AIRCRAFT & AIRPORT SAFETY DIVISION

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A PRELIMINARY MODEL STUDY OF A SMOKE REMOVAL CONCEPT FOR CABIN FIRES

by

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ABSTRACT

A study was conducted using a simple model of an aircraft cabin to examine a new concept for smoke venting during a cabin fire. Findings were based on continuous smoke and temperature measurements in the model and visual observations. Present ceiling construction materials were of sufficient fire resistance to contain a fire entirely within the cabin enclosure. A significant reduction in cabin smoke level was achieved with a polyethylene ceiling that readily melted immediately above the fire location and provided an opening for smoke removal through the "attic" and eventually outside of the aircraft. Additional studies were recommended to verify the findings of the simple model tests and to examine the practicality of implementing the concept in a real transport aircraft.

CONCLUSIONS AND RECOMMENDATIONS

This preliminary study, utilizing a simple model of an aircraft fuselage, demonstrated that a cabin smoke removal system consisting essentially of a meltable cabin ceiling and ventilated attic, could significantly reduce smoke levels during a cabin fire. These results need verification in terms of more acceptable and proven physical fire modeling techniques. The importance of actual aircraft geometry and the role of ambient wind conditions in the smoke removal process requires careful study. Furthermore, it is proposed that the benefit of the attic smoke removal system be examined for a realistic range of postcrash fire conditions. A separate study should be made of the feasibility of opening up a section of the upper fuselage in a real aircraft following a crash landing. This would preferably be conducted if the model tests were favorable to give impetus to pursuing this design problem with some degree of enthusiasm.

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INTRODUCTION

PURPOSE. The purpose of this study was to examine the feasibility of utilizing the significant attic space above a drop ceiling in a jumbo jet as a conduit for removing smoke during a cabin fire. This was accomplished by building and testing a simple model of an aircraft cabin and attic. The work was performed under NPD 18-471, "Aircraft Systems Fire Safety."

BACKGROUND. The most extensive application of automatic fire venting is for the protection of modern industrial and commercial buildings. The vents are distributed over the entire roof to assure reasonable venting of a fire regardless of its location. In one type of design, automatic venting occurs when a fusible link is melted by the fire allowing the spring-loaded vent cover to swiftly open. Quickly venting a fire near its point of origin provides for the removal of smoke and toxic combustion products that otherwise would accumulate within the building, and reduces flame spread possibly to the point of fire containment by releasing the heat as it is generated. Figure 1 illustrates the phenomena in play in a building fire with and without ceiling venting.

The interior of a jumbo jet is lined along the sidewall and ceiling with fire retardant paneling. A similar construction consisting of a Nomex honeycomb core, fiberglass sheet faces, and a Tedlar or Tedlar/PVC laminate finish is found in the three types of jumbo jets. Tests have demonstrated that these panels are highly resistant to penetration by intense flames, in some cases withstanding burn through in excess of 10 minutes when subjected to a burner simulating the heat generated by a large fuel fire. For this reason it is believed that during the several minutes when survival is possible from a cabin fire the smoke, heat, and gases generated by the fire will remain entrapped within the cabin enclosure. A safer condition would exist if some of these hazardous combustion products were vented into the atmosphere.

In the past, consideration of smoke venting during a postcrash cabin fire has been rejected because of the difficulty envisioned in its application to the peculiar geometry of an aircraft fuselage--a long, horizontal tube. AIA eliminated ceiling vents from study in their crashworthiness program of 1968 "because of the large size required to handle the smoke without any chimney height and because of the impracticality of opening a large hole above a broken point in the fuselage." This report only addresses in a very preliminary fashion the first part of the basis of rejection by AIA. Specifically, it was sought to determine if the large attic space above the drop ceiling in a jumbo jet could, in effect, act like a horizontal chimney for the removal of smoke from the cabin during a fire. The attic is especially large in a B-747, attaining a height of 52 inches at the fuselage center plane, compared to a distance of 100 inches from the cabin floor ceiling.

DISCUSSION

TEST ARTICLE AND INSTRUMENTATION. An isometric drawing of the crude model of an aircraft cabin used in this study is shown in figure 2. It consists basically of a steel box with overall dimensions of 48-inch length, 12-inch width, and 11-inch height, divided into two compartments--the upper and lower compartments representing the attic and cabin, respectively. The relative model dimensions bear no relationship with any aircraft, although the attic-to-cabin-height ratio is only slightly greater than that of a B-747. The metallic ceiling (divider) contains a rectangular hole and lugs for mounting and exposing ceiling materials to a pan of burning aviation fuel. Draft openings were made at both ends of the cabin and at the end of the attic opposite the fire. The placement of the draft openings was intended to establish a movement of smoke from the fuel pan end of the cabin to the opposite end, and to provide a capability of venting attic smoke that may be entering through a hole in the ceiling.

Measurements were made of smoke density and temperature. A smoke meter consisting of a light source and photoelectric cell was mounted near the cabin smoke vent with the light beam extending horizontally across the cabin width. Thermocouples fabricated of 28-gauge chromel-alumel wire were positioned at a number of cabin and attic locations. The thermocouple and smoke meter data were continuously monitored on Bristol (temperature calibrated) and Esterline Angus millivolt recorders, respectively.

TEST PROCEDURE. Several developmental tests were conducted to properly design the test article to produce the desired smoke movement and fire exposure conditions. These tests dictated the orientation of the test article within the fire test cell, the geometry of the ventilation openings, and the placement of the fuel fire pan. The latter was positioned to create maximum fire exposure on the ceiling specimen; the distance from the fuel surface to the ceiling was set at 4 inches. An adjustable, perforated draft control gate allowed for an adequate supply of air to feed the fuel pan fire while preventing smoke leakage from that end of the cabin. The size of the cabin smoke vent was selected to produce a finite accumulation of smoke within the cabin. Tests were performed in an enclosed fire test cell equipped with a large exhaust blower. One difficulty encountered was maintaining smoke movement inside the cabin in the desired direction. For this it was necessary to properly orient the test article within the airstream created in the test cell between the air intake louvers and exhaust blower.

Before each test, the ceiling specimen was mounted in place and the test article was reassembled. The exhaust blower was then turned on and the test article oriented to produce the desirable forced ventilation condition. About 22 ml of Jet A fuel was placed in the fuel pan and preheated to facilitate its ignition. The pan was quickly positioned inside the cabin and ignited with a match. Ignition was a signal for starting the test timer and remotely marking this event onto the recording chart paper. The draft control gate was adjusted to eliminate smoke leakage from that end of the cabin. A 5-minute test duration was usually adequate to satisfy the test objective.

TEST RESULTS AND DATA. A series of 11 tests was conducted during this preliminary study. The following is a description of the more significant results and data.

Initially, a test was performed to determine if a Nomex honeycomb panel, which is the type of panel construction used exclusively in all three jumbo jets, could withstand the fuel pan fire. The test was run for 13-1/2 minutes, or until all the Jet A fuel was consumed. The damage to the panel was limited to a length of 8-1/2 inches and consisted primarily of delamination of the finish materials. The Nomex honeycomb core was practically undamaged. Because of the fire resistance of the panel construction, the fire was confined within the cabin enclosure which resulted there in a rapid buildup of smoke. Conversely, when a thin slab of fire retardant (FR) polyethylene foam was submitted as the ceiling material, a significant reduction in cabin smoke and venting of smoke from the attic was observed. Figure 3 compares the cabin smoke level histories for the tests utilizing Nomex honeycomb panel and polyethylene foam ceiling materials. Total obscuration in about 50 seconds was measured when the ceiling consisted of the Nomex panel. However, although the initial smoke accumulation was similar with the polyethylene foam ceiling, a significant reduction in smoke was detected after the ceiling above the fire melted away and allowed some of the smoke to vent out through the attic. Although in this case the smoke level in the cabin never dropped below about 40-percent light obscuration per foot, it was later determined that the residual smoke level after burn through was related to the external draft conditions established before the test.

An indication of the fire dynamics involved in the test article is provided in figure 4 which contains smoke and temperature profiles measured when polyethylene foam was used as the ceiling material. The temperature above the fire near the ceiling ranged from about 800°F to 900°F. As indicated by the attic thermocouple above the fire, the ceiling burned occurred at 0.4 minute. However, an interval of about 0.5 minute transpired afterward before a corresponding reduction in smoke was experienced near the cabin vent outlet. Based on the elapsed time for the first indication of heat by the attic thermocouples (0.15 minute), the average heat convection velocity in the attic was about 20-30 ft/min.

In order to examine the repeatability of the measurements, a rerun was made of the polyethylene foam ceiling test. Figure 5 compares the smoke histories for these two tests. The most apparent difference between the data is that in one test the smoke was eventually vented from the cabin while in the other test it was not. This was true not withstanding the similarity of the accumulation of smoke and initiation of attic venting between tests. It therefore appears that differences in airflow fields surrounding the test article may be responsible for differences in smoke data after ceiling burn through. This tentative conclusion is consistent with the difficulties experienced in some tests in maintaining a directional movement of smoke from the fuel pan to the cabin exit. It therefore appears that any smoke removel system should be evaluated over a range of ambient wind conditions likely to be encountered in a real accident environment.

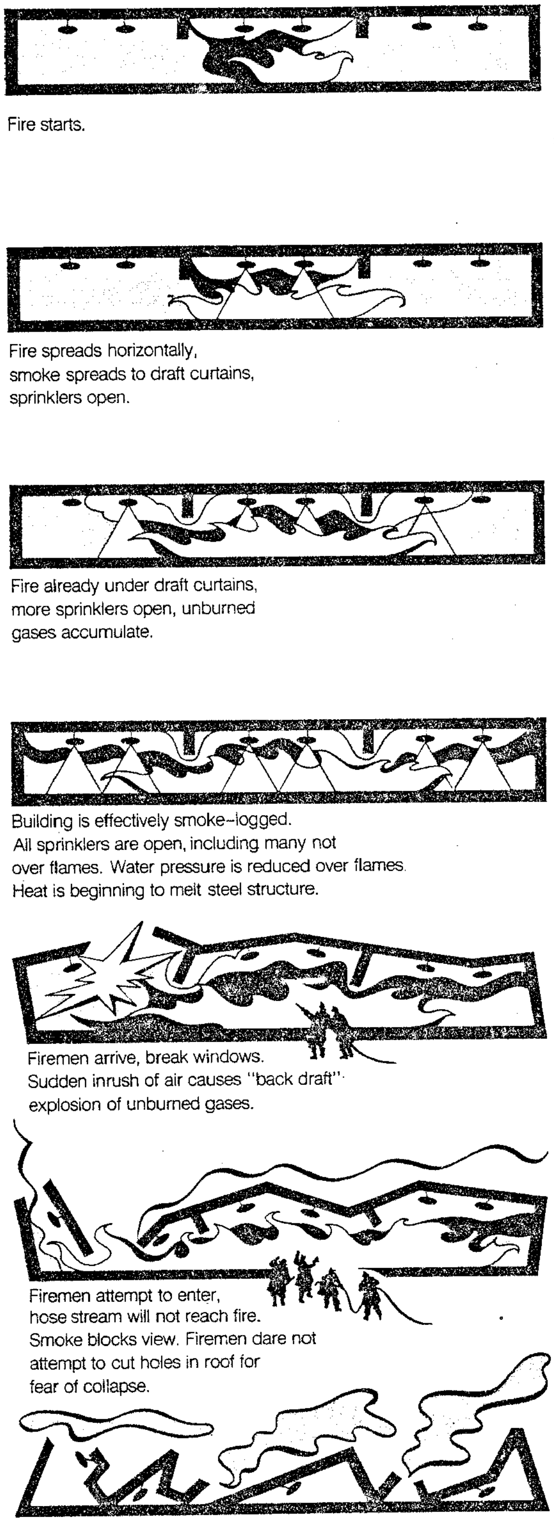
Although the 5/8-inch polyethylene foam ceiling provided for smoke removal through the attic, the large initial buildup of smoke in the cabin was undesirable. Thinner polyethylene foams were tested to determine if these ceiling materials would melt faster and thus provide an earlier and more effective smoke removal process. Figure 6 compares the cabin smoke histories measured with different foam ceiling thicknesses. A significant reduction in smoke was experienced with the thinner materials. In fact, the 1/8-inch foam specimen maintained the smoke level at near threshold values for almost 3 minutes. However, this particular sample was not fire-retardant treated and was observed to burn in about 2 minutes along its entire length. Although this behavior was not hazardous in this particular test procedure, it is likely that a combustible ceiling material, although meltable, will in a more realistic evaluation prove to be undesirable because it may promote rapid flame spread throughout the cabin. Ideally, ceiling and attic materials in the intended application should be noncombustible.

The greatest and perhaps insurmountable aspect of the attic smoke removal concept is the means by which an opening will be created in the upper fuselage. Therefore, a test was conducted to determine the benefit of smoke venting into a closed attic plenum. Figure 7 compares the cabin smoke history for this test with that measured with the same ceiling material but with the attic vent open. Some reduction in cabin smoke level was provided by the attic plenum; however, this can be significantly added to by proper attic venting. As shown in figure 7, the cabin smoke level exhibited a notable reduction shortly after the attic vent cover was removed.

The final test was performed to determine if the location of the ceiling opening had a bearing on the effectiveness of smoke removal. A small opening (4-inch square) was cut in a steel sheet ceiling, similar to the size formed by the melted polyethylene foam, and offset by 12 inches from the fuel pan. A plot of the smoke history for this test is compared in figure 8 with that measured when the ceiling material was polyethylene foam. Initially, there is some advantage to the preexisting ceiling opening. However, the smoke continued to gradually increase until an asymptotic value of 70- to 75-percent light obscuration was achieved. It appears the smoke can be most effectively removed from the cabin when the opening exists directly above the fire; this is attributed to optimum utilization of the upward buoyancy forces created by the fire to drive the smoke out of the attic. Thus, a suitable cabin ceiling design must be capable of opening up directly over any likely fire location.

Further information regarding the work may be obtained directly from Mr. Sarkos. Color viewgraphs and photographs showing the model and action shots during testing are also available.

Without venting



Fire starts.

Fire spreads horizontally,
smoke spreads to draft curtains,
sprinklers open.

Fire already under draft curtains,
more sprinklers open, unburned
gases accumulate.

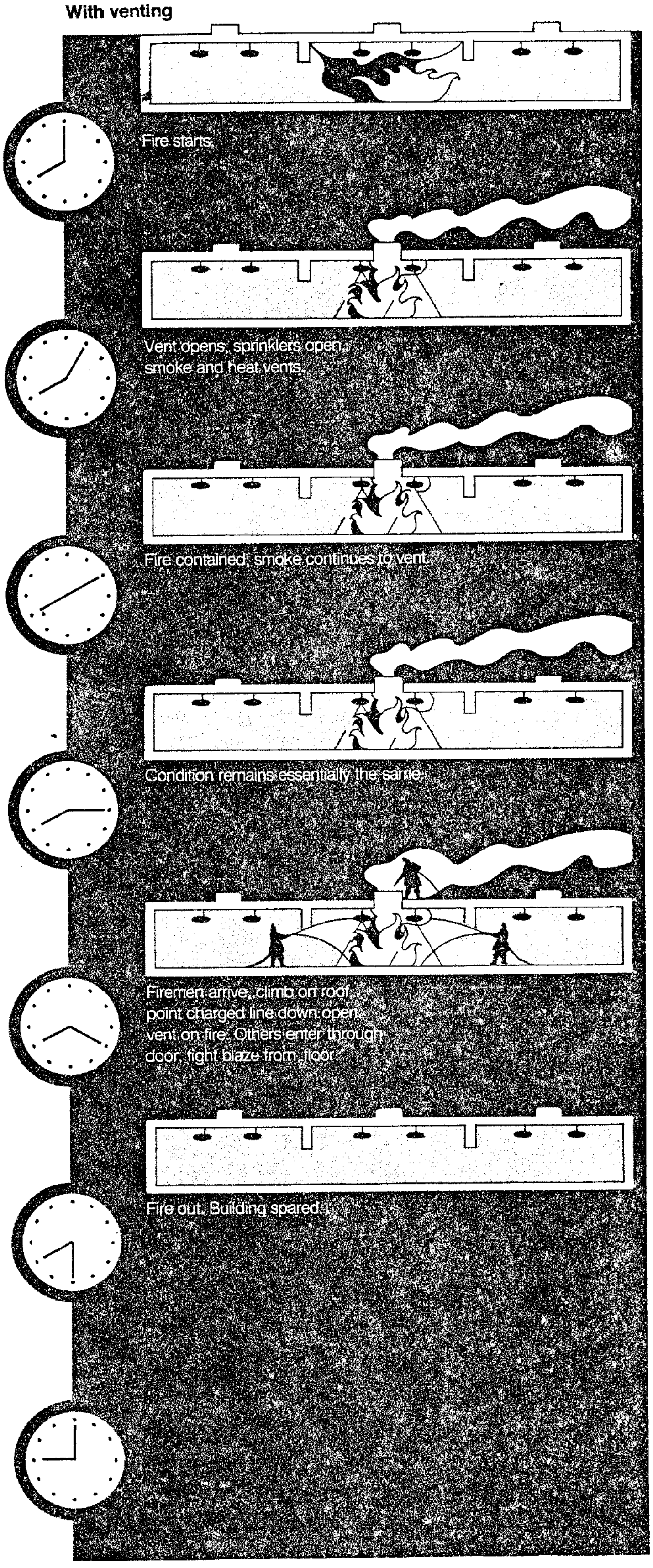
Building is effectively smoke-logged.
All sprinklers are open, including many not
over flames. Water pressure is reduced over flames.
Heat is beginning to melt steel structure.

Firemen arrive, break windows.
Sudden inrush of air causes "back draft"
explosion of unburned gases.

Firemen attempt to enter,
hose stream will not reach fire.
Smoke blocks view. Firemen dare not
attempt to cut holes in roof for
fear of collapse.

Fire out. Building destroyed.

With venting



Fire starts.

Vent opens, sprinklers open,
smoke and heat vents.

Fire contained; smoke continues to vent.

Condition remains essentially the same.

Firemen arrive, climb on roof,
point charged line down open
vent on fire. Others enter through
door, fight blaze from floor.

Fire out. Building spared.

Fig 1. Principle of Automatic
Fire Venting in an Industrial
Building

Reproduced courtesy Progressive Architecture magazine.

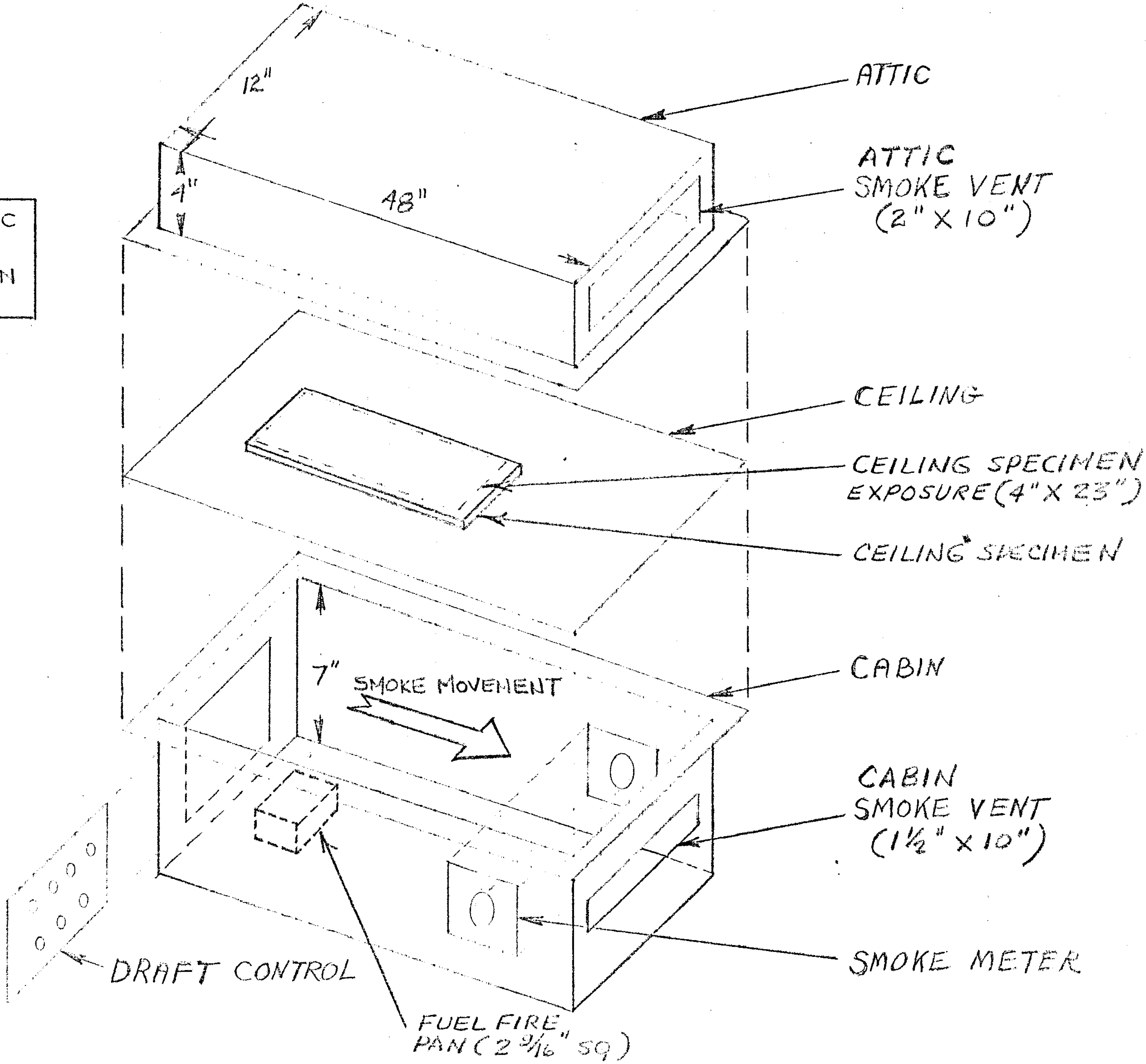


FIG 2. ISOMETRIC DRAWING OF AIRCRAFT CABIN MODEL

FIG 4. ATTIC TEMPERATURE AND CABIN SMOKE AND TEMPERATURE PROFILES OBTAINED WITH A POLYETHYLENE FOAM CEILING

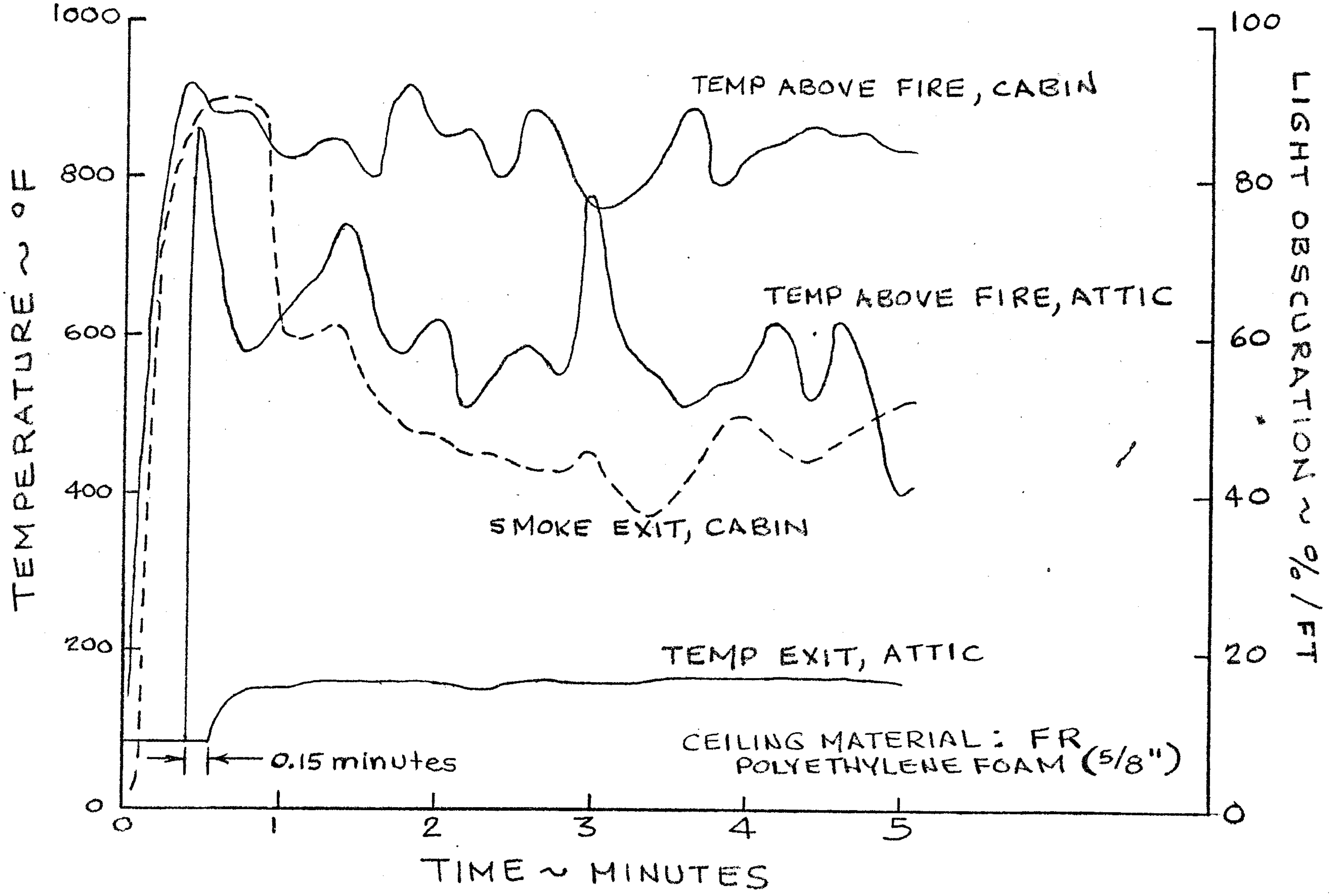


FIG 5. CABIN SMOKE DENSITY HISTORY FOR DUPLICATE TESTS (NOS. 5 AND 6). WITH A POLYETHYLENE FOAM CEILING

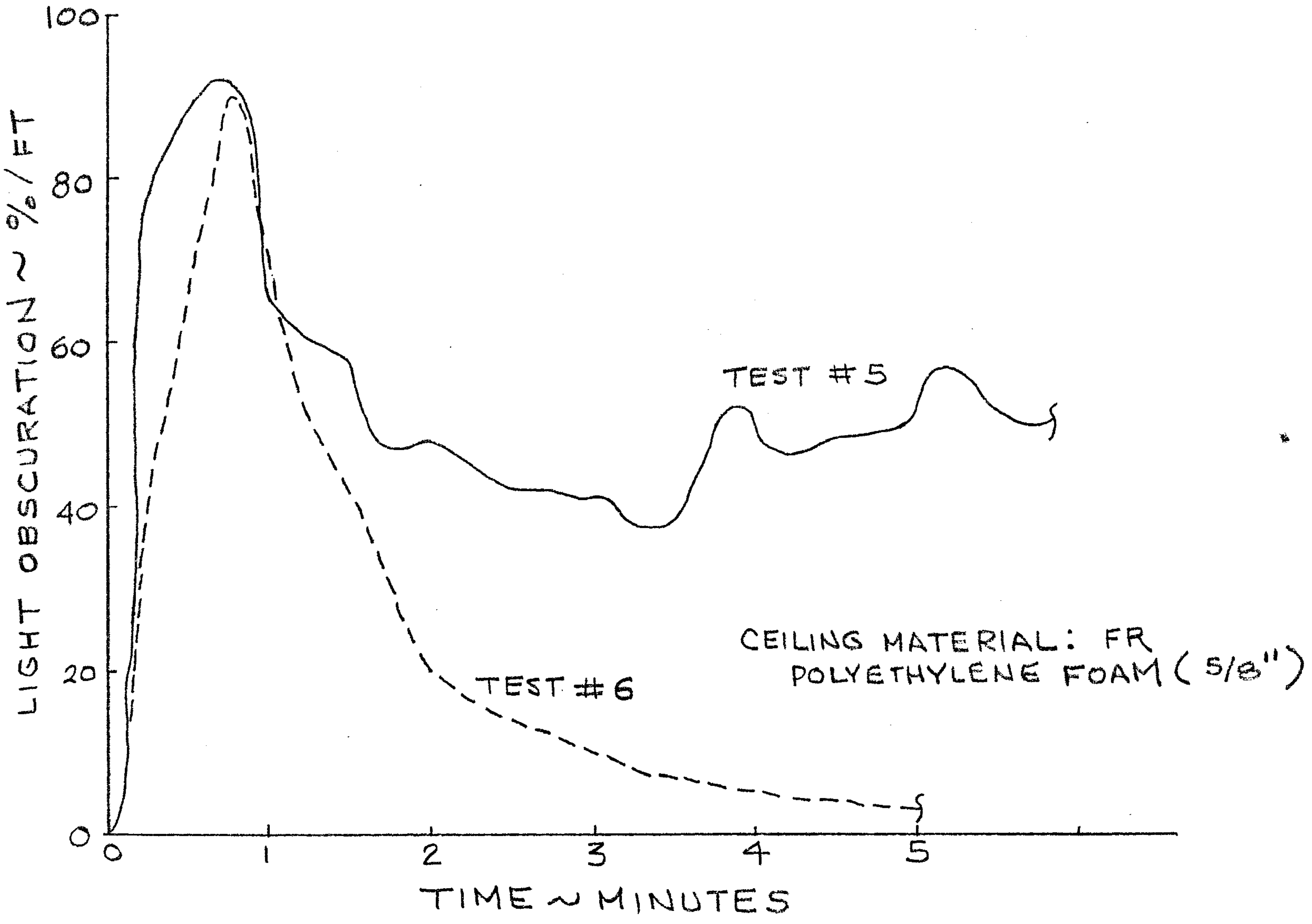


FIG 6. IMPROVEMENT IN CABIN SMOKE REMOVAL EFFECTIVENESS RESULTING FROM THE USE OF THIN CEILING MATERIALS

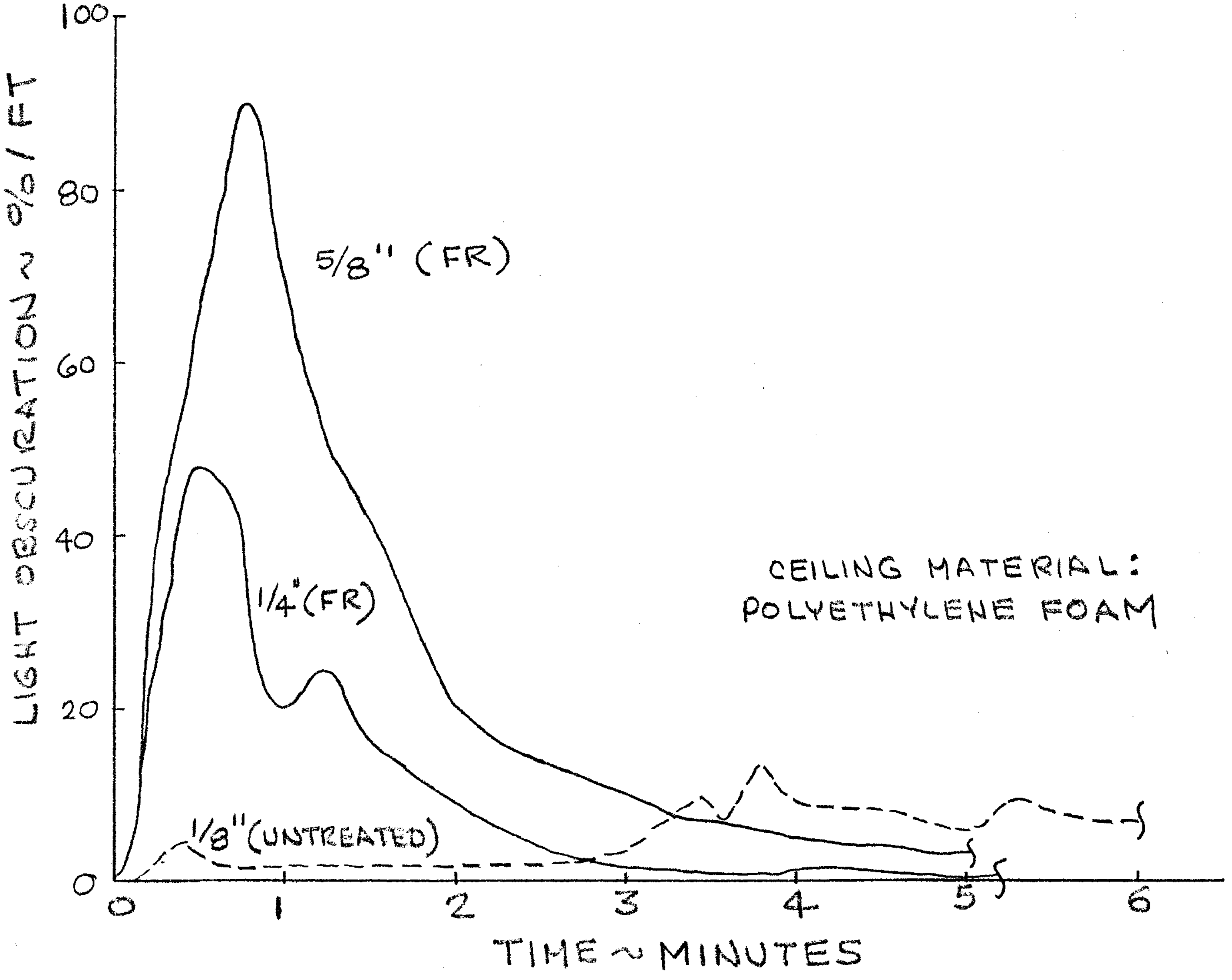
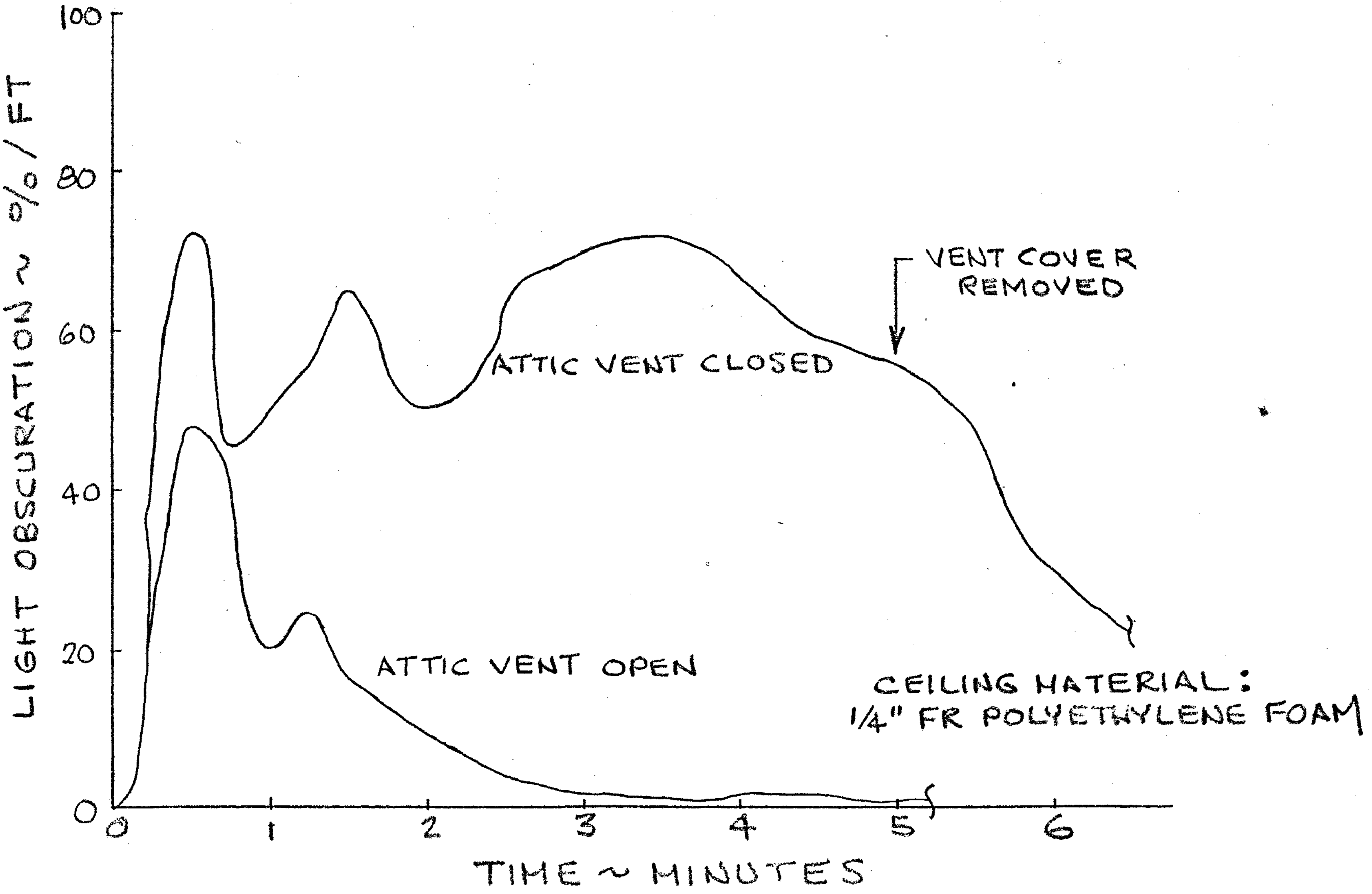
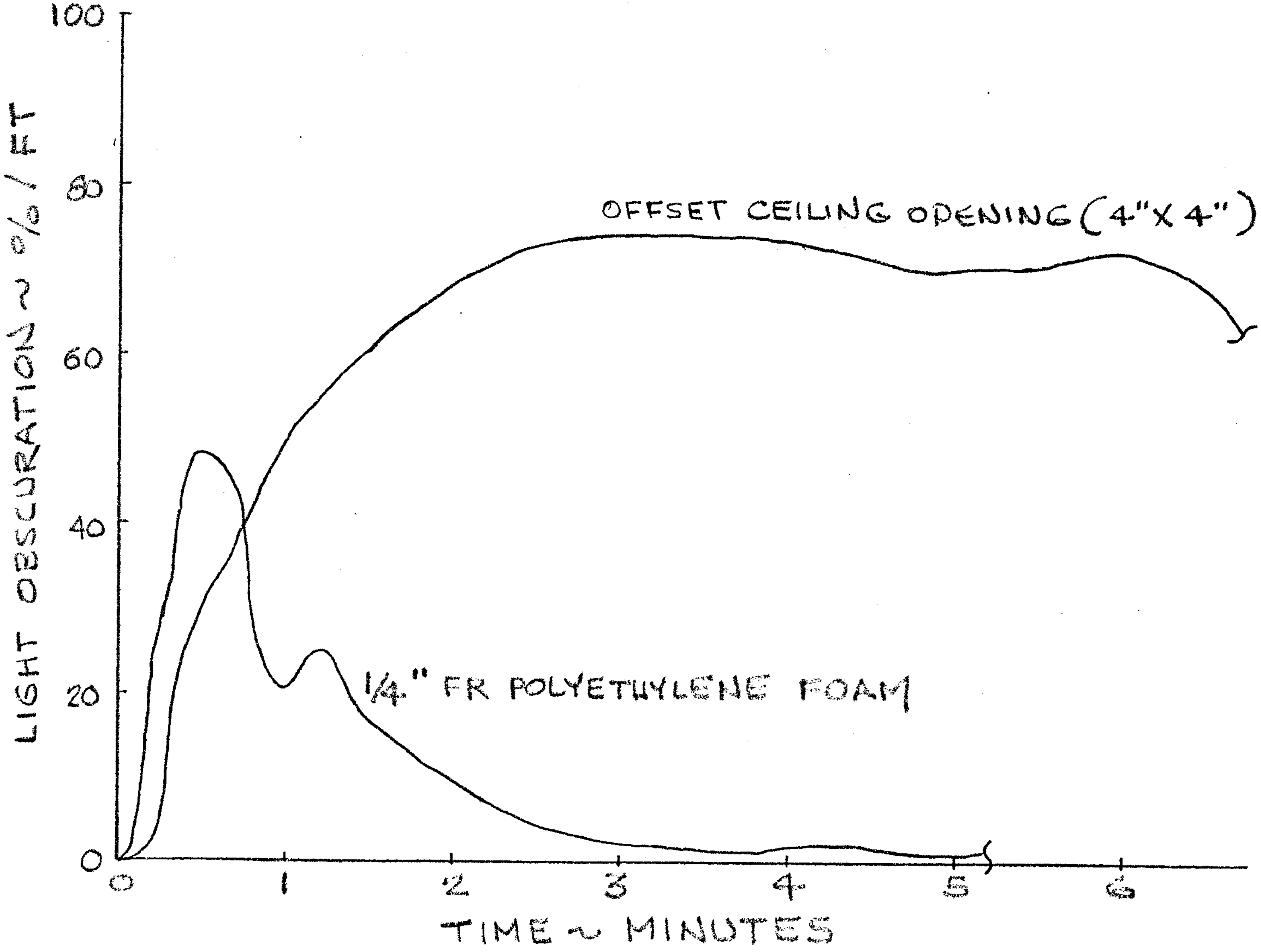


FIG 7. EFFECT OF ATTIC VENTILATION OPENING ON CABIN SMOKE REMOVAL PROCESS WITH A MELTABLE CEILING



CEILING MATERIAL:
1/4" FR POLYETHYLENE FOAM

FIG 8. EFFECT OF LOCATION OF CEILING OPENING ON CABIN SMOKE REMOVAL PROCESS



APPENDIX A

NA-77-16-LR

Distribution:
AED-1
ANA-1
ANA-2
ANA-4
ANA-5
ANA-64
ANA-100
ANA-200
ANA-300
ANA-400
ANA-500
ANA-600
ANA-700
ANA-420 (16)
ANA-523
ARD-1
AEM-1