Report No. FAA-RD-70-42

CHARACTERISTICS OF FIRE IN LARGE CARGO AIRCRAFT (PHASE II)

Julius J. Gassmann
National Aviation Facilities Experimental Center
Atlantic City, New Jersey 08405

SEPTEMBER 1970

FINAL REPORT

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Prepared for

FEDERAL AVIATION ADMINISTRATION

Systems Research & Development Service

Washington D. C., 20590

FSS 000479 R

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1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-RD-70-42		

4. Title and Subtitle	5. Report Date
CHARACTERISTICS OF FIRE IN LARGE CARGO AIRCRAFT (PHASE II)	September 1970
	6. Performing Organization Code
7. Author(s) JULIUS J. GASSMANN	8. Performing Organization Report No. FAA-NA-70-16
9. Performing Organization Name and Address National Aviation Facilities Experimental Center Atlantic City, New Jersey 08405	10. Work Unit No.
	11. Contract or Grant No. Project No. 530-001-01X
	13. Type of Report and Period Covered Final Report 1967 - 1970
12. Sponsoring Agency Name and Address FEDERAL AVIATION ADMINISTRATION Systems Research & Development Service Washington, D.C. 20590	
	14. Sponsoring Agency Code

15. Supplementary Notes

None

16. Abstract

The degree to which fire in large cargo compartments may be suppressed by shutoff of ventilation was investigated. Results of the tests indicated that this action alone would not protect the fuselage of large cargo aircraft from severe fire damage.

Peak air temperatures occurring during fire increased significantly with increasing compartment size from 1,000 to 2,000 cubic feet and were similar with further increase in size to 5,000 cubic feet. Temperatures in the order of 1,800°F were reached in these larger compartments.

An increase in percent loading resulted in a more severe fire condition for compartment volumes of all the sizes used in this program.

A single cargo fire test indicated the use of bromotrifluoromethane at the time of detection and ventilation shutoff may be an effective means of greatly reducing peak temperatures and pressures and providing a longer control time.

17. Key Words	18. Distribution Statement
Aircraft Fires Aircraft Cabins Fire Safety Transport Planes	Availability is unlimited. Document may be released to the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151, for sale to the public.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	21	$3.00

Form DOT F 1700.7 (8-69)

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INTRODUCTION

Purpose

The purpose of this project was to determine the relationship of compartment size, load factor, and air leakage rate to the degree of fire resistance required for cargo compartment interior materials when fires are controlled by oxygen starvation (ventilation shutoff) only.

Background

The current requirements as expressed in the Federal Aviation Regulations (FAR), Parts 25.855 and 25.857, were formulated in part from information available as a result of baggage compartment fire tests conducted at the Civil Aeronautics Administration (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 cubic feet.

Since the introduction of all-cargo air transports, compartment volumes as great as 8,000 cubic feet have been in use and the same regulations applied to these large compartments which are 30 times as large as those used in the previous investigation.

In addition to the above-mentioned CAA tests, fire investigations were made by-

1. American Airlines, Inc., on a simulated DC-6 all-cargo configuration at Norfolk, Virginia, 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 airflow (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.

2. The Federal Aviation Agency (FAA) on a 41-foot-long section of a C-130 cargo aircraft at the National Aviation Facilities Experimental Center (NAFEC), Atlantic City, New Jersey, and reported in Reference 3. These tests indicated that in large cargo compartments involving currently used packaging materials, fires can readily reach damaging proportions even though detection and airflow shutoff occur immediately.

Description of Test Article and Equipment: The test article used in this project 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.

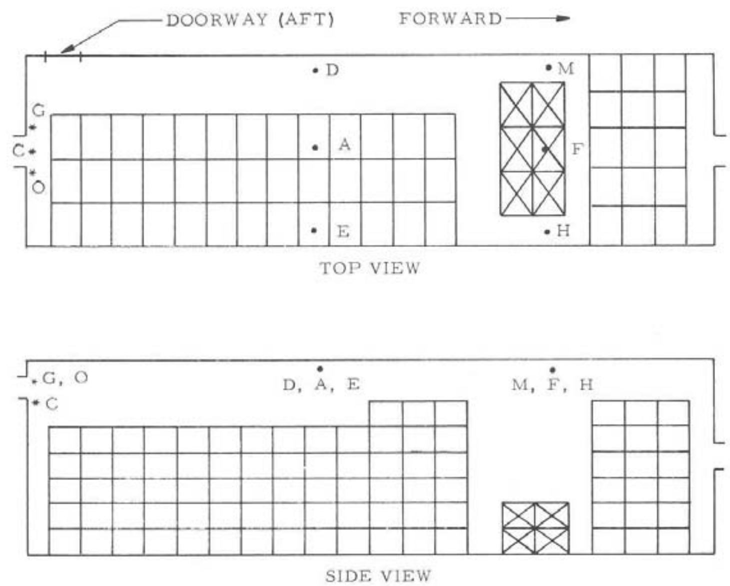
Two observation windows, each 1-foot square, were provided in each of the bulkheads. These were located just above the floor line. An air inlet, 14 inches in diameter, was located in the forward bulkhead 5 feet above the floor, and a baffle was provided to reduce inlet air velocities and localized effects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

The same compartment insulation used in a previous test program was used in this program. The insulation was quite inert since it had been exposed to a large number of relatively severe fires during the previous program. The compartment was instrumented with chromel-alumel thermocouples for measuring air temperatures at locations shown in Figure 1.

Ignition of the fire load was effected by an electric heating element. The element used was a Chromalox Electric Barbeque Lighter, Catalog No. CL-5, 500 watts, 120-volt alternating current service.

Instrumentation: Air temperatures at nine locations were recorded on five Honeywell Electronik strip chart duplex recorders. These were 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 a smoke meter. The presence of smoke was recorded on the strip chart in terms of percent light transmission per foot, 100 percent being the reading for clear air.

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 percent (by volume) and recorded the information on a Honeywell Electronik strip chart recorder.



LEGEND

- * OUTLET THERMOCOUPLE LOCATIONS.
- • CEILING THERMOCOUPLE LOCATIONS.
- ☐ LOCATION OF EACH OF THE 292 CARTONS REPRESENTING THE CARGO LOAD.
- ☒ LOCATION OF EACH OF THE 12 CARTONS REPRESENTING THE FIRE LOAD.

NOTE:

THE TOTAL CARGO, INCLUDING THE FIRE LOAD, WAS 47.2% OF THE COMPARTMENT VOLUME AND WAS CONSIDERED A NOMINAL 50% LOAD.

FIG. 1 PLAN VIEW OF THE 5000-CUBIC-FOOT COMPARTMENT

The airflow through the compartment was determined by use of calibrated orifices. These were introduced into the 14-inch-diameter air inlet duct between the straightener vanes and the compartment itself. A suitable slide damper arrangement was incorporated in order to facilitate rapid removal and replacement of the calibrated orifices as the test conditions demanded.

DISCUSSION

Procedure

Throughout this program, standard pieces of cargo were used both for the fire load and for the cargo load. This standard parcel consisted of a corrugated cardboard carton measuring 28 by 24 by 20 inches, weighing 4 pounds and filled with 16 pounds of excelsior. Thus, each parcel weighed a total of 20 pounds. Figure 2 shows a stack of 144 cargo parcels and one open parcel on the scale showing its contents. This stack represents about one-half the load used in the C-130 fuselage compartment when the 50-percent load tests were conducted.

In order to avoid inconsistencies in test results due to high humidity, as was discussed in Reference 3, the conduct of tests during or immediately following a damp spell was avoided. To assure that consistently dry fire loads were used in the tests, the moisture content of the fire load material was measured and, in general, tests were conducted only when the relative humidity of the excelsior was 20 percent or less as measured with a moisture indicator manufactured by Testing Machines, Inc., Model TMI 53-17, and sword-type sensor Model BRD 54672.

Tests were conducted in the 5,000-cubic-foot C-130 fuselage compartment using a loading of 2 percent by volume (nearly empty) and a loading of 50 percent (for all practical purposes, nearly full). In the 5,000-cubic-foot configuration, tests were conducted to determine the effect of various rates of leakage during the airflow shutoff period. Also, one feasibility test on extinguishment or fire control was conducted by introducing 100 pounds of bromotrifluoromethane.

In order to determine the effect of compartment size on the severity of fire and the amount of control afforded by airflow shutoff, the C-130 compartment was subdivided into compartments having total volumes of 2,000, 1,000, and 500 cubic feet. Tests were conducted in each of these compartments using a 2-percent and a 50-percent volumetric loading.

The loading of the 5,000-cubic-foot compartment is shown in Figure 1. For the 2-percent loading, only the fire load was used. This consisted of 12 standard parcels. When the 50-percent

FIG. 2 TYPICAL CARGO AND FIRE LOAD PARCELS

configuration was used, the same fire load was used and, in addition, 292 cargo parcels were used and arranged as shown in the figure. When tests were conducted in the 2,000-cubic-foot compartment, the fire load consisted of six parcels, and the additional cargo, when used, consisted of 120 standard parcels. The following table shows the number of standard parcels used in all the test configurations. The line marked as "2 percent" is only approximate and indicates the number of parcels used in the fire load. The line marked as "50 percent" indicates the total number of parcels used including those in the fire load.

LOADING TABLE

Volume Loading	Number of Parcels			
	5,000 cubic feet	2,000 cubic feet	1,000 cubic feet	500 cubic feet
2% Load	12	6	6	2
50% Load	304	126	63	31

Throughout this program, ignition was achieved by placing an electric barbecue lighter in the bottom center standard parcel of the fire load. Ignition (visible flame external to the cardboard container) usually occurred about 3 minutes after voltage was applied to the lighter. Twenty seconds after ignition, application of the voltage to the igniter was discontinued. During the ignition period and until detection occurred, airflow through the compartment was maintained at about one air change every 2 minutes. For example, 1,000 cubic feet per minute were provided for the 2,000-cubic-foot compartment whether the cargo load was 2 percent or 50 percent. At the time of detection (when 300°F was recorded by any one of the thermocouples), the airflow was shut off to near zero. The only exception was during the 5,000-cubic-foot compartment tests where the effect of greater than zero leakage was determined.

Although temperatures at nine different locations were recorded, only the highest temperature trace was used in evaluating the data, because the lower temperatures were of less significance. The convection currents due to the heat generated by the fires were more effective than the airflow through the compartment, so the highest temperature, even before detection and airflow shutoff, invariably occurred at the thermocouple located above the fire location rather than downstream or at the air outlet. Therefore, only the highest temperature recorded was used to determine detection, fire severity and for plotting the time-temperature curves.

SUMMARY OF RESULTS

As mentioned in the description of the test article, the insulating materials on the interior of the fuselage compartment were inert as a result of the many fire tests conducted in the previous program. Thus, the insulation in use throughout this program served only as a thermal protection to the structure of the compartment. Results of tests in the previous program indicated that interior insulating materials, when exposed to a cargo fire, generally produced combustible volatiles that resulted in a flash fire. Results of the present test program indicated that a flash fire can readily result from the cargo itself that is many times more severe, in terms of resulting pressure and duration as well as in temperature, than the flash fire produced from the insulating material. Thus, using the inert insulation throughout this program had little effect on the overall fire severity observed and at the same time, eliminated the slight variable that could result from new insulation.

Tests conducted in every configuration were made using a cargo loading of approximately 2 percent by volume and a cargo loading of 50 percent by volume. The 2-percent loading was called the "fire load," and such tests were conducted in order to establish the uniformity of fire starts through the point of detection and initiation of control. They also provided information on what to expect in a compartment loaded with only a small amount of combustible cargo, the remaining space being of a nature not affected by nor contributing to a fire. The 50-percent loading included the same type fire load as used in the 2-percent-loaded tests, and these tests were conducted in an identical manner. The 50-percent load tests represented typical compartments loaded to the maximum practical capacity with commonly used combustible cargo containers. These tests indicated that the 2-percent loading resulted in a slower temperature buildup, particularly after detection and airflow shutoff. Furthermore, the maximum temperature reached was somewhat lower, the duration somewhat longer, but no flash fires were evident. The 50-percent load tests usually resulted in a flash fire, sometimes quite violent, shortly after airflow shutoff. This generally produced higher temperatures and higher pressures with large quantities of smoke and fire being pushed out of the compartment outlets at audible velocities and resulted in a shorter burning time than the less violent fires produced by the 2-percent load configurations.

In the 5,000-cubic-foot, 2-percent load configuration, tests were conducted in which the airflow at the time of detection was reduced from 2,000 cubic feet per minute to values of 125, 98, 75, and 45 cubic feet per minute in addition to zero airflow. These tests indicated that the 75-cubic-foot-per-minute airflow was on the borderline of producing results the same as those produced when flow was reduced to zero airflow; that is, the fire did not recover into visible flaming after the initial flareup. Therefore, in the 50-percent load configuration, results were obtained under conditions of a leakage rate of 75 cubic feet per minute and compared with results of tests in which zero leakage was effected at detection. The time-temperature curves obtained during these two conditions are shown in Figure 3. There is little, if any, significant difference between two curves. Temperatures were recorded for 1 hour after ignition. By that time, the ambient temperature within the compartment had leveled off at 300°F in the zero airflow test and to 400°F in the 75-cubic-foot-per-minute airflow test. This difference is small considering the fact that in both tests temperatures of over 1,500°F were reached during the initial flareup.

Figure 4 shows temperatures attained as a result of fire in various size compartments with a 50-percent cargo loading. In each test, the fire was started under normal (1/2 volume air changes per minute) airflow conditions. At the time of detection (first indication of the presence of a 300°F ambient temperature), the airflow was shut off. These results indicate that the severities of the resulting fires during the initial flareups are quite similar in the cases of the 5,000- and 2,000-cubic-foot compartments. The results further indicated that the severity of the resulting fire was greatly reduced when the compartment size was 1,000 cubic feet. The maximum temperatures recorded were less than half those in the larger compartment tests.

When the compartment size was further reduced to 500 cubic feet, the fire resulted in a maximum ambient temperature of about 500°F. These temperatures diminished slowly for half an hour at which time the fire recovered and flared up more violently than the original flareup, usually reaching temperatures of over 1,000°F as shown in Figure 5. Thus, even in cargo compartments as small as 500 cubic feet, a dangerous condition is likely to exist unless additional control measures are taken.

In view of this potentially dangerous condition that exists when cargo fires are controlled by airflow shutoff, a feasibility test was conducted in which the fire was controlled by releasing an extinguishant into the compartment at the time of airflow shutoff. Test conditions were otherwise identical to the 5,000-cubic-foot compartment, 50-percent load tests. Results of this extinguishing test using 100 pounds of bromotrifluoromethane as the agent are shown in Figure 6. This represented a minimum agent concentration of 5 percent by volume for a nearly empty compartment. From these curves, it can be seen that the temperature rise was halted at the time of agent discharge, never reaching 400°F. This test was continued and observed for 2 hours after the start of the fire and at no time did the maximum temperature reach that of the original fire which was 350°F. At the end of the 2-hour period, the temperatures measured within the compartment had leveled off at 220°F. These results indicate more tolerable conditions and the method appears to be sufficiently effective in controlling this type fire to warrant further investigation.

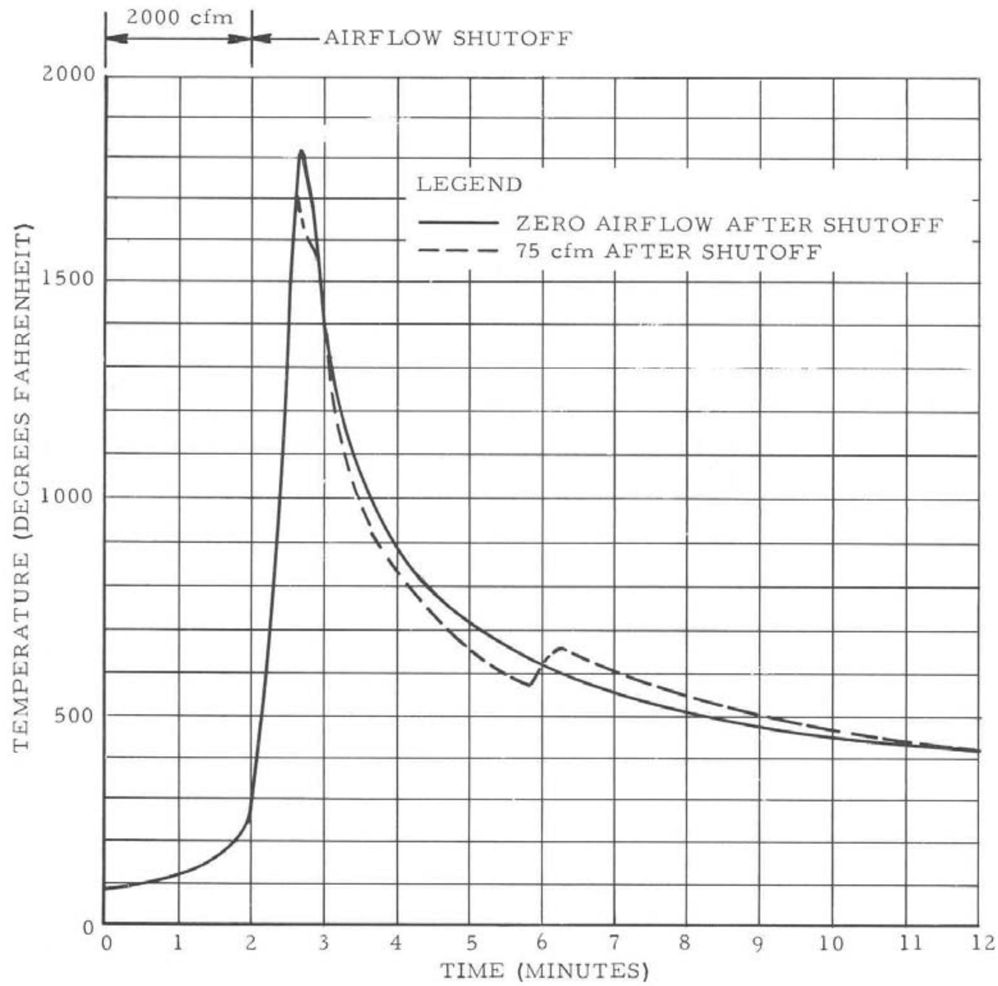


FIG. 3 MAXIMUM AMBIENT TEMPERATURE HISTORY DURING FIRE IN 5000-CUBIC-FOOT COMPARTMENT (FOR AIRFLOW REDUCTION FROM 2000 CUBIC FEET PER MINUTE TO 0 AND TO 75 CUBIC FEET PER MINUTE AT TIME OF DETECTION)

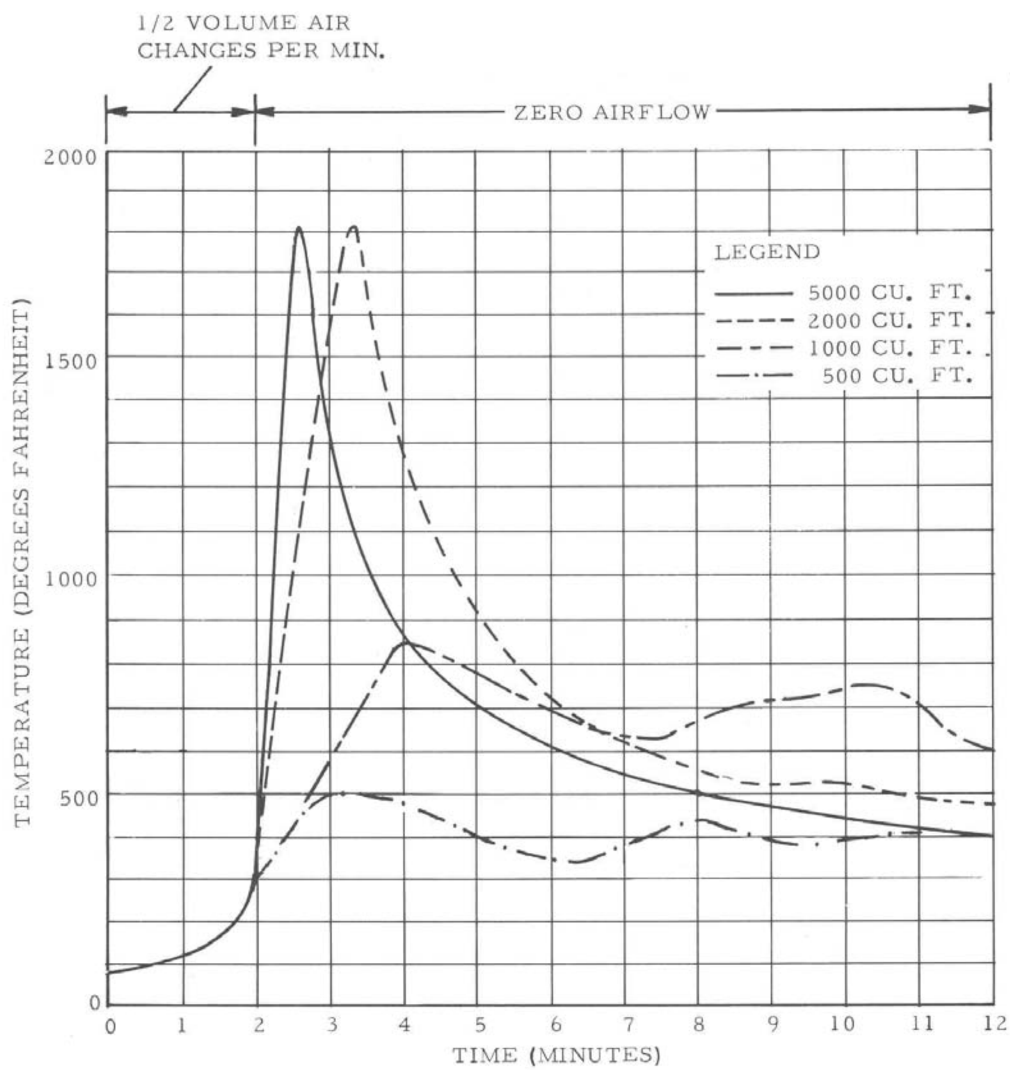


FIG. 4 TIME-TEMPERATURE CURVES SHOWING THE EFFECT OF COMPARTMENT SIZE ON FIRE SEVERITY WITH 50-PERCENT LOAD FACTOR

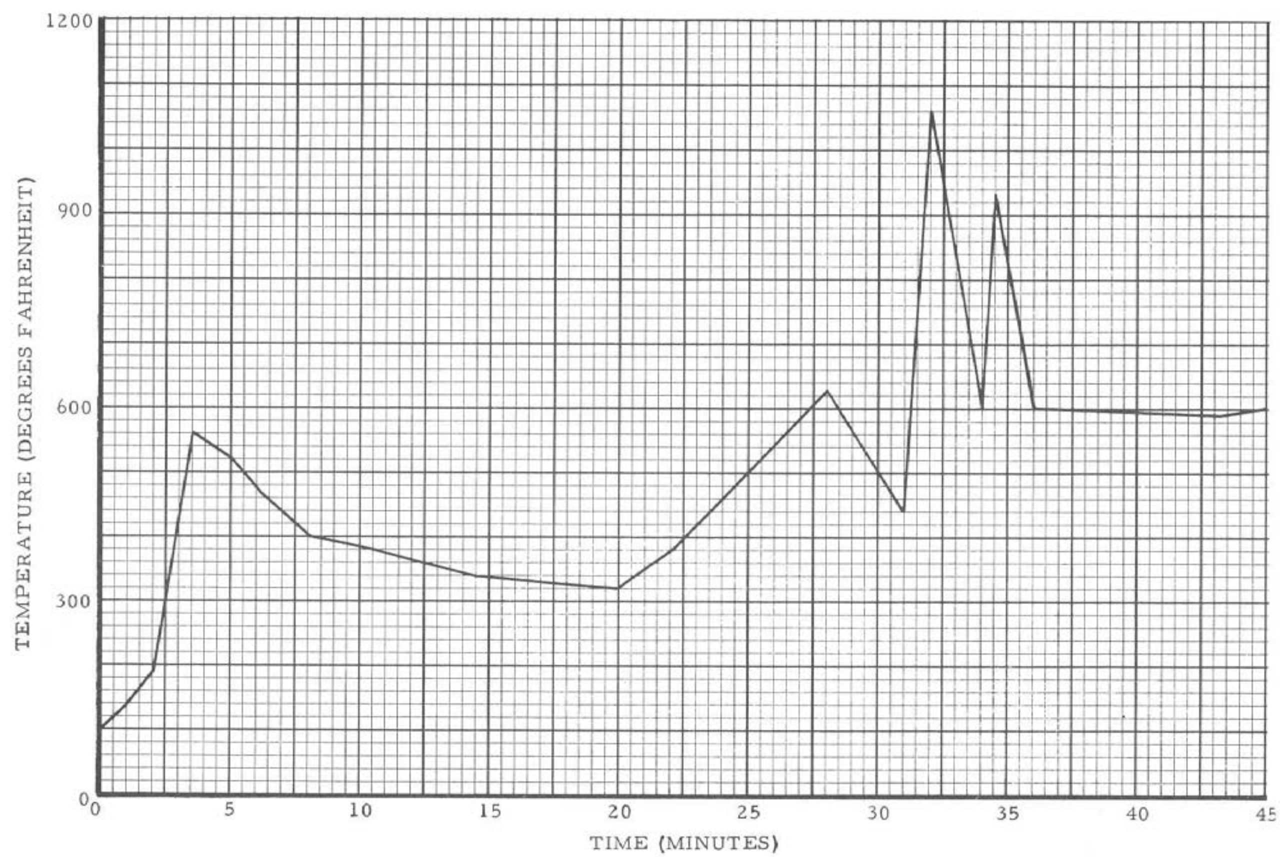


FIG. 5 TIME - TEMPERATURE CURVE OF A TYPICAL 500-CUBIC-FOOT CARGO COMPARTMENT FIRE

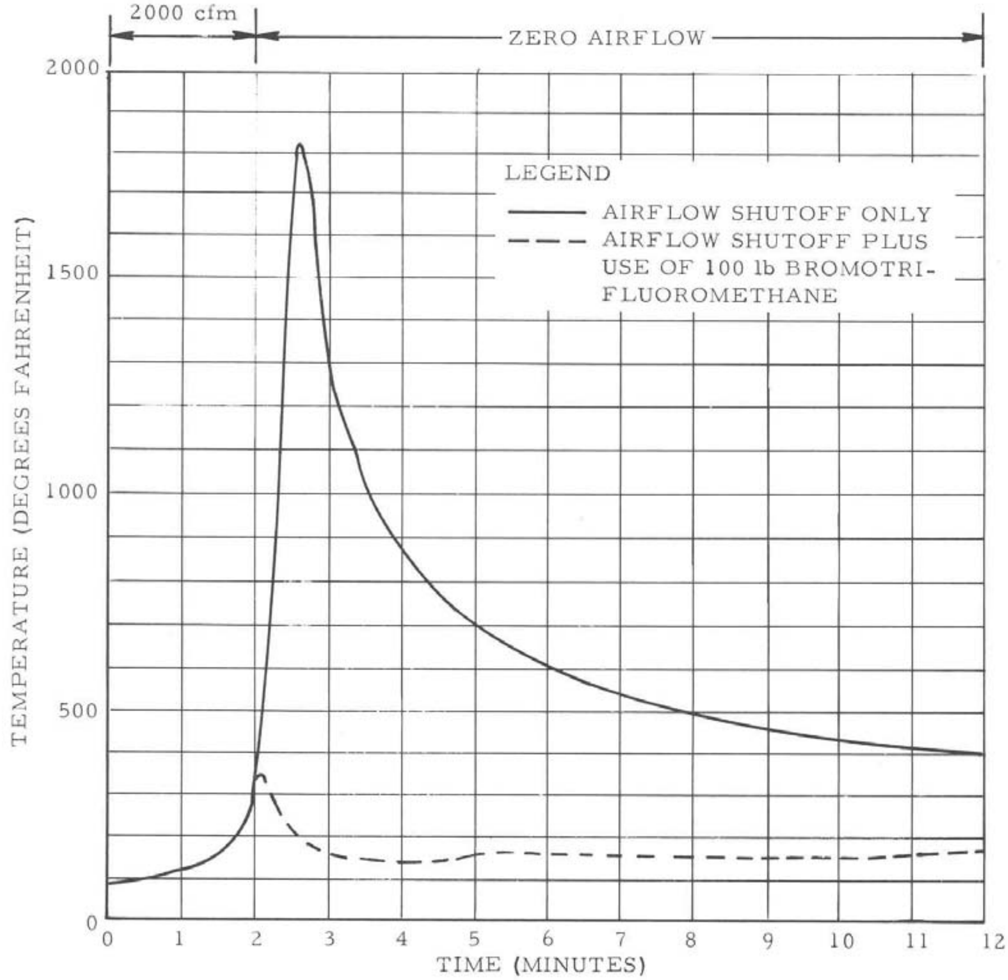


FIG. 6 TIME - TEMPERATURE CURVES SHOWING THE EFFECT OF AN EXTINGUISHANT IN CONTROLLING FIRES IN A 5000-CUBIC-FOOT COMPARTMENT

CONCLUSIONS

Based on the results of the tests conducted, it is concluded that--

1. If fire occurs in a cargo compartment of large volume and the ventilating air is shut off at the time of detection, the resulting ambient temperatures and pressures may be expected to be higher than those that would occur in class "D" size compartments.

2. The effect of increasing the cargo load factor on fire characteristics is to-- (1) increase the probability of a flash fire occurring, (2) increase the rate of ambient temperature rise, and (3) increase the maximum ambient temperature. Fires from a full cargo load (50-percent load factor) will produce flash fire, possibly of high severity shortly after ventilation shutoff. Fires from a small (2-percent load factor) cargo load produce a gradual increase in temperature, and the occurrence of flash fire is not probable, except from the volatiles given off by the interior materials during the cargo fire.

3. The amount of air leakage subsequent to detection of a cargo fire and ventilation shutoff is critical in keeping a cargo fire under control in compartments as large as 5,000 feet. Leakage rates of more than one air change per hour (75 cubic feet per minute) will not prevent flames from recurring within 30 minutes from ignition in this size compartment.

4. Fire in large loaded cargo compartments may be expected to result in a flash fire shortly after detection and the shutoff of ventilation air. The high momentary temperatures and overpressure and the sudden depletion of oxygen resulting from this occurrence provide basic criteria for fire protection design.

5. The use of bromotrifluoromethane extinguishing agent released at the time of detection of a cargo fire can prevent the occurrence of flash fire, greatly reduce the maximum temperatures, and provide significant improvement in fire control.

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ACKNOWLEDGEMENTS

The author wishes to acknowledge the valuable contributions made by the E. I. DuPont Company in providing the extinguishing agent and the agent-handling equipment, and to Pyrotector Incorporated for providing the aspiration-type nozzles which they developed. These nozzles were used in dispensing and distributing the extinguishant.