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EVALUATION OF AVCO/NASA RIGID FOAM AS A FIRE BARRIER FOR CABIN PROTECTION

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Purpose

To experimentally determine if fuselage sections backed with rigid foams will increase the "burn-through time" from an external fuel fire to the cabin interior. Also, to determine what effect the foam's decomposition products will have on the ambient conditions within the cabin.

Background

If the fuel tanks of an aircraft are ruptured during a forced landing, ignition of the fuel may occur resulting in a fire which envelops the aircraft. The fire will eventually melt the aluminum skin and produce fatal conditions for any passengers within the aircraft interior who may have survived the crash landing. Various factors affect the time it takes for the skin to melt, or the burn-through. These include the size and proximity of the fire, the wind velocity and direction, and the thickness of the skin exposed to the fire. Results of fire tests, at NAFEC, with a Boeing 707 fuselage section indicated that the "burn-through time" during a severe fire varied from 10 to 40 seconds, depending on the thickness of the skin (Reference 1). With the present exit design regulation which specifies evacuation from one side of the aircraft in 90 seconds or less, it is possible that many of the passengers will still be inside the aircraft when the skin melts. Moreover, if the aircraft is completely surrounded by fire, the survival of the passengers depends on the protection afforded by the skin. It is evident that any method which increases the "burn-through time" will also increase passenger survivability. One possibility is to adhere a material to the inside of the skin and thus protect the cabin interior after the skin has melted. This material should have good thermal and mechanical properties when exposed to the heat from a fuel fire. Ideally, this material should also have the following characteristics: ease of application to the skin; light enough to impose reasonable passenger limitations because of the increased weight of the aircraft; ability to withstand the loads and vibrations experienced by an aircraft during its lifetime; and compatibility with the existing design and design requirements of the aircraft.

One material which appeared to have sufficient thermal and mechanical properties, along with the above-mentioned characteristics, is rigid foam. Work at NASA Ames had resulted in the development of rigid foams as either thermal barriers against fuel fires or heat shield materials.

Parker, et. al., modified a rigid polyurethane system with thermally activated components whose purpose was to quench or suppress both the flame's propagation species and the flammable gaseous products of foam decomposition (Reference 2). The additives were VMCH polyvinyl chloride-acetate copolymer and potassium fluoborate; these compounds were added in amounts 10 percent by weight. A 1-inch slab of this foam was exposed to a JP-4 pan fire in tests performed at NASA. After 10 minutes, the backface temperature was about 380°F for a machine-mixed specimen and only 300°F for a hand-mixed specimen. These results indicated that this foam showed great promise for the purposes intended even though no apparent effort was made to measure smoke or toxic gases which may have been produced by the foam's decomposition. Pope, et. al., added Astroquartz fibers to this foam to increase the ablative performance during reentry (Reference 3). The quartz fibers also increased the structural strength of the foam, thereby further enhancing its applicability to increasing the "burn-through time."

NASA Ames also developed a rigid isocyanurate foam. They contracted AVCO to market this foam and modify it to meet any possible applications.

Test Procedure

The test setup is shown in Figure 1. Each test panel was bolted to the open end of a closed rectangular housing and exposed to the flame of a standard 2-gal/hr kerosene burner. The heat flux upon the aircraft skin was determined with a calorimeter and radiometer provided by AVCO. The total heat flux was 16.3 Btu/ft^2/sec, with radiative and convective contributions of 11.7 and 4.6 Btu/ft^2/sec, respectively. Although the total heat flux was higher than the generally quoted value of 10 Btu/ft^2/sec for a free-burning fuel fire, it is still well in the range to simulate these fires. This was evidenced by comparing the "burn-through time" of an unprotected test panel with a predicted value based on full-scale fire tests (Reference 1). The test panel burned through in a time period reasonably close to the predicted value. The burner's flame formed approximately a 6- by 11-inch elliptical imprint upon the test panel. This area is smaller than the 18- by 18-inch foam area; therefore, the fire did not burn through around the foam. The rectangular housing included a glass window at the back side for observing the foam during the tests.

Instrumentation was provided for the measurement of temperature and smoke concentration. The flame and skin temperatures were measured with 22 AWG chromel-alumel thermocouples. Stringer, former, foam, and inside air temperatures were measured with 30 AWG chromel-alumel thermocouples. An indication of the smoke density within the housing was made with a smoke meter utilizing a photocell/light source arrangement which measured the percentage of light transmission across a distance of 1 foot.

Description of Test Panels

Each test panel consisted of a 24- by 24-inch section of a Convair 880 fuselage backed by a layer of rigid foam. The skin was .042 inch thick. Two stringers and two formers, along with the foam, comprised the back side of each panel. A typical test panel is shown in Figure 2. Five panels were tested.

Panel No. 1. The quartz-reinforced, polyurethane foam (also designated as 5I-10AQB by NASA) was applied up to the stringer depth of 1 1/4 inches (Figure 2). Because of the high viscosity of this material, it could not be directly foamed in place. Instead, it was cut into blocks and adhered to the skin with unreinforced, or 5I-B foam. This difficulty in foaming also necessitated filling the cavity of each stringer with 5I-B foam.

Panel No. 2. The isocyanurate foam, or ICU, was also applied up to the stringer depth. Unlike the 5I-10AQB, the ICU could be directly foamed into place. However, the ICU has less resistance to abrasion than the 5I-10AQB. Rubbing your finger across the ICU without applying much pressure causes grains of the material to be removed.

Panel No. 3. The ICU foam was applied up to the former depth, or about 3 3/4 inches (Figure 3). Examination of the panel revealed that the foam was separated from the skin at two locations, indicating that difficulties also exist when foaming the ICU in place, i.e., it may have a tendency to separate from the skin.

Panel No. 4. This panel consisted of a composite of 5I-10AQB applied up to the stringer depth, a 2-inch layer of fiberglas, and a 1/32-inch fiberglas/epoxy laminate. The panel duplicated the cross-section that could exist in an aircraft. The sides of the composite were also made of the fiberglas/epoxy laminate and were adhered to the aircraft skin and backside laminate with fiberglas tape pasted over with epoxy. This apparently provided an airtight seal between the composite and the aircraft skin.

Panel No. 5. The final panel tested was a fuselage section without any foam or insulation on the back side.

Test Results

Panel No. 1. This panel was exposed to the burner fire for 7 minutes. Figure 4 shows the back side after the test. The foam burned through at a seam composed of 5I-B. However, the 5I-10AQB held up quite well and appeared to maintain its structural integrity. Separation of foam from the aircraft skin occurred at several locations, providing a passageway for heat from the external fire, smoke, and toxic gases from the decomposing foam. This separation appeared not to have been caused by the deformation of the foam, but rather by that of the aluminum skin. Molten stringer metal, as clearly shown in Figure 4, indicated that the temperature had risen to about 1200°F; i.e., the melting temperature of aluminum alloys.

Data from the smoke meter for this test (as well as the other tests) are shown in Figure 5. Smoke was first detected at about 15 seconds, and 100-percent light absorption occurred at about 60 seconds. Because of the rapid accumulation of smoke within the housing, the exact location of the smoke entrance could not be determined. For all practical purposes, the data from Panels Nos. 2 and 3 had a similar behavior, indicating that the passage of smoke into the housing did not depend on either the foam thickness or composition.

Temperature data for this test are shown in Figure 6. The flame temperature increased rapidly and leveled off above 2000°F. The first backside thermocouple to feel heat was that of the stringer which is to be expected since it was attached directly to the skin. Near the end of the test, the stringer temperature leveled off at about 1200°F and was thus consistent with the appearance of molten aluminum shown in Figure 4. Heat did not reach the thermocouple located midway through the foam until about 2 minutes, after which, the temperature increased rapidly and leveled off near the end of the test, probably then recording the flame temperature at the thermocouple location. The former, foam backside and inside air (located 3 inches from the foam backside) thermocouples all indicated a very gradual increase in temperature until shortly after 3 1/2 minutes, at which time a flash fire occurred. The inside air thermocouple was most affected by the flash fire and jumped to about 2000°F; it then decreased quite rapidly before leveling off at about 4 1/2 minutes. Any other thermocouples exposed to the flash fire also experienced temperature increases, but nothing as severe as that of the inside air thermocouple.

Panel No. 2. Figure 7 shows this test panel after a 5-minute exposure to the burner fire. Compared to the first panel, which was also foamed up to the stringer depth but with 5I-10AQB, the damage was more severe. Apparently, the ICU foam does not resist fire as well as the 5I-10AQB foam. Examination of the char of each foam indicated that the 5I-10AQB was of superior strength, probably because of the quartz fibers embedded in the 5I-10AQB. Similar to the first panel, the

ICU foam was observed to be separated from the aircraft skin at several locations.

Smoke quickly accumulated in the housing and, for all practical purposes, followed the same behavior as in the previous test (Figure 5). Observation through the window at the rear of the housing revealed that the smoke was egressing from the foam-aircraft skin interface. Apparently, smoke produced by the foam's decomposition entered the housing through voids formed by the foam separating from the aircraft skin. During the period which observation of the foam was possible, no smoke was observed to be leaving through the virgin foam backface.

The temperature history of the various thermocouples is shown in Figure 8. No flash fire occurred during this test. Comparing this data with that of the previous test (until the occurrence of the flash fire) showed the temperature to be higher for each thermocouple. This is especially evident for the thermocouples measuring the foam temperature and verifies the poorer resistance of the ICU foam to heat penetration from a fire.

Panel No. 3. This panel was exposed to the burner fire for 10 minutes. The panel backside after the test is shown in Figure 9. Compared to the previous two tests which exposed panels to the burner fire for shorter test times, the panel backside after this test was in much better condition because of its threefold increase in foam thickness. The foam again separated from the aircraft skin at several locations. After the termination of the burner flame, the foam was observed to be burning and continued to do so for an additional 3 to 4 minutes.

Smoke data resembled that obtained during the two previous tests (Figure 5). This further confirmed that the accumulation of smoke in the enclosure resulted from smoke entering through passageways between the foam and aircraft skin.

Compared to the two previous tests, the increase in foam, former, and air temperatures with time is much more gradual (Figure 10). The inside air temperature reached 130°F only after 10 minutes. The tripled foam thickness caused the milder temperature response.

Panel No. 4. Figure 11 shows the final panel tested after a 10-minute exposure to the burner flame. The backface had the best appearance of all the panels tested. However, as was the case for the previous tests, the panel separated from the aircraft skin. The foam also continued to flame for 2 to 3 minutes after the burner was shut off.

Smoke accumulation in the enclosure (Figure 5) was significantly less during this test than in the three previous tests which behaved similarly to one another. However, the first appearance of smoke again was observed at the foam-aircraft skin interface. The use of a fiberglas tape coated with epoxy for adhering the fiberglas/epoxy laminate sidewall to the aircraft skin provided an airtight seal and prevented any smoke from entering the enclosure until shortly after 1 minute. Once the smoke entered, it accumulated at a slower rate than in the previous tests, probably because of smaller entranceways.

Thermocouple data from this test are shown in Figure 12. The reduced temperatures were probably a result of both the sealing effect of the laminate and the thickness of the composite.

Panel No. 5. The burn-through time, as evidenced by a thermocouple measuring the inside skin temperature, was only 48 seconds and reemphasized the poor protection provided by the skin against fire penetration.

Summary of Evaluation

The test results verified that both the ICU and 5I-10AQB foams provided good thermal insulation against a fuel fire by forming a protective char with good ablative properties, and thus, when applied to the backside of an aircraft skin, helped increase the "burn-through time." Of the two foams, the 5I-10AQB provided better thermal insulation since it had a quartz matrix which enabled it to retain much of its structural integrity upon exposure to fire; however, 5I-10AQB was three times heavier than ICU, had a greater tendency to produce a flash fire, and could not be directly foamed to the skin. Since the ICU is relatively light and was easier to apply to the aircraft skin, it is probably a more practical solution to the burn-through problem. The most evident deterrent for using either of these materials was the formation of large amounts of smoke (100-percent light obscuration per foot occurred in less than 1 minute during three of the four tests) by the action of foam decomposition. The passage of smoke into the enclosure was aided to an unknown degree by not extending the foam completely to the sidewalls of the enclosure; however, this oversight was felt to emphasize an impractical requirement to both the foam application and its behavior during fire exposure -- the necessity for providing an airtight seal between the fire and aircraft interior. Modifications should be made to these foams to alleviate these deficiencies, if possible. Ideally, the design goal should be a light material which can be easily applied to an aircraft skin and which provides good thermal insulation without producing smoke or toxic and flammable gases.

REFERENCES

1. Geyer, G. B., "Effect of Ground Crash Fire on Aircraft Fuselage Integrity," Federal Aviation Administration, Report NA-69-37, December 1969.

2. Parker, J. A., Riccitiello, S. R., Gilwee, W. J., and Fish, R., "Development of Polyurethane as Thermal Protection Systems for Controlling Fuel Fires in Aircraft Structures," Ames Research Center, NASA, Moffett Field, Calif. 94035.

3. Pope, R. B., Riccitiello, S. R., and Parker, J. A., "Experimental Evaluation of Poyurethane Foam Composites for Low Heating Rate Thermal Protection," Ames Research Center, NASA, Moffett Field, Calif. 94035.

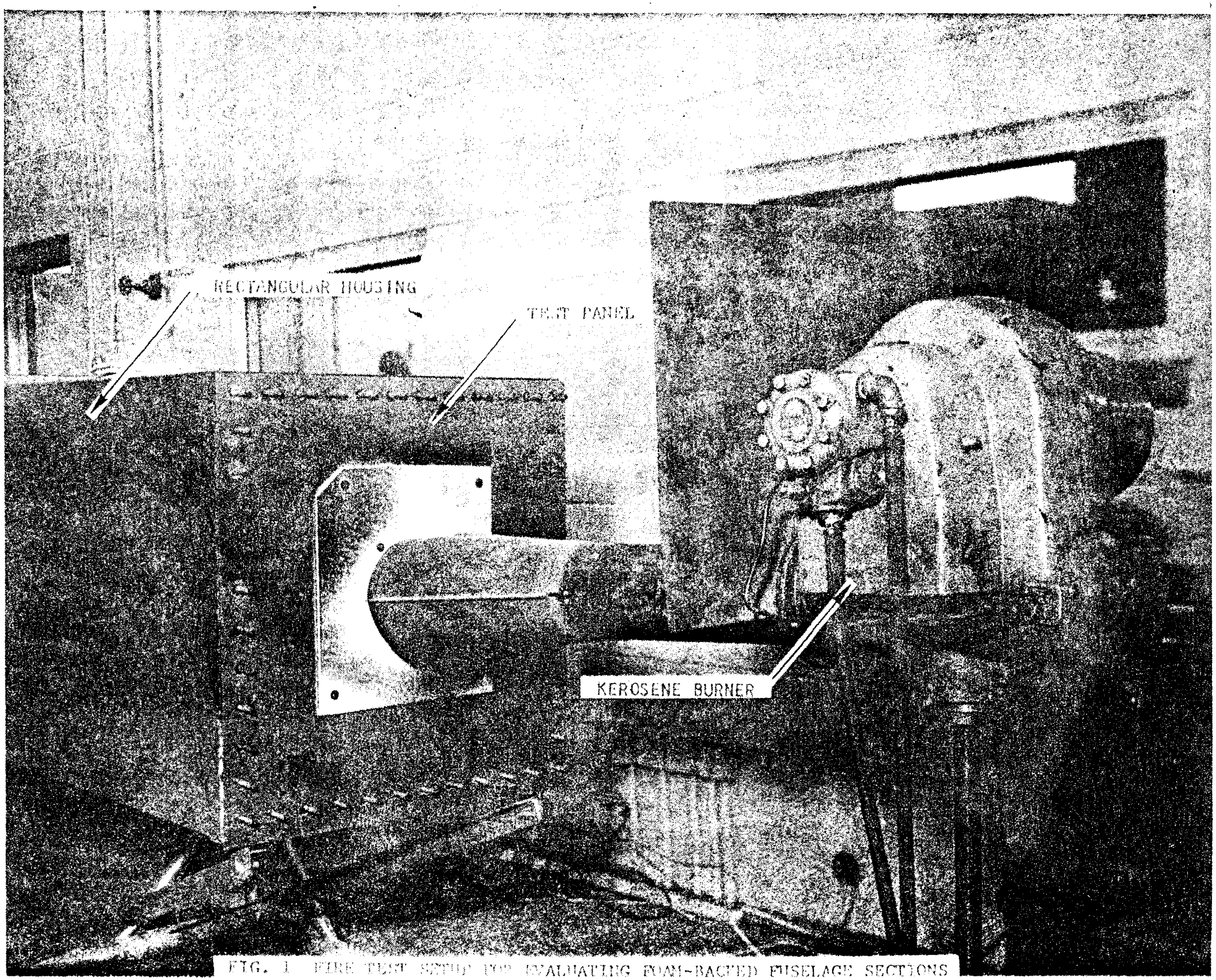

FIG. 1 FIRE TEST SETUP FOR EVALUATING FOAM-BACKED FUSELAGE SECTIONS

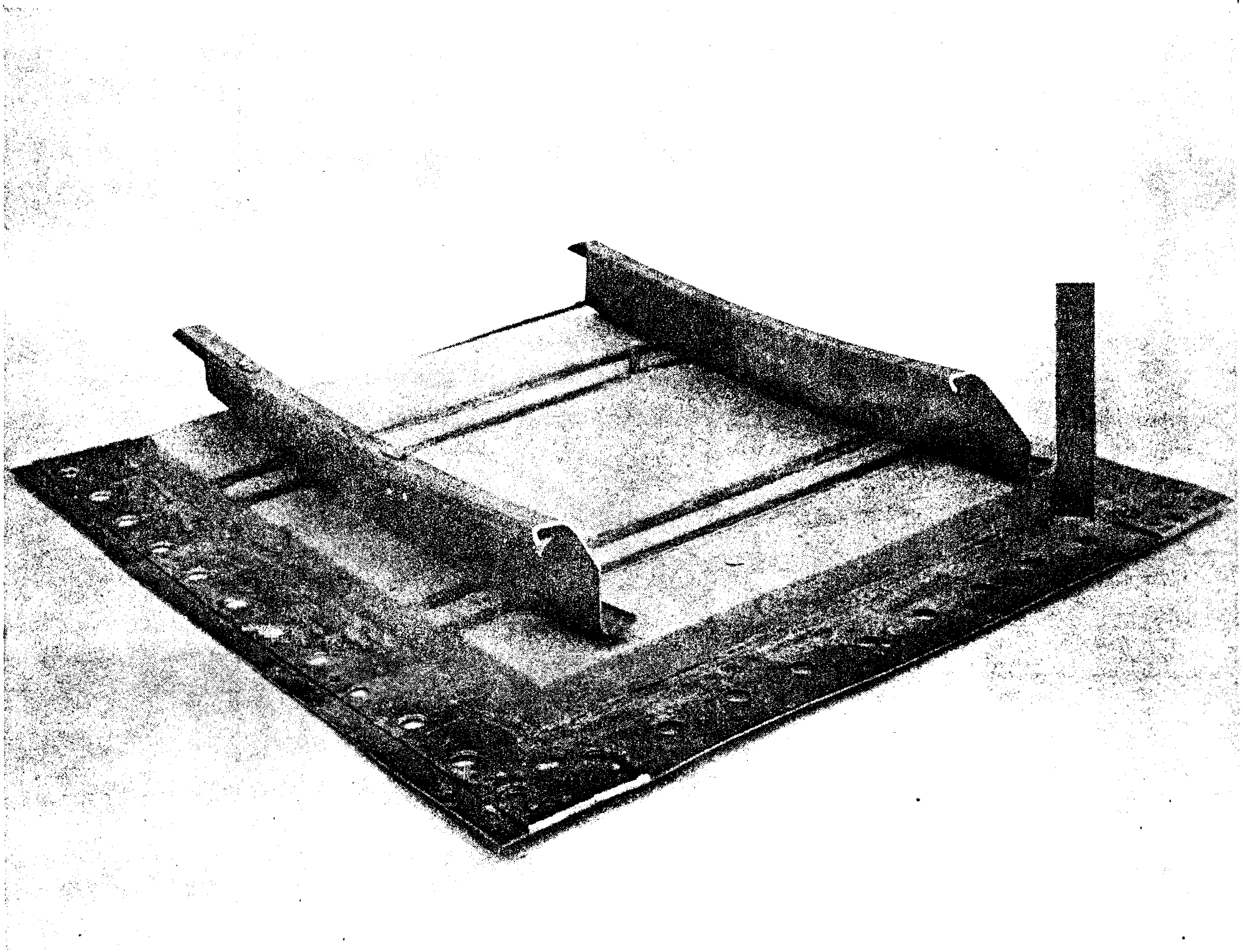

FIG. 2 FUSELAGE SECTION BACKED WITH QUARTZ-REINFORCED, POLYURETHANE FOAM APPLIED TO THE STRINGER DEPTH (PANEL #1)

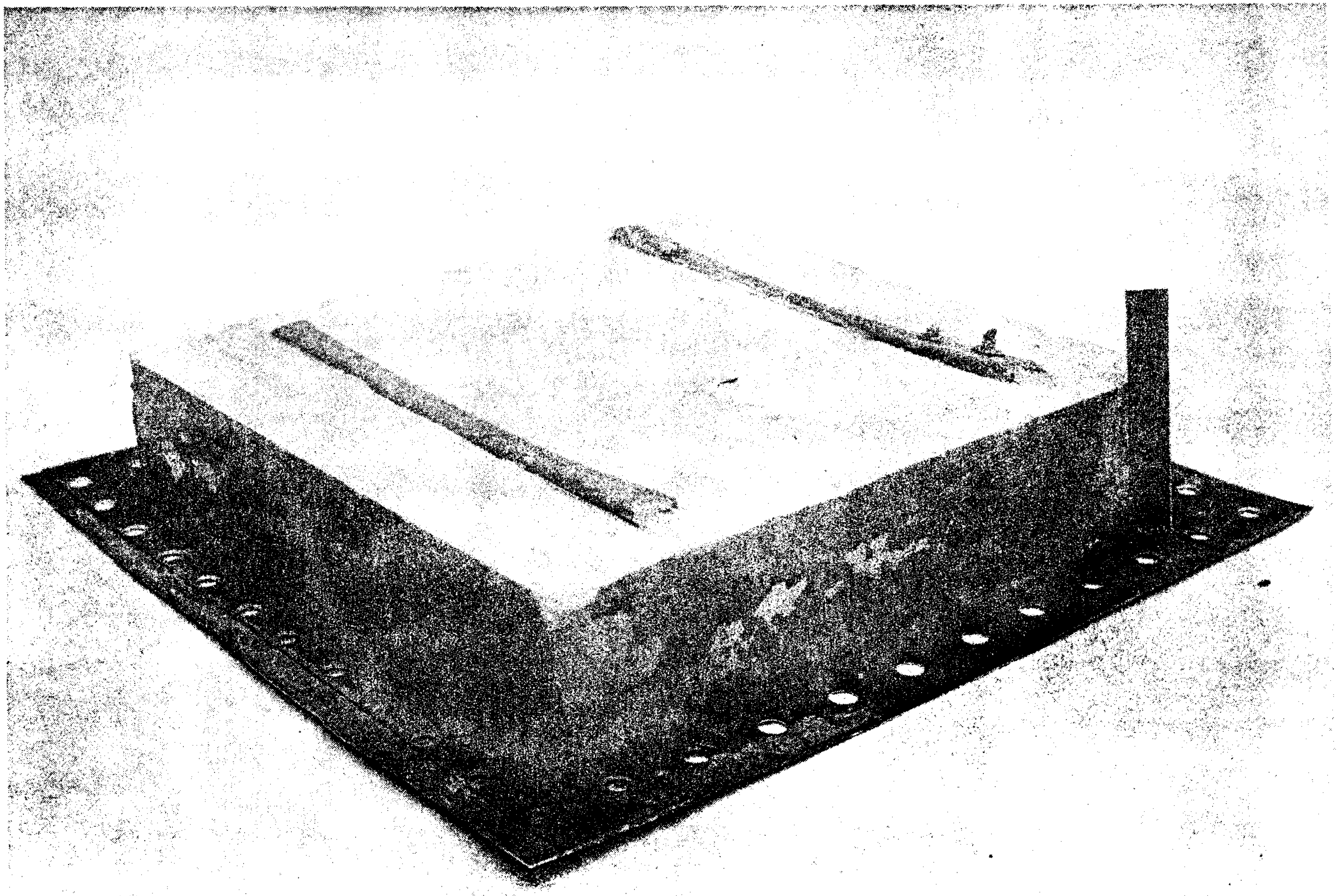

FIG. 3 FUSELAGE SECTION BACKED WITH ISOCYANURATE FOAM APPLIED TO THE FORMER DEPTH (PANEL #3)

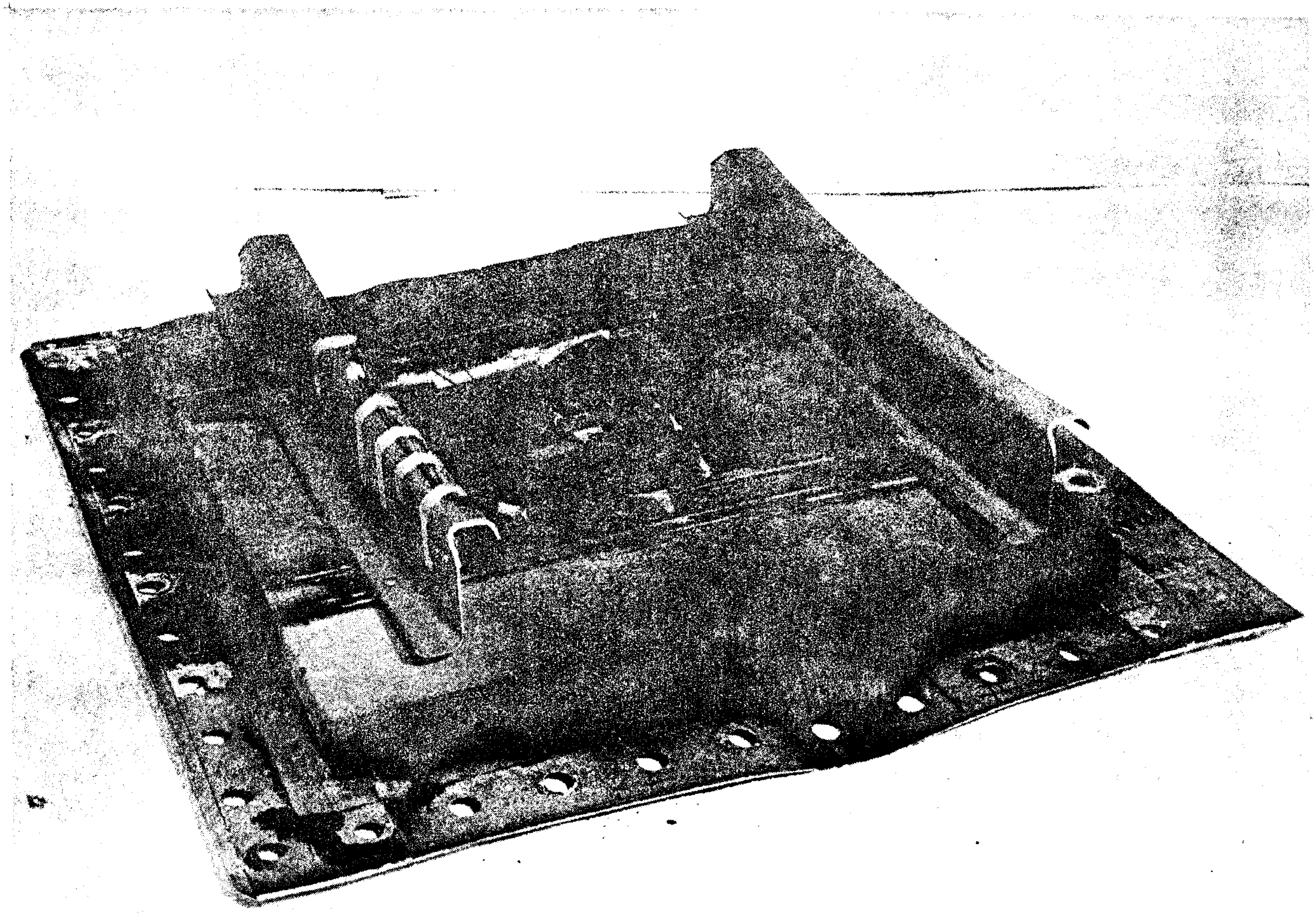

FIG.4 FUSELAGE SECTION BACKED WITH QUARTZ-REINFORCED. POLYURETHANE FOAM APPLIED TO THE STRINGER DEPTH (PANEL #1) AFTER 7-MINUTES FIRE EXPOSURE

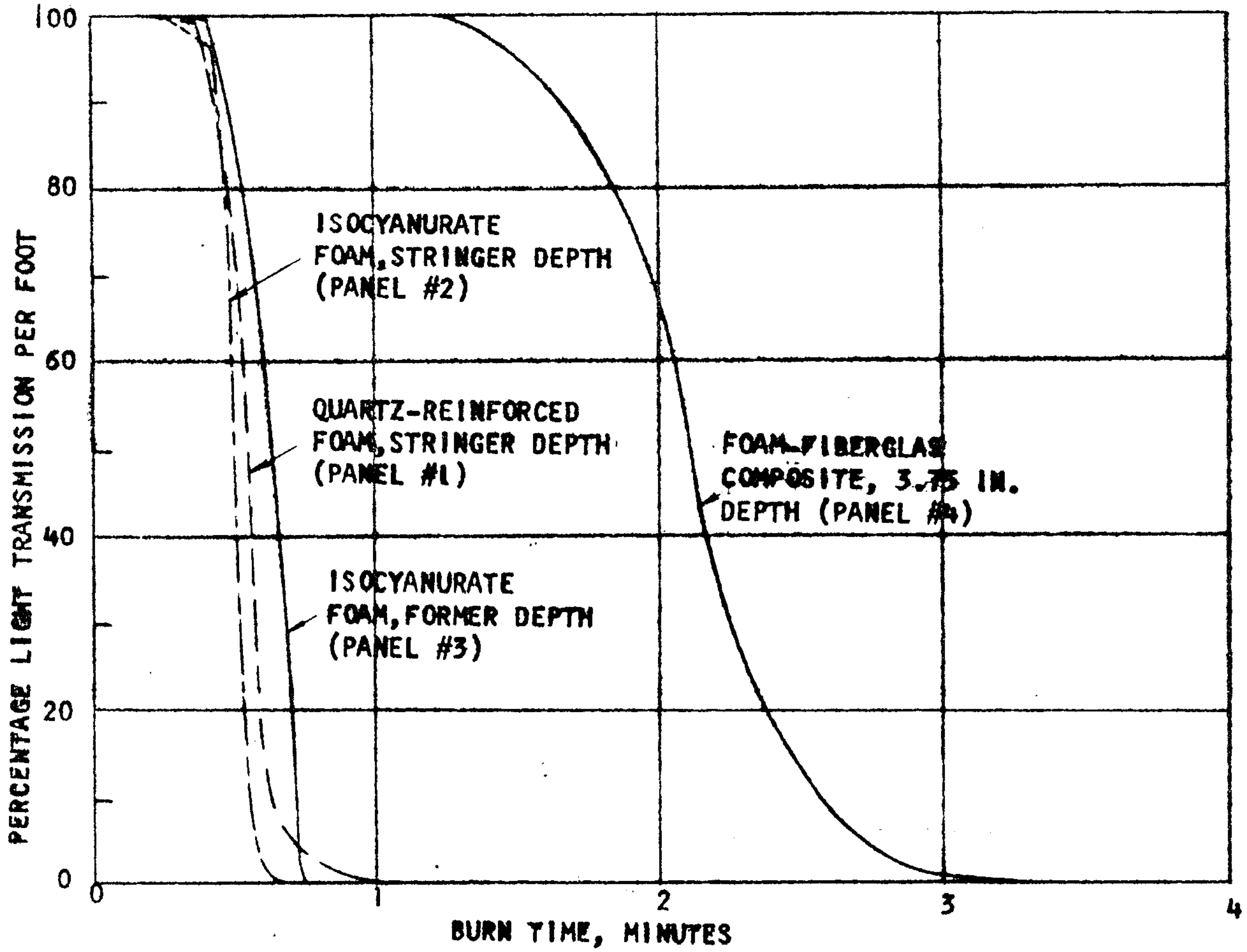

FIG. 5 SMOKE ACCUMULATION INSIDE TEST HOUSING FROM BURNING FOAM PANELS

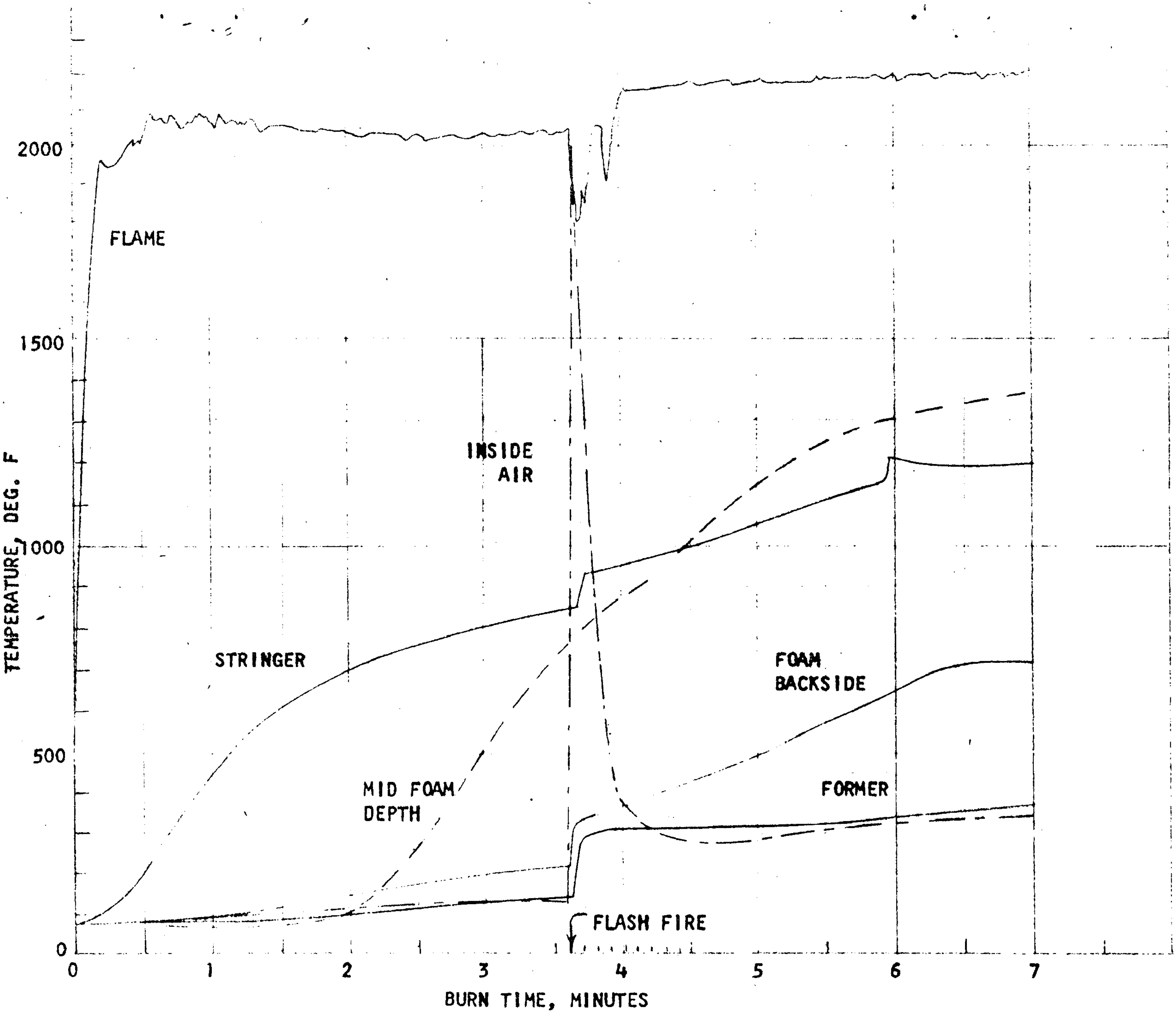

FIG. 6 TEMPERATURE DATA FOR FUSELAGE SECTION BACKED WITH QUARTZ-REINFORCED POLYURETHANE FOAM APPLIED TO THE STRINGER DEPTH (PANEL # 1)

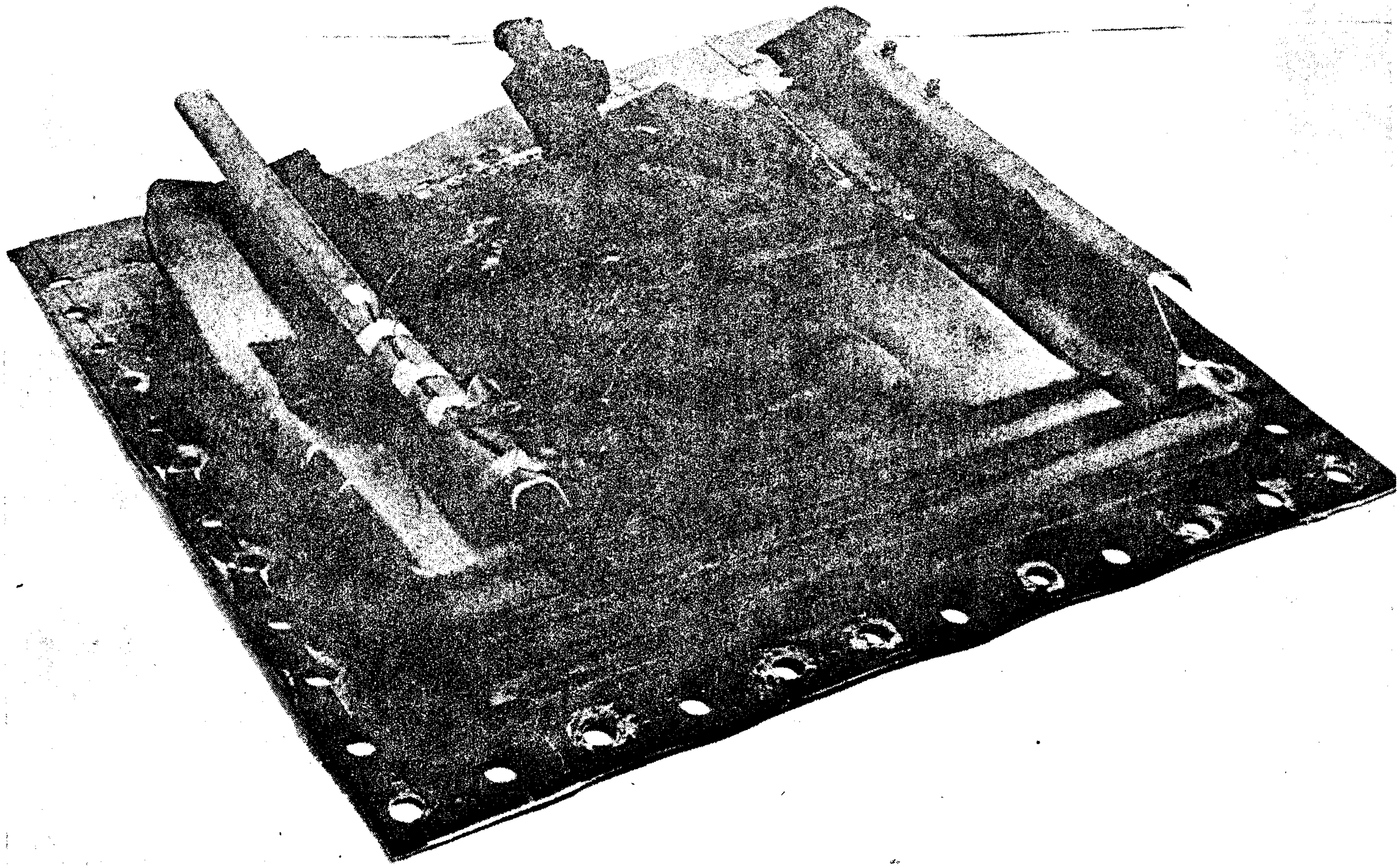

FIG. 7 FUSELAGE SECTION BACKED WITH ISOCYANURATE FOAM APPLIED TO THE STRINGER DEPTH (PANEL #2) AFTER 5-MINUTES FIRE EXPOSURE

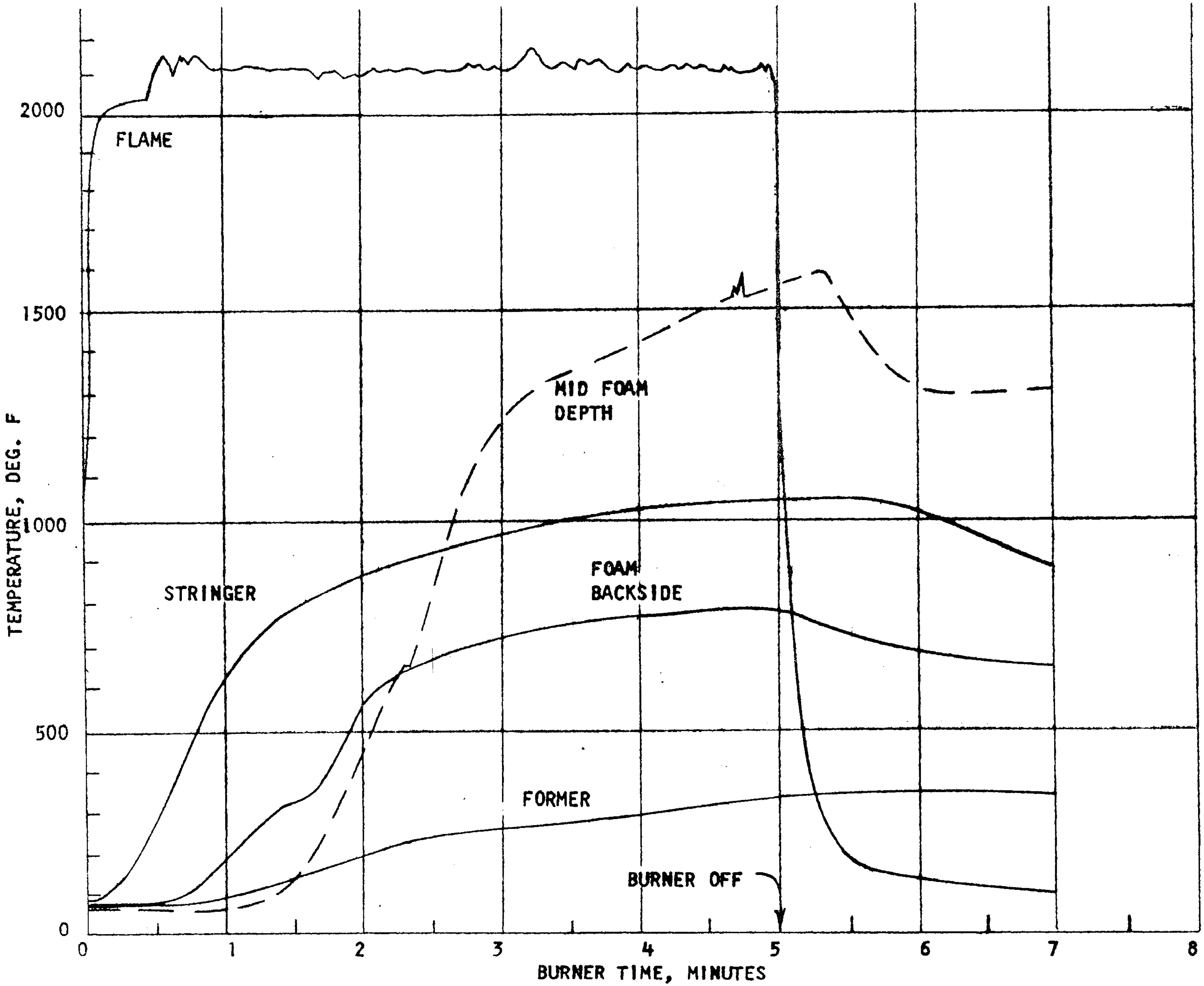

FIG. 8 TEMPERATURE DATA FOR FUSELAGE SECTION BACKED WITH ISOCYAURATE FOAM TO THE STRINGER DEPTH (PANEL #2)

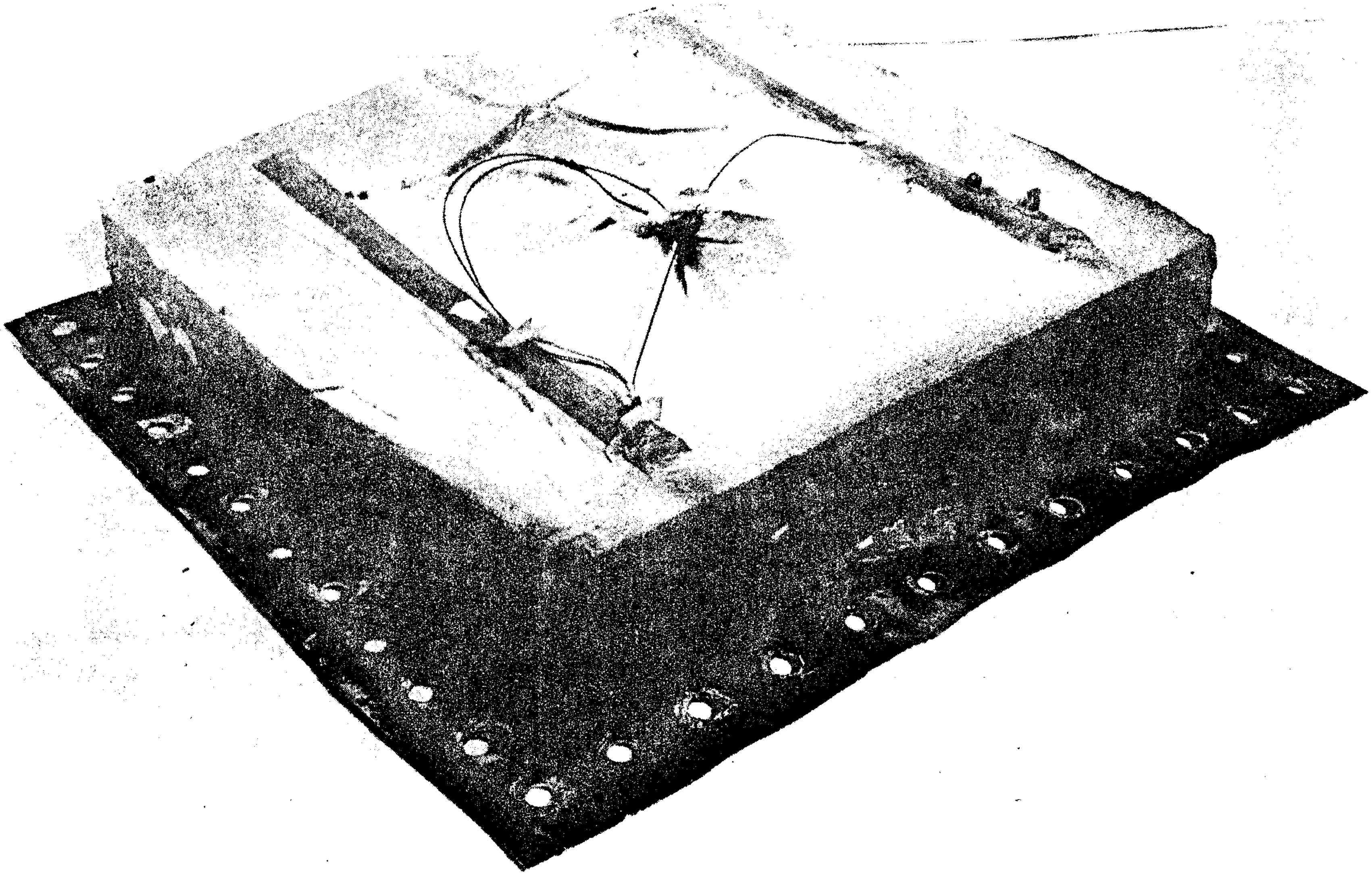

FIG. 9 FUSELAGE SECTION BACKED WITH ISOCYANURATE FOAM APPLIED TO THE FORMER DEPTH (PANEL #3) AFTER 10-MINUTES FIRE EXPOSURE

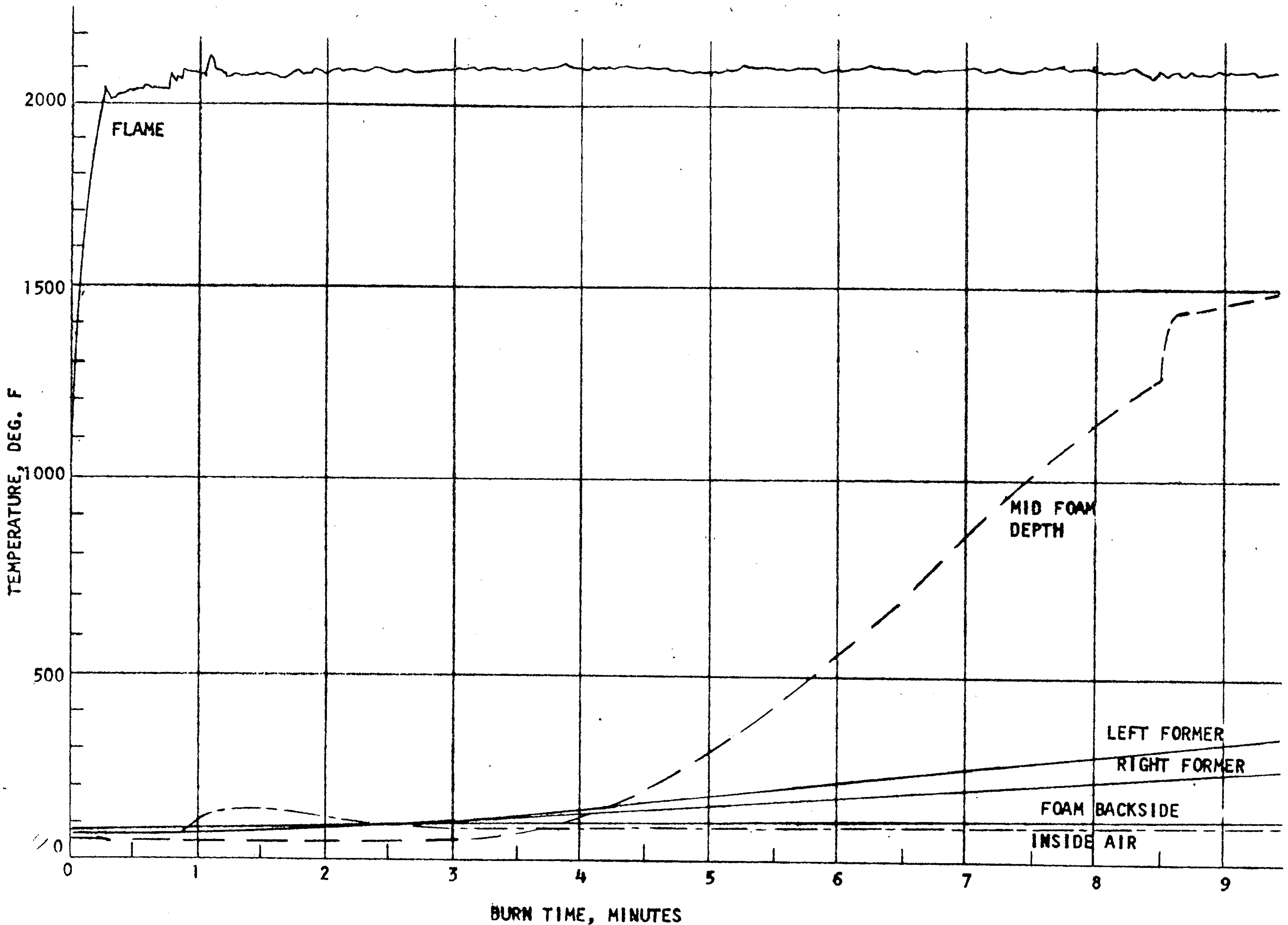

FIG. 10 TEMPERATURE DATA FOR FUSELAGE SECTION BACKED WITH ISOCYANURATE FOAM APPLIED TO THE FORMER DEPTH (PANEL #3)

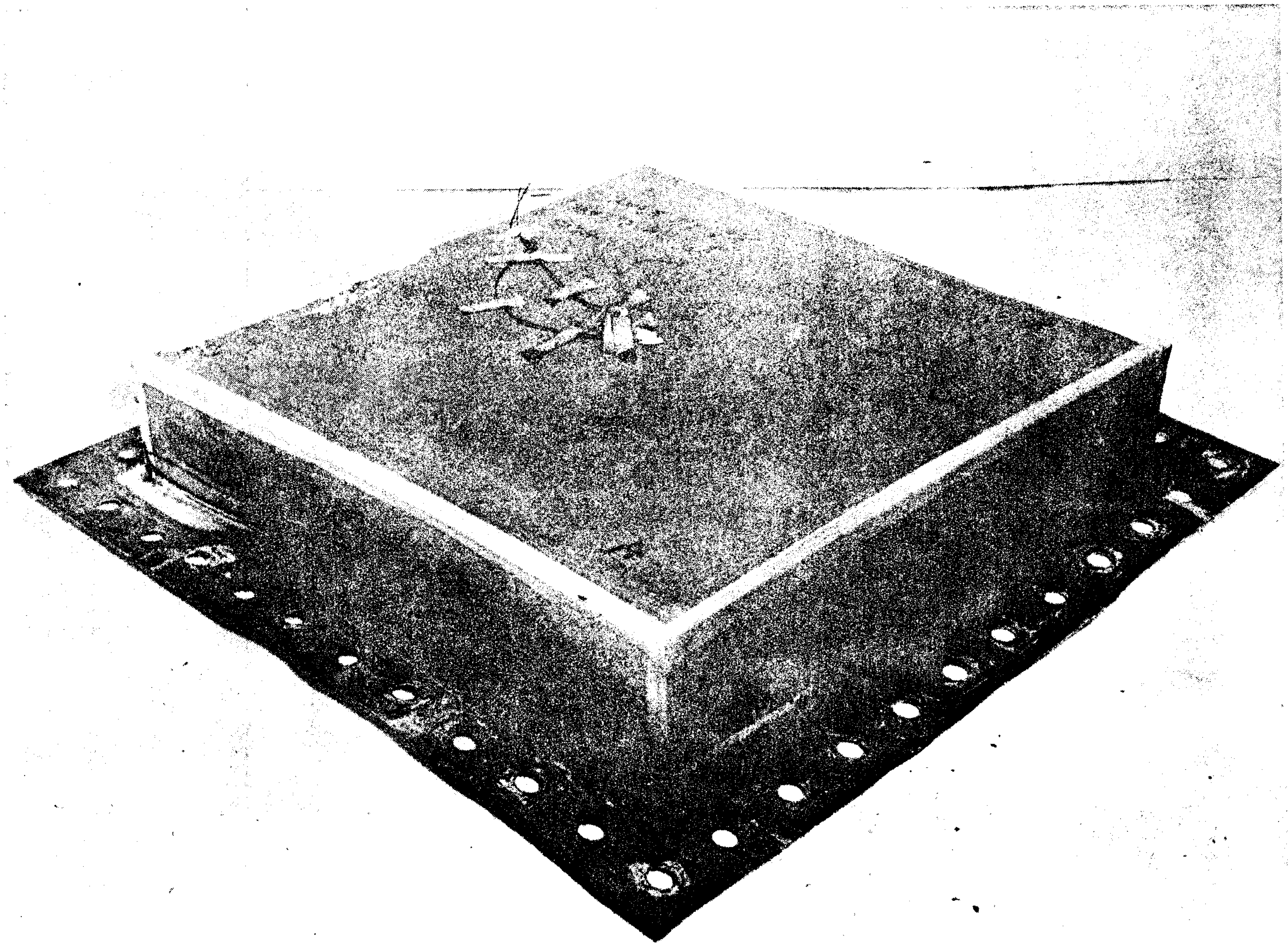

FIG. 11   FUSELAGE SECTION BACKED WITH 3 3/4" FOAM/FIBERGLAS
COMPOSITE AFTER 10-MINUTES FIRE EXPOSURE

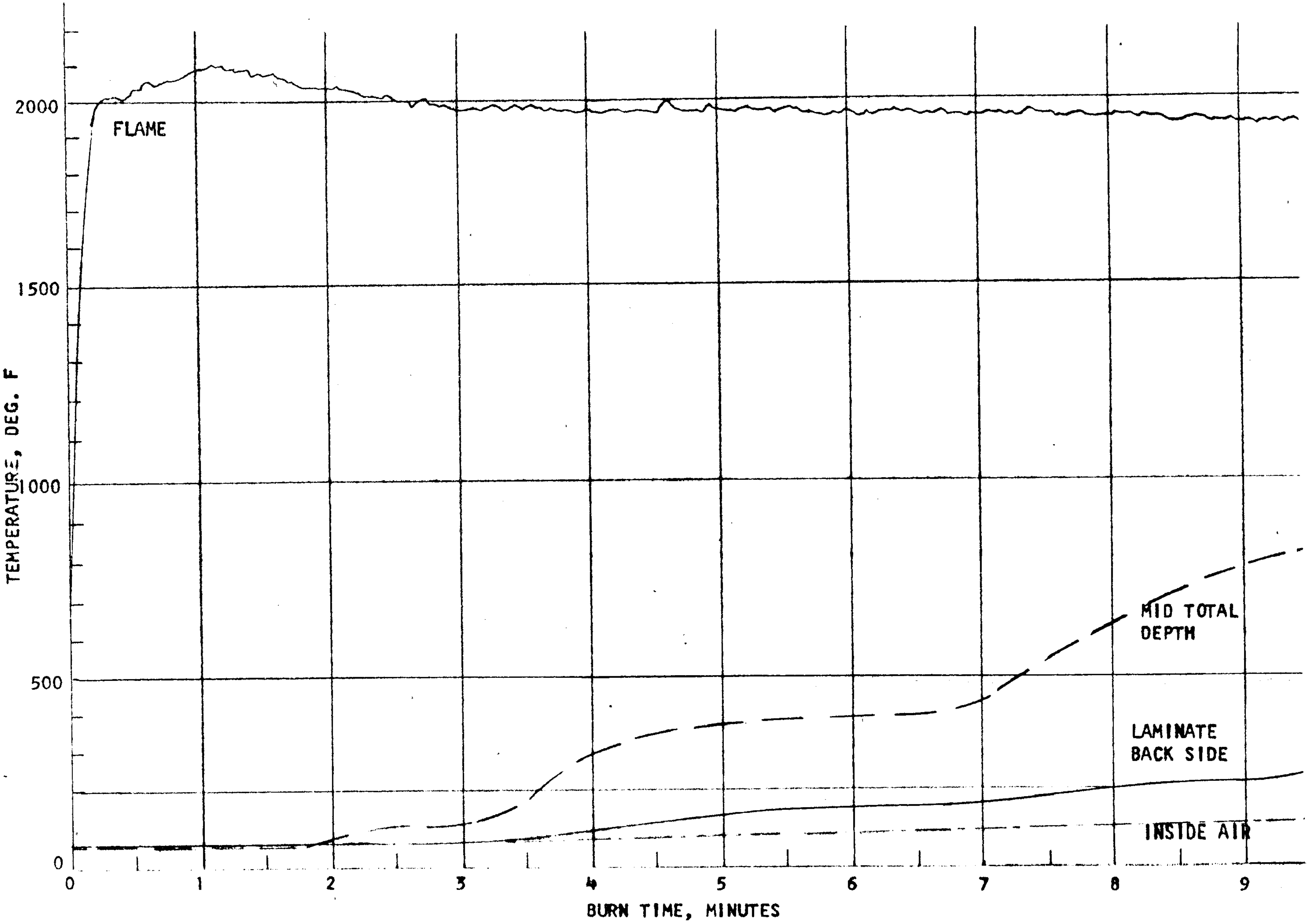

FIG. 12 TEMPERATURE DATA FOR FUSELAGE SECTION BACKED WITH 3 3/4" FOAM/FIBERGLAS COMPOSITE (PANEL #4)