PB-151357 PRICE $1.75

Fire-Extinguishing Studies of the Northrop F-89 Powerplant

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TECHNICAL DEVELOPMENT REPORT NO. 365

1614

CIVIL AERONAUTICS ADMINISTRATION
TECHNICAL DEVELOPMENT CENTER
INDIANAPOLIS, INDIANA

October 1958

U S. DEPARTMENT OF COMMERCE
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FIRE-EXTINGUISHING STUDIES OF THE NORTHROP F-89 POWERPLANT*

SUMMARY

A study was made of the control of in-flight turbojet powerplant fires by conducting full-scale tests on the F-89 fire-extinguishing system The early phases of this study showed that the F-89 fire-extinguishing system was ineffective in extinguishing fires of low, as well as high, intensity Seven modifications of this system were tested in an effort to accomplish successful extinguishment using bromochloromethane in a perforated tubing system Considerable improvement in extinguishment of fires was accomplished but not sufficient to warrant acceptance of the system

A high-rate-discharge system then was considered as a possible means of providing effective extinguishment A high-rate-discharge system, consisting of a manifold and distribution lines, was developed which effectively extinguished all fires ignited inside the engine bay, including those of a size which consumed all oxygen in the cooling air Dibromodifluoromethane was found more effective than bromochloromethane as the extinguishing agent

INTRODUCTION

The tests described in this report conclude fire-protection studies conducted on the F-89 aircraft powerplant Results of the first part of the program dealing with fire detection were presented in a previous Technical Development Report [1] This work was conducted during the period January to September, 1956, at the CAA Technical Development Center, Indianapolis, Indiana. It was sponsored jointly by the Wright Air Development Center and the CAA

Because of the dearth of information on the requirements for a fire-extinguishing system on afterburning engines and in nacelles having a relatively high rate of airflow, the F-89 installation was chosen for testing. Actual flight experience with aircraft of this category had indicated deficiencies in the fire-extinguishing system In a number of instances, the system had been activated without successful extinguishment This program was initiated so that these deficiencies could be eliminated

The primary purpose of this phase of the testing program was to evaluate the F-89 fire-extinguishing system and, if necessary, develop an improved configuration for the agent distribution system which would extinguish any fires of a size which could burn in the cooling air regardless of their location in the engine bay Also, it was intended to determine the comparative effectiveness of bromochloromethane (CB) and dibromodifluoromethane (DB) extinguishing agents, develop an optimum fire emergency procedure, and determine the effects of engine shutdown alone on the extinguishment of fires

DESCRIPTION OF TEST EQUIPMENT

Facility.

The test facility consisted essentially of a test chamber, a control room adjacent to the chamber, and two 1,750-hp blowers which supplied ducted air to the test article The control room contained the engine control panel, temperature recorders, a multiple manometer, and other equipment used in conducting the tests

Ram air from the blowers was ducted to a plenum chamber just forward of the aircraft and was introduced into the air intake of the left engine by means of an exit duct from the plenum The intake air was controlled by the blower operator to simulate the various conditions of flight under which the fire-extinguishing systems were to be evaluated Engine operation was

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*Manuscript submitted for publication August 1958

[1] Allen V. Young, "Fire-Detection Studies of the Northrop F-89 Power Plant," CAA Technical Development Report No 286, July 1956.

controlled from a panel in the control room The velocity of the ram air to the engine was measured by pickups mounted in the air intake of the engine Two explosion panels were installed in the doors in each of the two engine bay compartments to minimize damage to the airplane structure in the event of explosions inside the bays Indication of fires was provided by thermocouples mounted in the areas where fires were to be ignited and by fire-detector elements routed throughout the engine compartments

Test Article

The test article was the YF-89A airplane, Serial No. 46-679, manufactured by Northrop Aircraft, Inc It had undergone acceptance and evaluation tests by the Department of the Air Force at Edwards Air Force Base, California, prior to being transferred to the Center for fire-extinguishment studies

The aircraft was equipped with two J35-A-21A turbojet engines complete with afterburners For purposes of this study, only the left engine was instrumented and operated These engines were rated at 6,800 pounds thrust at 7,900 rpm at sea level for takeoff power with afterburner

Certain modifications were made to the test article to accommodate it to the test cell The nose section of the airframe back to Station 125, the tail section aft of Station 490, and a major portion of the wings were removed from the airplane before it was installed in the test cell. The test article was supported at the wing stubs by wall-mounted I-beam structures Before the test program was initiated, the powerplant installation was modified to make it conform as closely as possible to the F-89D models which were then in production

GENERAL TEST PROCEDURE

Tests were conducted under engine power conditions simulating taxi, takeoff, cruise, and maximum cruise in flight Preliminary fire-extinguishing tests indicated that the operation of the afterburner had no appreciable effect on the extinguishing requirements. For this reason the afterburner was not used in the later phases of the program Ram air from the blowers was supplied to the engine air inlet in amounts required to simulate the air inlet pressures for the various conditions of operation Table I defines the test conditions

TABLE I

TEST CONDITIONS

Simulated Operating Condition	Engine rpm (Per Cent Max. Rated rpm)	Engine Inlet Impact Pressure (Inches Hg)	Simulated Flight Speed (knots)
Taxi	80	0 1	45
Takeoff	100	0 8	130
Cruise	82	5 0	320
Maximum Cruise	100	7 0	370

The location of the test fires was determined from F-89 accident reports and by a survey of the engine to indicate the areas where the greatest fire hazard existed Sixteen locations were chosen as potential areas of fire, and throughout the series of tests, fires were ignited at these points to evaluate various agent distribution systems and several extinguishing agents These locations are indicated and numbered in Fig 1 Fires were not ignited at all 16 locations for all surveys, as failure to extinguish fires at any one location eliminated that particular extinguishing system configuration from consideration as a satisfactory system As soon as the fact was established that a distribution system would not extinguish fires in any area, the system was redesigned or improved and the test series begun again Because of the firewall separation between the compressor and burner sections, a fire was ignited in each section simultaneously to reduce the number of fires necessary and to make use of the agent which was discharged into both sections

JP-4 fuel was used for the test fires at flow rates of 0 475, 0 95, 1 90, 2 28, 3 20, 3 73, 4 20, and 4 60 gallons per minute (gpm) The fuel was introduced into the bay in a spray pattern

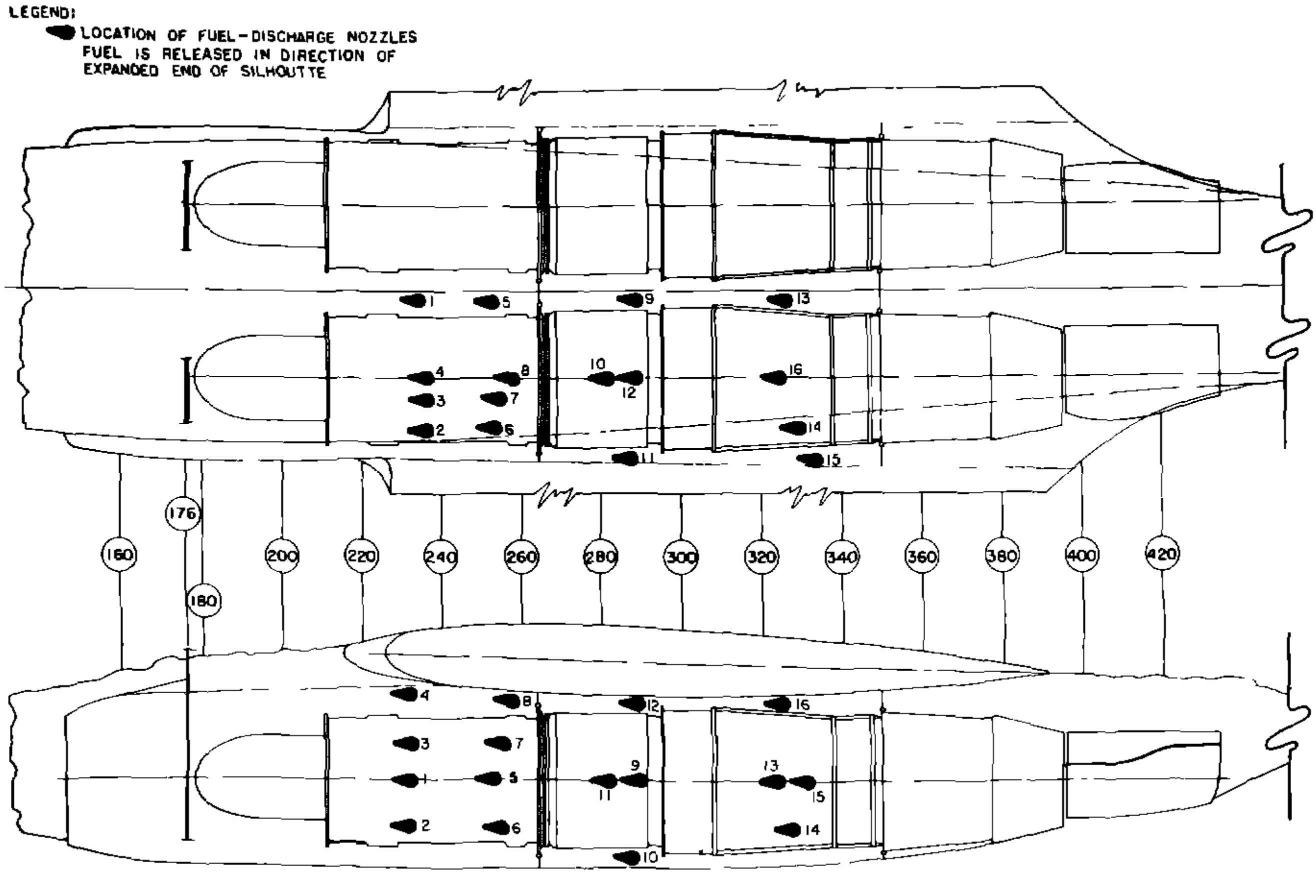


Fig 1 Test Fire Locations in Left Engine Bay of F-89 Aircraft

through holes drilled in a 1/4-inch copper tube and under a pressure of 25 psi to assure good mixing with the cooling air through the engine bay. Ignition was accomplished by means of a modified aircraft engine spark plug

A standard 378-cubic-inch extinguishing agent sphere, containing 13 5 pounds of CB pressurized with nitrogen to 400 psi, was used to evaluate the F-89 extinguishing system This was the quantity and pressurization required by this design DB and bromotrifluoromethane (BT) also were used in a number of tests to compare their effectiveness with CB Agent container sizes, fill ratios, and charging pressures were varied to determine their influence on the extinguishing effectiveness

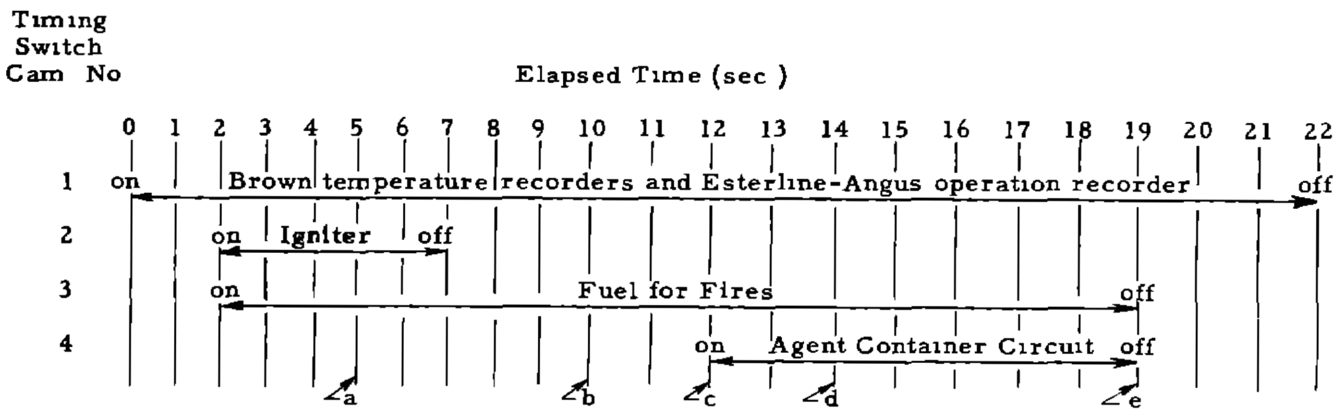
Each operation was recorded by a separate pen of an Esterline-Angus operation recorder so that a permanent comparative history was obtained of each test In order to duplicate the sequencing of events throughout the entire series of tests, an automatic sequence timer consisting of four cams was fabricated to control the various operations The timer switch was energized by closing one manual switch, and the sequence of events was begun Table II gives the timing sequence which was maintained throughout the series of tests

As can be seen from Table II, the fire was permitted to burn for a period of 10 seconds before extinguishment was attempted The fuel continued to be fed to the fire until the extinguishing agent inside the engine bay was dissipated The recording instruments were turned on automatically prior to the above operations and turned off after their completion

A complete Edison continuous-type detector system and an Edison unit-type detector system were mounted inside the engine bay independently of each other These were connected to indicating lights on the control panel in the control room and to individual pens of the Ester line-Angus operation recorder to provide visual and recorded evidence of the presence of fires in the engine bay

TABLE II

TIMING SEQUENCE OF TEST EVENTS



a - Point of fire detection
b - Point of engine shutoff
c - Point of agent release
d - Point of maximum agent concentration in engine bays
e - Point of agent dissipation

The test procedure used was one in which the power conditions of the engine were established and allowed to stabilize with the appropriate amount of ram air from the blowers The manual switch energizing the timer switch then was closed, starting the automatic sequence of events After the fire was started, the warning lights of the detector systems were monitored, and the engine was shut down five seconds after a fire warning was received The fire-extinguishing agent was discharged into the distribution lines several seconds later In case of a malfunction of the igniter, the circuit to the agent sphere could be opened, thus preventing needless discharge of the fire-extinguishing agent Extinguishment was noted by temperatures in the area of the fires, by the detector systems, and by visual inspection through windows in the engine bay doors

The first test fires were run at a flow rate of 0 475 gpm of JP-4 fuel released at a nozzle pressure of 25 psi When extinguishment was accomplished, the rate at which fuel was introduced into each engine section was increased to a maximum of 4 60 gpm From observations of a number of tests, the maximum quantity of fuel which could be introduced into the compressor section from a number of sources and completely burned was noted to be approximately 4 gpm Quantities in excess of this amount drained out through the doors and onto the floor Fuel was injected into each section from as many as four distinct sources to accomplish complete combustion of the larger fuel quantities and to distribute the fuel more completely throughout the engine section Even though fuel was injected from multiple sources, for the purposes of these tests it was considered as being one fire for that particular section.

As the tests proceeded, it became obvious that extinguishment of fire under simulated cruise flight power was more difficult than under other simulated flight or ground operating conditions Thus, in the latter stages of the program, the majority of tests were conducted at cruise setting

A total of 7 perforated tubing configurations and 3 open-end tubing systems were evaluated during the conduct of 234 fire tests

EVALUATION OF THE F-89 FIRE-EXTINGUISHING SYSTEM

Purpose

The purpose of the evaluation of the F-89 fire-extinguishing system was to determine the effectiveness of the production-type agent distribution system, and, if found inadequate, to modify the agent distribution system so that it would extinguish fires of any practical magnitude regardless of their location in the engine bay.

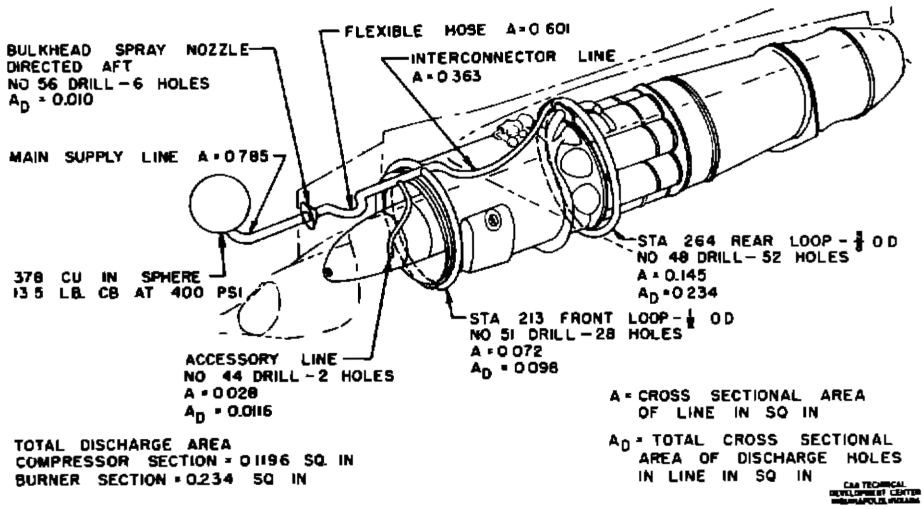


Fig 2 F-89 Powerplant Fire Extinguishing System

Description of System

The latest production extinguishing agent distribution system used in F-89 aircraft was installed in the engine bay of the test article as shown in Fig 2 It consisted of a 378-cubic-inch spherical container connected to two discharge rings, one in the compressor section and one in the burner section A spray nozzle was mounted on the aft side of the engine compartment forward bulkhead, integral with the main agent supply line, and directed aft A small line extended down into the accessory section from the forward compressor loop Line sizes, number and size of discharge holes, and cross-sectional areas of the various lines are indicated in Fig 2 The Air Force specified CB as the extinguishing agent The quantity of agent required for each zone of the engine bay was computed from the formula[2]

$$Q = 0.56W_a + 0.16V$$

where

Q = minimum quantity of agent to be discharged per zone in pounds

W_a = air flowing through the zone under normal cruising conditions in pounds per second

V = net volume (gross volume of the zone less the volume of major items of equipment) in cubic feet

Table III sets forth the estimated airflow, volume, and the computed extinguishing agent requirements for each powerplant zone

Prior to the actual conduct of the test fires, the complete extinguishing system was mocked-up and distribution tests were conducted to determine the actual amount of agent discharged from each section of the system Each length of tubing containing discharge holes was encased in plastic tubing to retain the agent after discharge and enable it to be weighed For these tests, an equivalent volume of carbon tetrachloride (CCl_4) was substituted for CB, thereby maintaining the 50 per cent fill ratio in the sphere The average amount of agent actually discharged from each part of the system during a series of three tests is shown in Table IV

The forward bulkhead spray nozzle and the compressor ring both discharge into the compressor compartment, so that the total amount of agent discharged into the compressor

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[2] See paragraph 3 3 1, Military Specification MIL-E-5352A, Amendment-1, dated February 16, 1954

TABLE III

COMPUTED EXTINGUISHING AGENT REQUIREMENTS FOR THE F-89 POWERPLANT

Zone	Net Volume* (cu ft)	Weight of Air Flowing Through Zone* (lb /sec)	Quantity of Agent Required (lb CB)
Accessory	6 45		1 03
Compressor	17 08	1.8	3 74
Burner, Turbine, Tailpipe, and Afterburner	36 7	5 0	8.67
		Total	13 44

* Northrop Aircraft Inc Drawing No 540875

compartment is the sum of these two quantities The quantity discharged into the various compartments, as determined from the distribution measurements of this system, was less than the design requirement for each compartment

The duration of the free discharge of 13 5 pounds of CB through this system was obtained by photographic analysis of the discharge and is represented by the curves of Fig 3 The first component of the extinguishing system to show indications of agent discharge was taken as the zero point on the graph and the indications of discharge from the other components are relative to this reference point No measurements were made of the amount of agent discharged during the time interval of maximum discharge It can be seen from this graph that the compressor discharge loop discharged a maximum quantity of agent for a duration of only 0 25 second, while the burner loop discharge continued for 1 4 seconds The line of the graph marked "Maximum Discharge of Agent" does not infer that either quantity or rate of agent discharged by all segments is the same but only that visually, in the time interval indicated on the abscissa, the discharge of agent from that segment reached its maximum The curve indicates the time for the agent to reach maximum discharge, duration of maximum discharge, and the time for all indication of discharge to disappear

Fire-Extinguishing Test

Procedure

The tests were conducted by selecting various fire locations, Fig 1, where test fires were ignited under all engine power conditions and extinguishing agent was discharged through

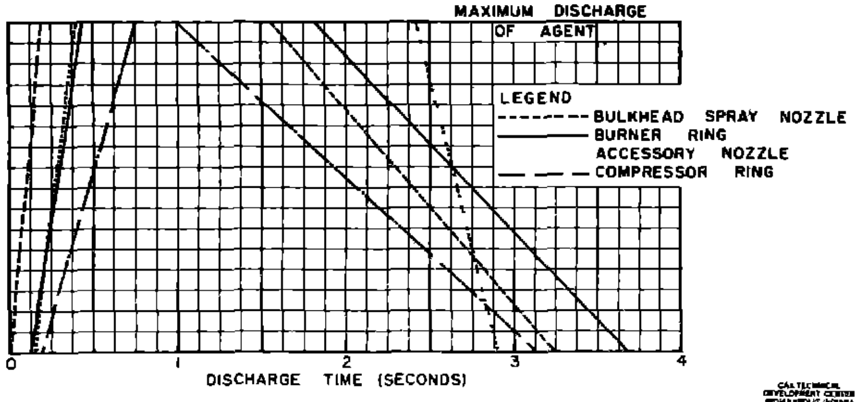

Fig 3 Agent Discharge Duration

TABLE IV

AGENT DISTRIBUTION
BY F-89 FIRE EXTINGUISHING SYSTEM

	Quantity of Agent Required (See Col 3, Table III) (lb CB)	Quantity of Agent Measured (lb CT)[1]	Per Cent of Total	Calculated (lb CB)[2]
Agent charge	13.44	11 66	100 0	13 44
Agent discharged from sphere		11 31	97 0	13 04
Agent remaining in sphere		0 35	3 0	0 40
Agent discharged by accessory nozzle	1 03	0 50	4 3	0 58
Agent discharged by forward bulkhead nozzle		0 60	5 2	0 70
Agent discharged from compressor ring	3 74	2 33	20 0	2 69
Total weight of agent discharged into compressor section	3 74	2 93	25 2	3 39
Agent discharged from burner ring	8 67	7 35	63 0	8 47
Agent lost in lines		0 53	4 5	0 60
Total weight of agent discharged from system		10 78	92 5	12 44
Total container and line loss		0 88	7 5	1 00

NOTE The theoretical quantities of CB are based on the percentages of the required amount of 13 44 pounds of CB which would have been discharged into each volume

(1) CT - Carbon tetrachloride, CCl_4

(2) CB - Bromochloromethane, CH_2BrCl

the plumbing system to determine if the fires could be extinguished and if flashback occurred. Tests were conducted using CB, BT, and DB agents with various agent container fill ratios. Modifications to the plumbing systems were made as the tests progressed in an effort to increase the concentration of agent in areas of the engine bay which had not been receiving an adequate supply

Results.

The first series of tests was conducted at each of the four power settings at fire locations 4 and 12, Fig 1 In this series of tests, 0.475 gpm of JP-4 fuel was released at each test location and permitted to burn for 10 seconds before extinguishment was initiated. Thirteen and one-half pounds of CB agent pressurized to 400 psi with nitrogen and contained in a 378-cubic-inch sphere was used for each test The fill ratio, $\left[\frac{\text{volume of agent}}{\text{volume of container}}\right]$ was 50 per cent Extinguishment was attempted with the engine continuing to operate at the designated power condition The test conditions and results are given in Table V.

TABLE V

EXTINGUISHING TEST CONDITIONS AND RESULTS
FOR FIRE LOCATIONS 4 AND 12

Fire Location	Number of Fire Tests	Simulated Test Condition	Fires Extinguished (No.)	Fires Extinguished (Per Cent)
4	3	Taxi	1	33
4	1	Takeoff	0	0
4	2	Cruise	2	100
4	2	Maximum Cruise	1	50
12	3	Taxi	3	100
12	1	Takeoff	1	100
12	2	Cruise	2	100
12	2	Maximum Cruise	2	100

After the completion of these eight tests, several facts were apparent. First, the fire was extinguished rapidly in the burner section but flashed back in the compressor section during four of the tests, due presumably to a lingering pocket of fire in that section which reignited the fuel still being injected into the bay Second, a considerable quantity of CB poured from the bottom of the compressor section onto the test cell floor following each discharge, indicating improper utilization of agent

The second study consisted of nine fire-extinguishing tests. For each test, fires were ignited at fire locations 8 and 16 simultaneously. During this series of tests, the fuel flow to the fire was maintained at 0 475 gpm and the agent container fill ratio was 50 per cent The type of agent was varied to include one test with DB. Engine power was maintained at the designated setting during extinguishing agent discharge The results of these tests are indicated in Table VI.

The percentage of fires extinguished was reduced, none being extinguished in the compressor section and only 55 per cent in the burner section This indicated that the system was relatively ineffective

The foregoing series of fires all had been conducted without shutting the engine down prior to discharging the agent into the engine bay In order to draw a direct comparison between results with and without engine shutdown the tests were conducted as follows

Five seconds after an indication of fire was given by one of the fire detector elements installed in the engine bay, the afterburner (when used) and then the engine were shut down The duration of the fire and the discharge of CB agent still were controlled by the timer The fuel flow to each fire location was 0 475 gpm The 50-per-cent agent container fill ratio was maintained but in two fires a 536-cubic-inch sphere was used to discharge 19 0 pounds of CB Table VII shows the results of this series of tests

The results of these few tests indicated that airflow was less and the system was more effective with the engine shut off Subsequent tests during the conduct of the program proved

TABLE VI

EXTINGUISHING TEST CONDITIONS AND RESULTS
FOR FIRE LOCATIONS 8 AND 16

Fire Location	Number of Fire Tests	Simulated Test Condition	Agent(1)	Quantity of Agent (lb)	Fires Extinguished (No)	(Per Cent)
8	2	Taxi	CB	13 5	0	0
8	2	Takeoff	CB	13 5	0	0
8	1	Takeoff	DB	16 2	0	0
8	2	Cruise	CB	13 5	0	0
8	2	Maximum Cruise	CB	13 5	0	0
16	2	Taxi	CB	13 5	1	50
16	2	Takeoff	CB	13 5	0	0
16	1	Takeoff	DB	16 3	1	100
16	2	Cruise	CB	13 5	1	50
16	2	Maximum Cruise	CB	13 5	2	100

(1) CB - Bromochloromethane
DB - Dibromodifluoromethane

TABLE VII

EXTINGUISHING TEST CONDITIONS AND RESULTS
FOR FIRE LOCATIONS 8 AND 16

Fire Location	Number of Fire Tests	Simulated Test Condition	Quantity of CB(1) (lb)	Fires Extinguished (No)	(Per Cent)
8	2	Takeoff	13 5	0	0
8	1	Taxi	13 5	0	0
8	1	Cruise	13 5	0	0
8	1	Cruise	19 0	0	0
8	1	Maximum Cruise	13 5	0	0
16	2	Takeoff	13 5	2	100
16	1	Taxi	13 5	1	100
16	1	Cruise	13 5	1	100
16	1	Cruise	19 0	1	100
16	1	Maximum Cruise	13 5	1	100

(1) CB - Bromochloromethane

this to be true During this series of tests three flashbacks occurred in the compressor section The larger quantity of extinguishing agent, maintaining the same fill ratio and pressurization, had no better extinguishing effect on the fire than the standard charge This indicated that the failures were not a matter of agent quantity, but rather agent distribution and rate of discharge

In an attempt to accomplish more uniform agent distribution in the compressor section, 15 no 48 holes were drilled in the interconnector line between the compressor distribution ring and the burner distribution ring This added 0 0675 square inch of discharge area in the compressor section, bringing the total discharge area in that section, exclusive of the accessory nozzle, to 0 1755 square inch These new holes discharged agent in an upward direction The total discharge area with this increase still was less than the feed line cross-sectional area Table VIII indicates the results achieved as a result of this first modification, with the engine being shut down prior to discharge of agent The rate of fuel flow to the fires was 0 475 gpm and the fill ratio of the extinguishing agent spheres was 50 per cent

TABLE VIII

EXTINGUISHING TEST CONDITIONS AND RESULTS
(F-89 Extinguishing System, Modification No 1)

Fire Location	Number of Fire Tests	Simulated Test Condition	Quantity of CB(1) (lb)	Fires Extinguished (No)	Fires Extinguished (Per Cent)
8	1	Taxi	13 5	0	0
8	1	Taxi	19 0	0	0
8	1	Takeoff	13 5	1	100
8	1	Takeoff	19 0	1	100
8	1	Cruise	13 5	0	0
8	1	Maximum Cruise	13 5	0	0
16	1	Taxi	13 5	0	0
16	1	Taxi	19 0	1	100
16	1	Takeoff	13 5	0	0
16	1	Takeoff	19 0	0	0
16	1	Cruise	13 5	1	100
16	1	Maximum Cruise	13 5	1	100

(1) CB - Bromochloromethane

Comparing these results with the results of previous runs, it can be seen that the extinguishing capabilities in the compressor section were improved at the expense of the burner section This indicated that the ability of the system to extinguish fires in the burner section prior to this modification was marginal, and any lesser rate of agent discharge in that section detracted from its fire-extinguishing capabilities Using 19 0 pounds CB in a 539-cubic-inch bottle did not improve the ability of the system to extinguish this small test fire Again with this configuration there were four instances of flashback, twice in each section Two mild explosions also occurred Large quantities of CB continued to pour from the engine bay after each bottle discharged

On the basis of the experience gained from the previous fires, it was apparent that the use of the afterburner had no effect on the ability of the system to extinguish fires, as the effect of the afterburner was lost by the time the afterburner and the engine were shut down and the bottle discharged Consequently, due to the large amount of maintenance required on the afterburner during the conduct of the test fires, its use was discontinued Also, there was no difference in extinguishing results between cruise and maximum cruise power settings, so the maximum cruise setting was eliminated to shorten the test program and to reduce the deterioration of the test article

The large quantities of CB which continued to drain from the engine bay after each bottle was discharged showed no improvement in agent utilization and indicated a need for better distribution and atomization of agent to accomplish extinguishment Since there is a reversal of airflow in the compressor section of the engine bay between low to high engine power settings, the system configuration must not only distribute agent throughout a compartment some 90 inches in length, but also must distribute the agent against the internal airflow under certain power conditions

From the data accumulated in the foregoing tests, it became apparent that one perforated ring in the compressor section was inadequate because of the length of the zone to be protected Multiple rings did not seem practical due to the numerous obstructions to distribution presented by the various hose lines and tubing, therefore, linear distribution lines parallel to the axis of the engine were investigated In the burner section, because of the high velocity of the linear airflow, perforated rings could function properly

To improve distribution, the perforated ring in the compressor section was removed and additional holes were drilled in the interconnector line until the total discharge area in the interconnector line was equal to the discharge area of the perforated ring, which was removed These holes were spaced along the length of the interconnector line to distribute the agent throughout most of the length of the compressor section For all these tests, 13 5 pounds of CB were discharged into the engine bay and the rate of fuel to the fire was maintained at 0 475 gpm The procedure followed included engine shutdown prior to discharge of the agent Table IX shows the results of the test fires conducted with this modification

TABLE IX

EXTINGUISHING TEST CONDITIONS AND RESULTS
(F-89 Extinguishing System, Modification No 2)

Fire Location	Number of Fire Tests	Simulated Test Condition	Fires Extinguished (No)	Fires Extinguished (Per Cent)
8	1	Taxi	1	100
8	1	Takeoff	1	100
8	1	Cruise	1	100
8	1	Cruise	1	100
2	1	Taxi	0	0
2	1	Takeoff	0	0
2	1	Cruise	0	0
16	1	Taxi	1	100
16	1	Takeoff	1	100
16	1	Cruise	1	100
16	1	Cruise	1	100
14	1	Taxi	0	0
14	1	Takeoff	0	0
14	1	Cruise	0	0

These tests proved only that fires in the upper regions of the engine compartments were being extinguished rapidly due to the proximity of the agent discharge lines, whereas those in the lower regions were being starved for agent and were not being extinguished In all previous tests, fire location 8 was the area which was receiving the least agent and had the least percentage of extinguishments With this latest change the converse was true The quantity of liquid CB draining from the engine bay was considerably reduced

To give added protection to the lower regions of the engine bay the following changes were incorporated in the next system modification.

1 In the burner section all of the holes discharging agent outward toward the engine bay doors and keel were sealed Smaller holes were drilled at these locations directing the agent aft, thus reducing the total discharge area in the burner section by 0 043 square inch

2 The discharge ring in the burner section was relocated 14 inches aft of the firewall separating the compressor and burner sections

3 Additional holes were drilled in the interconnector line in the compressor section

4 An additional longitudinal distribution line was added at the 7 o'clock position in the compressor section

5 The forward bulkhead spray nozzle was moved from the forward bulkhead and relocated at the tee-fitting of the interconnector line and directed forward

These latest changes are illustrated in Fig 4 The fuel to the test fire was released at a rate of 0 475 gpm In this series of tests, quantity, type, and pressurization of agent were varied to obtain a direct comparison of these factors, but the fill ratio was maintained at 50 per cent The test procedure included engine shutdown prior to discharge of the agent The results of the series of test fires conducted with this configuration are given in Table X Pressurization was 400 psi in all tests except those noted in the table

In the series of tests involving the third modification, neither the standard charge of CB nor a 19 0-pound charge of CB in a 536-cubic-inch sphere gave complete extinguishment of all test fires A standard charge pressurized to 600 psi did not extinguish the fire in the compressor section even though this higher pressure produced a tremendous mixing effect and the discharge could be heard above the engine roar Flashback occurred in five instances, four during normal cruise conditions and one during taxi power

In a survey of all power settings using DB as the agent, extinguishment was successful Even though very good results were accomplished using DB as the extinguishing agent in this latest system configuration, the problem was to develop a system using CB which would extinguish fires of a practical magnitude successfully

TABLE X

EXTINGUISHING TEST CONDITIONS AND RESULTS
(F-89 Extinguishing System, Modification No 3)

Fire Location	Number of Fire Tests	Simulated Test Condition	Agent(1)	Quantity of Agent (lb)	Fires Extinguished (No)	Fires Extinguished (Per Cent)
2	1	Taxi	CB	13 5	1	100
2	1	Takeoff	CB	13 5	1	100
2	1	Cruise	CB	13 5	0	0
2	1	Cruise	CB	13 5	1	100
2	1	Cruise	CB	19 0	0	0
2	1	Taxi	CB	19 0	1	100
2	1	Cruise	DB	16 0	1	100
2	1	Cruise	CB	13 5 (2)	0	0
2	1	Taxi	DB	16 0	1	100
2	1	Takeoff	DB	16 0	1	100
14	1	Taxi	CB	13 5	0	0
14	1	Takeoff	CB	13 5	0	0
14	1	Cruise	CB	13 5	0	0
14	1	Cruise	CB	13 5	0	0
14	1	Cruise	CB	19 0	1	100
14	1	Taxi	CB	19 0	0	0
14	1	Cruise	DB	16 0	1	100
14	1	Cruise	CB	13 5 (2)	1	100
14	1	Taxi	DB	16 0	1	100
14	1	Takeoff	DB	16 0	1	100

(1) CB - Bromochloromethane
DB - Dibromodifluoromethane

(2) These tests were conducted with an agent container pressure of 600 psi

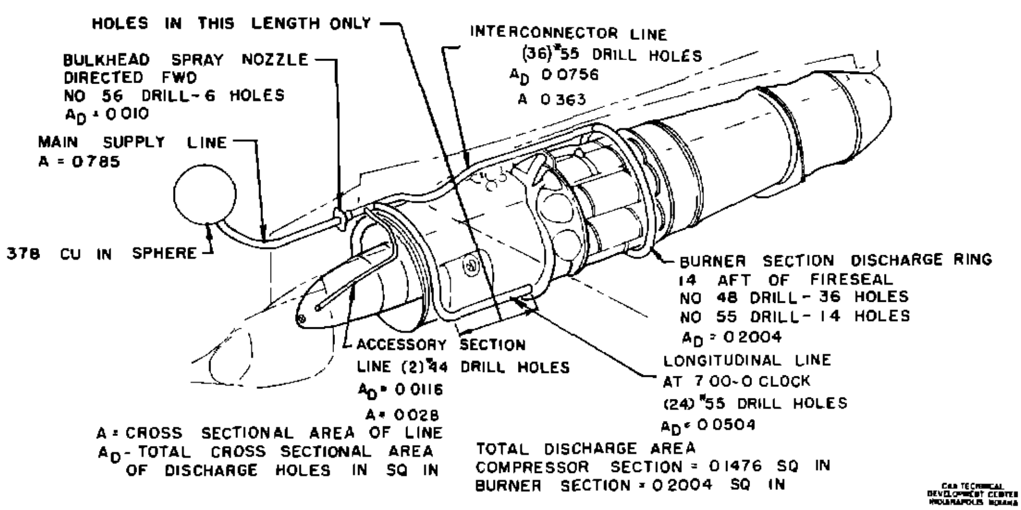

Fig 4 Modified Perforated Tubing Distribution System

TABLE XI

EXTINGUISHING TEST CONDITIONS AND RESULTS
(F-89 Extinguishing System, Modification No 4)

Fire Location	Number of Fire Tests	Simulated Test Condition	Quantity of CB(1) (lb)	Fill Ratio (Per Cent)	Fires Extinguished (No)	Fires Extinguished (Per Cent)
1	1	Taxi	13 5	50 0	1	100
1	1	Takeoff	13 5	50 0	0	0
1	1	Takeoff	10 5	37 0	0	0
1	1	Takeoff	13 5	37 0	0	0
1	2	Cruise	13 5	50 0	0	0
1	1	Cruise	9 5	35 0	0	0
1	2	Cruise	13 5	37 0	1	50
1	1	Cruise	20.5	55 0	1	100
1	1	Cruise	13 5 (2)	50 0	1	100
2	1	Taxi	13 5	50 0	1	100
2	1	Takeoff	13 5	50 0	1	100
2	1	Cruise	13 5	50 0	1	100
4	1	Taxi	13 5	50 0	1	100
4	2	Takeoff	13 5	50 0	2	100
4	1	Cruise	13 5	50 0	1	100
7	1	Taxi	13 5	50 0	1	100
7	1	Takeoff	13 5	50 0	1	100
7	2	Cruise	13 5	50 0	2	100
9	1	Taxi	13 5	50 0	1	100
9	1	Takeoff	13 5	50 0	1	100
9	1	Takeoff	10 5	37 0	1	100
9	1	Takeoff	13 5	37 0	1	100
9	2	Cruise	13 5	50 0	2	100
9	1	Cruise	13 5	37 0	1	100
9	1	Cruise	9 5	35 0	1	100
9	1	Cruise	13 5 (2)	50 0	1	100
12	1	Taxi	13 5	50 0	1	100
12	1	Takeoff	13 5	50 0	0	0
12	3	Cruise	13 5	50 0	1	33
13	1	Taxi	13 5	37 0	0	0
14	1	Taxi	13 5	50 0	1	100
14	1	Takeoff	13 5	50 0	1	100
14	1	Cruise	13 5	50 0	1	100
15	1	Taxi	13 5	50 0	1	100
15	1	Takeoff	13 5	50 0	1	100
15	2	Cruise	13 5	50 0	2	100

(1) CB - Bromochloromethane

(2) These tests were conducted with an agent container pressure of 550 psi

To improve extinguishment in the burner section, the discharge ring was removed and replaced by a short line extending the length of the burner cans at 1 o'clock and by another line at 8 o'clock extending the full length of the afterburner fuel line A total of 121 no 56 holes were drilled in these 2 lines, giving a total discharge area in the burner section of 0 2047 square inch This discharge area was less than that of the original system in the burner section The results of the fire tests with this configuration are given in Table XI In these tests the rate of fuel flow to each fire location was 0 475 gpm All other factors were varied as indicated in the table The engine was shut down prior to discharge of the agent

Tests at these several fire locations provided good coverage of both sections of the engine bay with a wide variation in the quantity of agent used and with two different sizes of agent container, namely, 378-cubic-inch and 536-cubic-inch Extinguishment was accomplished in a greater number of instances than was experienced in any of the preceding tests, but flashback continued to occur in the compressor section A total of 10 flashbacks occurred, 6 of which were at normal cruise The purpose of using the 536-cubic-inch sphere with the smaller amount of agent, as indicated by the container fill ratio column, was to determine if a greater quantity of propelling gas would aid agent distribution in the engine bay There was no improvement in extinguishment with this greater quantity of gas In the 44 tests conducted, 68 per cent of the fires in the compressor section were extinguished, and 82 per cent of those in the burner section were extinguished In these last tests, flashbacks occurred in the area next to the keel in the compressor section

A longitudinal 3/8-inch line with 18 no 56 holes was added at the 2 o'clock position on the engine in the compressor section to provide additional agent in this area The holes in the interconnector line were sealed. In the following series of tests, the fuel to each fire location was released at a rate of 0 475 gpm Thirteen and one-half pounds of CB under 400 psi pressurization in a 536-cubic-inch sphere was discharged in all tests The procedure included engine shutdown prior to the discharge of the agent The fill ratio for this charge was 37 per cent Table XII gives the results of the test fires with this configuration

TABLE XII

EXTINGUISHING TEST CONDITIONS AND RESULTS
(F-89 Extinguishing System, Modification No. 5)

Fire Location	Number of Fire Tests	Simulated Test Condition	Fires Extinguished (No)	Fires Extinguished (Per Cent)
5	1	Taxi	0	0
5	1	Takeoff	0	0
5	1	Cruise	0	0
13	2	Taxi	0	0
13	1	Takeoff	1	100
13	1	Cruise	0	0

These tests proved that the area adjacent to the keel inboard of the engine still was lacking sufficient agent to extinguish the fires Due to the inner construction of the engine bay doors, fire was able to remain in protected areas under the formers and stringers, causing a reflash after the agent had dissipated In the above series of tests, 6 of the 7 fires flashed back

In the subsequent tests, the line located at the 7 o'clock position was retained, and the line placed at the 2 o'clock position in the compressor section for the previous tests was altered as follows

1 The line was sloped from a 2 o'clock position at the interconnector tee-fitting to a 5 o'clock position at the aft end of the compressor section near the fire seal

2 A no 31 drill hole placed in the aft end of this line directed the agent aft

3. Nine no 56 drill holes in the first one-half of the line directed downward, and nine no 56 drill holes in the aft one-half of the line directed upward were added

Both CB and DB were used in 378-cubic-inch and 536-cubic-inch containers in the tests of the above system configuration and as indicated by the fill ratio column of Table XIII In all tests the container pressurization was 400 psi The fuel flow at each location was 0 475 gpm, but in some of the tests this quantity was released at each of two different locations in the compressor section to provide a larger quantity and greater dispersion of the fuel The test procedure included engine shutdown prior to discharging the agent Table XIII shows the results of the tests

All but one of the test fires in the burner section were extinguished Flashbacks occurred in 5 of the 7 tests conducted with fuel released simultaneously at locations 2 and 4 in the compressor section Three additional flashbacks occurred in this section during the entire series of test fires There was an insufficient number of tests in this series using DB as the agent to draw any specific conclusions as to the effectiveness of this agent

TABLE XIII

EXTINGUISHING TEST CONDITIONS AND RESULTS
(F-89 Extinguishing System, Modification No 6)

Fire Location	Number of Fire Tests	Simulated Test Condition	Fuel to Fire (gpm)	Agent[1]	Quantity of Agent (lb)	Fill Ratio (per cent)	Fires Extinguished (no)	Fires Extinguished (per cent)
1	1	Taxi	0 475	CB	13 5	50 0	1	100
1	1	Cruise	0 475	CB	13 5	50 0	1	100
1	1	Taxi	0 475	CB	13 5	37 0	1	100
1	1	Takeoff	0.475	CB	13 5	37 0	0	0
1	1	Takeoff	0 475	DB	16 2	37 0	1	100
1	1	Cruise	0 475	DB	16 2	37 0	1	100
1, 5	1	Taxi	0 95	CB	13 5	37 0	0	100
2, 4	1	Taxi	0 95	CB	13 5	50 0	1	100
2, 4	2	Takeoff	0 95	CB	13 5	50 0	0	0
2, 4	2	Cruise	0 95	CB	13 5	50 0	0	0
2, 4	1	Takeoff	0 95	DB	16 2	50 0	0	0
2, 4	1	Cruise	0 95	DB	10 0	30 0	0	0
3	2	Taxi	0 475	CB	13 5	50 0	2	100
3	1	Takeoff	0 475	CB	13 5	50 0	1	100
3	2	Cruise	0.475	CB	13 5	50 0	1	50
4	1	Cruise	0 475	CB	13 5	37 0	1	100
5	1	Taxi	0 475	CB	13 5	37 0	1	100
5	2	Takeoff	0 475	CB	13 5	37 0	1	50
5	1	Cruise	0 475	CB	13 5	37 0	1	100
6	1	Taxi	0 475	CB	13 5	50 0	1	100
6	1	Takeoff	0 475	CB	13 5	50.0	1	100
6	2	Cruise	0 475	CB	13 5	50 0	2	100
8	1	Taxi	0 475	CB	13 5	50 0	1	100
8	1	Takeoff	0 475	CB	13 5	50 0	1	100
8	1	Cruise	0 475	CB	13.5	50 0	1	100
10	2	Taxi	0 475	CB	13.5	50 0	1	50
10	3	Takeoff	0 475	CB	13 5	50 0	3	100
11	2	Taxi	0 475	CB	13 5	50.0	2	100
11	1	Takeoff	0 475	CB	13 5	50 0	1	100
11	2	Cruise	0 475	CB	13 5	50 0	2	100
12	1	Takeoff	0 475	DB	16.2	37 0	1	100
12	1	Cruise	0 475	DB	16 2	37 0	1	100
12	1	Cruise	0 475	CB	13 5	50.0	1	100
15	2	Takeoff	0 475	CB	13 5	37.0	2	100
15	1	Cruise	0 475	CB	13 5	37.0	1	100
15	1	Takeoff	0 475	CB	13 5	50 0	1	100
15	1	Cruise	0 475	CB	13 5	50 0	1	100

(1) CB - Bromochloromethane
DB - Dibromodifluoromethane

To improve the extinguishing ability of the distribution system in the compressor section, five no 57 drill holes were added in the short arc of tubing between the tee-fitting and the bend in the longitudinal section of line at the 2 o'clock position, directing the agent aft into the compressor section In the comparable length of tubing from the tee-fitting to the longitudinal line at the 8 o'clock position, four no 56 drill holes were added at an angle of 45° to the horizontal plane, directing the agent aft into the compressor section This configuration is shown on Fig 5

In the tests of this modification, the fill ratio was maintained at 50 per cent in a 378-cubic-inch sphere pressurized to 400 psi A much larger quantity of JP-4 fuel was discharged into the engine bay than in any of the preceding tests as indicated in Table XIV

TABLE XIV

EXTINGUISHING TEST CONDITIONS AND RESULTS
(F-89 Extinguishing System, Modification No 7)

Fire Location	Number of Fire Tests	Simulated Test Condition	Fuel to Fire (gpm)	Agent(1)	Quantity of Agent (lb)	Fires Extinguished (No)	(Per Cent)
2	1	Cruise	0 475	CB	13.5	0	0
2	1	Cruise	0 475	DB	16 2	1	100
2, 4	1	Cruise	0 95	CB	13 5	0	100
4	1	Takeoff	0 475	CB	13 5	1	100
4	1	Cruise	0 475	CB	13 5	1	100
8	1	Takeoff	3 73	CB	13 5	0	0
8	1	Cruise	3 73	CB	13 5	0	0
8	1	Cruise	3 73	DB	16 2	1	100
10	1	Takeoff	0 475	CB	13.5	1	100
15	1	Takeoff	3 73	CB	13 5	0	0
15	1	Cruise	3 73	CB	13 5	0	0
15	1	Cruise	3 73	DB	16 2	1	100

(1) CB - Bromochloromethane
DB - Dibromodifluoromethane

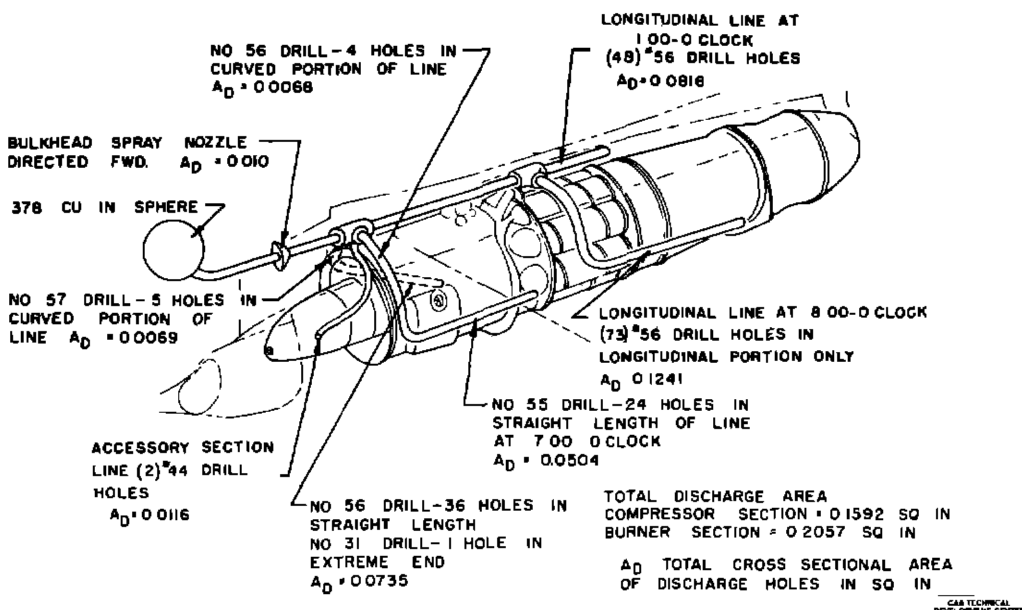

Fig 5 Final Configuration of Perforated Tubing Distribution System

In the last series of fire tests, as indicated in Table XIV, the fuel to the fire was increased to 3 73 gpm in six of the tests With this quantity of fuel, an extremely severe fire existed in the engine bay and, upon the discharge of 13 5 pounds of CB, continued to burn with practically no abatement For fires of this magnitude, on which 16 2 pounds of DB was used, however, extinguishment was instantaneous and there was no reignition even though raw fuel continued to be released into the engine bay Three flashbacks occurred in the compressor section and one in the burner section during the fire tests in which CB was used

At this point in the testing, it appeared that the more practical configurations of a perforated tubing system for this aircraft had been tested and evaluated The limitation of using CB agent in developing a system which would satisfactorily extinguish a fire of a magnitude which conceivably could occur in this engine bay imposed the requirement of such an elaborate system of plumbing to distribute the agent into all areas of the engine bay in sufficient quantities to extinguish even a small test fire, that it was considered impractical to investigate this type of distribution system any further Using this general type of distribution system, with 16 2 pounds of DB as the extinguishing agent, all fires with but one exception were extinguished

DEVELOPMENT OF A HIGH-RATE-DISCHARGE SYSTEM

The difficulties encountered in developing a perforated tubing distribution system led to consideration of a high-rate discharge (HRD) system to effect reliable fire extinguishment Tests on the perforated tubing system indicated that the amount, directions, and velocities of airflow within the fire zones of the F-89 powerplants result in rather severe agent distribution requirements It was believed that an open-end tubing system having a high rate of agent discharge would meet such requirements

Description

In order to deliver the agent into all compartments of the engine bay simultaneously, the supply line from the agent container was routed to a specially fabricated distributor located at the midpoint of the engine The distribution lines to areas of each compartment were connected to the distributor. The discharge ends of six open-end 1/4-inch o d. lines were spaced equally around the circumference of the engine just forward of the firewall between the compressor and the burner compartments and pointed at 45° helically from a direct forward position Six open-end 3/8-inch o d lines extended through the fire seal into the burner compartment and the ends were equally spaced around the circumference of the engine pointing 45° from a direct aft direction Each of these 12 lines was connected directly to the distributor located at the midpoint of the engine The 45° angle at the end of each line was used to impart a swirling and mixing action to the agent as it was discharged into the engine bay The distributor with the lines attached is shown in Fig 6 This system first was evaluated with CB but, because this type of system does not function at its peak efficiency using an agent with the physical characteristics of CB, the majority of the tests were run using DB

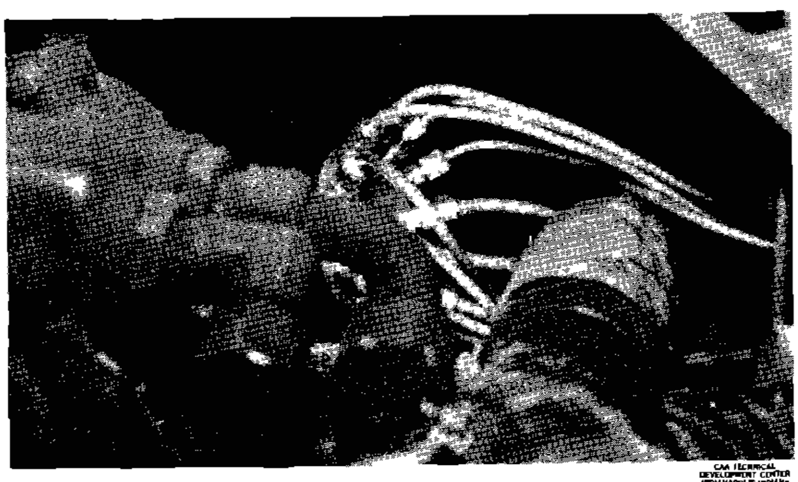

Fig 6 Distributor of HRD System with Discharge Lines Attached

Test Procedure

The test procedure for the HRD system was the same as for the perforated tubing system, with the sequence of events and the timing being held constant In all of the tests involving the HRD configuration, fuel was introduced at two or three different locations in each section of the engine bay to increase the quantity of fuel and to spread the fuel over a greater area which resulted in a more intense fire However, for these tests it still was considered as being one fire

Results

Table XV shows the results with the first HRD plumbing configuration The fill ratio was held at 50 per cent in a 378-cubic-inch sphere using both CB and DB pressurized to 400 psi with nitrogen as the extinguishing agents The engine was shut down prior to discharge of the agent

TABLE XV

EXTINGUISHING TEST CONDITIONS AND RESULTS
FOR HIGH-RATE-DISCHARGE SYSTEM

Fire Location	Number of Fire Tests	Simulated Test Condition	Fuel to Fire (gpm)	Agent(1)	Quantity of Agent (lb)	Fires Extinguished (No.)	(Per Cent)
2,4	1	Taxi	0 95	CB	13 5	0	0
2,4	1	Taxi	0 95	DB	16 2	1	100
2,4	1	Takeoff	0 95	DB	16 2	1	100
2,4	1	Cruise	0 95	DB	16 2	1	100
2,4	1	Taxi	4 2	DB	16 2	1	100
2,4	1	Takeoff	4 2	DB	16 2	1	100
2,4,8	1	Cruise	4 6	DB	16 2	0	0
13,15	1	Taxi	0 95	CB	13 5	1	100
13,15	1	Taxi	0 95	DB	16 2	1	100
13,15	1	Takeoff	0 95	DB	16 2	1	100
13,15	1	Cruise	0 95	DB	16 2	1	100
13,15	1	Taxi	4 2	DB	16 2	1	100
13,15	1	Takeoff	4 2	DB	16 2	1	100
13,15	2	Cruise	4 2	DB	16 2	2	100
13,15	1	Cruise	4 2	DB	16 2	1	100

(1) CB - Bromochloromethane

DB - Dibromodifluoromethane

In this series of tests, fire extinguishment in the burner section was successful in all cases However, in the compressor section there were two instances in which the fuel was reignited by a flashback from a pocket of fire in the forward part of the section, which remained after the agent was discharged into the bay As the quantity of fuel was increased, the resulting fire became more intense and destructive It was determined from this and the tests on modification No 7 of the perforated tubing system in which 3 73 gpm of fuel was released that, under these conditions of airflow, about 4 gpm was the maximum quantity of fuel which could support combustion with the amount of oxygen present in the compressor compartment Small quantities of fuel were observed draining from the engine bay in this test during the fire prior to agent discharge

To increase agent quantity in the forward half of the compressor section where reignition was occurring, each alternate discharge line directing agent into this section, or three in all, was repositioned to discharge agent at the midpoint of the compressor section, leaving the remaining three at the original location at the firewall The total length of discharge line remained the same as in the previous test In the tests evaluating this configuration, fuel was introduced into the compressor section at three different locations and into the burner section at two locations A standard fill ratio of 50 per cent with 16 2 pounds of DB in a

378-cubic-inch sphere pressurized to 400 psi with nitrogen was used Because the system was designed to operate most effectively at cruise power setting, these tests were conducted at that power setting only Engine shutdown was accomplished prior to the discharge of agent Table XVI shows the results of these tests

TABLE XVI

EXTINGUISHING TEST CONDITIONS AND RESULTS
(High-Rate-Discharge System, Modification No 1)

Fire Location	Number of Fire Tests	Fuel to Fire (gpm)	Fires Extinguished (No)	(Per Cent)
2,4,8	1	4 6	0	0
3,4,8	2	4.6	0	0
13,15	1	4 2	1	100
11,12	2	4 2	2	100

None of the preceding fires in the compressor section was extinguished, however, the intensity of the fires was diminished greatly after agent discharge In the burner section extinguishment was rapid and positive From a study of these results, it was determined that either the rate of discharge or quantity of agent discharged into the compressor section was not adequate

The 1/4-inch o d lines in the compressor section were replaced by 3/8-inch o d lines in the same position as the second HRD configuration This more than doubled the discharge area in the compressor section In the tests evaluating the HRD system, modification no 2, the engine power remained at cruise setting for all runs Both DB and BT were used in various fill ratios in a 378-cubic-inch sphere Container pressurization was 400 psi JP-4 fuel was introduced into each engine bay from multiple sources to obtain maximum dispersion, but for the purposes of these tests, it still was considered as being one fire in each section Table XVII gives the test conditions and results for this configuration

TABLE XVII

EXTINGUISHING TEST CONDITIONS AND RESULTS
(High-Rate-Discharge System, Modification No 2)

Fire Location	Number of Fire Tests	Fuel to Fire (gpm)	Agent(1)	Quantity of Agent (lb)	Fill Ratio (Per Cent)	Fires Extinguished (No.)	(Per Cent)
3,4,8	2	4 6	DB	16 2	50 0	2	100
3,4,8	1	4 6	DB	13 0	40 0	1	100
3,4,8	1	4 6	BT	11 1	50 0	0	0
11,12	2	4 2	DB	16 2	50 0	2	100
11,12	1	4 2	DB	13 0	40 0	1	100
11,12	1	4 2	BT	11 1	50 0	1	100

(1) BT - Bromotrifluoromethane

DB - Dibromodifluoromethane

This was the final HRD system evaluated and its design is illustrated in Fig 7 After it was determined that 16 2 pounds of DB would extinguish a maximum fire in the engine bay, the amount of agent was decreased to determine the minimum quantity required for extinguishment Extinguishment was accomplished with quantities of DB as low as 13 0 pounds, or a 40-per-cent fill ratio However, there was no excess agent to cool the hot surfaces and the danger of reignition was great The one test using 11 1 pounds of BT was not conclusive because it

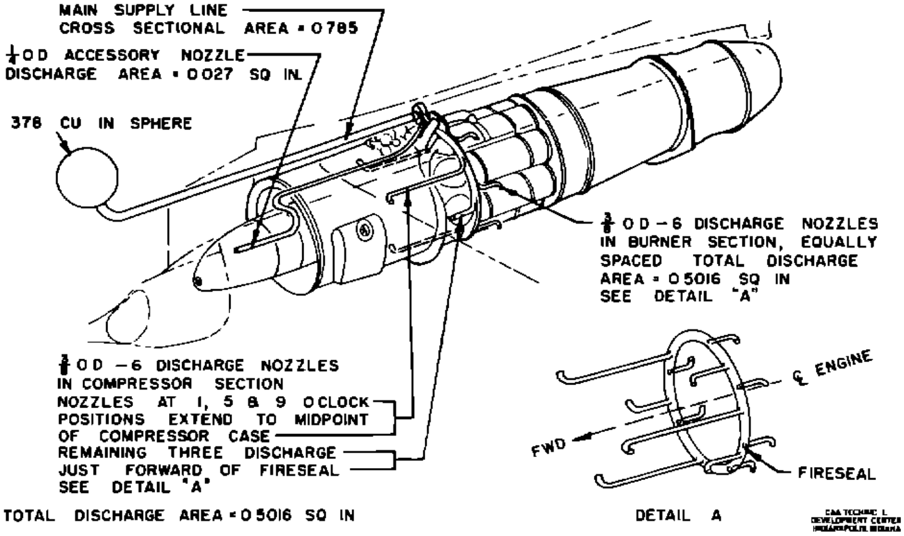

Fig 7 Final HRD System

extinguished the fire in the burner section but not in the compressor section, It was intended to investigate the capabilities of this agent further but at this point the doors on the engine bay of the test article had been burned away to the point where a tight seal could be maintained no longer Therefore, the fire tests on the F-89 test article were concluded

Discharge Duration and Distribution Measurements

The final HRD system was mounted on a framework in the same relative position as when installed inside the engine bay, and tests were run to determine the rate of discharge and the quantity of agent being discharged from each of the component lines These values were determined in the same manner as for the perforated tubing system described earlier in this report In both of these tests 13 5 pounds of CB were used as the agent Figure 8 shows the agent discharge time for the final HRD system This graph shows that the maximum discharge in the compressor section continued for 0 67 second and in the burner section for 0 65 second These two periods were overlapping for 0 44 second during which time all segments of the system were discharging their maximum quantities simultaneously The amount of agent discharged into the several compartments of the engine bay is shown in Table XVIII The quantity of agent being discharged from each nozzle was measured, however, in the table these quantities are totaled for the entire compartment because the variation between nozzles was small

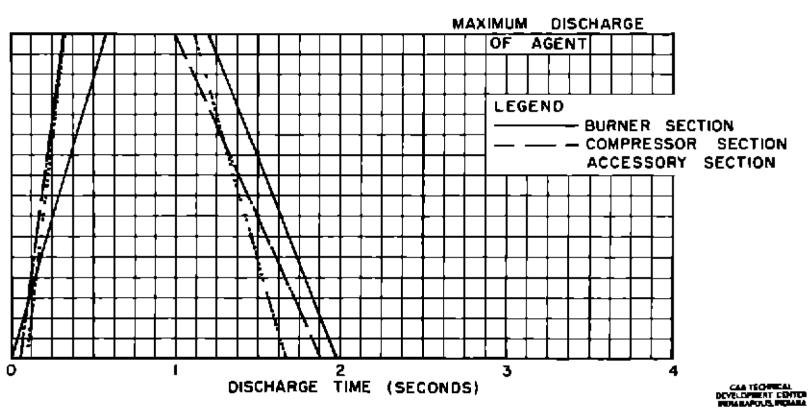

Fig 8 Agent Discharge Sequence

TABLE XVIII

AGENT DISTRIBUTION OF THE HRD FIRE-EXTINGUISHING SYSTEM

(Container charged with 13 5 pounds of CB[1] pressurized with nitrogen to 400 psi)

	Quantity of Agent	
	Measured (lb CB)	Per Cent of Total
Agent charge	13 5	100 00
Agent discharged from sphere	13 47	99 75
Agent remaining in sphere	0 03	0 25
Agent discharged by accessory nozzle	0 35	2 55
Agent discharged into compressor section	7 49	55 47
Agent discharged into burner section	5 34	39 51
Agent lost in lines	0 29	2 22
Total weight of agent discharged from system	13 18	97 53
Total container and line loss	0 32	2.47

(1) CB - Bromochloromethane, CH_2BrCl

It will be noted that the agent remaining in the sphere and lines after discharge was very small, indicating that the maximum quantity was utilized for fire extinguishment

GENERAL OBSERVATIONS

During the entire course of the fire tests, malfunctions of any items of either the powerplant installation or the fire extinguishing equipment were noted It is intended that this information will enable the manufacturers involved to improve their products further to increase the fire safety of aircraft in general

Deficiencies of the Perforated Tubing Agent Distribution System

Upon examination of the production perforated tubing discharge system after a number of fire tests, several deficiencies were noted Several of the discharge holes were covered in the installation by mounting clamps used to hold the tubing in position on the engine Metal shavings and burrs inside the discharge holes as a result of the drilling operation were forced back into the holes after discharge of the agent, resulting in restrictions of many of the holes Repeated discharge of the bromochloromethane resulted in corrosion of some of the holes, thereby sealing them so that the agent could not pass through

Deficiencies of Agent Containers

1 After the agent container had been discharged several times, some of the discharge holes in the perforated tubing system were found sealed as a result of the sealing compound used in the cartridge assembly (Walter Kidde Part No 931182)

2 In one instance the cartridge failed to fire

3 The frangible discs failed to rupture on one occasion, and on another, only a part of the segments were blown out of the disc resulting in restricted agent discharge

4 During the charging of a sphere a new disc was noticed to be leaking after pressurizing the sphere, allowing the nitrogen to escape slowly

Fire-Resistance of Components

After several large test fires in the engine bay, the cables by which the engine is lowered for inspection and maintenance were severely burned and weakened and failed on one occasion It is suggested that such cables be shielded from possible fire damage or be changed after a severe fire

During the conduct of the fire-extinguishing tests, considerable difficulty was encountered with the fires burning the wires which control the operation of the afterburner After a few 10-second fires, the afterburner would become inoperative resulting in a shutdown and a prolonged delay while the damage was being repaired The components which gave trouble repeatedly were

1 The soldered connections in the Cannon plugs and, in two instances, the Cannon plugs themselves, which melted under the heat of the test fires resulting in an open- or short-circuit This occurred in the electrical connections to the fuel valve, the air turbine valve, and the eyelid actuator valve

2 Control wires Many of the wires which control the afterburner and pass through the compressor section had little or no fire-resistance The primary wire on the afterburner ignition coil and the plastic insulated wire to the eyelid actuator valve are two of the wires which burned through and were replaced with high-temperature resistant wire in the course of the tests

3 Two hoses, namely, the fuel pressure vent line and the fuel valve solenoid vent line, were not fire-resistant

4 Relays In cases where short-circuits occurred, one or more relays in the afterburner relay box burned out

Fire Emergency Procedure

The general emergency procedure which worked best for this installation is the same as that found best for other similar installations Upon recognition of a fire the power of the engine is reduced to the minimum, all electric power to the engine is shut off, the flow of fuel, lubricating oil, and hydraulic fluid is stopped, and the fire extinguishing agent is directed to the engine on fire In the event of no agent discharge, the fire will gradually burn itself out once the flow of combustible fluids is stopped, the time required being dependent on the quantity of combustible fluids accumulated inside the engine bay

During the earlier phases of the tests, a direct comparison of the extinguishing characteristics of the system was obtained between emergency engine shutdown and no engine shutdown During 67 fire tests, it was found that the percentage of fires extinguished employing emergency engine shutdown procedures was 15 6 per cent greater than with no engine shutdown

Reliability of Recommended Fire Detector System

The detection of test fires by a continuous fire detector system and by a unit-type fire detector system installed in the test article prior to the tests confirmed the previous recommendations [3] During the conduct of the 234 extinguishing tests covered by this report the recommended unit-type detector system detected 89 4 per cent of the fires with an average alarm time of 3 86 seconds The continuous detector system, which was routed through both sections of the engine bay, detected 100 per cent of the fires with an average alarm time of 2 92 seconds

CONCLUSIONS

The conclusions drawn from the study follow

1 The F-89 perforated tubing system was not adequate for the control of in-flight engine fires

2 It is not practical to modify the F-89 perforated tubing system such that it will extinguish all fires in the engine bay

3 The HRD system shown in Fig 7 is effective in extinguishing fires occurring in the engine bay and resulting from flammable fluid system failures

4 The HRD system developed was superior in extinguishing effectiveness to the original F-89 perforated tubing system and all the configurations of this system which were tested

5 Bromochloromethane was not as effective an extinguishing agent as dibromodifluoromethane This is believed to be due primarily to the differences in physical characteristics, that is, volatility, upon discharge which affect agent utilization

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[3] Allen V. Young, "Fire-Detection Studies of the Northrop F-89 Power Plant," CAA Technical Development Report No 286, July 1956

6 Failure of the F-89 extinguishing system was the result of insufficient rate of agent discharge and distribution rather than inadequate quantity of agent

7 Atomization of CB during discharge of the F-89 perforated tubing system was not adequate as evidenced by the large quantities of liquid agent which poured from the engine bay following discharge

8 The minimum quantity of agent to effect extinguishment only is not sufficient Additional agent must be provided to cool the surfaces sufficiently to prevent reignition

9 Reignition can occur where the circumferential formers are deep or where accessories cause stagnant areas in which the fire can linger

10 After discharge of CB, corrosion will occur unless all aluminum parts are flushed

USCOMM-DC-55786