Fire-Detection Studies of the Northrop F-89 Power Plant

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SUMMARY

This report presents the results of an investigation of the fire- and overheat-warning systems in the F-89 power plant The existing systems were evaluated by full-scale tests for their over-all effectiveness The changes considered necessary were incorporated in improved configurations to give greater coverage and vastly improved fire detection

In general, systems utilizing continuous-type detector elements were more rapid and more reliable in detecting the presence of fire in the F-89 power plant than were unit-type systems The same coverage could be obtained only by increasing the number of detector elements of the unit-type system to a prohibitive number. By adding additional unit detectors in locations of greater effectiveness, however, the ability of the system to detect fires was greatly improved

The fire-warning system incorporated in the production models of the F-89 was found to be ineffective By increasing the number of detector elements and locating them in more strategic areas inside the engine bay, detection of approximately 90 per cent of all test fires was achieved in the engine-burner section and 100 per cent detection was achieved in the compressor section

The overheat-warning system functioned satisfactorily throughout the series of tests, and no changes are recommended for that system

INTRODUCTION

Some work has been done in the past on the fire-detection and fire-extinguishing characteristics and requirements of turbojet-engine installations, but little is known regarding the influence of the afterburner on the concepts established by earlier testing At the request of the Departments of the Air Force and Navy, an F-89 airplane powered by two J35-A-21A turbojet engines equipped with afterburners was obtained and installed in the test chamber at the Technical Development Center of the Civil Aeronautics Administration, Indianapolis, Indiana

The test program was divided into two parts, the first of which dealt with the fire-detection capabilities of the production system and with the changes in detector design or location necessary for optimum detection of in-flight engine fires The second phase consisted of an evaluation of the fire-extinguishing system and determination of a means for correcting inadequacies where they exist This report concerns only the detection phase of the program

The specific objectives of the fire- and overheat-detection study were (1) to evaluate the fire-warning system in the F-89 power plant and to develop improvements as necessary, (2) to evaluate other types of detection devices which lend themselves to this particular application, and (3) to evaluate the existing overheat-warning system

DESCRIPTION OF TEST EQUIPMENT

Facility

The test facility consisted essentially of a test chamber, a control room adjacent to the chamber, and two 1750-hp blowers which supplied air to the test article The control room contained the engine-control panel, temperature recorder, a multiple manometer, and other equipment used in conducting the tests

Ram air from the blowers was ducted to a plenum chamber just forward of the aircraft and was introduced into the air intake of the left engine by means of an exit duct from the

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plenum The intake air was controlled by the blower operator to simulate the various conditions of flight under which the fire-detecting and -extinguishing systems were to be evaluated Engine operation was controlled from a panel in the control room The velocity of the ram air to the engine was measured with pickups mounted in the air intake of the engine

Test Article

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

The aircraft was equipped with two J35-A-21A turbojet engines complete with afterburners For purposes of this study, only the left engine was instrumented and operated These engines are rated at 6800 pounds thrust at 7900 rpm at sea level for takeoff power with afterburner

The engines in the F-89 aircraft are arranged so that they may be lowered hydraulically from the bays to facilitate inspection and maintenance See Fig 1 Access to the engine is accomplished by removing doors from the bay, completely exposing the engine and afterburner Each bay is divided into two compartments by a forward stainless-steel firewall. An aft firewall, located where the afterburner is attached to the engine, serves to direct all of the cooling air between the afterburner and the afterburner shield See Fig 1. In this report, the forward compartment is designated the compressor compartment It encloses the compressor section of the engine, together with the fuel, oil, and hydraulic lines, the oil tank, and the engine controls The accessories are housed in a small dome mounted on the axis of the engine at the air intake The aft compartment contains the combustion chambers and the afterburner It is designated the burner section

The nose section of the airframe back to Station 125, the tail section aft of Station 490, and a major portion of the wings were removed from the airplane before it was installed in the test cell The test article was supported at the wing stubs by wall-mounted I-beam structures

Before the test program was initiated, the power plant was modified to make it conform as closely as possible to the F-89D models which were then in production These modifications, made in accordance with the airframe manufacturer's drawings, consisted of the following

1 A rectangular opening, 2 by 4 inches, was cut on the keel side of the transition duct just forward of the engine-air intake to provide ground cooling for the compressor section This revision was made according to Northrop drawing No 69-5105951, Sheet 1

2 Turning vanes were added inside the burner-compartment air-inlet scoop to distribute the cooling air in the burner compartment more evenly, in accordance with Northrop drawing No 69-5105951, Sheet 2

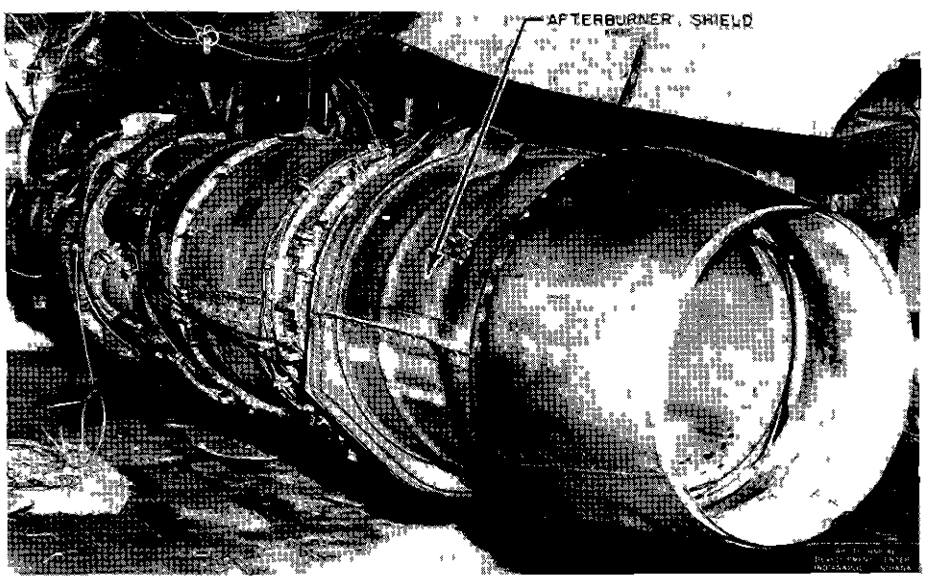

Fig. 1 J35-A-21A Engine in Lowered Position

3 The overheat-warning system which was not present in the prototype model was added according to Northrop drawing No 587823

GENERAL TEST PROCEDURE

Tests were conducted under engine-power conditions simulating taxi, takeoff, normal cruise, and maximum power in flight The engine rpm and the use of the afterburner for each condition are shown in Table I An appropriate amount of ram air to the engine-air inlet was supplied in each case

TABLE I

ENGINE POWER CONDITIONS

Simulated Flight Condition	Maximum Engine rpm (per cent)	Afterburner
Taxi	80	No
Takeoff	100	Yes
Cruise	82	No
Maximum Power	100	Yes

The location of the test fires was determined from F-89 accident reports and by a survey of the engine to indicate the areas where the greatest fire hazard existed Sixteen locations were chosen as potential areas of ignition, and throughout the series of tests, fires were ignited at these points to evaluate the detectors These locations are indicated and numbered in Fig 2 The size of the test fires was standardized at one-third gpm of JP-4 fuel under

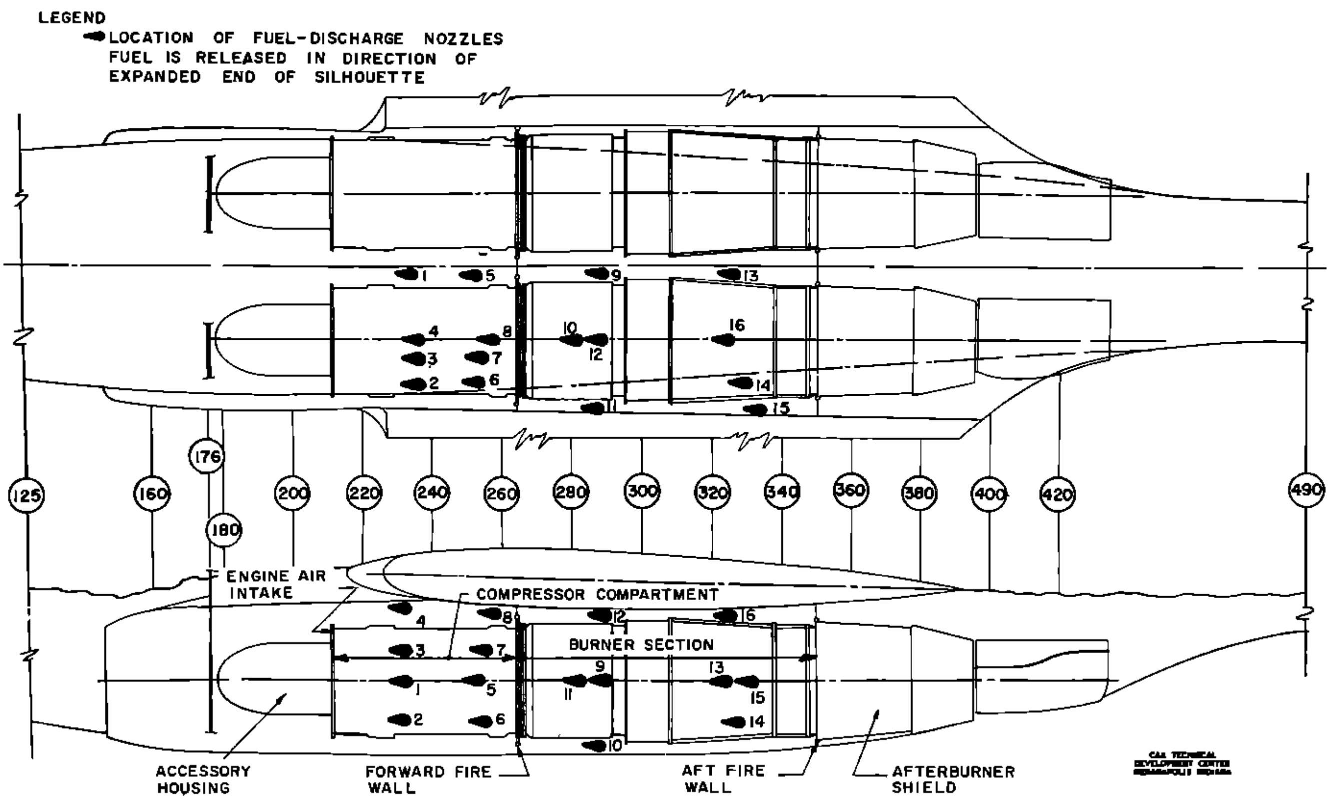

Fig 2 Test-Fire Locations in Left Engine Bay, F-89 Aircraft

20-psi nozzle pressure The detectors were exposed to these test fires for a maximum of 10 seconds Ignition was started by means of an aircraft spark plug in the fuel spray and it was indicated on an Esterline-Angus operation recorder The alarm time was recorded as the time interval between the release of the fuel and the alarm indication by the detector being tested The clearing time for each detector was recorded as the interval from the time the fuel flow ceased until the detector reset Each detector also was connected to a pen on the operation recorder so that the alarm and clearing times could be determined for each sensing element As many as 20 separate operations could be recorded simultaneously by the Esterline-Angus recorder, and the times could be measured to one-tenth second

The test procedure consisted of placing the various detectors in the desired locations and operating the engine at each of the four basic simulated flight-power settings while test fires were ignited at each of the designated fire locations The duration of the test fire and the response of the various detectors were recorded on the operation-recorder chart to form a permanent record

EVALUATION OF EXISTING FIRE-WARNING SYSTEM

The purpose of the evaluation of the existing fire-warning system was to determine, as closely as possible by laboratory methods, the degree of fire detection which existed on the F-89D models

The aircraft was equipped with Edison Type-A unit-type detectors for the fire-warning system This is a four-circuit system consisting of detector units, a relay panel, fire-warning lights, and a momentary contact-circuit test switch The four-circuit system is divided into two parts, each part consisting of two circuits for each engine bay The two circuits in each engine bay are further distributed throughout the entire bay to provide at least partial protection in case one of the circuits should malfunction Each is a permanently closed circuit through which no battery current flows When the rise in temperature is abnormally rapid (as in the case of fire), sufficient current is generated in the detectors to actuate the sensitive relay This relay in turn actuates a slave relay which closes the battery circuit to the respective fire-warning light The detector-unit elements are not destroyed when they operate, and the warning indication disappears when the fire is extinguished and reappears if fire recurs

In the compressor section the fire-warning system consisted of three units affixed to the engine and two units mounted on the keel as shown in Fig 3 The accessory section was protected by two units inside the dome-shaped housing For purposes of these tests, the compressor and accessory sections were considered as one section, with the units in the

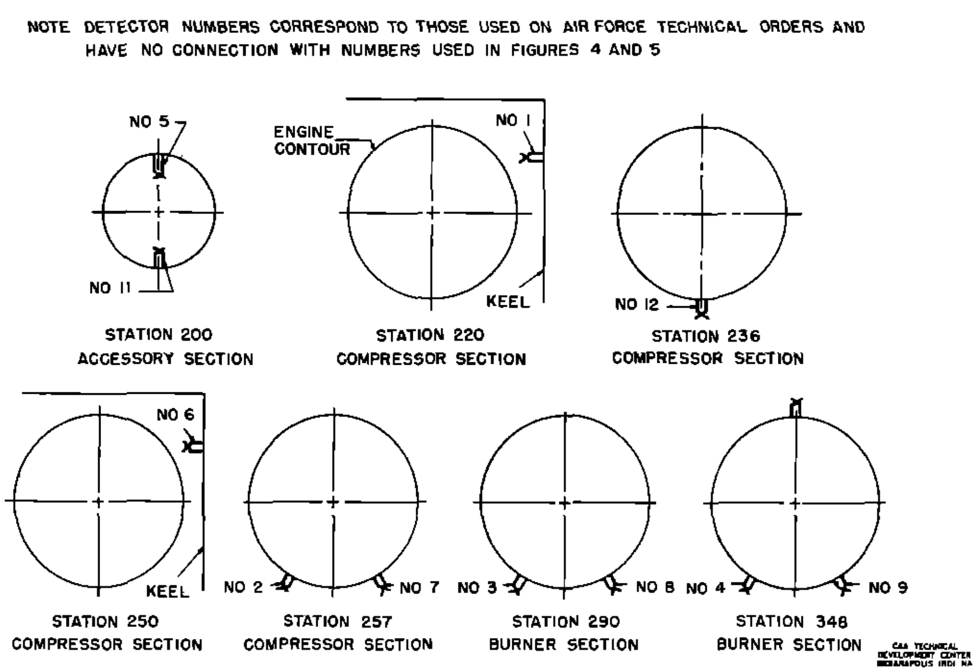

Fig 3 Location of Numbered Unit Detectors in Aircraft System

TABLE II

ALARM CHARACTERISTICS OF AIRCRAFT FIRE-DETECTOR SYSTEM*

Test Condition	Alarm Time						Detection	Average
	Test 1 (seconds)	Test 2 (seconds)	Test 3 (seconds)	Test 4 (seconds)	Test 5 (seconds)	Test 6 (seconds)	Efficiency (per cent)	Alarm (seconds)
Fire Location 1								
Taxi	5 5	**	4 3	4 3	4 0	4 2	83 4	4 46
Takeoff	4 3	**	5 4	5 6	5 3	5 7	83 4	5 26
Cruise	6 0	**	4 5	4 0	4 3	4 4	83 4	4 64
Maximum	5 8	**	**	4 3	6 2	6 7	66 7	5 75
Fire Location 2								
Taxi	1 8	2 2	3 0	**	**	**	50 0	2 34
Takeoff	1 7	3 2	3 2	**	**	**	50 0	2 70
Cruise	2 8	1 9	3 8	**	**	**	50 0	2 83
Maximum	1 8	2 8	5 7	**	**	**	50 0	3 43
Fire Location 3								
Taxi	**	4 2	5 5	**	**	**	33 3	4 85
Takeoff	**	**	**	**	**	**	0	--
Cruise	**	**	**	4 6	**	**	33 3	4 60
Maximum	5 0	**	**	**	**	**	16 7	5 0
Fire Location 4								
Taxi	5 0	**	**	5 3	4 2	4 7	66 7	4 80
Takeoff	4 0	**	**	**	6 8	5 0	50 0	5 26
Cruise	4 8	5 0	**	5 0	6 0	5 7	83 4	5 36
Maximum	2 8	5 8	4 8	**	**	7 0	66 7	5 10
Fire Location 5								
Taxi	4 0	**	5 0	3 3	4 2	3 2	83 4	3 94
Takeoff	**	**	**	**	**	5 7	16 7	5 70
Cruise	**	**	5 3	3 0	**	**	33 3	4 15
Maximum	**	**	**	**	**	**	0	--
Fire Location 6								
Taxi	1 5	1 3	1 7	3 8	3 2	7 0	100 0	3 08
Takeoff	1 5	2 3	2 7	3 6	3 2	5 7	100 0	3 17
Cruise	1 2	1 2	1 4	1 8	1 7	2 7	100 0	1 67
Maximum	1 1	4 0	3 3	3 2	3 0	3 3	100 0	2.98
Fire Location 7								
Taxi	**	**	**	3 2	**	**	16 7	3 2
Takeoff	**	**	**	**	**	**	0	--
Cruise	**	**	**	3 1	3 0	4 2	50 0	3 43
Maximum	**	**	**	**	**	**	0	--
Fire Location 8								
Taxi	**	2 8	**	**	**	4 7	33 3	3 75
Takeoff	**	5 3	**	**	**	**	16 7	5 30
Cruise	**	4 2	4 0	**	**	**	33 3	4 10
Maximum	**	**	**	**	**	**	0	--
Average Alarm Time	3 35	3 30	3 98	3 88	6 10	4 94		
	(per cent)	(per cent)	(per cent)	(per cent)	(per cent)	(per cent)		
Detection	56 2	43 7	50 0	46 8	43 75	50 0		
Over-all Average Detection							48 34	

*Thomas A Edison, Inc , Type-A
**No alarm

accessory section on the same circuit as those in the compressor section Owing to the very limited space in the accessory section, no fires were ignited there because it was evident that any fire in that section would be so concentrated that a detector placed in this area would give an indication immediately In the burner section, five units were mounted on the engine to provide the fire warning

These systems were connected to fire-warning lights on a panel in the test-cell control room and to a pen of an Esterline-Angus operation recorder, in order that a permanent record might be obtained of the alarm and clearing times for each test During the majority of the tests, comparison of the effectiveness of the aircraft system with other detector configurations was obtained through simultaneous testing In some cases the aircraft system was compared with one other system In other cases, three systems were tested simultaneously For test purposes, the fire-detector circuit in the compressor section was independent of the circuit in the burner section, and each circuit was connected to a separate pen of the operation recorder so that its response to test fires could be studied independently

Table II shows the alarm times for the aircraft system for a number of test fires in the compressor section, together with the detection efficiency under the various test conditions As can be noted from the table, the over-all percentage of alarm to the test fires was only 48 per cent. Similar data from the test fires in the burner section indicated that the existing fire-warning system in the burner section was only 23 6 per cent effective

Table III gives the average alarm and clearing times for the aircraft-detector systems from data accumulated during a number of tests

TABLE III

AVERAGE ALARM AND CLEARING TIMES
FOR EXISTING UNIT FIRE-DETECTOR SYSTEM*

	Alarm Time** (seconds)	Clearing Time** (seconds)	Detection Efficiency*** (per cent)
Compressor Section	3 7	4 8	48 3
Burner Section	5 8	5 4	23 6

*Thomas A Edison, Inc , Type-A.

**These times were computed by averaging the alarm and clearing times for the fires for which detection occurred during exposure to the 10-second test fires only

***The detection efficiency is the ratio between the fires detected and the total number of fires ignited

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These results indicate that the F-89 fire-warning system is inadequate They do not reflect deficiencies of the individual detector units, but they indicate that the number of units was insufficient and locations of the units were incorrect

DEVELOPMENT OF AN EFFECTIVE FIRE-WARNING SYSTEM

The first step in developing an effective configuration for a unit-type detector system in the compressor section was to determine the areas of greatest heat concentration during test fires This was accomplished by using a number of overheat detectors in a survey of the entire compressor compartment, mounting them circumferentially on the engine at the forward end and moving the ring progressively toward the rear after each series of test fires. Each overheat unit was connected to a separate indicator light and to a pen of the operation recorder so that the sequence and number of detectors which alarmed could be noted From the data obtained in this manner, the areas affected by each of the test fires were determined and an improved unit-type detector system was developed

The first configuration developed consisted of nine units in the compressor section located as shown in Fig 4 and represented as Nos. 1 through 9 This design increased the over-all average detection to 59 4 per cent Two additional units, Nos 10 and 11, were added to the compressor section as shown in Fig 5 This increased the alarm efficiency to

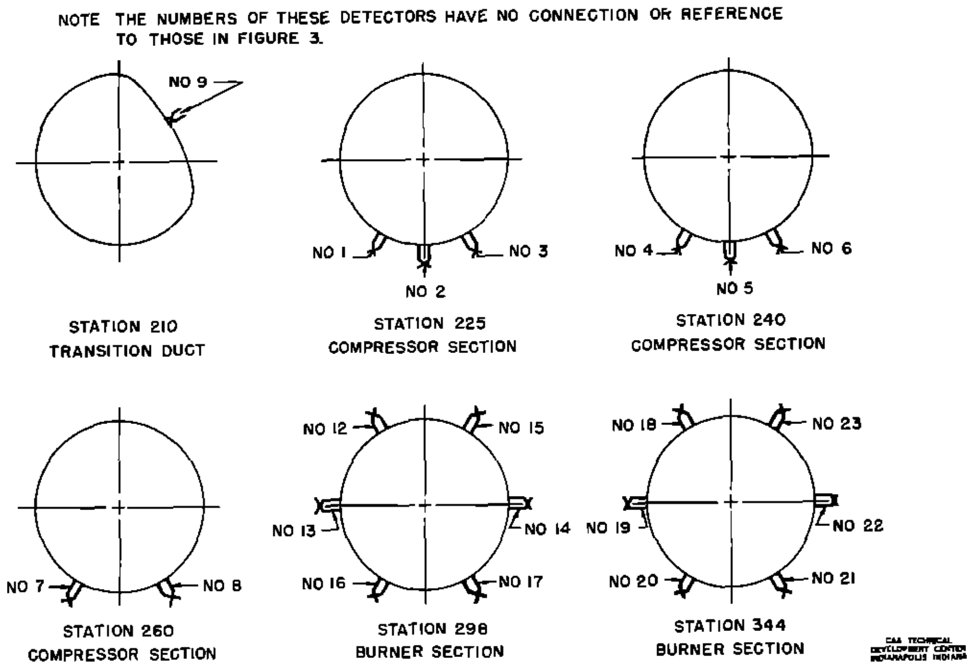

Fig 4 First Revision of Unit Detector Locations

87 5 per cent In an effort to increase the effective alarm rate further in the compressor section, the two units at the six o'clock position on the engine were relocated on the top of the engine and the two units already in that vicinity were repositioned as shown in Fig 6 With this final change in detector locations, 100 per cent detection of the test fires in the compressor section was accomplished Detector No 9 was eliminated after tests proved it was ineffective

Of the five units of the aircraft system in the burner section, four are located on the bottom part of the engine, two at Station 290, and two at Station 348 The fifth unit is located at the 12 o'clock position at Station 348 These locations are shown in Fig 3

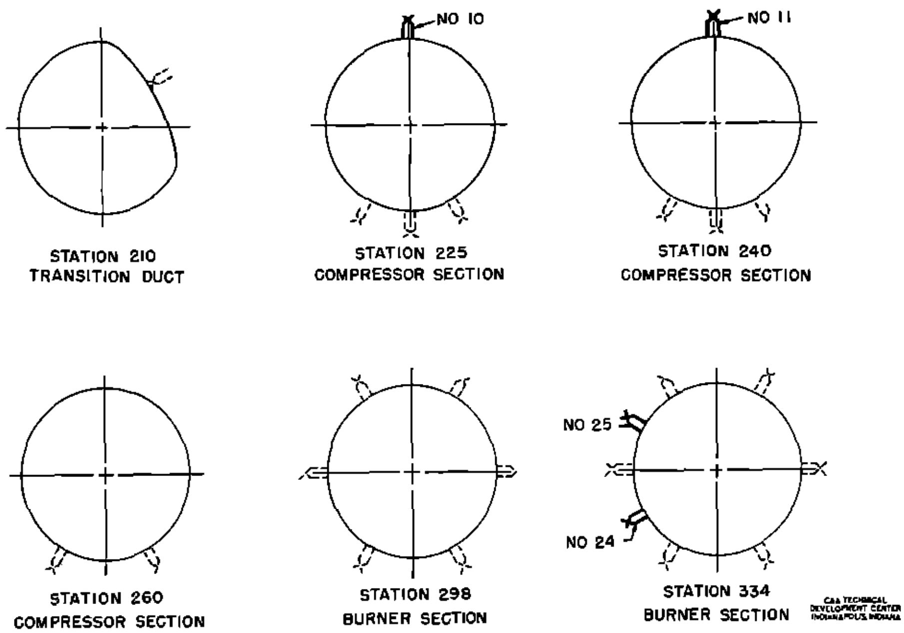

Fig. 5 Installation of Four Additional Unit Detectors

Because of higher velocities of cooling air in the burner section, intense stratification of fire was noted in this compartment In many instances this caused the flames to pass between adjacent units of the detector system without alarming either one Consequently, a destructive fire could exist for a considerable length of time without being detected This intense stratification, and the accompanying cooling of adjacent areas due to the high velocity of the air through this compartment, required the flames to impinge directly on a sensing element before an alarm would be given Thus, the best detector configuration would be normal to this airflow

The original pair of detectors at Station 290 (see Nos 3 and 8, Fig 3) were relocated at Station 298, and four were added at this station at the 1, 3, 9, and 11 o'clock positions This new configuration at Station 298 is shown by detectors Nos 12 through 17 in Fig 4 The three at Station 348 (Nos 4, 9, and 10, Fig 3) were replaced by a ring of six detectors at Station 344 located at the 1, 3, 5, 7, 9, and 11 o'clock positions These are Nos 18 through 23, Fig 4 These changes in detector location increased the efficiency of the system, and 69 2 per cent of the test fires were detected Two additional units were placed in the ring at Station 344 at the 8 and 10 o'clock positions (indicated by Nos 24 and 25, Fig 5), increasing the total number of units in this ring to 8 with a corresponding increase in detection efficiency to 88 3 per cent

With a total of 14 detector units in the burner section, any attempt to increase the detector efficiency would have resulted in the addition of such a large number of units as to be considered impractical Table IV is a compilation of the average alarm and clearing times on the final detector configuration

TABLE IV

AVERAGE ALARM AND CLEARING TIMES FOR THE PROPOSED UNIT-DETECTOR SYSTEM*

	Alarm Time (seconds)	Clearing Time (seconds)
Compressor Section	3 6	5 8
Burner Section	3 9	5 6

*Thomas A Edison, Inc , Type-A

From this information it was concluded that the detector configuration as shown in Fig 6 is the most practical system

Another phase of study in the development of an effective fire-warning system was that involving continuous-type systems The locations in the engine bay which would give optimum coverage and warning in event of fire were determined A continuous fire detector differs from the unit type in that it is similar in appearance to a heavy wire, occupies a line in the engine bay, and is sensitive along its entire length, the unit type monitors only a point Several examples of the continuous type of detector elements are shown in Fig 7 The continuous detectors shown include the thermal type (Edison Type-B) and the flame-sensitive type (made by American Machine and Foundry Company)

The thermal type of continuous detector comprises a temperature-sensitive element routed through the volume in which fire detection is desired, a control unit, a signal lamp, and a test switch The sensing element itself consists of an Inconel or stainless-steel tube containing a coaxial conductor insulated from the tube by a thermistor material. When the thermistor material reaches a predetermined temperature, the resistance of the thermistor decreases sufficiently to permit an electric current to flow and operate a relay in the control box The relay, in turn, operates the fire-warning light When the source of excessive heat is removed and the thermistor material cools below the preset temperature, the warning light goes out The sensing element forms one leg of a Wheatstone bridge, and the alarm temperature can be changed by replacing one of the resistors in the control box

The first continuous thermal-detector system used was the Edison Type-B, utilizing Part No 234-54G sensing element In the compressor section, two loops of sensing element were mounted circumferentially around the engine, extending two inches from the engine to

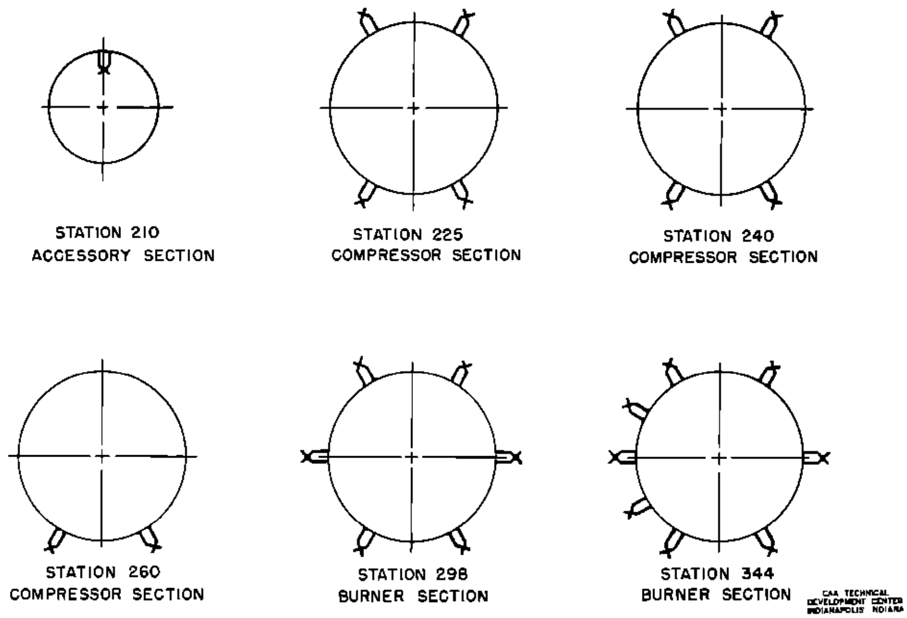

Fig 6 Final Configuration of Unit-Detector System

enclose the engine hoses, wires, and accessories The forward loop of the pair was 20 feet long, positioned at Station 235 with an extension leading down through engine island No 4 into and around the accessory section, then back out of the engine island to the control box The second loop was located at Station 261, it consisted of 10 feet of detector element with leads of high-temperature, heat-resistant wire to the control box These two loops are shown in Fig 8 Each loop was connected independently of the other to indicating lights and to

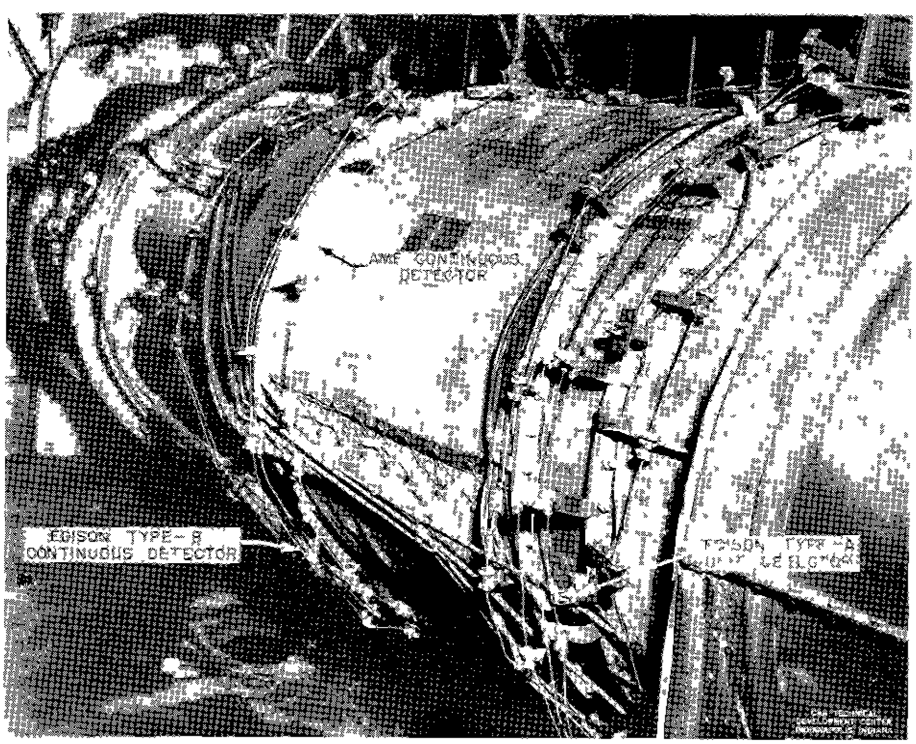

Fig 7 Arrangement of Detectors in Burner Section

TABLE V

RESPONSE AND CLEARING TIMES OF CONTINUOUS LOOPS IN COMPRESSOR SECTION*

Test Condition	Location of Individual Loops (Airframe Station)											
	Station 220		Station 225		Station 235		Station 245		Station 252		Station 261	
	Alarm (seconds)	Clear	Alarm (seconds)	Clear	Alarm (seconds)	Clear	Alarm (seconds)	Clear	Alarm (seconds)	Clear	Alarm (seconds)	Clea
Fire Location 1												
Taxi	3 0	15 8	3 8	10 1	4 2	11 8	3 7	10 3	**	**	**	**
Takeoff	2 4	6 3	2 7	12 3	2 5	11 5	2 2	13 4	**	**	**	**
Cruise	2 8	7 8	2 5	9 5	2 5	12 6	2 0	13 7	**	**	**	**
Maximum	**	**	2 8	9 0	1 9	12 4	1 8	13 0	3 8	2 4	**	**
Fire Location 2												
Taxi	4 7	6 0	3 6	12 5	2 7	11 2	2 8	15 8	2 2	12 2	**	**
Takeoff	6 1	5 0	3 7	7 7	2 8	13 2	3 3	9 2	7 3	1 8	**	**
Cruise	**	**	**	**	3 0	10 5	2 7	9 8	4 1	8 0	**	**
Maximum	**	**	**	**	2 2	8 7	2 7	9 4	**	**	**	**
Fire Location 3												
Taxi	**	**	8 3	10 3	7 0	8 0	7 7	8 0	6 8	4 3	**	**
Takeoff	**	**	5 8	6 5	4 9	8 2	4 7	13 7	4 2	11 7	**	**
Cruise	**	**	5 0	5 0	4 0	11 2	3 6	14 2	3 5	15 5	4 8	7 8
Maximum	**	**	**	**	3 5	9 1	3 7	10 3	3 2	14 2	4 1	6 9
Fire Location 4												
Taxi	**	**	12 8	30 2	6 5	18 7	4 6	13 8	4 2	8 9	**	**
Takeoff	**	**	6 0	16 3	4 0	10 6	3 0	17 7	3 6	7 0	**	**
Cruise	4 8	3 6	15 3	21 7	2 8	16 5	3 2	24 0	4 4	7 9	4 3	6 3
Maximum	**	**	**	**	3 2	13 8	3 2	17 7	3 3	7 3	**	**
Fire Location 5												
Taxi	3 3	7 5	3 6	8 0	4 1	8 1	2 4	10 4	3 2	6 6	3 0	9 0
Takeoff	**	**	3 7	8 0	2 0	8 7	2 2	10 7	2 5	4 8	3 5	8 7
Cruise	3 3	5 8	3 2	8 0	2 9	8 5	2 3	10 6	2 0	7 2	3 8	3 7
Maximum	**	**	**	**	2 4	7 9	3 2	7 7	1 7	7 6	2 2	5 0
Fire Location 6												
Taxi	5 6	5 4	**	**	3 8	14 3	2 7	14 5	1 8	16 3	9 5	8
Takeoff	**	**	**	**	3 0	11 2	2 5	14 0	2 8	16 3	**	**
Cruise	**	**	**	**	4 0	4 5	3 1	8 5	1 3	14 7	2 3	11 8
Maximum	**	**	**	**	2 5	12 3	3 0	13 0	3 7	15 0	4 7	9 8
Fire Location 7												
Taxi	**	**	**	**	**	**	5 8	17 6	5 5	18 5	5 5	16.5
Takeoff	**	**	**	**	**	**	7 1	12 3	5 2	20 2	2 3	19 3
Cruise	**	**	**	**	**	**	**	**	5 5	14 1	3 0	17 2
Maximum	**	**	**	**	**	**	**	**	6 0	12 8	2 3	17 7
Fire Location 8												
Taxi	**	**	**	**	**	**	5 8	10 2	3 0	12 0	**	**
Takeoff	**	**	**	**	**	**	**	**	3 0	10 3	4 0	8 3
Cruise	**	**	**	**	**	**	**	**	2 9	12 3	4 3	6 6
Maximum	**	**	**	**	**	**	**	**	2 5	11 0	6 3	3 7
Average Alarm Time	4 0		5 51		3 44		3 52		3 70		4 11	
	(per cent)		(per cent)		(per cent)		(per cent)		(per cent)		(per cent)	
Detection Efficiency	28 1		46 8		75 0		84 3		87 5		53 1	

*Thomas A Edison Inc , Type-B
**No alarm

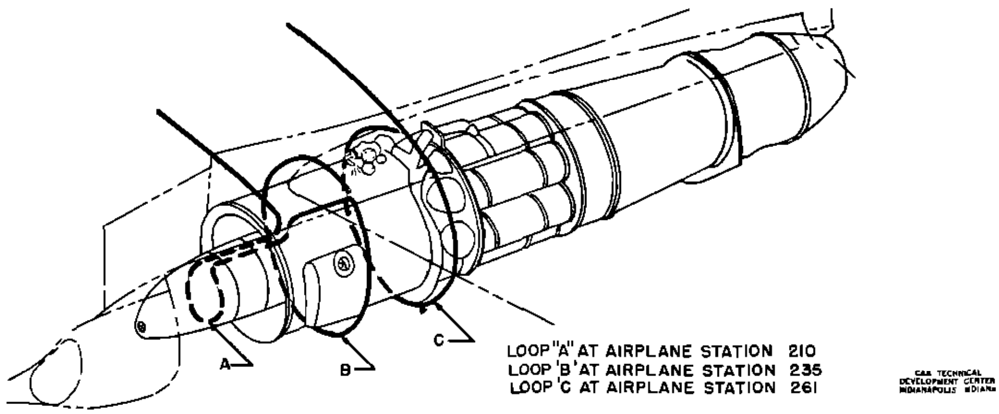

Fig 8 Exploring Detector Loops in First Location Tested

individual pens of the Esterline-Angus operation recorder In this manner the number and location of fires detected by each loop could be determined, together with the alarm and clearing times for each loop.

Table V shows the tabulated data for each test condition and for the various positions in which the loops were evaluated The resistance of each detector circuit was adjusted so that an alarm would be given when the detector element reached a temperature of 500° F The alarm times and detection efficiencies of combinations of the loops in pairs are given in Table VI Tests were conducted with the loops installed in pairs, first, a loop at Station 235 and one at Station 261, Fig 8, second, a loop at Station 220 and one at Station 252, Fig 9, and third, a loop at Station 225 and one at Station 245, Fig 10 As can be seen from the data recorded, no single loop provided 100 per cent detection of the test fires, however, a combination of loops at Stations 235 and 252 did give complete detection These were included in the final configuration of continuous detectors Two other combinations of loops missed only one fire between them, the remainder resulted in still lower detection efficiencies

As an alternative configuration of the continuous detector system, elements were placed axially along the engine in the compressor compartment In the first series of tests, four lengths were positioned at the 2, 5, 7, and 10 o'clock positions, and a complete series of test fires was run This configuration is shown in Fig. 11 The alarm times for the axially located

TABLE VI

EFFECTIVE FIRE DETECTION OF PAIRS OF CONTINUOUS LOOPS IN COMPRESSOR SECTION*

Airframe Station Numbers	Fires Detected (per cent)	Average Alarm Time (seconds)
220 and 245	84 4	3 64
220 and 252	96 8	3 76
220 and 261	68 7	4 07
225 and 245	75 0	4 22
225 and 252	96 8	4 32
225 and 261	84 5	4 77
235 and 245	84 5	3 48
235 and 252	100 0	3 57
235 and 261	96 8	3 72

*Thomas A Edison, Inc , Type-B

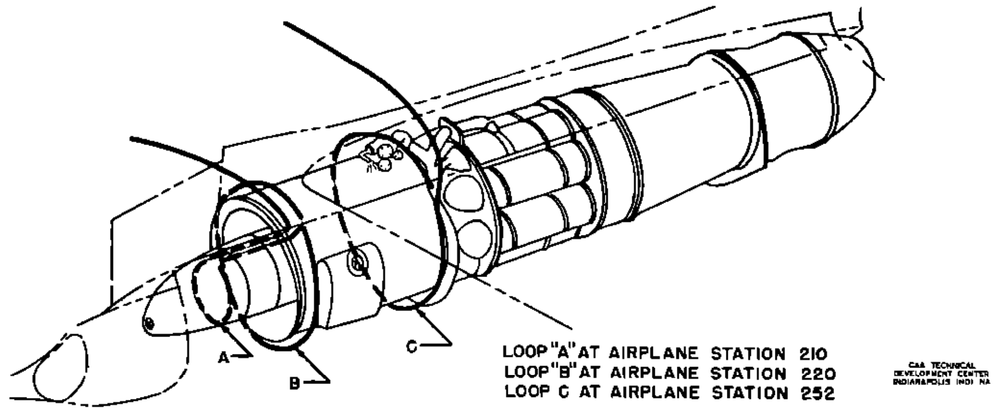

Fig 9 Exploring Detector Loops in Second Location Tested

continuous elements in the compressor section are listed in Table VII As can be seen from Column 1, this gave a total detection efficiency of 96 9 per cent In an attempt to increase the efficiency of the system, the four elements were rotated to the 3, 6, 9, and 12 o'clock position along the engine axially and the series of test fires was repeated From this arrangement of detector elements, 100 per cent detection of the test fires was obtained as shown in Column 2 In order to conserve on length of detector element required to give satisfactory detection, the element positioned at the 12 o'clock position was eliminated and the effectiveness of the three

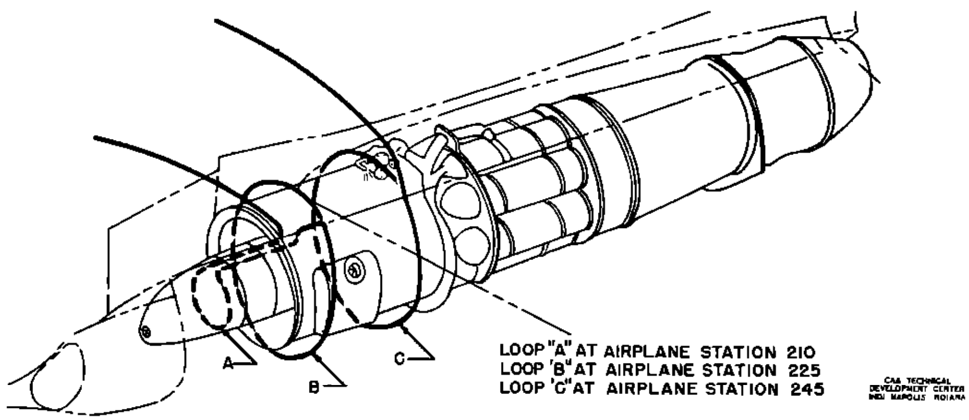

Fig 10 Exploring Detector Loops in Third Location Tested

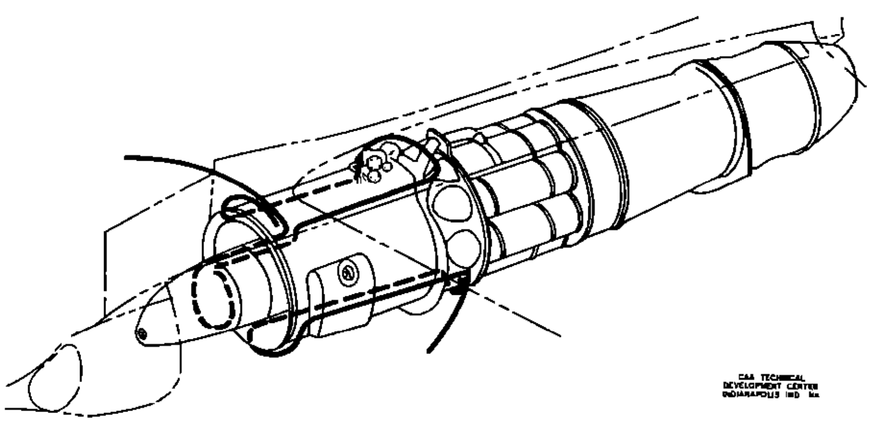

Fig. 11 Continuous Detectors Placed Axially at 2, 5, 7, and 10 O'clock Positions

TABLE VII

ALARM TIMES FOR AXIALLY LOCATED CONTINUOUS ELEMENTS IN COMPRESSOR SECTION*

Test Conditions	Axial-Element Location O'clock Positions		
	2, 5, 7, and 10 (seconds)	3, 6, 9, and 12 (seconds)	3, 6, and 9 (seconds)
Fire Location 1			
Taxi	4.6	3 4	3.5
Takeoff	5 0	2.8	3.2
Cruise	3 8	2 3	2.5
Maximum	6 8	2.6	2 8
Fire Location 2			
Taxi	2 8	2.7	2 7
Takeoff	2 7	2 0	2.0
Cruise	3.3	2.5	3.1
Maximum	2.8	2.4	2 4
Fire Location 3			
Taxi	3.8	4.5	4.5
Takeoff	2.8	3.0	4.2
Cruise	5 0	2.5	2.5
Maximum	3.7	3.9	4.4
Fire Location 4			
Taxi	5.2	3.2	5.8
Takeoff	4.8	3.8	6.0
Cruise	3 5	2.9	4 8
Maximum	4 3	3.0	5 0
Fire Location 5			
Taxi	3 3	2.3	3 8
Takeoff	3 6	3.7	4 5
Cruise	3.2	2 5	3 3
Maximum	2.8	7.4	5 8
Fire Location 6			
Taxi	1.8	2.3	2 3
Takeoff	1.5	2.0	2.0
Cruise	3.0	1.2	1.2
Maximum	1 6	1.9	1.9
Fire Location 7			
Taxi	7 3	3.3	3.0
Takeoff	5.3	1.8	2 0
Cruise	3.2	1.8	2.7
Maximum	3.8	1 4	9 2
Fire Location 8			
Taxi	4 6	4 6	4 8
Takeoff	5.6	3.0	3.2
Cruise	6.0	2.6	2.8
Maximum	**	3 6	3 8
Average Alarm Time	3 92	2.90	3 6
	(per cent)	(per cent)	(per cent)
Detection Efficiency	96.9	100.0	100.0

*Thomas A. Edison, Inc., Type-B.
**No alarm.

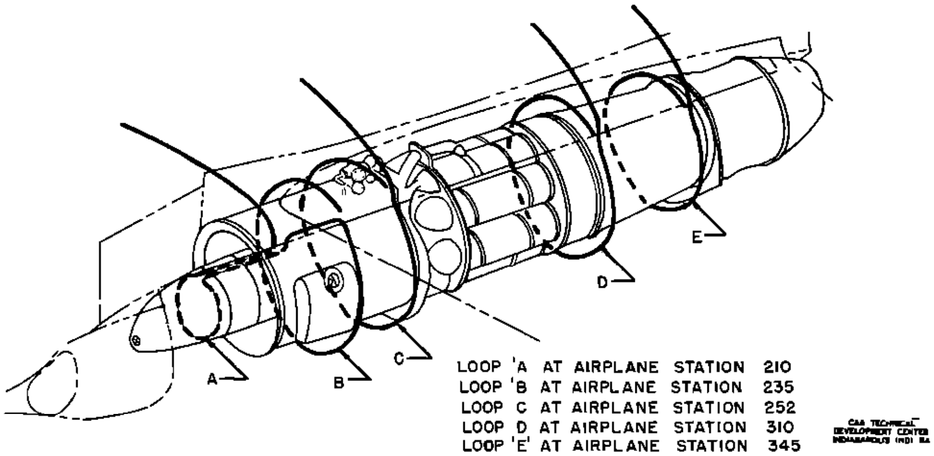

Fig 12 Final Configuration of Continuous Detectors Using Elements in Loops

elements at the 3, 6, and 9 o'clock locations was evaluated Again the response to the series of test fires was 100 per cent See Column 3, Table VII The length of detector required for the four axial elements, with an extension into the accessory section and return, was 30 feet, a length of only 25 feet was required after elimination of the 12 o'clock element This length could be reduced further by using a longer lead of high-temperature, heat-resistant wire and a special shorter length of detector for the forward element.

Fire detection in the burner section was obtained by mounting one continuous element loop at Station 310 and a second loop at Station 345 See Fig 12 The results of a series of test fires ignited in the burner section showed that 100 per cent detection was attained with this configuration Because of the high velocity of the air in the burner section and the linearity of the test fires, it was decided that elements placed axially in all likelihood would be ineffective, therefore, this particular arrangement of detector element was not tested Each loop in the burner section required 10 feet of detector element, or a total of 20 feet for both loops

Table VIII summarizes the average alarm and clearing times obtained in the foregoing tests

TABLE VIII

AVERAGE ALARM AND CLEARING TIMES
FOR PROPOSED CONTINUOUS DETECTOR SYSTEM*

	Alarm Time (seconds)	Clearing Time (seconds)
Compressor Section		
Axial	3 1	10 7
Loop	3 2	12 1
Burner Section		
Loop	2 5	9 0

*Thomas A Edison, Inc , Type-B.

From these data it can be seen that a very positive and effective fire-warning system can be designed utilizing the continuous-type detector element. A total of 45 feet of element is all that is required to provide optimum protection under all ground and flight operations

Another type of continuous fire-warning system evaluated was a flame-sensitive type manufactured by the American Machine and Foundry Company.[1] This detector senses flame

[1] The patents covering this detector are owned by Petcar Research Corporation, 361 Main Street, Medfield, Massachusetts

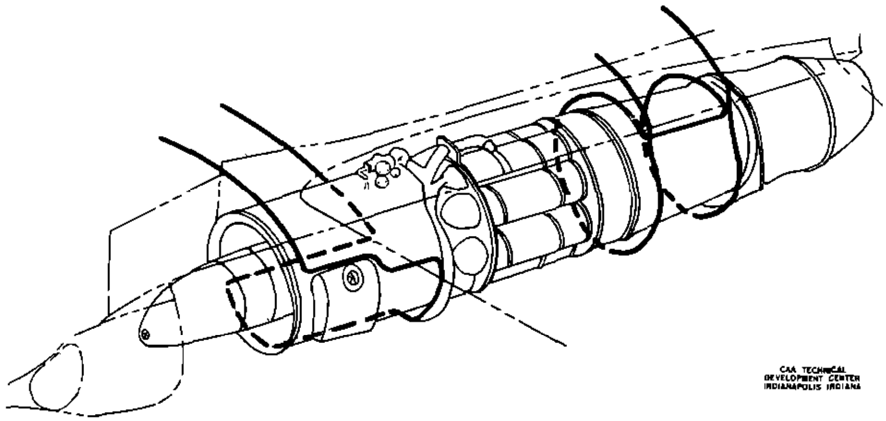

Fig 13 Flame-Sensitive Detectors Placed Axially at 3, 6, and 9 O'clock Positions and in Loops at Stations 315 and 347

only and does not operate on the heat principle The system consists of the sensing element and a transmitter and receiver housed in a single control unit The sensing element consists of a conductor (aircraft-control cable or stainless-steel tubing) routed through but insulated from the nacelle and engine A 3-volt ac signal generated by the transmitter is impressed upon the sensing element This signal has a very low harmonic content The sensing element, forming a loop in the fire zone, returns to the receiver which has been tuned to the second harmonic of the transmitted signal When a flame bridges the sensing element and ground, the waveform of the transmitted signal is altered, producing a second harmonic This signal is detected and amplified by the receiver and used to turn on a warning light to indicate the presence of flame The system has almost instantaneous alarm and clearing reactions to the presence of flame

In the burner section, circuits of aircraft-control cable were installed at Stations 315 and 347 circumferentially around the engine In the compressor section, elements of stainless-steel tubing were mounted axially at the 3, 6, and 9 o'clock positions These are shown in Fig 13 All elements were insulated from the engine and nacelle, and a complete fire survey was conducted Table IX gives the average alarm and clearing times for this configuration The alarm and clearing times listed are those required for the fuel to ignite and for the flame to reach the element As can be seen from Table IX, the alarm and clearing times are very short

TABLE IX

AVERAGE ALARM AND CLEARING TIMES
FOR PROPOSED CONTINUOUS DETECTOR SYSTEM*

	Alarm Time (seconds)	Clearing Time (seconds)
Compressor Section		
Axial	2 1	4 8
Burner Section		
Loop	1 2	2 4

*American Machine and Foundry Company, flame-sensitive type.

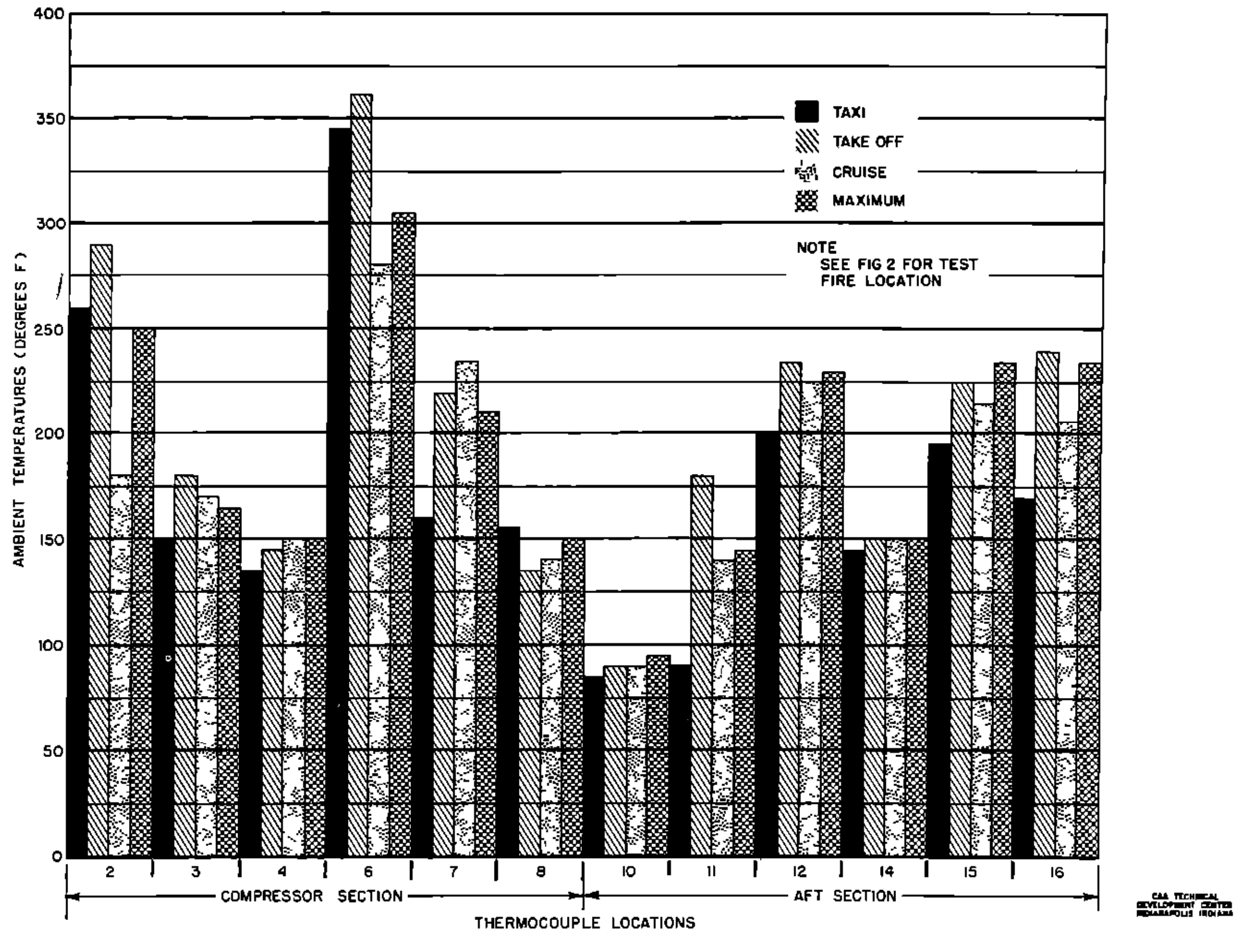

Fig 14 Ambient Temperatures Inside Engine Bays of F-89 Aircraft

EVALUATION OF OVERHEAT SYSTEM

The overheat-warning system consists of 23 Fenwal overheat-warning detectors preset to actuate at 350° F , warning lights, and a circuit-test switch The circuit is wired in parallel and normally is open Action by any one detector closes the circuit and activates the warning lights on the fire-extinguisher-control panel Each overheat detector is cylindrical in shape and consists of an outer shell and two inner struts separated by a slight gap A rise in temperature causes the outer shell of the detector nearest the heat source to expand and the two inner struts to establish contact This closes the system circuit and grounds the warning light When the temperature cools below the critical point, the circuit opens and the warning light goes out

Each unit of the overheat-warning system was connected to a pen of the Esterline-Angus operation recorder Because of the heating effect of the blowers on the air ducted to the engine, the ambient-air temperature inside the engine bays did not reproduce the ambient temperature which would be experienced during flight A temperature survey inside the engine bays during these simulated flight power settings, however, did not indicate the presence of any abnormally high temperatures which would cause the overheat system to alarm

During the actual conduct of the test fires, the overheat-warning units in the vicinity of the fires, as a rule, would indicate the presence of a heat source This was limited somewhat by the remoteness of the units from the areas where the fires were ignited The overheat-warning units were placed on the airframe structure inside the bays in locations which would give a warning if any structural members became unduly overheated For this purpose they were well located

Figure 14 shows the ambient temperatures measured at locations where test fires were to be ignited Measurements were made under four conditions of engine operation The temperature of inlet air supplied to the power plant while measurements were made was 125° F Desired engine and ram-air conditions were established, and the temperatures were allowed to stabilize before being recorded At no time during the performance of these runs did the overheat system alarm

CONCLUSIONS

The following conclusions are drawn from the data accumulated during the conduct of the fire tests

1 The fire-warning system, which is being installed in the F-89D models currently in production, is inadequate
2 The fire-warning system in operational models of the F-89, as well as in future production models, can be improved greatly by relocating existing detector units and by addition of more units
3 The continuous-type detector systems provided better detection of power-plant fires than did the unit type, and they are preferred over the unit-type detectors
4 The overheat-warning system functioned satisfactorily throughout all of the fire tests

RECOMMENDATIONS

On the basis of tests conducted, it is recommended that the existing fire-warning system of the F-89 aircraft be modified to incorporate the changes indicated by this study to be necessary for greater effectiveness or be replaced by a continuous-type system as described in this report It is recommended further that the overheat-warning system be retained in its present form