DETERMINATION OF MEANS TO SAFEGUARD AIRCRAFT FROM POWER-PLANT FIRES IN FLIGHT

PART VI

THE NORTH AMERICAN TORNADO
(AIR FORCE XB-45)

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SUMMARY

The results of an investigation of the fire-protection measures incorporated in the design of the North American XB-45 airplane power plant are presented. The study included the evaluation of the existing fire-prevention and fire-control measures and the development of improved measures where needed. Tests were conducted under simulated flight conditions and represented the first flight-fire studies conducted on a modern jet power plant by the Technical Development and Evaluation Center of the Civil Aeronautics Administration. Results of the investigation are presented in three sections entitled (1) Fire Detection, (2) Fire Extinguishment, and (3) Design Aspects of Fire Protection.

The effectiveness of the unit type of fire-detection system used in the XB-45 test article and in B-45 production-model airplanes is indicated, and means for improving these systems are presented. The continuous type and the volume type of fire detectors which are now in the late stages of development were installed in the nacelle and were tested. The system requirements and the performance under the conditions of testing are given.

Evaluation tests on the XB-45 fire-extinguishing system indicated that the distribution and the rate of discharge of the carbon dioxide extinguishing agent by the system were generally in accordance with the original design calculations for the system. The results of the fire-extinguishing tests and of carbon dioxide concentration measurements indicated that provisions for extinguishing fires in the aft compartment of the nacelle were adequate and that such provisions in the forward compartments of the nacelle were inadequate. This inadequacy was due to ineffective sealing which resulted in compartment air flows in excess of the original design values on which the extinguishing requirements were based.

A comparative analysis indicated that the B-45 production-airplane extinguishing system is somewhat less effective than the XB-45 system, and although probably adequate for extinguishing nacelle aft-compartment fires, the B-45 system is inadequate for extinguishing nacelle forward-compartment fires. Methods for improving the effectiveness of the extinguishing system are presented.

The flight-fire emergency procedure for B-45 aircraft was analyzed, and suggested improvements are presented.

The influence of the engine-inlet air pressure and of the engine rpm on the effectiveness of the XB-45 extinguishing system was determined by measurements of the carbon dioxide concentration and by fire tests. High engine-inlet pressures seriously reduced the extinguishing effectiveness in the forward nacelle compartments, but they had little effect in the aft compartment. High engine rpm reduced the effectiveness somewhat in all compartments.

There is presented a comparative analysis which indicates that the effectiveness of the carbon dioxide extinguishing system may be increased by discharging the agent from open-end tubing rather than from perforated tubing.

A comparison of extinguishing agents is made on the basis of quantity requirements when the XB-45 perforated-tubing extinguishing system was utilized and when an open-end-tubing system was utilized.

The factors of design and construction of the XB-45 power plant which were beneficial and those which were detrimental to the prevention and control of fires are presented and discussed.

INTRODUCTION

Fire protection of turbojet-powered aircraft is a subject which has been of immediate concern to the military services and to aircraft manufacturers during postwar years. It is also of interest to the CAA because of the prospective use of such aircraft commercially and because of the desire on the part of this agency to aid in providing maximum operational safety. Fire testing of the power plant of the North American XB-45 airplane was a result of this mutual interest.

The test nacelle was received from the Department of the Air Force in September 1949, and actual testing commenced in April 1950 The program was essentially completed in September 1951, although use of the power plant for special studies which were requested by the Department of the Air Force continued beyond that date

The general purpose of the investigation was to obtain information pertinent to the prevention and control of fires in the XB-45 and the B-45 airplane power plants The interpretation and the application of test results in the design of turbojet power plants was also of primary interest The method used in investigating fire protection in the XB-45 power plant consisted of an evaluation of existing design and the development of improved design where a need for such development was indicated

TEST FACILITY

The tests were conducted at the TDEC, Indianapolis, Indiana A photograph and a schematic layout of the test facility utilized are shown in Figs 1 and 2 This facility consisted essentially of a test chamber, a control room adjacent to the chamber, and two large blowers which supplied air to the engines The control room contained the engine-control panel , temperature recorders, a multiple manometer, and other equipment used in the conducting of the tests A view of this room and of the equipment is shown in Fig 3

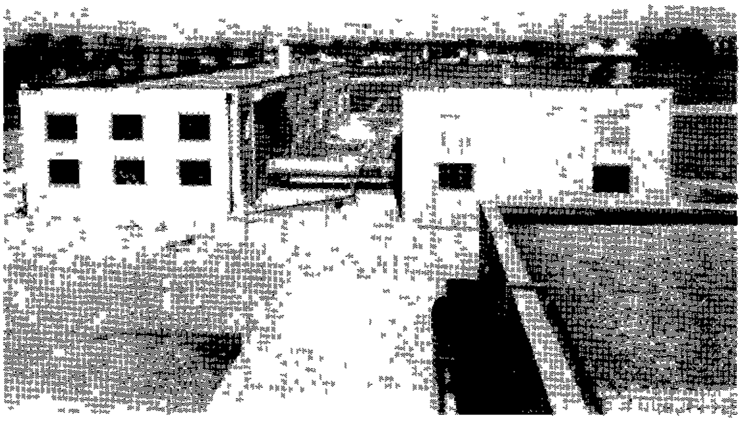

Fig 1 Turbojet Fire-Test Facility

TEST ARTICLE

The test article was the right-hand twin-engine nacelle of a North American Tornado medium bomber (Air Force XB-45, Serial No 45-59479) A photograph of the airplane is shown in Fig 4 The nacelle on which tests were conducted is shown installed in the test chamber in Fig 5

The test nacelle, an integral part of the airplane-wing center section, housed two Allison turbojet engines (Models J-35-A-9 and -11) rated at 3750 pounds thrust each at 7700 rpm Air intake was at the forward end of the nacelle, and exhaust discharge was at the aft end Access to the engines and to the attachment points was provided by the use of removable hinged doors located on the forward lower inboard and outboard side of the nacelle and made from 1/4-inch aluminum flak plate for protecting the engine Access to the exhaust tail pipe was provided by three removable sections which comprised the aft lower portion of the nacelle Small inspection doors were provided in the upper portion of the nacelle for access to the oil-tank filler caps, the spark plugs, and the engine connections Louvers, ducts, and openings were provided for compartment ventilation, drainage, and venting

Each engine was supported by two horizontal-trunion type of mounts near the engine midpoint and by a steady support assembly that connected the top forward mounting point of the aft frame of the engine to the nacelle structure The two side mounts transmitted the engine

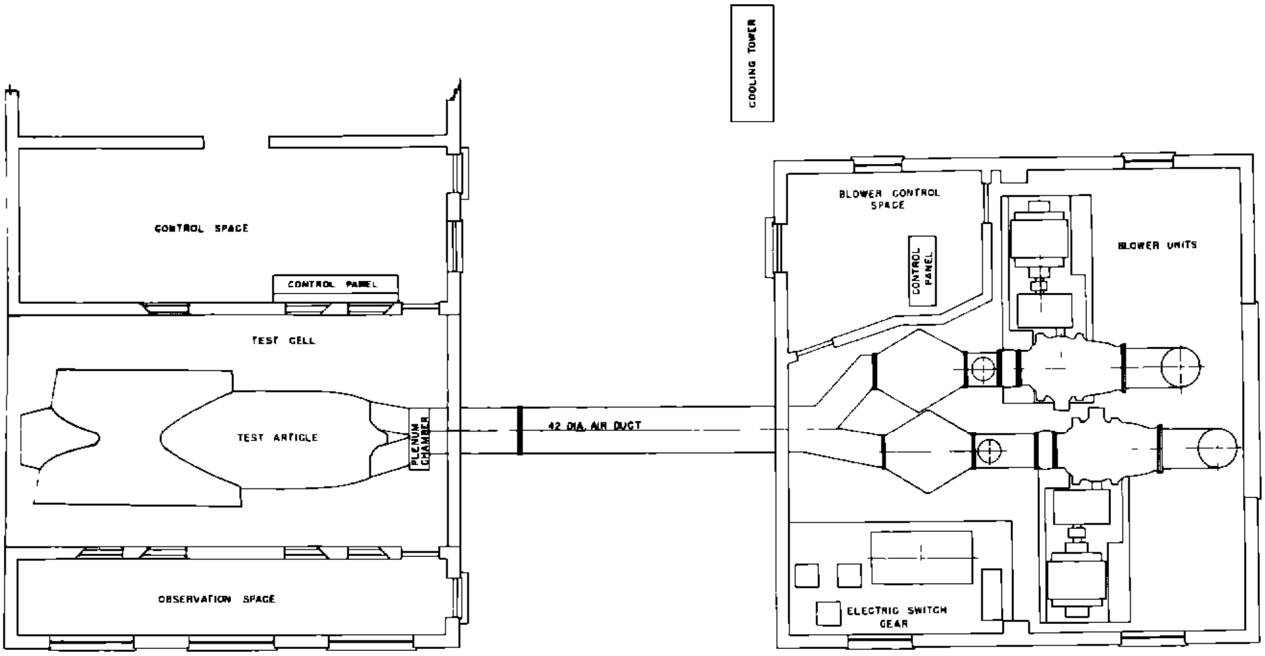

Fig 2 Schematic Layout of Turbojet Fire-Test Facility

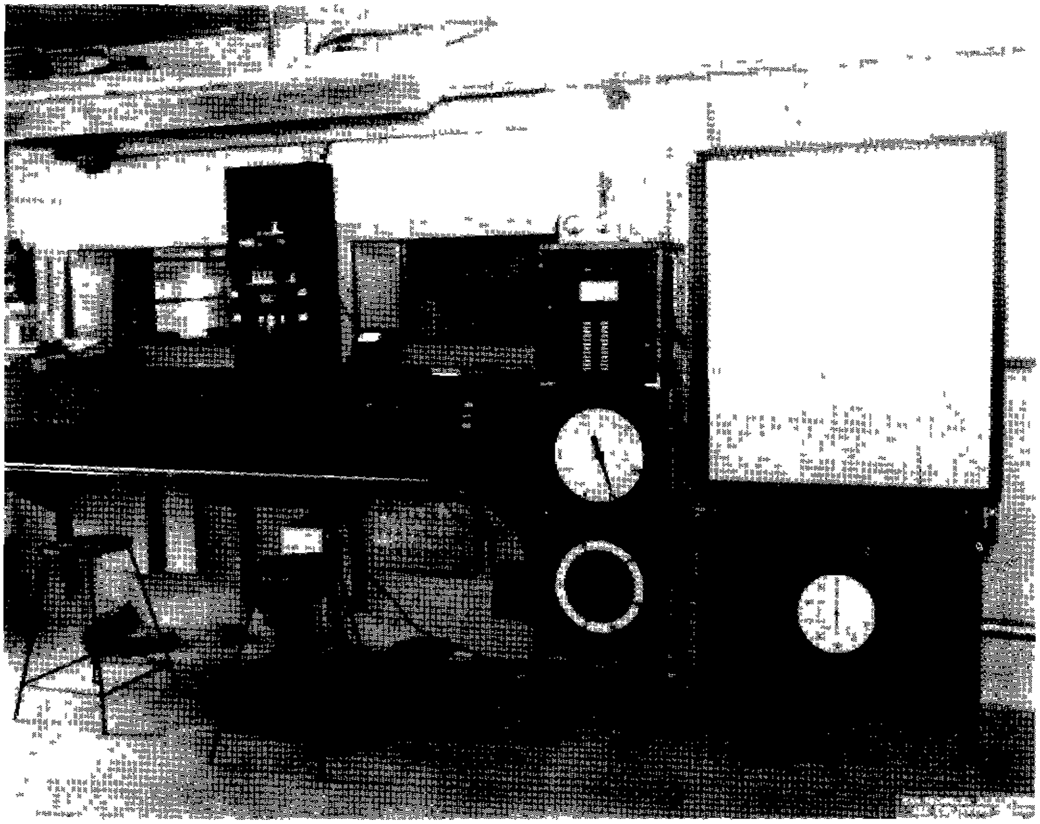

Fig 3 Control Room and Instrumentation

Fig 4 North American "Tornado"

loads to the nacelle, and the adjustable steady support permitted vertical alignment of the engine A view of the No 4 engine installed in its mounting position is shown in Fig 6

The nacelle was divided into three compartments by stainless steel fire walls, as indicated in Fig 7 These compartments were designated (1) No 3 engine-compressor compartment, (2) No 4 engine-compressor compartment, and (3) nacelle aft compartment Each compressor compartment housed an engine-gear case and a compressor case and contained numerous combustible-fluid, compressor air-bleed, and engine-drain lines as well as the spark-ignition harness and the oil tank The compressor compartments were separated from the engine air inlets by engine air-guide seals (see Fig 6) They were also separated from the nacelle aft section by stainless steel fire walls The aft compartment was common to the burner can, turbine, tail-cone and tail-pipe sections of both engines

The primary nacelle compartments were ventilated by the use of flush-type louvers and aspirators as shown and described in Fig 7 Insulation of the nacelle aft structure from exhaust-system heat was provided by insulating blankets and by ventilating air Isolation provisions of the nacelle consisted of

1 A transverse fire wall separating the compressor compartments from the aft compartment
2 A longitudinal fire wall separating the compressor compartments
3 A stainless steel housing around the main fuel strainer and the fuel lines and fittings located along the nacelle keel structure, which was also of stainless steel
4 Stainless steel shields protecting the wing structure, the main landing-gear trunion, and the fuel cell
5 Stainless steel construction of the extreme aft portion of the nacelle to provide resistance to exhaust heat and fire

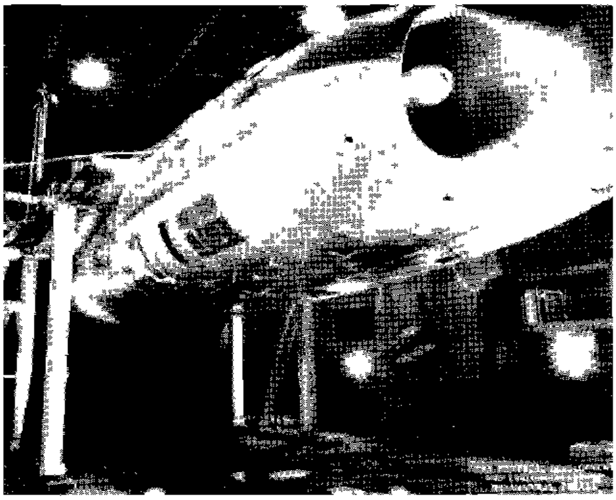

Fig 5 Test Nacelle

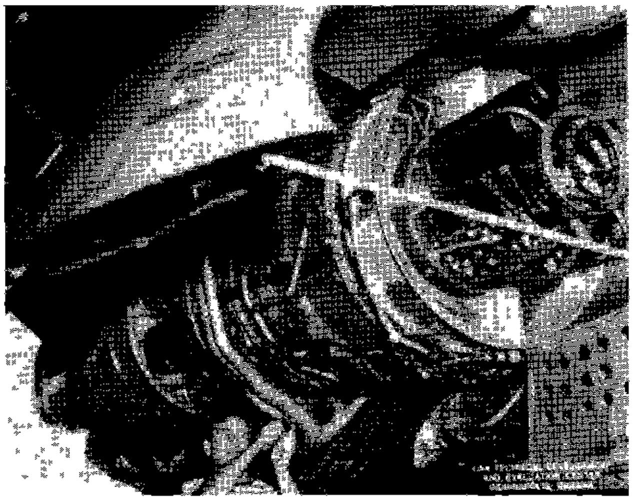

Fig 6 No 4 Engine Installation

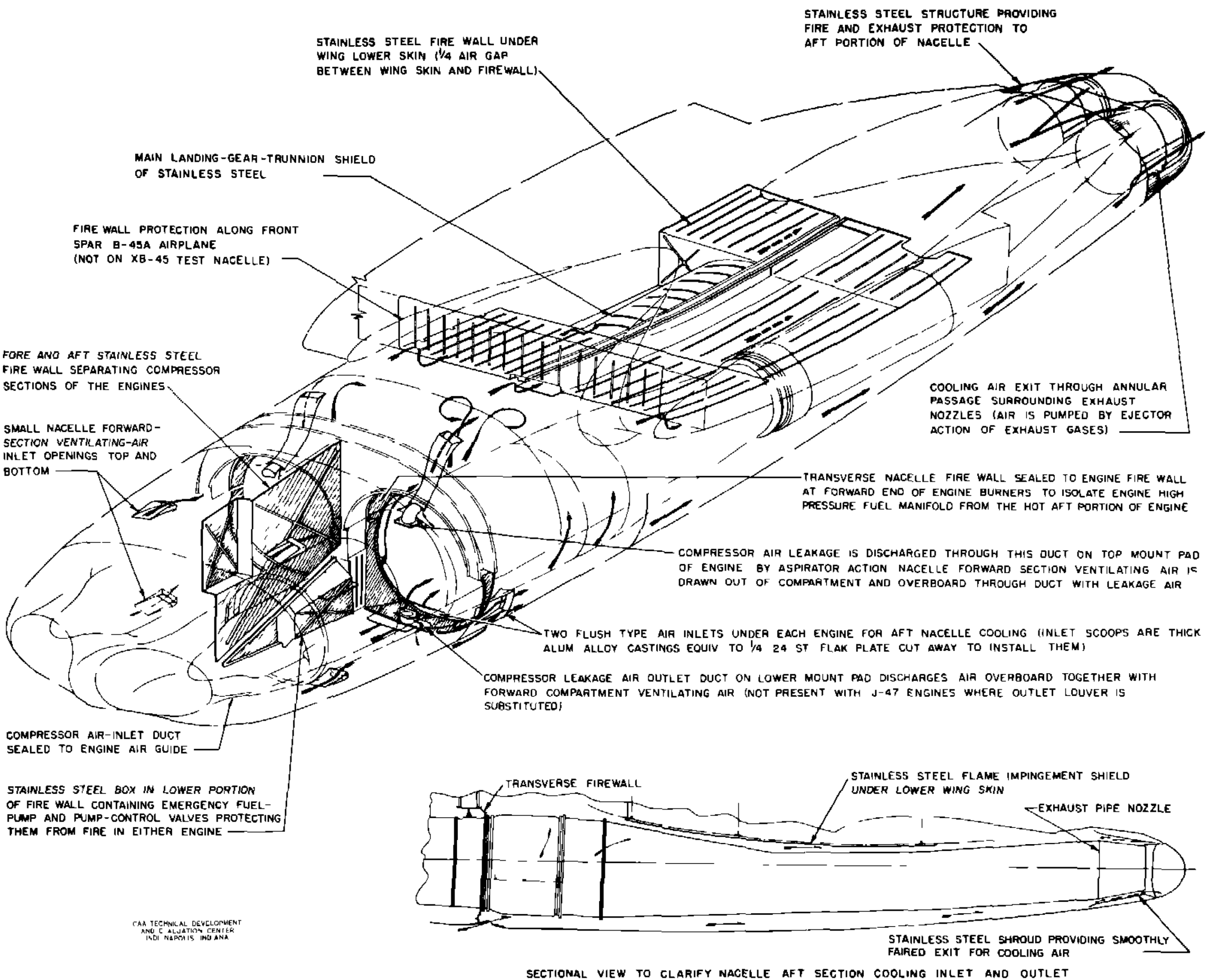

Fig 7 B-45 Nacelle Ventilating and Insulating Provisions

In addition to the primary nacelle compartments, the power plant included an engine-accessory compartment at the front end of each engine These compartments were housed by bullet-shaped aluminum cowl pieces bolted to the engines They each contained the fuel, oil, and hydraulic pumps, the fuel regulator, the alternator, the starter generator, the tachometer, and the necessary connecting lines which pass across the engine air inlet through islands to the compressor compartment A view of the No 4 engine-accessory compartment uncovered is shown in Fig 6 The cowl piece which covers the compartment is shown in position in Fig 8 Within the compartment, a separate blast tube provided the generator with cooling air

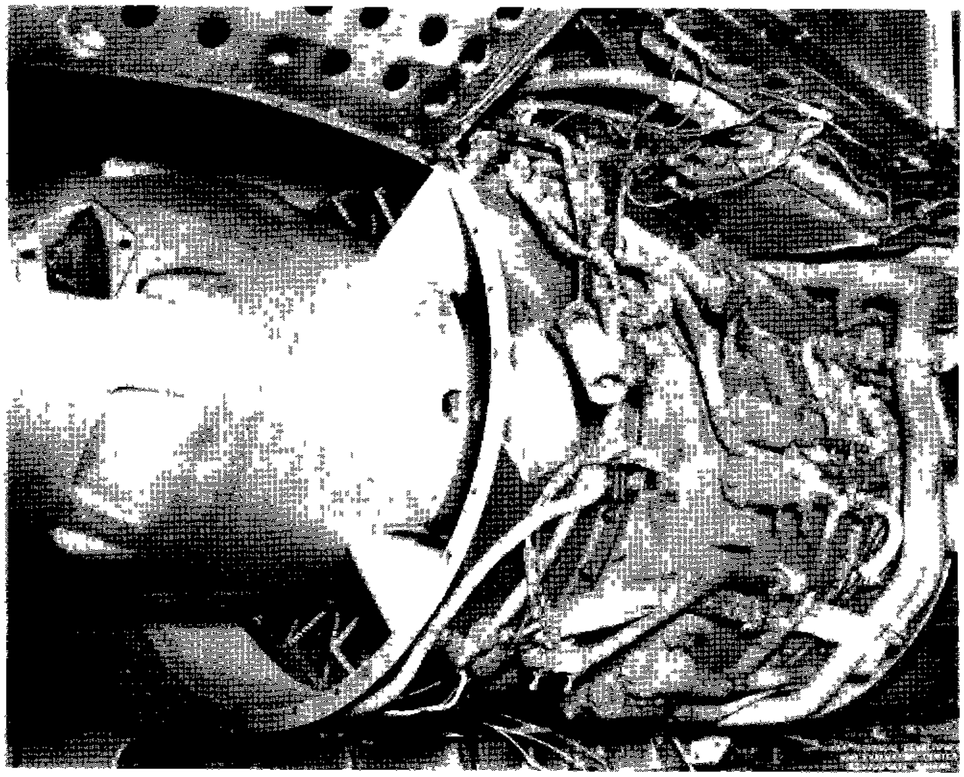

Fig 8 Engine Air-Guide and Accessory-Section Arrangement

Modifications were made on the power-plant test article prior to fire testing These modifications included

1 Removal of the fuel bladder cells located in the wing structure above the aft compartment of the nacelle Fuel lines were connected to the main fuel filter from the facility pump room to provide engine fuel and fuel for test fires
2 Covering of the engine spark-plug ignition coils with asbestos and water glass to protect them from damage by test fires
3 Closing all cabin air-heater ducts
4 Disconnecting and plugging the anti-icing system
5 Making the hydraulic system inoperative
6 Disconnecting the engine generators from the battery

FIRE DETECTION

Objectives

The objectives of this phase of study were (1) to evaluate the detector systems used in the XB-45 and in B-45 aircraft and to make recommendations for improving such systems, (2) to determine requirements for continuous and volume types of detector systems installed in the XB-45 power plant, and (3) to obtain information on the operating characteristics of the various systems used in the tests

Scope

Tests were conducted on fire-detection systems of the unit type, the continuous type, and the volume type Unit-type systems are those which utilize sensing elements that occupy a point in the nacelle space and that operate from excessive temperature or excessive rate of temperature rise at or immediately surrounding that point Continuous-type detectors are those which occupy a line in the nacelle space and are similar in shape to a wire This type operates from excessive temperature or excessive rate of temperature rise at any location in the nacelle space occupied by and surrounding the wire Volume-type detectors are those which "see" or monitor a volume in the nacelle space and which will operate from the occurrence of fire anywhere within its volume of vision

Tests on the various systems were conducted to obtain data regarding these objectives

1 The number or length of sensing elements necessary in each nacelle fire zone to give satisfactory coverage
2 Desirable and effective locations of sensing elements for each fire zone
3 Desirable and effective mounting or positioning of sensing elements in each fire zone

When practical to do so, the following additional information was obtained

4 The time required for each system to alarm in full-scale testing
5 The sensitivity of the systems
6 The operation and maintenance characteristics of the system

Procedure

The investigation of fire detection in the XB-45 airplane power plant consisted essentially of tests on various detector systems rather than on individual sensing elements of these systems Such tests were made by causing gasoline fires to occur at different locations within nacelle compartments and by observing the ability of the separately installed systems to detect them The tests were conducted in most instances with engines operating at normal cruising rate (from 88 to 92 per cent maximum) and with ram pressure provided at the engine inlets Test fires were of sizes which would not seriously damage the nacelle structure within ten seconds

The study of unit and continuous types of detector systems involved an investigation of the air-flow and flame patterns occurring in each compartment This was accomplished by observing, through Plexiglas windows installed on the sides of the nacelle, the flame patterns and conditions existing during a fire Thermocouples mounted within the compartments and connected to recording pyrometers were also used to determine effective sensing-unit locations

No testing was considered necessary for establishing requirements for the engine-accessory compartments because of their small size A single unit-type detector element within these compartments was believed to provide adequate coverage

Since the nacelle structure was essentially symmetrical about a vertical longitudinal plane, tests were conducted on one side only

TESTS ON UNIT-TYPE DETECTORS

Description of Systems Tested

The Edison Type A rate-of-rise detector system originally installed by the air-frame manufacturer and a Fenwal overheat detector system installed in the test nacelle by TDEC personnel were used in the determination of unit-type fire-detector requirements

The Edison fire-detector system as installed in XB-45 and B-45A airplanes consisted of four separate warning circuits, one for each engine Each circuit contained 21 detector units wired in series, a sensitive relay, a slave relay, a thermal test unit, and a fire-warning light The full-scale fire-detection tests on the Edison system were conducted with the sensing elements located and mounted as shown in Fig 9 The system was that installed by the air-frame manufacturer except for the changes indicated on the drawing The resistance of the Edison

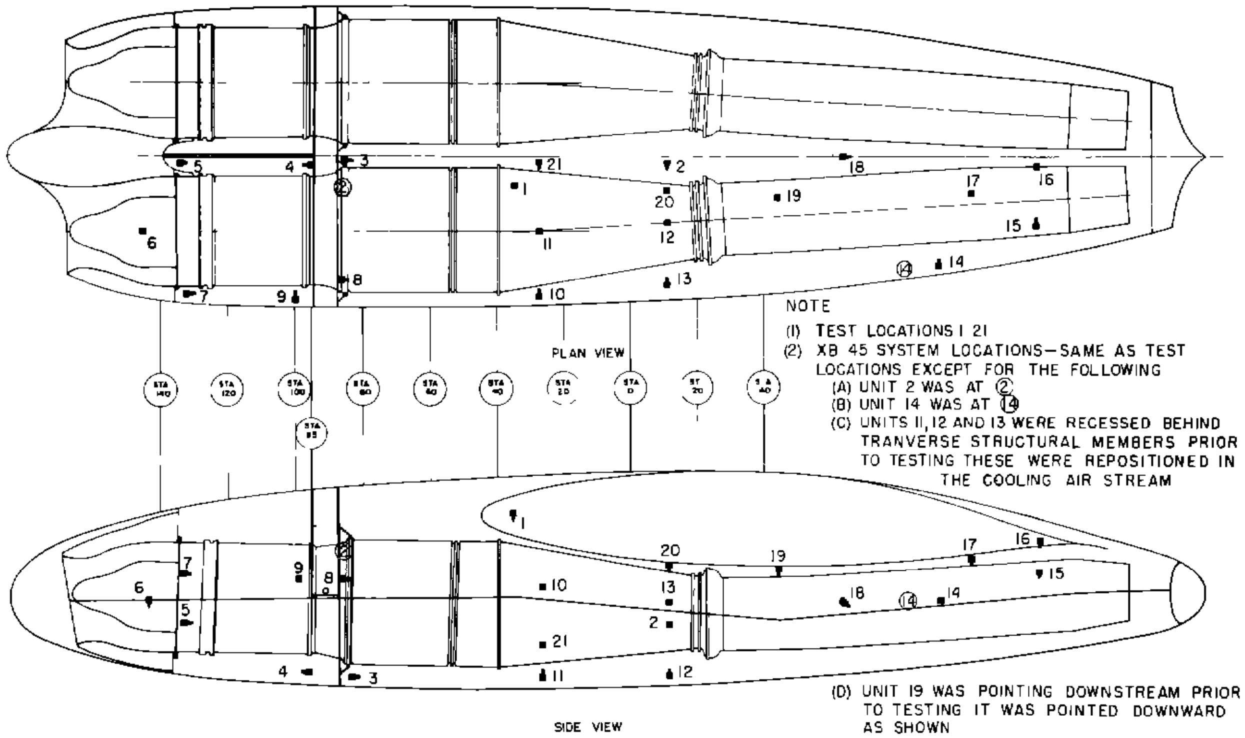

Fig 9 Test Locations of Edison Detectors, No 3 Engine, XB-45 Nacelle

circuit was

Resistance of sensing-element circuit = 3 6 ohms
Resistance of sensitive relay = 3 4 ohms

The Fenwal sensing elements (Model 17343-7) were the thermoswitch type of overheat units which operated by the difference in coefficient of expansion of two dissimilar metals and which were factory-set to operate at 525° F Sensitivity of the Fenwal system was unaffected by the number of elements in the circuit or by circuit resistance The Fenwal overheat detector system used on B-45C airplanes consisted of eight separate circuits, two for each engine The forward-nacelle circuit for each engine contained one sensing element in the engine-accessory compartment and three elements in the compressor compartment, plus a single element located in the fuel-line compartment and common to both engine circuits The aft-nacelle circuit for each engine contained nine elements plus a single element located between and common to both engine circuits The mounting positions of the Fenwal sensing elements in the test installation were similar to those used in B-45C aircraft and are indicated in Fig 10

Procedure

Requirements for unit-type detectors were determined by separate studies and tests which were conducted in the No 3 engine-compressor compartment and on the No 3 engine side of the nacelle aft compartment Fire testing was conducted by igniting gasoline released at a rate of 0 6 gallons per minute (gpm) for 10 seconds from 1/4-inch pinched-end supply lines placed at various positions within the nacelle During the tests, both engines were operated under simulated flight conditions The fire pattern and effective detector-unit locations were determined by the observation of fires through Plexiglas windows, by the use of thermocouples, and by the use of individually connected detectors

The test-fire locations were selected as being representative of locations of potential fire hazards such as flammable-fluid leaks or burner-can failures For the No 3 compressor-compartment tests, fire locations corresponded to those shown in Fig 11 for the No 4 engine The fire locations used in the aft-compartment tests are listed in the tables of results and are illustrated in Fig 11

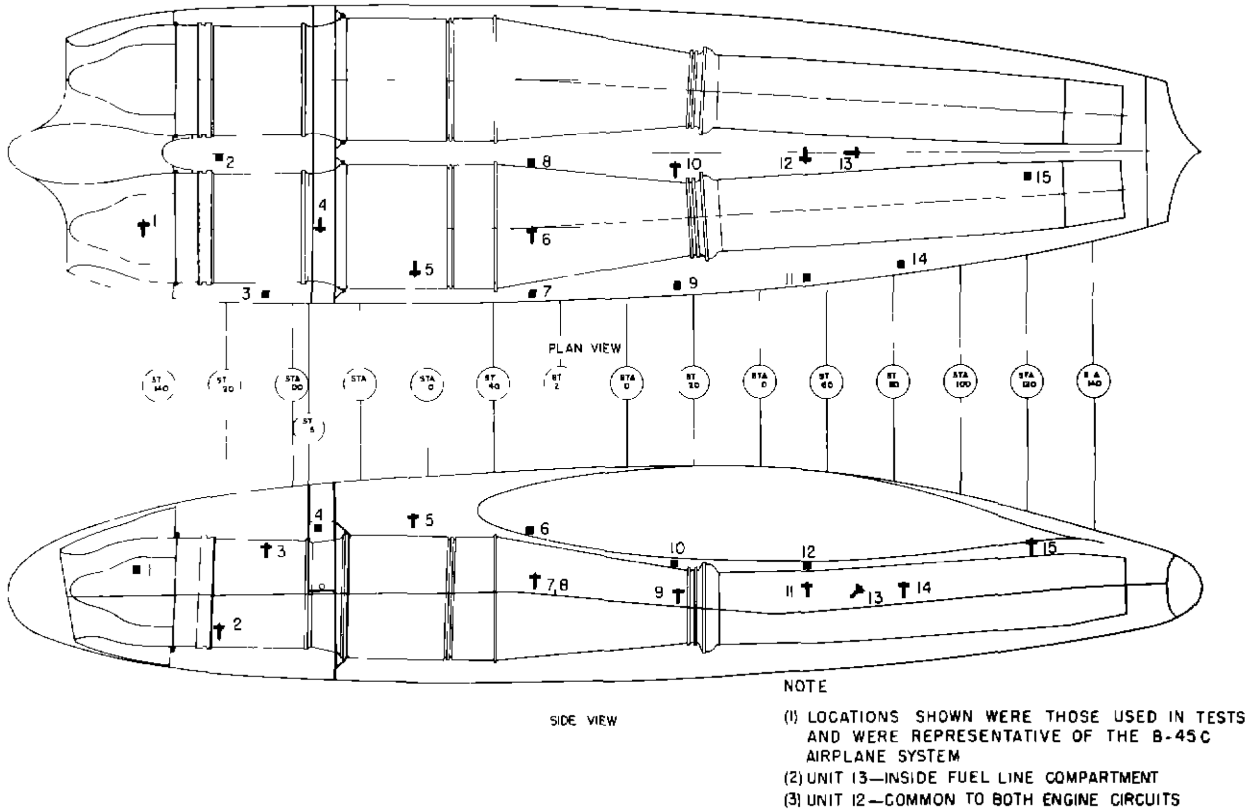

Fig 10 Test Locations of Fenwal Detectors, No 3 Engine, XB-45 Nacelle

Results and Discussion

A Compressor-Compartment Tests

During tests in which air was supplied to the engine inlets to simulate the pressures existing for normal flight, test fires were observed to be of a blow-torch nature indicative of high air flow There was no evidence of a collection of excess fuel, and fire emerged from inlet and outlet nacelle louvers The fire pattern indicated that positive pressures existed in the compartment because of ram-air leakage and because of ineffective sealing between the compressor compartment and the engine inlet duct Such leakage was not in accordance with design intention However, subsequent inspection of operating B-45 aircraft indicated that appreciable leakage existed around the seal in production models Test conditions in the XB-45 were therefore considered representative of service conditions in this respect

Fire tests conducted with thermocouples and with detector sensing elements both mounted in the inlet and outlet louvers of the No 3 engine-compressor compartment showed that these openings were effective locations for detecting compartment fires Test results indicated that the bottom outlet louver, the bottom inlet louver, and the top outlet and inlet louvers, respectively, were the most effective and dependable locations Detectors in the outlet louvers were mounted in the annular opening between the ejector exhaust and the louver duct

Tests were conducted with the engine-inlet static pressure at zero gage, thereby eliminating the effect of leakage around the air-guide seal Under these conditions, the fires were observed to be of a type indicative of low, nondirectional air flow An excess of fuel was noted to exist during the tests and to drain toward the aft portion of the longitudinal fire wall and keel structure which separate the two engine-compressor compartments This drainage pattern caused a concentration of fire in the area adjacent to the fire wall, regardless of the position at which fuel was released or ignited Temperature surveys made in this area with thermocouples indicated that maximum temperatures occurred approximately six inches above the bottom doors adjacent to the fire wall and in the rear half of the compartment Both Edison and Fenwal sensing elements mounted in this region consistently detected the fires

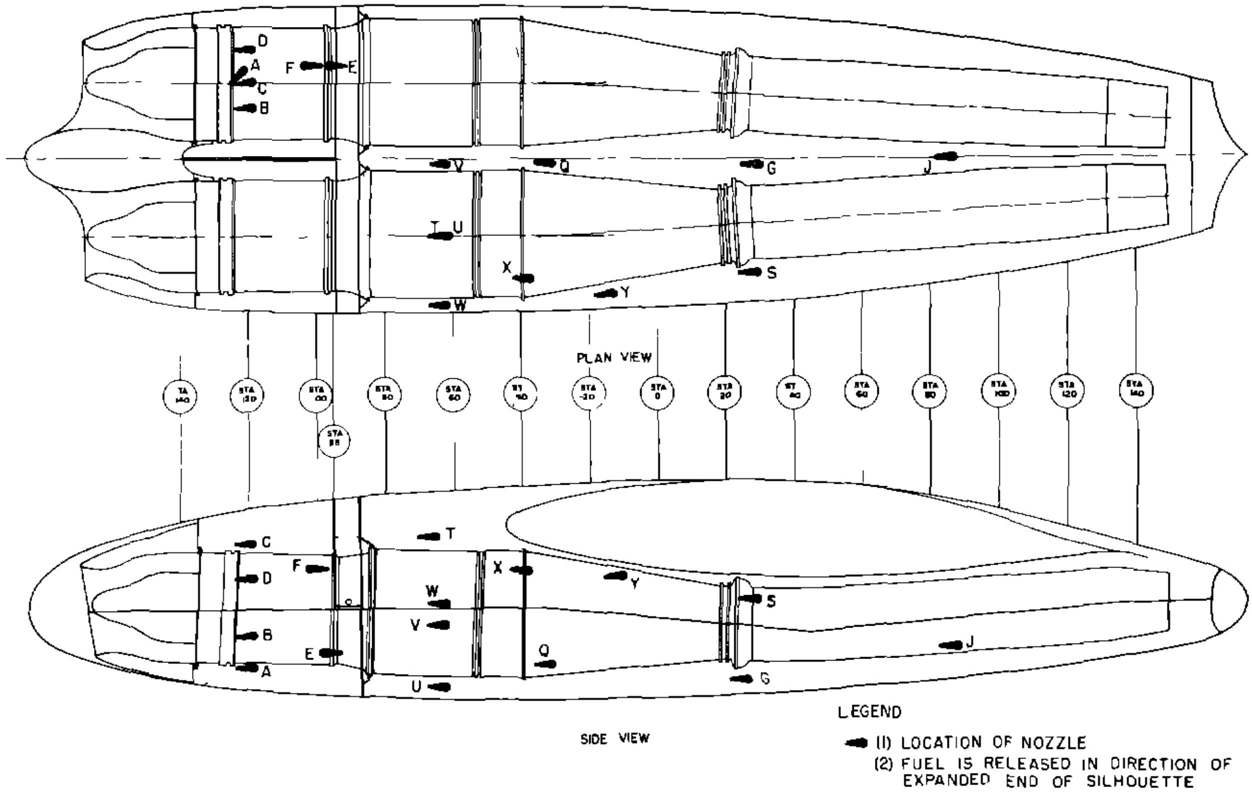

Fig 11 Fire-Nozzle Locations for Detector and Extinguishing Studies, XB-45 Nacelle

The average time for alarm was 6 seconds by the Edison system and 14 seconds by the Fenwal system Subsequent bench tests on three of the Fenwal sensing units indicated that, when they were exposed to a 1500° F flame in accordance with Society of Automotive Engineers (SAE) specifications AS-401, their operation was slow The time for operation was in excess of the 5-second requirement of this specification

B Aft-Compartment Tests

Results of the fire tests conducted in the aft compartment are shown in Table I, which lists the time required for alarm by each detector system and also lists the individual Fenwal elements causing an alarm From Table I, it will be noted that the Edison system detected the fires at all nine fire locations with the exception of Location J, which was aft of the fuel strainer The Fenwal system detected the fires at all nine locations with the exception of Location U (lower burner-can region) and Location J All Fenwal sensing elements detected one or more of the test fires

Additional testing indicated that a single sensing element mounted 12 inches from the keel and 24 inches aft of the fuel strainer on the aft bottom nacelle door would detect fires at Location J

The velocity of cooling air flow through the aft compartment was noted to be relatively high This was indicated by observation and by air-flow measurements It resulted in fire being carried large distances downstream Fires originating near the forward end of the compartment adjacent to the engine burner cans were detected by sensing elements as far as 13 feet downstream However, detectors placed at the ejector outlet did not detect such fires The placement of sensing units below the engine in the lower nacelle regions was found to be desirable because drainage of flammable fluids was toward these areas The relatively high-velocity channeling of cooling air in the aft compartment permitted effective detection of fires by unit-type systems The utilization of nacelle stations that were more restrictive to air flow than others was found to be effective Such stations in the XB-45 nacelle were -40, +20, and +100

TABLE I

AFT-COMPARTMENT TEST RESULTS FOR UNIT-TYPE DETECTORS

Test Conditions Engine rpm, 90 per cent of rated, gasoline supply to fire, 0 6 gpm

Test Number	Fire Location (See Fig 11)	Edison System Alarm Time (seconds)	Fenwal System	
			Units Which Produced Alarm	Respective Alarm Times (seconds)
1	T (Burner-can region)	2	5, 6, 9, 10	5-1/2, 8, 4, 4
2	T	5	5, 6, 9, 10	4, 6, 4, 4
3	W (Burner-can region)	4	5	4
4	W	4	5	3
5	V (Burner-can region)	6	8, 13	5, 6
6	V	6	8, 13	5, 5
7	U (Burner-can region)	4	13	7
8	U	4	No detection	-
9	U	5	No detection	-
10	U	6	13	5
11	U	5	No detection	-
12	U	4	No detection	-
13	U	8	13	4
14	X (Turbine region)	2-1/2	7, 10, 11, 14, 15	7, 8, 8, 6, 28
15	X	2	7, 10, 11, 14, 15	6, 9, 6, 6, 8
16	Q (Turbine region)	8	12, 13, 14	8, 6, 8
17	Q	10	12, 13	10, 5
18	Q	6	12, 13	7, 8
19	Q	6	12, 13	10, 6
20	Q	5	12, 13	8, 6
21	G (Tail-cone region)	2	12, 13	4, 4
22	G	4	12, 13	13, 4
23	S (Tail-cone region)	2	11, 14, 15	4, 4, 7
24	S	2	11, 14	6, 5
25	S	2	11, 14, 15	4, 5, 5
26	S	2	11, 14, 15	3, 4, 4
27	J (Aft of fuel strainer)	No detection	No detection	-
28	J	No detection	No detection	-
29	J	No detection	No detection	-
30	J	No detection	No detection	-
31	J	3	No detection	-
32	J	No detection	No detection	-
33	J	2	No detection	-

Conclusions

The following was concluded from the study of unit-type detector-system requirements of the XB-45 nacelle

1 The most effective locations of sensing elements for a unit-type system were those shown in Fig 12
2 The locations and mounting of the Edison system elements installed by the air-frame manufacturer were satisfactory, provided the modifications shown in Fig 12A were incorporated
3 The locations and mounting of the Fenwal system elements installed in accordance with the B-45C nacelle system were satisfactory, provided the modifications shown in Fig 12B were made
4 Air-flow and drainage considerations provide the most logical basis for the effective placement of unit-type sensing elements in compartments such as the XB-45 nacelle compressor and aft compartments
5 For effective operation, sensing elements must be exposed in the air stream and must not be recessed behind structural members or protected by their own junction boxes

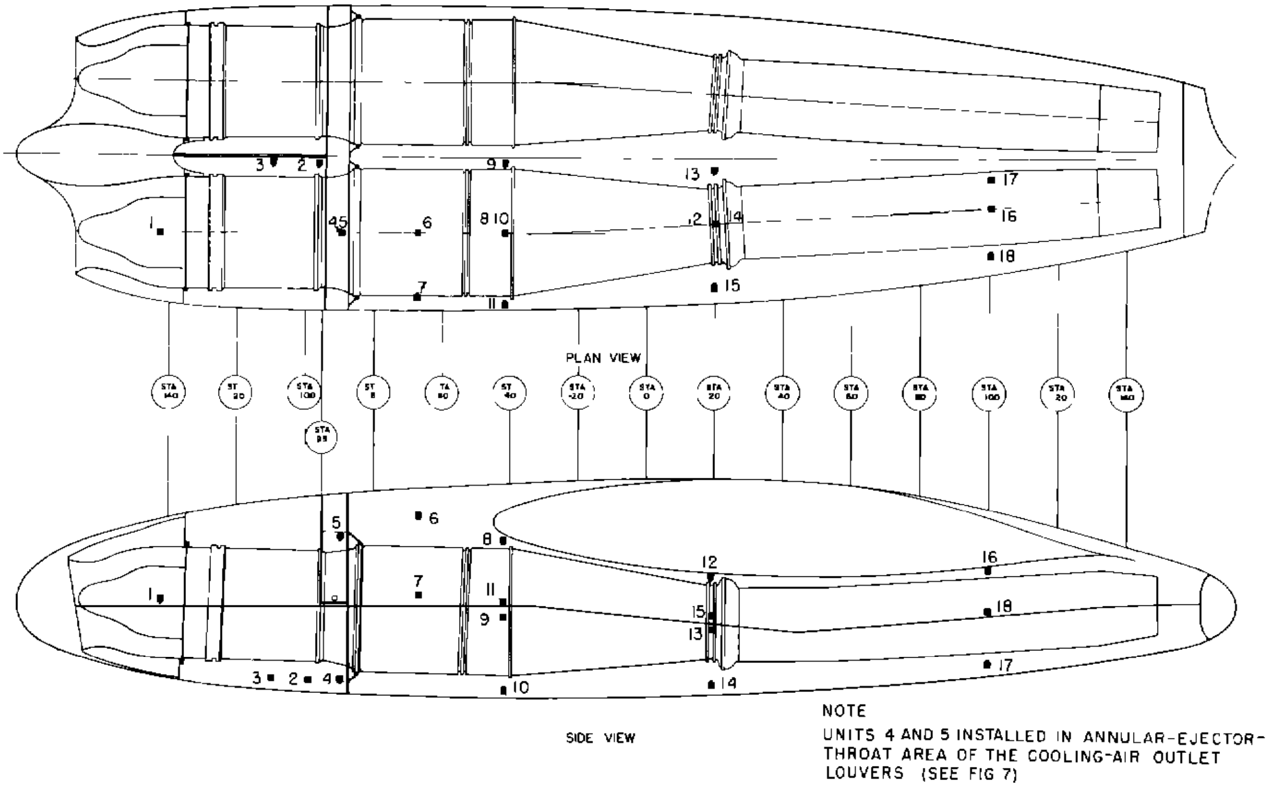

Fig 12 Recommended Detector Locations, Unit-Type Detector System No 3 Engine, XB-45 Nacelle

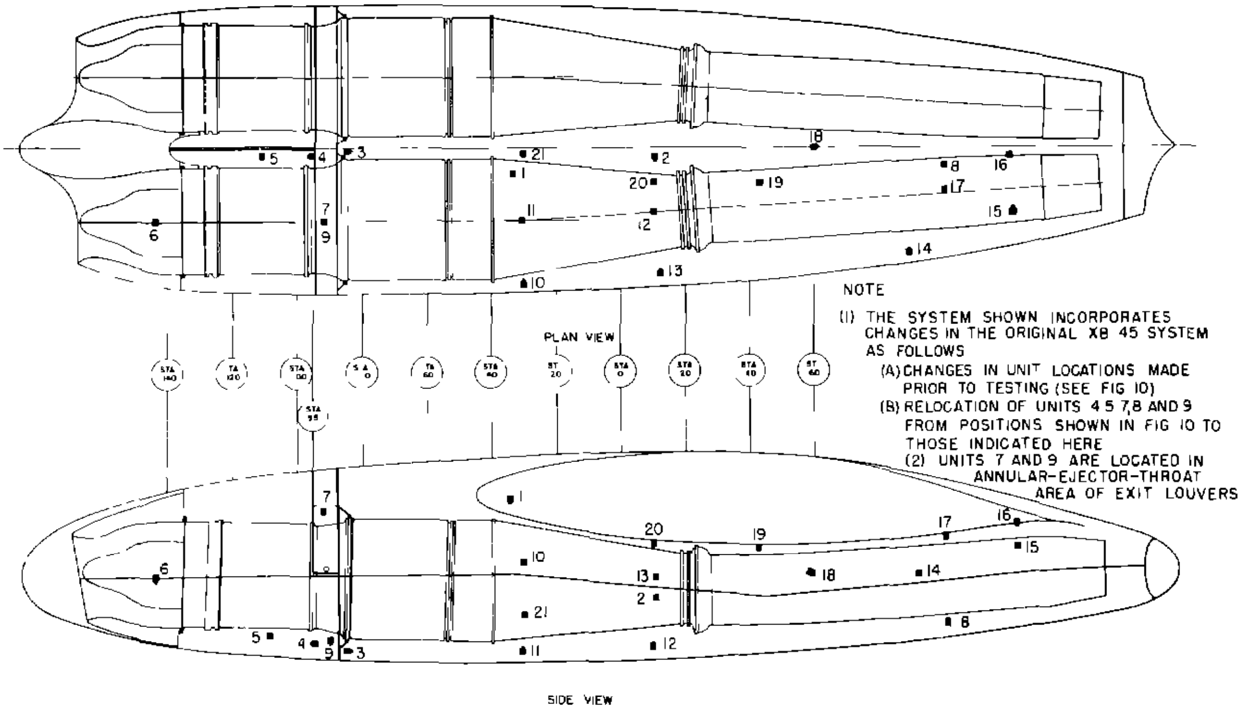

Fig 12A Recommended Locations of Edison System Unit-Type Detectors

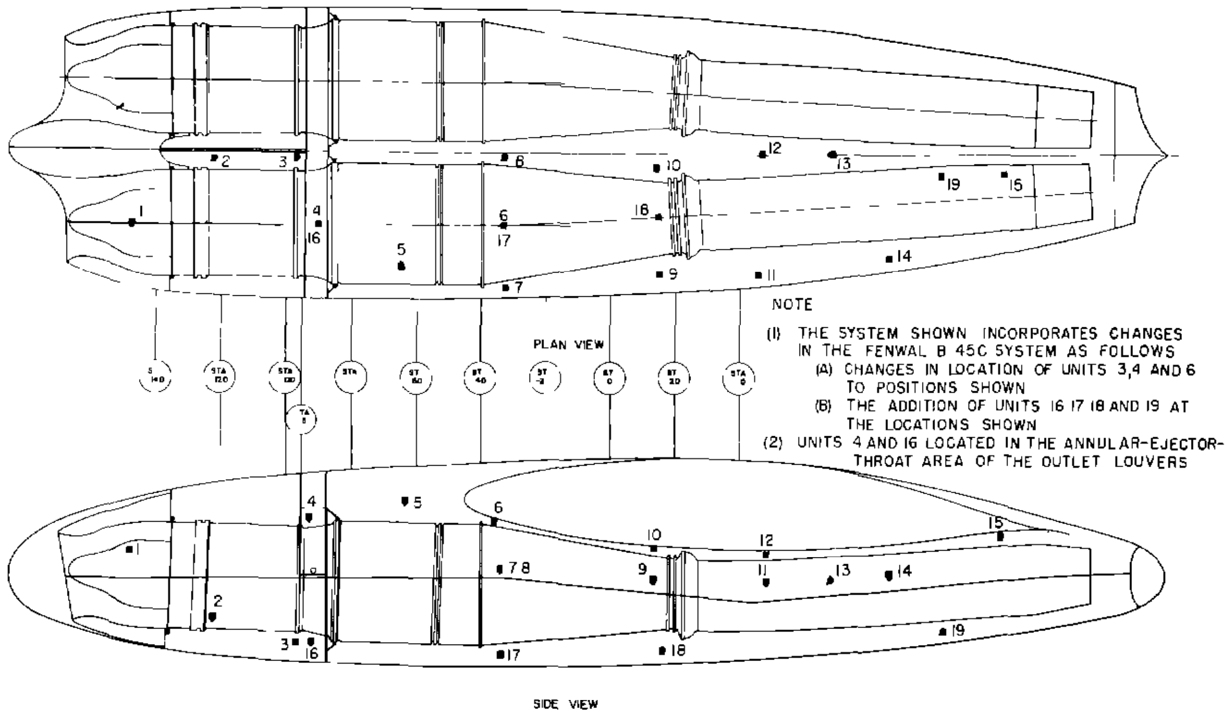

Fig 12B Recommended Locations of Fenwal System Unit-Type Detectors

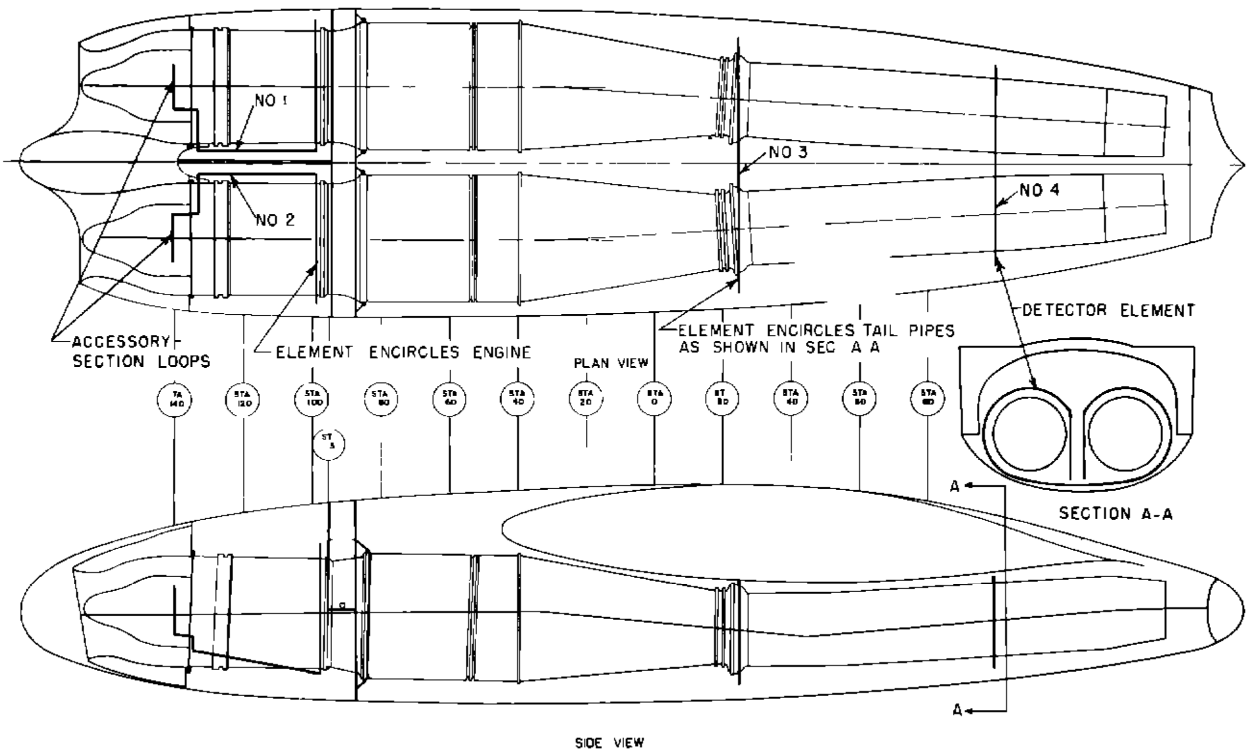

Fig 13 Continuous-Type Detector Locations, XB-45 Nacelle

TESTS ON CONTINUOUS-TYPE DETECTORS

Description of System Tested

Continuous-type detector tests were conducted with the Walter Kidde continuous detector The sensing elements of this system were composed of 20-foot lengths of 0 062-inch OD inconel tubing containing two wires fused into and insulated by previously broken ceramic spaghetti Detection occurs because the resistance of the ceramic decreases sharply at a predetermined elevated temperature and in so doing completes a circuit to an amplifier which signals an alarm When the source of heat is removed the element cools, the electrical resistance of the ceramic increases, and the signal clears [1] The elements used in the tests alarmed at 500° F when heated slowly in a furnace

Procedure

A brief series of tests which used a single sensing element mounted on the lower-nacelle hinged door was conducted in the No 3 engine-compressor compartment Tests were also conducted in the aft compartment Two elements located around the engine tail pipes, as shown in Fig 13, were used Each element was connected to an individual control box The alarm time was recorded by an operation-time recorder The continuous detectors were tested under the same simulated flight and fire conditions as were the unit type of detectors

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[1] For more details, see descriptive literature entitled "Kidde Continuous Type Resetting Fire Detectors, Sensing Elements 801000," Walter Kidde & Company, Inc , Belleville, N J , June 25, 1952

TABLE II

AFT-COMPARTMENT TEST RESULTS FOR CONTINUOUS-TYPE DETECTORS

Test No	Engine RPM (per cent)	Fire Location (See Fig 11)	Alarm Time From Start of Fire: Detector at Station +23 (seconds)	Alarm Time From Start of Fire: Detector at Station +100 (seconds)
1	90	T (Burner-can region)	2	-
2	90	T	2	-
3	90	W (Burner-can region)	6	8
4	90	W	4	5
5	90	V (Burner-can region)	5	-
6	90	V	4	-
7	90	U (Burner-can region)	4	-
8	90	U	4	-
9	90	U	6	-
10	90	U	5 1/2	-
11	45	U	3 1/2	-
12	90	U	6	-
13	90	U	3	-
14	90	U	5	6
15	90	X (Turbine region)	3	4
16	90	X	2	2
17	90	Q (Turbine region)	7	7
18	90	Q	2	8
19	90	Q	7	6
20	90	Q	5	-
21	90	Q	3	-
22	90	G (Tail-cone region)	-	2
23	90	G	-	3
24	90	S (Tail-cone region)	2	2
25	90	S	2	2
26	90	S	-	2
27	90	S	-	2
28	90	J (Aft of fuel strainer)	-	3
29	90	J	-	2
30	45	J	-	4
31	90	J	-	3
32	90	J	-	2 1/2
33	90	J	-	2
34	90	J	-	3
35	90	J	-	2

Results and Discussion

The tests conducted in the No 3 engine-compressor compartment verified the results of previous tests on unit detectors with regard to flame pattern and effective locations for detectors The single continuous element detected all test fires satisfactorily

Results of the tests conducted in the aft compartment are shown in Table II The two elements mounted transversely at nacelle stations +23 and +100 provided detection of test fires at the nine locations used No false alarms or system malfunctions occurred

Conclusions

1 Four sensing elements, one in each compressor compartment and two in the aft compartment, were sufficient to provide adequate detection of nacelle fires
2 The location and mounting of sensing elements shown in Fig 13 provided satisfactory detection of nacelle fires The element installed in each compressor compartment of B-45 aircraft should be mounted so that parts of its length will be adjacent to the lower

portion of the keel structure and will also pass across the air-outlet louvers In the aft compartment, the elements should be mounted in the restricted areas of air flow and should not be recessed behind structural components

3 The sensitivity, operation, and maintenance characteristics of the system were satisfactory

TESTS ON VOLUME-TYPE DETECTORS

Description of System Tested

The only volume-type detection system available for fire testing in the XB-45 nacelle was the photoelectric system manufactured by the Fireye Corporation, Cambridge, Mass This system was made up in the basic units pictured in Fig 14, and it consisted of an amplifier or power-supply unit, a test-switch assembly, and nine infrared-sensitive detector units The detector units were connected individually to the amplifier by coaxial cables and to the test-switch assembly by a single lead One amplifier was designated Type 71BA2, Model 1000, Serial D-50, and the other was designated Air Force Part No D60-107-2 A variable resistor was installed in the circuit for test purposes, and it permitted amplifier-sensitivity adjustments during the tests

Each detector unit consisted of a small lead sulfide photoelectric cell mounted behind a Corning 2540 infrared-transmitting filter glass The cell had a field of view somewhat greater than a 90° cone A small test light (GE Type 329) mounted at the base of the detector unit provided a means for checking the operation of each sensing element as well as of its associated components within the amplifier Detector units used in the tests were Air Force Part No D60-107-1

The test-switch assembly (Part No D60-107-3) consisted of a selector switch for directing test voltage to individual detectors and a dual-relay arrangement which interrupted

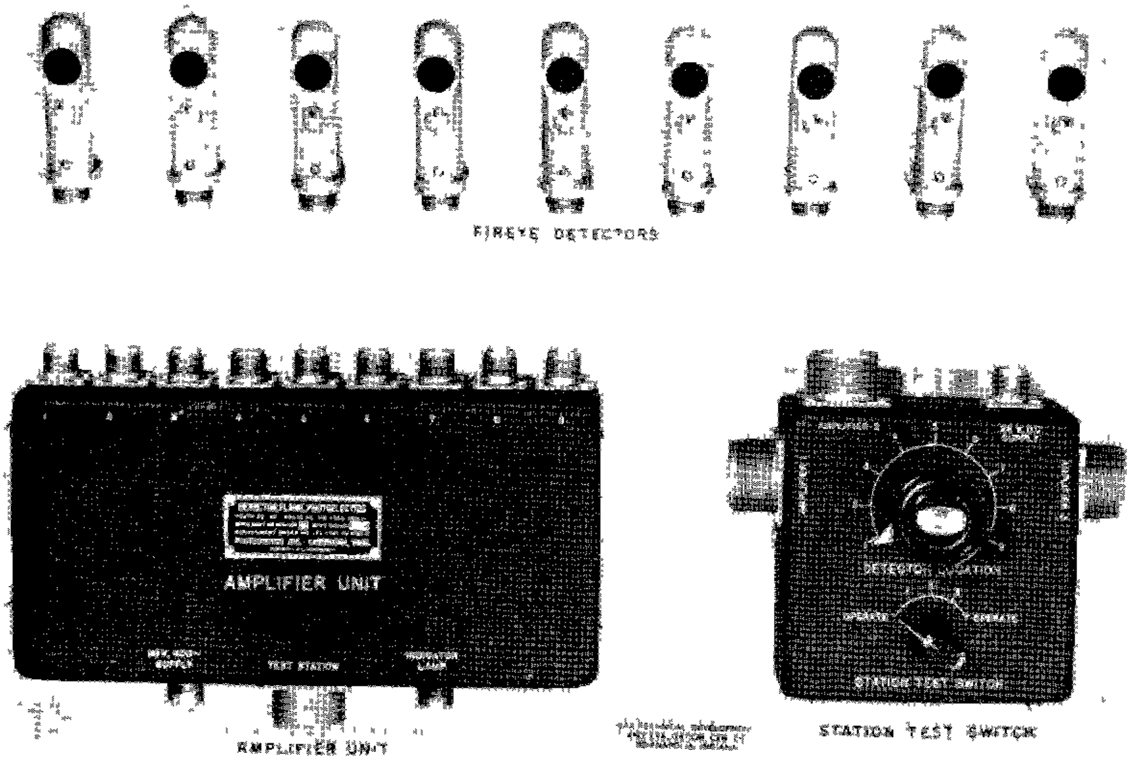

Fig 14 Fireye Detector-System Components

TABLE III

LOCATIONS OF FIREYE SENSING UNITS USED IN FIRE TESTS ON THE NO 4 ENGINE-COMPRESSOR COMPARTMENT

Location
This unit was mounted on the forward air-seal structure of the compressor compartment and was 7 inches above the bottom of the keel and 5 inches outboard of the keel plane The center of vision was 20° outboard of the aft direction and in a horizontal plane See Fig 15
This unit was mounted 11 5 inches above the inboard-engine mounting trunion on the forward face of the vertical keel-support strut The center of vision was 40° outboard of the forward direction in a horizontal plane See Fig 16
This unit was mounted at nacelle station -123 on the first bulkhead aft of the forward air-seal structure and 2 inches above the forward outboard door-hinge line The center of vision was horizontal and directly aft See Fig 17
This was mounted at nacelle station -132 on the forward air-seal structure 2 inches outboard of the longitudinal fire wall The center of vision was directly aft in a horizontal plane See Fig 18
This unit was mounted at 1 30 o'clock on the forward face of the trunion-support-yoke bulkhead (station -90) The center of vision was slightly inboard of, and 40° below, a horizontal forward line See Fig 16

the d-c test-light voltage and caused the test light to flicker at approximately 10 cps The system was designed to respond to a gasoline fire burning in a shallow container 2 1/2 inches in diameter and placed 10 feet from the detector unit

Essentially, the detector system utilizes the light-modulation characteristics of flames The signal from the photocell is amplified by a tuned amplifier whose peak response is approximately 10 cps The output from the tuned amplifier is fed to a limiter circuit which limits strong signals to a value comparable to that from a weak signal A discriminator circuit and a signal amplifier then operate the fire signal [2,3]

A Compressor-Compartment Tests

Procedure

Full-scale fire tests were conducted in the No 4 engine compartment only The results were considered to be applicable to both the No 3 and the No 4 engine-compressor compartments because they were similar in size and configuration Five Fireye sensing units were mounted in the compartment as described in Table III and shown in Figs 15 to 18, inclusive

The fire used in the tests was very small in comparison to the size generally used in detection studies and was provided by supplying aviation gasoline through a small oil-burner type nozzle at a rate of 0 02 gpm Each test consisted of igniting such a fire and permitting it to burn for ten seconds The time required for alarm by the detector system, or, in the event of no alarm, the maximum voltage of the signaling circuit was noted during each test Three

[2] For the detailed description and characteristics of the Fireye detector system, see "Fireye Type FD-2 Fire Detectors for Aircraft," Technical Information Bulletin J, Fireye Corporation, Cambridge, Mass , October 1950

[3] "Tests of a Photoelectric Fire Detection System," Memorandum Report MCREXE-664-491-L, U S Air Force Air Materiel Command, Wright-Patterson Air Force Base, Dayton, Ohio, February 23, 1951

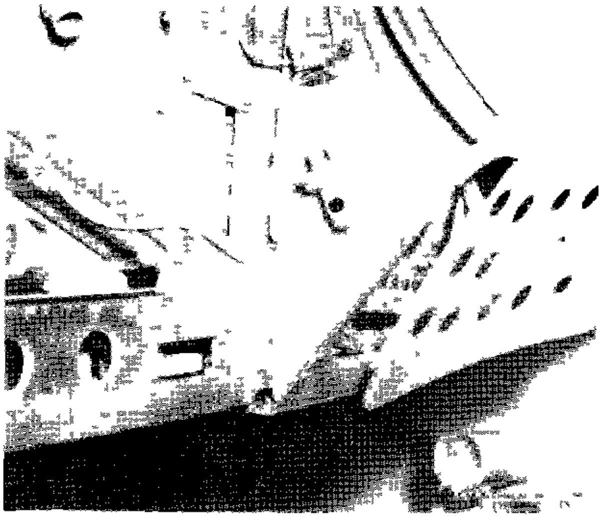

Fig 15 Location of Fireye Detector Unit X-1

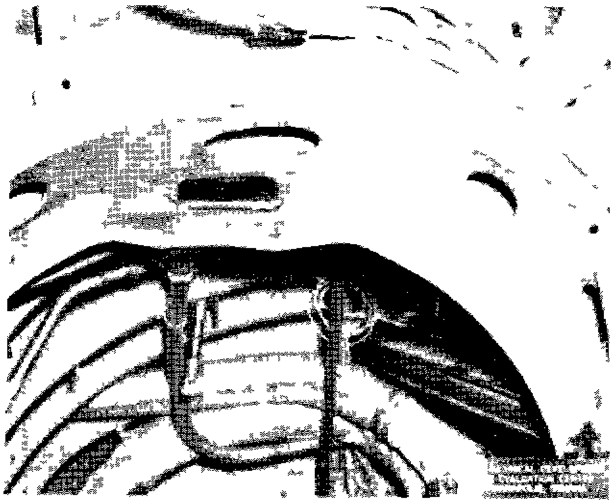

Fig 16 Locations of **Fireye Detector** Units 2 and 5

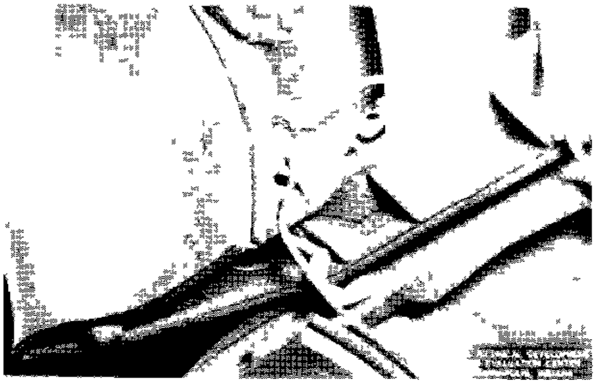

Fig 17 Location of Fireye Detector Unit 3

Fig 18 Location of Fireye Detector Unit 4

tests were normally made for each test condition A total of 188 tests were made during four hours of intermittent engine operation

Tests were conducted with the fire nozzle at six different locations, show[illegible] in Fig 11, and with engines operating at 60 and 90 per cent of rated rpm The testing inc[illegible]d measurements of ambient and sensing-unit temperatures under the conditions of testi[illegible]t without fire

Results and Discussion

The sensing units which individually caused alarm are listed for each fire location in Table IV Also listed are the minimum amplifier-sensitivity settings at which alarm occurred with all sensing units connected It is noted from Table IV that all fires were detected either by unit X-1 or by unit 3 Together, they provided complete coverage of the compartment

No testing was done to determine the most effective positioning and direction of mounting of each sensing unit It was reasoned that optimum positioning was obtained by mounting the sensing eye so that its center of vision bisected the space to be monitored

TABLE IV

TEST RESULTS ON FIREYE DETECTORS
IN THE NO 4 ENGINE-COMPRESSOR COMPARTMENT

Fire Location (See Fig 11)	Sensing Units Causing Alarm Signal	Minimum Sensitivity Setting for Alarm (All Five Connected)*		Engine RPM
		Less Than 10 Seconds (per cent)	Less Than 5 Seconds (percent)	(per cent)
A	X-1, 3	50	70	90
B	X-1, 2	6	6	90
B	X-1, 2	6	6	60
C	X-1, 2, 4, 5	-	-	60
C	Entire System	4 5	3	90
D	3, 5	8	8	90
E	X-1, 3	50	50	90
F	2, 3, 4, 5	4 5	8	90

* Percentage values are based on rated sensitivity of the amplifier By comparison, the minimum sensitivity setting at which the system would alarm on the manual TEST switch was 8 per cent of the rated sensitivity

The results listed in Table IV show that all test fires were detected with the amplifier sensitivity greatly reduced Detection of all fires occurred with an amplifier sensitivity setting equal to 50 per cent of maximum

During one series of test runs, the temperature of each detector-unit mounting bracket and that of ambient air in the vicinity of each detector unit were recorded by means of thermocouples The maximum bracket temperature recorded was 150° F, and the maximum ambient-air temperature recorded was 170° F

During the investigation there were no false alarms by the Fireye detector system from test-cell operating conditions and no indication of potential sources of trouble in this respect One instance of detector-system malfunctioning occurred during the tests and resulted in an appreciable reduction in sensitivity The trouble was found to be the result of a worn spot on the insulation of a wire in the amplifier unit, and it was corrected by using a small piece of tape on the affected area

In connection with the study of sensitivity requirements, a bench test was conducted to determine the effect which the number of sensing units monitoring a flame may have on the alarm-signal strength Three sensing units were mounted side by side on a panel and were connected to the amplifier The alarm signal resulting from the use of one, two, and three units was observed when the units were exposed to a flame from a 2 1/2-inch-diameter pot placed approximately ten feet away It was observed that under conditions in which a single unit produced a signal below alarm strength, additional units increased the signal strength slightly However, in no instance was such an increase of sufficient magnitude to cause an alarm signal by the use of three or two units when one unit would not do so It was concluded that, from a practical viewpoint, no additive effect occurred from the monitoring of a fire by a multiplicity of sensing units

Conclusions

The following conclusions are made on the basis of the tests conducted

1 The use of two Fireye sensing elements in each engine-compressor compartment of the XB-45 nacelle was adequate for indicating the presence of small fires at any location within these compartments This number of sensing elements consistently detected very small fires
2 The optimum locations for sensing units in the engine-compressor compartments were those designated X-1 and 3 (Table III and Figs 15 and 17) Location 2, Fig 16, was the third most effective location
3 In order that they might not be rapidly heated by fires which may occur, sensing units of the volume type of detector should be mounted in recessed areas or in places which are not in an air stream This is in direct opposition to the method used in the placement of conventional types of fire and overheat detectors which are actuated by exposure to heat from the fire
For optimum coverage the center of vision of the Fireye sensing unit should, as nearly as possible, bisect the space to be monitored
4 In a system using two sensing units in each compartment at the recommended Locations X-1 and 3 and with maximum amplifier sensitivity, the detection of small, nondamaging ten-second fires was very rapid
5 A sensitivity equal to 50 per cent of that available from the Type 71BA2, Model 1000, Serial D-50 amplifier and used in conjunction with the two sensing units X-1 and 3 was found adequate for detection of compressor-compartment fires
6 There were no indications that normal operating conditions of the B-45 airplane would cause the Fireye detector system to false-alarm This, however, should be the subject of further investigation under actual service conditions

B Aft-Compartment Tests

Procedure

In determining detector requirements for the aft nacelle compartment, fire tests were conducted under static conditions and under simulated-flight operating conditions The locations of sensing units of the Fireye system, installed for test purposes, are shown in Fig 19 The test fire used in the static tests was the same as that used in the compressor-compartment studies and was produced by igniting aviation gasoline sprayed from a No 2 oil-burner nozzle at a rate of 0 02 gpm A photograph of the test fire is shown in Fig 20

The tests under simulated flight conditions were conducted using a fire burning 0 6 gpm of gasoline in order to obtain results comparable to those for other detector types It was also found that smaller fires would not burn at most fire locations because of the high, cooling air flow existing in the aft compartment

In both the static and the simulated-flight tests, the fire nozzle was placed at various locations throughout the compartment, and test fires of ten seconds' duration were conducted at each location Fire locations used in the static tests are shown in Fig 19 Those used in the simulated-flight tests are shown in Fig 11

At each fire location, the following information was obtained

1 Time for detection of the fire
2 Magnitude of the signal produced by each sensing unit of the system
3 Minimum amplifier-sensitivity setting at which the system would cause a signal of alarm magnitude within ten seconds

Measurements of sensing-unit and of ambient temperatures during engine operation (90 per cent of rated rpm) and immediately after engine shutdown were obtained by means of thermocouples and recording pyrometers

Results and Discussion

Results of the tests under static conditions and using 0 02-gpm fires are given in Table V This table shows the fires which were detected by each sensing unit of the system, and it aids in the selection of the most effective combination of sensing units

In arriving at an optimum combination of units, geometric considerations led to the selection of centrally located units where possible and to the use of a minimum number of units located on the outboard sides of the engine tail pipes From Table V it is noted that units 11, 15, and 18, which are all located between the tail pipes, detected (in combination) all test fires except those at fire locations K, O, and Q These locations, as noted in Fig 19, are in the vicinity of the burner cans and in the forward portion of the compartment As shown in

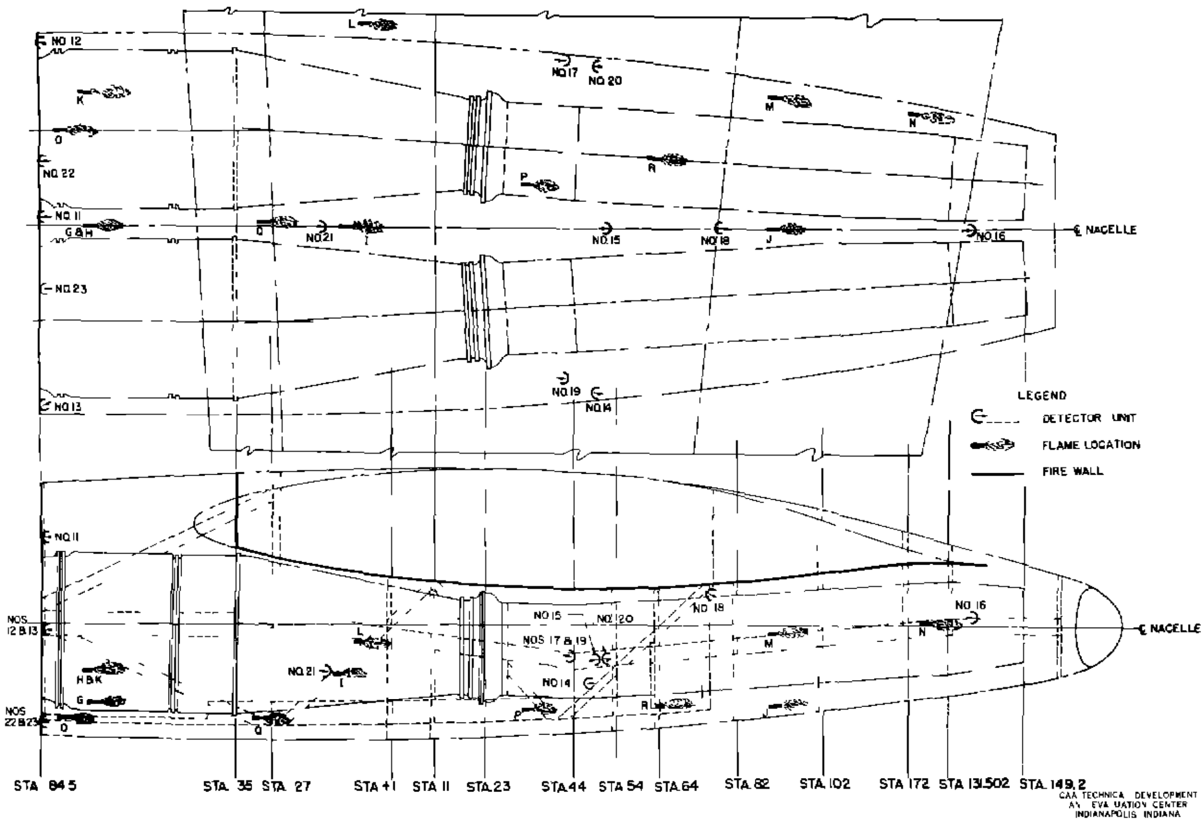

Fig 19 Fireye Detector-Unit and Test-Fire Locations
Aft Compartment, XB-45 Nacelle

Table V, unit No 22 alarmed fires K, O, and Q, and it evidently provided effective coverage of fires in the burner-can region of the No 4 engine Unit No 23, corresponding in location to No 22 but for the No 3 engine, should likewise be expected to provide equally effective coverage of the burner-can region of this engine The optimum combination of units for the entire compartment was thus indicated to consist of units 11, 15, 18, 22, and 23

Further interpretation of the test data of Table V along with geometric considerations of the compartment indicate that the addition of units 12, 20, 13, and 14 to the afore-mentioned combination should permit an appreciable reduction of amplifier sensitivity

The results of the tests conducted under simulated flight conditions are given in Table VI and show that the 0 6 gpm gasoline test fires were rapidly detected by a Fireye system consisting of five units Nos 11, 15, 18, 22, and 23 The maximum recorded temperatures of ambient air and of the Fireye sensing units during test conditions simulating flight are shown in Tables VII A and VII B The maximum temperatures of the units during engine operation varied from 130° to 205° F, and the maximum ambient temperatures ranged from 135° to 207° F Thus, in a number of instances, the maximum recorded temperatures during operation exceeded the 180° F limitation recommended by the Department of the Air Force for the model of sensing unit tested More recent models, however, are understood to operate satisfactorily at higher temperatures

Conclusions

On the basis of the foregoing studies, the following conclusions were reached

1 The use of a Fireye system consisting of five sensing units – Nos 11, 15, 18, 22, and 23 – provided good detection of fires and constituted an effective system for the aft compartment
2 Optimum locations for those sensing units are shown in Fig 19 Additional effective locations were those of units 12, 13, 14, and 20

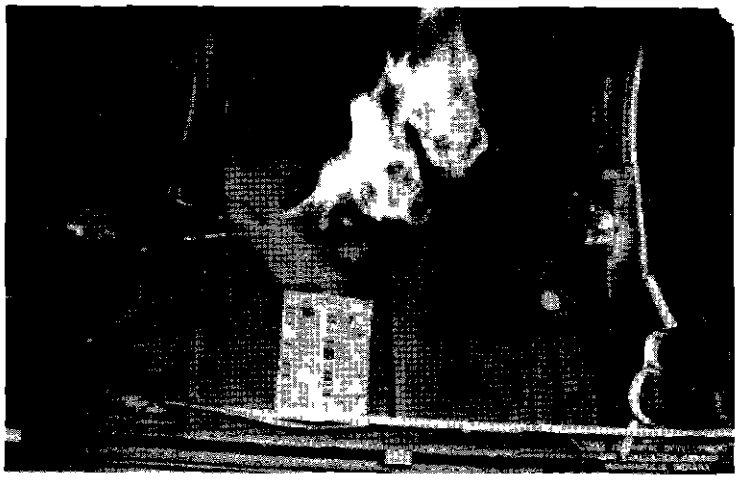

Fig 20 Test Fire Used in Fireye Detector Tests

TABLE V

AFT-COMPARTMENT TEST RESULTS ON FIREYE DETECTORS
(ENGINES NOT OPERATING)

Fire Location

Detector Number	H	I	J	K	L	M	N	O	P	Q	R
*11	X	X			X						
12				X	X			X			
13	X										
*15		X			X				X		X
16			X				X				
17		X		X	X	X					X
*18			X			X	X				
19	X										
20					X	X	X				X
*22	(X)	(X)		(X)				X	X	X	

Note X - Actual test data

(X) - Based on practical considerations Unit No 22 was not installed when tests were conducted at fire locations H, I, and K

* - Denotes sensing units which, when used simultaneously, provided detection of all fires

TABLE VI

AFT-COMPARTMENT TEST RESULTS ON FIREYE DETECTORS (SIMULATED FLIGHT CONDITIONS)

Test Conditions Engine rpm, 90 per cent,
engine-inlet total pressure, 1 5 inches Hg,
gasoline supply to fire, 0 6 gpm

Test No	Fire Location (See Fig 11)	Amplifier Sensitivity Setting (per cent of rated)	Alarm Time Using Units 11, 15, 18, 22, 23 (seconds)
1	J	100	2 0
2	J	50	1 5
3	J	50	1 0
4	S	100	1 3
5	S	50	1 5
6	S	50	1 5
7	G	100	1 5
8	G	50	1 2
9	G	100	2 0
10	Q	100	1 5
11	Q	50	1 5
12	Q	50	2 5
13	T	100	1 0
14	T	100	1 5
15	T	50	1 5
16	U	100	1 1
17	U	50	1 1
18	U	14	3 0
19	V	100	3 0
20	V	50	3 0
21	V	14	1 0
22	W	100	4 0*
23	W	50	1 5
24	W	14	2 0
25	X	100	7 5*
26	X	50	5 0
27	X	14	4 0

* The results for fire locations W and X do not reflect the normal influence of reduced amplifier sensitivity The reason for reduced time for alarm at lower sensitivity setting was not determined

3 Sensing units should be mounted in recessed areas or in places which are not in an air stream and which will not be directly exposed to fires

4 The time required for detection of fires by the Fireye system was normally between two and three seconds from the instant fuel was released

5 The sensitivity of the Fireye system was high in comparison with all other types of detectors tested Effective detection of aft-compartment fires occurred when the five units listed under item 1 were used with the amplifier sensitivity set below 50 per cent of maximum

6 The temperatures existing in the aft compartment of the nacelle at some locations exceeded the 180° F limitation for the installation of the model of Fireye sensing units tested Units which will give satisfactory service at higher ambient

TABLE VII A

MAXIMUM TEMPERATURES OF FIREYE SENSING UNITS IN THE AFT COMPARTMENT

Sensing Unit Locations*	Maximum Recorded Temperatures During Engine Operation** (degrees F)	During Engine Shutdown (degrees F)
11	157	167
12	173	170
13	160	155
14	130	149
15	205	191
16	191	253
17	135	157
18	153	174
19	201	191
20	158	158
22	125	224

* For locations, See Fig 19
** Engine operation varied from 60 to 90 per cent of rated rpm

TABLE VII B

MAXIMUM TEMPERATURES OF AMBIENT AIR IN THE AFT COMPARTMENT

Thermocouple Locations				Maximum Recorded Ambient Temperatures	
No 9	Station	Position	Engine No	During Engine Operation (degrees F)	During Engine Shutdown (degrees F)
I	-10	9 00 o'clock	3	207	218
II	+80	9 00 o'clock	3	180	193
III	-30	9 00 o'clock	4	189	229
IV	+21	2 30 o'clock	4	196	222
V	+100	11 00 o'clock	4	135	238
VI	+135	11 00 o'clock	4	135	238

temperatures are needed Tests indicated that the strength of the test signal should also be increased to provide for proper operation of the test circuit under relatively high ambient temperatures

C Effect of Sensing-Unit Temperature on System Sensitivity

Procedure

A number of bench-type tests were conducted on the Fireye detector system to determine the variation in system sensitivity with the temperature of the sensing unit The equipment consisted of a Fireye system amplifier unit, Type 71BA2, Model 1000, Serial D-50, and of three sensing units, No 1 (unmarked) and Serial Nos 3 and 82, Part No D60-107-1 These parts were connected in accordance with the manufacturer's instructions, and the system was operated by a 400-cps, 115-volt power supply

The testing apparatus consisted of a small, electrically heated box in which a sensing unit could be mounted and of a signaling device for providing an alternating source of infrared radiation The signaling device consisted of a slotted disk behind which was mounted a 6-watt, 110-volt lamp The disk was gear-driven at 600 rpm by a synchronous motor and provided an alternating source of infrared radiation at a frequency of 10 cps The tests were conducted by heating each sensing unit to the desired temperature and then determining the maximum distance, between the lamp and the sensing unit, at which the Fireye system would alarm within ten seconds after initial exposure to the signaling source The temperature of the sensing unit was measured by means of a thermocouple mounted in its base Results were obtained over a range in temperature of 86° to 300° F

Test Results

Results of the tests are shown graphically in Fig 21 Sensitivity of the system at various temperatures is given in terms of the maximum distance between the sensing unit and the signal source, at which distance the system would produce an alarm within ten

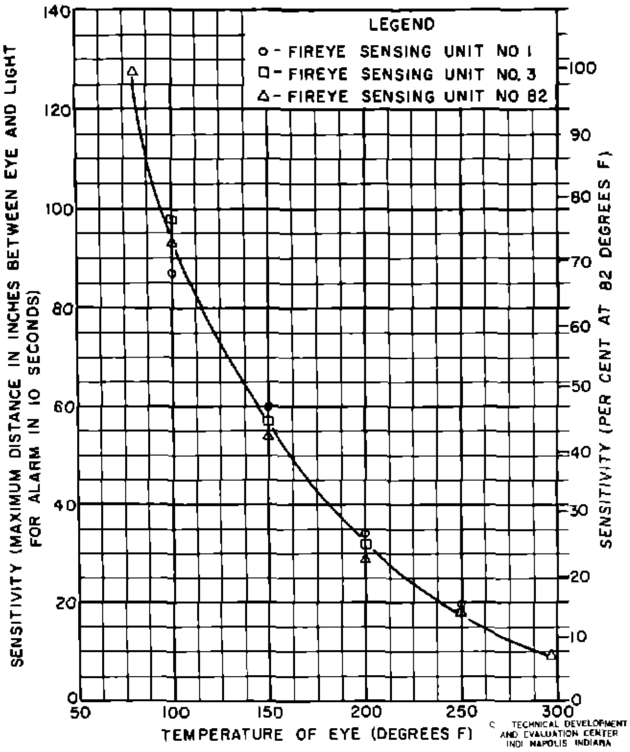

Fig 21 Effect of Sensing-Unit Temperature on the Sensitivity of Fireye Detector Units

seconds It is also given in terms of per cent of the measured sensitivity at 82° F The elevated sensing-unit temperature is noted to reduce appreciably the sensitivity of the Fireye system There is also an indication from the shape of the curve that reduced temperatures (below 82° F) greatly increase sensitivity

Conclusions

On the basis of test results, it is concluded that elevated sensing-unit temperature produces an appreciable drop in sensitivity of the detector system The influence of this temperature effect requires consideration when making installations of the detector system in aircraft power plants

FIRE EXTINGUISHMENT

Objectives

The primary objective of this phase of the test program was to evaluate the equipment and the procedures used in connection with the extinguishment of power-plant fires in the XB-45 airplane

An additional objective was to obtain test data which would indicate the importance of various factors involved in the extinguishment of fires and which would provide the basis of recommendations for improving fire control in the experimental Model XB-45 and in production-model B-45 airplanes

Description of Systems

A The XB-45 System

The XB-45 airplane fire-extinguishing system used carbon dioxide and consisted of a perforated-tubing distribution system for each twin-engined nacelle and also consisted of the necessary feed lines, direction valves, and agent cylinders required for operation It included a main bank and a reserve bank of cylinders (two-shot system), each bank consisting of five 853-cubic-inch cylinders equipped with one-inch flood valves and with flexible siphon tubes The cylinders were stored in the fuselage, and the discharge could be directed to either nacelle

In the original design of the system, quantity requirements for each nacelle compartment were computed by use of the formula

$$Q = 0.2V \quad (1)$$

where

Q = quantity of carbon dioxide required, in pounds,

V = net volume of the compartment, in cubic feet

By use of this formula, all compartments were presumed to be Class C zones (zones through which the quantity of flowing air is relatively small compared to the volume of the region) In compliance with the Department of the Air Force regulations for experimental aircraft, the actual quantity supplied was twice the calculated value Detailed computations are shown in Table VIII A total of five supply cylinders, each containing 20 pounds of carbon dioxide, was used for each of the two shots

The tests were conducted on the part of the airplane system that protected the right-hand nacelle, a schematic drawing of which is shown in Fig 22 Pertinent dimensions and design data of the system are given in Tables IX and X For the tests, conditions in the production-model airplanes were simulated by locating two agent supply cylinders in the wheel well adjacent to the test nacelle and two at a position simulating that of the wheel well at the opposite nacelle A total of 61 6 pounds of carbon dioxide was supplied by the four winterized cylinders, each containing 15 4 pounds Reference in this report to the XB-45 extinguishing system refers to that system which is shown in Fig 22 and which has the agent supply described in the foregoing section rather than that supply used by the manufacturer in the XB-45 airplane

TABLE VIII

COMPUTATION OF CO_2 QUANTITY REQUIREMENTS FOR THE XB-45 NACELLE

Hazard	Net Volume (V) (cubic feet)	Design Factor	CO_2 Required (pounds)	CO_2 Required for Experimental Aircraft (pounds)
Engine No 3 Accessory Compartment	2 0	0 2V	0 4	0 8
Engine No 3 Compressor Compartment	22 0	0 2V	4 4	8 8
Engine No 4 Accessory Compartment	2 0	0 2V	0 4	0 8
Engine No 4 Compressor Compartment	22 0	0 2V	4 4	8 8
Fuel-Line Duct	2 5	0 2V	0 5	1 0
Aft Compartment (Common)	237 0	0 2V	47 4	94 8
Total			57 5	115 0*

* Total quantity of CO_2 actually used was 100 pounds

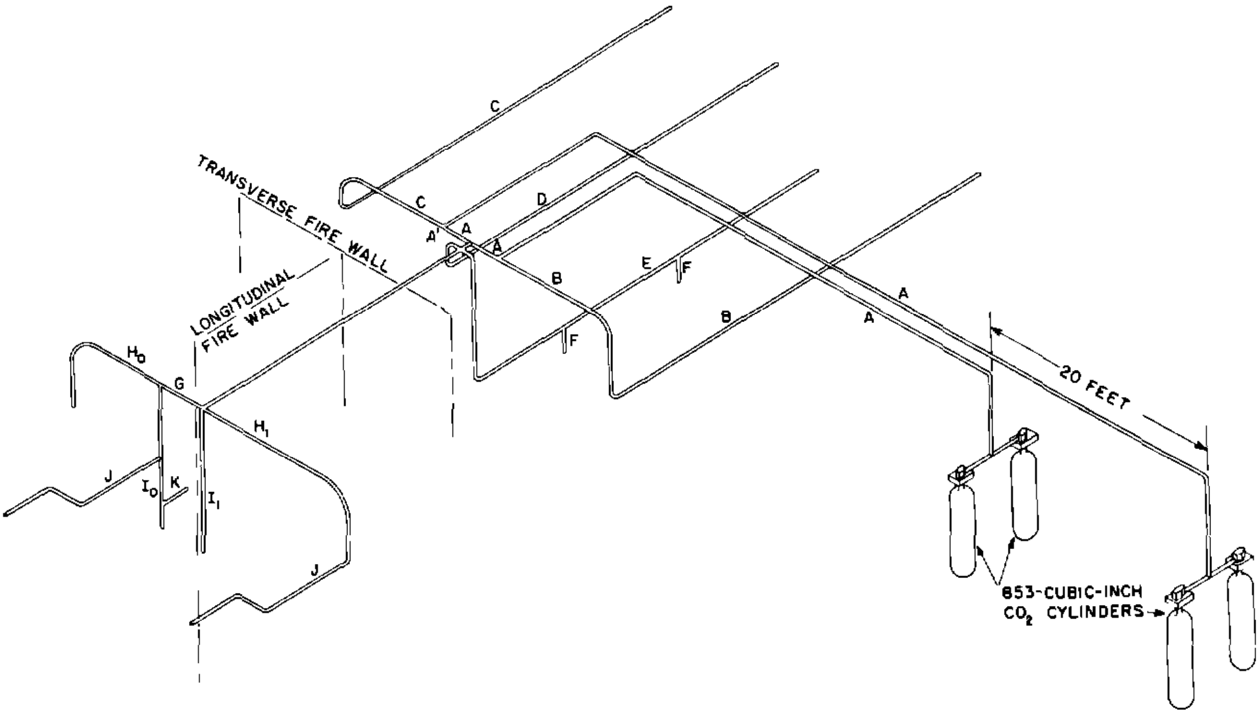

Fig 22 Diagrammatic Layout of XB-45 Airplane-Nacelle Fire-Extinguishing System Used in Tests

TABLE IX

LINE DIMENSIONS OF NACELLE FIRE-EXTINGUISHING SYSTEMS

Line*	XB-45 Airplane				B-45 Airplane			
	No of Lines	Line Size (OD x Wall) (inches x inches)	No of Holes	Diameter of Holes (inches)	No of Lines	Line Size (OD x Wall) (inches x inches)	No of Holes	Diameter of Holes (inches)
A	2	1 1/2 x 0 035	0	--	1	2 x 0 035	0	--
A'	1	1 1/4 x 0 035	20	3/32	1	- - -	-	--
B	1	1 x 0 028	55	3/32	1	1 x 0 028	61	3/32
C	1	1 x 0 028	54	3/32	1	1 x 0 028	61	3/32
D	1	1 x 0 028	46	3/32	1	1 x 0 028	46	3/32
E	1	1 x 0 028	52	3/32	1	1 x 0 028	49	3/32
F	2	1/4 x 0 012	2	0 067	2	1/4 x 0 012	2	0 107
G	1	1 x 0 028	0	--	1	3/4 x 0 020	0	--
G'	1	5/8 x 0 020	0	--	1	3/4 fitting	0	--
H_o	1	1/2 x 0 020	23	1/16	1	1/2 x 0 020	19	1/16
H_I	1	1/2 x 0 020	23	1/16	1	1/2 x 0 020	17	1/16
I_o	1	1/2 x 0 020	23	1/16	1	1/2 x 0 020	12	1/16
I_I	1	1/2 x 0 020	23	1/16	1	1/2 x 0 020	13	1/16
J	1	1/4 x 0 012	1	0 135	1	1/4 x 0 035	1	0 107
K	1	1/4 x 0 012	1	0 067	1	1/4 x 0 012	1	0 107

* For line identification, see Fig 22

B The B-45 System

A description of the extinguishing system in B-45 airplanes and a comparison of this system with the XB-45 system tested are presented to permit the application of test results to production models

The B-45 airplane fire-extinguishing system used carbon dioxide and consisted of a perforated-tubing distribution system of essentially the same general configuration as that used in the XB-45 model In contrast to the XB-45 system, however, it provided for a single shot only and utilized four 853-cubic-inch cylinders, two in each wheel well Each cylinder contained a winterized charge of 15 4 pounds, providing a total charge of 61 6 pounds of carbon dioxide

In the design of the system, quantity requirements for each nacelle compartment were computed by assuming that the nacelle compressor compartments were Class D hazards (zones through which there is very little or no air flow) and that the aft compartment was a Class C hazard For the Class D hazards, the quantity of agent was computed with the use of the formula

$$Q = 0\ 14V \qquad (2)$$

where

Q = quantity of agent required, in pounds,

TABLE X

DESIGN DATA ON XB-45 AND B-45 AIRPLANE FIRE-EXTINGUISHING SYSTEMS

Compartment	Number of Lines		Line Size (OD x Wall)		Number of Discharge Holes		Diameter of Discharge Holes		Total Discharge Area		Ratio (Discharge Area in Compartment / Total Discharge Area of System)	
	XB-45*	B-45**	XB-45* (inches x inches)	B-45** (inches x inches)	XB-45*	B-45**	XB-45* (inches)	B-45** (inches)	XB-45* (square inches)	B-45** (square inches)	XB-45	B-45
Aft	4	4	1 x 0 028	1 x 0 028	227	217	3/32	3/32	1 566	1 497	0 83	0 864
No 3 Engine Compressor	2	2	1/2 x 0 020	1/2 x 0 020	46	31	1/16	1/16	0 141	0 095	0 075	0 055
No 4 Engine Compressor	2	2	1/2 x 0 020	1/2 x 0 020	46	31	1/16	1/16	0 141	0 095	0 075	0 055
No 3 Engine Accessory	1	1	1/4 x 0 012	1/4 x 0 035	1	1	0 135	0 107	0 014	0 009	0 007	0 005
No 4 Engine Accessory	1	1	1/4 x 0 012	1/4 x 0 035	1	1	0 135	0 107	0 014	0 009	0 007	0 005
Fuel Duct												
Forward	1	1	1/4 x 0 012	1/4 x 0 012	1	1	0 067	0 107	0 0035	0 009	---	---
Aft	2	2	1/4 x 0 012	1/4 x 0 012	2	2	0 067	0 107	0 007	0 018		
Total	3	3	--	--	3	3			0 0105	0 027	0 006	0 016

* **Values listed for the XB-45 system were from actual measurements** This system was designed to use 5 cylinders of 846-cubic-inch capacity each In the tests however, only 4 **cylinders were used** The total main feed-line area was 3 20 square inches

** **Values listed for the B-45 system** were taken from North American Aviation Inc drawings This system was designed to use 4 cylinders of 846-cubic-inch capacity each **The total main feed-line area was** 2 928 square inches

V = net volume of the compartment, in cubic feet

For Class C hazards, the formula Q = 0 2V was used Results of these computations are shown in Table XI, which also shows the design values of the compartment air flow, the values on which the hazard classifications were based

For the purposes of comparison, the pertinent dimensions and design data of the B-45 system are given in Tables IX and X with those for the XB-45 system The following differences in the systems are noted

1 The total nozzle areas in the primary nacelle compartments are smaller in the B-45 system
2 The supply line which carries the agent to the forward nacelle compartments is smaller in the B-45 system
3 The feed-line area for the B-45 system is smaller than the area for the XB-45 system
4 The ratio of compressor-compartment nozzle area to total-system nozzle area is smaller for the B-45 than for the XB-45 system

TABLE XI*

COMPUTATION OF CO_2 QUANTITY REQUIREMENTS FOR THE B-45 NACELLE

Hazard	Classification of Hazard	Net Volume (V) (cubic feet)	Nacelle Cooling Air Flow (pounds per second)	Factor***	CO_2 Required (pounds)
Aft Compartment	C	236	6 0	0 2V	47 2
No 3 Compressor Compartment	D	22	0 3	0 14V	3 08
No 4 Compressor Compartment	D	22	0 3	0 14V	3 08
Total		280			53 36**

Note The discharge period was calculated to be 2 45 seconds with the limiting factor being the one-inch flood valves on each cylinder

* The information contained in this table was taken from Proposal Drawing 147-953048, North American Aviation, Inc Although not shown in the table, small quantities of agent were supplied to the engine accessory compartments and to the nacelle fuel duct

** CO_2 actually used was 61 6 pounds

*** Since August 1950, the USAF has made use of bromochloromethane extinguishing systems rather than of CO_2 systems in new aircraft Agent quantity requirements are based on the formula

$$Q = 0\ 56\ Wa + 0\ 16\ V$$

where

Q = Quantity of bromochloromethane required for a 2-second discharge (in pounds)

Wa = Air flow through compartment under cruise conditions (in pounds per second)

V = Gross volume of compartment (in cubic feet)

From the design differences, the B-45 system would be expected to result in a lower rate of agent discharge and to be less effective than the XB-45 system tested, particularly in the forward nacelle compartments

EVALUATION OF THE XB-45 NACELLE FIRE-EXTINGUISHING SYSTEM

Evaluation of the XB-45 fire-extinguishing system was accomplished by the measurements of

1 Distribution of the agent by the system to the various nacelle compartments
2 The duration of agent discharge
3 The concentrations of agent resulting from the discharge of the system under simulated flight conditions
4 The effectiveness of the system in extinguishing actual fires under simulated flight conditions

Agent Distribution

One of the primary functions of an extinguishing system is to provide adequate distribution of an agent to all potential fire locations This requires the supply of adequate quantities of the agent to each nacelle fire zone and requires its proper distribution within each zone

An indication of the quantity of an agent supplied to each fire zone of the nacelle by the XB-45 extinguishing system was obtained by mock-up tests The system was removed from the nacelle and was supported in the open in its normal position Water was discharged through the system from supply cylinders that were equipped with siphon tubes and with one-inch flood valves Two cylinders were connected to each of the two primary feed lines, Fig 22, and were positioned to simulate conditions in B-45 production aircraft (two cylinders in each wheel well) Each 853-cubic-inch cylinder contained 15 pounds of water and was pressurized with nitrogen between 450 and 500 psi The quantity discharged to each forward zone or compartment was caught by large aerology balloons which covered the perforated tubing of the system The quantity discharged from the aft portion of the system was calculated as being equal to the difference between the total quantity discharged and the quantity released from the forward portion A ten per cent loss of agent within the system was assumed in this calculation Three tests were made, and the results are given in Table XII

From the distribution ratios thus determined, the quantities of carbon dioxide which the system would discharge into the various nacelle compartments were computed and are shown in Table XIII Also shown are the results of distribution computations based on system nozzle-area ratios for both the XB-45 and the B-45 systems The values listed indicate that (1) the XB-45 system discharged less agent into the forward compartments and more into the aft compartment than expected from the design calculations based on nozzle-area ratios, and (2) the B-45 system will discharge less agent into the forward compartments and more into the aft compartment than will the XB-45 system

In addition to the foregoing, some information on the distribution of carbon dioxide within the various nacelle compartments by the XB-45 extinguishing system was obtained by agent-concentration measurements This is discussed later in this report

TABLE XII

DISTRIBUTION OF WATER BY THE XB-45 FIRE-EXTINGUISHING SYSTEM

Test No	Accessory Compartments		Compressor Compartments		Fuel Duct	Aft Compartment (Computed)	Assumed 10 Per Cent Loss	Total
	No 3 Engine (pounds)	No 4 Engine (pounds)	No 3 Engine (pounds)	No 4 Engine (pounds)	(pounds)	(pounds)	(pounds)	(pounds)
1	0 26	0 35	3 50	3 67	0 80	49 02	6 4	64 0
2	0 23	0 35	2 86	2 73	0 86	50 57	6 4	64 0
3	0 29	0 45	3 76	3 78	0 90	48 42	6 4	64 0
Average	0 26	0 38	3 37	3 42	0 85	49 34	6 4	64 0

TABLE XIII

COMPUTED DISTRIBUTION OF CO_2 BY THE XB-45 AND BY THE B-45 FIRE-EXTINGUISHING SYSTEMS*

Discharge Quantity

	Total		Accessory Compartments				Compressor Compartments				Aft Compartment		Fuel Duct	
			No 3		No 4		No 3		No 4					
	(pounds)	*(per cent)*	*(pounds)*	*(per cent)*	*(pounds)*	*(per cent)*	*(pounds)*	*(per cent)*	*(pounds)*	*(per cent)*	(pounds)	(per cent)	(pounds)	(per cent)
Test results, XB-45 system (on basis of water-discharge ratios)	61 6	100 0	0 28	0 45	0 40	0 65	3 60	5 84	3 64	5 93	52 77	85 66	0 91	1 47
Expected distribution XB-45 system (on basis of nozzle-area ratios)	61 6	100 0	0 41	0 7	0 41	0 7	4 62	7 5	4 62	7 5	51 2	83 0	0 37	0 5
Expected distribution B-45 system (on basis of nozzle-area ratios)	61 6	100 0	0 31	0 5	0 31	0 5	3 39	5 5	3 39	5 5	53 8	86 8	0 68	1 1

* These values are based on the assumption of no loss of CO_2 during discharge

TABLE XIV

DISTRIBUTION OF CO_2 IN THE NO 3 ENGINE-COMPRESSOR COMPARTMENT BY THE XB-45 EXTINGUISHING SYSTEM

Test Condition	Compartment Region							Minimum Value Recorded
	Longitudinal Distribution of CO_2			Lateral Distribution of CO_2				
	Forward (Station -126) (per cent)	*Central* (Station -110) (per cent)	*Aft* (Station -96) (per cent)	*12 o clock* (per cent)	*6 o'clock* (per cent)	*3 o'clock* (per cent)	*9 o clock* (per cent)	(per cent)
Static	42	52	59	50	51	51	48	27
Pressure 6 inches Hg Windmilling	34	43	39	44	27	38	43	25
Pressure 6 inches Hg, 90 per cent rpm*	16	23	17	22	17	18	18	10

* Values tabulated are average maximum concentrations recorded Longitudinal-distribution values are averages of four pick-up locations Lateral-distribution values are averages of three pick-up locations

Duration of Discharge

The discharge duration for 61 6 pounds of carbon dioxide by the XB-45 extinguishing system was measured by means of colored motion pictures With the system mounted in the open and with an air blast of approximately 90 mph passing over it to make the discharge visible throughout the test, the carbon dioxide was released and motion pictures were taken A large clock, capable of being read to 1/100th of a second, was placed within view of the camera for timing the discharge These tests showed that the total discharge time was 2 9 seconds, and the apparent full-strength discharge time was 1 0 second The total time listed is the elapsed time between the first and the final visual indications of discharge The apparent full-strength discharge time is that which elapsed between the instant the rate no longer appeared to increase and the instant it first appeared to decrease

Agent Concentration

The objective of this phase of testing was to determine the concentrations of carbon dioxide within the nacelle compartments when the XB-45 extinguishing system is discharged under simulated flight conditions Specifically, measurements were made to determine (1) the average maximum concentration of carbon dioxide resulting in each compartment from the discharge of the system, (2) the resulting distribution of the agent within each compartment, and (3) the resulting time-versus-concentration relationship in each compartment

The test procedure consisted of measuring, by the use of a gas analyzer, the concentrations of carbon dioxide occurring within the XB-45 nacelle when discharging the fire-extinguishing system under conditions simulating those which exist in flight and which result from following the prescribed fire-emergency procedure for the B-45 airplane Since this procedure calls for both engines being shut down, the tests were conducted with engines windmilling Depending on the airplane speed and altitude, the total engine-inlet air pressure would vary, so that tests were conducted at various values ranging from 0 to 7 inches of Hg The tests covered a range of simulated speeds up to approximately 425 mph at sea level or up

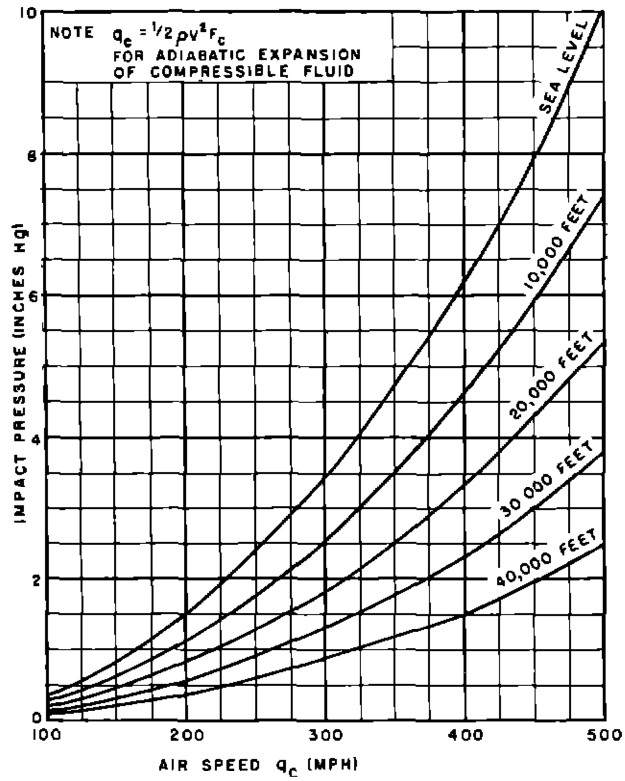

Fig 23 Pitot Impact (total) Pressures at Various Air Speeds and at Standard Altitudes

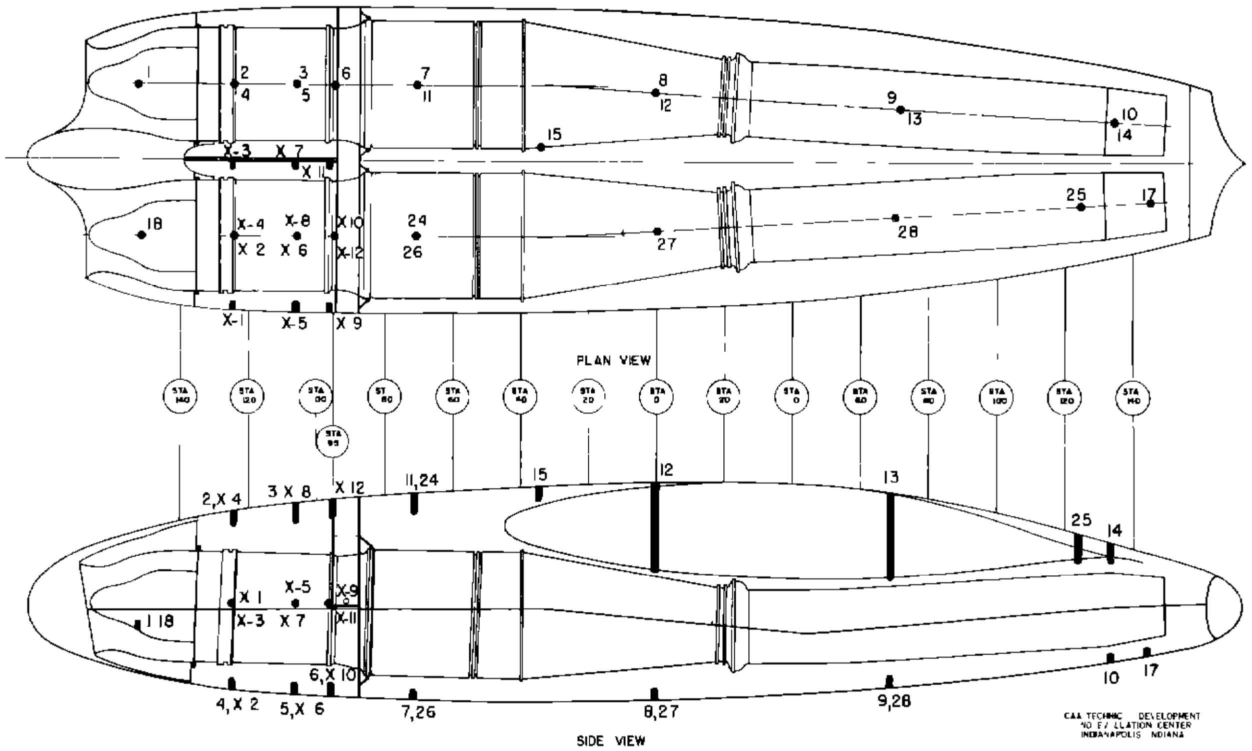

Fig 24 Location of Sampling Points, Carbon Dioxide Concentration Measurements

to 490 mph at 10,000 feet altitude For purposes of interpretation of results in this and other sections of the report, the calculated standard-condition relationships between air speed, total pressure, and altitude are shown in Fig 23

Instrumentation consisted of an installation in the nacelle of numerous sampling tubes through which the analyzer drew the gas samples during a test The designations and locations of the sampling points are shown in Fig 24 Each test was conducted by providing the desired total pressure to the engine inlets and allowing the rpm of the windmilling engine to stabilize The analyzer was then operated during the discharge of the agent In all tests, 61 6 pounds of carbon dioxide were discharged through the XB-45 extinguishing system The four cylinders used contained winterized charges of 15 4 pounds of carbon dioxide each and were located two in each simulated wheel-well position

This gas analyzer used in the tests was built by Statham Laboratories, Inc , and it was designed specifically for recording extinguishing-agent concentrations as they may occur in aircraft It is capable of recording rapidly changing concentrations and consists essentially of 18 analyzer units, a vacuum pump for drawing the gas samples through the units, and an 18-channel oscillograph for recording the concentrations as indicated by transducers in the analyzer units A complete description of this instrument is given in a separate report [4] These tests represented the initial effort to utilize this instrument in full-scale tests

The results of concentration measurements are presented by graphs and tables which show (1) the average maximum concentrations occurring within each primary nacelle compartment for various engine-inlet air pressures (various simulated flight speeds), (2) the distribution of carbon dioxide within each compartment, and (3) the time-versus-concentration relationship resulting in each compartment Discussion of these results is given in greater detail in the following paragraphs

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[4] 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

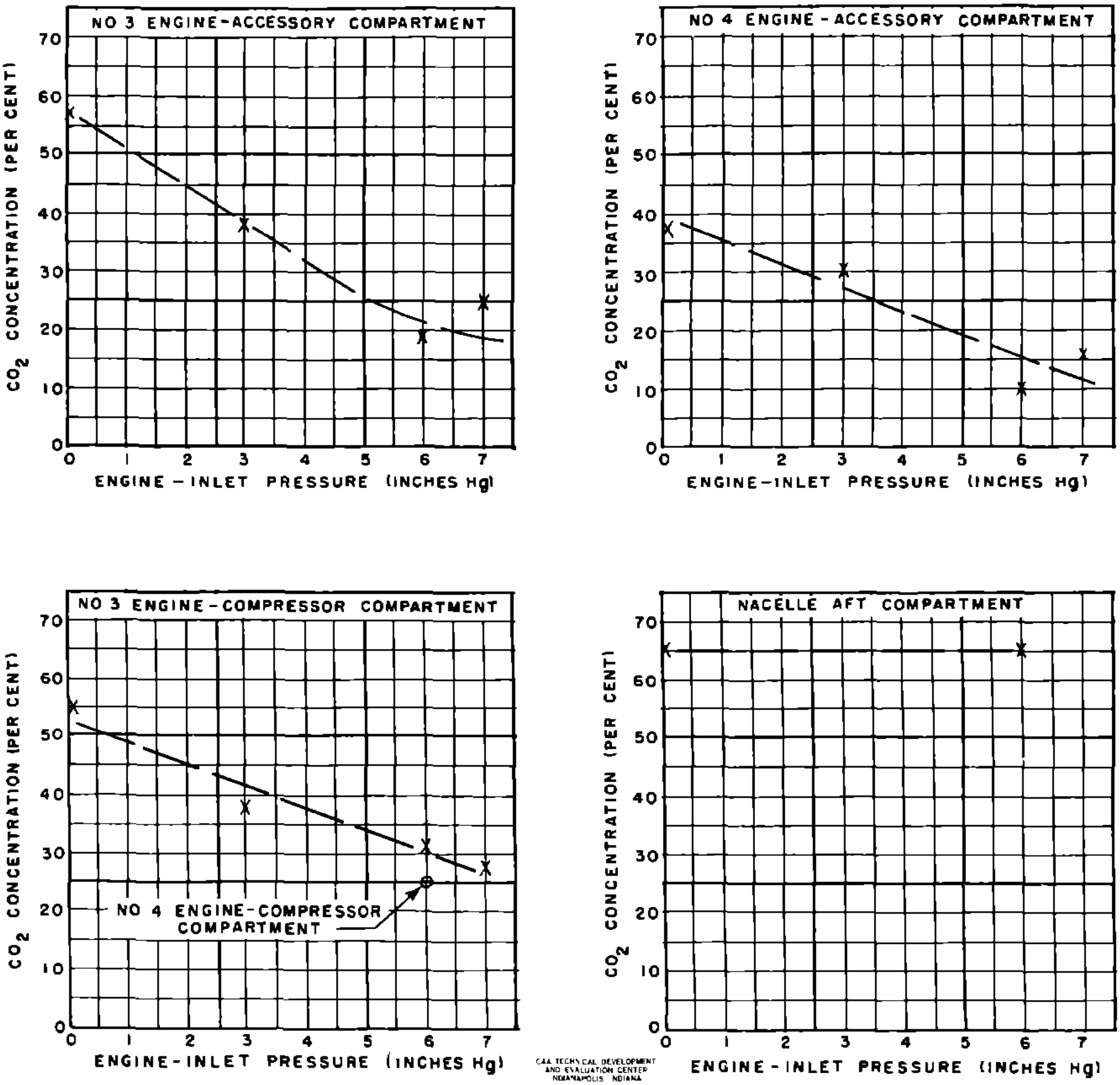


Fig 25 Effect of Engine-Inlet Total Pressure on Carbon Dioxide Concentrations Resulting From Discharge of XB-45 Extinguishing System With Engines Windmilling

1 The maximum concentrations that occurred during discharge of the XB-45 extinguishing system under various engine-inlet air pressures are shown in Fig 25 Each plotted point on the curves represents the average maximum concentration determined from numerous pickups and from two test runs The accessory-compartment data was obtained by one pickup, the compressor-compartment data from two pickups (except for the tests at 6 inches of Hg, where 12 pickups were used), and the aft-compartment data from 13 pickups

The required value of average maximum concentration of carbon dioxide for fire extinguishment cannot be specified exactly because of the nonuniform agent distribution that may occur within a compartment and because of the unknown magnitude of influence which the method of introducing the agent may exert It is generally recognized that oxygen concentration must be reduced from the normal 21per cent to 15 per cent or lower, in order to prevent combustion of such fluids as gasoline and kerosene For homogeneous mixtures, this would require a carbon dioxide concentration of at least 28 5 per cent On the basis of this figure and the comparative data obtained by actual fire tests, a tentative value of 40 per cent carbon dioxide concentration was selected as representing a desirable minimum requirement

From the graphs in Fig 25, it is noted that maximum average carbon dioxide concentrations occurring in the aft nacelle compartment were well above the minimum requirement and were unaffected by the air pressure at the engine inlets In all forward compartments, the required concentrations were below the recommended minimum at high engine-inlet air pressures They were appreciably reduced by increased pressure

2 Distribution studies were made in the No 3 engine-compressor compartment and in the No 3 engine side of the aft compartment Tests were conducted under static conditions and under simulated flight conditions The pickup locations are shown in Fig 24 The results were analyzed by calculating the average concentrations for various regions within the compartments from the maximum concentrations recorded For distribution analysis, the compressor compartment was divided into three longitudinal regions represented by the nacelle stations -126 (forward region), -110 (central region), and -96 (aft region) It was also divided into lateral regions represented by the engine clock positions 12 o'clock (upper region), 6 o'clock (lower region), 3 o'clock (compartment outboard region), and 9 o'clock (inboard, or keel region) Likewise, the aft compartment was divided into four longitudinal regions represented by nacelle stations -70, 0 0, +70, and +135 For this compartment, information was obtained concerning the upper and lower lateral regions only

The analysis of test results is shown in Tables XIV and XV In addition to average maximum concentrations for each of the regions, the lowest single reading recorded for each test condition is listed as an indication of the weakest local concentration The following comments regarding distribution of carbon dioxide within the compartments are based on the values shown in the tables

a Discharge of the XB-45 extinguishing system under static conditions produced an even distribution of carbon dioxide in the compressor compartment However, under conditions simulating flight with ram air supplied to the engine inlets and with engines windmilling, carbon dioxide concentration was much lower below the engine than it was in the upper and side regions of the compartment The minimum recorded concentration listed in the table occurred in the forward lower region This information indicates greater air-guide-seal leakage and greater air flow in the lower portion of the compartment and a need for the distribution of greater quantities of carbon dioxide in this area

TABLE XV

DISTRIBUTION OF CO_2 IN AFT NACELLE COMPARTMENT BY XB-45 EXTINGUISHING SYSTEM*

Test Conditions	Compartment Region						Minimum Value Recorded
	Longitudinal Distribution of CO_2				Lateral Distribution of CO_2		
	Station -70 (per cent)	Station 0 (per cent)	Station +70 (per cent)	Station +135 (per cent)	Upper (per cent)	Lower (per cent)	(per cent)
Static	60	85	67	81	58	84	25
Pressure 6 inches Hg Windmilling	54	68	72	71	62	69	45
Pressure 0 inches Hg 90 per cent rpm	53	58	64	52	55	57	35

* Values tabulated are average maximum concentrations recorded Longitudinal distribution values are averages of 4, 3 3 and 4 pick-up locations, respectively Lateral distribution values are averages of 5 and 8 pick-up locations respectively

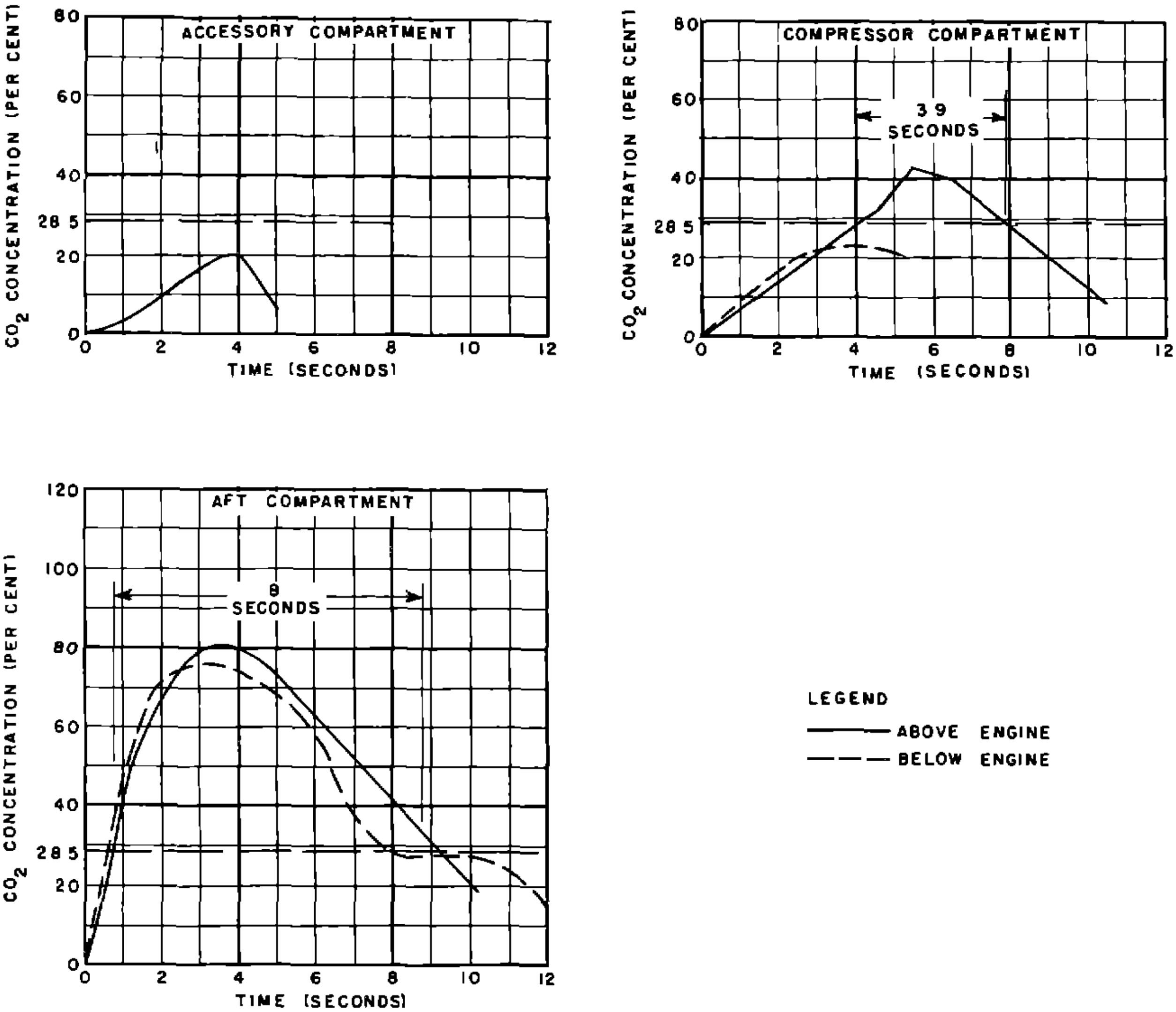


Fig 26 Time-Versus-Carbon Dioxide Concentration Relationship Resulting in Nacelle Compartments From Discharge of XB-45 Extinguishing System

b Table XV shows that carbon dioxide concentrations above and below the tail pipe were approximately equal Longitudinally, higher concentrations occurred in the aft portion of the compartment

3 The duration and magnitude of carbon dioxide concentrations occurring in the nacelle compartments from the discharging of the XB-45 extinguishing system are indicated by the graphs of Fig 26 Actual time-concentration recordings obtained with the gas analyzer are shown in this figure Results are plotted from single-point pickup locations and were obtained with engines windmilling and with a total air pressure of 6 inches of Hg at the engine inlets

From Fig 26, it is noted that

a The agent concentration in the No 3 engine-accessory compartment never reached the minimum value of 28 5 per cent considered to be necessary for fire extinguishment

TABLE XVI

RESULTS OF FIRE-EXTINGUISHING TESTS
CONDUCTED IN LOWER REGION OF NO 3 ENGINE-COMPRESSOR COMPARTMENT

Test Conditions Gasoline supply to fire, 0 6 gpm, agent discharged, 61 6 pounds CO_2

Engine-Inlet Total Pressure (inches Hg)	Engine RPM No 3 (per cent)	Engine RPM No 4 (per cent)	Extinguishing Procedure*	Air-Guide Seal	Fire Extinguished
0 0	90	0	B	Original	Yes
0 0	90	0	C	Original	Yes
0 1	45	45	A	Original	Yes
0 2	90	0	B	Original	No
1 0	90	Windmilling	B	Original	Yes
1 0	90	Windmilling	B	Original	Yes
1 0	90	Windmilling	C	New	Yes
1 0	90	Windmilling	C	New	Yes
1 0	90	Windmilling	B	Original	Yes
2 0	90	Windmilling	C	Original	Yes
2 0	90	Windmilling	B	Original	No
2 0	90	Windmilling	B	Original	No
3 0	90	Windmilling	C	Original	No
3 0	90	Windmilling	C	New	No
3 0	Windmilling	Windmilling	C	New	No
3 0	90	Windmilling	B	Original	No
5 0	90	Windmilling	C	Original	No
5 0	90	Windmilling	B	Original	No
5 0	90	Windmilling	B	Original	No
5 0	45	Windmilling	C	Original	No
7 0	90	Windmilling	C	New	No
7 0	Windmilling	Windmilling	C	New	No

* Extinguishing Procedure
- A - Throttle was chopped rapidly 5 seconds after start of fire CO_2 was released 10 seconds later
- B - CO_2 was released 10 seconds after start of fire Engine was not shut down during procedure
- C - CO_2 was released 5 seconds after start of fire Engine was not shut down during procedure

b Above the engine in the No 3 compressor compartment, the agent concentration exceeded 28 5 per cent for 3 9 seconds and exceeded 40 per cent (the recommended minimum) for 1 2 seconds Below the engine, it never reached 28 5 per cent

c The agent concentration exceeded 28 5 per cent for approximately 8 seconds and exceeded 40 per cent (the recommended minimum) for approximately 6 4 seconds in the aft compartment both below and above the No 3 engine tail pipe

Full-Scale Fire Tests

The ability of the XB-45 fire-extinguishing system to extinguish fires was determined by causing it to discharge the agent under various conditions of engine operation and by observing the effect on fires ignited at different locations within the nacelle The majority of the tests were conducted on a fire resulting from the release of aviation gasoline from a pinched-end tube at a rate of 0 6 gpm In some instances, standard hydraulic fluid (AN-VVO-366B) was also supplied at a rate of 0 4 gpm The detailed conditions for each test that was run are shown in Tables XVI and XVII Evaluation tests were conducted in the No 3

TABLE XVII

RESULTS OF FIRE-EXTINGUISHING TESTS CONDUCTED IN AFT NACELLE COMPARTMENT

Engine RPM No 3 (per cent)	Engine RPM No 4 (per cent)	Engine-Inlet Total Pressure (inches Hg)	Fuel to Fire*	Test Procedure**	Fire Location (See Fig 11)	Fire Extinguished
Windmilling	Windmilling	6 0	Gasoline	H	J	Yes
Windmilling	Windmilling	6 0	Gasoline	H	J	Yes
45	45	0 0	Gasoline	H	J	Yes
90	90	0 0	Gasoline	H	J	Yes
90	90	0 0	Gasoline	H	J	Yes
45	45	0 0	Gasoline	H	Y	Yes
90	90	0 0	Gasoline	H	Y	Yes
45	45	0 0	Gasoline + Oil	D	Y	Reflash 10 seconds
45	45	0 0	Gasoline + Oil	F	Y	Reflash 22 seconds
90	90	0 0	Gasoline + Oil	E	Y	Yes
90	90	0 0	Gasoline + Oil	D	Y	Reflash 22 seconds
45	45	0 0	Gasoline + Oil	G	Y	Yes

* Fuel Supply to Fire
Gasoline was at a rate of 0 6 gpm oil was standard AN-VVO-366B hydraulic fluid at 0 4 gpm

** Test Procedure
- H - Agent was released 5 seconds after start of fire Engines were not shut down
- D - Hydraulic fluid was released for 20 seconds, gasoline was released and ignited. Agent was released 5 seconds after start of fire Flow of gas and oil was stopped 5 seconds after release of agent Engines were not shut down
- E - Hydraulic fluid was released for 10 seconds, then gasoline was released and ignited Agent was released 5 seconds after start of fire Flow of gas and oil was shut off after extinguishment Engines were not shut down
- F - Hydraulic fluid was released, gasoline was released and ignited at 20 seconds, agent was released at 25 seconds gasoline flow was shut off at 30 seconds, oil flow was shut off at 42 seconds Engines were not shut down
- G - Hydraulic fluid was released, gasoline was released and ignited at 20 seconds, throttles were chopped at 22 seconds, agent was released at 25 seconds, gasoline and oil were shut off at 29 seconds

Agent discharged = 61 6 pounds of CO_2

engine-compressor compartment and in the aft nacelle compartment The quantity of agent which was used was 61 6 pounds of carbon dioxide The minimum quantity of agent required for extinguishment was also determined for each compartment

A Compressor-Compartment Tests

The fire tests conducted in the upper region of the No 3 engine-compressor compartment were made with the No 3 engine operating at 90 per cent of rated rpm, at engine-inlet air pressures of 0, 2, 3, 4, 5, and 7 inches Hg The extinguishing system discharged the agent five seconds after fire ignition No shutoff procedure was used prior to the discharge Under these conditions, all fires were extinguished by the XB-45 extinguishing system.

The results of fire tests conducted in the lower region of the compartment are given in Table XVI From the table it is noted that fires in the lower region were extinguished by the XB-45 system when the engine-inlet air pressure was below 2 inches Hg For pressures above this, the fires were not extinguished Failure of the system to extinguish fires was observed to be due to ram-air leakage through the lower half of the engine air-guide seal, which leakage caused air flow in this region to be greatly in excess of the design value During the course of testing, the seal was replaced with an improved seal of the type which was used in the production-model B-45 airplanes This, however, did not noticeably improve the extinguishing effectiveness

B Nacelle Aft-Compartment Tests

The extinguishing studies made in this compartment included tests (a) with engines windmilling and with engines at 45 per cent and at 90 per cent of rated rpm, (b) with engine-inlet air pressures of 0 and of 6 inches Hg, (c) with both gasoline and oil and with gasoline alone

TABLE XVIII

REQUIRED QUANTITIES OF AGENT FOR EXTINGUISHING NACELLE FIRES WITH XB-45 EXTINGUISHING SYSTEM

Test Conditions Gasoline Supply to Fire 0 6 gpm
Size of CO_2 Cylinders 853 cubic inches
5-second fire engines not shut off

Compartment	Fire Location (See Fig 11)	Engine RPM No 3 (per cent)	Engine RPM No 4 (per cent)	Engine-Inlet Total Pressure (inches Hg)	Total CO_2 Discharged Into Entire Nacelle (pounds)	Number Cylinders Used	Fire Extinguished
No 3 Engine Compressor	A	45	Windmilling	5 0	61 6	4	No
No 3 engine Compressor	A	90	Windmilling	5 0	92 4	6	No
No 3 engine Compressor	A	90	Windmilling	5 0	107 8	7	No
No 3 engine Compressor	A	90	Windmilling	5 0	123 2	8	Yes
Aft	J	90	90	0 0	61 6	4	Yes
Aft	J	90	90	1 0	31 0	4	Yes
Aft	J	90	90	1 0	26 0	4	Yes
Aft	J	90	90	1 0	20 0	4	No

used for producing the test fire, and (d) with test fires located at two positions, J and Y See Fig 11 The conditions and the results of each test are given in Table XVII

All gasoline test fires were extinguished by the XB-45 extinguishing system with engines windmilling and also under the more severe air-flow conditions resulting from engine operation at 45 and at 90 per cent of the rated rpm Hydraulic-fluid fires were extinguished in all tests, however, in this instance, continued engine operation after agent discharge caused fire reflash Detailed studies of the reflash hazard were made and are reported elsewhere in this report

C Agent-Requirement Tests

In addition to the evaluation tests, studies were made to determine the minimum quantity of an agent that is required to extinguish fires in the compressor and aft compartments when the perforated-tubing system is used in the XB-45 nacelle The previous test results when the standard B-45 airplane supply of 61 6 pounds of carbon dioxide was used indicated that the quantity of the agent discharged into the aft compartment was possibly in excess of requirements and that the concentration of agent in the compressor compartment was inadequate Agent-requirement tests were therefore designed to indicate the extent of unbalance and to indicate the feasibility of overcoming existing inadequacies by supplying additional quantities of the agent Such additions were not expected to increase the rate of discharge or to change the balance of the system The test conditions as well as the test results are given in Table XVIII The quantities of agent listed are those discharged through the entire nacelle system to all nacelle compartments

As shown in the table, a total system discharge of 123 pounds of carbon dioxide was necessary to extinguish compressor-compartment fires A total system discharge of 26 pounds was necessary to extinguish aft-compartment fires Previous distribution measurements indicated that, of the total charge, 5 84 per cent was discharged into the No 3 compressor compartment and 85 66 per cent into the aft compartment See Table XIII On the basis of these values, the tests indicated that 123 x 0 0584, or 7 18, pounds of carbon dioxide to the compressor compartment and 26 x 0 856, or 22, pounds to the aft compartment were necessary to extinguish fires The ratio of agent quantity requirements for the two compartments was $\frac{7\ 18}{22} = 0\ 33$, whereas the measured system-discharge ratio was $\frac{5\ 84}{85\ 66} = 0\ 07$ These figures indicate the degree of distribution unbalance

Conclusions

The evaluation studies of the XB-45 airplane-nacelle fire-extinguishing system indicated that inadequate protection was provided to the forward nacelle compartments and that adequate protection was provided to the aft nacelle compartment A comparison of the B-45 production-airplane extinguishing system with the XB-45 system indicated that nacelle forward-compartment protection in the B-45 models is probably less effective than in the XB-45 airplane

The following specific conclusions are drawn from the test results

1 The supply of carbon dioxide to the nacelle forward compartments by the XB-45 extinguishing system was somewhat less than expected from design calculations
2 The air flow in the compressor compartments was a great deal higher than was originally estimated, and the classification in design calculations of these compartments as Class D hazards was in error Inadequate sealing between the compartments and the engine inlets resulted in air flow that was in excess of original estimates The air-guide seal was particularly ineffective in the lower half of the compartment where it was attached to the nacelle forward hinged door This resulted in relatively high compartment air flow at high engine-inlet air pressures
3 Measurements of the duration of carbon dioxide discharge indicated that the rate and duration were in approximate agreement with design values
4 The concentration of carbon dioxide resulting from the discharge of 61 6 pounds of carbon dioxide (the standard charge for the B-45 production airplanes) through the XB-45 extinguishing system was found, by gas analysis and by fire tests, to be adequate in the aft compartment of the nacelle and to be inadequate in the forward accessory and compressor compartments under conditions simulating those following flight-fire procedures

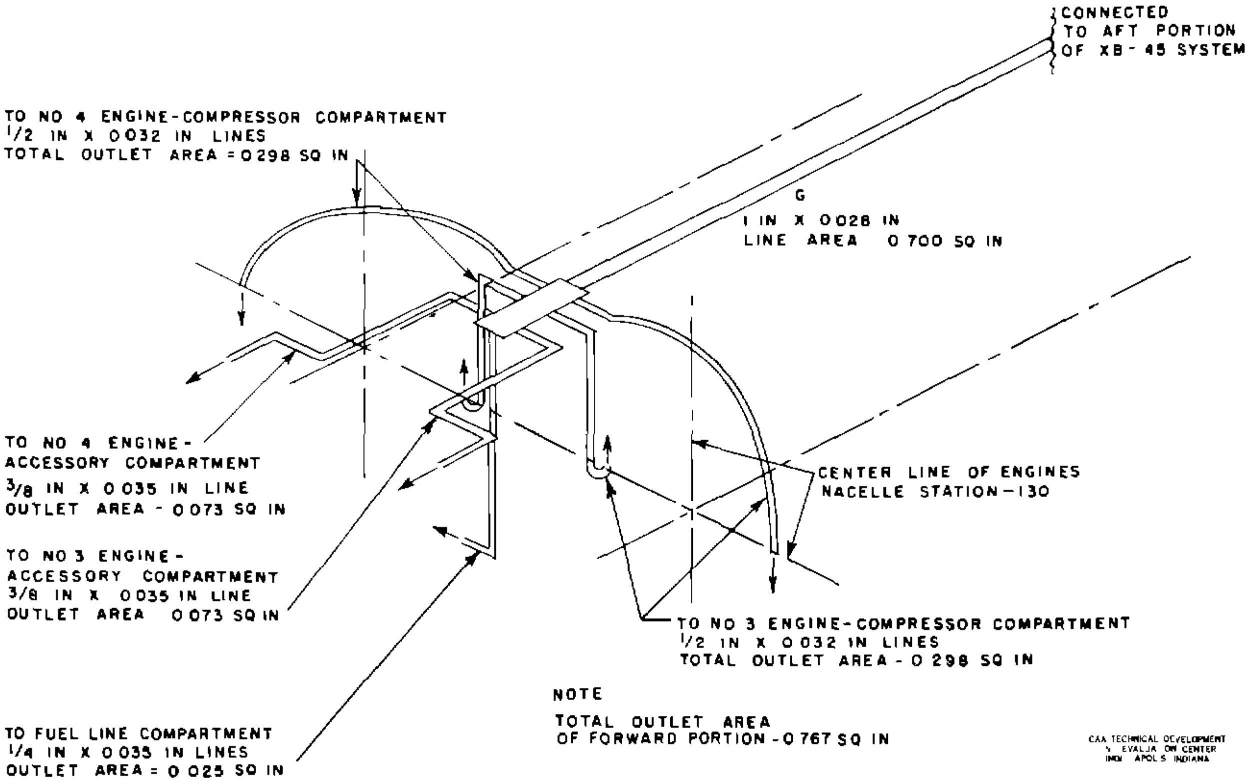


Fig 27 Forward Portion of XB-45(M) Extinguishing System

5 The distribution of carbon dioxide within the nacelle compartments by the XB-45 extinguishing system was adequate in the aft compartment and inadequate in the compressor compartments Under conditions for which the extinguishing system was designed, the distribution of the agent within the compressor compartments was adequate, but barely so
6 The time during which the carbon dioxide concentrations remained above the recommended minimum value of 40 per cent was indicated to be about 6 4 seconds in the aft compartment and to be about 1 2 seconds in the upper region of the compressor compartments This was under conditions simulating those during flight-fire emergency procedure when the engines are windmilling and when ram air is supplied at the engine inlets The recorded concentrations in the lower compressor-compartment regions and in the engine-accessory compartments never reached 40 per cent
7 The quantity of agent (61 6 pounds of carbon dioxide) provided by the XB-45 extinguishing system for the entire nacelle was adequate However, the distribution of the agent by the system to the various nacelle compartments was such that excessive quantities were discharged into the aft compartment and inadequate quantities were discharged into the forward compartments Fire-extinguishing tests indicated that a change in the characteristics of system distribution rather than an increase in the agent quantity was needed to improve the effectiveness of the system

DEVELOPMENT OF AN IMPROVED CARBON DIOXIDE EXTINGUISHING SYSTEM

The evaluation tests previously conducted on the XB-45 system indicated that additional protection was needed in the forward compartments of the nacelle Two revisions were considered desirable, namely, (a) to replace ineffective seals between the engine air inlets and the compressor compartments to reduce air flow in the compartments, and (b) to modify or supplement the extinguishing system in order to provide higher concentrations of carbon dioxide in the lower regions of the compressor compartments and in the engine-accessory compartments The studies made here were for the purpose of accomplishing item (b)

Modification of the XB-45 System

The ability of the XB-45 extinguishing system to extinguish fires in the forward nacelle compartments was improved a great deal by modifying the forward portion of the system

TABLE XIX

DESCRIPTIONS OF VARIOUS MODIFIED EXTINGUISHING SYSTEMS USED IN THE FIRE TESTS ON THE XB-45

System Designation	Description
XB-45 (1)	This system consisted of the forward portion only of the XB-45 system The extinguishing-agent cylinder was connected at the upstream end of feed line G See Fig 22
XB-45 (2)	This system was almost the same as system XB-45(1), but it had the ends of the distribution lines H_O and I_I opened and had a 90° angle attachment on the end of line I_I for directing the CO_2 blast across the air stream below the engine See Fig 22
XB-45 (3)	This system was almost the same as the XB-45 extinguishing system, but it had the ends of lines H_O and I_I open and had a 90° angle attachment on the end of line I_I for directing the CO_2 blast across the air stream below the engine
XB-45 (M)	This system was almost the same as the XB-45 extinguishing system, but it had the forward portion replaced with a distributor block and single-outlet open-end lines See Fig 27

The modification consisted of the replacement of the perforated tubing in the compressor compartments with open-end tubing as shown in Fig 27 Descriptions of the various configurations or systems tested in arriving at the final modification are given in Table XIX The conditions and results of individual tests on these systems are given in Tables XX, XXI, and XXII

The initial series of tests using the forward portion of the XB-45 system, which is designated system XB-45(1), indicated a need for greater protection in the lower region of the compressor compartment See Table XX The second series of tests, using system XB-45(2), showed that the effectiveness of the system was greatly improved by directing carbon dioxide across the lower region of the compartment See Table XXI The third series of tests indicated that opening the ends of lines in both compressor compartments, as in system XB-45(3), did not materially reduce the extinguishing effectiveness in the aft compartment See Table XXII In the final series of tests conducted on system XB-45(M), 0 6-gpm gasoline test fires were extinguished under high ram-pressure conditions Very severe test fires (2 5 gpm), however, were not extinguished

From these studies, it was concluded that a modification in the design of the XB-45 extinguishing system in accordance with that designated as system XB-45(M) was a means by which the effectiveness of the original system could be appreciably increased However, the modified system did not extinguish severe fires which completely enveloped the compressor compartment The improved effectiveness of system XB-45(M) was considered to be a result of (1) a slight additional supply of carbon dioxide to the forward compartments and (2) a more effective distribution of the agent from the utilization of a blast effect obtained by discharging the agent from open-end tubing across the air stream

TABLE XX

RESULTS OF FIRE-EXTINGUISHING TESTS USING SYSTEM XB-45(1) IN THE NO 3 ENGINE-COMPRESSOR COMPARTMENT

Test Conditions Gasoline supply to fire, 0 6 gpm,
No 3 engine operating at 90 per cent rpm,
5-second fire, engine not shut off

Engine-Inlet Total Pressure (inches Hg)	Fire Location (See Fig 11)	CO_2 Discharged by Entire System (pounds)	Fire Extinguished
5	B	12 6	Yes
5	B	6 0	Yes
5	B	5 0	Yes
5	B	4 0	No
0	A	8 0	Yes
0	A	6 0	No
0	A	5 0	No
3	A	8 0	No
5	A	12 0	No
5	A	15 4	No
5	A	20 0	No

TABLE XXI

RESULTS OF FIRE-EXTINGUISHING TESTS IN THE NO 3 ENGINE-COMPRESSOR COMPARTMENT AND USING SYSTEM XB-45 (2)

Test Conditions Gasoline supply to fire, 0 6 gpm,
No 3 engine operating at 90 per cent rpm,
5-second fire, engine not shut off,
Engine-inlet total pressure, 5 inches Hg

Fire Location (See Fig 11)	Total CO_2 Discharged Into Entire System (pounds)	Fire Extinguished
B	6 0	Yes
B	4 0	Yes
B	3 0	No
A	15 4	Yes
A	10 0	Yes
A	8 0	Yes
A	5 0	Yes
A	5 0	Yes
A	4 0	Yes
A	4 0	Yes
A	3 0	No
A	2 0	No
C	5 0	Yes
C	4 0	Yes

Development of a Supplementary System

A supplementary carbon dioxide extinguishing system, intended to provide additional protection to the forward nacelle compartments, was designed and installed in the test nacelle This system, designated S-1, is shown in Fig 28 It utilized open-end tubing for discharging the agent By directing the outlets as shown in the illustration, the agent was distributed around the engines by a high-velocity swirling action, thereby utilizing dynamic as well as static effects to accomplish extinguishment

The test conditions and the results of fire tests conducted with the system are shown in Table XXIII, and they indicate that (1) gasoline fires (0 7 gpm) in the lower region of the compressor compartment and under high ram-air conditions were extinguished by utilizing system S-1 alone with a minimum of 4 pounds of carbon dioxide, (2) very severe gasoline fires (2 5 gpm) covering the entire compartment were extinguished by 7 0 pounds of carbon dioxide, and (3) under extremely severe fire conditions created by the release of 2 5 gpm of gasoline and by the prior removal of the lower portion of the air-guide seal, 9 pounds of carbon dioxide extinguished the fire

It was concluded that system S-1 using a standard 7 5-pound charge of carbon dioxide should provide adequate protection against fires in the compressor compartments of the

TABLE XXII

RESULTS OF FIRE-EXTINGUISHING TESTS USING SYSTEM XB-45 (3) AND SYSTEM XB-45(M)

Test Conditions Quantity of CO_2 discharged, 61 6 pounds, 5-second fire, engine not shut off

System	Engine-Inlet Total Pressure (inches Hg)	Engine RPM		Fire Location (See Fig 11)	Gasoline Supply to Fire (gpm)	Fire Extinguished
		No 3 (per cent)	No 4 (per cent)			
XB-45 (3)	3	90	Windmilling	A	0 6	Yes
XB-45 (3)	7	90	Windmilling	A	0 6	Yes
XB-45 (3)	7	90	Windmilling	A	0 6	Yes
XB-45 (3)	7	90	Windmilling	A	0 6	Yes
XB-45 (3)	6	90	Windmilling	J	0 6	Yes
XB-45 (3)	6	Windmilling	Windmilling	J	0 6	Yes
XB-45 (M)	8	Windmilling	Windmilling	A	0 6	Yes
XB-45 (M)	8	90	Windmilling	A	0 6	Yes
XB-45 (M)	3	Windmilling	Windmilling	Z*	2 5	No
XB-45 (M)	8	Windmilling	Windmilling	Z	2 5	No
XB-45 (M)	8	Windmilling	Windmilling	Z	2 5	No
XB-45 (M)	8	Windmilling	Windmilling	Z	2 5	No

* Fire Location Z - No 3 engine-compressor compartment This fire filled the entire compartment and was produced by releasing gasoline from a 3/8-inch perforated ring mounted at the forward fire wall around the engine A very severe fire resulted

nacelle The use of this system to supplement the regular XB-45 or the B-45 nacelle system was considered to be a satisfactory means for providing adequate protection to the forward nacelle compartments

FLIGHT-FIRE EMERGENCY PROCEDURE

The emergency procedure to be followed in the event of a fire in aircraft in flight is a fire-control measure carried out to reduce the intensity and the destructiveness of the fire and to establish optimum conditions for extinguishment In the light of these objectives, a study was made of the emergency procedure for the B-45 airplane

The procedure established by the Department of the Air Force for B-45 aircraft in the event of a power-plant fire is as follows

1 Close the switches of the fuel shutoff valves for both engines in the affected nacelle
2 Press the fire-extinguisher switch for the affected nacelle
3 Turn off the power controls for both engines
4 Shut off the fuel supply from the wing tanks on the related side of the airplane and from the cross-flow shutoff valves
5 Do not restart either engine of the affected nacelle

The following comments on this procedure are made on the basis of fire tests and observations during these tests

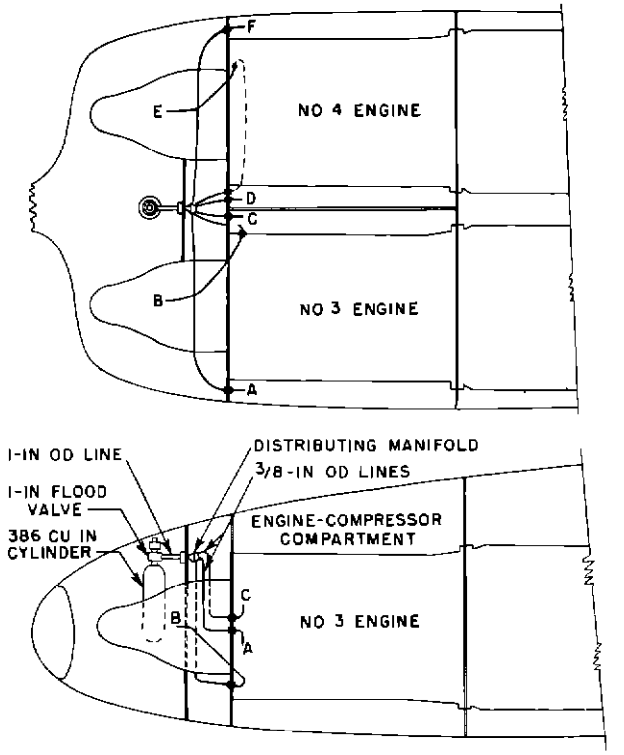
The procedure includes shutting off the engine fuel at all possible points in the system However, immediate and simultaneous shutoff at all points should stop fuel flow more rapidly than the foregoing procedure Further, shutoff of hydraulic-fluid pressure and of engine oil is not included

TABLE XXIII

RESULTS OF FIRE-EXTINGUISHING TESTS IN THE NO 3 ENGINE-COMPRESSOR COMPART
USING SUPPLEMENTARY CO_2 SYSTEM S-1

Test Condition 5-second fire, engine not shut off when operating

Engine-Inlet Total Pressure (inches Hg)	Engine RPM No 3 (per cent)	Engine RPM No 4 (per cent)	Fire Location (see Fig 11)	Gasoline Supply to Fire (gpm)	Air-Guide Seal	Size Cylinder Used (cubic inches)
4	45	45	A	0 72	Normal	386
6	90	Windmilling	A	0 72	Normal	386
8	Windmilling	Windmilling	A	0 72	Normal	386
8	Windmilling	Windmilling	A	0 72	Normal	386
8	Windmilling	Windmilling	A	0 72	Normal	205
8	Windmilling	Windmilling	A	0 72	Normal	205
8	Windmilling	Windmilling	A	0 72	Normal	205
8	Windmilling	Windmilling	Z	2 5	Normal	386
1	Windmilling	Windmilling	A	0 72	Lower portion removed	386
4	Windmilling	Windmilling	A	0 72	Lower portion removed	386
4	Windmilling	Windmilling	A	0 72	Lower portion removed	386
6	Windmilling	Windmilling	A	0 72	Lower portion removed	386
6	90	Windmilling	A	0 72	Lower portion removed	386
8	Windmilling	Windmilling	A	0 72	Lower portion removed	386
8	Windmilling	Windmilling	Z	2 5	Lower portion removed	386
8	Windmilling	Windmilling	Z	2 5	Lower portion removed	386
8	Windmilling	Windmilling	Z	2 5	Lower portion removed	386



NOTE
TUBE 'A' AT THE NACELLE DOOR-HINGE LINE IN NO 3 ENGINE-COMPRESSOR COMPARTMENT OPEN END OF TUBE POINTS DOWNWARD
TUBE B' ACCESSORY SECTION OF NO 3 ENGINE, OPEN END OF TUBE POINTS DIRECTLY FORWARD
TUBE "C" ADJACENT TO KEEL IN NO 3 ENGINE-COMPRESSOR COMPARTMENT OPEN END OF TUBE POINTS UPWARD
TUBE "D' ADJACENT TO KEEL IN NO 4 ENGINE-COMPRESSOR COMPARTMENT OPEN END OF TUBE POINTS UPWARD
TUBE E ACCESSORY SECTION OF NO 4 ENGINE, OPEN END OF TUBE POINTS DIRECTLY FORWARD
TUBE F' AT THE NACELLE DOOR-HINGE LINE IN NO 4 ENGINE-COMPRESSOR COMPARTMENT, OPEN END OF TUBE POINTS DOWNWARD

Fig 28 Supplementary Extinguishing System (S-1) for the Forward Portion of the XB-45 Nacelle

The primary ignition source, the hot exhaust surface, is gradually eliminated by shutting off the engines as prescribed Tail-pipe ignition tests on the XB-45 nacelle were conducted in which both gasoline and hydraulic fluid were sprayed on the tail surfaces In all instances where the engines were shut down by moving the power controls to OFF prior to discharging the extinguishing system, aft-section fires were extinguished without reflash occurring Exhaust-surface temperature measurements, however, indicated that during such a shutdown procedure the temperature of the tail pipe remained dangerously high for several seconds after the power had been cut off Prevention of reignition may have been due to the relatively long period of time during which carbon dioxide concentrations in the aft section remained high See Fig 26

The final item (5) of the prescribed procedure is obviously advisable to prevent reignition

The reduction of air flow in nacelle compartments is desirable because it reduces the extinguishing requirements appreciably Such reduction is not effectively accomplished by the established procedure Engine shutdown in the case of the XB-45 actually increased the air flow in the compressor compartments because the flow was a result of air-guide-seal leakage This leakage increased with the increased static pressures at the engine inlets

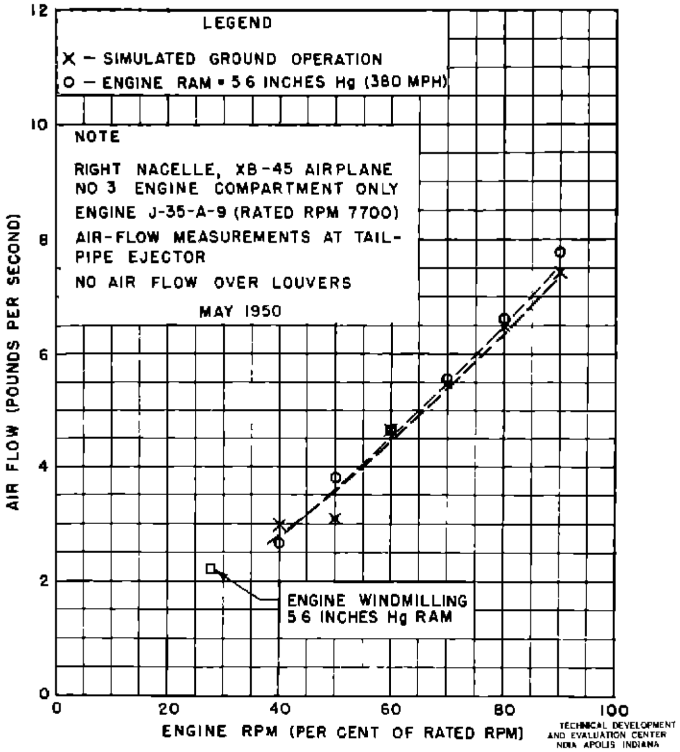


Fig 29 Effect of Engine Speed and Inlet Pressure on Aft-Compartment Air Flow

during engine shutdown In the aft compartment, the air flow was found to be influenced by engine rpm as indicated in Fig 29 If it is assumed that by following the established emergency procedure the extinguishing agent is discharged immediately after the fuel is cut off, then the engine rpm will not be greatly reduced at the time of discharge This is illustrated by Fig 30, in which the engine rpm versus the time from throttle cutoff has been plotted for various engine-inlet air pressures Failure to reduce the air flow in the aft compartment did not prove to be critical because of the large quantity of carbon dioxide discharged into the region

In connection with the evaluation of fire control in the XB-45 nacelle, measurements of carbon dioxide concentrations occurring in the different compartments were taken under various conditions of engine operation Both engine-inlet air pressure and engine rpm affected the compartment air flow and in so doing influenced the concentration of carbon dioxide resulting from the discharge of the extinguishing system The effect of the inlet pressure on the carbon dioxide concentration is shown in Fig 25, and the effect of the engine rpm is shown in Fig 31 From these figures, it is noted that conditions of low inlet pressure and low engine rpm produced optimum conditions for extinguishment

Another air source which may exist and which is not eliminated by the foregoing emergency procedure is that resulting from the discharge of thermal anti-icing air into the compressor compartments The elimination of this source of air prior to the discharge of the extinguishing agent should be accomplished

EXTINGUISHING-SYSTEM DESIGN

Although no specific study was made regarding the details of the extinguishing-system design, the tests conducted in connection with the evaluation of the XB-45 system and with the improvement of this system provided some indications regarding the weakness of present methods for obtaining fire control and regarding the influence of certain factors on extinguishing-system effectiveness

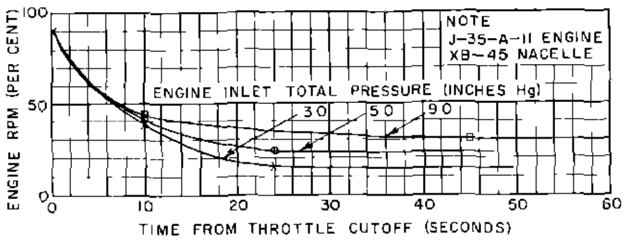


Fig 30 Engine RPM During Shutdown by Rapid Throttle Cutoff

TABLE XXIV

COMPARISONS BETWEEN PERFORATED-TUBING AND OPEN-END-TUBING SYSTEMS
(Physical Dimensions and Performance Within the No 3 Engine-Compressor Compartment)

	XB-45 System	S-1 System
Quantity of CO_2 discharged into compartment, in pounds (Based on distribution tests using water)	3 6	2 8
Number of discharge lines	2	2
Size of discharge lines (inches ID)	0 460	0 315
Type nozzle outlets	46 holes, 1/16-inch diameter	open-end tubing
Total outlet area (square inches)	0 161	0 156
Location of outlets	Perforated tubing over top and down one side of engine at nacelle station -122, 13 inches aft of forward fire seal	One outlet on each side of engine at nacelle station -130, 5 inches aft of forward fire seal Outlets directed to produce swirling action around engine and normal to longitudinal axis
Effectiveness by fire tests	Extinguished 0 6 gpm local gasoline fires only when engine-inlet total pressure was less than 2 inches Hg when	Extinguished 2 5 gpm gasoline fires covering entire compartment when engine-inlet total pressure was 8 inches Hg and with part of engine air-guide seal removed
Average of maximum CO_2 concentrations during discharge, in per cent *	28	41
Time-versus-concentration relationship resulting from CO_2 discharge	See Fig 32	See Fig 32

* The value listed for the XB-45 extinguishing system was determined with engines windmilling and with an engine-inlet total pressure of 6 inches Hg The corresponding value listed for system S-1 was determined with engines windmilling and with an engine-inlet total pressure of 8 inches Hg

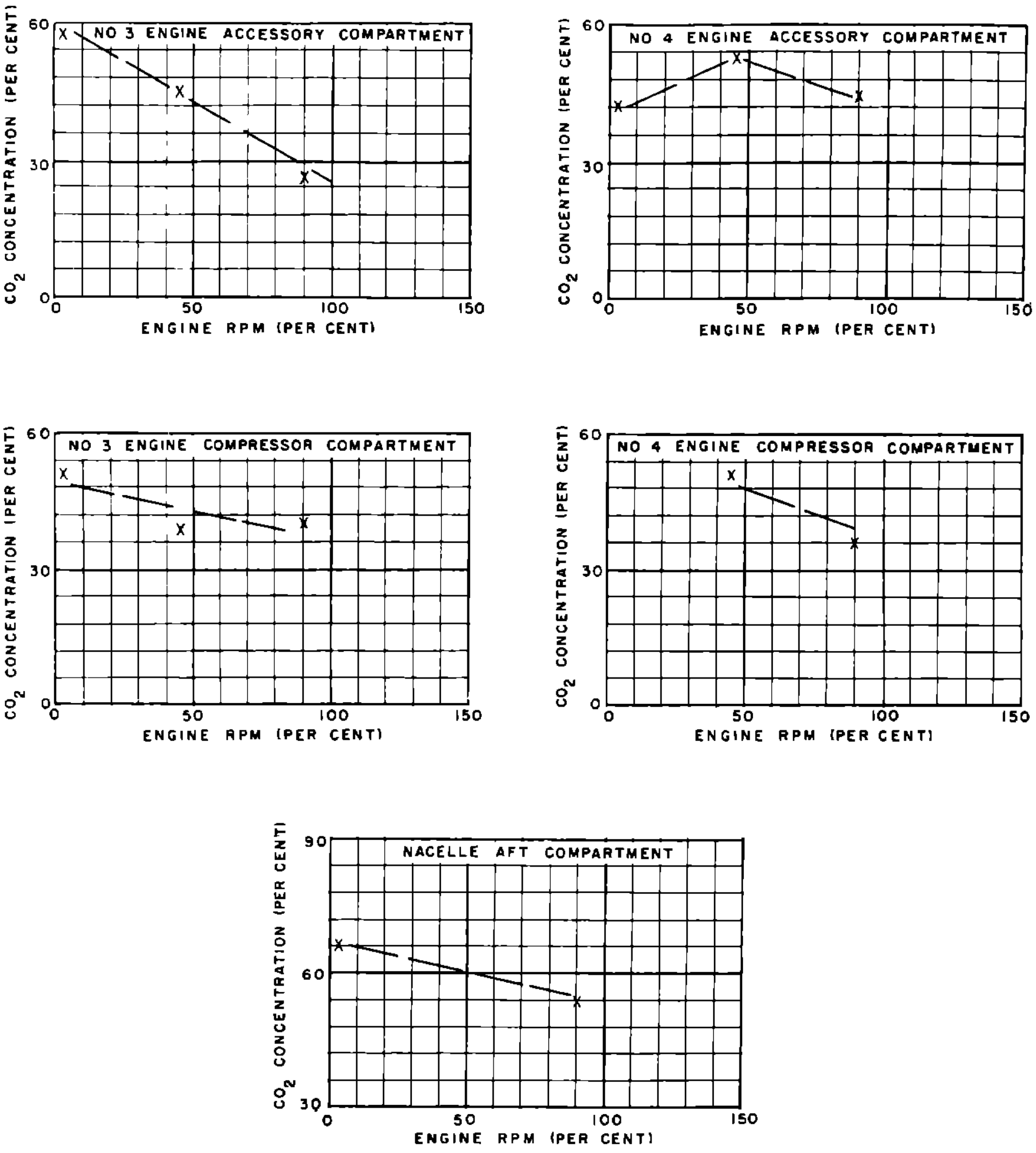


Fig 31 Effect of Engine RPM on Carbon Dioxide Concentrations Resulting From Discharge of XB-45 Extinguishing System at Zero Engine-Inlet Total Pressure

Evaluation of Design Method Used for the XB-45 Airplane

Test results indicated that fire control in the nacelle compressor compartments was inadequate It is important to note that such failure was primarily a result of ineffective sealing which permitted excessive air flow in these compartments rather than a result of improper design of the extinguishing system itself Essentially, the XB-45 extinguishing system provided the rate and duration of discharge as well as the quantities of carbon dioxide intended for the various compartments The distribution of the agent within the compartments was satisfactory for conditions of air flow assumed in the design

Use of the empirical relationships Q = 0 2V for Class C zones and Q ≈ 0 14V for Class D zones appeared to provide adequate quantities of an agent However, a more direct relationship between quantity Q, volume of the zone V, and air flow is needed The generalization made in the use of the present zone classifications is not sufficient basis for good design

The design of the system plumbing appeared to provide adequate rate and distribution of carbon dioxide for the presumed values of compartment air flows and volumes, and it was generally in accordance with that intended by the designer

Comparison of Open-End and Perforated-Tubing Systems

In the tests involving modification of the XB-45 extinguishing system and the development of a supplementary system for the forward nacelle compartments, a much higher order of effectiveness was realized from the use of the open-end-tubing system S-1 than from the XB-45 perforated-tubing system Although system-distribution measurements indicated that the quantity of carbon dioxide discharged into the No 3 engine-compressor compartment was

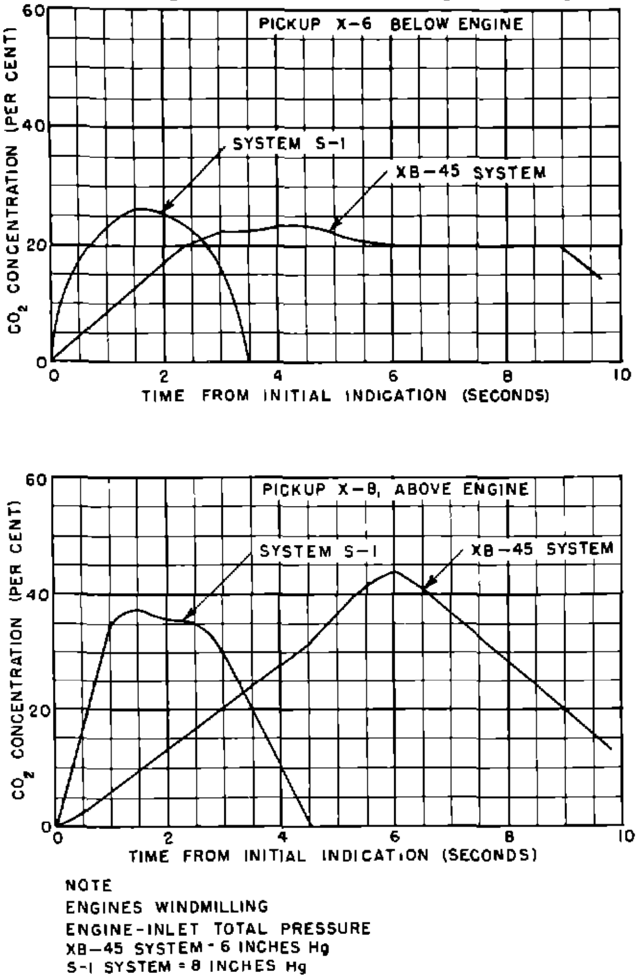


Fig 32 Comparison of Time-Versus-CO_2 Concentration Measurements in the No 3 Engine-Compressor Compartment for Perforated-Tubing and Open-End-Tubing Systems

in comparative tests 2 8 pounds and 3 6 pounds, respectively, system S-1 was much more effective in extinguishing fires For comparison, a listing of differences in the two systems and their relative effectivenesses is presented in Table XXIV The difference in time-versus-concentration relationships resulting from the use of the two designs is shown in Fig 32 These curves represent the average length of time, as determined at 12 pickup locations, that carbon dioxide existed within the compartment, and they indicate the types of discharge resulting from the use of the two extinguishing systems The peak concentrations shown, however, are not representative of the average for the compartment

The differences which contributed to the greater effectiveness of the system S-1 are considered to be as follows

1 By eliminating the gradual increase and decrease of the discharge rate, there was more efficient utilization of the agent Motion pictures showed that in the case of the XB-45 system the rate of discharge at the outlets gradually increased for one second, remained at full strength for one second, and then receded for a period of 0 9 second The time-versus-concentration curves of Fig 32 indicate that this type of discharge resulted in a gradual increase and decrease in agent concentration In comparison, the discharge of the agent by system S-1 is noted to have resulted in a very rapid increase and decrease in concentration
2 The utilization of mechanical as well as of inerting effects of the agent resulted from the use of system S-1 By blasting the agent across the air stream, an effective mechanical action was created Such action was not obtained with the perforated-tubing system
3 There was improved distribution of carbon dioxide by high-velocity discharge across the air stream and by utilization of the pressure or expansion effects from the higher discharge rate, thereby interrupting the existing air flow and forcing carbon dioxide in all directions

Comparison of Extinguishing Agents

The quantity of various agents required to extinguish nacelle fires when different systems were used was determined by fire-extinguishing tests By such tests, the relative effectivenesses of the agents under the different conditions of discharge were determined The conditions under which the tests were conducted are given in Table XXV The test results, also listed in the table, indicated that

1 When the XB-45 perforated-tubing system or a portion thereof was used, methyl bromide was the most effective agent poundwise, and dibromodifluoromethane, bromochloromethane, and carbon dioxide showed decreasing effectiveness in the order named
2 When the open-end-tubing system S-1 was used, methyl bromide and dibromodifluoromethane were equally effective and were more effective than carbon dioxide and bromochloromethane
3 Bromochloromethane is not a suitable agent for use in open-end-tubing systems such as system S-1 This is probably due to the low volatility of this agent and to the failure of the open-end type of system to aid vaporization mechanically

The fact that both the XB-45 and the S-1 systems were designed expressly for carbon dioxide is emphasized The comparison is made merely to obtain information on agents in the different environments

TABLE XXV

RESULTS OF TESTS COMPARING EXTINGUISHING AGENTS

Engine RPM (per cent)	Engine-Inlet Total Pressure (inches Hg)	Extinguishing System	Fire Location (See Fig 11)	Gasoline Supply to Fire (gpm)	Quantity of Agent Required for Extinguishment			
					CO_2 (pounds)	CH_2BrCl (pounds)	CH_3Br (pounds)	CBr_2F_2 (pounds)
90	1 0	XB-45	J	0 8	26	24	16	20
90	1 0	Aft Portion of XB-45	J	0 8	20	20	14	16
Windmilling	8 0	S-1	Station -100 9 00 o'clock	0 7	4	>4	2	2

DESIGN ASPECTS OF FIRE PROTECTION

The following section of this report describes aspects of the XB-45 airplane power-plant design and construction which influence the prevention and control of fires Factors which contribute toward the presence or absence of fire hazards and those which strengthen or weaken fire control were determined by inspection, by observation during detection and extinguishment tests, and by a study of service reports In some instances, the characteristics of certain hazards were investigated by additional testing

FIRE PREVENTION

Phases of Design Contributing to Fire Prevention

1 The nacelle compartition separates engine-compressor compartments from the engine-burner system and from the exhaust system See Fig 7 The primary ignition source is thereby separated from compartments containing numerous high-pressure fuel lines and other flammable-fluid lines
2 There is isolation of the engine-fuel strainer and of the lines passing through the aft compartment from the engine exhaust systems The strainer is covered with steel, and the lines are housed in a steel duct
3 Generally, a high quality of hose and fittings for fluids are used
4 There is a separation of some electrical-system components from zones containing fluid lines Relays, circuit breakers, and terminals are in a separate compartment between and forward of the compressor compartments See Fig 15
5 There is isolation of the engine accessories in a separate compartment, and measures are taken to separate the accessory-section fluid lines from the starter-generator by use of a generator blast tube
6 Provisions are made for sealing, to a limited extent, between compartments

Phases of Design Contributing to Fire Hazard

The following conditions existing in the XB-45 power plant are contributing factors that increase the probability of occurrence of fires

1 Inadequate Confinement of Exhaust System

The hot surfaces of the engine exhaust systems housed within the nacelle aft compartment provide an ignition source which is exposed and which is present under normal engine operating conditions Insulating blankets which cover the tail cones and the tail pipes do not adequately isolate the hot surfaces Flammable fluids, when released in the aft compartment, may contact exposed exhaust surfaces or may get between the blanket and the surfaces where they will readily ignite

Detailed studies of this hazard were made by conducting tests in which aviation gasoline and hydraulic fluid (AN-VVO-366B) were released in the aft compartment under various conditions of engine operation The results of these tests are given in Table XXVI and show that both fluids ignited when the engine exhaust-gas temperatures were well within the range of normal operation (500° to 1328° F)

Tests were also conducted to determine whether reignition from the exhaust surfaces would occur during the extinguishing procedure in flight-fire emergencies When the engines were shut down and the extinguishing system was discharged five seconds later, existing aft-section fires were extinguished and did not reignite However, as indicated in Figs 33 and 34, the engine-exhaust-surface temperatures continued to be dangerously high for several seconds after engine shutoff The relatively long period of time that high carbon dioxide concentrations existed in the aft compartment upon discharge of the XB-45 extinguishing system, Fig 25, was apparently sufficient to prevent reignition

2 Unisolated Hydraulic-System Line in Aft Compartment

The presence of a hydraulic line in the aft compartment represents a potential supply of flammable fluid within a zone having an exposed ignition source Failure of this line has resulted in a fire during flight

TABLE XXVI

TEST RESULTS ON IGNITION OF GASOLINE AND HYDRAULIC FLUID BY NO 3 JET-ENGINE EXHAUST CONE

Engine-Inlet Total Pressure (inches Hg)	Engine RPM (per cent)	Exhaust-Gas Temperatures (Engine Instrument) (degrees F)	Tail-Cone* Outer-Surface Temperatures (degrees F)	Test Results Sprayed Hydraulic Fluid (0 3 gpm)	Gasoline (0 6 gpm)
8 5	50	572	530	No ignition in 30 seconds	- - -
8 0	70	662	580	No ignition in 30 seconds	No ignition in 30 seconds
5 7	48	707	650	No ignition in 36 seconds	- - -
4 5	45	752	700	Ignition in 29 seconds	No ignition in 33 seconds
3 5	46	842	770	Ignition in 13 seconds	Ignition in 1 5 seconds
7 8	82	752	670	No ignition in 30 seconds	No ignition in 30 seconds
7 5	88	842	750	No ignition in 30 seconds	No ignition in 30 seconds
5 4	90	932	860	No ignition in 32 seconds	No ignition in 31 seconds
2 8	90	1022	925	Ignition in 4 5 seconds	Ignition and explosion in 4 seconds

* Recorded by thermocouple welded to exposed surface of No 3 engine-exhaust cone, Nacelle Station +10 where fluids were directed

3 **Inadequate Drainage Provisions**

The large dish-pan areas of the lower portion of the XB-45 nacelle and the negative static pressures existing in nacelle compartments resulting from the use of ejector cooling seriously complicate the drainage problem The use of shallow-cup receivers mounted on the lower nacelle doors to catch engine drainage, Fig 20, allows flammable fluids and vapors to be present within the nacelle This is particularly hazardous in the aft compartment where an ignition source is normally present Gravity drainage holes in the lower doors are of inadequate size and number to provide good drainage In compartments where negative static pressures exist, the use of such drainage holes is of questionable value because of the tendency for air to flow inward and to interrupt drainage flow in flight

In the nacelle aft compartment, inadequate provisions for engine drainage permit fuel which collects in the tail pipe during false starts to drain into the aft end of the nacelle This condition has resulted in nacelle fires during ground operation

The termination of oil-tank and engine-gear-case vent lines and of oil-tank scupper drains within the compressor compartments represents a hazard, because it results in the release of flammable fluids and vapors inside the nacelle

4 Indirect Routing of Fuel Lines

The engine-fuel supply system is such that it requires the routing of lines the entire length of the nacelle from the aft end to the extreme forward end of the engine where the engine high-pressure fuel pump is mounted From this point, high-pressure fuel is returnedto the burner cans Such indirect back-and-forth routing is conducive to hazardous conditions

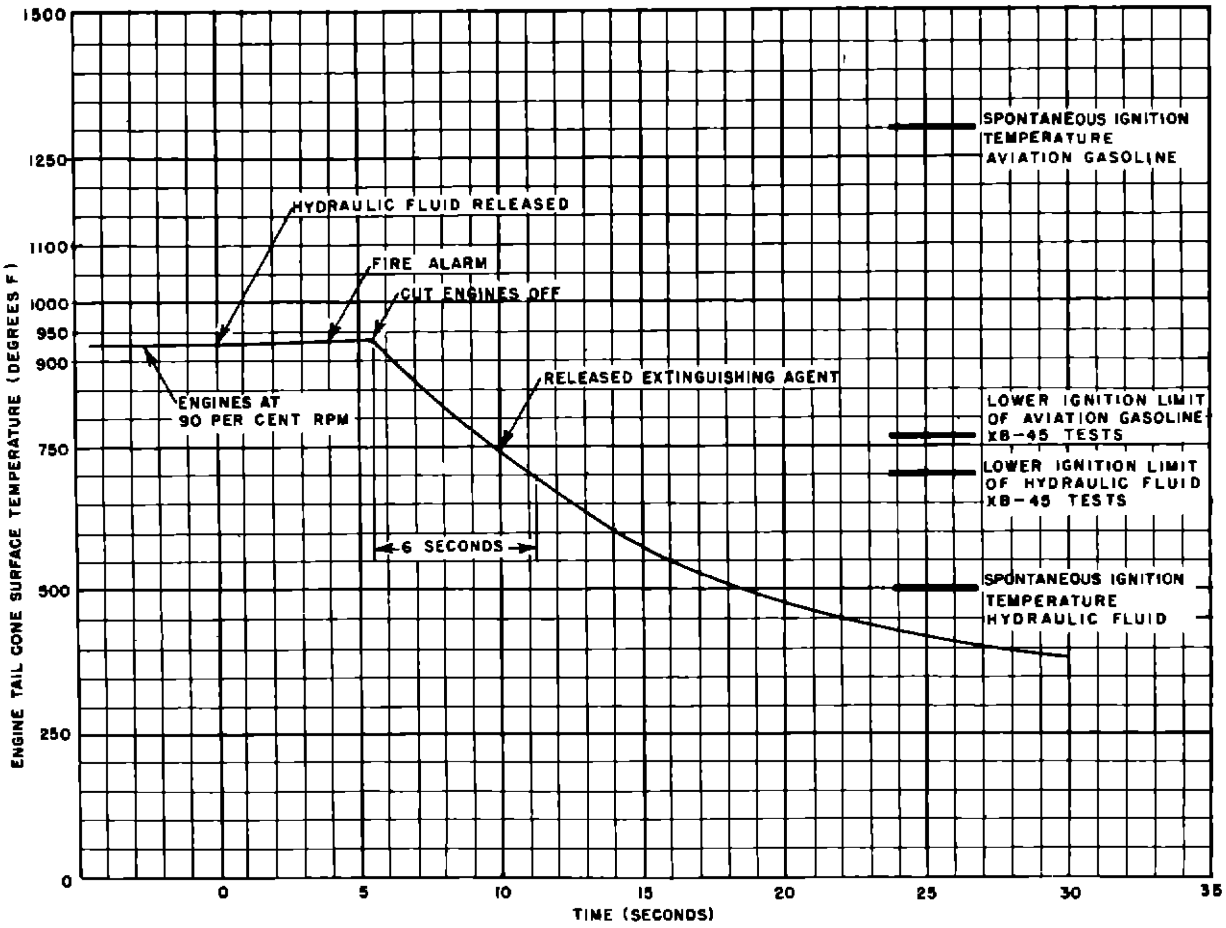


Fig 33 Tail-Cone Surface Temperatures Measured During a Test Fire and Engine Shutdown From 90 Per Cent Rated RPM

5 Inadequate Isolation of Potential Ignition Sources and Flammable-Fluid Lines in Engine-Accessory Compartments

The proximity of flammable-fluid lines, starter-generator, and alternator drive shaft within the engine-accessory compartments represents a highly hazardous condition Mechanical failures of the drive-shaft bearings have, in service, resulted in the rupture of flammable-fluid lines and have caused fires Fluid from minor fluid leaks has also been ignited by the starter-generator Inadequate isolation of potential sources of flammable fluids from potential ignition sources is indicated by inspection and by service experience

6 Inadequate Isolation of Accessory Compartment From Engine Air Inlet

The location of flammable-fluid pumps and attached fluid-carrying lines in the engine air-inlet area, Fig 6, constitutes a serious hazard Fluid-system failure in the accessory compartment may cause overheating in the engine or may cause an explosion as a result of flammable fluids entering the engine at the air inlet

7 Inadequate Sealing

The compartment seals used in the XB-45 nacelle were neither fluidtight nor vaportight, as evidenced during tests in which some fluid leakage past compartment bulkheads occurred The engine air-guide seal also failed to prevent engine-inlet air from entering the compressor compartments Sealing of the generator air blast from the fluid lines in the accessory compartment is inadequate, as evidenced by ground fires that have occurred in service as a result of the ignition of fluid leaks by the generator

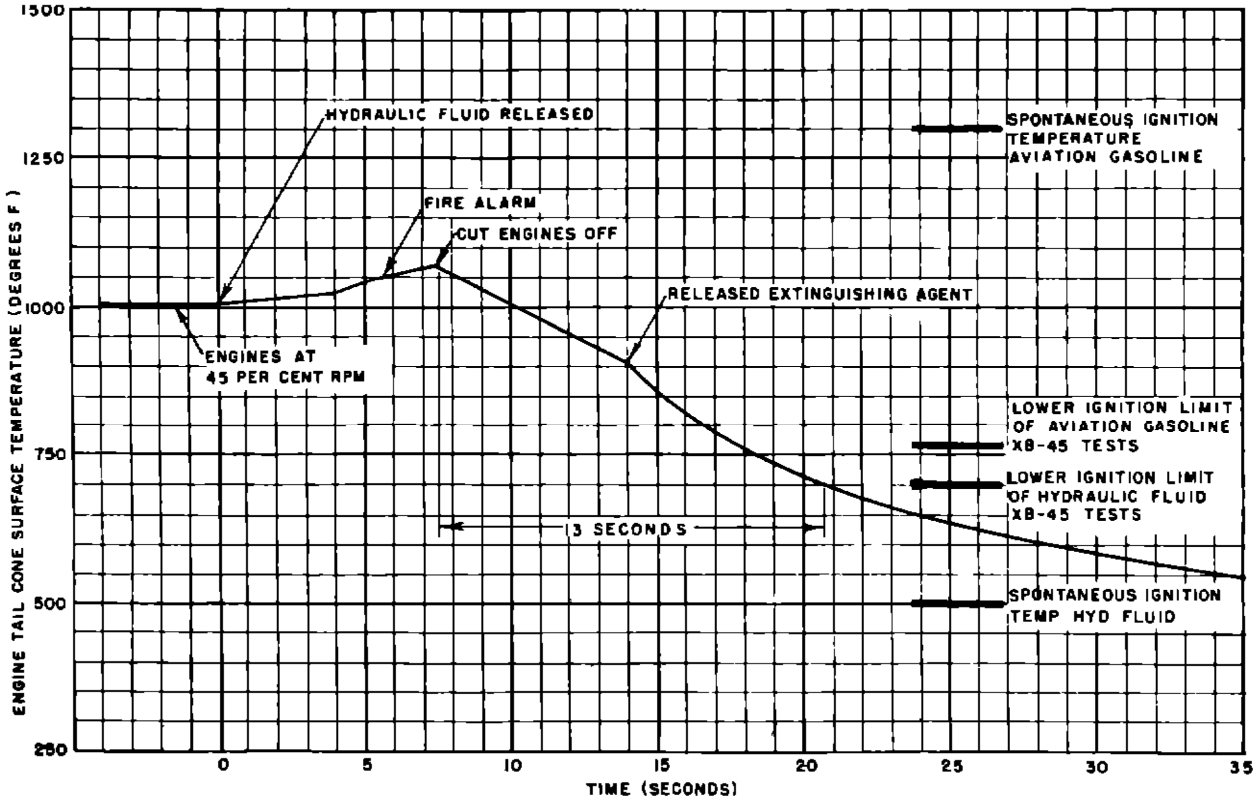


Fig 34 Tail-Cone Surface Temperatures Measured During a Test Fire and Engine Shutdown From 45 Per Cent Rated RPM

The compartment containing relays and electrical components carrying heavy current, Fig 15, is separated but not sealed from the compressor compartments

8 Lack of Positive Flammable-Fluid Confinement

The use of hose clamps on the low-pressure, engine-fuel supply lines and the omission of safety wire or locked fittings on other fluid-line fittings contributes to the presence of hazardous conditions

FIRE CONTROL

Features of the XB-45 Power-Plant Design and Construction Which Aid the Control of Fires

1 The utilization of a fire-detection system
2 The use of flammable-fluid hose which, from numerous fire tests, appeared to have good resistance to damage by fires of short duration
3 The use of steel fire walls, shields, and structure as shown in Fig 7 Steel was also used for the keel structure, engine mounts, oil tanks, and fuel-line duct This increased fire resistance
4 The use of fire-resistant silicon-rubber seals at the fire walls
5 The compartition of the nacelle to confine fires to local areas
6 The separation of the engine air inlet from the nacelle compartment This reduces air flow and thus decreases the extinguishing requirements
7 The use of shutoff valves in the engine-fuel supply lines
8 The utilization of a fire-extinguishing system

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Phases of Design and Construction Which Result in Weakness in Fire Control

1 Inadequacies in the fire-detection system used

These were indicated under the section of this report entitled "Fire Detection"

2 Poor fire resistance of the skin structure of the nacelle

An exception was the lower forward doors, which were covered by 1/4-inch aluminum flak plate and which proved to have high fire resistance in the tests Both aft-section flight fires and forward-section test fires resulted in rapid failure of the nacelle skin Such failures increase the extinguishing requirements greatly and were not considered in the extinguishing-system design

3 Poor fire resistance of a small aluminum line from the fuel-pressure transmitter

This line contains static fuel under high pressure, and its rapid failure during a ten-second fire test resulted in the release of large quantities of fuel within the nacelle

4 Poor fire-resistance and poor confinement ability of the aluminum cowling of the engine-accessory compartment See Fig 8

5 Inadequate sealing

Failure of the engine air-guide seal, Fig 6, to prevent the engine ram air from entering the compressor compartments caused the XB-45 extinguishing system to be inadequate in this area

6 The absence of a shutoff valve in the oil-tank gravity feed line, thus making oil shutoff impossible in the event of line failure

7 The inability to shut off hydraulic-system pressure during the fire emergency procedure

This was not practical because of the need for this system in operating flight-control surfaces

8 The discharge of anti-icing air into the compressor compartments

The air flow from this source was not accounted for in the extinguishing-system design and is not eliminated by present emergency procedures

9 The nonseparation of the two engine-exhaust systems

This represents a weakness in fire control in the sense that both engines must be shut down in the event of fire If they were properly isolated, this would not be necessary

10 The internal ribbed construction of the nacelle

This type of construction was found to increase turbulence and to provide pockets where flammable fluids will collect These pockets also provide areas in which the fire is protected from the air stream and from the extinguishing agent The use of a smooth inner construction was found to reduce extinguishing requirements greatly for the aft nacelle compartment [5]

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[5] Charles A Hughes, "Aircraft Fire Extinguishment, Part II, Effect of Air Flow on Extinguishing Requirements of a Jet Power Plant Fire Zone," CAA Technical Development Report No 205, May 1953

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