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PRELIMINARY WIDE BODY (C-133) CABIN HAZARD MEASUREMENTS DURING A POSTCRASH FUEL FIRE

by

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ABSTRACT

This report describes a C-133 wide body cabin fire test facility and preliminary data obtained under simulated postcrash fuel fire conditions. The major goal of attaining repeatable cabin hazard measurements resulting from an external fuel fire was partially attained but requires additional work. From the tests conducted thus far, it is concluded that heat, smoke, and toxic gases are significantly stratified; heat and smoke are greater hazards than carbon monoxide; and oxygen is not significantly depleted. These preliminary findings are for an unfurnished, ventilated cabin with an external fuel fire adjacent to a door opening.

INTRODUCTION

Purpose

The purpose of this report is to describe preliminary tests and data obtained in a C-133 aircraft configured to resemble a wide-body cabin. The tests were performed with an external fuel fire adjacent to a type A entry door opening and without interior materials installed inside the cabin. The work was performed under NPD 18-471, "Aircraft Systems Fire Safety."

Background

The interior of a transport aircraft cabin is lined and furnished with a wide variety and large quantity of synthetic (plastic) and natural organic materials. Selection of these materials is primarily based on weight, cost, durability, mechanical strength, aesthetics, and fire safety. Typically, today's modern wide-body transport is furnished with a wool pile carpet, polyurethane seat cushions, blended wool/nylon seat covers, and a composite structure for the sidewall, stowage bin and ceiling surfaces; composed of a synthetic, paper-like (Nomex) honeycomb core, fiberglass sheetfacings, and a thin plastic film finish. Panel fabrication is difficult and expensive, because of special processing of the highly thermal-resistant plastics and because the panels must be handmade to fit fuselage contours and meet customer (airline) design requirements. For example, the cost of the nonmetallic materials inside a B-747 cabin is estimated to be in excess of 1.5 million dollars.

Any enclosure constructed of organic materials will burn when subjected to a fire of adequate intensity. Since 1947 the Federal Aviation Administration (FAA) has placed restrictions on the allowable flammability behavior of interior materials. The purpose of these regulations is to minimize the likelihood of an in-flight fire from a small ignition source and to reduce the flame spread or involvement of the cabin in the event of an uncontrollable fire. Periodically, the FAA has upgraded the severity of the flammability requirements as improved fire resistant materials were developed and made available for cabin usage. However, a number of accidents have also occurred which revealed the dangers associated with the smoke and toxic gas emissions generated by the burning interior materials. Smoke accumulation within the cabin can obscure visibility and seriously impede rapid cabin evacuation. Some products of combustion are irritants which cause lachrymation of the eyes and attack the respiratory system. Others, such as carbon monoxide (CO) and hydrogen cyanide (HCN), are systemic poisons which in sufficient concentrations can be incapacitating and lethal.

Over the past several years, the FAA has issued separate regulatory notices dealing with flammability, smoke, and toxic gas emission characteristics of cabin materials. Almost all respondents agreed with the desirability of screening materials based on these factors; however, there was general disagreement as to if and what steps could now be taken. These areas of disagreement can only be resolved by conducting realistic, full-scale cabin fire tests. The basic questions that must be answered are: How do interior materials contribute to the cabin fire hazard? How can interior materials be selected to confidently minimize cabin fire hazards?

Although some full-scale cabin fire tests have been performed in the past, these have been either insufficient or inconclusive. Many have been "one-shot" affairs that left more questions than answers. Others have been unrealistic, uncontrollable, or lacking in basic instrumentation. Less than a year ago, full-scale cabin fire tests were initiated at the FAA's National Aviation Facilities Experimental Center (NAFEC) using a surplus C-133 aircraft modified into a wide-body configuration.

DISCUSSION

Test Article Description

A drawing of the C-133 wide-body cabin fire test article is shown in figure 1. The fuselage diameter of a C-133 is 200 inches, which is slightly smaller than that of a DC-10 (216 inches). Since the cargo deck is located much closer to the belly than in a commercial transport, an aluminum covered wooden floor was installed about 3 feet above the cargo floor in order to provide a wide-body type of contour. The installed floor extends from the cockpit bulkhead to the rear cargo ramp, a distance of about 76 feet. An 8-foot ceiling was also installed along the length of the installed floor. The calculated volume of the interior air space is 13,200 ft.^{3}, making the C-133 by far the largest test bed ever used for the study of cabin fires. Two standard wide-body type A door openings about 60 feet apart were cut along one side of the fuselage. During present testing, an external fuel fire has been placed adjacent to the forward door while the aft door allows for smoke and gases to exhaust into the atmosphere.

In order to assure use of the test article for numerous fire tests, the aircraft interior was stripped of all combustible materials, covered with a noncombustible liner, and protected with a CO_2 fire suppression system. Figure 2 is an aft view photograph of the C-133 interior. The noncombustible sidewall and ceiling liner consist of a fibrous ceramic insulation enwrapped in a fiberglass cloth. A CO_2 discharge nozzle is seen in figure 2 slightly below the ceiling. This is one of four nozzles located in the main cabin; additional separately-controlled nozzles protect the areas beneath the installed floor and at the fuel fire pan. A perforated tube CO_2 dispensing system is installed above the drop ceiling. The noncombustible liner and CO_2 fire suppression system, along with steel sheeting atop the fuselage skin surrounding the fire door, has provided a very durable test article. Almost 50 fuel fire tests have been conducted without any significant damage except for extensive soot deposits.

Instrumentation

The hazards arising out of a cabin fire include heat, flame, smoke, depleted air, and irritating and toxic combustion gases. Extensive instrumentation has been provided at numerous locations throughout the cabin in order to record the level of these hazards as a function of time. Heat and flame are detected with thermocouples and heat flux transducers, smoke by use of light beams and photosensitive devices, and numerous gases with specific continuous analyzers (CO, O_2, etc.) or by batch sampling during a test and analyzing the mixture afterwards (HCN, HCl, NO_2, etc.). The incapacitating and lethal nature of the cabin environment will also be indicated by direct exposure and monitoring of test rats, during burns involving interior materials. Temperature, heat flux, smoke density (light transmission), CO, CO_2, and O_2 are now being measured at various cabin locations during the present test phase involving the burning solely of jet fuel. The complete data capability will eventually include 128 channels of computer acquired/ reduced data, batch gas sample analyses, test animal responses, and motion picture/video coverage.

Scenario

The scenario consists of an airplane involved in a low-impact, highly-survivable crash resulting in an external fuel spill fire adjacent to an open door in an intact fuselage. Figure 3 is a photograph of a typical test. In order to control the degree of flame penetration into the cabin, a wooden barrier was erected to negate the effect of random ambient winds and a fan provides adjustable simulated wind. As shown in the photograph, even a fuel fire of moderate size (4 foot square in this instance) produces high flames and thick smoke, and would appear to be overwhelming. Larger and more realistic fires corresponding to much greater fuel spills would be even more imposing. However, based on other experiments and accident experiences, it appears that ambient wind velocity and opening area are more critical factors than the size of the fuel fire.

Program

A three-phase test program extending into 1979 is planned. The first phase which is in progress consists of determining the cabin hazards created by an external fuel fire. Preliminary data obtained during the initial stages of this work is the subject of this report. Later, by installing typical lining and furnishing materials clustered around the fire entry opening, the involvement and contribution of interior materials to the overall cabin hazard will be established. Finally, the most difficult task will be to correlate laboratory and full-scale test results for the flammability, smoke and toxic gas emission characteristics of cabin materials. At the end of the program, we will have a better understanding of the various hazards present in a cabin fire and have developed reliable tests and procedures for selecting materials for cabin usage that will minimize the hazards resulting from a cabin fire.

Preliminary Test Results

The major emphasis of the present work is to attain repeatable results from replicate fire tests. This is a prerequisite for performing tests with a furnished interior in order to establish the hazards solely from the fire involvement of interior materials. Figure 4 is a temperature-time plot for five replicate tests at a cabin symmetry plane location 35 feet aft of the fire and 3.5 feet above the floor. The fan was set to produce an average simulated wind velocity at the fire door of about 6 mph. Two family of curves are evident in figure 4. On one family, the flames continuously penetrated into the cabin, resulting in an ever-increasing cabin temperature; however, for the other family, the flames penetrated for about a minute at the beginning of the test but later receded and the resulting cabin temperature leveled off. The two-family behavior was probably related to the ambient conditions, possibly in combination with the steel-covered wind barrier. However, no correlation could be made with measurements taken during each test of ambient wind speed and direction, temperature, and relative humidity.

For this reason, the wind barrier and fan have been removed and testing is now underway with larger fires to determine if predictable and repeatable results are attainable with existing ambient winds. Nevertheless, the data obtained with the wind barrier and fan presented in this report provides useful information about the characteristics of a cabin fire.

Smoke buildup during replicate tests exhibited a trend consistent with that of temperature. Figure 5 is a plot of smoke concentration, as measured by the percentage of light transmission across 1 foot, versus time for the same tests described previously for temperature except for one test when the smoke meter was inoperative. The measurement station of the smoke meter was the same as that of the thermocouple but was 2 feet closer to the ceiling where the smoke was denser. When the flames penetrated into the cabin throughout the test, the smoke density increased continuously, but when the flames were observed to recede outside the smoke density leveled off at about 75-to 85-percent light transmission per foot, corresponding to a visibility of approximately 10-20 feet. However, because of the significant amount of smoke stratification, visibility as high as several feet above the floor was practically unobscured across the entire cabin length during those tests when the flames receded.

The intensity of the fire at the entry door was measured with total heat flux transducers. Figure 6 shows the heat flux history at three elevations, 22-inches inboard, and at the fire entry door. At 6 inches and 3 feet 6 inches, the heat flux was significantly higher than at 5 feet 6 inches. This behavior is probably the result of heat transfer from turbulent flame fluctuations predominating at the higher elevation in contrast to that from the thicker or more uniform flame plume nearer to the floor. At the lower elevations, the heat flux varied from about 7-12 Btu/ft.^{2} sec., with fluctuations up to 15 Btu/ft.^{2} second resulting from flames licking on the transducers, which is comparable to levels measured from large fuel fires. In this respect, the test fire is representative of a large fuel fire.

The radiative heat flux drops off significantly with separation distance from the fire. Figure 7 is a heat flux history plot on the cabin wall directly across from the fire door (15-16 feet) at the ceiling and 5 feet 6 inches above the floor. From the initial rise in heat flux, it appears that the fire becomes fully developed by about 30 seconds. For the next minute, the heat flux was fairly steady at an average value of about 0.5 Btu/ft.^{2} sec., while thereafter a gradual increase with time was recorded. This increase may have resulted from additional radiation on the cabin wall from the hot gases accumulating at the ceiling. At the measured wall heat flux levels, present honeycomb composite materials used in wide-body jet interiors would not ignite nor degrade to any significant degree.

There was significant stratification of heat, smoke, and gases in the cabin. A temperature-time plot at three symmetry plane elevations located 35 feet aft of the fire door is shown in figure 8. At 5 feet 6 inches, near the head of a standing person, the temperature was considerably higher than at the lower levels, 3 feet 6 inches and 1 foot, closer to the head of a crawling person. For example, a temperature of 200°F was reached in 30 seconds at 5 feet 6 inches versus $2\frac{1}{2}$ minutes for the same temperature at 3 feet 6 inches. The cooler region near the floor is extensive, as evidenced by the two lower-level curves which are practically coincident over the first several minutes. This qualitative behavior appears to prevail throughout the cabin. Figure 9 shows the temperature histories at the exhaust door, 60 feet aft of the fire door, plotted at the same symmetry plane elevations as figure 8. The two plots are similar although the temperatures near the exhaust door are appreciably cooler than at the forward station. In figure 9, the temperature profile closest to the floor is flat, indicating the cool ambient air which enters the cabin through the lower portion of the exhaust door.

Figure 10 shows the carbon dioxide (CO_2) concentration history at 2 symmetry plane elevations located 35 feet aft of the fire. The CO_2 concentration is slightly higher at 7 feet 11 inches (1 inch below ceiling) than at 5 feet 6 inches. However, the degree of stratification of CO was far more significant at this station. The maximum CO concentration at the ceiling sampling location was approximately 0.5 percent (or 5000 ppm). But at 5 feet 6 inches CO was not detectable instrumentally with our gas analyzer (Beckman IR analyzer, Model 864) which has a threshold detection limit of less than 100 ppm. Thus, it appears that the degree of stratification of gases may be strongly related to molecular weight. The amount of oxygen (O_2) depletion at this station was found to be insignificant. As expected, the lowest O_2 concentration was detected near the ceiling, but never dropped below about 18 percent.

A better indication of the amount of heat stratification is provided by a vertical temperature profile. Such a symmetry plane profile at a station 35 feet aft of the fire is found in figure 11 at various times into the test. At this station the hot ceiling gas layer extended at least 2-1/2 feet below the ceiling for the first 2 minutes of the test. By 3 minutes the hot gases were clearly extending closer to the floor

FIGURE 1

C-133 WIDE BODY CABIN FIRE TEST ARTICLE

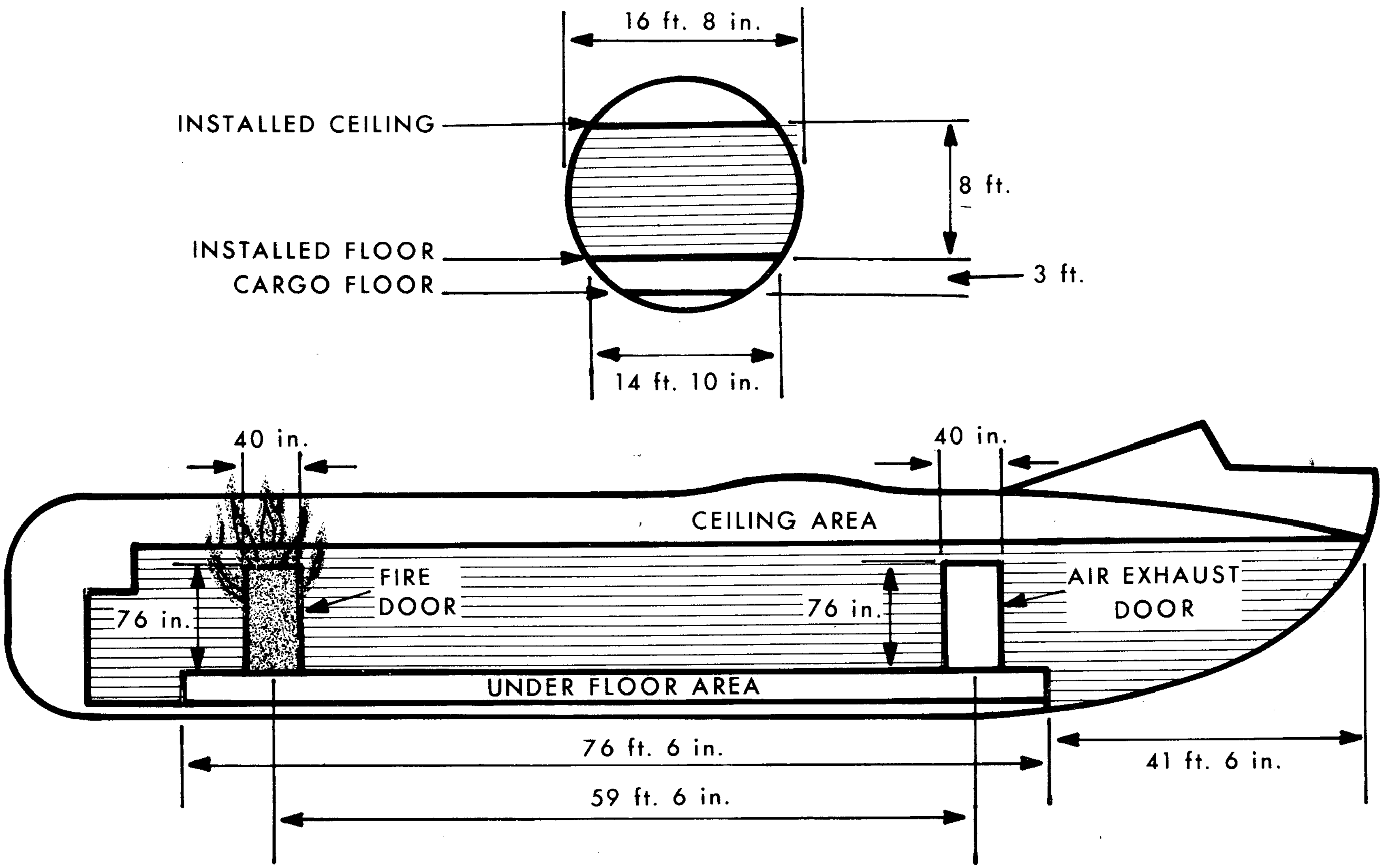

FIG. 3 TYPICAL FIRE TEST SHOWING WIND BARRIER AND AIR DUCT

FIGURE 5

REPEATIBILITY OF SMOKE DENSITY FOR FOUR REPLICATE TESTS AT DIFFERENT AMBIENT CONDITIONS (PRELIMINARY DATA)

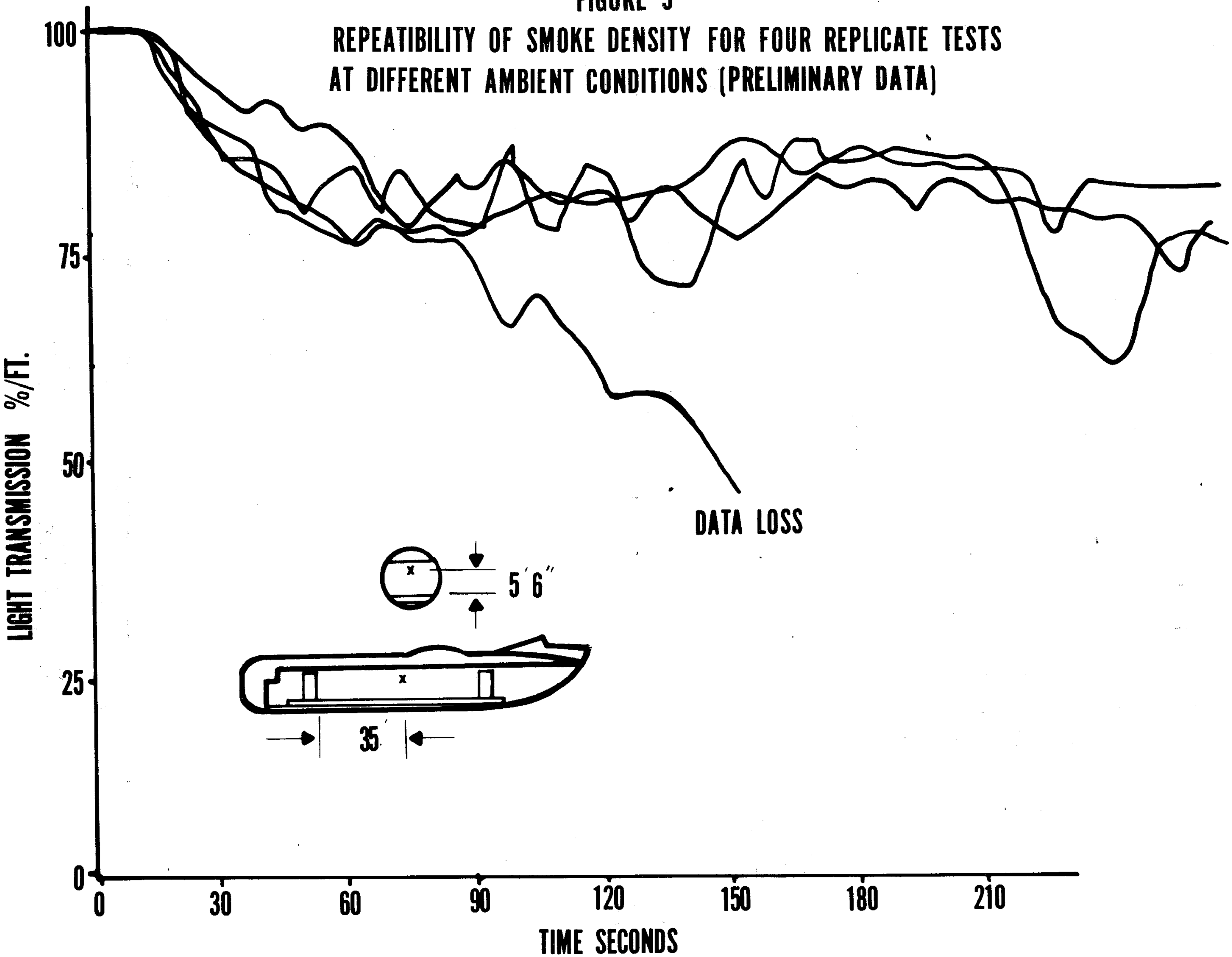

FIGURE 6

HEAT FLUX AT FIRE DOOR (PRELIMINARY DATA)