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CHARACTERISTICS OF FIRE IN LARGE CARGO AIRCRAFT

TECHNICAL REPORT

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by
Julius J. Gassmann
National Aviation Facilities Experimental Center

FEDERAL AVIATION AGENCY

AIRCRAFT DEVELOPMENT SERVICE

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SUMMARY

An investigation was made to determine the requirements for protecting large cargo aircraft against in-flight cargo fires. Tests were conducted within an instrumented fuselage of a large cargo aircraft using ordinary packing material as cargo. These tests demonstrated the need for suitable detection means, air-flow shutoff controls and adequate insulation properly installed.

A procedure was developed which may be useful in conducting in-flight certification tests on smoke detection system installations. A method of generating the smoke was selected on the basis of uniformity, cleanliness and freedom from odor as a result of its use during evaluation.

INTRODUCTION

The current requirements as expressed in the Federal Aviation Regulations, Part 25.855 and .857 were formulated in part from information available as a result of baggage compartment fire tests conducted at the CAA Technical Development and Evaluation Center (TDEC) at Indianapolis, Indiana in 1950 and reported in Reference 1. This work was aimed at providing safety from fires originating in personal luggage or cargo of the type normally carried in the belly compartments of passenger aircraft. The largest compartment used in that investigation had a volume of 270 cu. ft.

Since the introduction of all-cargo air transports, compartment volumes as great as 8,000 cu. ft. have been in use and the same regulations apply to these large compartments which are thirty times as large as the compartments used in the previous investigation.

In addition to the above mentioned CAA tests, fire investigations were made by American Airlines, Inc. on a simulated DC-6 all-cargo configuration at Norfolk, Va. during the winter of 1952-1953 (Reference 2). These tests indicated that relatively large fires and high temperatures could develop; that such fires are difficult to extinguish but could be controlled by stopping the air flow (oxygen starvation); that the fires could be confined under these conditions if good thermal insulation was provided and that heat detectors provided satisfactory early alarms and remained operational.

The purpose of this test program was to determine adequate protection against fires in large cargo compartments. A secondary purpose was to provide a suitable method for generating smoke for use in certification tests on smoke detection installations.

DESCRIPTION OF TEST ARTICLE AND EQUIPMENT

The test article used in this program was a 41-foot section of a Lockheed C-130 airplane fuselage, the section that lies between Stations 245 and 737. Aluminum bulkheads were fabricated and attached to the ends of the fuselage section. This provided a compartment with a volume of 5,000 cubic feet.

Two observation windows, one foot square, were provided in each of the bulkheads. These were located just above the floor line. An air inlet, 14 inches in diameter, was located in the forward bulkhead 5 feet above the floor and a baffle was provided to distribute the air so as to eliminate any jets as well as dead spaces within the compartment. An air outlet was provided in the aft bulkhead. This outlet was 14 inches in diameter, fitted with a damper for controlling air flow, and located 1 1/2 feet from the top of the bulkhead. The 14 inch diameter duct attached to this outlet contained an axial flow fan which was capable of moving well over the desired 2,000 cubic feet per minute and a set of straightener vanes and pressure pickups for measuring the air flow.

The entire interior of the compartment with the exception of the floor was covered with fiberglas insulation. This insulation was intended to be equivalent to that proposed for the C-141 cargo aircraft. Two-inch thick batting was placed between the belt-frames and ribs and a one-inch thick blanket was then placed over the entire interior. Most of the sidewalls of the compartment, particularly in the vicinity of the test fires, were covered in addition to the fiberglas insulation with a hardboard liner to a heighth of 8 to 9 feet. Because a large number of test fires accompanied by high temperatures were planned, the entire interior except for the areas covered with hardboard liner was covered with one-inch mesh chicken wire to keep the insulation in place throughout the program. Exterior and interior views of this compartment are shown in Figures 1 through 4.

Chromel-alumel thermocouples were installed on the test article for monitoring temperature throughout the test series. Forty-eight thermocouples were attached to the interior surface for measuring material surface temperature of the sidewalls and ceiling. Eleven thermocouples were located so as to measure the temperature of the inlet air, air temperatures within the compartment, and outlet air temperatures. Twenty-four thermocouples were attached to the belt-frames and the outside skin. The exact locations of these thermocouples are shown in Figures 5 and 6.

Gas sampling lines were installed so that samples could be drawn from any point along the top center line and anywhere along the starboard side three feet above the floor.

A smoke density meter was installed, outside, on the aft bulkhead. This can be seen in Figure 2. The smoke sample was drawn from a location within the compartment one foot forward of the outlet through a one-inch line to the meter and discharged back into the compartment. This external arrangement eliminated most of the temperature problems that would have been encountered if the meter had been mounted internally during the fire tests. The cargo compartment smoke detectors, when used, were mounted in the space directly forward of the air outlet and 6 to 12 inches from the aft bulkhead.

Nearly half of the full-scale tests were conducted with the compartment filled to 50% of its volumetric capacity. Twenty-three boxes, 36x48x88 inches, and twelve boxes, 12x36x88 inches were used. These were arranged to cover the floor areas indicated in Figure 6 (as the "pallets") with the exception of the small dotted area near the door. The volume of these 35 boxes represented 46% of the compartment volume. The fire load represented another 2%. For all practical purposes, this was considered a 50% load factor and is referred to as such throughout this report.

Ignition of the fire load in the full-scale tests was effected by a heating element. The element used was a Chromalox Electric Barbecue Lighter, Catalog No. CL-5, 500 watts, 120 volt ac service.

A smoke generator, designed for generating smoke by burning a potassium chlorate-lactose mixture consisted of a metal container, five inches in diameter and 6 1/2 inches deep, open on top and an oil burner electrode mounted so an ignition arc occurred between the electrode and the center of the bottom of the container. The electrode and the container were connected by high tension ignition wire to an oil burner ignition transformer. A sheet of transite was placed under the smoke generator to insulate it both thermally and electrically from the compartment floor.

INSTRUMENTATION

The recording instruments used in the test series are shown in Figure 7. Temperatures from the 48 locations on the interior surface of the compartment were recorded on two Thermo Electric profile recorders. The 24 temperatures of the outside skin and belt-frames were also recorded on one of these recorders by proper positioning of the selector switches shown in Figure 8. When these temperatures were recorded, only the forward half of the interior surface temperatures could be recorded.

The ten air temperatures were recorded on five Honeywell Electronik strip chart duplex recorders. These are the two-pen continuous recording type instruments with an event indicating pen on the right-hand margin of each. A sixth Honeywell Electronik strip chart duplex recorder was used to record the output of the smoke meter. The presence of smoke was recorded on the strip chart in terms of percent light transmission per foot, 100% being the reading for clear air and 70% being the mid-point of the detection range as specified by the current Aerospace Standard AS-400A. The system was checked with a 70% screen loaned by the Pyrotector Corp. When the screen was introduced, the system read 68%. For the purpose of the test series, this was considered adequate.

The carbon dioxide and the carbon monoxide concentrations within the compartment were monitored by four MSA, LIRA Model 200 infrared analyzers. The information was recorded by two Honeywell Electronik strip chart duplex recorders. Two of the instruments measured CO_2 with a range from 0 to 25%. The third instrument measured CO with a range from 0 to 0.5% and the fourth measured CO with a range from 0 to 0.05%.

The oxygen content of the atmosphere within the compartment was monitored with a Davis gas analyzer. This instrument had a range from 0 to 25% and recorded the information on a Honeywell Electronik strip chart recorder.

The air flow through the compartment was determined by measuring the air flow in the 14 inch diameter exhaust duct. An inclined manometer shown in Figure 2 was used to indicate the velocity head as measured by a pitot tube in the duct two feet downstream of the straightner vanes and a wall static pickup at the same location. The velocity of the air movement within the compartment was measured and the direction determined with an Alnor velometer and a Hastings portable air meter Model AB-12. A multiple pen Esterline Angus operation recorder was used to record the time for detection of the various smoke or fire detecting and indicating devices used in the tests.

PROCEDURE

Three types of tests were conducted in this program. The first was a series of smoke tests in which smoke was generated chemically. The second was a series of limited combustible tests which were actually starts of fires and were conducted for the purpose of approximating smoke and fire characteristics during the detection phase of a fire. The third was a series of full-scale fire tests. These tests were conducted for determining smoke and fire characteristics during the detection and oxygen depletion stages, the effect of interior materials on smoke and fire severity and the ability of the insulation to protect the aircraft structure from the heat produced by full-scale fires. These full-scale tests were conducted in lightly loaded compartment (2% cargo) and one that was 50% filled with cargo.

1. Smoke Tests: Throughout these tests, the smoke generator was located on the floor, ten feet from the forward end. The smoke detector was located near the outlet which was in the aft wall 9 1/2 feet above the floor. In these tests, equal weights of potassium chlorate and lactose were mixed and placed in the metal container. With the desired rate of air flow through the compartment, the mixture was ignited and at the same time the recorders were started. The operations recorder recorded the time from ignition to detection and the duration of the signal. As a check on the operation of the smoke detectors, a record of the smoke density was made in terms of percent light transmission. This procedure was repeated while varying the amounts of potassium chlorate and lactose from 50 grams each to 250 grams each and a air-flow rates of 1000 CFM and 2000 CFM.

One reason that the potassium chlorate and lactose method of generating smoke was chosen in preference to other methods was that it was accompanied by less corrosive by-products, toxic gases, oil vapors or staining fluids than other known methods. The only noticeable evidence remaining after many tests was a coating of white powder on the exhaust grill. Other reasons for choosing this method were that the materials are readily available at drug and chemical houses throughout the country and the burning rate (therefore the smoke generation rate) is quite consistent and relatively uneffected by atmospheric conditions of temperature and humidity.

It should be noted, however, that while the burning or smoke generation is taking place, high temperatures within the container and considerable sputtering will be present. Care should be taken to protect the surface on which the container is resting as well as any surface within a few feet from being damaged by the heat. Attention is also called to the fact that this mixture is in the same class as gun powder, and the person preparing and handling the mixture should use normal safety precautions, particularly the wearing of safety glasses and the guarding against static sparks.

2. <u>Fire Tests:</u> Compartment air flow was determined by measuring the velocity head in the exhaust duct. The average velocity in the exhaust duct was calculated using the formula $V = \left(\frac{h}{2.168 \times 10^{-4}}\right)^{1/2}$ where V is the velocity in feet per second and h is in inches of water as indicated on the inclined manometer. The maximum air flow that the exhaust fan could draw through the compartment was 2800 CFM. The damper was used as necessary to obtain the 2000 CFM used in simulating the C-141 aircraft conditions and the 1000 CFM for simulating the C-130 aircraft conditions.

Measurements were also made of the air velocities within the compartment. Readings were taken at 150 locations throughout the compartment, ranging from one foot above the floor to two feet below the ceiling. This was done with a flow rate through the compartment of 1500 CFM and 2800 CFM. Although these readings ranged from as low as 5 feet per minute to as high as 400 feet per minute, the results indicated that no high speed jets, high turbulence or dead spots existed within the compartment.

Photographic coverage was provided during the conduct of the full-scale fire tests except in those tests where the fire was obscured by the simulated cargo. Motion pictures were taken of the start and the progress of the fire through one of the observation ports at the rate of 12 frames per second. In order to correlate the fire progress with time, a chronometer was imposed in one corner of the camera's view.

All of the full-scale tests and some of the smaller, limited material fires were ignited internally with a Chromalox electric barbeque lighter. The heating element of the lighter was inserted through a slot centered in the side of the cardboard box to be ignited. When voltage was applied, the element became "red hot" and ignited the excelsior in the immediate vicinity. Approximately three minutes elapsed between the time the voltage was applied and visible flame broke through the side of the cardboard box. The appearance of the first visible flame outside of the box was considered the start of the test.

Most of the preliminary or limited fires were ignited by a mixture of magnesium chips and rifle powder. Thirty grams of each and two electrodes were placed in an envelope and electrically ignited. The magnesium chips were added to the gun powder because the powder itself burned so rapidly that it usually failed to ignite the combustible material which was either rags, newspaper mache or excelsior. This method of ignition was used for both internal ignition tests and open fire (external ignition) tests.

The burning magnesium produced a sizeable puff of white smoke at the beginning of the ignition period but this was taken into consideration when the time-smoke curve was analyzed.

In these tests, the size of the fire was limited by providing insufficient material to allow a normal spread or growth of fire. This was done to limit the heat and temperature so that no damage or deterioration to the interior materials would result. This made it possible to conduct a large number of tests under varied conditions to provide information on detection and other information needed to plan an effective full-scale test series.

Materials used in these tests were rags, newspaper mache and excelsior. The amounts of the combustible used in a single test varied from 8 to 20 pounds. When fires were simulated that started as fires external to the cargo, the materials were placed in cardboard boxes open on the top and ignited on the top. When deep seated fires were simulated, the combustible was placed in cardboard boxes, sealed and ignited near the center. In these tests, time was recorded as of the initiation of ignition.

RESULTS AND DISCUSSION

1. Smoke Tests: The results of the smoke tests are shown in Table I. The first column shows the weight in grams each of potassium chlorate and lactose burned (200 means 200 grams potassium chlorate and 200 grams of lactose). The second and third columns represent results in the compartment with a 50% load factor while the fourth and fifth columns represent the results in the empty compartment. The "yes" and "no" refer to whether detection occurred in that particular test.

In one of the test series, a smoke detector was mounted near the ceiling at the mid-point of the compartment. Results of these tests indicated that detection was obtained 10 to 15 seconds sooner and retained as long or longer by this detector than the one located at the aft end but in all cases it detected only when the aft detector did so. In none of the smoke tests did the centrally located detector alarm unless the aft detector also alarmed.

The results of these tests indicate that for certification purposes a smoke detection system should function with the smoke generator located as far as practical from the smoke sensors under the following conditions: In compartments of 2,500 to 5,000 cubic feet, the required amount of potassium chlorate and lactose to be burned should be 150 grams of each when 1,000 CFM is the ventilation rate, and 200 grams of each when 2,000 CFM is the ventilation rate through the compartment.

2. Limited Material Fire Tests: In some of the deep seated ignition tests, visible flames appeared in less than a minute while in others the fire was contained within its container for as long as 4 1/2 hours.

In none of these tests did detection by any of the medias investigated occur prior to the appearance of visible flame external to the fire package. Therefore, the time required for detection as listed in Table II was measured from the instant that the visible flames appeared. In this series, no actual detectors were employed. The times for detection as given in the table were (1) time for a thermocouple to reach 200°F. (2) time for the CO concentration to reach 0.02% (3) time for the smoke meter to reach 90% and 70% light transmission, respectively. In evaluating the results in this table, the sensing equipment simulated system installations (1) for temperature sensing as unit sensors located at the ceiling spaced five feet apart, (2) and (3) as a CO sensor and a smoke sensor located just before the air exit of the compartment.

In Table II, spaces indicate that no detection occurred for this particular condition before the material was consumed or before more than fifteen minutes elapsed between the start of the test and detection. From an examination of the results shown in Table II, it is evident that the type of material or the air flow through the compartment have no more effect on detection than other variables which were not controlled such as humidity, the manner in which an internally ignited fire grows and breaks out of its container, etc. It is also evident that excelsior produces as much CO and smoke in addition to temperature as do rags and paper mache. For these reasons and the fact that excelsior is more easily dried, packed uniformly and has a more uniform burning pattern, it was decided to use excelsior in the full-scale fire tests.

The concentration of carbon dioxide was recorded throughout all tests from a level of three feet above the floor and from near the compartment outlet. Since the maximum concentration during detection did not exceed 3%, it was considered negligible and of no significance and was not mentioned in the results.

3. Full-Scale Fire Tests: Throughout the full-scale fire tests, the moisture content of the fire load was kept fairly constant except for the test shown in Figure 17. This will be discussed in detail later. In this test series, temperatures were taken of the ambient air near the ceiling of the compartment as shown in Figure 5. These temperatures were taken in locations generally occupied by thermal detectors when such systems are incorporated. The temperatures shown in the curves in Figures 9 through 20 are the maximum temperatures recorded in these locations. In every case, they occurred in the vicinity of the fire and not at the compartment outlet. The other detection phenomena were sampled at the compartment outlet which experience has dictated as being the most advantageous location for smoke and CO sensors.

The effect of interior material on the severity of a cargo fire is indicated by comparison of the results shown in Figures 9 through 12. The results shown in Figure 9 are of a typical compartment completely lined with fiberglas blankets and with Rigitrim 6A hardboard covering most of the sidewalls. The floor was metal and contained four type 463-L pallets. Of particular interest is the high resultant temperature and the drop in oxygen which remained at zero for five minutes. A flash fire occurred during this test starting 7.9 minutes after the start of the test and ending at 8.1 minutes.

The results of a fire in the compartment subsequent to the interior materials having been inerted as a result of previous fires but with new Conolite hardboard installed are shown in Figure 10. Results were similar to those of the previous test except that the oxygen remained at zero for only one minute. A flash fire occurred during this test being active from 6.02 to 6.16 minutes after start of the test.

The results of a fire in a compartment in which the interior materials were inert except for one 4x9 foot sheet of Rigitrim hardboard are shown in Figure 11. The results of this fire were very similar to those of the two previous tests except for the oxygen which dropped to only 3%. A flash fire occurred in this test also although it was not as clearly defined. The duration of this flash fire was from 6.9 to 7.5 minutes after the start of the test.

The results of a fire in the compartment in which the entire interior was inert are shown in Figure 12. From these results, it can be seen that the maximum temperature was 200°F less than in the three previous configurations, that the total heat as represented by the area under the temperature curve was considerably less and that starvation of the flames occurred with 9% oxygen. No flash fires occurred under these conditions.

In each of these tests, the time from the first visible flame to the time of closing the damper to effect zero air flow was approximately five minutes. Thus the only significant variable was the type and amount of interior material of a resinous nature which gave off volatiles when heated by the burning cargo.

The effect of the speed of detection on the severity of a cargo fire is indicated by a comparison of results shown in Figures 12 through 15. In this group of tests, all factors were kept constant except the time from the start of the test to the shutting off of the ventilating air. This time was varied from zero as shown in Figure 13 to 4 1/2 minutes as shown in Figure 12. Results of all four of these tests indicate that there was very little difference as a result of the speed of detection effecting control procedure. In all cases, the maximum temperature was approximately 1200°F, oxygen starvation was effective when a low of 10% oxygen was recorded and the area under each curve was relatively the same.

The effect of the burning rate of the cargo involved in a fire can be seen by comparing the results in Figure Nos. 16 and 17. Both of these tests were conducted in the compartment with an inert interior. The cargo in these two tests was of the same material but the burning rate was effected by the moisture content. The very fast burning cargo, Figure 16 produced a temperature of 1300°F and the oxygen dropped to 7% when the flames disappeared and the fire settled down to a smoldering mass, while the slow burning cargo produced a temperature of not quite 700°F and the flames disappeared when the oxygen had dropped only to 15%.

The effect of load factor on the burning characteristics of a cargo fire was determined by conducting a number of tests in the cargo compartment while it contained simulated cargo which occupied 50% of its volume.

Figure 18 shows the results of one of four tests conducted in a compartment with an inert interior and with a 50% cargo load factor. All four of these tests gave almost identical results. Also the time from the start of the test until the air flow was shut off was approximately five minutes in each test.

Figure 19 shows the results of a test similar to the four above except that detection was assumed at the start of the test so that the air flow was zero right from the start. The results of this test were almost identical to those of the above four runs except that the maximum temperature was 200°F less or about 500°F. This is a significant difference particularly in that during preliminary testing where temperatures of 500°F were experienced, no apparent effect on the fiberglas blanket or the fiberglas hardboard liner was experienced. These results indicate first, that the presence of cargo in a compartment has a very considerable effect on the maximum temperature attained within the compartment during a fire provided that the air flow in the compartment is reduced to near zero when detection occurs and secondly, that the speed of detection has an additional and significant effect on the maximum temperature attained within the compartment. This second observation is completely contrary to the observation made during the conduct of the full-scale fire tests in an empty compartment. In the empty compartment tests, the speed of detection had no measurable effect on the burning characteristics or on the maximum temperature attained within the compartment.

In order to substantiate the significance of shutting off the air flow at the time of detection to a compartment with a 50% load factor, a test was conducted in which the air flow was set at 1,000 cubic feet per minute and allowed to continue. The results of this run are shown in Figure 20. They indicate that before the 240 pounds of combustible material in the fire load was consumed, during the first fifteen or twenty minutes, the 2x3 frame work of the fire resistant cargo became ignited and continued to burn becoming increasingly more severe until the test was terminated at 48 minutes. By that time, the inside ambient temperature had reached almost 1500°F and some structure temperatures had reached 900°F.

Throughout the full-scale fire tests, data was taken on the various phenomena considered suitable for detection. Since all of the full-scale tests were similar in that the type and amount of combustible and the means of ignition were the same in each, the results were summarized and averaged. These are shown in the bar graph in Figure 21. The first four bars are from data taken from recordings of parameter signal strength vs time. For example, the first bar represents the time for detection that could be expected from a heat sensor that was to alarm at 200°F. The actual values shown are those taken from the temperature curves recorded using a thermocouple as the heat sensor. The results of the eighteen tests represented by this bar indicated that the minimum time for detection was 0.7 minutes, the maximum time was 2.8 minutes and the average time for the eighteen runs was 1.7 minutes as represented by the horizontal line through the cross hatched area. The last two bars show the results of tests on actual detection systems. The summary of these two systems is based on only four test runs since electrical wiring as well as the systems themselves would be damaged by temperatures of 700°F. The systems were installed only for tests during which maximum temperatures of not over 500°F were expected.

The results shown under the heading of "Detectors, smoke" are those of the Pyrotector Inc. smoke detection system. This system is set to operate at a nominal 70% (70% $\pm$10% light transmission per foot) and is approved for use in aircraft. The results shown under the heading of "Detectors, Ionization" are those of the Pyr-A-Larm fire detection system. This is an industrial system and signals from the presence of relatively large ions. The sensitivity of this system cannot be expressed at this time since no bases or yardstick for this parameter as related to cargo fires has been devised.

CONCLUSIONS

Based on an analysis of the results of tests conducted in the C-130 fuselage section, it is concluded that:

1. Fires in large cargo compartments involving currently used packaging materials can readily reach damaging proportions even though detection and air flow shut-off occur immediately.

2. In order to protect the structure of a large compartment containing a small amount of cargo from fire damage by ventilation shut-off, a well designed interior insulation system must be provided with particular attention given to the thermal insulating adequacy to the belt frames and to the types of fastenings used.

3. The detection of fire in large cargo compartments by thermal detection systems is a more rapid and reliable means than by carbon monoxide or smoke detection systems when considering all the conditions likely to be encountered.

4. The smoke generator described in this report using potassium chlorate and lactos is a relatively clean, reliable and controllable means of producing smoke for evaluating smoke detection systems in aircraft.

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1. Asadourian, L. A.: Evaluation of Flight Fire Protection Means for Inaccessible Aircraft Baggage Compartments. CAA Technical Development Report No. 146, June 1951.

2. Smith, Mark H.: Simulated DC-6A Fire Test Program (Preliminary Report) (Supplement #1) (Supplement #2) (Supplement #3) American Airlines, Inc., Engineering Department Report No. LDC-6A-9920-X1R, September 1952, March 1953.

ACKNOWLEDGMENTS

The author wishes to acknowledge the valuable assistance given by the FAA regions in outlining the program.

Acknowledgment is also made to the Lockheed Corporation, Marietta, Georgia, Pyrotector Incorporated, Hingham, Mass., and Pyrotronics Div. (Pyr-A-Larm), Newark, N. J. for their participation in the program.

APPENDIX I

List of Illustrations and Tables

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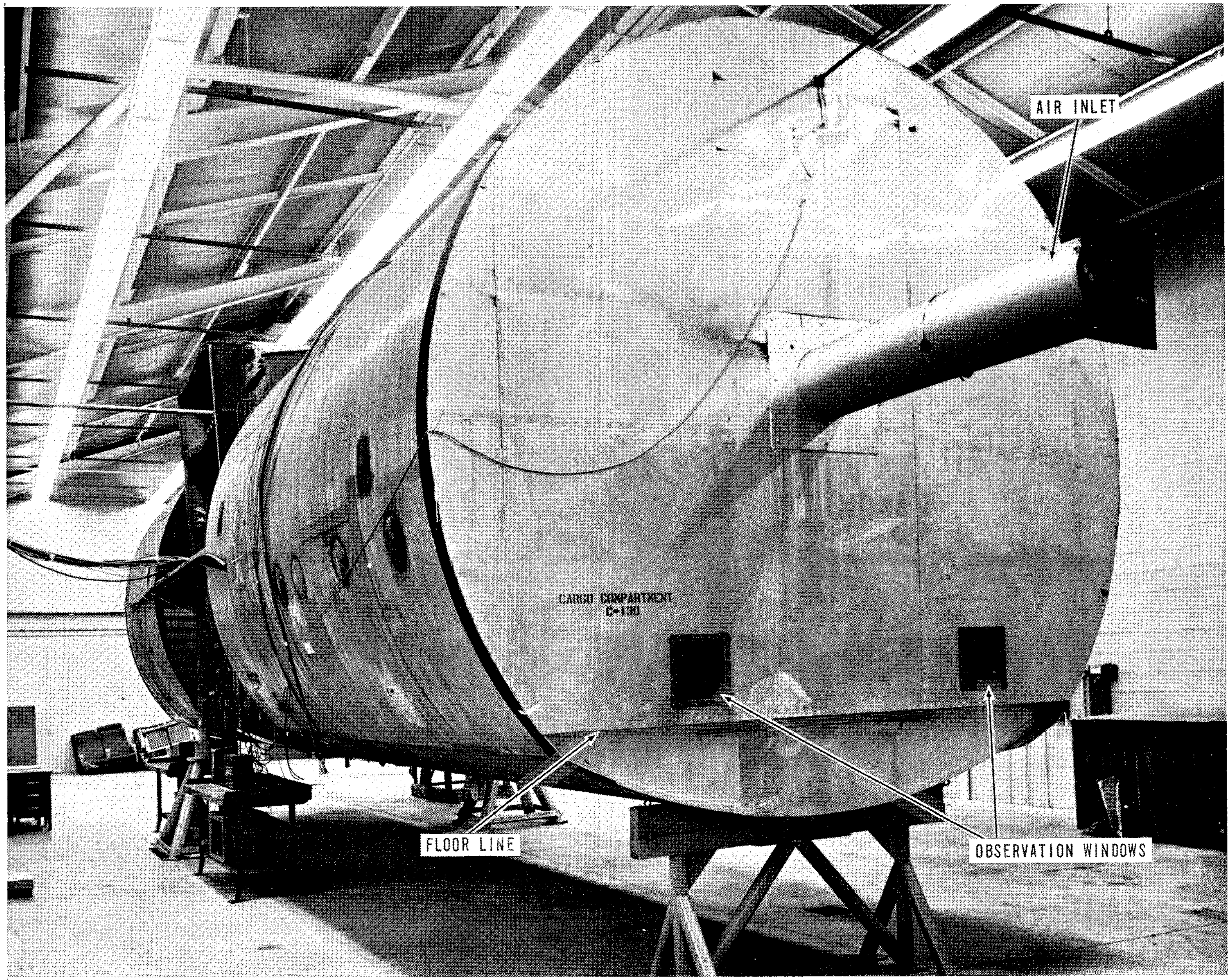

FIG. 1 C-130 FUSELAGE SECTION - FORWARD END

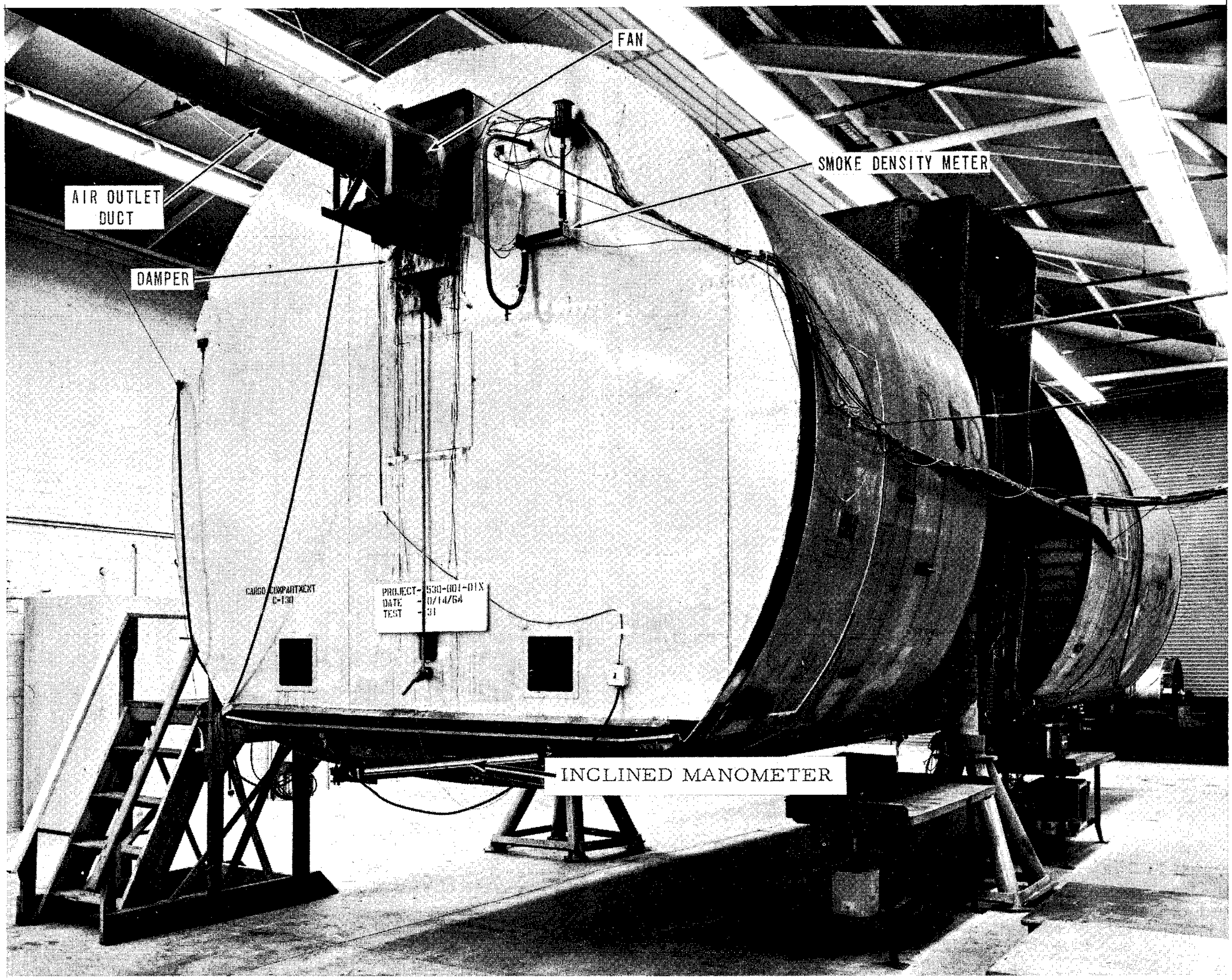

FIG. 2 C-130 FUSELAGE SECTION - AFT. END

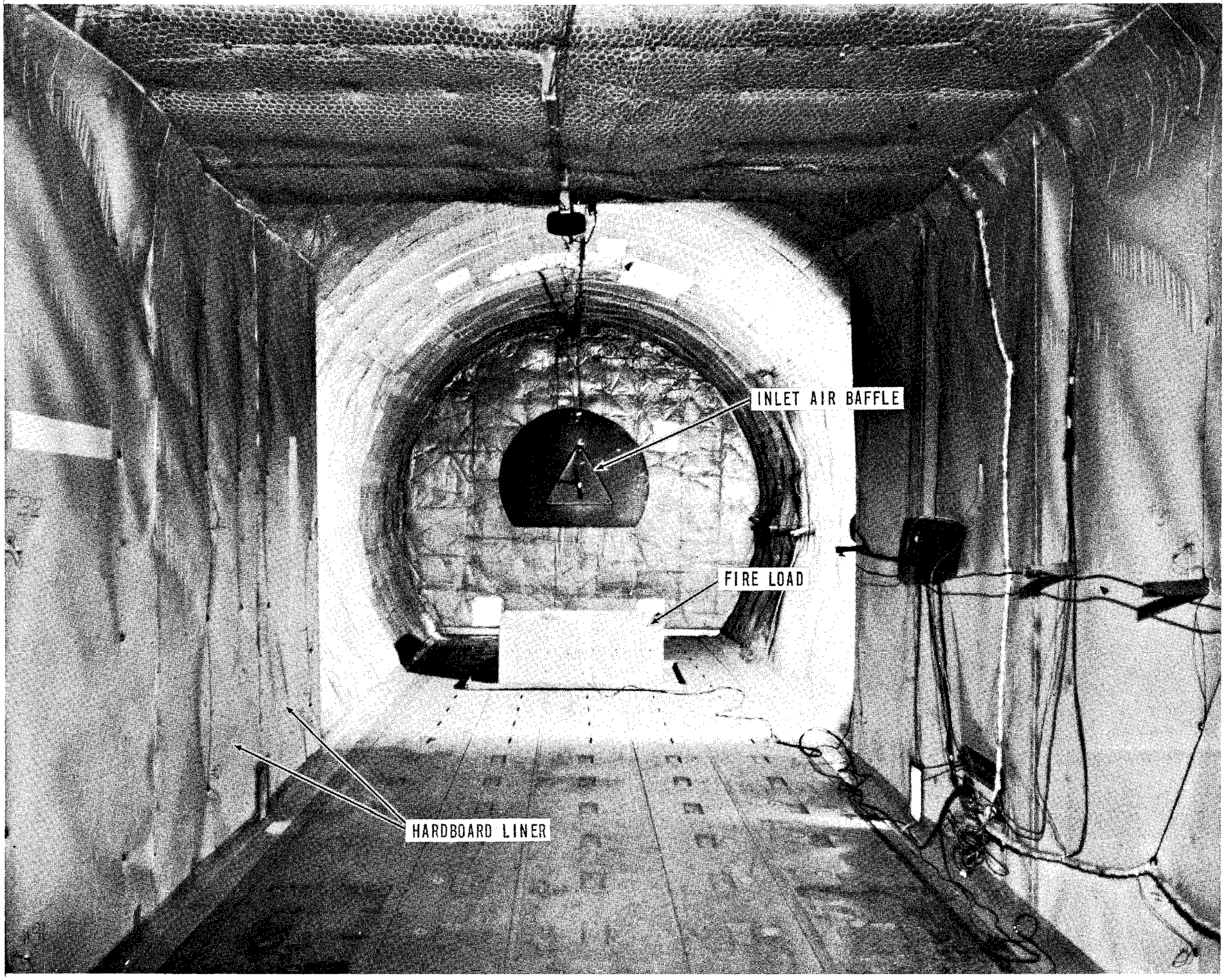

FIG. 3 C-130 INTERIOR LOOKING FORWARD

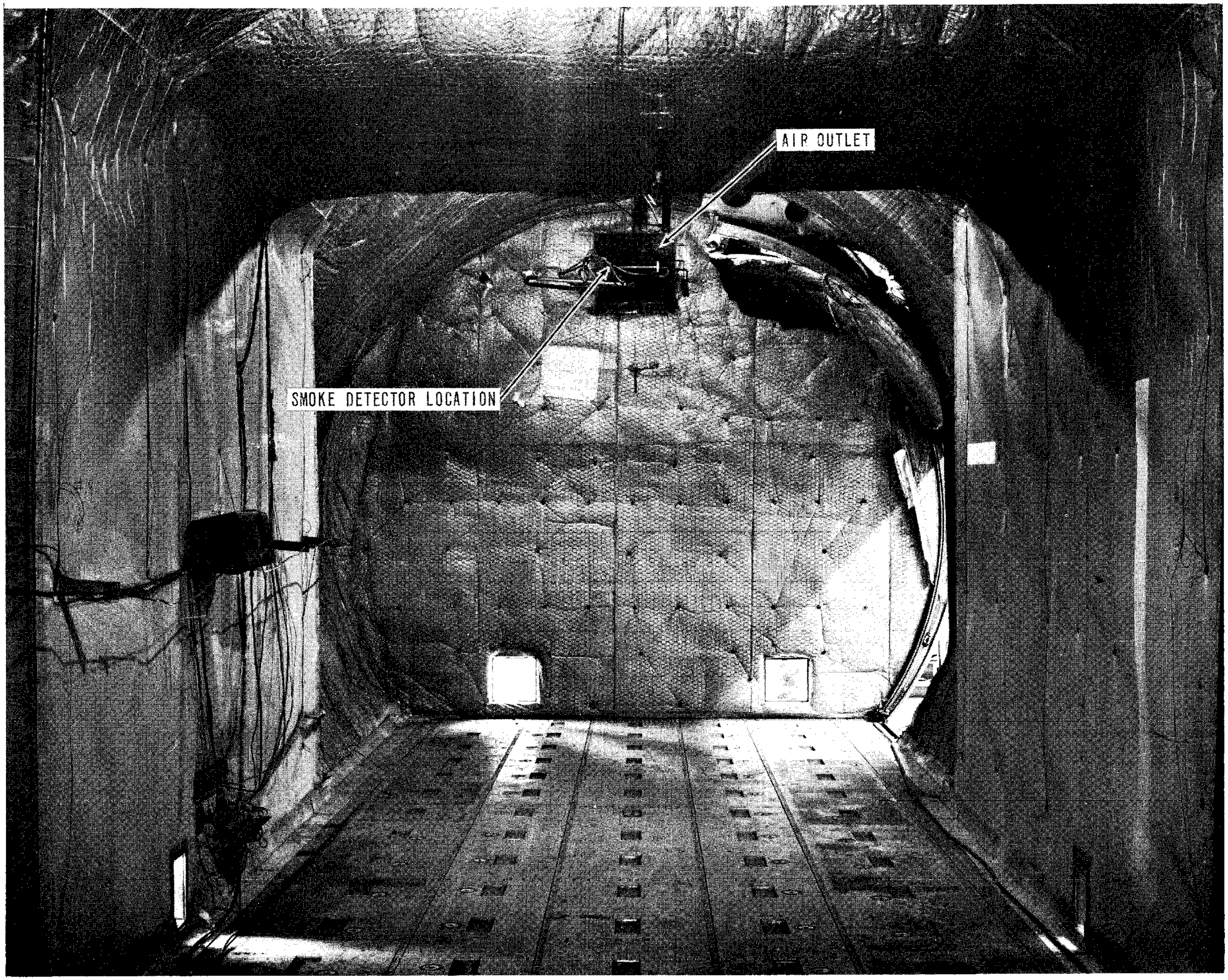

FIG. 4 C-130 INTERIOR LOOKING AFT.

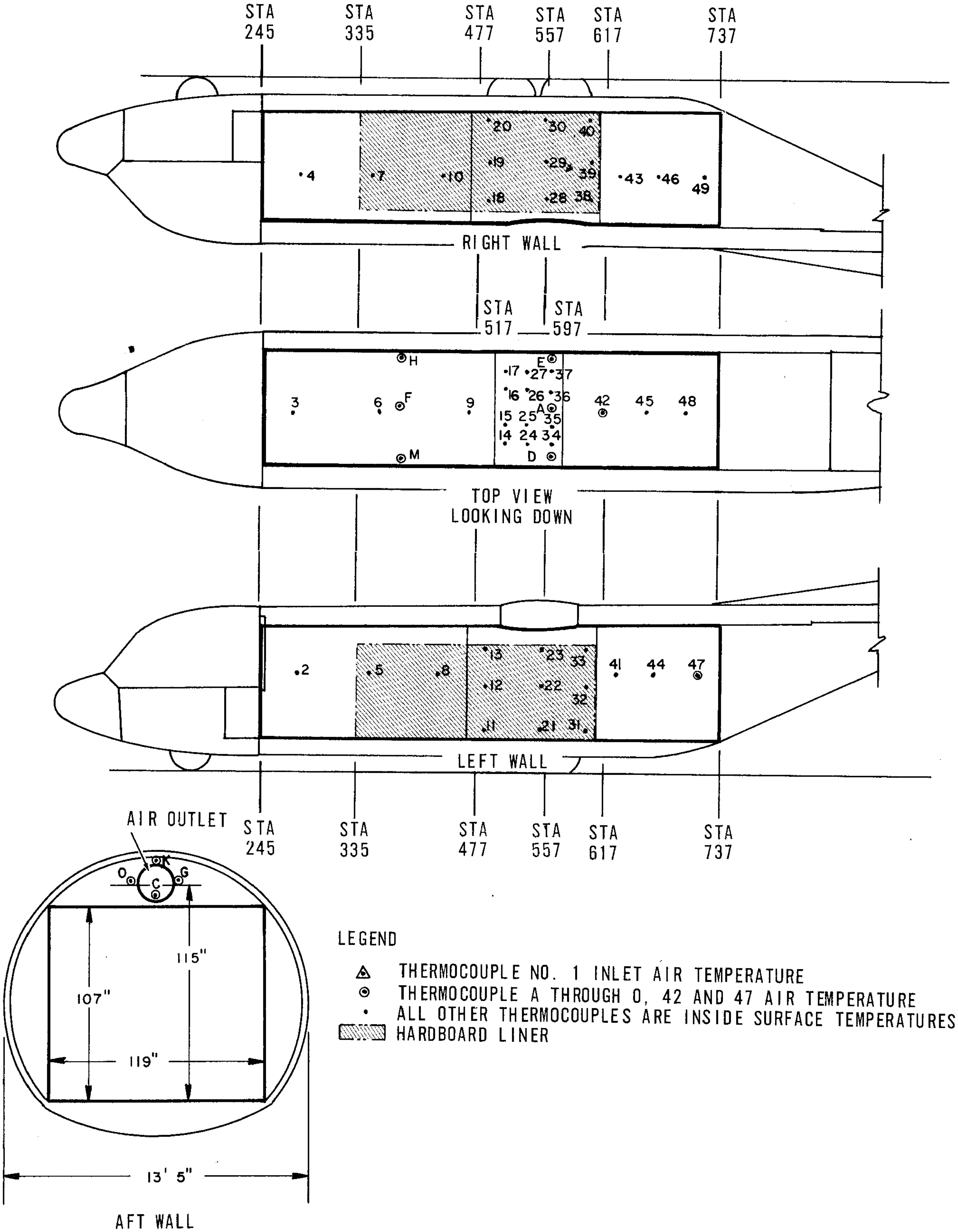

FIG. 5 C-130 FUSELAGE SECTION SHOWING THE LOCATION OF THE INTERIOR THERMOCOUPLES

LEGEND

• THERMOCOUPLES 1-18 ATTACHED TO BELT FRAMES

⊙ THERMOCOUPLES 19-24 ATTACHED TO OUTSIDE SKIN

NOTE:

THERMOCOUPLE GRID LOCATED CENTRALLY ABOVE FIRE AREA

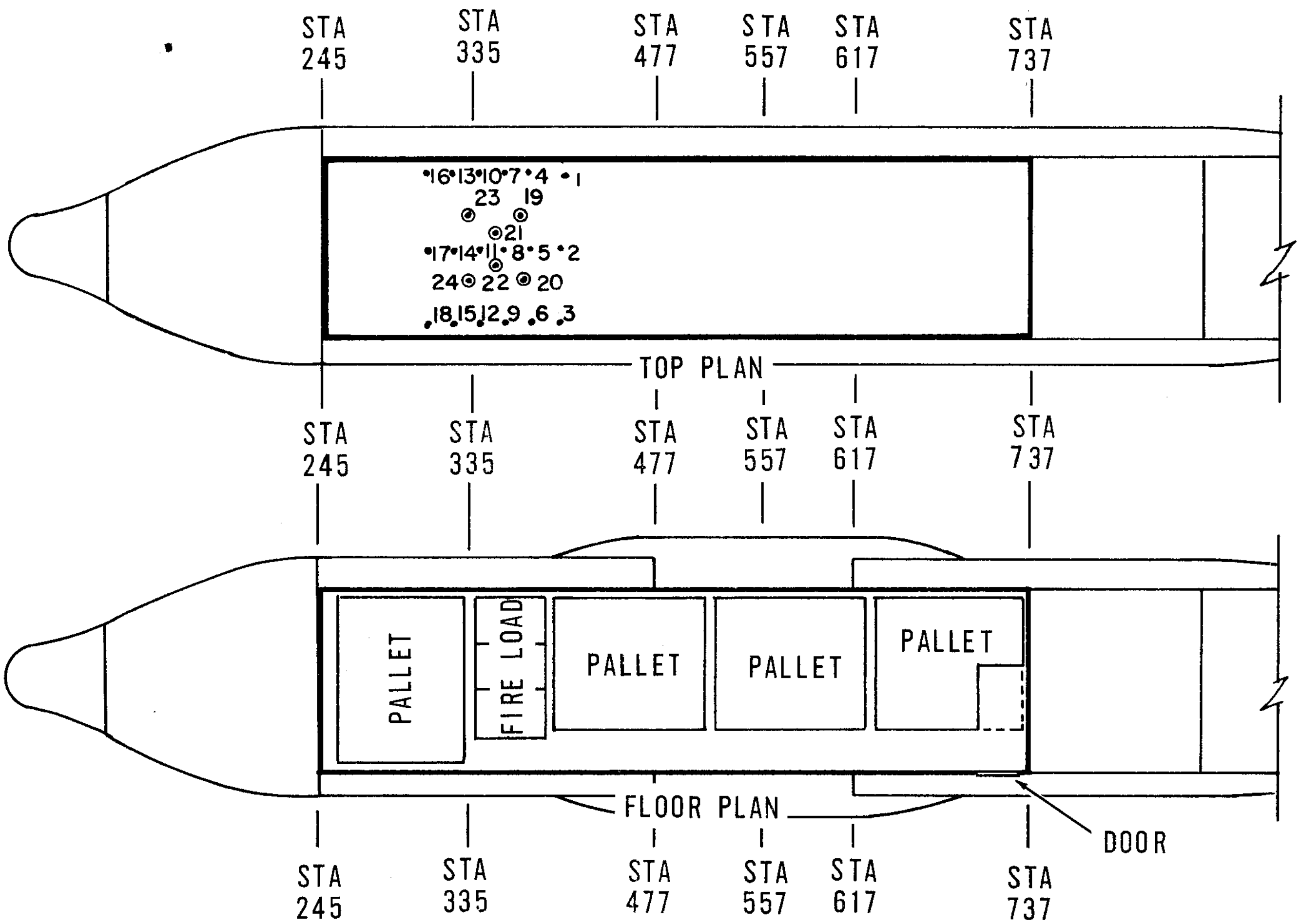

FIG. 6 C-130 FUSELAGE SECTION SHOWING FLOOR ARRANGEMENT AND LOCATION OF THE STRUCTURALLY MOUNTED THERMOCOUPLES

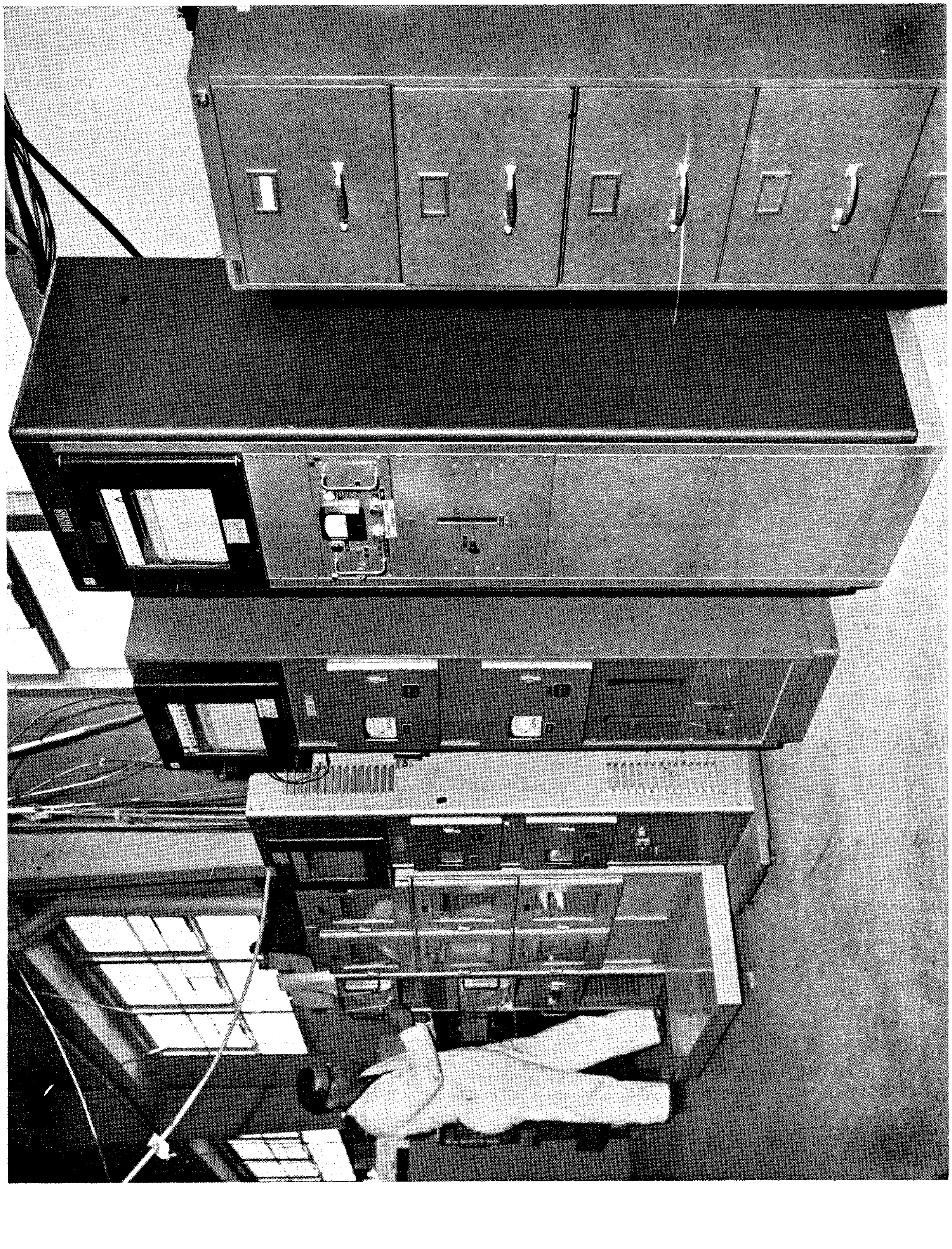

FIG. 7 RECORDING EQUIPMENT

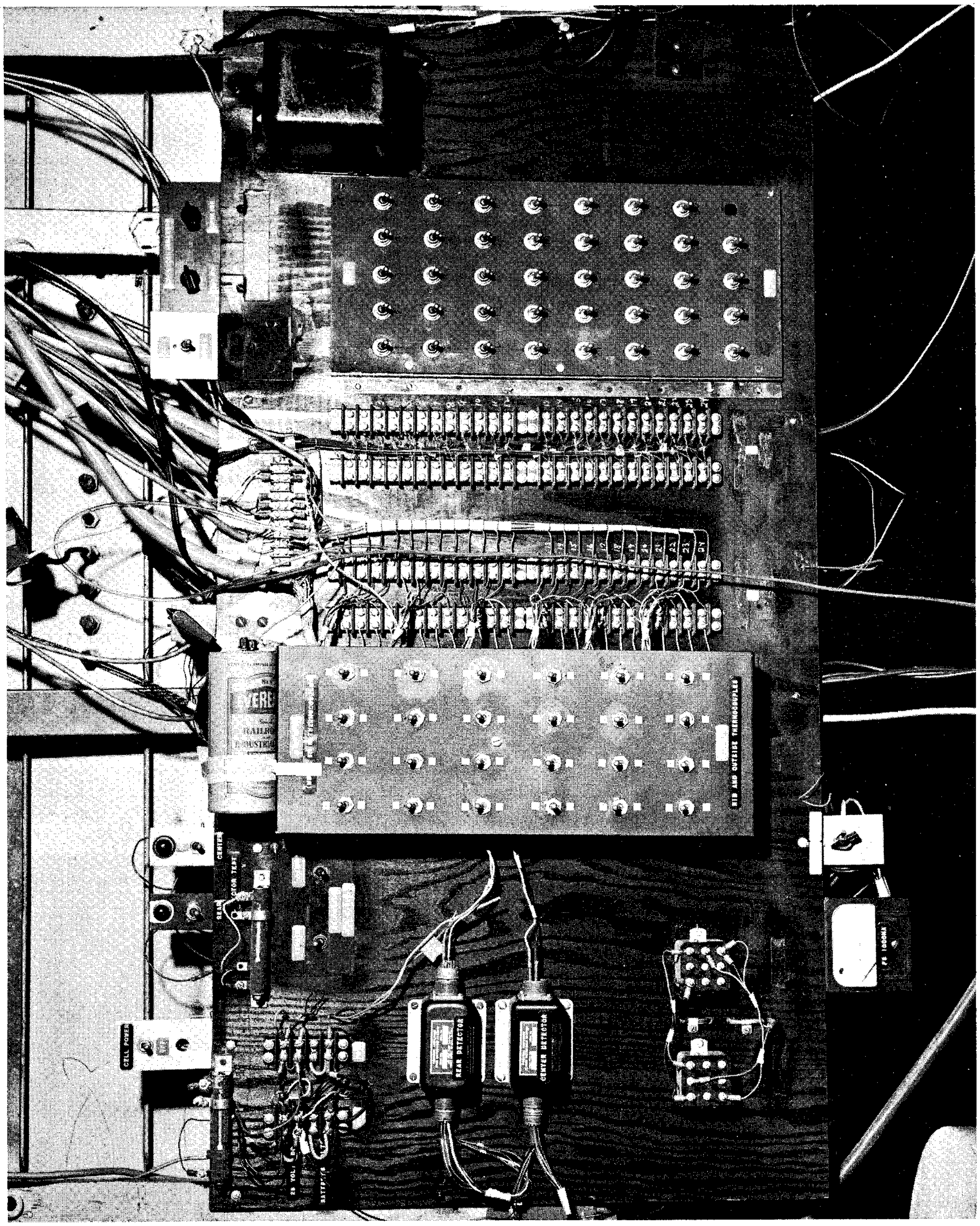

FIG. 8 CONTROL PANEL

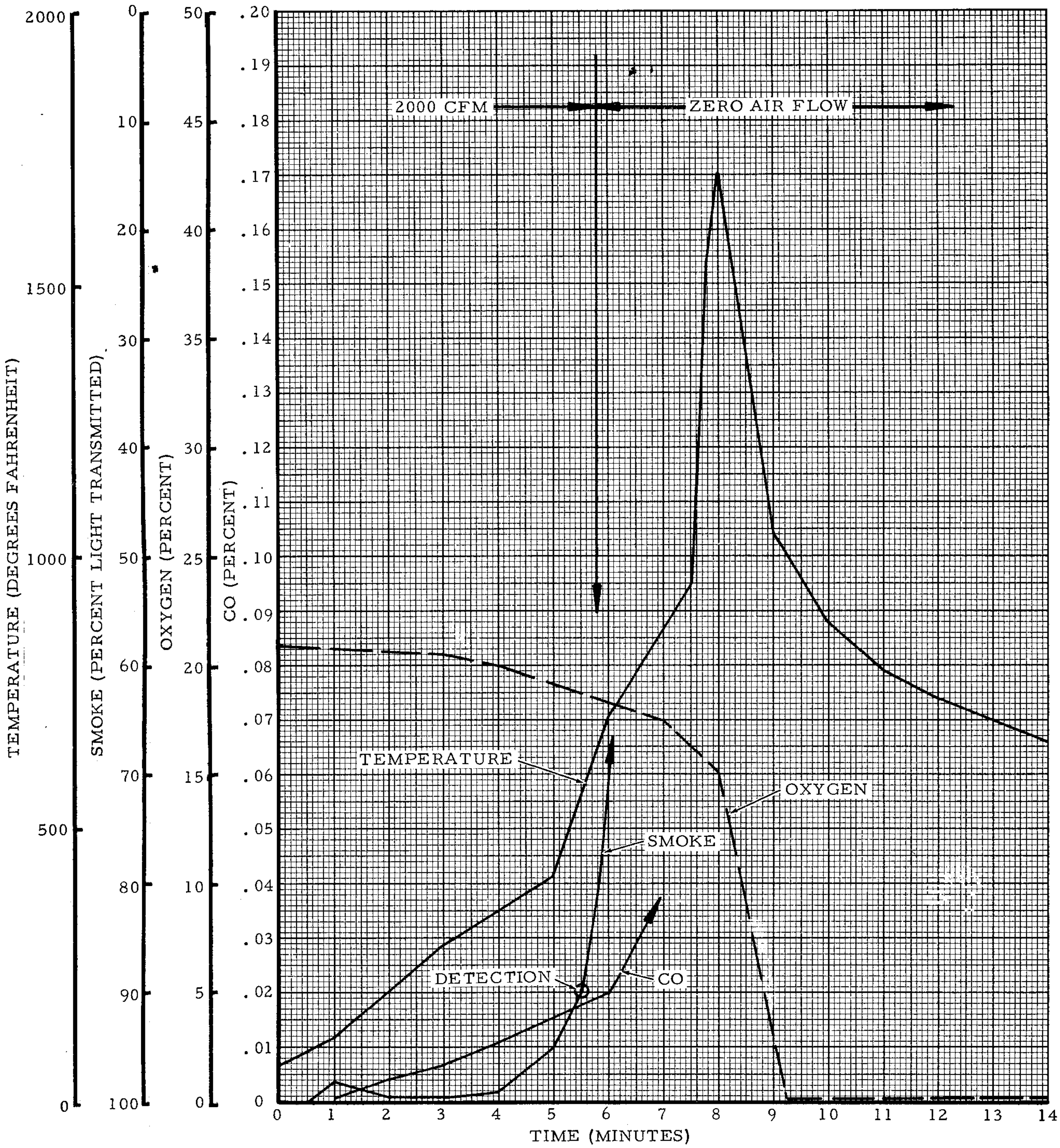

FIG. 9 TEMPERATURE, SMOKE, CARBON MONOXIDE AND OXYGEN RECORDINGS DURING CARGO COMPARTMENT FIRE. (SERVICEABLE BLANKET INTERIOR WITH 25% COVERED WITH RIGITRIM 6A)

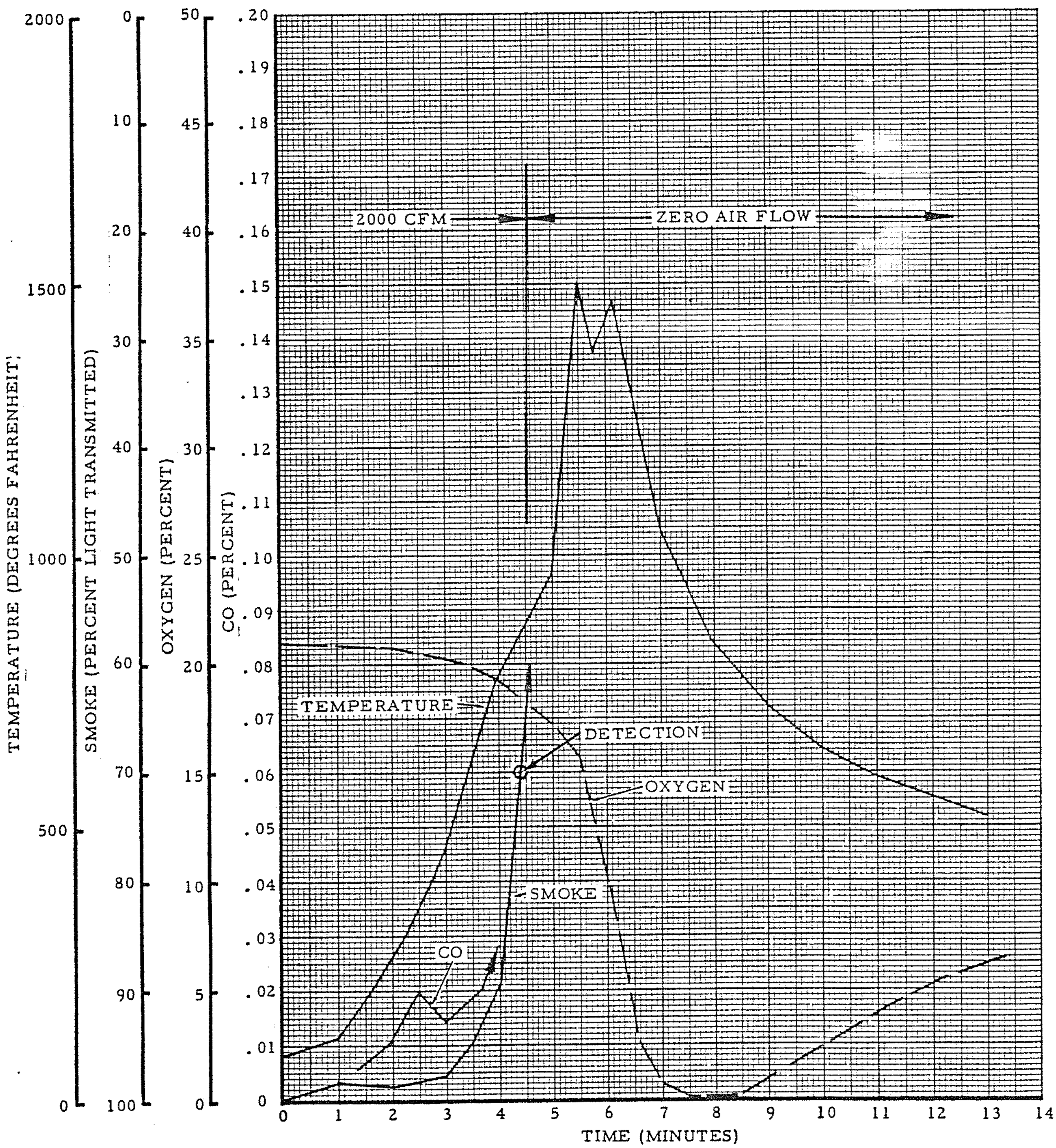

FIG. 10 TEMPERATURE, SMOKE, CARBON MONOXIDE AND OXYGEN RECORDINGS DURING CARGO COMPARTMENT FIRE. (CONOLITE HARDBOARD LINER COVERING 20% OF INTERIOR SURFACE)

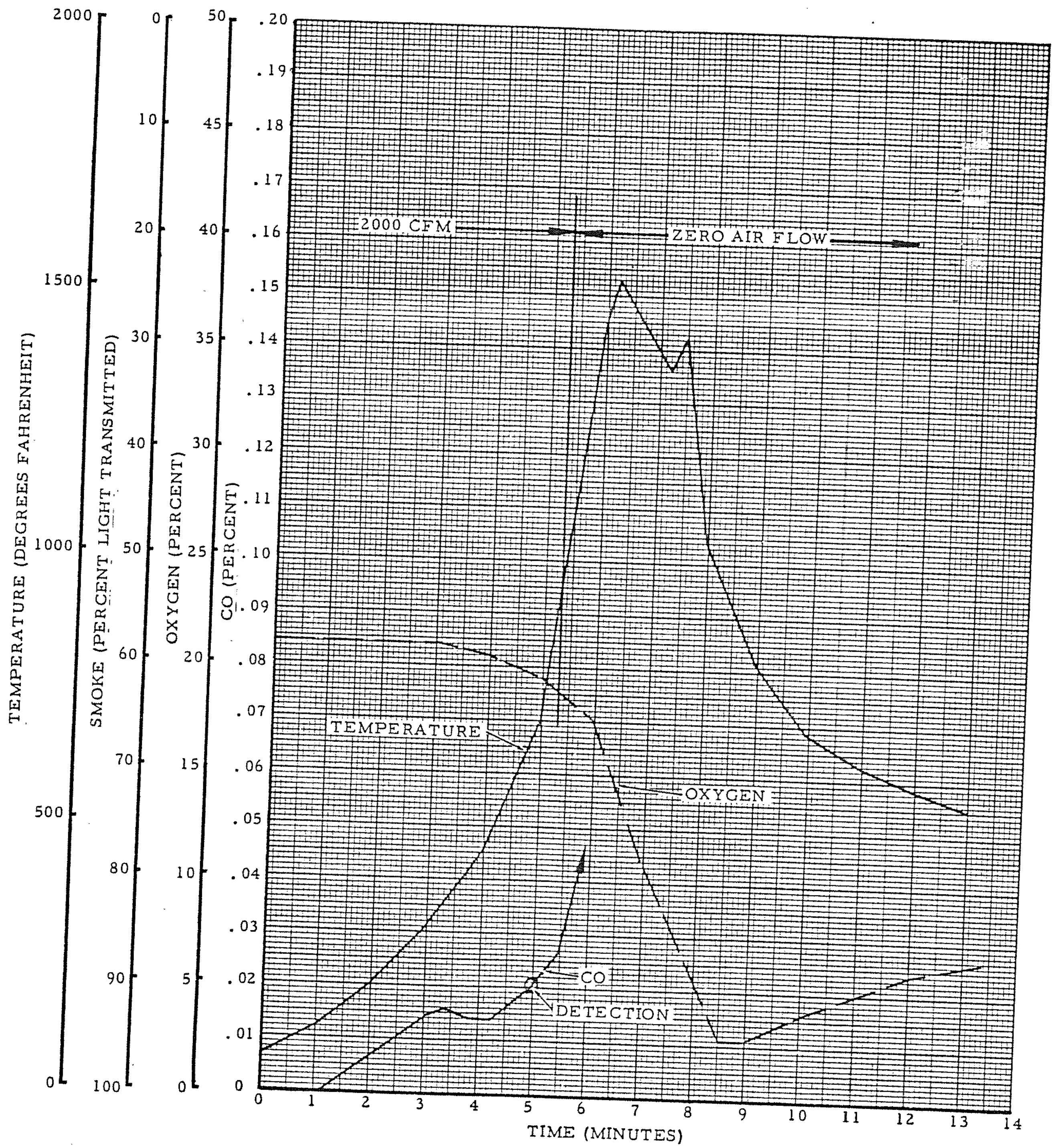

FIG. 11 TEMPERATURE, SMOKE, CARBON MONOXIDE AND OXYGEN RECORDINGS DURING CARGO COMPARTMENT FIRE. (RIGITRIM 6A COVERING 2% OF INTERIOR SURFACE)

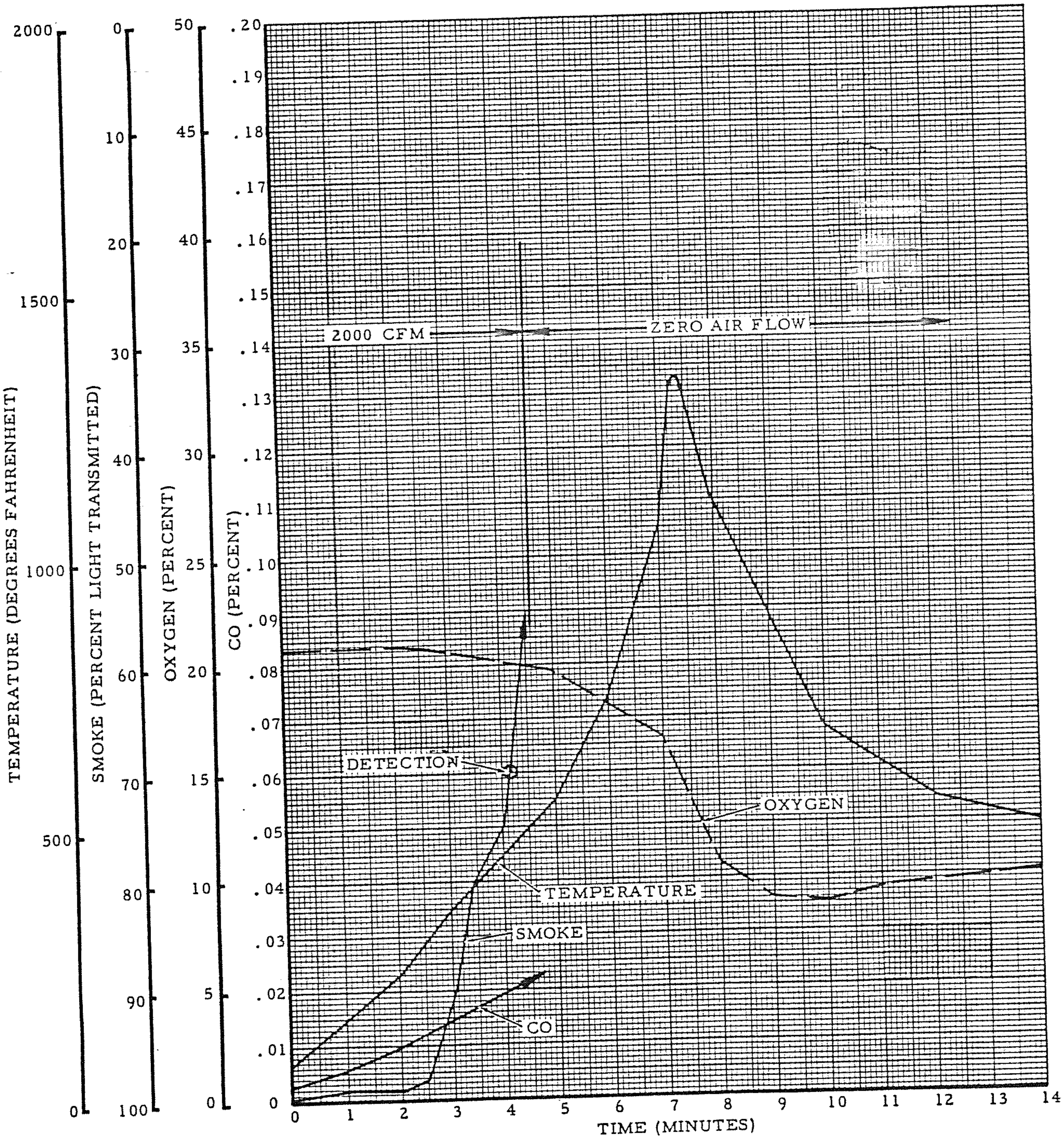

FIG. 12 TEMPERATURE, SMOKE, CARBON MONOXIDE AND OXYGEN RECORDINGS DURING CARGO COMPARTMENT FIRE. (HIGH AIR FLOW, NORMAL DETECTION)

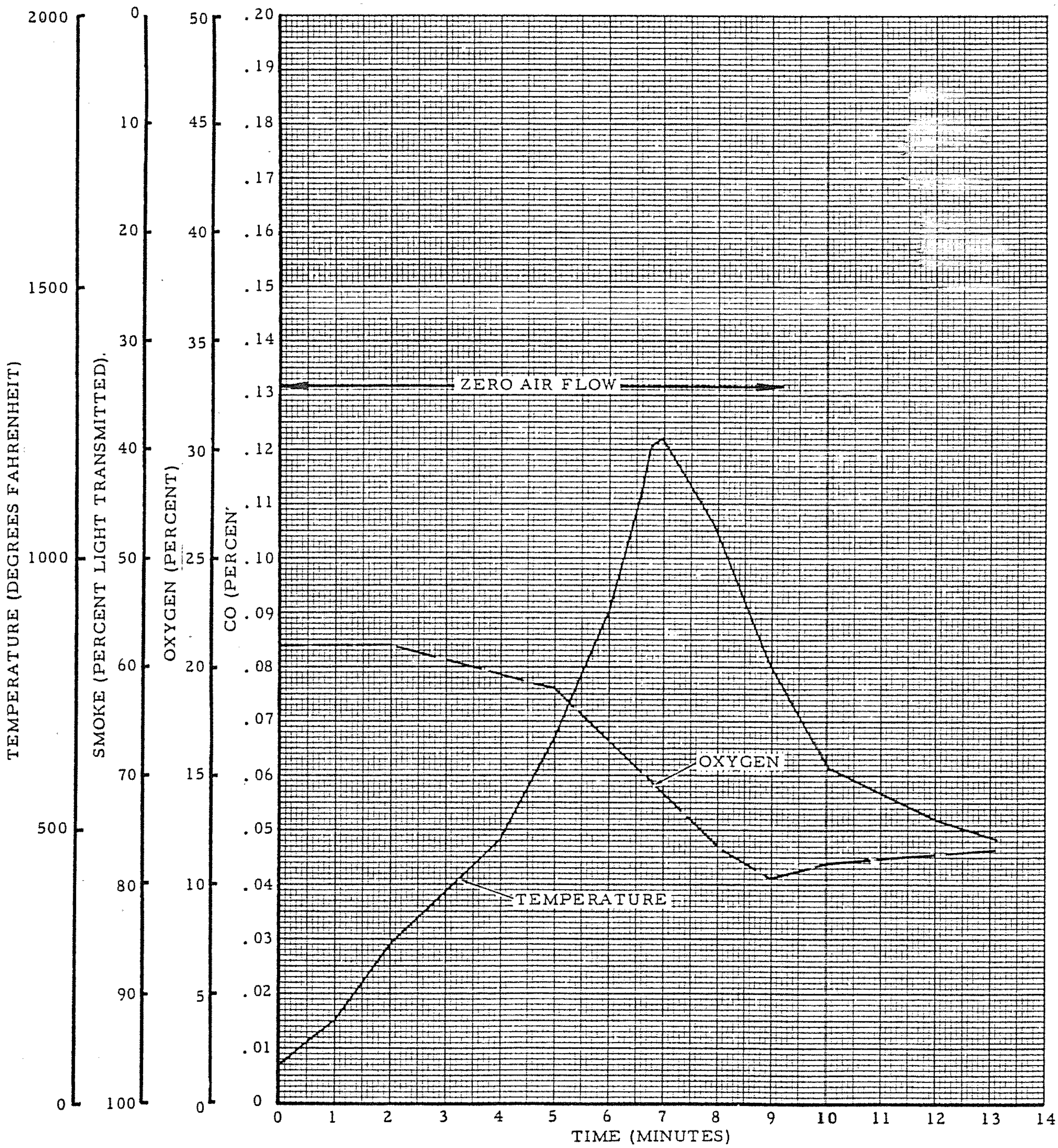

FIG. 13 TEMPERATURE, SMOKE, CARBON MONOXIDE AND OXYGEN RECORDINGS DURING CARGO COMPARTMENT FIRE. (NO AIR FLOW, DETECTION ASSUMED AT START)

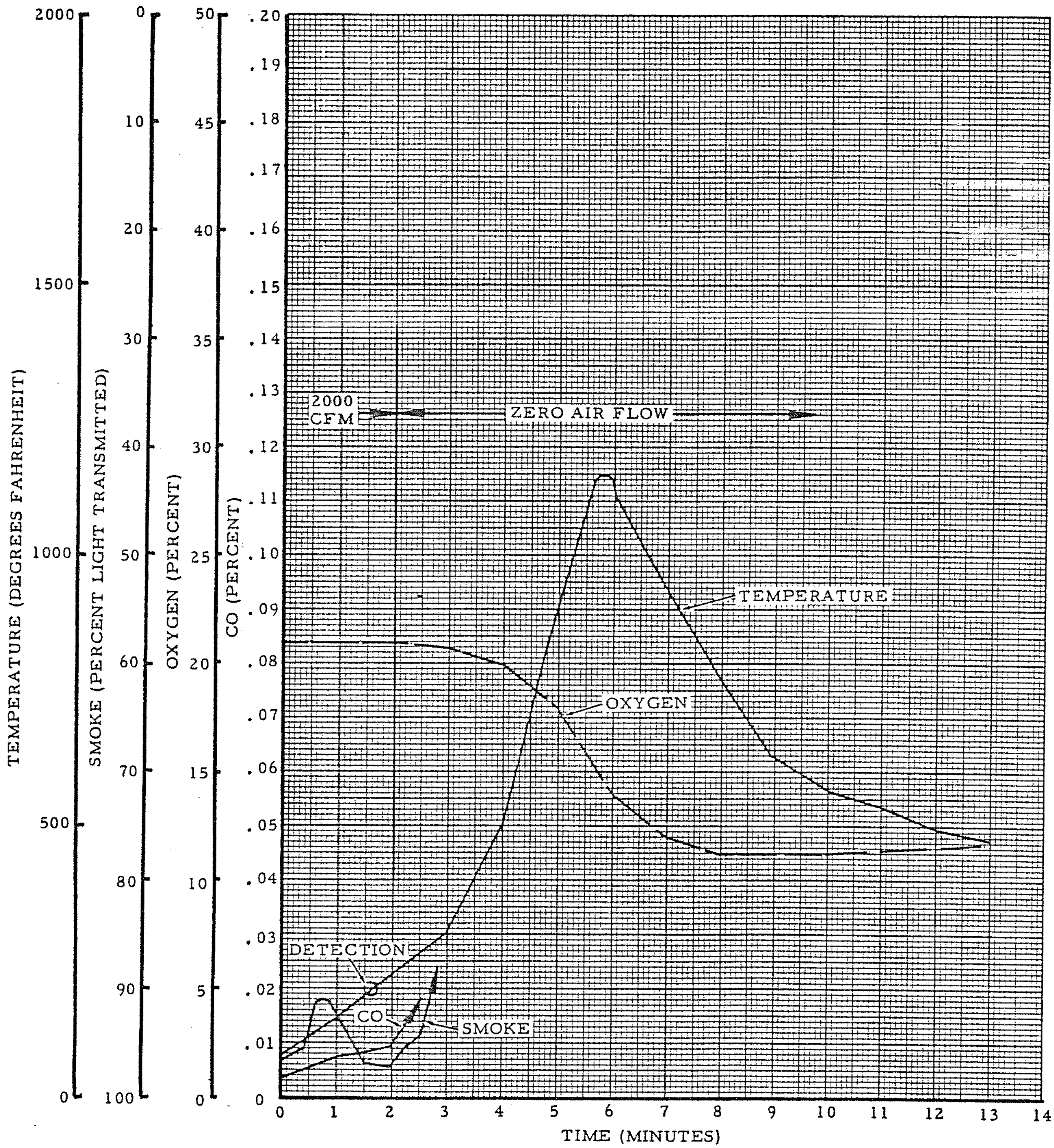

FIG. 14 TEMPERATURE, SMOKE, CARBONMONOXIDE AND OXYGEN RECORDINGS DURING CARGO COMPARTMENT FIRE. (HIGH AIR FLOW, EARLY DETECTION)

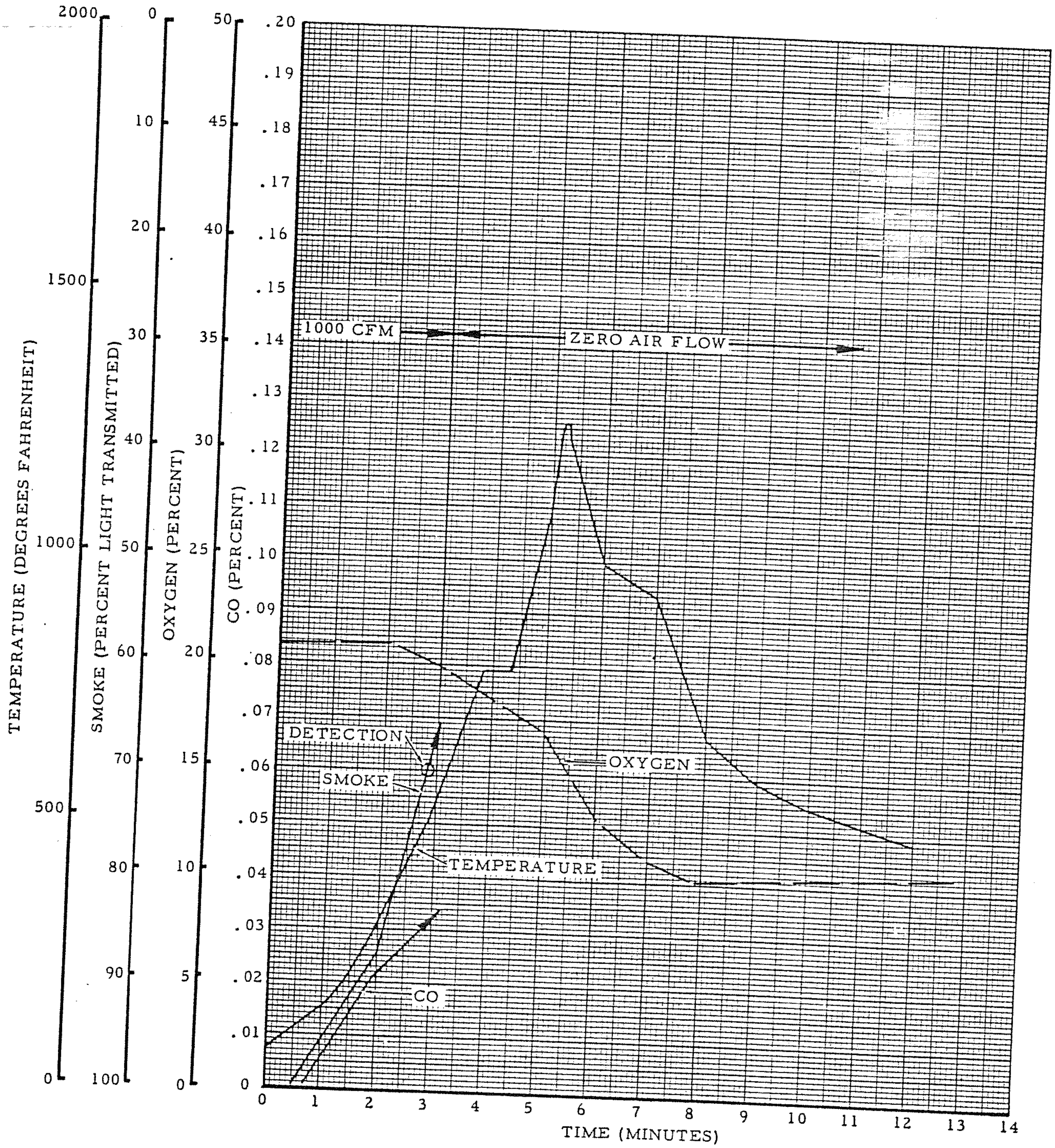

FIG. 15 TEMPERATURE, SMOKE, CARBON MONOXIDE AND OXYGEN RECORDINGS DURING CARGO COMPARTMENT FIRE. (LOW AIR FLOW, NORMAL DETECTION)

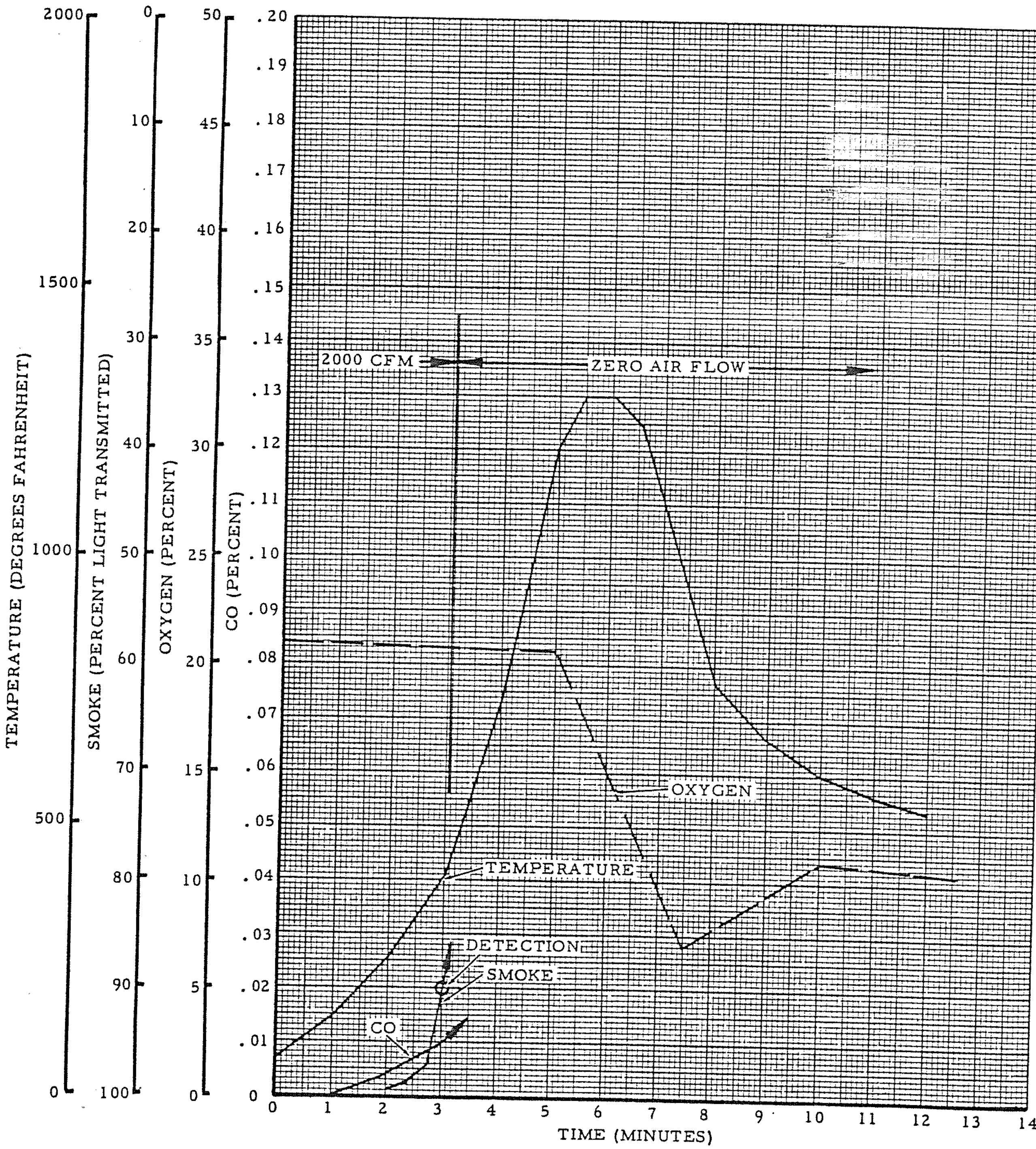

FIG. 16 TEMPERATURE, SMOKE, CARBON MONOXIDE AND OXYGEN RECORDINGS DURING CARGO COMPARTMENT FIRE. (FAST BURNING CARGO)

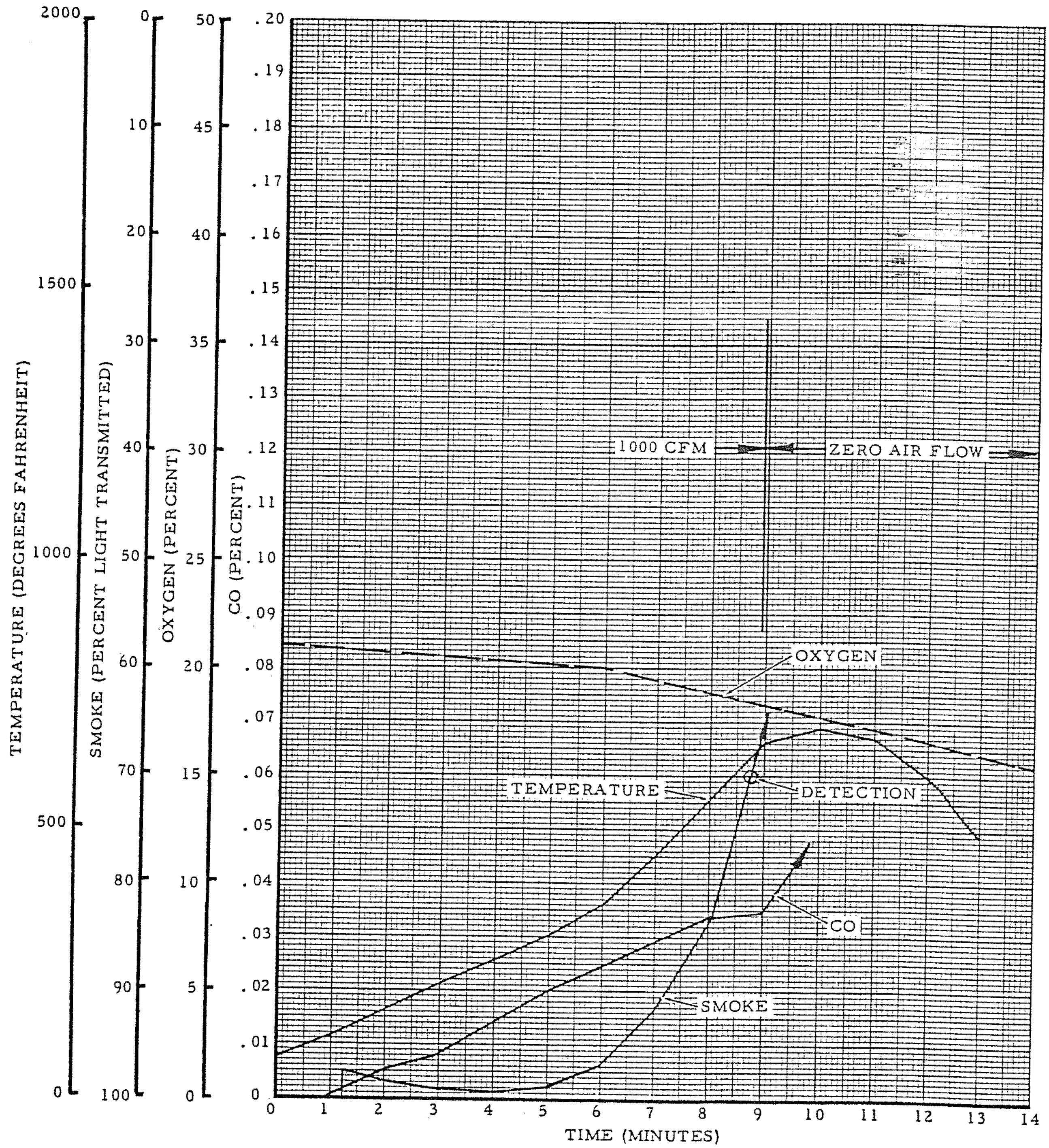

FIG. 17 TEMPERATURE, SMOKE, CARBON MONOXIDE AND OXYGEN RECORDINGS DURING CARGO COMPARTMENT FIRE. (SLOW BURNING CARGO)

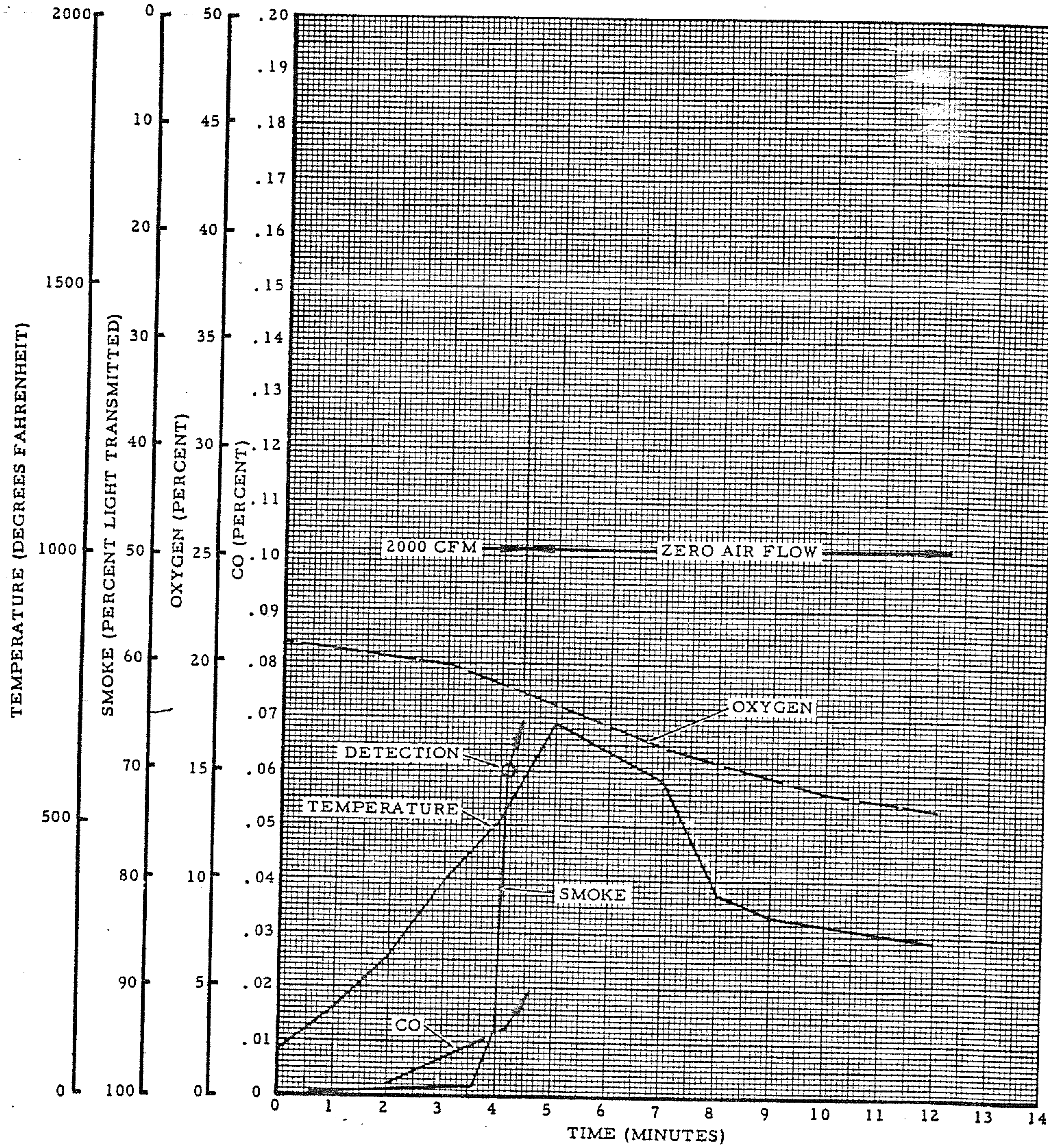

FIG. 18 TEMPERATURE, SMOKE, CARBON MONOXIDE AND OXYGEN RECORDINGS DURING CARGO COMPARTMENT FIRE. (COMPARTMENT LOADED WITH CARGO - 50% BY VOLUME HIGH AIR FLOW, NORMAL DETECTION)

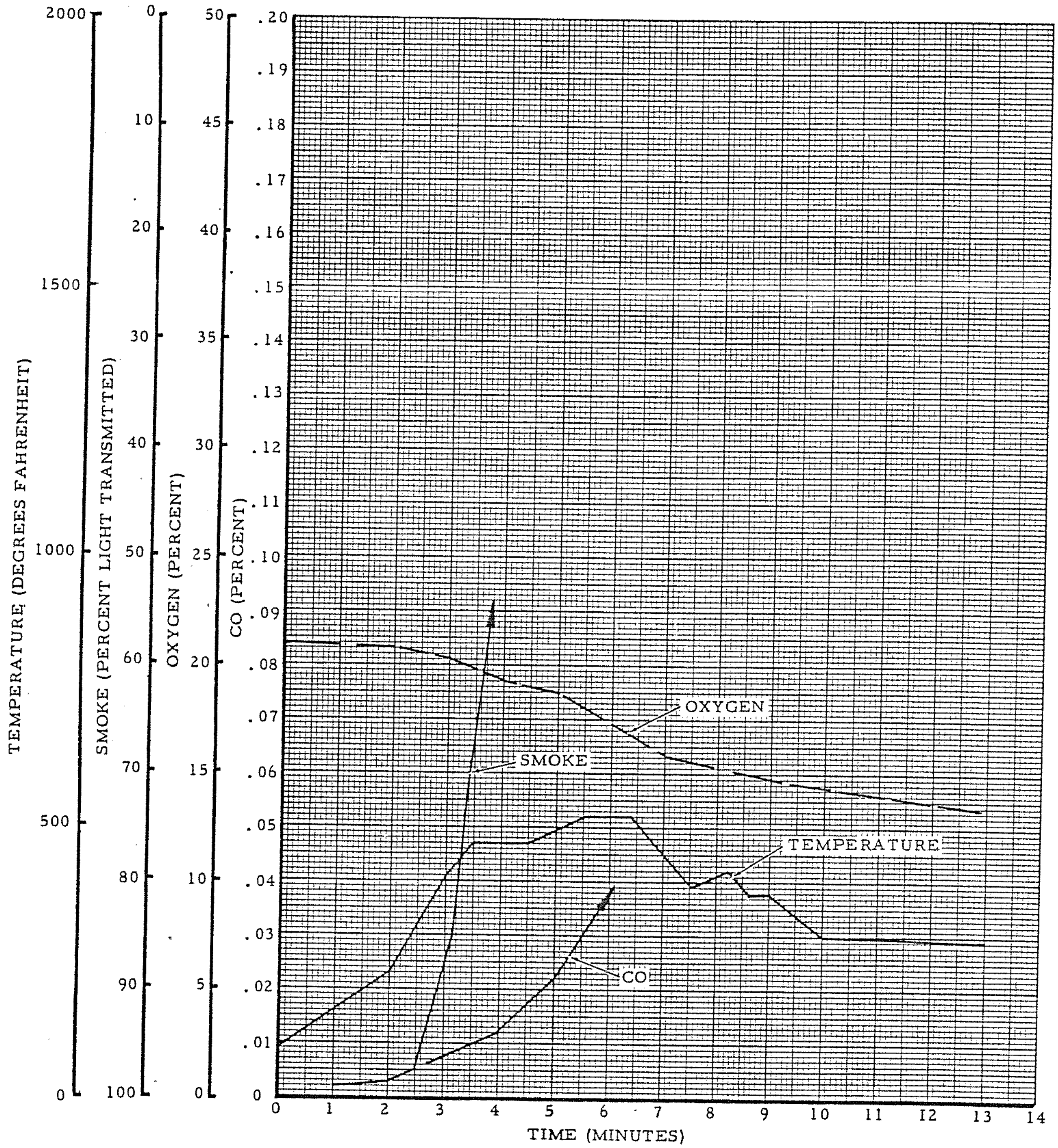

FIG. 19 TEMPERATURE, SMOKE, CARBON MONOXIDE AND OXYGEN RECORDINGS DURING CARGO COMPARTMENT FIRE. (COMPARTMENT LOADED WITH CARGO - 50% BY VOLUME NO AIR FLOW, DETECTION ASSUMED AT START)

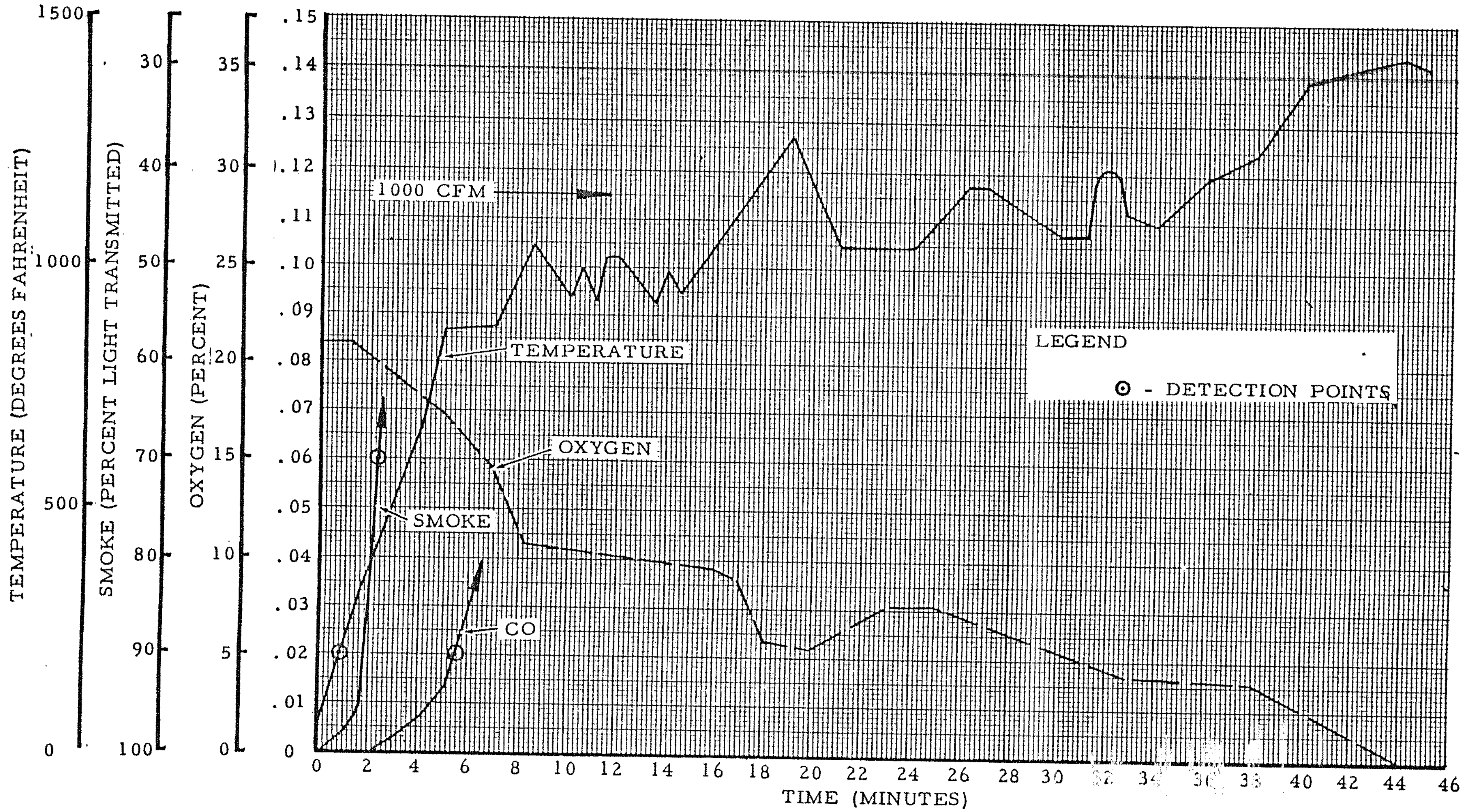

FIG. 20 TEMPERATURE, SMOKE, CARBON MONOXIDE AND OXYGEN RECORDINGS DURING CARGO COMPARTMENT FIRE. (COMPARTMENT LOADED WITH CARGO - 50% BY VOLUME AIR FLOW - 1000 CFM CONTINUOUS)

NOTES:

CROSS HATCHED AREAS EXTEND FROM MAXIMUM TO MINIMUM DETECTION TIMES.

AVERAGE TIMES FOR DETECTION ARE SHOWN BY HEAVY BARS THROUGH CROSS HATCHED AREAS.

THE NUMBER AT THE BASE OF EACH BAR INDICATES THE NUMBER OF TESTS FROM WHICH DATA WAS AVAILABLE.

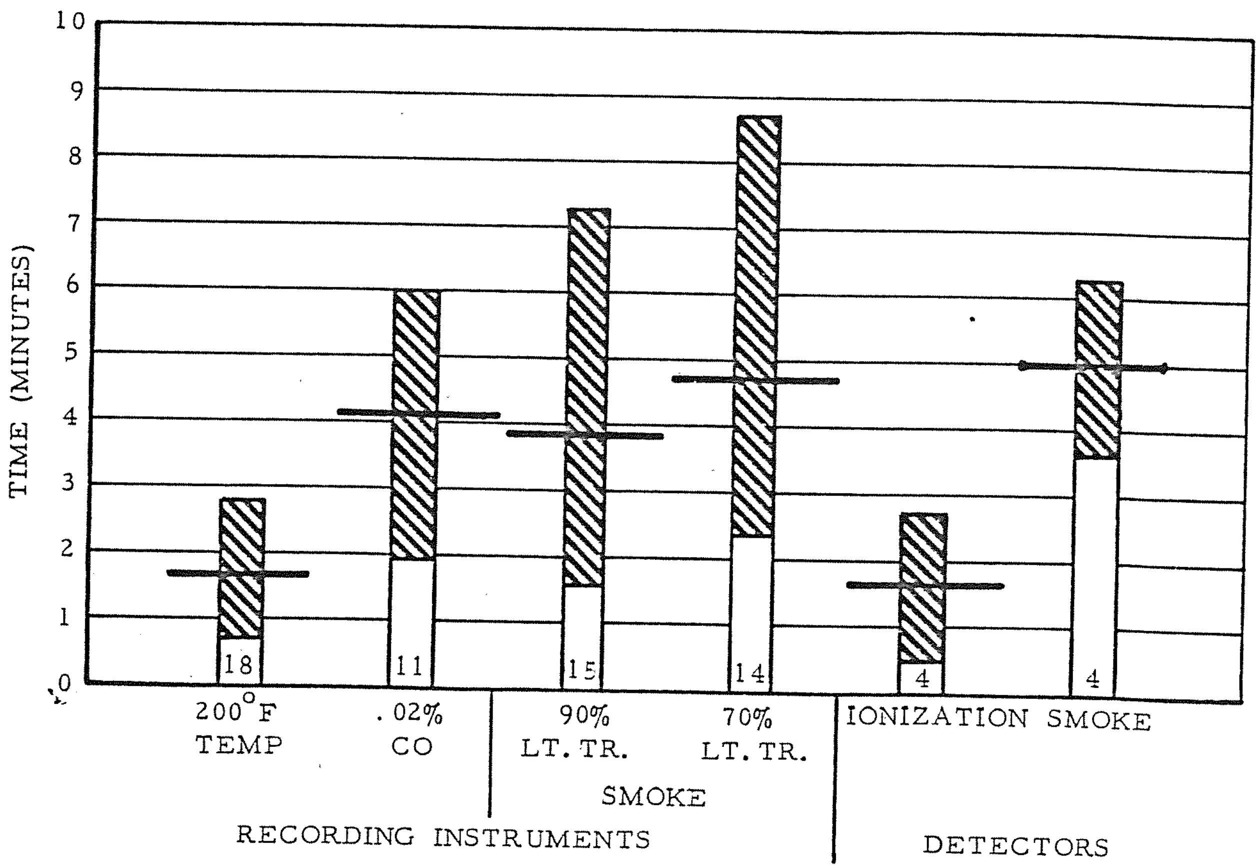

FIG. 21 RESULTS OF THE DETECTION TESTS - FULL-SCALE FIRES

TABLE I

CHEMICALLY GENERATED SMOKE DETECTION TEST RESULTS

1000 CFM Air Flow — DETECTION OCCURRED

Wt. of Smoke Generating Chem. (gms each)	50% Load Factor		Empty	
50	No	No	No	No
100	Yes	No	Yes	No
150	Yes	Yes	Yes	Yes
200	Yes	Yes	Yes	Yes

2000 CFM Air Flow — DETECTION OCCURRED

Wt. of Smoke Generating Chem. (gms each)	50% Load Factor		Empty	
50	No	No		
100	No	No	No	No
150	No	No	Yes	No
200	Yes	Yes	Yes	Yes
250	Yes	Yes	Yes	Yes

Notes:
1. Volume of compartment - 5000 cubic feet.
2. Wt. (gms) was the weight each of the two ingredients (lactose and potassium chlorate) used to generate the smoke.
3. Each result indicated is the result of one test.

TABLE II

RESULTS OF DETECTION TESTS

Run	Air Flow	Material		Type of Ignition	Time for Detection[1]			
					Temp.	CO	Light Trans.	
			Wt.				90%	70%
(No.)	(CFM)	(Type)	(lbs.)		(min.)	(min.)	(min.)	(min.)
58	2800	Excelsior	8	External	1.0	5.2		
59	"	"	"	"	1.5	5.0	2.6	
60	"	"	16	"	0.4	2.7	0.5	
61	"	"	20	Internal	4.2	0.8	1.8	15
62	"	"	"	"	6.1	0.1	1.0	
63	"	"	"	"	0.9	1.0	7.0	
65	"	Paper	"	"	8.5	14.0		
66	"	"	16	External	0.4	5.7	6.7	
67	"	Rags	8	"	1.5			
68	"	"	16	"	1.5	4.2		
69	"	"	20	Internal	2.7	6.3	2.7	
70	"	"	"	"	1.5	2.6	1.5	
71	"	"	"	"	2.1	7.0	2.3	
72	"	"	"	"	3.6	7.0		
73	"	"	"	"	2.3	6.0	3.0	
74	"	Excelsior	16	External	1.0	2.7	1.0	2.4
76	"	"	"	"	1.0	3.0	1.0	2.0
77	1000	"	8	"	1.0	3.0	1.0	
78	"	"	8	"	0.7	3.0	0.7	
99	2000	"	8	"	0.8	8.0	0.8	
100	1000	"	8	"	0.7	2.8	0.7	
101	2000	"	16	"	0.4	2.6	0.4	1.0
102	1000	"	"	"	0.4	2.1	0.7	1.0
103	2000	"	"	Internal	3.8	9.0		
104	1000	"	"	"	1.3	4.4	4.5	

NOTE: (1) The time for detection is given in minutes required for the temperature sensor to reach 200°F, the CO meter to indicate 0.02% and the smoke meter to indicate 90% and 70% light transmission, respectively.