OPERATING CHARACTERISTICS OF CONTINUOUS-TYPE FIRE AND OVERHEAT WARNING SYSTEMS

by

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Abstract

In order to update and validate the requirements of MIL-F-7872[1], the operating characteristics of continuous-type fire and overheat warning systems were determined. Test data obtained will be applied to the specification. The systems investigated employed continuous lengths of thermistor, eutectic salt, and pneumatic heat-sensing detector elements. The performance parameters measured for each type of detector element included the following:

1. Fire alarm time - the time to signal an alarm after a detector element is exposed to a 6-inch diameter propane burner flame at temperatures ranging from 1100°F **(593°C)** to 2000°F (1093°C).

2. Fire alarm reset time - the time for the alarm signal to clear after the element is removed from the flame.

3. Overheat alarm temperature - the temperature at which an overheat alarm is signalled when the detector element is gradually heated in a laboratory furnace.

4. Overheat alarm reset temperature - the temperature at which the alarm signal clears after the furnace is shut off and the element cools.

Besides providing valuable insight for updating **MIL-F-7872,** the results obtained on detector fire and overheat responses also have significance for the selection of Halon replacement agents. For example, during the time required for an engine nacelle detector to alarm and for the pilot to carry out the required emergency procedures before discharging the fixed fire extinguishers, an engine nacelle fire can increase in size rapidly. The size and intensity of the fire encountered will affect both the type and quantity of replacement agent required for effective extinguishment without reignition. Further investigation is needed to determine the effects of fire size and intensity upon agent selection and sizing.

Introduction

It was necessary to determine detector operating characteristics as functions of temperature in order to update and validate the requirements given in MIL-F-7872 for continuous-type thermal aircraft fire and overheat warning systems. In a cooperative effort Walter Kidde Aerospace, Fenwal Safety Systems, and Systron Donner, respectively, provided samples of thermistor, eutectic salt, and pneumatic continuous-type thermal detectors for testing. Descriptions of the detector test items provided for evaluation are contained herein.

In a comprehensive test program the operating, or performance, characteristics of the three types of detector elements were determined. These characteristics included 1) the fire alarm time as a function of propane flame temperature, 2) the reset time as functions of flame temperature and burner heating time, 3) the overheat alarm temperature, and 4) the overheat reset temperature.

Summary of results

The fire response characteristics of thermistor, eutectic salt, and pneumatic detector elements were measured by means of "in-and-out" flame tests conducted in a standard 6-inch diameter propane burner at temperatures ranging from approximately 1100°F (593°C) to 2000°F (1093°C). An "in-and-out" test consists of inserting the element into the test flame and immediately removing it from the flame when an alarm is signalled. Tests were conducted at an element height of 3-1/4 inches above the face of the burner for all elements. For the pneumatic elements, additional "in-and-out" tests were performed at an element height of 1-1/4 inches and yielded essentially the same results. In addition to the "in-and-out" tests, the fire alarm response and repeatability characteristics of the elements were determined in other tests where the elements, after signalling an alarm, were kept in the burner for residence times up to 65 seconds. The overheat response characteristics of the three types of elements were also determined. The test results are presented and discussed below.

Discussion of test results

"In-and-Out" Flame Tests of All Three Types

The variations of fire alarm time versus temperature for the three types of elements are illustrated below in Figure 1, while Figure 2 shows the corresponding relationships between fire alarm reset time and temperature. The thermistor, eutectic salt, and pneumatic detector elements which were tested to obtain these data are described in Tables I, II, and III (Specimen Nos. 1, 4, and 8, respectively.)

Figure 1 indicates that all of the elements alarmed within 5 seconds at 2000°F and within 10 seconds at 1500°F, as required by MIL-F-7872. As temperature decreased below 1500°F the behaviors of the elements were different. For both the thermistor and eutectic salt elements, alarm time continued to increase gradually to approximately 11 seconds at 1170°F. For the pneumatic elements, however, alarm time increased more rapidly to approximately 1) 12 seconds at 1400°F, 2) 21 seconds at 1200°F, 3) 33 seconds at 1123°F, and 4) 60 seconds at 1103°F. It appeared that the thermistor and eutectic salt elements conducted heat more rapidly and thus alarmed faster than the pneumatic element at temperatures below 1500°F. Since the pneumatic element contains helium gas, the element appears to conduct heat less rapidly than the other elements and thus require more time for its internal pressure to rise and signal an alarm.

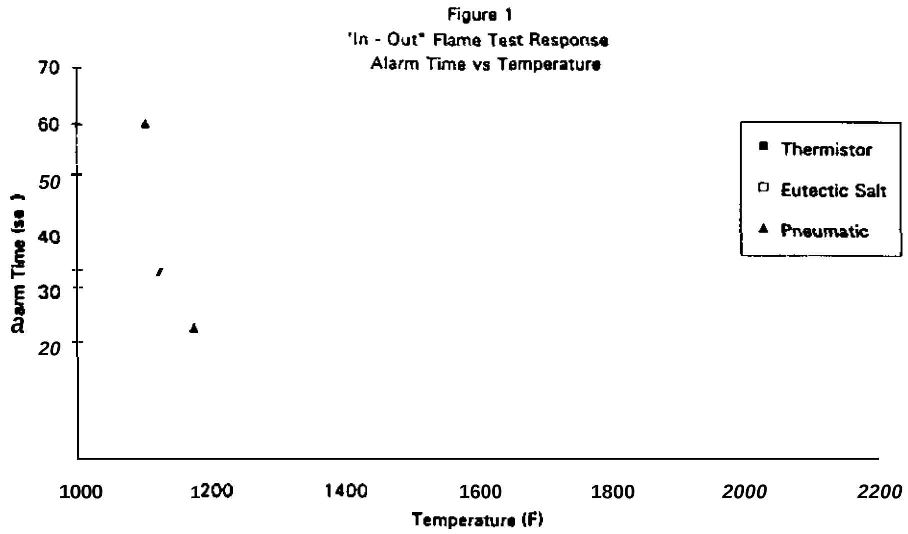
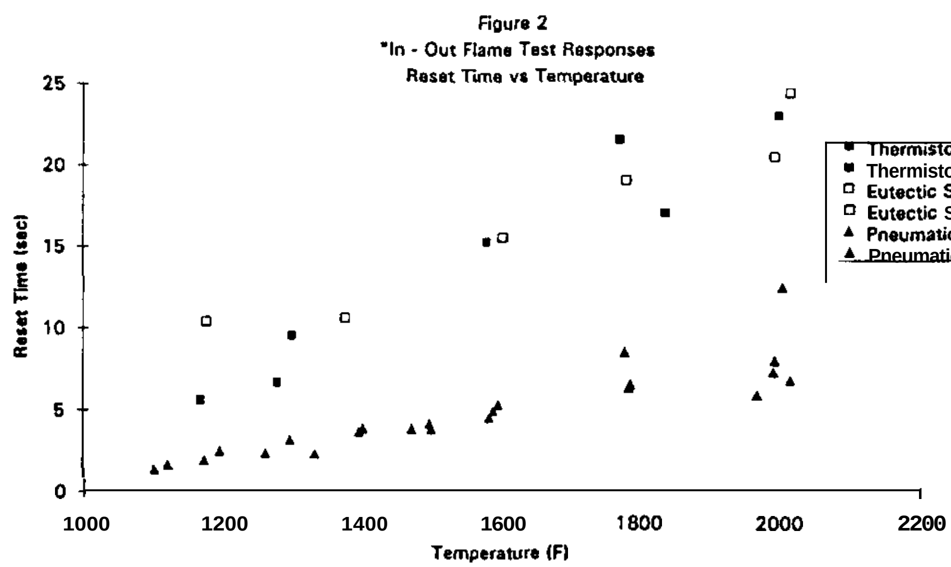


Figure 2 shows that the fire alarm reset (clear) times were significantly lower for the pneumatic element than for the thermistor and eutectic salt elements. Because the pneumatic element absorbed less heat at a given temperature, the element temperature and internal gas pressure fell more rapidly when removed from the test flame. Over the test temperature range of 1100" to 2000°F, reset times ranged from 1.3 to 12.5 seconds, respectively. For the thermistor and eutectic salt detectors reset times ranged from approximately 5 to 24 seconds over the same temperature range, indicating that longer cool-down times were needed before reset occurred.



Thermistor and eutectic salt types **of** elements.

Fire Response Characteristics. Both types of elements met the following fire response requirements of MIL-F-7872:

1. Signalled an alarm within *5* seconds at 2000°F and within 10 seconds at 1500°F.
2. Maintained the alarm signal until the alarm cleared (reset) after removing the element From the flame.

Neither type always met the additional requirement to automatically clear the alarm signal (reset) in not more than 30 seconds following extinguishment of the fire. Elements with lower alarm temperature ratings than others had higher reset times because longer cool-down times were required for an alarm to clear. ***Also,*** for both types reset times increased with the length **of** time heated in the burner (burner time) at a given temperature before removal from the test flame. For example, both types reset within 30 seconds at all flame temperatures from 1100° to 2000°F only when the burner time did not exceed *20* seconds.

Overheat Response Characteristics. The measured overheat alarm and reset temperatures **of** both types fell within the rated alarm ranges when the elements were heated in the laboratory test furnace. For the eutectic salt "discrete" elements, the overheat alarm and reset temperatures were independent of the length heated for lengths greater than one inch. The extensive earlier flame testing conducted on both types had no adverse effects upon the overheat alarm characteristics. The elements exhibited consistent and repeatable detection capability. They did not **miss** any alarms, nor did they show any perceptible shifts in properties due to any degradation or irreversible changes.

Pneumatic-type elements.

Fire Resoonse Characteristics. Under limited "in-and-out'' test conditions, in which an element was removed from the test flame within one second after an alarm was signalled, the element met the following fire response requirements of MIL-F-7872:

1. Signalled an alarm within *5* seconds at 2000°F, and within 10 seconds at 1500°F, when a six-inch length was heated in the test flame.
2. Maintained the alarm signal until the alarm cleared (reset) after removing the element from the flame.
3. Cleared the alarm signal (reset) within 30 seconds after removing the element from the flame.

In other tests conducted at burner times of up to ***65*** seconds per run at flame temperatures ranging from 1100° to 2000°F. the elements exhibited erratic behavior and sometimes failed to alarm due to irreversible hysteresis effects which occurred. Systron Donner, supplier of the elements, stated that only "in-and-out" tests should be conducted at any flame temperature in order to minimize the burner heating time. They stated that longer burner times will degrade the elements through the escape of hydrogen gas by diffusion through the heated stainless steel wall of the element. Systron Donner stated they perform only “in-and-out” tests on their pneumatic elements and that numerous “in-and-out” tests can be performed without degrading the elements.

The likelihood of hydrogen gas escaping by diffusion during prolonged heating of an element, e.g., with burner times of up to 65 seconds, was confirmed in discussions at NAWCADWAR (Code 606) with Dr. John DeLuccia, research metallurgist. At 2000°F, he calculated that hydrogen gas would diffuse through the 0,018-inch stainless steel wall of the element in approximately 20 seconds. He also stated that the elements were subject to other irreversible hysteresis effects due to 1) possible oxidation of the titanium hydride core which could reduce or prevent the reabsorption and release of the hydrogen gas, and 2) accumulation of excess hydrogen gas inside the element which would raised the internal gas pressure. Dr. DeLuccia further determined that at 2000°F the helium gas diffusivity is far too low for any helium gas to escape through the element wall.

For the reasons discussed above, only “in-and-out” flame tests were conducted on a new element (Specimen No, 8, Table III) in order to eliminate or minimize hysteresis effects and to define more clearly the alarm and reset performance characteristics. The “in-and-out” tests were run at temperatures ranging from 1100° to 2000°F. and yielded the repeatable fire response characteristics described earlier in Figures 1 and 2.

Overheat Response Characteristics. The measured overheat alarm and reset temperatures fell within the rated alarm ranges only in tests conducted on a new element or one which had experienced only “in-and-out’’ flame testing.

Following the series of 23 “in-and-out’’ tests conducted on a new element (Specimen No. 8) to determine its fire response characteristics, it was demonstrated that the overheat behavior of the element could be degraded by a single 30-second exposure to a 2000°F flame due to the irreversible hysteresis effects which occur. The degradation was indicated by a substantial decrease in overheat alarm temperature from an initial measured value of 521°F to 335°F following the 30-second flame exposure.

Significance **for** selection **of** Halon replacement agents.

Besides providing valuable insight for updating MIL-F-7872, the results obtained on detector fire and overheat responses also have significance for the selection of Halon replacement agents. For example, during the time required for an engine nacelle detector to alarm and for the pilot to carry out the required emergency procedures before discharging the fixed fire extinguishers, an engine nacelle fire can increase in size rapidly. The size and intensity of the fire encountered will affect both the type and quantity of replacement agent required for effective extinguishment without reignition. Further investigation is needed to determine the effects of fire size and intensity upon agent selection and sizing.

Conclusions

Thermistor and eutectic-salt type detection systems.

The thermistor and eutectic-salt types of detector elements exhibited consistent and repeatable alarm and reset capability under all test conditions due to the reversible changes which occurred with temperature in the electrical resistance of the sensing element materials. In all of the test runs conducted on two elements of each type, the elements did not miss any alarms, nor did they show any perceptible shifts in performance characteristics due to any degradation or irreversible changes in sensor properties.

Pneumatic-type detection systems.

The pneumatic-type of detector element exhibited consistent and repeatable alarm and reset capability only during limited "in-and-out" testing, in which the element was removed from the test flame within one second after an alarm was signalled to prevent the generation of excess hydrogen. When heated to its fire alarm temperature, a pneumatic element releases hydrogen gas from its titanium hydride core which trips the pressure switch in the responder unit and signals an alarm. The release of the hydrogen gas is an irreversible process because most of the gas is not reabsorbed into the core when the element cools. Release of excess hydrogen significantly increases the internal gas pressure and reduces the overheat alarm temperature.

It was demonstrated that the overheat behavior of an element could be degraded by a single 30-second exposure to a 2000 °F flame due to the irreversible hysteresis effects which occurred after the prolonged exposure. In this test the degradation was indicated by a substantial decrease in the overheat alarm temperature from an initial measured value of 521°F to 335 °F following the 30-second exposure.

Test item descriptions

Thermistor detector elements

Thermistor detector elements and a control unit (P/N 89909450-01) were supplied by Walter Kidde Aerospace, Inc. The alarm temperature ratings of the elements which were tested are given below in Table I:

Table I

Specimen No.	Part No.	Length	Alarm Temp.(°F)*
1	234 10400	104"	495± 5%'
2	21804100	41"	400± 5%[4]

* Entire length heated to this temperature.

Eutectic salt detector elements

Eutectic salt detector elements and **a** control unit (P/N 35009-20) were supplied by Fenwal Safety Systems, Inc. The alarm temperature ratings of the elements which were tested are given below in Table II:

Table **II**

Specimen No.	Part No.	Length	Alarm Temp.(°F)*
3	35560-2-255	5 ft.	255 ± 5%**
4	35680-2-765	10 A.	765 ± 5%

*One inch or more heated to this temp.
** Bleed air leak detector.

Pneumatic detector elements

Pneumatic detector elements with built-in responder units were supplied by Systron Donner. The alarm temperature ratings, lengths, and part numbers of the elements which were tested are given below in Table III:

Table III

Specimen No.	Element Length	Alarm Temp.(°F)	
		Fire*	Overheat**
5+	8 ft.	1000	475 ± 25
6+	8 ft.	1000	475 ± 25
7++	19 ft.	1050	525 ± 30
8++	19 A.	1050	525 ± 30
9x	28 ft.	1050	525 ± 30

*12-inch length heated to this temp.
** Entire length heated to this temp.
+ P/N 3951-06-1000/475-8.
++ P/N 3951-03-10501525-19
x **P/N** 6413-02-1050/525-28

Test methods

Test methods, consisting of the test equipment and test procedures described below, were devised in order to determine the operating characteristics of the detector elements and to validate that the detectors met the following requirements of MIL-F-7872:

Paragraph 3.5.1 Fire Resoonse. The system shall indicate a fire within 5 seconds after any 6-inch portion of the entire sensing element arrangement is exposed to a 2000°F flame of the flame test burner. The systems shall maintain the fire signal for the duration of the fire and shall automatically clear the signal in not more than 30 seconds following extinguishment of the fire.

Paragraph 4.6.25 Response time to 1500°F flame. Flame tests shall conducted in accordance with the flame test conditions of 4.5.4. using a flame temperature of 1500°F. ***An*** alarm shall occur in not more than 10 seconds after flame application.

Paragraph 4.6.13 Overheat calibration. Where overheat detection is provided, the test of 4.5.3 shall be repeated for overheat detection. The response temperature shall be designated by the manufacturer. The starting temperature of the heat source shall be 50°F below the specified response temperature. The temperature at which the system responds to overheat shall be within plus or **minus** 6 percent of the specified response temperature.

Test equipment

Standard propane burner test unit

The fire response tests were conducted using a standard 6-inch propane burner[1,2] test facility which was designed, fabricated and packaged in a unit that fits into a laboratory exhaust hood, as illustrated in Figures 3 and 4. The test unit is complete with the burner, pressure gauges, flow metering orifices, and valves for controlling the propane gas flow, combustion mixing air flow, and cooling air flow for maintaining flame temperature and uniformity. The burner unit provides reproducible test flames ranging in temperature from approximately 1100° to 2050°F (593" to 1121°C) with a heating capacity of 65,000 Btu/hour at a temperature of 2000°F (1093°C). Propane gas is supplied from a 20-pound bottle. **A** test-specimen holding fixture mounted on roller bearings **is** located on top of the burner unit. Flame temperatures were measured with a Type K (chromel-alumel), 14 **AWG** unshielded thermocouple extending 3 inches horizontally into the center of the burner flame.

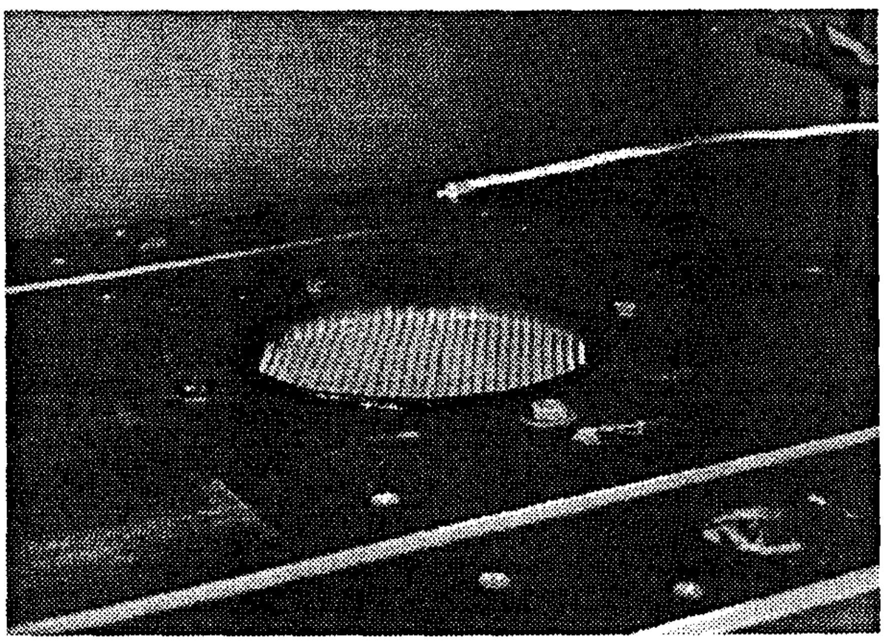


Figure **3.** Laboratory Test Burner

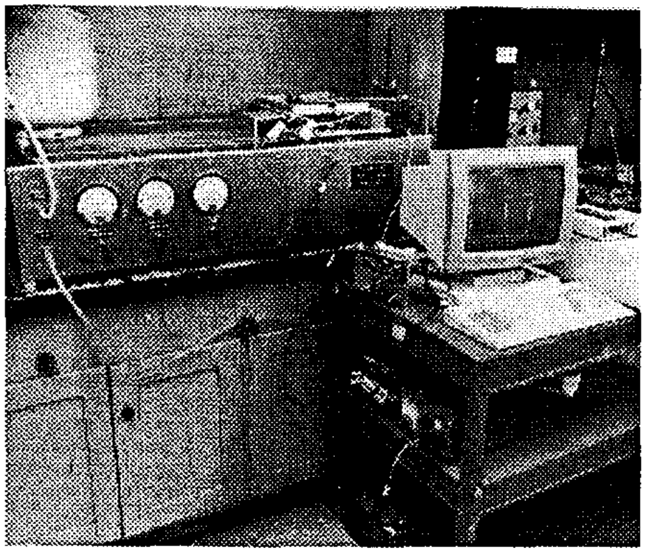


Figure 4. Laboratory Test Set Up

Laboratory test furnace

The overheat response tests of the detector elements were conducted in a Lindberg Hevi-Duty forced-air convection furnace, as illustrated in Figure **5.** Its maximum temperature rating is 1350°F, with a 5-KW heating capacity. The internal dimensions of the furnace chamber are **12-**1/2" wide, 14-1/2" high, and 13-1/2" deep. Furnace temperatures were measured with Type K (chromel-alumel), 14 AWG unshielded thermocouples inserted into the furnace chamber near the detector element being tested.

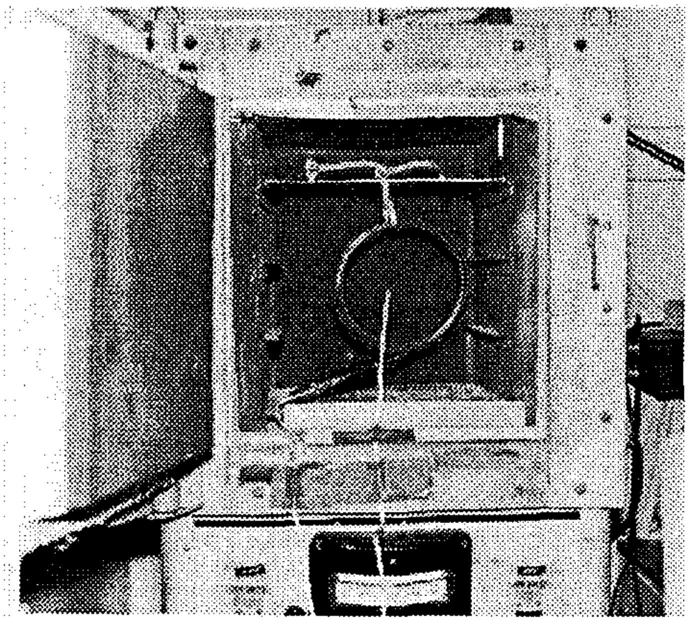


Figure 5. Laboratory Test Furnace

Computerized data acquisition system

The data acquisition system is shown in the block diagram of Figure 6 and is illustrated in Figure 4. The system employed a Zenith Model A-248/AT personal computer containing a 80286 Microprocessor Memory Card having 2 megabytes data storage capacity and an Omega Model WB-FAI-16 plug-in data acquisition board. The system is known as a White Box interface system that provides both the hardware and software required. Included is a card which plugs into one of the internal slots of an IBM compatible PC/AT, a terminal box external to the computer for making connections to the thermal detector being tested, and a user-friendly, menu-driven software package. This system was used for measuring and recording temperature versus time data during the fire and overheat response tests. The software allows easy setup and operation without programming. Data are logged to a virtual disk in the extended RAM memory and then is transferred to a floppy disk after data collection is complete. The floppy is read with a spreadsheet program, Lotus 1-2-3 to provide printouts in tabular and graph forms for data analysis.

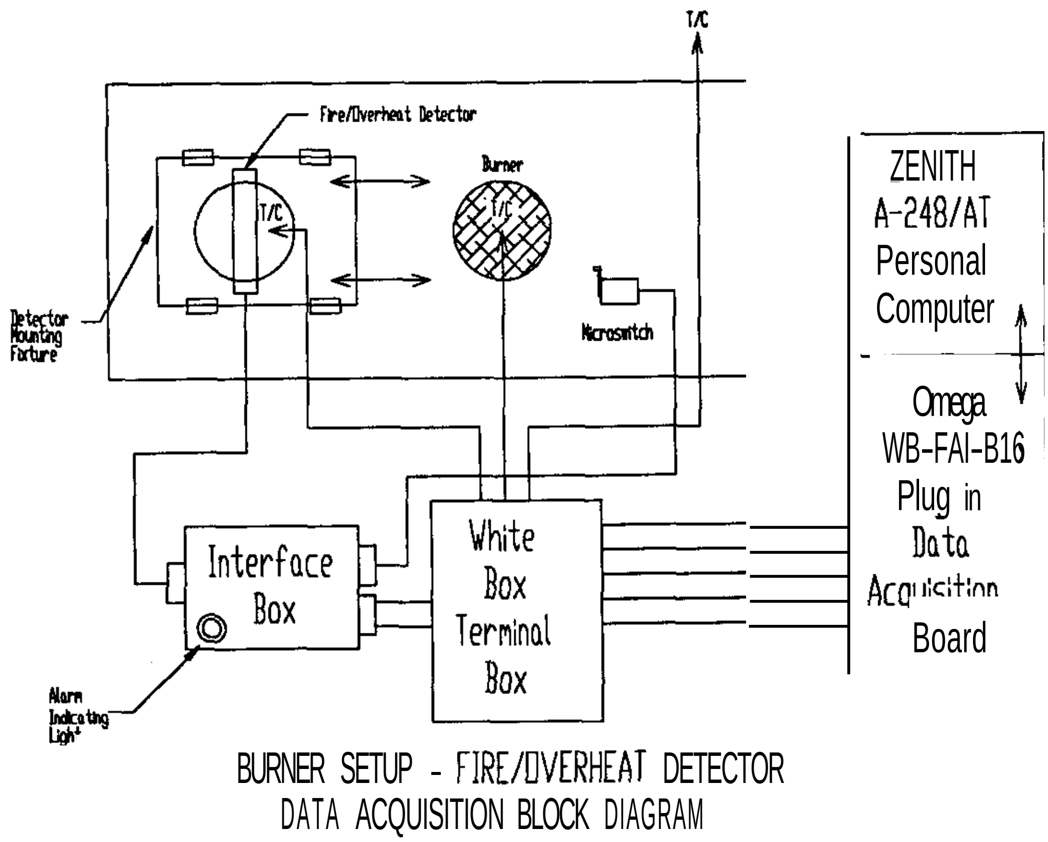


Figure 6. Data Acquisition System

Detection test circuit

In the detection test circuit for the fire response tests, signals from the detector and the microswitch on the test burner unit pass into the interface box containing a red indicating light (alarm light) that comes on when the detector being tested reaches its activation temperature. After the detector is removed from the burner and is sufficiently cooled, the alarm light goes out and indicates that the alarm circuit has reset itself.

For the overheat response tests the detector sample and the two thermocouples are placed inside the forced-air convection furnace used for the tests, as illustrated in Figure *6*. The detector and thermocouple connections to the detection test circuit remain the same. The temperature at which the alarm light goes on is the overheat alarm temperature of the element.

Test procedures

Fire alarm time

Fire alarm time is measured using the standard propane burner test unit, computerized data acquisition system, and detection test circuit illustrated in Figures **3** and **4.** Alarm times were measured at flame temperatures ranging from approximately 1100" to 2050°F (593" to 1121°C).

At the start of each test, a detector test specimen clamped in the holding fixture is rolled into position over the middle of the burner flame. Tripping of the microswitch signals the start of the test run to the data acquisition system. The test measurement data were recorded at 0.1-second intervals. Alarm time is the elapsed time from when the microswitch closes to when the alarm light comes on. The test measurements consist of 1) thermocouple temperature readings and 2) voltages across the microswitch and alarm light in the test circuit. The alarm times are determined from the times at which the voltage changes occurred. For verification, digital timers also recorded the alarm times in some of the burner test runs.

Fire signal reset time

Reset time is the elapsed time from when the detector element is removed from the burner to when the alarm light goes out. At a given flame temperature reset time increases with time heated in the burner (burner time.) Hence, tests were made with different burner times. Burner time was indicated by the time which elapsed between the closing and reopening of the microswitch. Reset times and burner times were measured for each detector element after exposure to flame temperatures ranging from approximately 1100° to 2050°F (593" to 1121°C). The test data **were** recorded at 0.1-second intervals during the fire response tests. The test measurements consisted of thermocouple temperature readings and voltage levels across the microswitch and the alarm light in the test circuit. The reset and burner times were determined from the times at which the voltage changes occurred. For verification, digital timers also recorded the reset times in some of the burner test runs.

Overheat alarm temperature

In this test, various lengths of detector elements were placed at room temperature inside the laboratory test furnace, as illustrated in Figure 5, with electrical connections made to the element by means of MIL-W-25038[5] heat-resistant lead wires connected to the data acquisition system. The furnace was then heated to a temperature approximately 50°F below the minimum rated overheat alarm temperature of the element being tested. When the furnace reached steady-state conditions, the temperature controller setting was increased to approximately 50°F above the maximum overheat alarm rating. The test measurements consisted of thermocouple temperature readings and the voltage across the alarm light in the test circuit. For these tests data were recorded at 2-second and 5-second intervals. The furnace temperature increased at the rate of approximately 4° to 8°F per minute until the alarm temperature was reached, as signalled by the alarm light coming on.

Overheat alarm reset temperature

Following the overheat alarm, the furnace was shut off to permit cooldown. Reset of the alarm circuit occurred when the alarm light went out. The overheat alarm reset temperature was the temperature measured at the time of reset.

References

1. MIL-F-7872, "Fire and Overheat Warning Systems, Continuous, Aircraft: Test and Installation of', 18 August 1980.

2. Technical Standard Order TSO-C11d, Part 514, Regulations of the Administrator, "Fire Detectors", Federal Aviation Administration, Washington, D.C.

3. Data Sheet No. 1422-34, Rev. B, "Resistance vs. Temperature", Walter Kidde Aerospace, Inc.

4. Data Sheet No. 1422-20, Rev. B, "Resistance vs. Temperature", Walter Kidde Aerospace, Inc.

5. ME-W-25038, "Wire, High Temperature and Fire Resistant", General Specification for", 12 December 1980.