind tunnel was inoperable and the air required was supplied by blowers. When the wind tunnel was used, air entered the main cooling air duct of the nacelle at the leading edge of the wing and also passed over the wing and nacelle. When the blower system was substituted, air was directed into the main duct only, and no air passed over the nacelle and wing except that drawn by the propeller.

Before any tests were conducted, it was decided in conference with the Department of the Air Force, that all B-36 nacelles would have a new fire barrier installed. This barrier was called a "fire curtain," rather than a firewall, because it was to be fabricated of a flexible material rather than of sheet metal. However, at the time that the work was done, a suitable flexible material had not been found.[2] Therefore, the fire curtain in the test nacelle was constructed of sheet steel. Figures 2 and 3 show how this was done. The openings into the

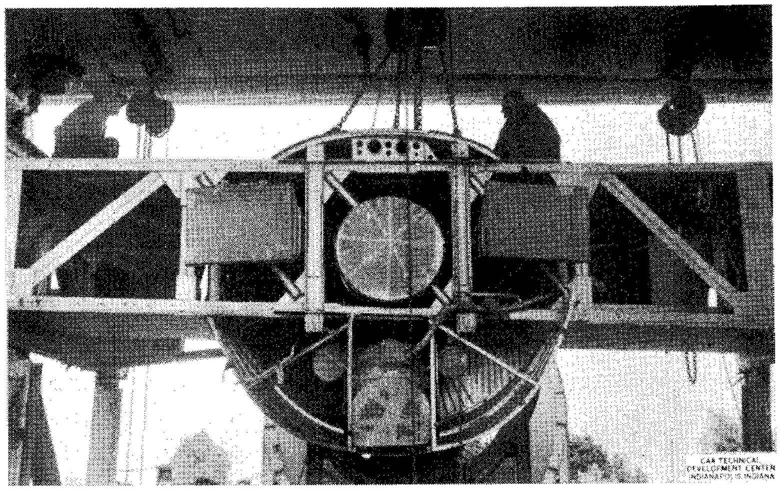

Fig. 2 View of Nacelle at Cleavage Plane Prior to Installation of Fire Curtain

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[2] Ultimately, a satisfactory flexible fabric was developed for use on B-36 aircraft. This consisted of 1/4-inch-wide stainless steel strips woven into a mat which was coated with neoprene.

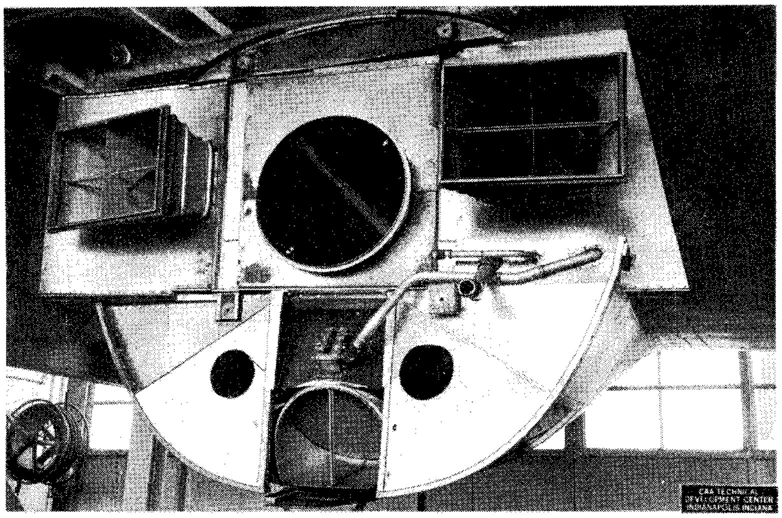

Fig. 3 View of Sheet Metal Fire Curtain Installed at Cleavage Plane

trailing edge of the wing were covered as well as the area in the airplane where the quick-engine-change (QEC) nacelle was attached.

With the installation of the fire curtain, the nacelle consisted of three major zones as shown in Fig. 4. Zone 1 was the zone containing the engine, and was located in the aft part of the nacelle. Zone 2 contained the heat exchangers and the turbosupercharger exhausts. It was located forward of Zone 1 in the middle lower half of the nacelle. Zone 3 contained, among other things, the turbosuperchargers, carburetor intake ducts, the antidetonation (ADI) tank, and the turbo oil tank. It was the most forward zone and extended above Zone 2. The cooling air duct in the center of the nacelle passed through all of the zones but was considered as part of Zone 1 since its main function was to convey air to that zone.

Following the installation of the fire curtain, a study was made of the agent concentrations produced in the nacelle by the original fire-extinguishing System A, and by a proposed modification, System B. See Fig. 5. This was accomplished by use of an extinguishing agent concentration recorder.[3] In conducting these agent concentration tests, flight

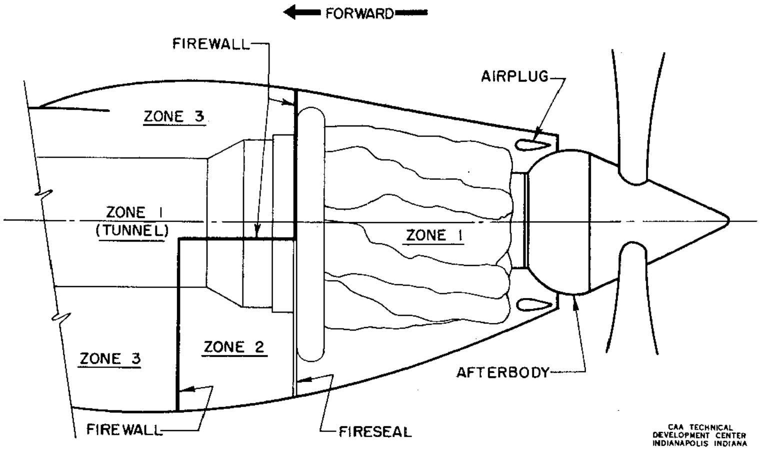

Fig. 4 Designation of Major Zones of B-36 Nacelle

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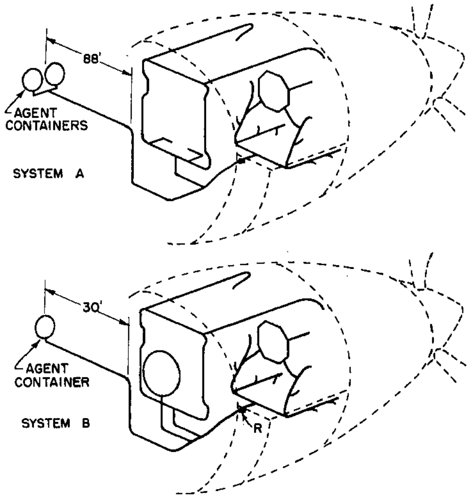
[3] James D. New and Charles M. Middlesworth, "Aircraft Fire Extinguishment, Part III, An Instrument for Evaluating Extinguishing Systems," CAA Technical Development Report No. 206, June 1953.



SYSTEM "C" WAS SIMILAR TO "B" EXCEPT FOR HOLE LOCATIONS IN TUBES. SYSTEM "D" WAS SIMILAR TO "C" EXCEPT THAT A RESTRICTION WAS INSTALLED AT CONNECTION "R".

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Fig. 5 Schematic Diagrams of Fire-Extinguishing Systems Tested

conditions were simulated by operation of the B-36 engine while a blast of air from the wind tunnel passed through and around the nacelle. When engine operation reached a steady state, an emergency situation was assumed and emergency procedure[4] was initiated. This included shutting down the engine, feathering the propeller, and discharging the agent when the propeller stopped turning. The wind tunnel continued to blow air at the nacelle. Bromochloromethane (CB) was the extinguishing agent used in these tests, with 36 pounds per shot (18 pounds in each of two 945-cubic-inch spherical containers pressurized to 400 psi with nitrogen) for the original System A, and 33 pounds in one 945-cubic-inch container pressurized to 400 psi with nitrogen for the proposed System B.

Following the agent-concentration measurements, preliminary fire tests were conducted. The number of tests was limited to seven, with four in Zone 3, one in Zone 2, and two in Zone 1. The procedure adopted was first to ignite gasoline, then add hot oil to the fire at the rate of 3 gallons per minute (gpm) until the fire had burned for approximately 8 seconds. Emergency procedure followed and when the propeller stopped turning in approximately 7 seconds, the agent was discharged.

Unfortunately, the testing program could not be continued at that time because the wind tunnel was undergoing modifications. When the modification work extended far beyond the allotted time for completion, it became necessary to abandon fire testing temporarily. As a result of the preliminary analysis and fire tests, the proposed System B was revised. The changes were incorporated in a production prototype designated System C, and a study of agent concentrations was made with the new System C during actual flight tests. These tests were conducted at Convair, Fort Worth, Texas, in June 1955, using the agent concentration recorder to measure concentrations of CB and dibromodifluoromethane (DB). On the basis of these tests a further modification was proposed and an extinguishing system incorporating the proposed change, System D, was set up at the laboratory where it could be viewed during discharge. The change involved the use of a restrictor, the purpose of which was to divert more agent into Zone 3 at the expense of the other zones. The distribution of agent into each zone with and without the restrictor was determined by discharging water and carbon tetrachloride and catching and weighing the quantities leaving each portion of the system. High-speed moving pictures of the spray action also were taken.

During the period that the wind tunnel was inoperative, the B-36 QEC nacelle was removed from the wing stub to permit the retrofitting of a firewall improvement kit. The kit

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[4] See (1) a, Table III.

was designed to strengthen the fire barrier between Zone 1 and the forward zones by improving the sealing between mating and intersecting surfaces, and by patching all unrequired and unused openings.

Upon completion of the firewall improvements, the wind tunnel still was not available, and it became necessary to resort to a substitute means of providing airflow in order to continue the test program. A blower system which provided ducted air was connected to the air ducts in the leading edge of the B-36 wing. Using this arrangement, the normal airflow that would occur in flight over the outside of the nacelle was not duplicated. However, it was desirable to make additional concentration measurements in order to observe whether the restrictor that had been developed to be used in the extinguishing system was changing the distribution as desired.

The tests were conducted with the agent concentration recorder, the probes of which were installed in the same respective locations they occupied during the flight tests. Emergency shutdown measures were executed prior to discharge of the agent. Tests were made with and without the restrictor in the system, with CB and DB extinguishing agents, and at simulated low and high altitudes. Altitude changes were simulated by changing the ram pressure through adjustment of the blowers.

Following the measurement of agent concentrations, a fire-testing program was conducted to determine the effectiveness of extinguishing System D. To compensate for the lack of airflow over the nacelle when the blowers were in use, the B-36 engine was kept operating during the extinguishment tests to provide at least some semblance of airflow to give direction to external flames. However, extinguishment was difficult to accomplish, particularly in Zone 2. For a time, it even was difficult to determine whether reignition was occurring or whether extinguishment had not been complete. Several courses were pursued in the study of this particular problem. First, the location of possible hot-surface ignition sources in Zone 2 was determined by means of Thermocolor paint. Then the time-temperature relationships of such surfaces during engine shutdown were obtained by the use of thermocouples. Finally, various methods of coping with the hot surfaces were investigated; (1) the surfaces were cooled by air bled off the main duct, (2) the surfaces were covered with asbestos and waterglass to keep fuel and oil away from them, and (3) the surfaces were cooled by water spray. The third method was investigated by using a spherical container partially filled with two gallons of water and pressurized with nitrogen. The water was sprayed on each of the hot surface areas through small-diameter lines for approximately 15 seconds at each discharge. The effect of decreased ventilation also was studied. For this, a special door was fabricated and mounted forward of the louvered door. This door could be closed during emergency procedure to seal off the louvered openings effectively.

Eventually, the wind tunnel was restored to operating condition and used to simulate flight conditions for the remaining fire tests. Hot oil flowing at a rate of 6 gpm was used as fuel for all the fires. After engine temperatures had stabilized for medium cruise conditions, the oil was allowed to flow for 10 seconds to see if hot-surface ignition would occur. In some cases this part of the procedure was repeated. Then after a brief period in which the excess oil was allowed to drain away, the oil flow again was started and the oil ignited by a spark-plug igniter. The fire was allowed to burn for approximately 10 seconds at the end of which time emergency procedure was executed, and as soon as the propeller stopped turning, the extinguishing system was discharged. Three agents were used at different times: CB, DB, and bromotrifluoromethane (BT). When CB was used the container was pressurized to 425 psi at 70° F.; when the other agents were used the containers were pressurized to 600 psi.

RESULTS AND DISCUSSION

Tests on the Original Extinguishing System A.

The original fire-extinguishing system in the B-36 was designed to discharge 24 pounds of methyl bromide in 2 seconds. This quantity was determined from the formulas $0.40\ W_a$ (for zones in which the airflow is large compared to the region volume) and $0.11\ V$ (for zones through which there is little or no airflow). W_a represents the pounds of air per second passing through a zone under cruising conditions and V represents the gross volume of the zone in cubic feet. It was determined further that, in order to provide the discharge of 24 pounds of agent within the prescribed 2-second period, two 945-cubic-inch spheres, each containing 16 pounds of methyl bromide, would need to be discharged simultaneously. Approximately 88 feet of 0.035-inch by 1 1/4-inch o.d. magnesium tubing was used to convey the agent from the spheres to the nacelle most remote from the spheres. When methyl bromide fell into disfavor because of its corrosiveness and toxicity, it was replaced in B-36 aircraft by CB. The system itself was not redesigned. The weight of CB required was determined

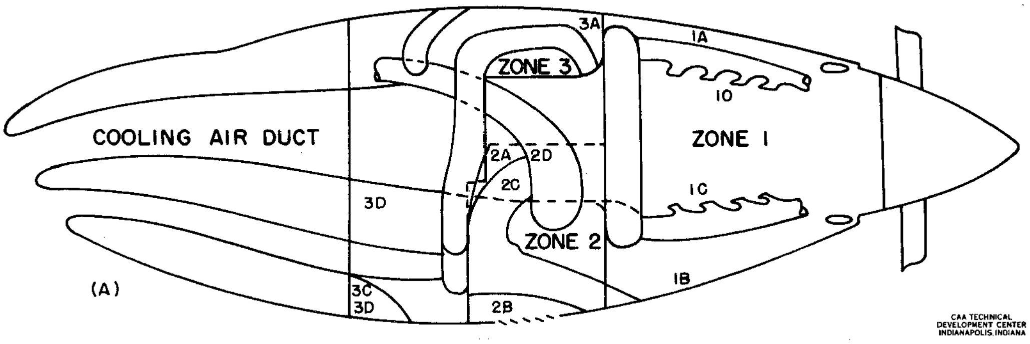

Fig. 6A Probe Locations for Preliminary Sampling of Agent Concentrations Using System A

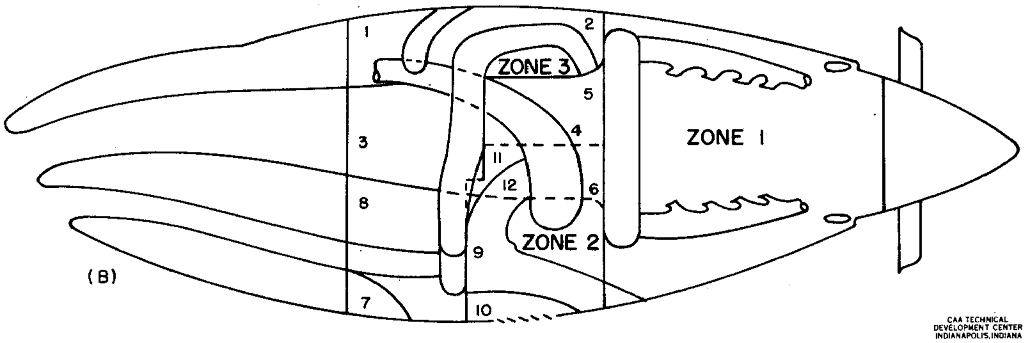

Fig. 6B Probe Locations Used for Flight and Later Laboratory Investigations

simply on the basis of maintaining the same volume of agent. Because of the difference in specific gravity of the two agents, the weight of the CB charge became 36 pounds. In both cases, the agent was pressurized to 400 psi with nitrogen.

Motion pictures of the system during discharge of methyl bromide and CB indicated that the effective discharge time in each case was less than 2 seconds. Immediately after discharge, the quantity of CB remaining in the supply line was found to be 1.12 pounds or 3.1 per cent of the initial 36 pounds.

The relative concentrations of CB extinguishing agent occurring in the nacelle fire zones upon discharge of the original System A were measured at probe locations described in Table I and shown in Figs. 6 and 7. For these tests, 36 pounds of CB agent were discharged under airflow conditions simulating emergency shutdown of the engine from normal cruise operation. The resulting concentration versus time records are shown in Fig. 8.

Use of the agent concentration recorder to evaluate extinguishing systems is not an exact science at this time. However, previous investigations have indicated that approximately 15 per cent relative concentration in all areas of a zone for a period of 1/2-second or more will extinguish short-duration fires. The interpretation of data is predicated on this basis and on the assumption that the readings taken represent the areas of weakest concentrations.

In Zone 1, the concentrations were relatively low at all points and insufficient to produce extinguishment of fire. In Zone 2, concentrations were appreciably higher than in Zone 1 although at probe location 2C insufficient agent vapor was indicated. However, this probe was located inside the shroud on the downstream side of the heat exchanger and the reading did not portray conditions within the zone proper. In Zone 3, some concentration of agent was recorded. This resulted from leakage of agent from Zone 2 as no agent was released directly into Zone 3.

Tests on a Proposed Extinguishing System B.

A conference was held at Fort Worth, Texas, on October 27 and 28, 1953, to consider ways and means of improving B-36 aircraft fire protection. The fire-extinguishing system

TABLE I

LOCATION OF EXTINGUISHING AGENT SAMPLING POINTS IN THE B-36 NACELLE

Probe Designation TDC No. (System A)	Convair No.	Location
	1	Centerline above engine air duct and distribution line pointing aft.
3A	2	Engine bulkhead upper centerline aft of carburetor air scoop.
	3	Right-hand side below turbo oil tank pointing aft.
	4	Between fuel flow transfer valve and heat anti-icing duct pointing horizontally.
	5	At master control fuel injection pump distribution lines, right-hand side pointing down.
	6	Engine oil sump, right-hand side pointing up.
3B	7	Right-hand side of oil cooler exit air duct pointing down.
3D	8	Right-hand side near fire curtain at fuel and oil lines.
	9	Zone 2 centerline, 18 inches above cowl pointing down.
2B	10	Adjacent to lower cowl louver panel, left-hand side pointing forward.
2A	11	Upper Zone 2, left-hand side, approximately 8 o'clock viewing forward.
2C	12	Downstream exhaust primary left-hand heat exchanger (in cooling shroud).
2D		Upper Zone 2, right-hand side, approximately 8 o'clock viewing forward (similar to 2A).
3C		Inside oil cooler duct aft of oil cooler.
1A		Above No. 2 cylinder bank.
1B		Below No. 5 cylinder bank.
1C		Under engine shrouding at No. 4 cylinder bank.
1D		Under engine shrouding at No. 2 cylinder bank.

was a subject for discussion at that time along with the fire-detection system, improved sealing of the firewalls, and the installation of a new fire curtain. The latter improvement, in effect, isolated the nacelle from the wing and created a new zone. It was considered desirable to have the extinguishing system protect this zone as well as the others. Two ways were proposed for doing this: (1) retain the existing system and add a secondary system designed to protect the new zone only, and (2) redesign the existing extinguishing system to protect all three zones. The latter was considered the better choice because it offered increased protection at less cost and weight.

A redesigned system was installed in the test nacelle for preliminary fire test evaluation. The system may be described as follows: two 945-cubic-inch spheres were mounted in each wing. The two in the left wing were manifolded to engines 1, 2, and 3 and connected to the existing nacelle fire-extinguisher distribution tubing, with additional nacelle tubing for Zone 3 fire protection. Check valves and electrically operated directional valves directed the agent flow through the manifold tubing to the engine selected at the engineer's panel. This arrangement provided two shots for any one of the three left wing reciprocating engines, or one shot each for any two of the three engines. The arrangement was duplicated in the right wing but there was no crossover between the left and right wing installation. Only a portion of this system, consisting of one 945-cubic-inch sphere with 30 feet of 0.035-inch

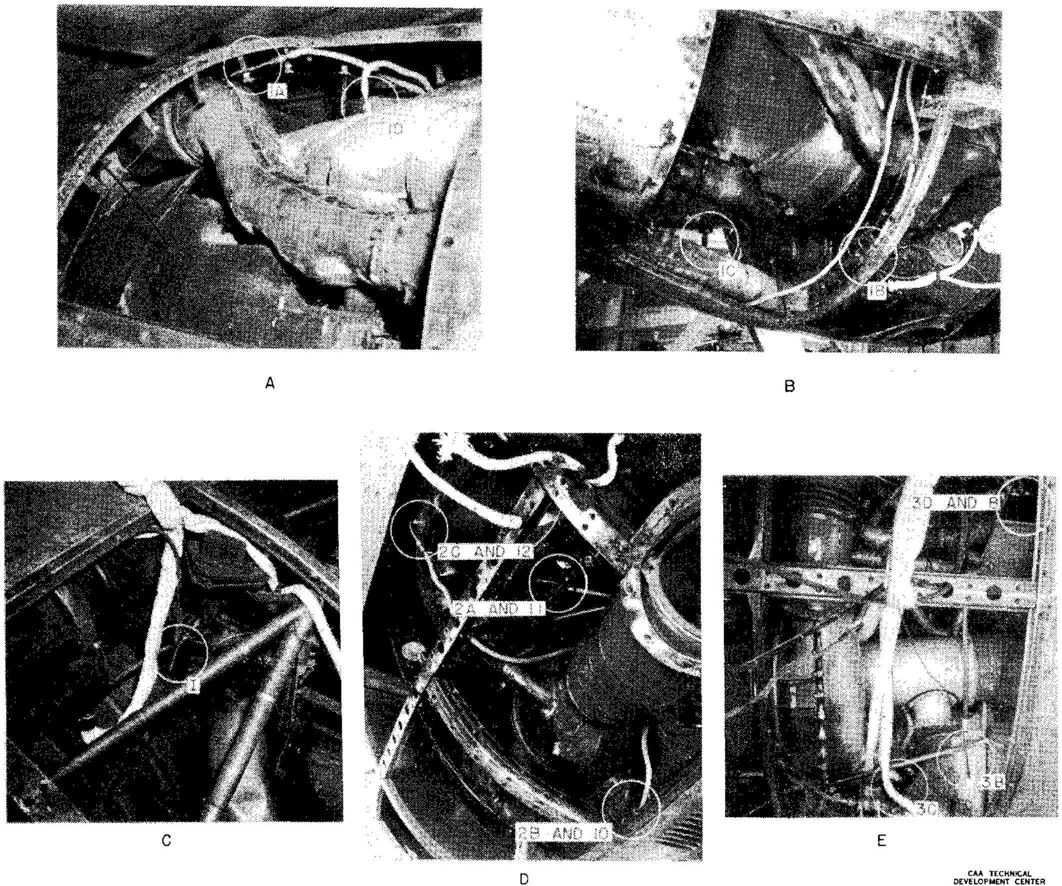

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Fig. 7 Probes in B-36 Test Nacelle - A and B, Zone 1, D, Zone 2, and C and E, Zone 3

by 1 1/4-inch o.d. tubing and the revised distribution system inside the nacelle, was used for testing purposes. This was equivalent to the testing of the system as applied to a nacelle most remotely located from the supply container.

Agent concentration measurements were made in the nacelle zones during discharge of 33 pounds of CB through the proposed new extinguishing System B. For these tests the system was fired after emergency shutdown of the engine from normal cruise power. The CB agent container was pressurized to 400 psi with nitrogen. The probe locations at which agent concentrations were measured were the same as for previous tests on the original B-36 airplane extinguishing system. These are described in Table I and shown in Figs. 6 and 7. Results of the tests are shown graphically in Fig. 8.

The single measurement made in Zone 1 indicated that concentrations produced in this zone were approximately the same as those produced by the original system and were not sufficient to extinguish fires. The single measurement made in Zone 2 at probe location 2D indicated that concentration of agent in Zone 2 provided by System B was sufficient to extinguish fires in this zone. The agent provided inside the shroud downstream of the heat exchanger, as indicated by probe 2C, was ample for extinguishment and considerably higher than was produced by the original System A. Measurements made in Zone 3 indicated that System B provided concentrations at locations 3A and 3D sufficient to extinguish fires. However, the concentration at location 3B was inadequate. No agent was provided in the oil cooler by System B and therefore, no concentration was recorded by probe 3C. In summation, the results of the concentration measurements indicated that System B provided inadequate protection.

A fire-test evaluation of System B using 3-gpm oil fires produced the results given in Table II. The selection of test fire locations was guided somewhat by the results of the concentration measurements and by a knowledge of what the system was intended to accomplish.

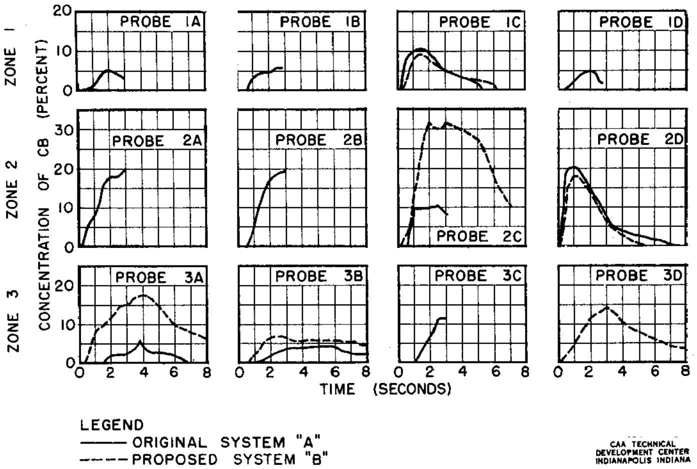

Fig. 8 CB Concentrations Produced by the Original System A and by the Proposed Fire-Extinguishing System B

Zones 2 and 3 were to be fully protected. Zone 1 was not to be protected except in areas near the engine accessories. Therefore, the fact that the fires in Zone 1 were not extinguished was not unexpected. As noted in Table II, the protection in Zone 3 appeared to be marginal, with fires at 3 of 4 locations being extinguished. The single fire ignited in Zone 2 was extinguished.

TABLE II

PRELIMINARY FIRE TESTS OF REDESIGNED EXTINGUISHING SYSTEM

Test No.	Operating Condition	Fire Nozzle Location	Fire Extinguished
1	Cruise	Center Zone 3 pointing down and aft.	Yes
2	Cruise	Center Zone 3 pointing down and aft.	Yes
3	Cruise	Inboard-side Zone 3 pointing forward.	No
4	Cruise	Inboard-side Zone 3 pointing forward.	Yes
5	Cruise	Outboard-side Zone 2 pointing aft under turbo.	Yes
6	Cruise	Zone 1 pointing aft on crankcase between banks 1 and 2.	No
7	Ground	Zone 1 pointing aft on crankcase between banks 1 and 2.	No

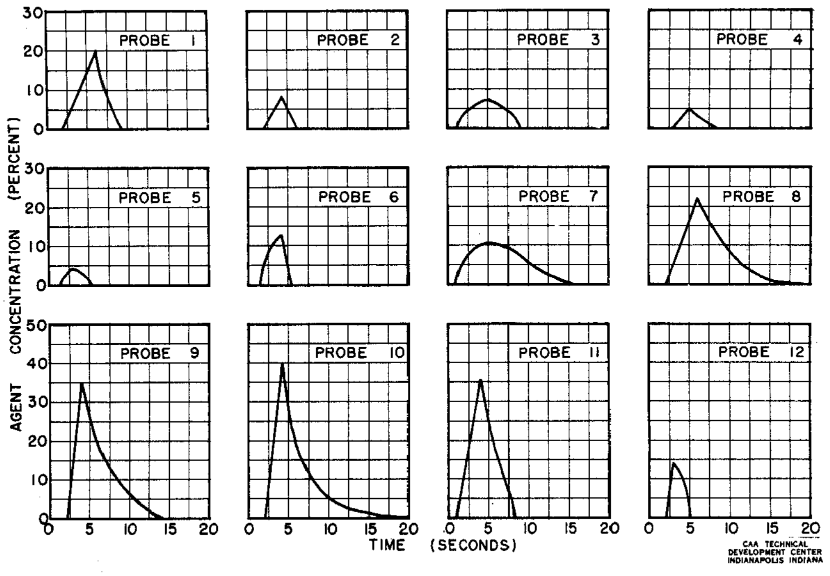

Fig. 9 CB Concentrations at 2,000 Feet Altitude Produced by System C and Using 33 Pounds of Agent, 425 PSI Container Pressure

Tests on a Proposed Extinguishing System C.

As a result of the evaluation of the proposed System B, certain hole revisions were made and a new system, designated as System C, was installed in a B-36 airplane for flight tests. These were conducted at Convair, Fort Worth, Texas, and consisted of recording the concentration of agent produced at 12 nacelle locations. Ten tests were made at various flight altitudes, using CB and DB agents. Other variables included agent quantity, agent container pressure, and position of the engine air plug which affected Zone 1 airflow and static pressure. The specific conditions under which each test was made are shown in Table III. The location of probes used in obtaining agent concentrations are described in Table I. Results of each test are shown by graphs in Figs. 9 through 18. Graphs for probes 1, 2, 3, 4, 7, and 8 in each of these

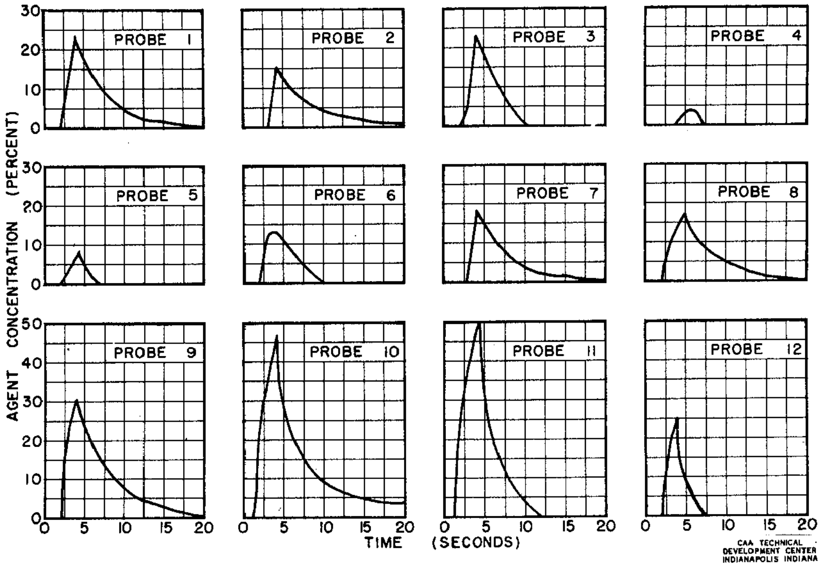

Fig. 10 CB Concentrations at 5,000 Feet Altitude Produced by System C and Using 33 Pounds of Agent, 425 PSI Container Pressure

TABLE III

FLIGHT TEST CONDITIONS(1) RESULTING IN AGENT CONCENTRATIONS AS SHOWN IN FIGURES 9 THROUGH 18

Fig. No.	Altitude (ft.)	Extinguishing Agent(2)	Quantity of Agent (lb.)	Container Pressure (psi)	Indicated Airspeed (mph)	Position of Air Plug	Free Air Temperature (°C.)
8	2,000	CB	33	425	140	Open	16
9	5,000	CB	33	425	170	Open	24
10	20,000	CB	33	425	170	Open	-4
11	20,000	CB	33	425	170	Closed	-5
12	20,000	CB	25	425	170	Open	-8
13	2,000	DB	39	425	140	Open	16
14	5,000	DB	39	425	170	Open	16
15	20,000	DB	39	425	170	Open	-9
16	20,000	DB	39	600	170	Open	-9
17	20,000	DB	18.8	600	170	Open	-9

(1) Conditions common to all tests conducted were as follows:

a. Tests were conducted on the No. 1 powerplant. Agent was discharged as part of the in-flight fire emergency procedure consisting of: (1) feathering the propeller; (2) moving mixture control to idle cutoff; (3) shutting off the engine fuel and oil valves; (4) releasing the agent immediately after engine rotation ceases; and (5) turning off ignition. Power settings on all other engines were set for medium cruise.

b. A single 945-cubic-inch spherical agent container was used.

c. Extinguishing System C was used.

(2) CB - Bromochloromethane

DB - Dibromodifluoromethane

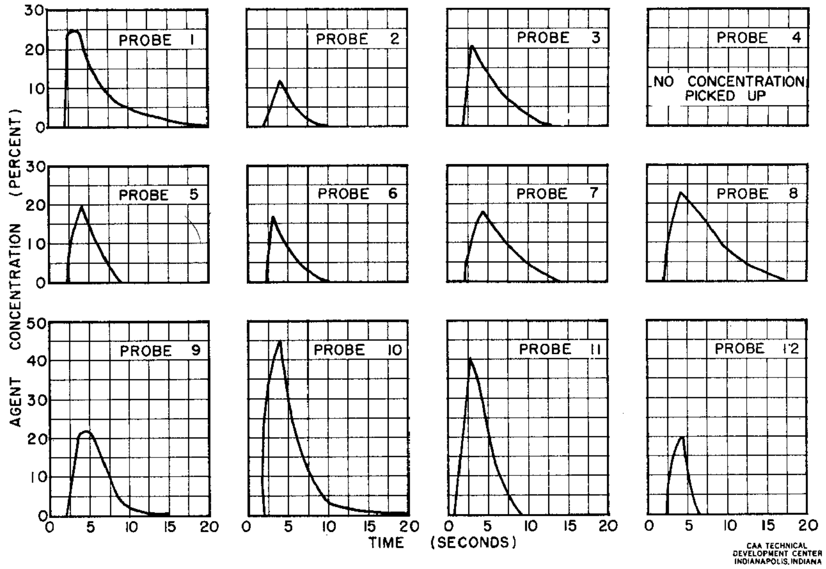

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Fig. 11 CB Concentrations at 20,000 Feet Altitude Produced by System C and Using 33 Pounds of Agent, 425 PSI Container Pressure

figures indicate conditions in Zone 3; those for probes 5 and 6 indicate conditions near the engine accessories inside the main air duct; and those for probes 9, 10, 11, and 12 indicate conditions in Zone 2.

In general, the CB concentrations resulting from the discharge of 33 pounds of agent appeared to be adequate in Zone 2 but low to marginal in the other zones. A slight improvement was evident when the discharge was measured at higher altitudes although the average condition still would be considered marginal. There appeared to be no advantage in closing the air plug prior to discharge, nor was there any advantage in increasing the volume of propellant gas in the container and reducing the agent to 25 pounds.

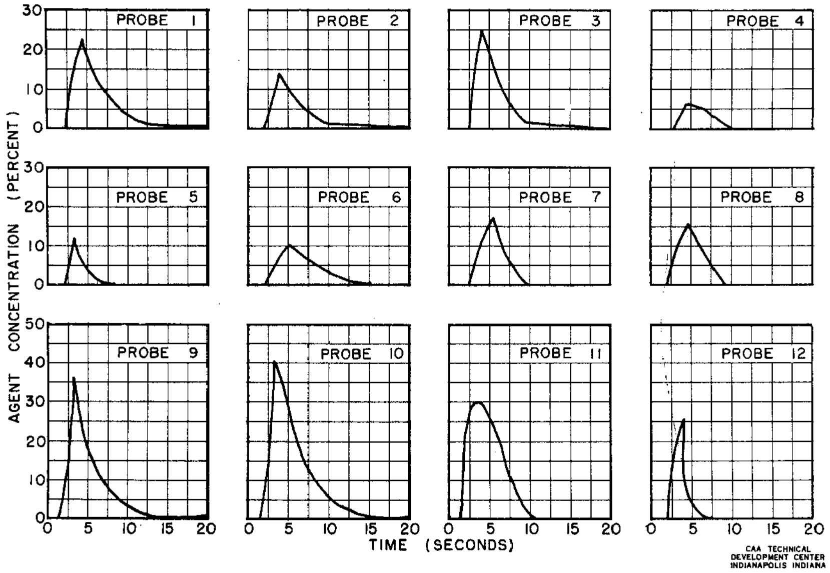

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Fig. 12 CB Concentrations at 20,000 Feet Altitude Produced by System C and Using 33 Pounds of Agent, 425 PSI Container Pressure, and with Air Plug Closed

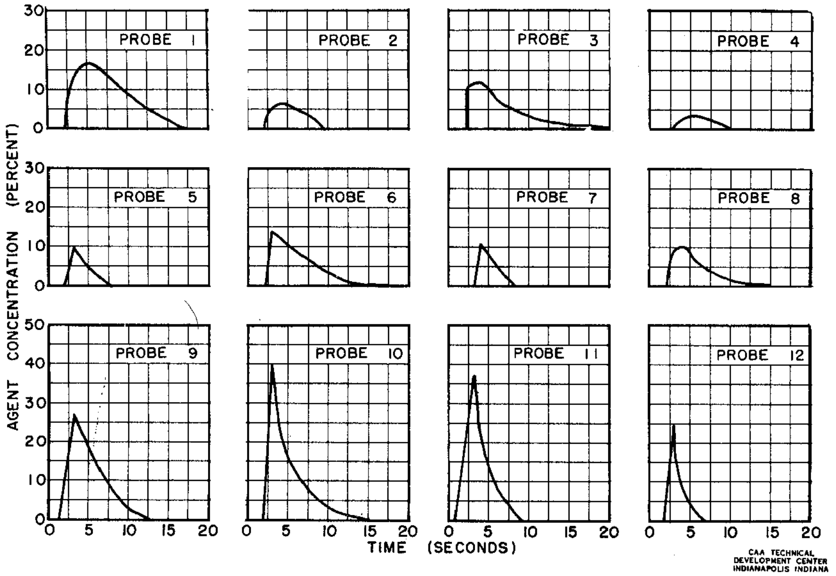

Fig. 13 CB Concentrations at 20,000 Feet Altitude Produced by System C and Using 25 Pounds of Agent, 425 PSI Container Pressure

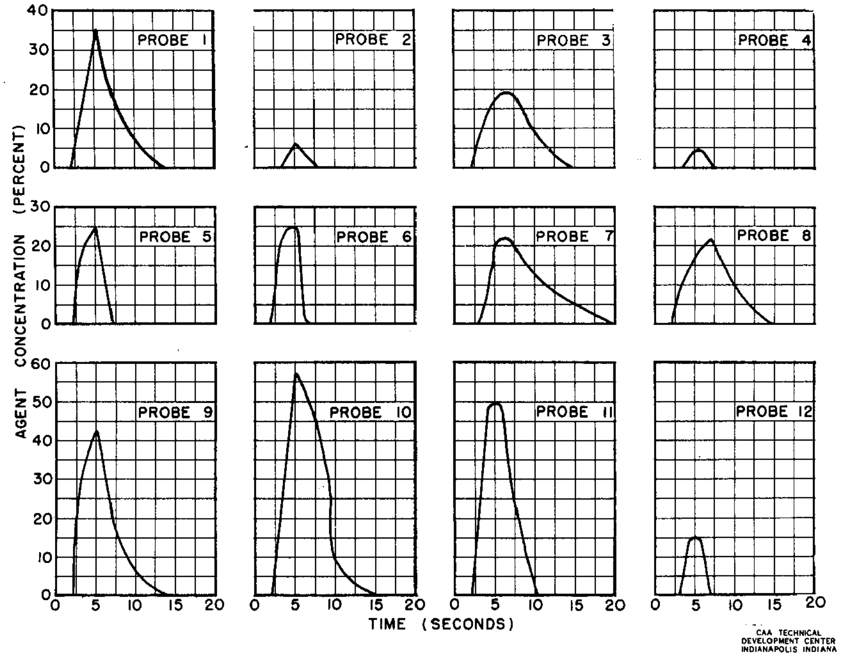

Fig. 14 DB Concentrations at 2,000 Feet Altitude Produced by System C and Using 39 Pounds of Agent, 425 PSI Container Pressure

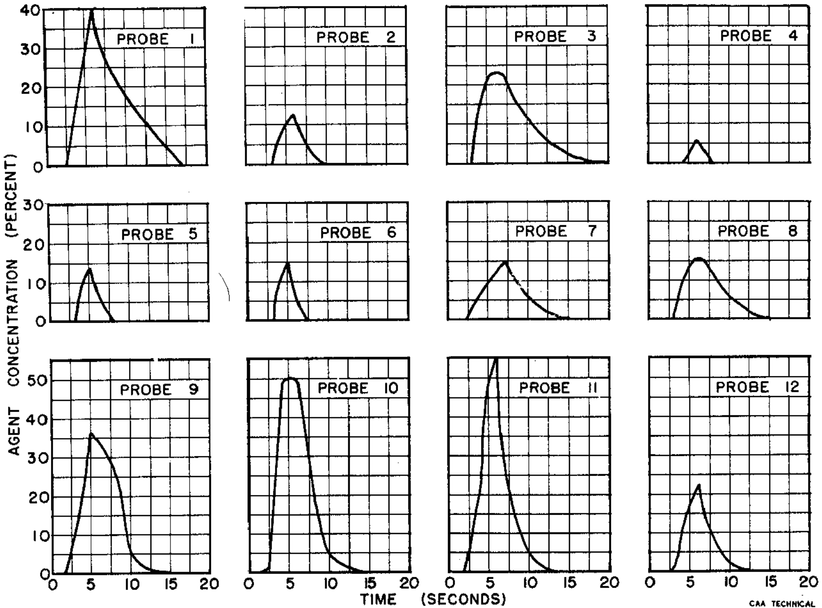

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Fig. 15 DB Concentrations at 5,000 Feet Altitude Produced by System C and Using 39 Pounds of Agent, 425 PSI Container Pressure

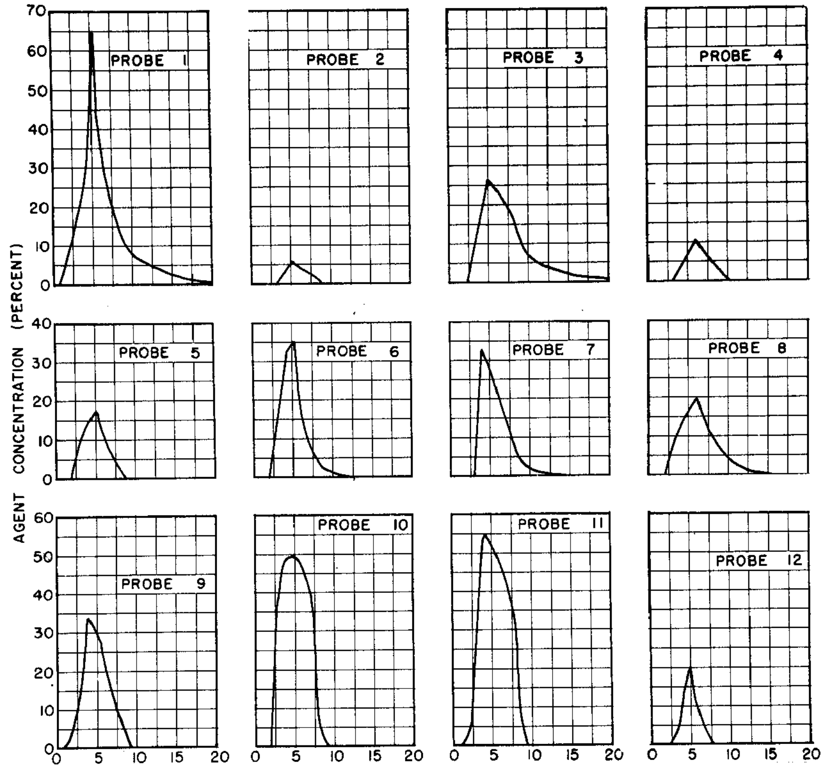

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Fig. 16 DB Concentrations at 20,000 Feet Altitude Produced by 39 Pounds of Agent, 425 PSI Container Pressure

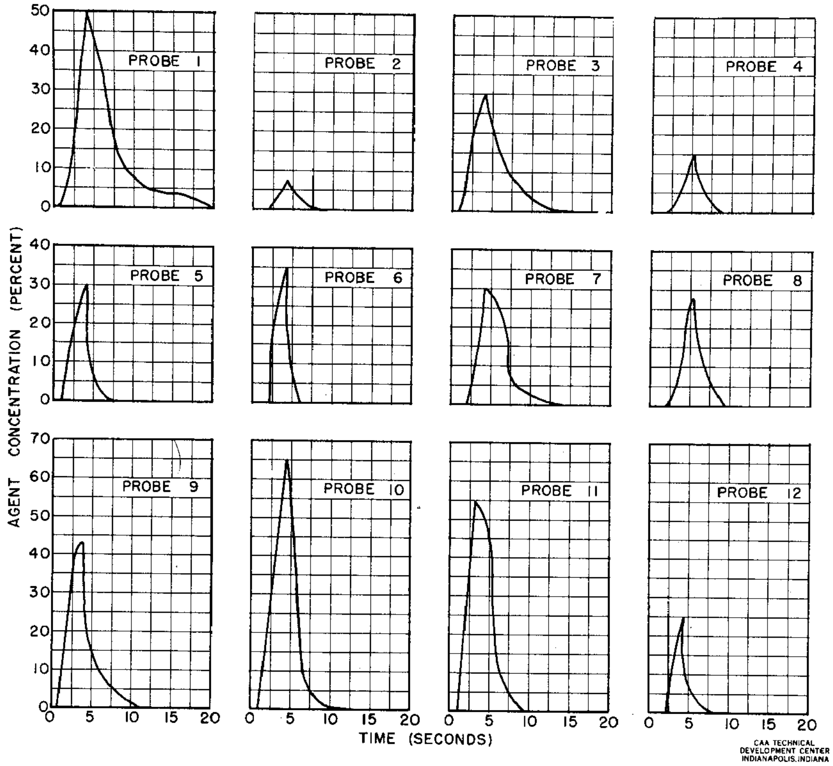

Fig. 17 DB Concentrations at 20,000 Feet Altitude Produced by System C and Using 39 Pounds of Agent, 600 PSI Container Pressure

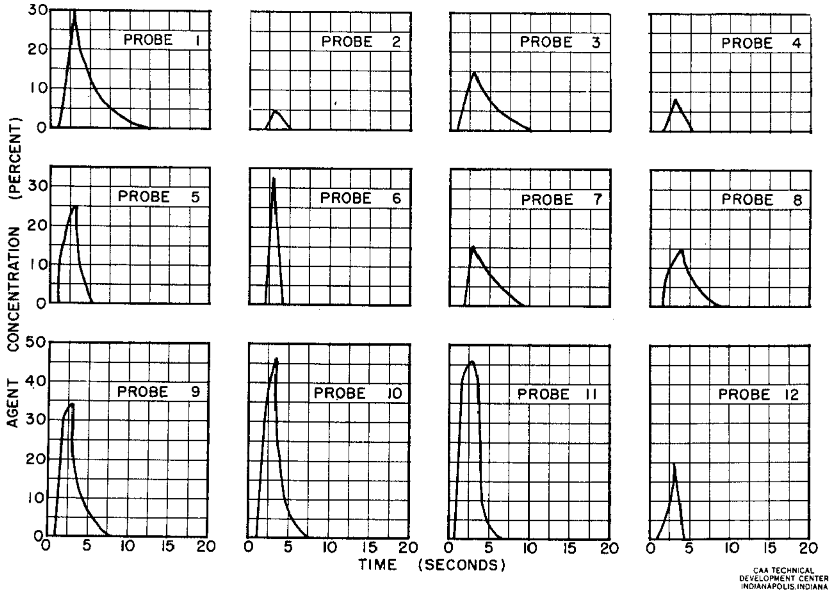

Fig. 18 Concentrations at 20,000 Feet Altitude Produced by System C and Using 18.8 Pounds of Agent, 600 PSI Container Pressure

Using DB instead of CB, the concentrations produced by discharging 39 pounds of agent again were apparently adequate in Zone 2. In Zone 3, concentrations were not uniform, and since some were rather low, the protection for the zone appeared inadequate. At the low altitude of 2,000 feet, the concentration appeared to be adequate near the engine accessories but at higher altitudes protection also was considered marginal. The use of a higher propellant gas pressure of 600 psi instead of 425 psi raised the peak concentrations in most cases, but a reduction in the quantity of agent to 18.8 pounds was not compensated for by the increased pressure.

The highest concentration measured in most cases in Zone 3 was at the upper forward part of the zone. Values decreased in a downward or rearward direction from that point as shown by the comparative magnitude of concentrations shown at probe locations 1, 3, 8, and 7 in that order, and probes 2 and 4 in that order. The location of these points may be noted in Fig. 6b. There was little difference in the concentration in the forward part of Zone 2, bottom or top as shown by probes 10 and 11, but near the center the concentration generally was less, as indicated by probe 9. Probe 12, located in the space under the shroud, was omitted from consideration. Inside the main air duct, Zone 1, higher agent concentrations in the area of the lower engine accessories occurred (probe 6) than in the area of the upper accessories (probe 5) although the difference was minor.

Distribution Measurements on Modified Versions of System C.

After studying the results of the flight tests on extinguishing System C, it was concluded that the concentrations of agent in Zone 3 should be increased. However, since the system tubing already was in production, there was a natural reluctance to make any major revisions. If the improvement was to be effected, it would have to be done by some means that would not necessitate stopping production. From the design of the system, it was conjectured that the agent could be diverted from the main supply line into Zone 3 by inserting a restrictor in the line downstream of the point where the Zone 3 distribution lines branched off. The intended function of the restrictor simply was to restrain the flow of agent so that the paths into Zone 3 would have less resistance. A series of 19 tests was completed to study the effect of the use of the restrictor. Water and carbon tetrachloride were discharged through the system and caught in plastic bags to determine the proportion of agent discharged into each zone. There was a certain amount of variation in results. Also, some tests were eliminated from consideration altogether because an undetermined amount of agent loss occurred when plastic bags tore open from over-inflation by the propellant gas. However, of the 19 tests, several were selected as representative. The data for these are presented in Table IV. Test 1 of this table was conducted with a system equivalent to that used during the previous flight tests but with slight hole modifications. Another test (Test 2) of the same configuration was made with the agent pressurized to 600 psi instead of 400 psi. The agent discharged into Zone 3 increased slightly. In further attempts to redistribute the agent, several plugs having various size orifices were inserted in the feed line and several tests were made with each size. A plug with a 3/4-inch-diameter orifice appeared to effect the desired redistribution of agent. The results of a typical test with this size plug are shown in Test 3. A simplified restrictor shown in Fig. 19 then was designed to duplicate the performance of the 3/4-inch plug. Test results using this restrictor are shown as Test 4, Table IV. The results for the last two tests in the table were obtained with the same 3/4-inch restrictor installed in a newly fabricated extinguishing system intended for installation in all flying B-36 aircraft.

Tests on a Proposed Extinguishing System D.

Upon concluding the distribution measurements, the new system, designated System D, was installed in the test nacelle and preparations were made to take agent concentration measurements and conduct actual fire tests under simulated flight conditions. At the time the concentration tests were made, the wind tunnel was not available and the blower system was used. This provided airflow inside the nacelle only, and entrance pressures at the intake duct on the wing leading edge were equivalent to those for the flight conditions simulated. The subsequent fire-extinguishing tests were conducted using the wind tunnel which produced an airflow of 150 mph over the test nacelle.

1. Agent Concentration Measurements.

The measurement of agent concentrations produced within the nacelle fire zones were conducted primarily to determine the improvement effected in agent concentrations in Zone 3 by the extinguishing system restrictor. In addition, the tests provided information on the effect of the engine air-plug position, flight altitude, agent used, and agent container pressure.

TABLE IV

TYPICAL TEST RESULTS OBTAINED WITH SELECTED MODIFICATIONS TO THE AIRCRAFT EXTINGUISHING SYSTEM C

Test No.	Weight of Agent Caught Zone 1	Zone 2	Zone 3	Pounds Total	Remarks
1	9.3	9.5	6.5	25.3	Modified flight test System C, 400 psi container pressure.
2	9.3	9.1	7.0	25.4	Modified flight test System C, 600 psi container pressure.
3	8.6	9.1	7.5	25.2	Modified flight test System C, 3/4-inch plug.
4	8.7	8.8	7.8	25.3	Modified flight test System C, 3/4-inch restrictor.
5	8.6	9.3	7.9	25.8	Production system, 3/4-inch restrictor.
6	9.0	9.1	7.5	25.6	Production system, 3/4-inch restrictor.

Specific conditions for each test are shown in Table V. Agent sampling probes were located in the same respective positions as for the previous flight tests and numbered in accordance with the Convair order shown in Table I. Agent concentration measurements are shown graphically in Figs. 20 through 24. Graphs numbered 1, 2, 3, 4, 7, and 8 in each figure indicate conditions in Zone 3; those numbered 5 and 6 indicate conditions near the engine accessories inside the main air duct; and those numbered 9, 10, 11, and 12 indicate conditions in Zone 2.

When 33 pounds of CB were discharged, the concentrations produced with and without the restrictor were shown in Fig. 20 for simulated low-altitude, and in Fig. 21 for simulated high-altitude operation. The effect of the restrictor under low-altitude conditions was negligible in all zones. Under simulated high-altitude conditions, it appeared to increase the concentrations by a moderate amount in Zone 3 and had little effect on Zones 1 and 2. When 39 pounds of DB were discharged at simulated high-altitude conditions, using 425 and 600 psi agent container pressure, use of the restrictor increased concentrations in Zone 3 in both

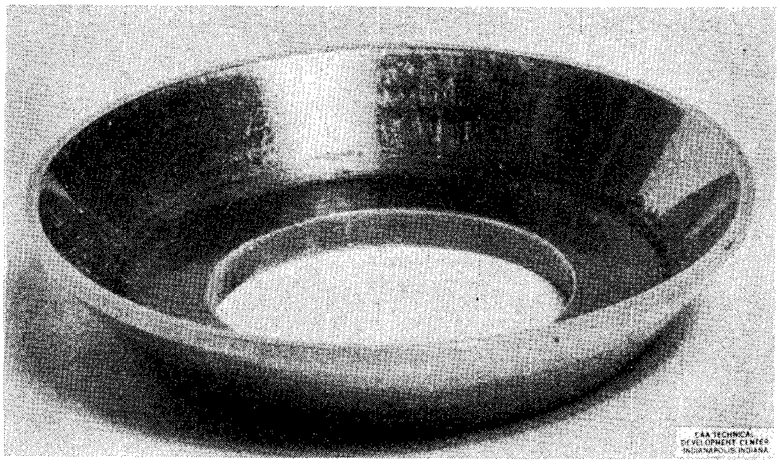

Fig. 19 Restrictor Used in Final Production System Mockup

TABLE V

TEST CONDITIONS(1) RESULTING IN AGENT CONCENTRATIONS AS SHOWN IN FIGURES 20 THROUGH 23

EXTINGUISHING SYSTEM D

Fig. No.	Simulated Altitude (ft.)	Extinguishing Agent and Quantity(2) (agent)	(lb.)	Agent Container Pressure (psi)	Position of Air Plug	Restrictor Used in Extinguishing System
19	Low	CB	33	425	Open	No
19	Low	CB	33	425	Open	Yes
20	High	CB	33	425	Open	No
20	High	CB	33	425	Open	Yes
21	High	CB	33	425	Closed	No
22	High	DB	39	425	Open	No
22	High	DB	39	425	Open	Yes
23	High	DB	39	600	Open	No
23	High	DB	39	600	Open	Yes

(1) Engine stopped and propeller feathered prior to discharge of extinguishing system in all tests.

(2) CB - Bromochloromethane
DB - Dibromodifluoromethane

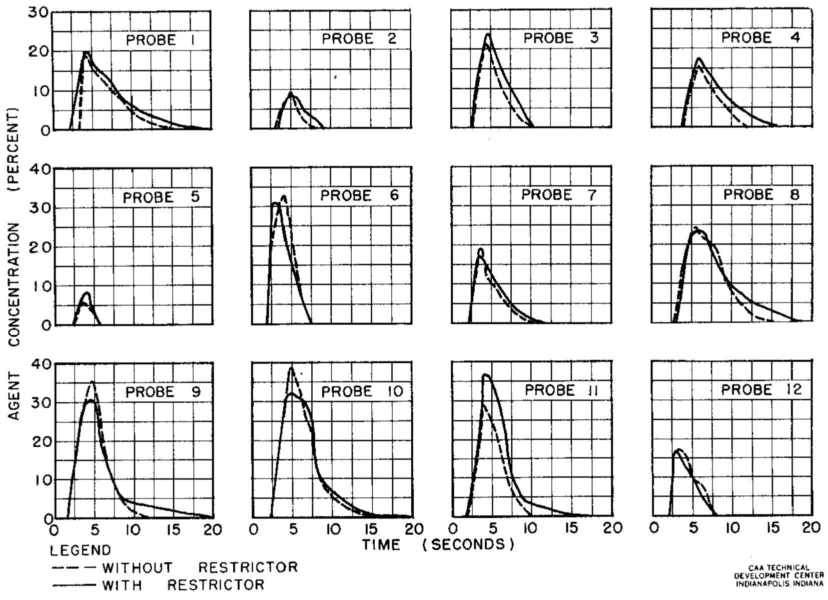

Fig. 20 CB Concentrations at Simulated Low Altitude Produced by System D

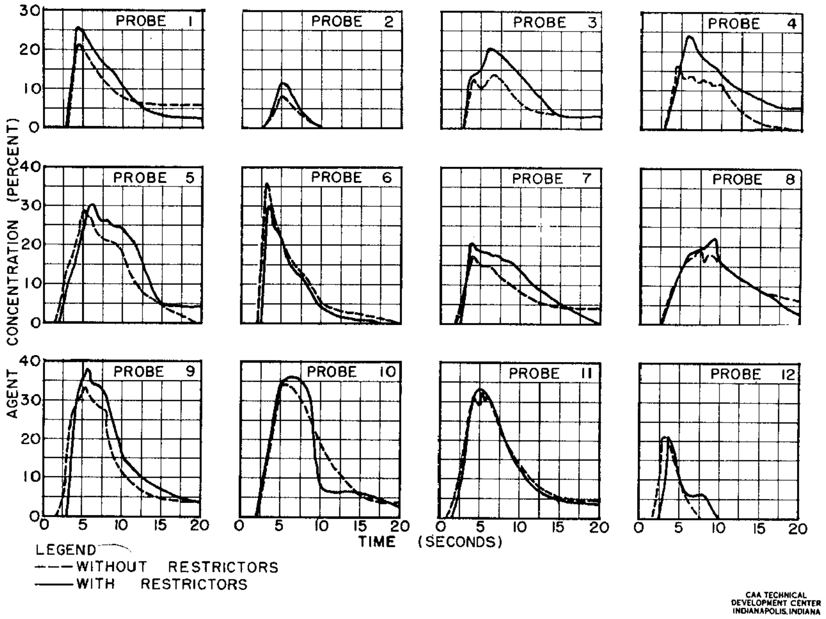

Fig. 21 CB Concentration at Simulated High Altitude Produced by System D

instances and caused slight reductions in concentration of agent in Zones 1 and 2. These results are shown in Figs. 23 and 24. In summation, the restrictor provided a slight improvement in Zone 3 and a slight decrease in concentrations in Zones 1 and 2.

Results of the test conducted with the air plug closed are shown in Fig. 22. A comparison of these with the results in Fig. 21 (without restrictor) indicates that closing the air plug increased concentrations in all zones to some extent.

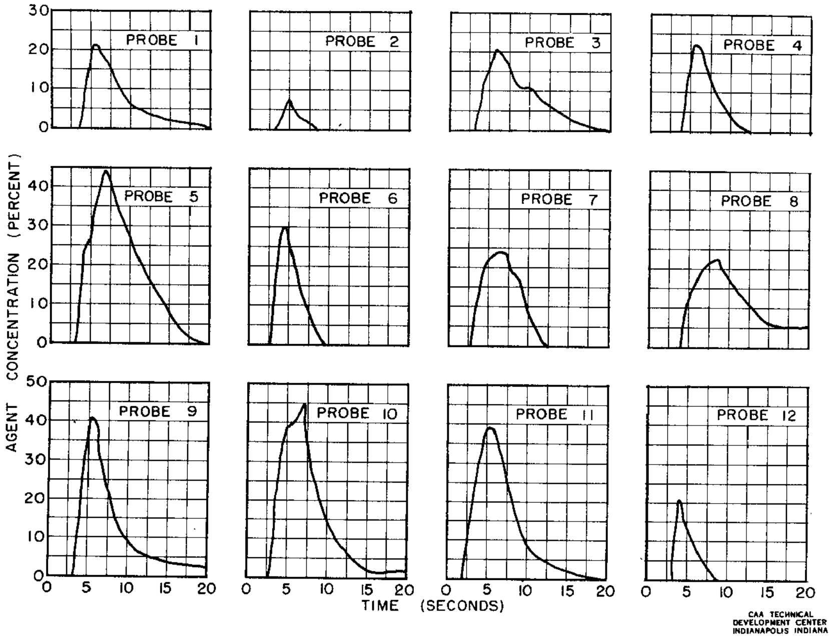

Fig. 22 CB Concentrations Without Restrictor and with Air Plug Closed Using Extinguishing System D

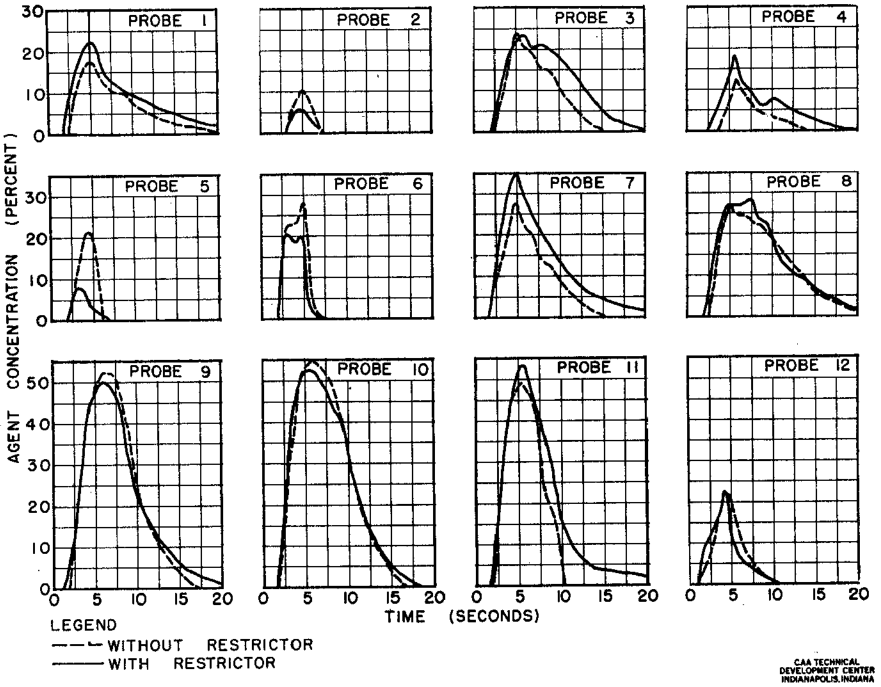

Fig. 23 DB Concentration at Simulated High Altitude (425 PSI) Using Extinguishing System D

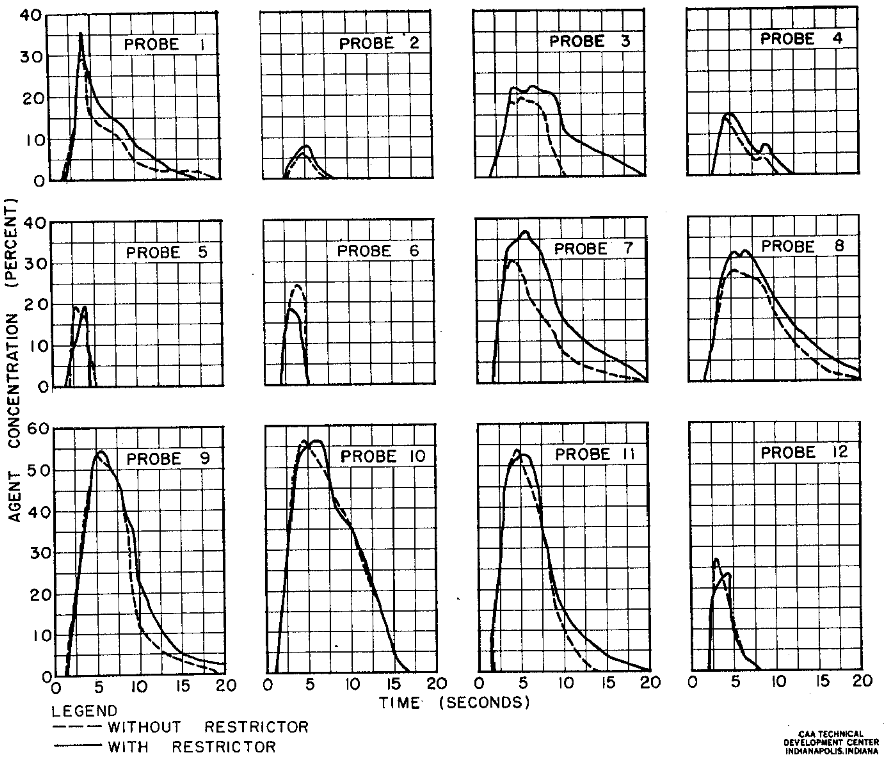

Fig. 24 DB Concentrations at Simulated High Altitude (600 PSI) Extinguishing System D

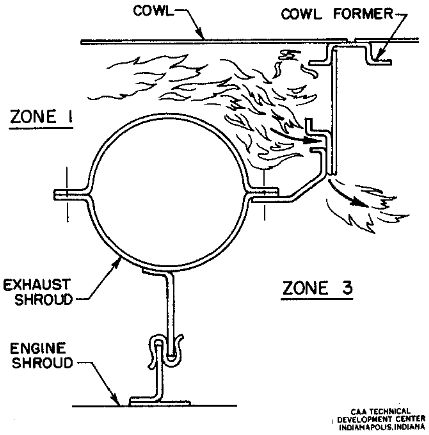

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Fig. 25 Cross Section Taken at the Firewall to Show Where Zone 1 Fires Penetrate into Zone 3

A comparison of the results shown in Figs. 20 and 21 show that agent concentrations in Zone 1 were considerably higher under simulated high-altitude conditions than under simulated low-altitude conditions. Concentrations in Zones 2 and 3 essentially were the same under the two conditions.

Figures 21 and 23 provide a comparison of results obtained with 33 pounds of CB and 39 pounds of DB. Without the restrictor installed, the CB charge produced somewhat higher agent concentrations in Zone 1 and much lower concentrations in Zones 2 and 3 than the DB charge. With the restrictor installed, the CB charge produced much higher concentrations in Zone 1 and much lower concentrations in Zones 2 and 3 than the DB charge. These results indicate differences in distribution, due possibly to the differences in specific gravity and volatility of the two agents.

The graphs in Figs. 23 and 24 provide a comparison of concentrations produced by DB agent container pressures of 425 psi and 600 psi. These results show that the higher pressure produced a negligible increase in concentrations.

2. Fire-Extinguishing Tests.

Following completion of the agent concentration measurements using extinguishing System D, the wind tunnel became available and a number of fire-extinguishing tests were conducted at a tunnel airspeed of 150 mph. These tests were made as a final check on extinguishing effectiveness and to provide a check on the interpretation of agent concentration measurements.

According to a study made in 1949, a large percentage of fire incidents occurring in operating B-36 aircraft was the result of exhaust-system failures in Zone 1. The extinguishing system was not designed to combat such fires. In lieu of this type of protection, the firewall between Zone 1 and the adjoining zones was improved and strengthened. During the fire-testing program, the effect of the revamping was observed. For the most part, the improved firewall was an effective barrier. However, one area was discovered where unburned fuel and flame could penetrate the lap joint between Zone 1 and Zone 3. This occurred in the manner illustrated in Fig. 25. The joint was fairly tight and normally would not permit the passage of flames. During a fire, however, sufficient warpage occurred to permit appreciable leakage. Fire did not enter Zone 2 in a similar manner through the fire seal in the lower portion of Zone 1. The quantity of agent discharged inside the main duct for use against Zone 1 fires was equal approximately to that discharged into Zone 2 but the concentrations measured in Zone 1 were comparatively low because of the high airflow through the main duct. Fires were more difficult to ignite in this airstream but they could be ignited, as was demonstrated by two tests using a 2-gpm flow of gasoline. These fires were extinguished by the system using CB as the agent. Oil fires originating at the engine might be more difficult to extinguish because oil clings to the engine surfaces; and oil fires outside the confines of the engine in Zone 1 probably would escape extinguishment because of the low agent concentration in the space surrounding the engine. Protection for the airplane then would depend on the integrity of the firewalls and fire curtains, plus curtailment of flammable fluid flow and elimination of the ignition sources by engine shutdown.

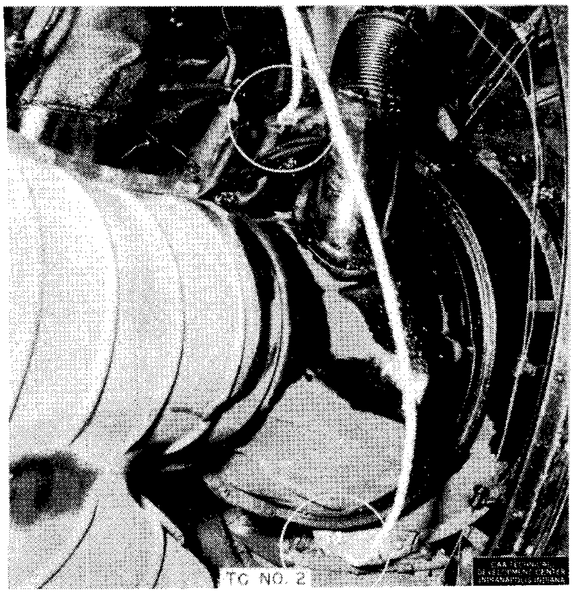

Fig. 26 Unshrouded Portions of the Exhaust Stacks

Fire-test results in Zone 2 were not consistent. Extinguishment was successful in only 15 of the 30 tests conducted. Gasoline was the fuel used in five fire tests and oil preheated to 160° F. was used in the rest. Rates of 2-, 3-, and 6-gpm were used at various times, but this fact appeared to have little bearing on results. Stopping the flow of fuel to the fire immediately prior to attempted extinguishment had negligible effect. The reason failure occurred in so many instances was not readily apparent as the concentration of agent was considered sufficient to extinguish fires. Two explanations were possible; either the fire was reignited by some hot surface inside the zone or fire persisted in some protected area until the agent had dissipated. An attempt was made to locate the suspected hot spots and having located them, to determine whether something could be done to make them ineffectual.

Four unshrouded areas on the exhaust stacks near the turbosuperchargers were found to be at temperatures in excess of 800° F. during normal operation. Two of these spots near the right-hand turbosupercharger are circled in Fig. 26; the others were in comparable positions near the left-hand turbosupercharger. The lower circled area was the hottest of the four, and was given further study. A thermocouple was placed on the forward side of this stack and designated as thermocouple No. 1. The thermocouple shown in the lower circled area was designated thermocouple No. 2. Time-temperature relationships following engine shutdown for two operating conditions were determined by use of the two thermocouples and a Brown temperature recorder. The records are plotted in Fig. 27 for normal cooling and forced air cooling with air from the main air duct. The air was directed on the side where the No. 2 thermocouple was attached. With normal cooling, approximately 50 seconds were required for at least one part of the stack to cool from 1,000° F. to 800° F. With forced air cooling, the maximum temperature recorded was only 880° F., and 12 seconds were required to cool to 800° F.

A stream of oil preheated to 160° F. was sprayed on the exposed surfaces. When the surfaces were cooled with the cooling air, the oil failed to ignite but when the oil was sprayed on the surfaces without benefit of the cooling air, ignition took place within approximately 5 seconds. Although the cooling air appeared to be instrumental in preventing ignition, it was not considered advisable to introduce free air into the zone because once a fire started, the free air would assist combustion. As an alternative means of preventing ignition, the exposed surfaces were covered with asbestos and waterglass. Following this, fires continued to ignite. Still another attempt to cool the hot surfaces by spraying a limited amount of water on them over a period of several seconds met with little success.

During the tests to study prevention of ignition by cooling and by covering, fires were started ultimately and intentionally by the spark-plug igniter. When extinguishment was attempted such fires frequently reignited. This led to the conclusion that other factors were involved. Observers noted that, during extinguishment tests, fires tended to persist near the

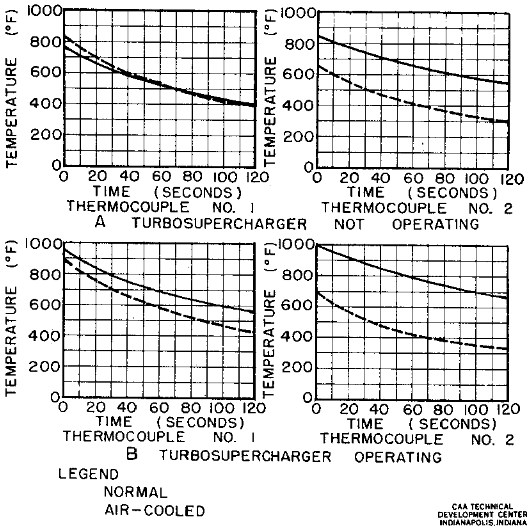

Fig. 27 Curves Showing Decline of Exhaust Stack Temperature Following Engine Shutdown

exhausts and particularly in the spaces between the stacks and the shrouds. Apparently, it was possible for oil to leak into these spaces and ignite. The agent, however, did not enter these spaces in sufficient concentrations to extinguish these isolated fires simultaneously with the main body of fire.

The possibility of fires persisting for this reason was confirmed further by additional tests in which the louvers in the bottom of the zone were covered by means of an auxiliary door. This door, when closed as part of the emergency procedure, was intended to assist extinguishment by preventing the escape of agent through the louvered openings, thereby maintaining the high agent concentration for a longer duration. However, fires usually continued to remain in and around the shroud spaces during the whole period that extinguishment was taking place, although they were extinguished inside the zone.

The wind tunnel furnished cooling air for the concluding series of tests; therefore, the results can be assumed to be more indicative of what might occur during a fire in actual flight. Simulated cruise conditions were established for each test. Then oil was sprayed from a nozzle inside Zone 2 for periods of 30 seconds to see whether it would ignite on hot surfaces. It did not ignite. In every case, in order to conduct a fire test, the oil had to be ignited intentionally by a spark-plug igniter. However, once ignited, the fires could not be extinguished with 33 pounds of CB. In a single test with 27 pounds of BT agent, the fire was not extinguished. No tests were conducted using DB. Again the fires were observed in the shroud spaces around the stack outlet even though the fires in the zone proper were extinguished.

To combat flames lingering in the shroud spaces, it would seem expedient to increase the amount of agent being admitted to them. Accordingly, four of the nozzles delivering agent to these regions were drilled out so that the orifice of each was approximately four times its original size. This modification appeared to effect some improvement but fires continued to escape extinguishment. Two other nozzles which delivered agent to these spaces were left unmodified. It is doubtful that the enlargement of these orifices would have provided sufficient additional agent. In all probability, larger diameter lines leading up to the orifices would be needed.

CONCLUSIONS

The following conclusions are based on the tests conducted:

1. The final version of the B-36 fire-extinguishing system (System D), using a 33-pound charge of CB or a 39-pound charge of DB, provides concentrations of agent in Zone 2 sufficient to extinguish fires. However, it does not produce concentrations in certain areas of Zones 1 and 3 sufficient to assure extinguishment in these zones.
2. The provisions for extinguishing fires are inadequate in all zones. Although Zone 2 receives adequate concentration and distribution of agent in the zone proper, insufficient agent is provided the shrouded spaces, and inadequate shrouding of hot exhaust surfaces permits fuel or oil to enter shrouded areas. This results in fires occurring within shrouded areas which cannot be extinguished by System D and which cause reignition of fuel or oil in Zone 2.
3. In evaluating the provisions for in-flight fire control on aircraft powerplants, the measurement of agent concentrations must be supplemented by assurance that the zone is isolated from sources of reignition or that such sources are eliminated by the control procedure.
4. The fire-seal provisions between Zone 1 and Zone 2 prevent sizable Zone 1 fires from entering Zone 2. However, fire and unburned fuel in Zone 1 may enter Zone 3 through joints in the fire seal between these zones.