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Evaluation of the Fire-Detection and -Extinguishing Systems of the Navy XP6M-1 Airplane

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UNITED STATES DEPARTMENT OF COMMERCE

OFFICE OF TECHNICAL SERVICES

Evaluation of the Fire-Detection and -Extinguishing Systems of the Navy XP6M-1 Airplane

By

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Aircraft Division

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EVALUATION OF THE FIRE-DETECTION AND -EXTINGUISHING SYSTEMS OF THE NAVY XP6M-1 AIRPLANE*

SUMMARY

This evaluation of the fire-detection and -extinguishing systems of the Navy XP6M-1 airplane was made using a steel mockup of the XP6M-1 nacelle and a dummy engine. The airflows for flight and surface-operating conditions were simulated during the tests.

The fire-detection system was evaluated by igniting small test fires within the nacelle. The fire-extinguishing system was evaluated by conducting quantity and rate-measurement tests, by measuring extinguishing-agent concentrations during discharge of the system, and by full-scale fire-extinguishing tests.

The original continuous detector system, with elements mounted circumferentially, was found to be ineffective in detecting test fires in the lower half of the nacelle; however, a continuous system, with its elements mounted longitudinally in the lower portion of the nacelle, proved to be effective in alarming these same test fires.

Results of the evaluation tests of the fire-extinguishing system indicated that the system provided rapid discharge of agent, but its effectiveness in extinguishing fires was found to be marginal.

INTRODUCTION

Incorporated in the design and construction of the Navy XP6M-1 airplane by the Glenn L. Martin Company were a number of unusual fire-protection design features. These included the use of bromotrifluoromethane extinguishing agent, use of a high-rate-discharge (HRD) extinguishing system with open-end tubing outlets, and use of a continuous or wire-type fire-detection system. The nacelle design incorporated closely spaced transverse formers with deeply recessed spaces between them; this aggravated the problem of extinguishing-agent distribution. A rotary type of cooling airflow around the engine was used, creating conditions quite different from those used in any previous fire-detection and -extinguishing studies.

Because of the unusual fire-protection features involved in the design of the XP6M-1 powerplant, the Department of the Navy Bureau of Aeronautics desired that evaluation studies be made of the fire-detection and -extinguishing systems prior to flight tests of the airplane. The CAA Technical Development Center (TDC) undertook this project under sponsorship of BuAer. The studies covered by this report were completed in July 1955.

EQUIPMENT AND GENERAL PROCEDURE

The test article was a steel mockup of the No. 1 nacelle of the XP6M-1 airplane, with the outer casing of a J-71 engine installed. The XP6M-1 fire-detection system and the fire-extinguishing system were installed in the test article. Operational conditions of the XP6M-1 airplane were simulated within the nacelle by ducting air from two 1,750-hp blowers into the front of the nacelle and by extracting air from the rear of the nacelle with two 100-hp blowers arranged in tandem. This arrangement simulated the ram air entering the front of the nacelle in flight and the aspirator action of the jet exhaust on the rear compartment. An observation room adjacent to the test cell contained the control panel, time recorder, temperature gages, manometers, and other equipment used in the tests. A schematic layout of the facility is shown in Fig. 1.

For the detector tests, fire nozzles including a spark ignitor were installed in locations A through L in Zones 1 and 2 of the nacelle. See Figs. 2, 3, and 4. For extinguishing tests, fire nozzles were installed at locations 1 through 6, as shown in Fig. 5. These were chosen

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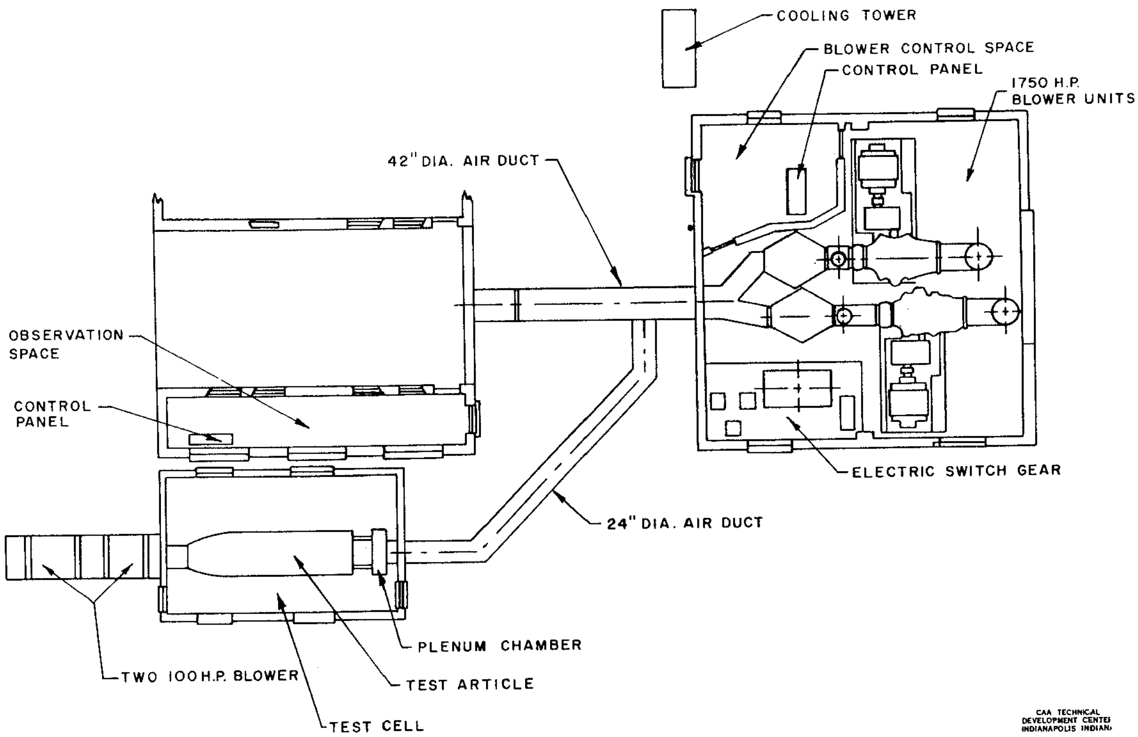


Fig. 1 Schematic Layout of Test Facility

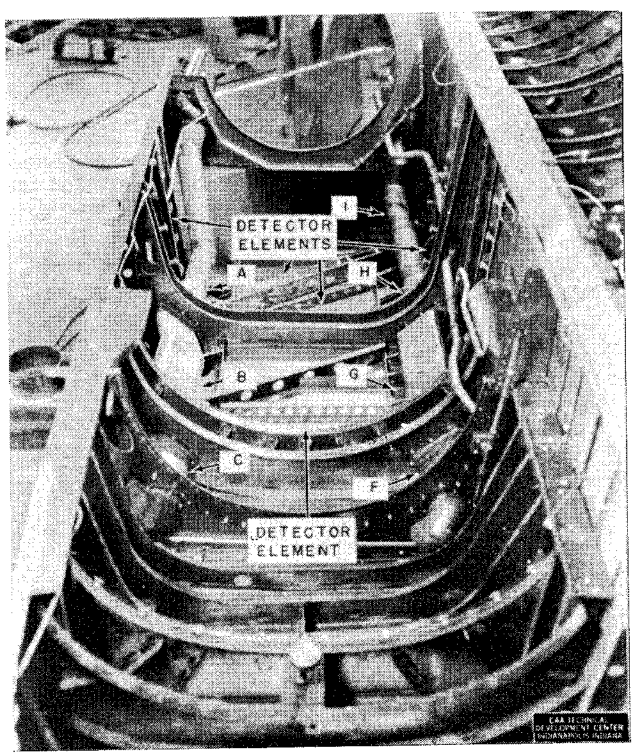


Fig. 2 Locations of Fire Nozzles and Detector Elements in Zone 1

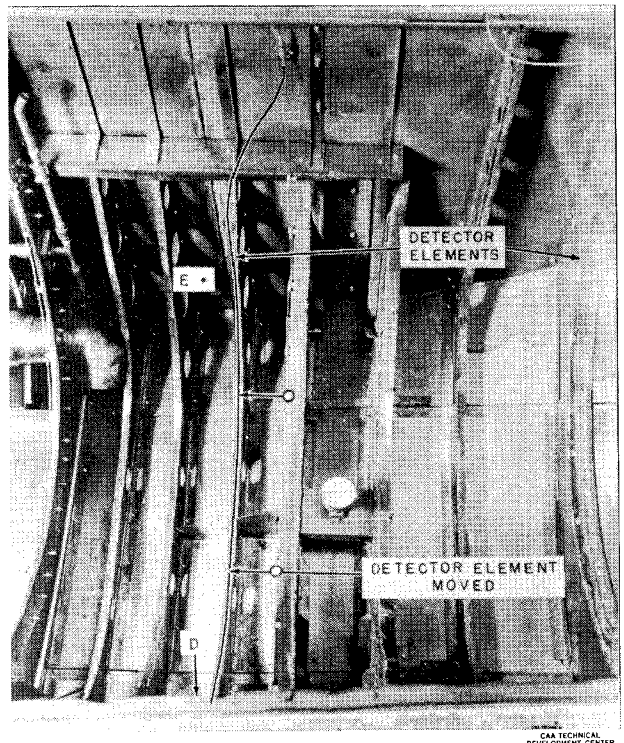


Fig. 3 Locations of Fire Nozzles and Detector Elements in Zone 2

because they are locations where fire hazards exist. Plexiglas windows were installed near all test-fire locations to permit observation of the fires and study of airflow patterns.

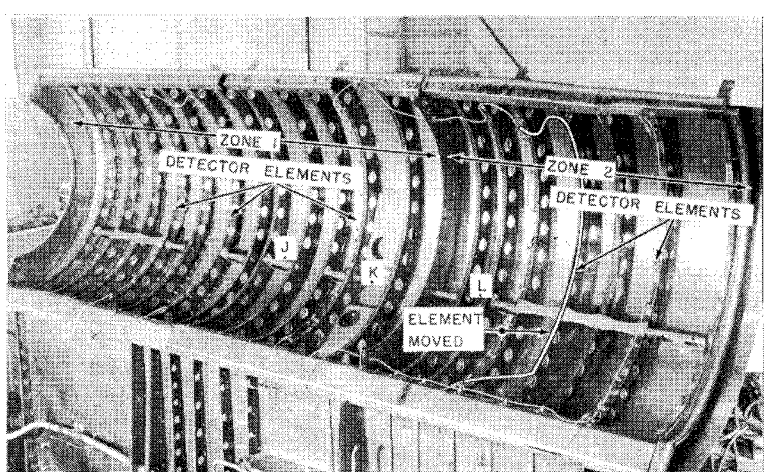


Fig. 4 Locations of Detector Elements and Fire Nozzles in Top Doors

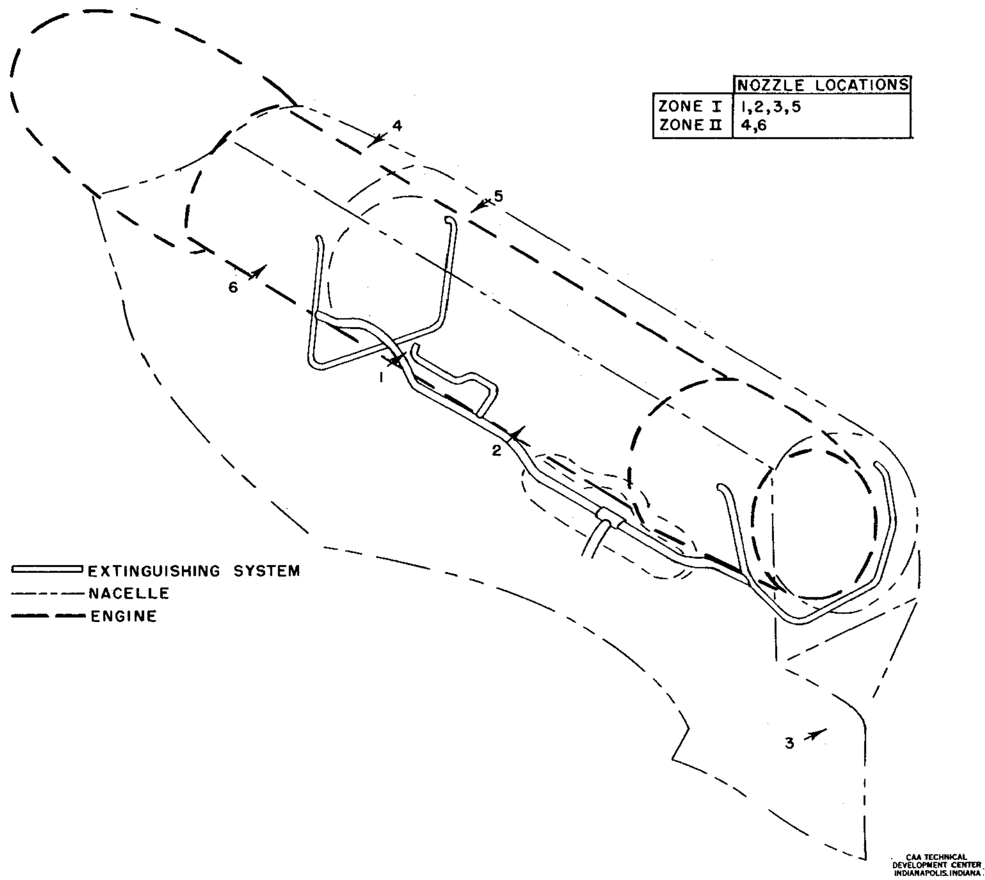


Fig. 5 Fire Nozzle Locations

EVALUATION OF THE ORIGINAL FIRE-DETECTION SYSTEM

Description of System.

A continuous-type detector system, manufactured by Walter Kidde and Company, Inc., was installed in the XP6M-1 nacelle mockup. The locations of detector elements were the same as for the airplane itself. They are shown in Figs. 2, 3, and 4. This system consisted of several sensing elements of various lengths and an amplifier used to signal an alarm. The total length of elements used was 55.8 feet. The control box was set to produce an alarm at an element resistance of 15,049 ohms. This represented an alarm setting at a minimum temperature of 500° F., with the entire length of element exposed.

Procedure.

The following procedure was used for conducting the fire-detection tests:

1. The rates of airflow through the nacelle required to simulate the test condition were established.
2. The test-fire ignitor was turned on and fuel flow was started from the fire nozzle.
3. The test fire was allowed to burn for 10 seconds or until detection occurred. After several tests were made at a given location and no detection occurred, a test fire was allowed to burn for 25 seconds.

An Esterline-Angus time recorder was used to record the sequence of events during each detector test. The test fires burned gasoline at rates of 0.238 or 0.37 gallon per minute (gpm). The recorded time for detection was the interval between the start of the fire and the instant a response was obtained from the detection system.

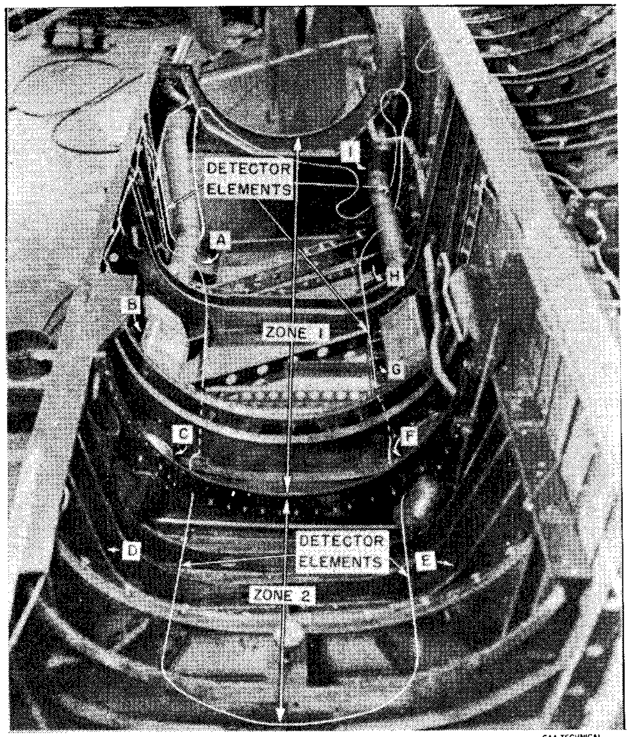


Fig. 6 Location of Longitudinal Detector System and Fire Nozzle

Results.

The data obtained from the evaluation tests are given in Table I. It may be noted that the system generally was ineffective in detecting the test fires.

From observations of the direction of flame travel at various locations in the lower half of the nacelle, the primary direction of airflow was noted to be circumferential rather than axial in both the compressor and rear zones. Test fires tended to parallel the circumferentially mounted detector elements, and it appeared that longitudinal mounting of the elements should be much more effective.

EVALUATION OF LONGITUDINALLY MOUNTED DETECTOR ELEMENTS

Description of System.

In view of the results obtained during the evaluation tests of the original XP6M-1 detector system, an additional system was installed in the test nacelle along with the original circumferential system.

In the new system, a continuous loop containing a total length of 44 feet of detector element was mounted in the lower part of the nacelle, principally in a longitudinal direction. See Fig. 6. It was routed to provide coverage of the forward air outlets and lower forward area of the nacelle. The direction of mounting was normal to the observed direction of airflow and fire. The control box was set to produce an alarm at an element resistance of 19,048 ohms. This represented an alarm setting at a minimum temperature of 500° F., with the entire length of element exposed.

Procedure.

The test procedure was similar to that used in the evaluation of the original fire-detection system. Test-fire locations were the same as for the previous evaluation tests in the lower nacelle regions. See Fig. 6. Additional locations in the upper nacelle areas also were used. They are shown in Fig. 4.

TABLE I

RESULTS OF TESTS OF THE ORIGINAL XP6M-1 FIRE-DETECTION SYSTEM WITH CIRCUMFERENTIALLY MOUNTED ELEMENTS

Operating Condition Simulated	Measured Airflow Zone 1 (pps) *	Measured Airflow Zone 2 (pps) *	Test Fire Fuel Rate (gpm) **	Alarm Time for Fires at Various Locations (Seconds) Zone 1 A	B	C	F	G	H	I	Zone 2 D	E
Flight	3.5	7.8	0.24	X	4.0	X	X	X	4.0	X	7.0	X
Flight	3.5	7.5	0.37	9.75	2.5	24.5	X	6.0	2.5	X	3.5	5.0
Surface	3.3	9.6	0.24	X	6.0	X	X	7.0	8.5	X	X	5.5
Surface	3.2	9.3	0.37	X	3.0	X	X	2.5	5.25	X	X	6.5

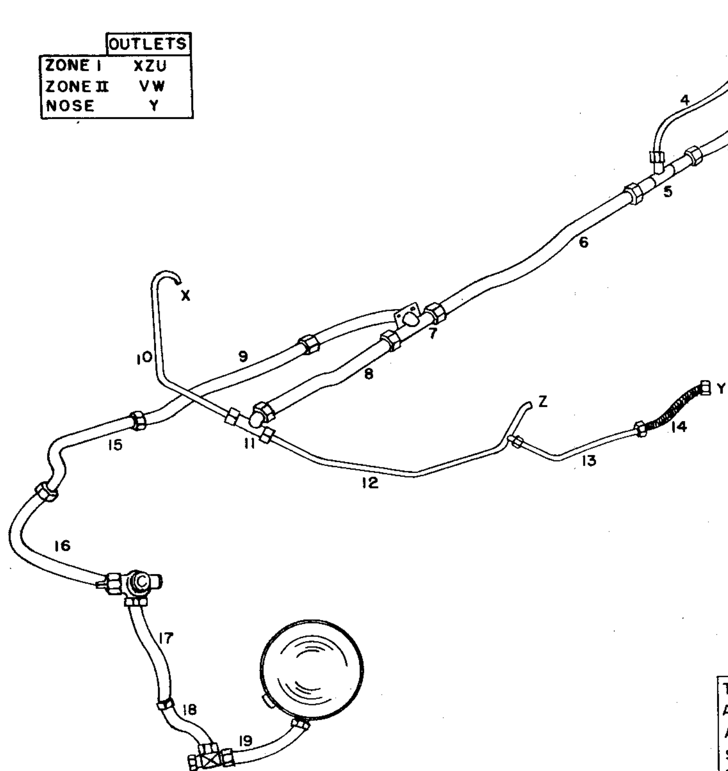
X indicates that no alarm occurred in 25 seconds.

* The airflows supplied for test purposes were intended to simulate conditions in the XP6M-1 nacelle. This was not possible in Zone 2 under flight conditions with the facilities available. Estimates of airflows provided by the Glenn L. Martin Company were as follows:

Flight operation: Zone 1 - 3.5 pounds per second; Zone 2 - 16.0 pounds per second.
Surface operation: Zone 1 - 3.3 pounds per second; Zone 2 - 10.7 pounds per second.

** Aviation fuel, 100/130 octane.

OUTLETS	
ZONE I	XZU
ZONE II	VW
NOSE	Y



NO.	LENGTH	I.D	TUBE VOLUME CUBIC. INCHES
1	81	.585	26.7
2	15	.585	4.05
3	22	.944	15.4
4	28.5	.585	7.7
5	FITTING		
6	38.5	1.180	42.0
7	FITTING		
8	18.5	1.180	20.1
9	44.5	1.430	69.6
10	23	.694	8.68
11	FITTING		
12	46	.694	17.45
13	18	.335	1.59
14	10	.335	.92
15	57	1.430	90.8
16	50	1.430	85.0
17	29	1.370	42.7
18	41	1.370	60.3
19	24	1.370	35.3
TOTAL VOL. OF TUBING			523.29
APPROX. VOL. OF FITTINGS			50.5
APP. VOL. TUBE & FITTINGS			573.79
SPHERE VOLUME			945
TOTAL VOLUME OF SYSTEM			1518.75

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Fig. 7 XP6M Fire-Extinguishing System

Results.

For comparison, the results of the tests conducted simultaneously on the system with elements mounted longitudinally in the lower portion of the nacelle and the original system, with circumferentially mounted elements, are given in Table II. All test fires in the lower portion of the nacelle were detected by the longitudinal system. All fires in the upper portion except at location K, Fig. 4, under simulated flight operation, were detected by the original circumferential system. In the lower regions of the nacelle, the detector elements mounted longitudinally provided much better detection than those mounted circumferentially.

EVALUATION OF THE FIRE-EXTINGUISHING SYSTEM

Description of System.

The XP6M-1 fire-extinguishing system provided by the Glenn L. Martin Company is shown in Fig. 7. For test purposes, tubing, fittings, directional valve, and agent container were connected in the same manner as in the XP6M-1 airplane.

In the original design of the system by the manufacturer, quantity requirements were determined by the formulas given in Specification MIL-E-5352, paragraph 3.3.1, as follows:

$$Q = (0.56)(Wa) + (0.16)(V) \qquad (1)$$

where

Q = pounds of agent required for extinguishment

Wa = pounds of air flowing through the zone per second (standard cruise condition)

V = net volume of zone, in cubic feet.

TABLE II

RESULTS OF TESTS ON CIRCUMFERENTIAL AND LONGITUDINAL FIRE-DETECTION SYSTEMS

Condition	Measured Airflow Zone 1 (pps)	Measured Airflow Zone 2 (pps)	Detector System	Alarm Time for Fires at Various Locations* (Seconds) Zone 1: A	B	C	F	G	H	I	J	K	Zone 2: D	E	L
Surface	3.04	9.04	Circumferential	X	2.1	X	X	4.0	5.8	X	8.5	4.7	X	X	9.0
			Longitudinal	2.2	1.25	4.5	2.8	2.8	2.75	5.5	**	**	7.75	2.8	**
Flight	3.54	7.72	Circumferential	X	2.1	X	X	6.7	2.3	X	7.4	X	4.0	X	5.0
			Longitudinal	4.5	2.0	9.5	2.0	1.5	2.4	5.7	**	**	1.5	6.8	**

X indicates that no alarm occurred in 25 seconds.

* Test-fire fuel rate = 0.37 gallon per minute of aviation gasoline.

** No longitudinal elements were installed in upper half of nacelle.

The original values of airflow, zone volumes, and line-loss factor supplied by the Glenn L. Martin Company are as follows:

	Airflow (pounds per second)	Volume (cubic feet)
Zone 1	2.10	82.0
Zone 2	6.6	27.0
Nose Compartment	0.3	2.4

Line-loss factor = 0.0083

Agent-quantity calculations are as follows:

Nose Compartment:
$Q = (0.56)(0.30) + (0.16)(2.40) = 0.552$ pound.

Zone 1:
$Q = (0.56)(2.10) + (0.16)(82) = 14.275$ pounds.

Zone 2:
$Q = (0.56)(6.6) + (0.16)(27.0) = 8.01$ pounds.

Line Losses:
Q = line length times cross-sectional area of tube times 0.0083
= 525 times 0.851 times 0.0083 = 3.71 pounds.

Total = 26.547 pounds.

The revised estimated airflow data received from the Glenn L. Martin Company for conditions of engine shutdown during enactment of flight fire-emergency procedure are as follows:

Zone 1 = 6.08 pounds per second.

Zone 2 = 9.86 pounds per second.

Agent-quantity calculations using the revised airflow data are as follows:

Nose Compartment:
$Q = (0.56)(0.30) + (0.16)(2.40) = 0.552$ pound.

Zone 1:
$Q = (0.56)(6.08) + (0.16)(82) = 16.52$ pounds.

Zone 2:
$Q = (0.56)(9.86) + (0.16)(27.0) = 9.84$ pounds.

Line Losses:
Q = line length times cross-sectional area of tube times 0.0083
= 525 times 0.851 times 0.0083 ≠ 3.71 pounds.

Total = 30.07 pounds.

All full-scale evaluation studies of the extinguishing systems were conducted using the same quantity of agent (27 pounds) and pressurization (580 psi) to be used in the XP6M-1 airplane. The airflows used for the tests are shown in the tables. The agent container was a Walter Kidde 945-cubic-inch sphere equipped with a valve outlet for 1 1/2-inch-OD tubing. Calculated fill ratio was 50 per cent.

Scope of Tests.

The evaluation of the XP6M-1 fire-extinguishing system was accomplished by:

1. Measuring the distribution of agent to each zone.
2. Determining the duration and rate of agent discharge.
3. Measuring the agent concentrations resulting from the discharge of the system under simulated flight and surface conditions.
4. Determining the effectiveness of the system in extinguishing fires under simulated flight and surface-operating conditions.

Agent Distribution.

In order to determine the amount of extinguishing agent discharged into each zone, containers were placed at each nozzle outlet to collect the liquid discharged during a test. The extinguishing bottle was filled to 50 per cent capacity and was pressurized with nitrogen to 400 psi for each test. Two tests were conducted using 16.9 pounds of water, and one test was conducted using 27.44 pounds of bromochloromethane.

The results of the distribution measurements made on the XP6M-1 extinguishing system are given in Table III. This table shows the average quantities discharged from all nozzles in each zone for two tests, one using water and one using bromochloromethane. The quantities are given as percentages of the total charge in the agent container. For purposes of comparison, the calculated quantity required and desired distribution of bromotrifluoromethane also are shown.

TABLE III

RESULTS OF DISTRIBUTION TESTS
ON THE XP6M-1 EXTINGUISHING SYSTEM

Agent	Total (pounds)	Quantity Discharged (per cent of total) Zone 1	Zone 2	Nose Compartment	Loss
Water	16.9	48.4	41.6	0.8	9.2
Bromochloromethane	27.44	44.0	47.9	0.7	7.4
Bromotrifluoromethane*	30.6	55.0	32.0	1.8	11.2

* These are not test values, but they indicate the calculated desired distribution.

Duration and Rate of Discharge Measurements.

A consecutive sampler was used to determine the discharge time of a nozzle. This sampler consisted of a track 16 feet long and 8 inches wide, and a cart containing 48 cans, each 1 1/2 inches by 3 inches in size and 47 inches deep. The cart was drawn by a hydraulic actuator along the full length of the track at a constant speed of 15 cans per second. The sampler was located so that the nozzle was above the cans and the liquid discharged into them as they passed. A microswitch located on the track completed the circuit to the detonator of the extinguishing bottle containing the agent, thereby effecting the discharge of the agent at the moment the first can started to pass under the discharge nozzle.

Tests were conducted on nozzle Z in Zone 1 by discharging water, and on nozzle W in Zone 2 by discharging water in the first test and bromochloromethane in the second test. Figures 8 and 9 show the discharge rate of agent for each bucket plotted against time for outlet nozzles Z and W. It may be noted in Fig. 8 that the discharge of agent from nozzle W of Zone 2 began later than the discharge of agent from nozzle Z in Zone 1, and it was of longer duration. The duration of effective discharge was approximately 1.7 seconds for bromochloromethane at nozzle W in Zone 2.

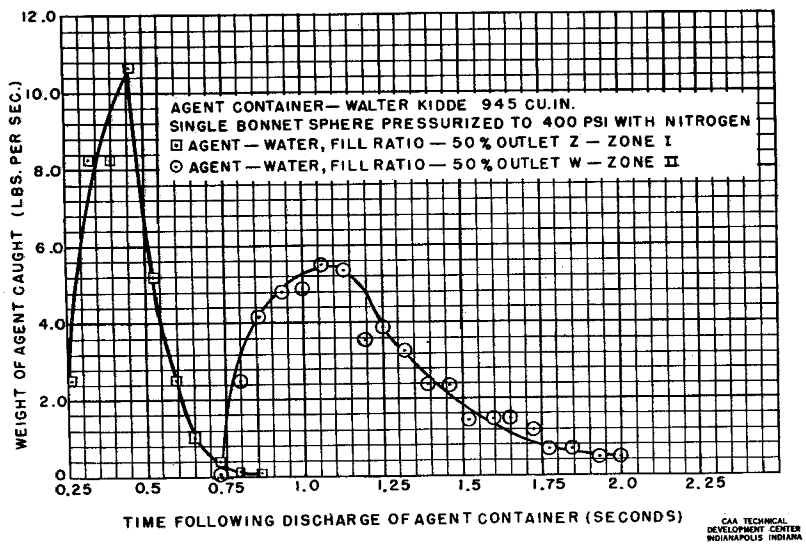

Fig. 8 Rate of Discharge from Extinguisher Outlets Z and W

Agent Concentration Measurements.

Extinguishing-agent concentration measurements were obtained by using a gas analyzer.[1] Sampling tubes were installed at 18 locations throughout Zones 1 and 2 of the nacelle. See Figs. 10, 11, and 12.

The following procedure was used for measuring the extinguishing-agent concentrations:

1. Approximate rates of airflow through the nacelle were established to simulate the test condition.
2. Operation of the gas analyzer was started.
3. The extinguishing system was discharged and agent concentrations were recorded.

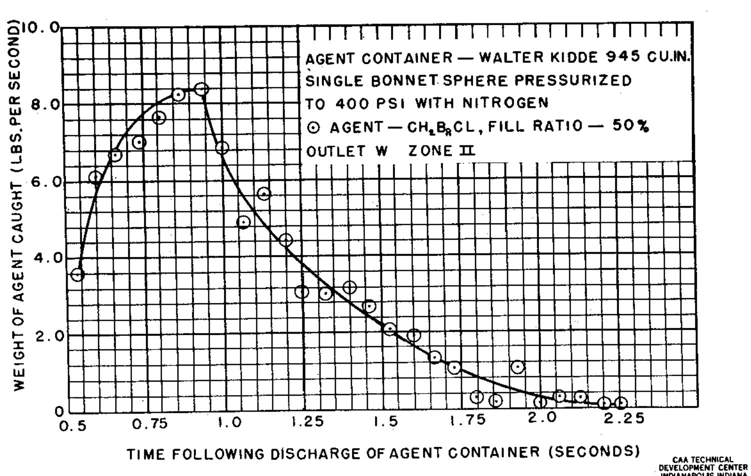

Fig. 9 Rate of Discharge from Extinguisher Outlet W

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[1] 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.

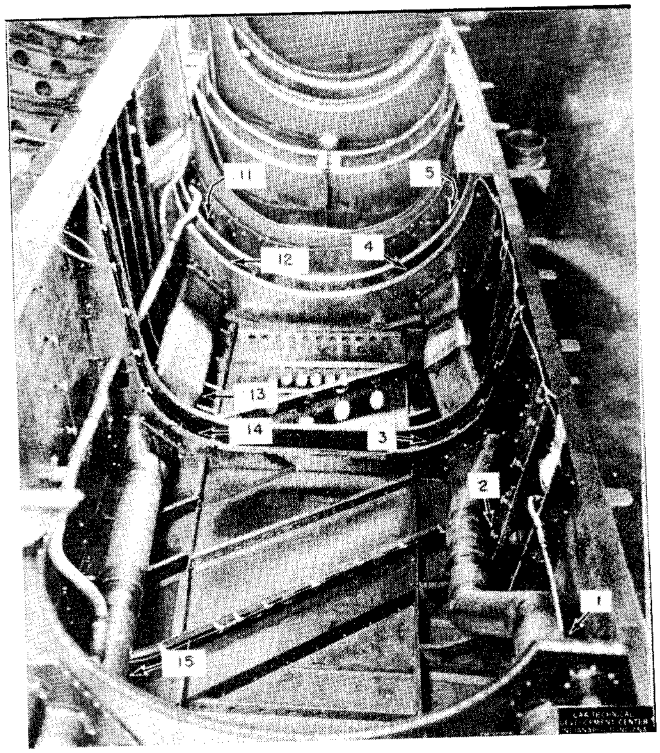

Fig. 10 Location of Sampling Tubes in Zone 1

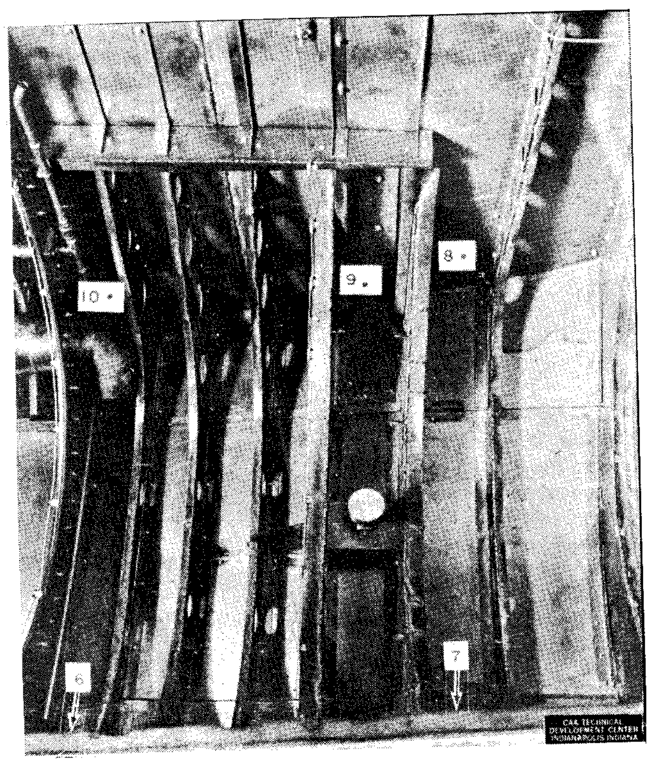

Fig. 11 Location of Sampling Tubes in Zone 2

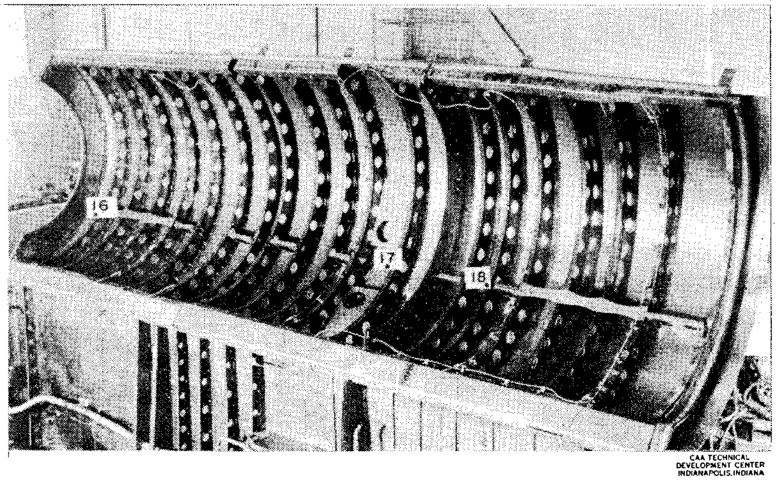

Fig. 12 Location of Sampling Tubes in Top Doors

Agent concentration measurements were conducted under simulated flight and surface conditions using bromotrifluoromethane agent pressurized with nitrogen to 580 psi. The results of the agent concentration tests are shown in Table IV. It will be noted that some of the concentrations in the upper areas of the nacelle are below the minimum of 15 per cent desired for assuring extinguishment.

Fire-Extinguishing Tests.

A series of nine fire-extinguishing tests was conducted under simulated flight conditions existing after enactment of flight fire-emergency procedures. A series of six test runs was made under simulated surface-operating conditions existing with engine power on. The test fires used for extinguishing tests burned JP-4 fuel at the rate of 4.92 gpm. Methyl bromide, pressurized to 580 psi with nitrogen, was used as the extinguishing agent in all of the tests except the two final tests. These were conducted under simulated flight conditions using bromotrifluoromethane as the extinguishing agent.

After establishing approximate rates of airflow through the nacelle required to simulate the test condition, the procedure for conducting the fire-extinguishing tests was as follows:

	Elapsed Time from Start (seconds)
1. Ignitor and primer fuel were turned on.	0
2. Main fuel (JP-4) to fire was turned on.	5
3. Ignitor and primer fuel were turned off.	10
4. Extinguishing agent was discharged.	15
5. Main fuel to fire was turned off.	25

The results of the fire tests are shown in Table V. The one failure which occurred under simulated surface conditions was in the upper region of Zone 2 and in an area of low agent concentration. See Table IV, pickup location No. 18.

TABLE IV

EXTINGUISHING-AGENT CONCENTRATION MEASUREMENTS

Test Condition	Airflow Zone 1 (pps)	Airflow Zone 2 (pps)	Amount of Agent (lb.)	Maximum Per Cent Concentration at Pickup Locations* Zone 1: 1	2	3	4	5	11	12	13	14	15	16	17	Zone 2: 6	7	8	9	10	18
Flight** 480 Knots	6.26	8.18	27.7	15	30	17	35	25	32	32	30	25	12	10	67	15	36	39	6	16	7
Surface***	3.39 (reverse flow)	9.35	27.6	51	51	54	43	30	17	42	62	67	46	51	25	23	19	22	14	46	2

* See Figs 10, 11, and 12 for pickup locations.

** Following enactment of flight fire-emergency procedure (engine shut down). Estimated airflow for XP6M-1 airplane: Zone 1 - 6.08 pounds per second; Zone 2 - 9.86 pounds per second.

*** Engine on full power. Estimated airflow for XP6M-1 airplane: Zone 1 - 3.3 pounds per second, reverse flow; Zone 2 - 10.7 pounds per second.

TABLE V

RESULTS OF FIRE-EXTINGUISHING TESTS

Test No.	Test Condition	Measured Airflow Zone 1 (pps)	Measured Airflow Zone 2 (pps)	Extinguishing Agent*	Weight of Agent (lb.)	Fire Location** (see Fig. 5)	Fire Extinguished
1	Flight***	5.53	7.70	CH_3Br	31.0	1	Yes
2	Flight	5.80	8.20	CH_3Br	27.5	1	Yes
3	Flight	5.46	7.40	CH_3Br	28.0	2	Yes
4	Flight	5.42	7.48	CH_3Br	27.5	3	Yes
5	Flight	5.40	7.40	CH_3Br	27.5	5	Yes
6	Flight	5.28	7.23	CH_3Br	27.5	6	Yes
7	Flight	5.54	7.64	CH_3Br	27.0	4	Yes
8	Surface****	3.06*****	8.62	CH_3Br	26.5	4	No
9	Surface	3.07*****	8.65	CH_3Br	27.0	6	Yes
10	Surface	3.72*****	8.92	CH_3Br	27.0	1	Yes
11	Surface	3.57*****	9.01	CH_3Br	27.25	2	Yes
12	Surface	3.53*****	8.90	CH_3Br	27.0	3	Yes
13	Surface	3.50*****	9.12	CH_3Br	27.0	5	Yes
14	Flight	5.90	8.15	CF_3Br	27.5	1	Yes
15	Flight	5.95	8.20	CF_3Br	27.0	6	Yes

*Extinguishing agent in 945-cubic-inch spherical container was pressurized with nitrogen to 580 psi.

**Test-fire fuel (JP-4) rate was 4.9 gallons per minute.

***Flight conditions: Following enactment of flight fire-emergency procedure (engine shut down). Estimated airflows for XP6M-1 airplane: Zone 1 - 6.08 pounds per second; Zone 2 - 9.86 pounds per second.

****Surface conditions: With engine at full power. Estimated airflows: Zone 1 - 3.3 pounds per second, reverse flow; Zone 2 - 10.7 pounds per second.

*****Reverse flow.

CONCLUSIONS

As a result of the evaluation testing of the XP6M-1 fire-detection and fire-extinguishing systems, it is concluded that:

1. The original circumferential fire-detection system is inadequate. The detector elements installed to encircle the engine are not in the most advantageous positions because the airflow primarily is circular.
2. The additional longitudinal fire-detection system was effective in alarming fires occurring in the lower half of the nacelle.
3. The values listed in Table III for water and bromochloromethane indicate that less agent is discharged into Zone 1 and somewhat more agent is discharged into Zone 2 than is specified by the design calculations for CF_3Br.
4. The duration of extinguishing-agent discharge from any outlet of the system is less than two seconds.
5. The extinguishing-agent concentration measurements indicate that the extinguishing system will produce adequate concentrations of agent for extinguishing fires in most areas of the nacelle. Low concentrations were recorded in the upper areas of the nacelle, however.
6. The results of the full-scale fire-extinguishing tests indicate that fires can be extinguished in all areas except the upper area of Zone 2 where a failure to extinguish a fire occurred under simulated surface conditions.

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