NA-543
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FAA-ADS- 44

A STUDY OF AIR TRANSPORT PASSENGER CABIN FIRES AND MATERIALS

TECHNICAL REPORT

DECEMBER 1965

by
John F. Marcy
National Aviation Facilities Experimental Center

FEDERAL AVIATION AGENCY
AIRCRAFT DEVELOPMENT SERVICE

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This report was prepared by NAFEC
under Project 510-001-05X
for the Aircraft Development Service

THE RESULTS PRESENTED HEREIN WERE OBTAINED DURING THE PERIOD 1962-1964 AND APPLY TO TYPICAL FOUR-ENGINE PISTON POWERED AIRCRAFT.

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SUMMARY

A study of the combustion characteristics of aircraft cabin interior materials was made to establish the relative fire hazards inherent in aircraft. Standard laboratory tests were conducted on each of the cabin interior materials used in a four engine civil transport to determine their flammability, smoke and toxic characteristics. In addition to the laboratory tests, fire tests were conducted "in situ" inside an airplane fuselage at different locations to determine the relative ease with which the materials would ignite and burn. In these tests, time for self-ignition, rapidity of flame spread, extent of burned area, smoke and toxic gas produced were obtained for various sizes of ignition sources with and without normal ventilation.

A study revealed that the most important factor affecting the degree of fire hazard present inside an aircraft cabin was the flammability of the material in which fire originates. It was shown that materials which have superior self-extinguishing properties are poor ignition sources and confer a high degree of fire protection to the aircraft interior. In the large-scale fire tests, it was shown that the interior materials used in a passenger cabin can produce a flash fire with little or no warning. Heat, smoke and toxic gases generated by the fire up to about the time of the flash fire were low compared to human survival limits.

INTRODUCTION

This investigation was conducted to obtain a better understanding of the nature and extent of the fire hazard within the passenger cabin of a modern air transport aircraft and to determine the ease of ignition, rate of flame propagation and the amounts of smoke and toxic gases produced by cabin materials used in interior furnishings and construction.

BACKGROUND

Minor passenger cabin fires often occur in airline operation and have been discovered in sufficient time to be extinguished without causing any harm to passengers or serious damage to the aircraft. Most of the fires were traceable to the carelessness of passengers smoking which frequently involved the seat upholstery. In several cases, fire developed inside the air duct at the floor level and was caused by the ignition of an accumulation of highly combustible debris fanned to a blaze by ventilation air. In at least three fires, which occurred in unoccupied large jet transports, the fire remained undetected and resulted in extensive damage to the interior of the fuselage. In one fire of this type, the entire fuselage was destroyed by fire.

The cabin fire problem, resulting from the use of large quantities of combustible material in aircraft interiors is currently being investigated. A regulatory safeguard for limiting fire hazard is contained in FSS Release 259, dated August 26, 1948. This release specified the use of flame-resistant interior cabin materials for aircraft and established both a fire test method for evaluating materials and a maximum allowable burn rate in the horizontal position of four inches per minute.

An event that sparked renewed interest in the problem of fire protection in this area was the occurrence of a cabin fire in a four engine modern jet transport in February of 1961 (Reference 1) which gutted the interior. The airplane was at the time unoccupied and parked on the ground. Subsequent tests by the manufacturer on a mock-up of this airplane demonstrated the vulnerability of the interior materials to a large-scale fire.

Subsequent to the above mock-up fire tests, a comprehensive program was instituted by the Federal Aviation Agency to study the characteristics of typical transport materials. A report (Reference 2) covering the first phase of the program was published. This report gave the results obtained from standard laboratory tests on the flammability ratings of some 100 materials which had been selected as a representative cross section of all materials used in modern large commercial air transports. Extensive fire testing on interior materials has also been carried on in recent years by some of the large aircraft companies (Reference 3 and 4).

The present report contains the results of the second phase of the project. The earlier laboratory fire tests on individual samples of interior materials was extended to include full-scale tests on the materials inside the aircraft under conditions simulating normal operation. The test article used in the test program consisted of a civil transport fuselage with complete cabin furnishings and interior decor. At the time the test program was initiated, this airplane was being phased out of airline operation. Although this particular airplane had been built less than eight years ago, the composition of the interior materials differed markedly from those materials currently used in modern jet transports. Leather and wool, used in great abundance in the older type transports, have been replaced in large part by the synthetics and plastics typical of the modern jet transport. Of even greater significance to the fire hazard is the decline in the use of latex foam padding for the seats. The newer type cabins instead use polyurethane or other foamed plastics which have, to a great extent, replaced latex.

Materials differ markedly in their ability to ignite, burn and withstand exposure to fire. The two main categories of materials are combustible and non-combustible. Most interior materials belong to the first group which includes natural and synthetic fibers, leather and a variety of plastics. In certain applications, as in aircraft construction, safety requires that the materials withstand fire for a specified time limit or if ignited, burn no more than at a specified rate. Test methods (Reference 5) have been developed and limits set for the classification of materials in accordance with their ability to burn or withstand the effects of heat.

These classifications in decreasing order of severity are: (1) fireproof, (2) fire-resistant, (3) flame-resistant, and (4) flash-resistant. The particular classification which applies to the interior materials is that of flame-resistant. At present, Federal Regulations require that materials meeting this classification shall not propagate flame at a rate greater than four inches per minute in the horizontal position.

In addition to the flame propagating characteristics of materials, there are other important factors that need to be investigated. Some of these are: (1) flash-point temperature, (2) self-ignition temperature, (3) flame-spread index, (4) potential and rate of heat release and (5) tendency of the material to smolder, smoke and produce toxic combustion products as these affect visibility and survival. These factors are all related to the general fire problem of concern to aviation safety and were considered in this report.

DISCUSSION

Test Equipment Description

1. Laboratory Tests

a. Horizontal Rate of Burning Apparatus: This apparatus is used in both the FSS Release 453 and Federal Specifications CCC-T-191b, Method 5906 (Reference 6).

b. Vertical Rate of Burning Apparatus: This apparatus is used in Federal Specifications CCC-T-191b, Method 5902 (Reference 6).

c. Radiant Panel Flame-Spread Apparatus: This apparatus is used in Federal Specification 00136a and was developed by the National Bureau of Standards (References 7 and 8).

d. Flash and Self-Ignition Temperature Apparatus: This apparatus was originally developed by the U. S. Bureau of Mines, Department of the Interior, in cooperation with the Navy Department, Bureau of Ships, for use with plastics. (Reference 9).

2. Full-Scale Tests

a. Test Article: This consisted of a transport fuselage with complete cabin furnishings. All fire tests were conducted in the main passenger cabin. Tests were performed on the original equipment and on replacement materials with improved flame-resistant qualities.

b. Temperature Recording: This was accomplished by use of #26AWG wire chromel-alumel thermocouples connected to potentiometer recorders of both the continuous and scanning types.

c. Flame and Fire Propagation Recording: This was accomplished by visual observation and by the use of 16 mm color movie cameras, supplemented by temperature rise data as obtained by thermocouple recordings.

d. Smoke Recording: This was accomplished by means of a smoke meter connected to a continuous potentiometer recorder. The apparatus consisted essentially of an incandescent light source at one end of a tube and a Weston 856 photocell at the other end which measured the absorption of light by smoke through a distance of one foot.

e. Carbon Monoxide, Carbon Dioxide and Oxygen Concentrations Recording: This was accomplished by infrared and paramagnetic type gas analyzers connected to continuous potentiometer recorders. Gases were sampled continuously through two, 1/4-inch copper tubes at two levels, one at the ceiling and the other directly above the window both in the immediate vicinity of the fire tests. Full-scale range of the analyzers were for carbon monoxide measurements 0 to 500 PPM and 0 to 5000 PPM, for carbon dioxide 0 to 25% and for oxygen 25 to 0%.

f. Trace Toxic Gases Concentration Recording: This was accomplished by the use of two liter vacuum cylinders connected to three separate 1/4-inch copper tubes for sampling gases at three locations. Chemical analysis of the gas samples was performed by a commercial testing laboratory using a series of reagent tubes specific for each gas.

Test Procedures and Measurements

1. Laboratory

a. Flammability Tests: Materials were cut out of the airplane cabin and subjected to standard fire tests. Tests were conducted on both the surface and backing materials, singly and in combination. New materials with superior flame-resistant properties, selected for comparison with the original transport furnishings, were likewise tested.

b. Flash-Point Temperature, Self-Ignition Temperature and Toxic Gas Concentration Tests: Materials were cut out of the airplane cabin and these, with the new materials, were shipped to a commercial testing laboratory for standard tests.

c. Radiant Heat Tests: The back cushion assembly of the cabin seat was subjected to the heat of seven 375-watt infrared lamps.

Temperature at which the material became self-flaming and the rapidity of flame spread at elevated temperatures were measured.

2. Airplane Cabin

a. Fifteen-Second Fire Exposure Test Series: A Bunsen burner attached to a three foot handle and fed from a small propane tank was held rigidly against various parts of the interior of the cabin for a period of fifteen seconds. The flame was adjusted to a height of 1 1/2 inches. The severity of this flame was equal to that of the flame used in the standard laboratory tests. These tests were designed to determine whether or not the materials were self-extinguishing under a short exposure time. Maximum fire damage resulting from this type of exposure was also determined.

b. Continuous Fire Exposure Test Series: Tests were performed utilizing the same burner as described previously. The burner flame was held in contact with various parts of the cabin until the material subjected to the fire would either start to flame or would show no further tendency to burn at which time the burner was removed. Measurements were made of: (1) time required for the material to start to flame of its own accord, (2) time that flaming persisted after removal of the ignition source, (3) cabin temperature and humidity, (4) smoke density, and (5) carbon monoxide, carbon dioxide and oxygen concentrations. When a severe fire developed, it was extinguished with water or carbon dioxide.

Tests were repeated with the burner flame size increased to 10 inches in height when the less flammable materials could not be ignited to a self-sustaining fire with the 1 1/2-inch burner flame.

Due to the difficulty of igniting floor materials from above with a gas burner, these materials in some tests were also heated electrically (800 watts) from underneath. In addition, in a few tests, hexamethylmine powder was spread on the floor and burned to increase the fire intensity.

Air flow of 1100 CFM provided normal ventilation to the cabin so that the influence of this factor on the propagation of the fire could be determined. Tests were conducted with and without air flow at different locations within the cabin for direct comparison.

In the last two tests in the series (Test Nos. 41 and 42), the fire was allowed to burn out of control. In addition to the measurements already mentioned, the cabin was instrumented for recording air and surface temperatures throughout the test area. Also, air samples inside the cabin were taken by evacuated bottles at various intervals during the fire tests. These bottles later were shipped to a testing laboratory for chemical analysis of the combustion gases.

Test Results and Analyses

1. Laboratory Fire Tests:

The tests were conducted on sample pieces of the material subjected to standard tests. Used materials which were part of the original cabin equipment and new materials intended for partial re-upholstery of the interior of the cabin were included in the test program. The materials tested are listed in Table I. The table shows the location, use and composition of each material in the cabin. Also listed are the corresponding test numbers for identification with other test data.

Test data on the relative flammability of the interior materials, as obtained in the horizontal position, vertical position and radiant panel tests, are given in Tables II, III and IV. The results of these tests show that the only fabric or covering materials used in the cabin interior which were not self-extinguishing in the horizontal position were the wool curtains and cotton headrest covers. In the vertical position which constituted a more severe test, the wool seat covers were also found not to be self-extinguishing. Aside from these materials and the latex and polyurethane foams, all the other materials were considered to have good flame resistance. None of the materials tested failed to satisfy the present regulations requiring a burn rate not to exceed four inches per minute.

Increased flame resistance of the curtains and seats, as shown by the test data, was accomplished by substituting modacrylic (Reference 10) for wool, vinyl fiberglas for vinyl cotton (simulated leather) and vinyl foam (References 11 and 12) for latex foam. These new materials were self-extinguishing in the horizontal and vertical positions with a relatively short burn length.

Covering materials singly and in combination with the back-up materials with which these materials form an assembly as in the cabin furnishings were exposed to the standard radiant panel fire test. This test may be considered more representative of an actual fire especially when the padding materials, such as latex foam, are more flammable than the covering material as is usually the case with the cabin seats.

The results of the radiant panel tests are given in Table IV with data on the relative amounts by weight of smoke produced by the burning materials. It should be noted that flammability of the materials increases directly with the flame-spread index number.

The test data show that the seat cushion in the original cabin equipment had a flame-spread index of 670 (red oak 100) compared to an index of only 1.6 with the new seat materials. Similar improvements brought about by the use of the new materials in other parts of the cabin interior are also shown. Unlike most synthetic fabrics tested, the modacrylic plastic fabric did not show any visible flaming when exposed to radiant heat. However, the fabric does char readily when exposed to heat compared to wool and forms a tenuous black crust unlike nylon and other synthetics which melt to form burning droplets. The effectiveness of a fiberglas fabric covering material in reducing significantly the flame-spread index figures for the sidewall, hatrack and liner of the cabin is shown in the table from a comparison of the figures given for both the original and new materials. The low index figures obtained for much of the cabin with the original materials and with all the new materials are directly related to the difficulty of setting fire to the cabin interior as was experienced and reported later in the full-scale fire tests.

Test data on the ignition, burning and smoke characteristics of the cabin materials are given in Table V. The data show that the flash-point temperature of latex foam (324°F) is considerably lower than vinyl foam (741°F) or that of any of the other materials tested. The material with the lowest self-ignition temperature (675°F) was the vinyl cotton fabric (simulated leather) used in the armrest covering as original material. The densest smoke was produced by the foam padding materials.

Test data on the relative concentration of gases (Reference 13 and 14) liberated during the burning of the sample materials at a temperature of 1150°F in the laboratory tests are given in Table VI. Also shown in the table are the concentrations of gases obtained during the large-scale fire tests inside the cabin. The MAC figures (Reference 15) or maximum allowable concentration in parts per million of air for an eight hour exposure of each of the suspected gases is also listed in the table. The purpose of the MAC column was only to provide some relative comparison of the toxic hazard between each of the gases detected.

Gas concentrations obtained in the laboratory tests which are shown to exceed the MAC values do not necessarily indicate that a toxic hazard would develop in a cabin fire. As shown in the test data, the number of gases produced by any one sample may be large. Methods of identifying and measuring the specific gases by modern techniques, such as mass spectrometry, were not successful in earlier tests. Chemical analysis is difficult and time consuming. The most readily available and direct means for both qualitative and quantitative determinations would seem to be provided by reagent tubes specific for each single chemical compound or group of related compounds such as the halogenated groups. Of special interest in the laboratory tests were the large concentrations of hydrogen chloride, hydracyanic acid, unsaturated hydrocarbons and halogenated hydrocarbons obtained with the modacrylic fabric. Also to be noted was the large arsine concentration obtained with plywood. In general, carbon monoxide proved to be the most significant toxic gas.

The fire tests, both in the laboratory and in the airplane cabin, were conducted on the materials essentially at room temperature. Thus, a separate investigation was undertaken to determine the increase in flammability with preheating of the materials which would be more typical of the later stages of a large-scale fire. In the tests, a seat cushion was subjected to the radiant heat of a bank of infrared lamps. With the wool seat cover heated to a surface temperature of 250°F, the cushion in contact with the standard 1 1/2-inch burner flame became flammable in 5 to 6 seconds, and within 20 seconds, the entire seat was enveloped in flames. It was also found that when the interior latex temperature of the cushion reached 410°F, the gas vapors arising above the seat could be ignited by a match causing the cushion to flame rapidly. This test would tend to confirm the very low flash-ignition temperature obtained for latex foam in the laboratory tests as shown in Figure V.

2. Airplane Cabin Fire Tests

a. Short Exposure Fire Tests: In a series of preliminary tests, the 1 1/2-inch standard burner flame was applied to various parts of the cabin interior for a period of fifteen seconds, then removed. This is consistent with current interpretation of FSS Release 453 test requirements. The only material that was not self-extinguishing and continued to burn after fifteen seconds was the wool curtain material. Repeating this test with a paper safety match, the material developed a self-sustaining flame in less than ten seconds and could have caused a major fire in the cabin if not extinguished. None of the other materials, including the seat upholstery, continued burning. The maximum charred area, aside from the curtain, was about 2 inches by 4 inches. The foam padding of the seats and other backing materials were not affected by this mild fire exposure. No effect of cabin ventilation air flow on the fire was noted.

b. Fire Test Nos. 1 to 40: The location of the tests in the cabin are shown numbered in Figure 1. Of the forty-two tests conducted, only in the last two tests (Test Nos. 41 and 42) were the fires allowed to get out of control and envelop the whole interior of the cabin. A summary of the fire test data is given in Table VII.

For the first group of forty tests, the data show that in only eight tests did the fire continue to burn to the extent that it had to be extinguished to prevent a major fire. These larger fires occurred only in the seat cushion, wool curtain and sidewall over the air duct. Extensive fire damage resulted during two tests (Test Nos. 18 and 30) from the spread of fire from low flammable materials to the wool curtain and acrylic window pane which ignited and burned. The severe fire condition in the sidewall (Test No. 35) developed only after being pressurized with ventilation air flow which caused failure to the weakened vertical air duct. The result was that air was forced out through the sidewall and directly into the fire to fan the blaze. This was the only test which showed any significant effect of the presence of ventilation air flow on fire.

The minimum time required for the material under test to become flammable upon application of a constant ignition source and to burn of its own accord is shown in Table VII. Also shown is the maximum time flaming persisted for any one exposure after removal of the burner. Duration of the fire test varied from as low as four minutes to thirty minutes. The test was stopped when it became evident that continued burner exposure would not increase the size of the fire or would, if allowed to continue burning, cause excessive damage to the interior and endanger test personnel. The extent of flame spread with time for some of the larger fires and the damage inflicted are shown by the photographs in Figures 2 to 8. The data for the contour mapping of flame propagation were obtained from color motion picture film. The figures show the relatively slow initial increase in fire size in contrast to the rapid build-up in fire which occurred just prior to extinguishment.

The flammability characteristics of the new materials as compared to those of the original equipment are shown by the test data in Table VII. No serious fire hazard could be demonstrated using the 10-inch burner flame as an ignition source with the more flame resistant cabin interior materials.

The advantage of using fiberglas fabrics to protect the more flammable materials, such as foam padding, is apparent from the test results. Flame penetration and fresh air are prevented by the fiberglas fabric from reaching the backing material. Latex foam was seen to heat up very slowly and smolder as long as the seat upholstery material remained relatively intact. However, once the covering material was destroyed, the foam padding burned rapidly with an open flame.

Difficulty was encountered in extinguishing burning latex foam. Total immersion in water was required. Polyurethane foam burned more rapidly than either latex or vinyl foam, but unlike latex, it did not smolder. Of the three foam materials, only vinyl foam could not be ignited to a self-sustaining fire in the seat cushion tests summarized in Table VII.

Test personnel donned self-rescue breathing apparatus only during a few of the more severe tests for greater safety and comfort. Very little smoke and discomfort were experienced during all but a few of the fire tests.

Concentrations of smoke and carbon monoxide produced are shown in Table VII. The values given are comparatively low for the majority of fires. Dangerous concentrations of carbon monoxide only occurred during the latter stages of the large fires.

The relation between the various flammability ratings of materials, as established by different laboratory tests, and the extent of the fire hazard, represented by the same materials when ignited inside the cabin, is shown in Table VIII. Materials such as wool and latex foam with a high burn rate and flame-spread index suffered extensive damage in cabin fires in direct comparison to modacrylic fabric, vinyl foam and vinyl fiberglas which resisted ignition and burning.

c. Fire Test No. 41: Test No. 41 was conducted in the forward section, left-side area of the cabin which had been in part retro-fitted for this test with new materials of a more flame-resistant type. Instrumentation within the cabin is shown by the drawing in Figure 9. The test area, before and after the fire, is shown by the photographs in Figures 10, 11 and 12. Since the new materials would not burn beyond safe limits and were, in addition, self-extinguishing within the limits of the tests, it was necessary to use some of the original more flammable materials to start the fire. This was done by igniting the wool-covered latex foam cushion of seat No. 2 with a standard 10-inch burner flame. Seat Nos. 1 and 3, in front and behind the test seat, had been reupholstered with new materials for this test.

A self-sustaining fire over the forward edge of the seat cushion developed within less than one minute burner exposure. Progress of the fire over the top surface of the seat was slow. Smoke below the handrail was light and did not require that self-rescue breathing apparatus be worn by test personnel until 11 1/2 minutes after the fire test was in progress. The back cushion of the seat was observed to ignite only after 14 minutes (840 seconds) at which time the cabin was evacuated by test personnel and observations continued from the outside windows of the cabin.

Of special interest was the fact that test personnel did not experience any discomfort from heat or unusual difficulty in seeing through the smoke while inside the cabin. The occurrence of a flash fire followed evacuation of the cabin by less than one minute. Evidence of the flash fire was furnished by the sudden high pressure release of smoke from openings in the windows and through fuselage cracks. After the flash fire which had endured for about one minute and was smothered by lack of oxygen, the only fire that continued to burn was a deep seated fire inside the latex foam cushions of the test seat. This seat had to be removed from the fuselage before the fire could be brought under control.

Water proved ineffective in fighting this type of fire and the latex foam generally suffered complete destruction. Although CO_2 was dumped inside the cabin from a Cardox system following the flash fire, this was a precautionary measure designed to protect the fuselage. This action was believed to have been superfluous in view of the sudden drop in both oxygen and temperature following the flash fire.

The fire damage was extensive along the ceilings, upper sidewalls and the immediate area surrounding the seat that was set on fire for the test as shown by the photographs in Figures 10, 11 and 12. The modacrylic fabric curtains were completely charred by the severe fire and radiant heat exposure while the wool curtains were only partially charred. From this experience, it appears that self-extinguishing synthetic materials which are difficult to burn by a small ignition source may burn equally as well as the more flammable natural fiber materials when both are subject to a severe fire. The hatrack portion directly above the fire was severely damaged. The vinyl fiberglas fabric for the most part resisted flame penetration and provided considerable protection to the hatrack. The modacrylic fabric used on seat Nos. 1 and 3, adjacent to the seat that was set on fire (Seat No. 2), was severely charred (Figure 10). However, the exposed back of the cushion of seat No. 1 was only slightly charred (Figures 11 and 12). The modacrylic fabric on the front side of seat No. 3 was completely charred. The vinyl foam for this seat protected by a fiberglas cover underneath the modacrylic fabric showed no signs of fire damage. The wood paneling was slightly charred near the ceiling level. No damage, other than a slight puckering of the carpet near the test fire, was noticed. There was no discoloration of its vinyl cover from heat. The mohair rug did not show any visible signs of fire damage. The acrylic windows in the immediate fire area had been protected by a thin aluminum sheet and only showed slight damage (frosting). Smoke damage was extensive throughout the cabin. A greasy film was found deposited on the surfaces left undamaged by fire, especially on the metal surfaces and floor apparently from a condensation of volatiles and water vapor.

Air and surface temperatures of the interior of the cabin are shown by the curves in Figure 13. Only continuous recordings were plotted. Other temperature data obtained were only of limited use because of too low scanning speeds. Of significant interest was the very slow increase in temperature over a comparatively long period of time followed by an abrupt and extremely rapid rise which was followed by an equally rapid drop. Such a behavior pattern for the cabin fire would appear to be more closely related to a Class B fire (gases and liquid fuels) than to a Class A fire (solid combustible materials). The rapid flame spread from the fire source (Thermocouple No. 4) to the entire interior of the cabin occurred in a period of approximately 30 seconds. Self-extinguishment of the flash fire, as shown by the curves, was even more rapid. After extinguishment of the fire, the temperature returned to almost normal which implied that open flaming had ceased. The short duration of the fire was indicative of a relatively small amount of heat liberated during flash fire. Since the steep rise in the air temperature curves at various points may be assumed to correspond to the passage of flame, it was possible to calculate the rate of flame spread along the ceiling as being approximately 68 feet per minute.

There was a very slow increase in temperature for the first 13 1/2 minutes of the test. Smoke density, carbon monoxide and oxygen concentrations during the latter part of the fire test were plotted with temperature rise for time comparison in Figure 14. The curves show a very abrupt rise in carbon monoxide concentration from a relatively safe level of 100 PPM accompanied by a sudden rise in temperature after about 30 seconds. Decrease in oxygen content of the air from 20% or about normal to zero percent occurred almost simultaneously with increase in carbon monoxide. Smoke density increase with time was more gradual as shown in Figure 15. About 1 1/2 minutes before the flash fire, the smoke density suddenly increased to a higher level.

From the test results, it was concluded that from a safety viewpoint flame exposure rather than carbon monoxide inhalation, would be the primary danger to life (Reference 16). Smoke during the early part of the fire would likely be sufficient to cause serious discomfort and panic before the more serious effects of carbon monoxide and heat were felt.

The synergistic effect of combining toxic gases on the health hazard could not be considered in this limited study of the problem (Reference 17). Although the percent concentration for each of the toxic gases may be low compared to its MAC number, the total effect of all the gases on the health hazard can only be surmised.

d. Fire Test No. 42: Test No. 42 was conducted in the mid-section left-side area of the test cabin. Instrumentation within the cabin is shown in the drawings of Figure 16. The test area, before and after the fire, is shown by the photographs in Figures 17 and 18. All the materials in the test area, except for seat Nos. 2, 6 and 7, consisted of the original materials. The fire was started in exactly the same manner as in Test No. 41. Self-flaming time was about two minutes or twice the time required in Test No. 41. Presence of the fire could be detected at the rear of the cabin by odor in less than one minute. Due to more humid conditions of the cabin, the fire was slower in developing than in the previous test. Fire was confined entirely for the first 26 minutes of the test to the bottom seat cushion. The back cushion of the test seat ignited after 31 minutes. This was followed within one minute as in Test No. 41 by a flash fire. The outpouring of smoke from the cabin during this time interval made it impossible to continue visual observations. Following the flash fire, burning inside the cabin was allowed to continue unhindered for another 30 minutes at which time firemen and test personnel entered the cabin to determine the extent of fire damage and to extinguish any remaining fires still burning. Because of the extreme heat, it became necessary to abandon the cabin. Shortly after the doors and emergency windows were closed in preparation for dumping CO_2, a second flash fire occurred which was more violent than the first. Flames were forced out the camera openings in the acrylic windows. This experience demonstrated the danger of admitting fresh air to a confined smoldering fire.

Both carbon dioxide and water were used in large quantities to extinguish the fire. After about two hours, it was possible to safely re-enter the cabin to remove seats that were still smoldering. Damage due to delay in attempting to control the fire was much more extensive than in the previous test as seen in Figure 17 and 18. The intensity of the fire was so severe as to destroy the part of the hatrack above the fire and melt down the aluminum supports. The ceiling also suffered severe damage sufficient to melt the aluminum panel in the center section. Mineral wool insulation in the ceiling adjacent to the test fire showed severe deterioration. Both the modacrylic and wool curtains were completely charred by the fire. Seat upholstery utilizing modacrylic and wool were almost completely destroyed in the center area of the fire. Wood paneling showed extensive charring over the upper part of the side-walls and along the galley ceiling. However, only the thin veneer sheeting of the panel which tended to peel off was affected by the heat. All the acrylic windows showed some frosting due to heat melting the material. The window next to the fire burned through one layer of acrylic pane although protected by a thin aluminum sheet. Adjacent unprotected windows did not suffer any burn throughs. The portion of the hatrack and sidewall reupholstered with vinyl fiberglas fabric did not show any further deterioration from that in Test No. 41. Very little damage was experienced by the floor materials. The wool/latex cushions of the test seat were completely destroyed in the fire as shown in the photographs of fire damage in Figures 17 and 18. Seats shown missing had been removed from the cabin after the test to control the still smoldering fire in the latex foam. The seat behind the test seat (Figure 17) shows the destruction of the modacrylic upholstery. However, the fiberglas covering for the back cushion remained virtually intact and the vinyl foam padding was not affected by fire. Note that damage shown to the bottom cushion resulted from previous localized fire tests.

Continuous recordings of temperature inside the cabin are shown in Figure 19. The general pattern of the curves was similar to that in Test No. 41. The main difference was in the much slower drop in temperature following the flash fire. The time required for the air temperature in the cabin to drop to 400°F was about five minutes. The more combustible ceiling materials normally present in cabins were absent in this rerun test which had some effect on the test results.

The curves relating temperature, smoke, carbon monoxide, oxygen and pressure with one another are shown in Figure 20. The curves differ from those obtained in Test No. 41 by the more gradual rise in smoke density and oxygen deficiency. The cabin pressure curve is shown to follow closely that of the air temperature. Pressure drop following the flash fire was equally as rapid as pressure build-up. Cabin internal pressure only lasted about one minute.

CONCLUSIONS

Within the limits of the test conditions under which the project was conducted utilizing a large transport passenger cabin as a test article, it is concluded that:

1. Fire propagation throughout the interior furnishings of an aircraft cabin is only possible from the ignition of the more flammable materials. For the test cabin, these materials were limited to the curtains, seat cushions and pressurized sidewall ducts.

2. Flammability ratings of the individual interior materials as obtained in standard laboratory tests may be used to predict the degree of fire hazard present within any aircraft cabin.

3. Low flammable materials such as modacrylics, vinyl foam and vinyl fiberglas are available which are capable of greatly reducing the extent of the fire damage which may arise from fire incidents in passenger cabins.

4. The use of a fiberglas covering material to protect the more flammable underlying material such as foam padding from fire penetration is effective in reducing the extent of the fire damage.

5. Flame propagation from ignition of a latex seat cushion is slow to develop during an initial stage of 15 to 20 minutes. Once the flames have reached the top of the seat, further progress of the fire is greatly acclerated. Thus, from a relatively small fire that appears harmless, a dangerous flash fire may develop within a few minutes.

6. The most hazardous furnishings in the cabin interior were the wool curtains which were capable of being ignited by the flame of one ordinary paper safety match to cause a major fire.

7. Damage to the interior of the cabin by a flash fire is extensive with most damaged areas occurring above the window level, especially along the ceiling.

8. Occurrence of a flash fire in the cabin is accompanied by a rapid increase in flame propagation, smoke density, temperature, air pressure, carbon monoxide and oxygen deficiency.

9. Up to the time of the sudden occurrence of the flash fire, ambient temperature and carbon monoxide concentration inside the cabin continued to remain low compared to human survival limits.

10. Smoke as compared to heat or carbon monoxide would be the most severe factor affecting the safety and comfort of passengers during the early stages of the fire.

11. All the samples of cabin interior materials tested show that these produce a large number of trace toxic gases in addition to carbon monoxide.

12. Carbon monoxide occurs in greater toxic concentrations than that of any other gases present in the cabin atmosphere.

13. An extensive cabin fire was self-extinguished following a flash fire by oxygen starvation except for localized deep-seated smoldering fires inside latex foam cushions.

14. Low-flammable rated materials are capable of very rapid flame propagation and burning when subjected to the radiant heat from a large cabin fire.

15. The tendency of certain materials such as latex foam to continue smoldering after open flaming has ceased, greatly complicates the task of fire fighting.

16. Smoldering fires inside the cabin produce a flash fire when fresh air is admitted during fire fighting operations.

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TABLE I

AIRPLANE CABIN INTERIOR MATERIALS DESCRIPTION
AND
RELATED FIRE TESTS

Test Location	Cabin Fire Test No.	Equipment	Interior Materials Composition
Floor			
Aisle	4, 15, 16, 24, 25	Original	Mohair rug backed by cotton and jute.
Under Seat	3, 17, 22, 26	Original	Vinyl sheet bonded to neoprene pad.
Seat			
Base	5	Original	Red vinyl cotton fabric bonded to perforated aluminum sheet.
Side Arm	6	Original	Tan leather cover over 3/16 inch foam pad bonded to 1/8 inch pad bonded to aluminum sheet.
	7	Original	Tan simulated leather cover replacing leather above.
	34	Replacement	Gray vinyl fiberglas fabric replacing leather above.
Cushion	1, 2, 23, 41, 42	Original	Blue 100% wool cover over muslin cover over 4 inch latex foam pad.
	27, 28, 33	Replacement	Dark blue 100% modacrylic cover over vinyl fiberglas cover over 4 inch vinyl foam.
	36, 37	Replacement	Dark blue 100% modacrylic cover over vinyl fiberglas cover over 4 inch polyurethane foam.
	38	Replacement	Dark blue 100% modacrylic cover over 4 inch polyurethane pad.
Sidewall			
Below Window	8	Original	Red vinyl cotton cover bonded to hard board over 3/4 inch reddish insulation pad over 1 1/2 inch yellowish insulation batt.
		Replacement	Gray vinyl fiberglas cover replacing cotton fabric above.
Over Airduct	18	Original	Red vinyl cotton cover over 1/8 inch fiberboard liner.
	35	Replacement	Gray vinyl fiberglas fabric replacing cotton cover above.
Between Windows		Original	Gray vinyl cotton cover unsupported over 4 inch insulation batt.
		Replacement	Gray vinyl fiberglas cover unsupported over 4 inch insulation batt.
Curtain	40	Original	Gold 100% wool fabric.
	29, 30, 39	Replacement	Dark blue 100% modacrylic fiber.
Bulkhead	12, 13, 14	Original	Laminated wood 3/32 inch bonded to 1/2 inch paper honeycomb assembly bonded to yellowish insulation pad.
Window		Original	Triple acrylic panes each 5/16 inch thick.
Hatrack			
Lower Part	9, 20, 21	Original	Tan leather cover over 1/2 inch reddish insulation pad bonded to corrugated aluminum airduct.
	31, 32	Replacement	Vinyl fiberglas cover replacing leather above.
Middle Part		Original	Tan leather cover over 1/2 inch reddish insulation pad bonded to 1/8 inch laminated wood liner.
		Replacement	Vinyl fiberglas cover replacing leather above.
Upper Part		Original	Tan leather cover over 1/8 inch felt pad bonded to 1/8 inch laminated wood bonded to 5/16 inch paper honeycomb assembly.
		Replacement	Vinyl fiberglas cover replacing leather above.
Ceiling	10, 11, 19	Original	Gray vinyl cotton cover unsupported over 4 inch insulation batt.
		Replacement	Vinyl fiberglas cover replacing vinyl cotton above.

TABLE II

LABORATORY STANDARD FIRE TESTING OF MATERIALS
TEST METHOD 5906 - HORIZONTAL POSITION

Material	Ignition Time (min.)	Flaming Time (min.)	Burn Rate Initial 1.5 in. (in./min.)	Burn Rate Final 10 in. (in./min.)	Burn Length (Measured from Start Wire) (in.)	Total Char Length (in.)
Mohair aisle rug	0.07	1.42	I		0.0	
Vinyl/Neoprene under seat flooring	0.07	2.00	I		0.0	
Wool seat upholstery	0.05	0.35	I		0.0	0.7
Modacrylic seat and curtain upholstery	0.03	0.20	I		0.0	0.4
Leather armrest and hatrack covering	0.07	1.61	I		0.0	1.3
Simulated leather armrest covering	0.03	0.89	I		0.0	1.0
Cotton headrest covering	0.04	3.36	4.0	3.4	X	12+
Wool curtain	0.05	5.81	1.9	2.0	X	12+
Vinyl fiberglas hatrack and ceiling covering	0.05	0.28	I		0.0	
Vinyl fiberglas armrest and sidewall covering	0.04	0.70	I		0.0	
Vinyl cotton headliner covering	0.03	0.27	I		0.0	0.5

Designations:

I - Self-extinguishing, burned less than 1.5 inches.
X- Not self-extinguishing, burned completely.

TABLE III

LABORATORY STANDARD FIRE TESTING OF MATERIALS
TEST METHOD 5902 - VERTICAL POSITION

Material	Ignition Time (min.)	Flame Time[1] (min.)	Burn Rate (12 sec. Burner Time Included) 0-12 in. (in./min.)	Burn Rate (12 sec. Burner Time Included) 12 in. (in./min.)	Total Burn Length (in.)
Mohair aisle rug	0.05	0.39	4.7	I	2.6
Vinyl/Neoprene under seat flooring	0.05	0.48	0.8	I	0.8
Wool seat upholstery	0.03	0.55	X	16.1	12+
Modacrylic seat and curtain upholstery	0.03	0.06	19.5	I	6.0
Leather armrest and hatrack covering	0.05	0.14	5.1	I	1.7
Simulated leather armrest covering	0.03	0.00	20.3	I	4.1
Cotton headrest covering	0.03	0.84	X	11.6	12+
Wool curtain	0.03	1.06	X	9.7	12+
Vinyl fiberglas hatrack and ceiling covering	0.03	0.00	14.7	I	2.5
Vinyl fiberglas armrest and side wall covering	0.03	0.00	6.9	I	1.2
Latex foam padding	0.02	3.97	X	1.4	6+[2]
Vinyl foam padding		0.00	17.5	I	3.5
Mineral wool insulation ceiling batt	0.03	0.00	17.6	I	3.5

Designations:

I - Self-extinguishing, burned less than 12 inches.
X - Not self-extinguishing, burned completely.

Notes:

(1) Measured after the burner flame was removed.
(2) Sample only 6 inches in length.

TABLE IV

LABORATORY STANDARD FIRE TESTING OF MATERIALS
TEST METHOD - NBS RADIANT PANEL

Material	Ignition Time (min.)	Burn Length (in.)	Smoke Factor (mg.)	Heat Factor (°C)	Flame-Spread Factor (Fs)	Flame-Spread Index (I_s)	Remarks
Mohair aisle rug (O)	0.13	6	1.4	39	2.45	21	
Vinyl/Neoprene under seat flooring (O)	0.10	12	15.3	66	8.86	134	Flashed.
Wool seat upholstery (O)	0.16	10	0.1	29	18.6	114	
Wool curtain (O)	0.15	15+	0.1	61	44.0	545	
Modacrylic seat and curtain upholstery (R)	0.00		0.6	2	1.00	0.4	No visible flaming, Material charred completely.
Leather armrest and hatrack covering(O)	0.11	14	0.3	37	1.55	12	
Wool and latex seat cushion (O)	0.11	15+	11.6	181	17.3	670	
Modacrylic/Vinyl foam cushion (R)	0.12	8	1.9	8	1.0	1.6	
Vinyl foam seat padding (R)	0.08	15+	14.5	65	4.76	65	Flashed, melted.
Seat base assembly (O)	0.19	9	1.4	17	7.99	28	Flashed.
Leather armrest assembly (O)	0.11	9	3.2	60	3.84	47	Flamed inside panel.
Simulated leather armrest assembly (O)	0.09	15+	4.0	112	8.47	194	Flashed.
Leather covered lower hatrack assembly(O)	0.16	14	0.7	82	17.0	283	
Leather covered middle hatrack assembly (O)	0.16	13	0.5	75	13.3	196	
Leather covered upper hatrack assembly (O)	0.17	12	1.5	95	10.3	201	
Vinyl fiberglas covered middle hatrack assembly (R)	0.09	5	0.3	22	1.36	6	
Vinyl cotton ceiling assembly (O)	0.08		1.0	38	1.00	8	
Vinyl fiberglas ceiling assembly (R)	0.07	2	0.5	10	1.00	2	
Vinyl cotton sidewall assembly (O)	0.12	13	8.2	88	21.9	300	
Vinyl fiberglas sidewall assembly (R)	0.12	11	9.9	104	1.24	27	

Designations:

O - Original cabin materials.
R - New replacement materials.

TABLE V

IGNITION, BURNING AND SMOKE CHARACTERISTICS OF CABIN INTERIOR MATERIALS

Material	Sample Wt.[1]-gm. Initial	Final	Weight Loss (%)	Ignition Time[2] (secs.)	Burning Time (secs.)	Flash-Point Temp. (°F)	Self-Ignition Temp. (°F)	Smoke Quantity & Color	Flame Height (in.)	Remarks
Mohair rug	7.58	4.46	41	47.1	45.6	703	1054	Lt/White	6	
Vinyl/Neoprene carpet	14.1	11.6	18	24.3	45.5	563	990	Mod/Wh.Gray	8	
Wool	5.73	4.14	28	43.8	10.3	671	1105	Lt/White	7	
Modacrylic	6.44	4.54	29	60.5	3.1	558	1008	Hvy/White	3	Rapid burning.
Simulated leather	9.54	6.08	36	42.8	48.4	513	675	Hvy/Lt Gray	5	
Leather	9.94	5.98	37	36.5	118.1	451	1000	Lt/White	12	
Latex foam	5.48	2.67	51	28.0	42.4	324	871	Hvy/Dk Gray	12	
Vinyl foam	4.79	3.15	34	52.4	12.3	741	None	Hvy/White	2	
Polyurethane foam	2.87	2.44	15	None	None	None	None	Mod/White	0	No flaming observed Melted.
Polyether foam	0.83	0.49	40	23.6	12.1	644	None	Lt/White	2	Sample disintegrated.
Mineral wool (red)	2.05	1.28	37	33.3	2.3	644	1027	Moderate	3	Flame out within 80 secs.
Mineral wool (white)	1.38	1.11	19	None	None	None	None	Lt/White	0	No ignition or burning observed.
Felt padding	6.54	4.31	34	45.0	25.6	689	1137	Lt/White	10	
Plywood	4.32	1.07	75	36.8	25.4	637	937	Lt/White	8	
Acrylic pane	24.6	13.5	45	72.6	201.7	774	None	Lt/White	12	

Notes:

(1) Specimen size - 5 in. x 1/2 in. x 1/2 in.
(2) Temperature of combustion coil - 1180°F.

TABLE VI

CONCENTRATIONS OF TOXIC GASES PRODUCED BY BURNING INTERIOR MATERIALS

Material	Max. Allow. Concen.[1] (ppm)	Laboratory Tests[2][3] Wool (5.4 gms) (ppm)	Modacrylic (7.3 gms) (ppm)	Leather (12.3 gms) (ppm)	Simulated leather (17.3 gms) (ppm)	Latex Foam (3.3 gms) (ppm)	Polyurethane Foam (0.6 gms) (ppm)	Vinyl Foam (2.0 gms) (ppm)	Plywood (3.3 gms) (ppm)	Acrylic (12.1 gms) (ppm)	Mineral Wool (0.5 gms) (ppm)	Airplane Cabin Tests, Fire Test 41: Bottle 13[4] (ppm)	Airplane Cabin Tests, Fire Test 41: Bottle 10[5] (ppm)	Airplane Cabin Tests, Fire Test 42: Bottle 8[6] (ppm)	Airplane Cabin Tests, Fire Test 42: Bottle 9[7] (ppm)
Carbon Dioxide	5000	1000	700	6250	2700	3750	550	480	1675	1590	350	300	200	375	600
Carbon Monoxide	100	50	630	140	1900	600	30	190	450	1020	75	65	450	5	5750
Hydrogen Chloride	5		25			4									
Hydrogen Sulphide	20														
Sulphur Dioxide	5	0.1	0.1	0.1		0.03									
Phosgene	1				0.8										
Nitrogen Dioxide	5			1							0.1				
Ammonia	100														
Hydracyanic Acid	10		62	0.2											
Benzene	25					15		15							
Arsine	0.05								5						
Hydrazine	1														
Hydrogen Fluoride	3														
Unsaturated Hydrocarbons[8]			1600+		680	5	2	5	68			3	0	500	450
Halogens[9]	1			0.7											

Notes:

(1) Maximum allowable 8-hour concentration as per American Conference of Governmental Hygienists (1962).
(2) Concentrations obtained with commercial reagent tubes with dilution of combustion products in 270 liters of air.
(3) Specimen size - 5 in. x 1/2 in. x 1/2 in.
(4) Gas sample taken 14 minutes after start of fire.
(5) Gas sample taken 16 minutes after start of fire.
(6) Gas sample taken 18 minutes after start of fire.
(7) Gas sample taken 33 minutes after start of fire.
(8) Calculated on the basis of acetylene.
(9) Calculated on the basis of chlorine.

TABLE VII

AIRPLANE CABIN FIRE TEST DATA SUMMARY

Test Location	Test No.	Ignition Source: Burner Flame Size (in.)	Ignition Source: Other	Cabin Airflow	Self-Flam.	Self-Extin.	Self-Flaming: Earliest Occur. (min.)	Self-Flaming: Max. Duration (min.)	Charred Area	Test Duration (min.)	Smoke Dens. (%) (1)	CO Concen. Above Window (ppm)	CO Concen. At Ceiling (ppm)
Floor													
Aisle	4	1.5	Chem. Flame	No	No	Yes			2" x 2"	7.3			
	15	10		No	No	Yes			4" x 6"	10.0	1.3	20	
	16	10		No	No	Yes (2)	5.2	0.33	5" x 6"	5.7	7.0	3	
	24		Elect. Heater	No	No	Yes			3" x 20"	12.0			
	25	1.5	Elect. Heater	No	No	Yes			4" x 24"	17.0 (3)	6.0	6	
Under Seat	3	1.5	Chem. Flame	No	No	Yes			1" x 1"	10.0			
	17	10		No	Yes	Yes	3.3	0.33	6" x 6"	13.0	4.5	5	
	22	10		Yes	Yes	Yes	0.7	0.50	4" x 5"	10.0	2.0		
	26	0	Chem. Flame Elect. Heater	No	No	Yes			4" x 24"	22.5	1.0	5	
Seat													
Base	5	1.5		No	Yes	Yes	2.1	0.17	1" x 5"	10.0	1.5		
Side Arm	6	1.5		No	Yes	Yes	2.0	1.00	5" x 10"	16.0	3.5		
	7	1.5		No	No	Yes			4" x 10"	21.0	9.5		
	34	10		No	No	Yes	0.3	0.58	9" x 14"	10.0	26	20	80
Cushion (bottom)	2	1.5		No	Yes	No	6.9	Continuous	Extensive	25.3	65	85	430
	33	10		Yes	Yes	Yes	2.0	0.33	2" x 7"	10.0	19	25	
	41	10		No	Yes	No	1.0	Continuous	Extensive	18.0	90+	500+	5000+
	42	10		No	Yes	No	2.0	Continuous	Extensive	30.0	95+	500+	5000+
Cushion (back)	1	1.5		No	Yes	No	2.0	Continuous	Extensive	29.0	8.0	40	250
	23	10		No	Yes	No	3.7	Continuous	Extensive	8.0	59	500+	350
	27	1.5		Yes	No	Yes			2" x 6"	10.0			
	28	10		Yes	Yes	Yes	0.5	0.17	6" x 9"	11.3			
	36	1.5		No	No	Yes (4)			1" x 6"	10.0			
	37	10		No	Yes	Yes (5)	0.5	0.10	8" x 17"	10.0			
	38	10		Yes	Yes	No	2.3 (6)	Continuous	Extensive (6)	18.0	78	500+	
Sidewall													
Over Air Duct	8	1.5		No	No	Yes (7)			2" x 7"	10.0	1.0	35	
	18	10		No	No	No	1.7	0.50	Extensive	9.5	14	60	10
	35	10		Yes	Yes	No	8.0	Continuous	Extensive	10.0	65	300	950
Curtain	29	1.5		No	Yes	Yes (8)	0.1	0.17	2" x 7"	5.0	2.0	60	
	30	10		No	Yes	No	0.6	0.17	Extensive	4.3	44	500+	
	39	1.5		No	No	Yes			3" x 4"	5.0			
	40	1.5		No	Yes	No	0.2	Continuous	Extensive	2.0			
Bulkhead	12	1.5		No	Yes	Yes	2.0	2.83	3" x 13"	10.0	1.0		
	13	10		No	Yes	Yes	0.5	1.33	5" x 12"	3.0	1.0		
	14	10		No	No	Yes			6" x 24"	1.0	2.5		
Hatrack													
Lower Part	9	1.5		No	Yes	Yes	0.4	7.5	18" x 36"	7.9	6.0		
	20	1.5		Yes	Yes	Yes	0.6	0.41	3" x 5"	3.0			
	21	10		Yes	Yes	Yes	1.3	3.68	13" x 14"	4.9	3.5		
	31	1.5		No	No	Yes			2" x 4"	5.0	14		
	32	10		Yes	Yes	Yes	0.1	0.17	6" x 11"	5.0	12		
Ceiling	10	1.5		No	Yes	Yes			3" dia.	10.0	2.5		
	11	1.5		No	Yes	Yes			5" dia.	10.0			
	19	10		No	Yes	Yes			9" x 15"	10.0	16		

Notes:

(1) Percent of light absorption in one foot distance.
(2) Fire spread to base fabric which ignited and burned.
(3) Burner flame applied for only last seven minutes of test.
(4) Polyurethane foam smoldered under fiberglas cover but did not flame. Cavity in pad 3" x 8" x 18".
(5) Severity of fire due to lack of fiberglas cover protection over foam pad.
(6) Earliest occurrence of polyurethane pad flaming.
(7) Fire spread to curtain which ignited and burned.
(8) Fire spread to acrylic pane which ignited and burned.

TABLE VIII

RELATION OF LABORATORY FLAMMABILITY DATA
ON INTERIOR MATERIALS TO CABIN FIRES

Material	Laboratory Fire Tests				Airplane Cabin Fire Tests						
									Self-Flaming		
	Hor. Burn Rate (in./min)	Vert. Burn Length (in.)	Flame-Spread Index (I_s)	Flash-Point (°F)	Cabin Test No.	Ignition Flame Size (in.)	Self-Flam.	Self-Extin.	Earliest Occur. (min.)	Max. Duration (min.)	Charred Area
Wool curtain (O)	2.0	X	545		40	1.5	Yes	No		Continuous	Extensive
Modacrylic curtain (R)	I	I	0.4	558	39	1.5	No	Yes			3" x 4"
Wool/Latex foam cushion (O)	I/X	X/X	670	671/324	2	1.5	Yes	No		Continuous	Extensive
Modacrylic/Vinyl foam cushion (R)	I/I	I/I	1.6	558/741	27	1.5	No	Yes			2" x 6"
					33	10	Yes	Yes	2.0	0.33	2" x 7"
Leather armrest (O)	I	I	47	451	6	1.5	Yes	Yes	2.0	1.00	5" x 10"
Simulated leather armrest (O)	I	I	194	513	7	1.5	No	Yes			4" x 10"
Leather hatrack (O)	I	I	196		9	1.5	Yes	Yes	0.4	7.50	18" x 36"
					21(1)	10	Yes	Yes	1.3	3.68	13" x 14"
Vinyl fiberglas hatrack (R)	I	I	6		31	1.5	No	Yes			2" x 4"
					32(1)	10	Yes	Yes	0.1	0.17	6" x 11"

Designations:

I - Self-extinguishing.
X- Not self-extinguishing.

(O) - Original airplane cabin materials.
(R) - New replacement materials.

Note:

(1) Pressurized airflow.

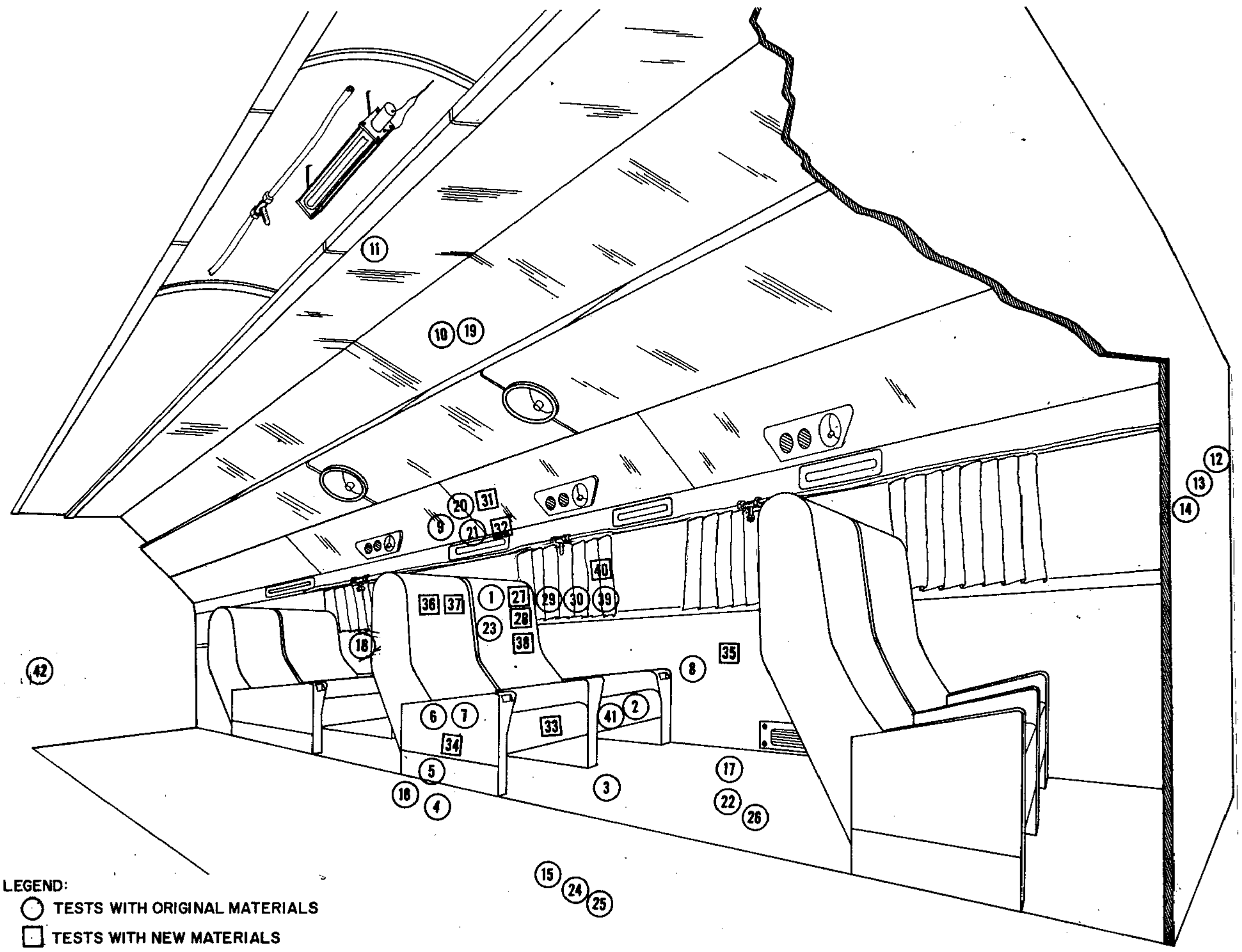


FIG. 1 FIRE TEST LOCATIONS IN FORWARD SECTION OF AIRPLANE CABIN

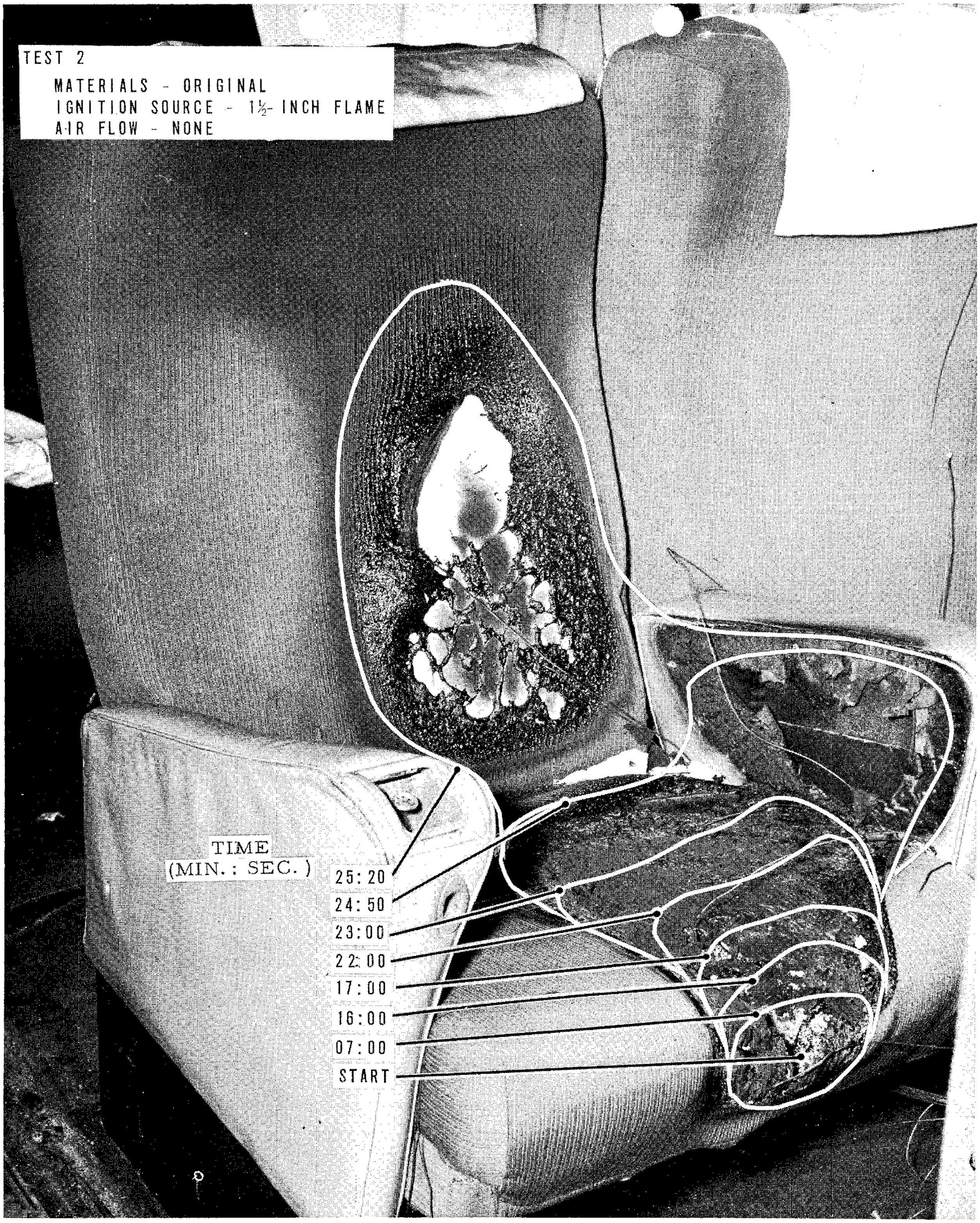


FIG. 2 WOOL/LATEX SEAT CUSHION FLAME PATTERN AND FIRE DAMAGE

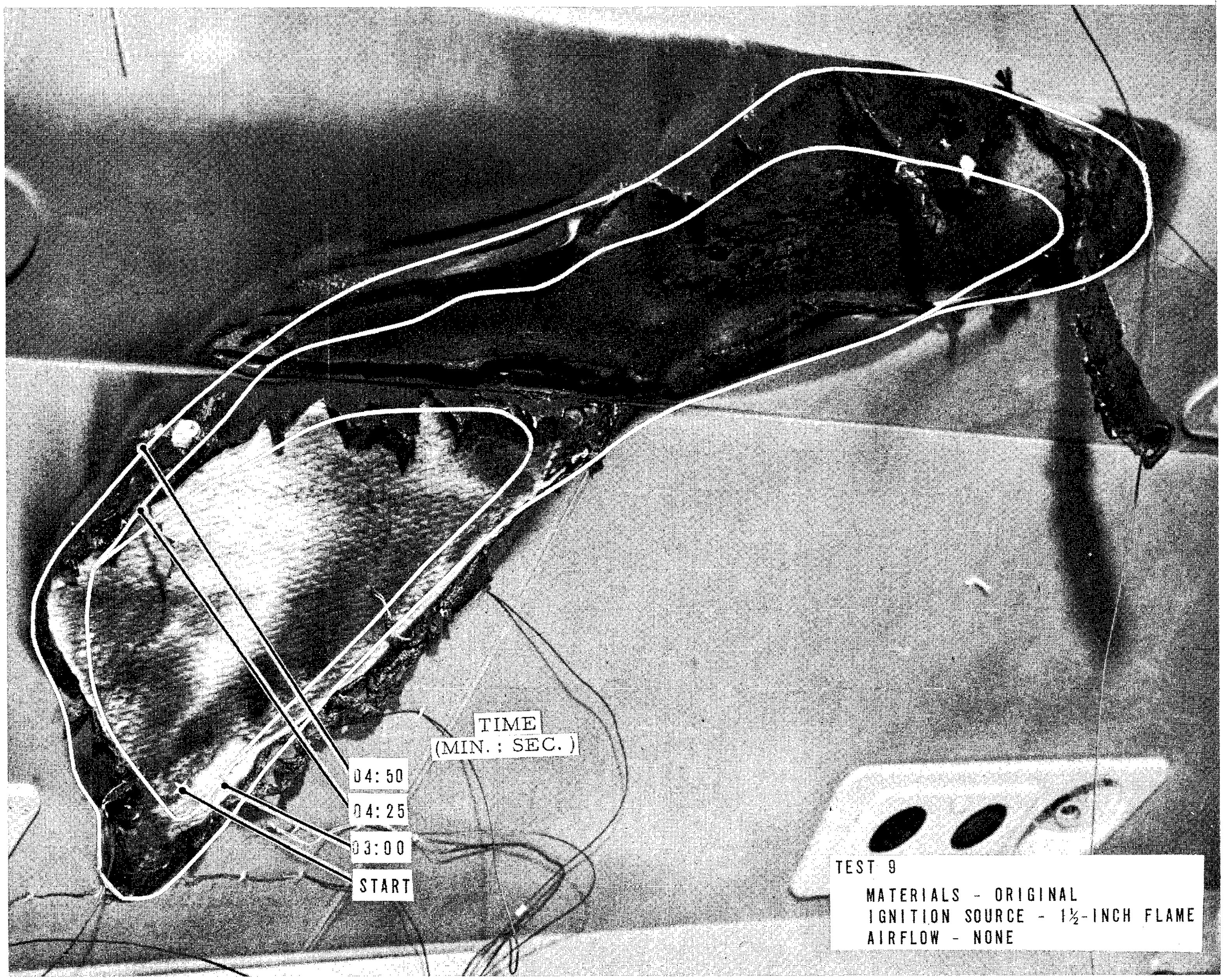


FIG. 3 HATRACK FLAME PATTERN AND FIRE DAMAGE

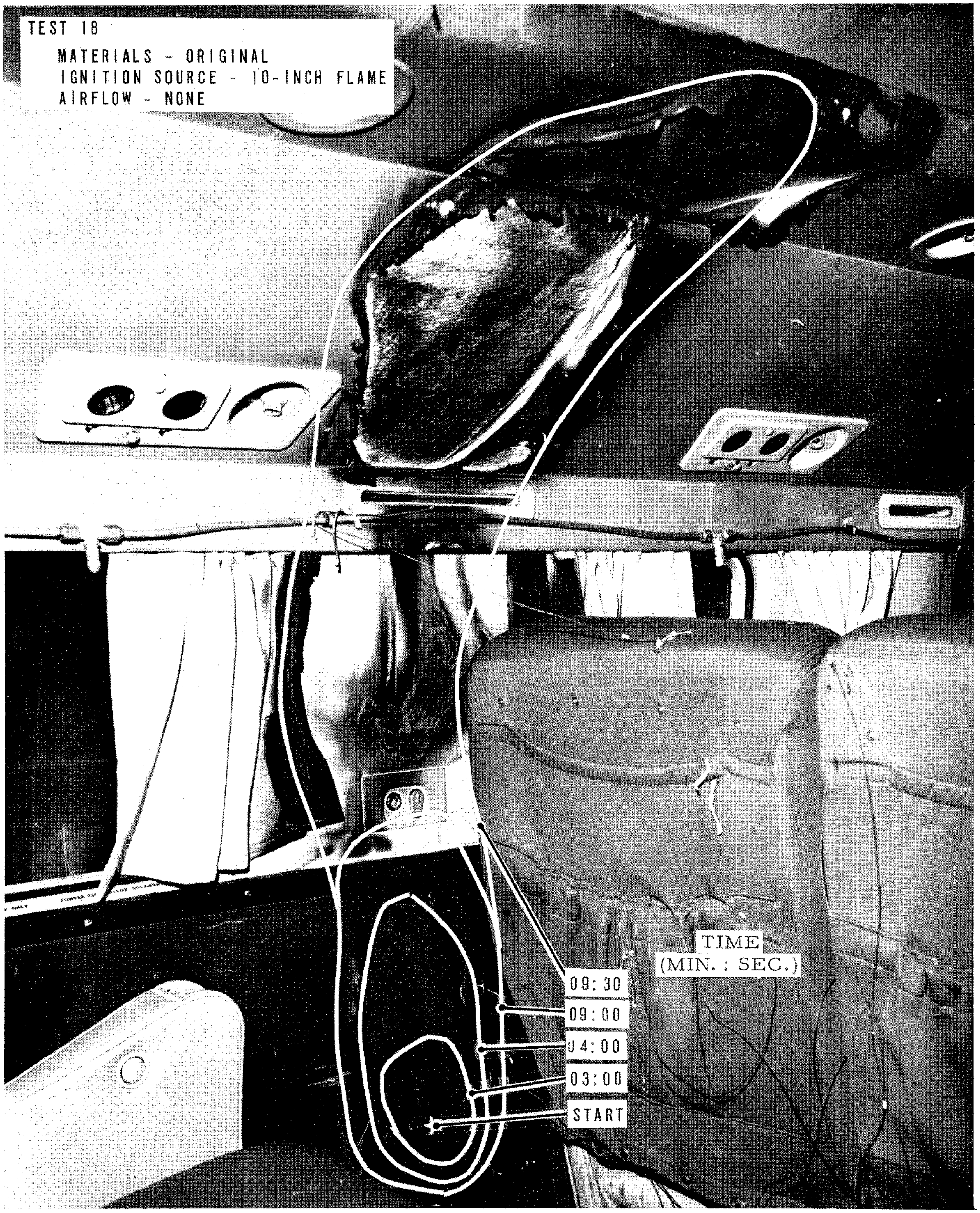


FIG. 4 SIDEWALL FLAME PATTERN AND FIRE DAMAGE

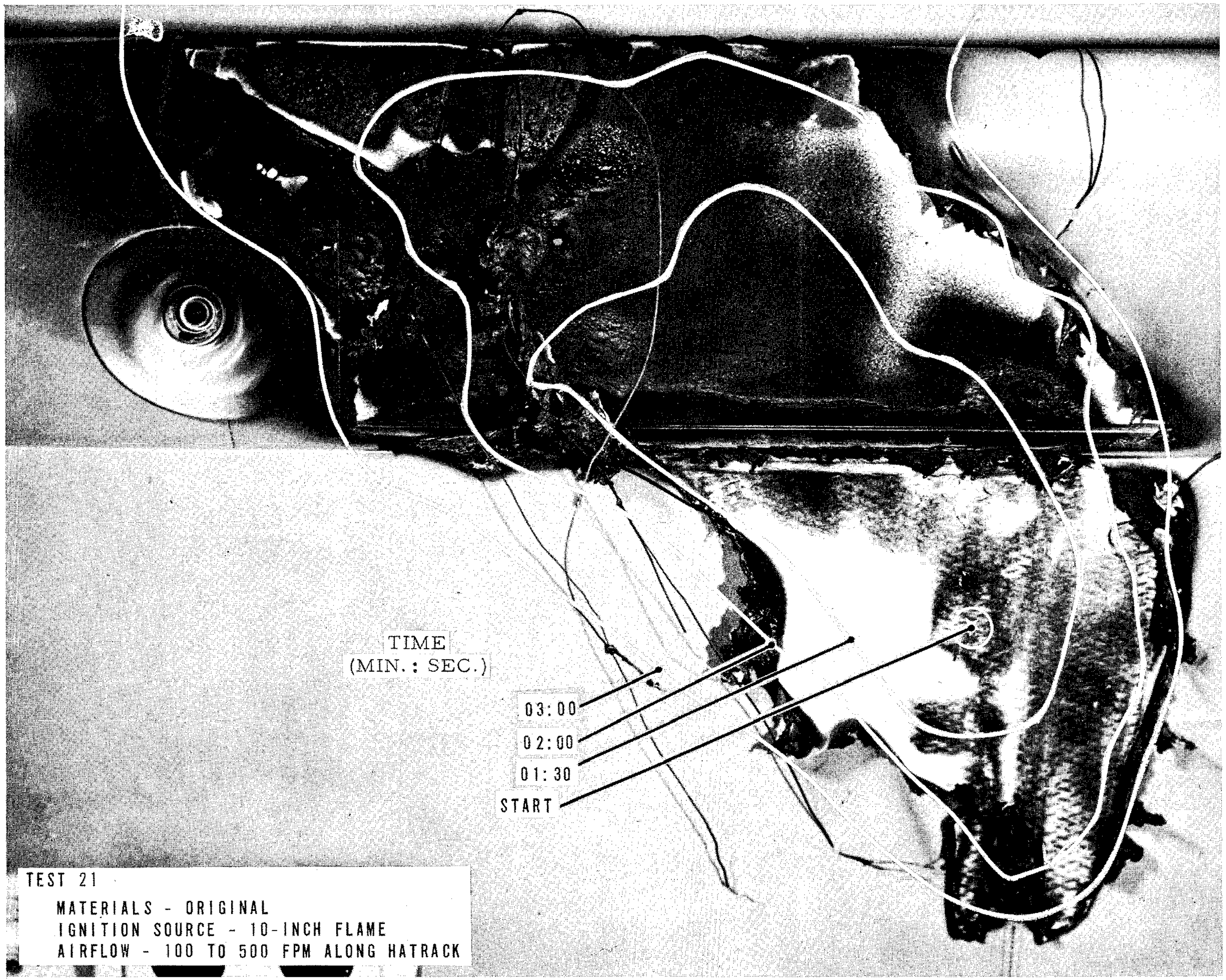


FIG. 5 HATRACK FLAME PATTERN AND FIRE DAMAGE WITH AIR FLOW

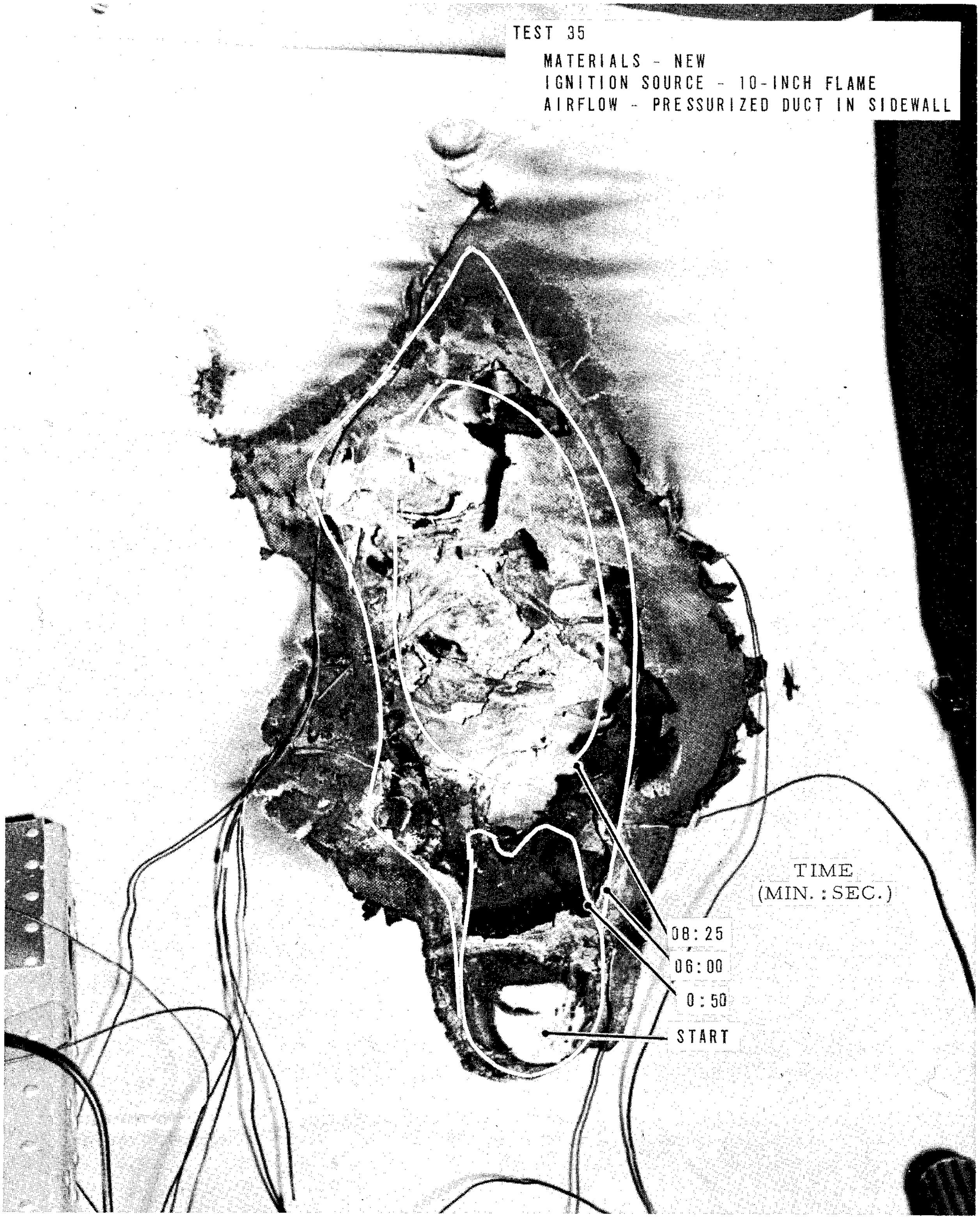


FIG. 6 PRESSURIZED SIDEWALL FLAME PATTERN AND FIRE DAMAGE

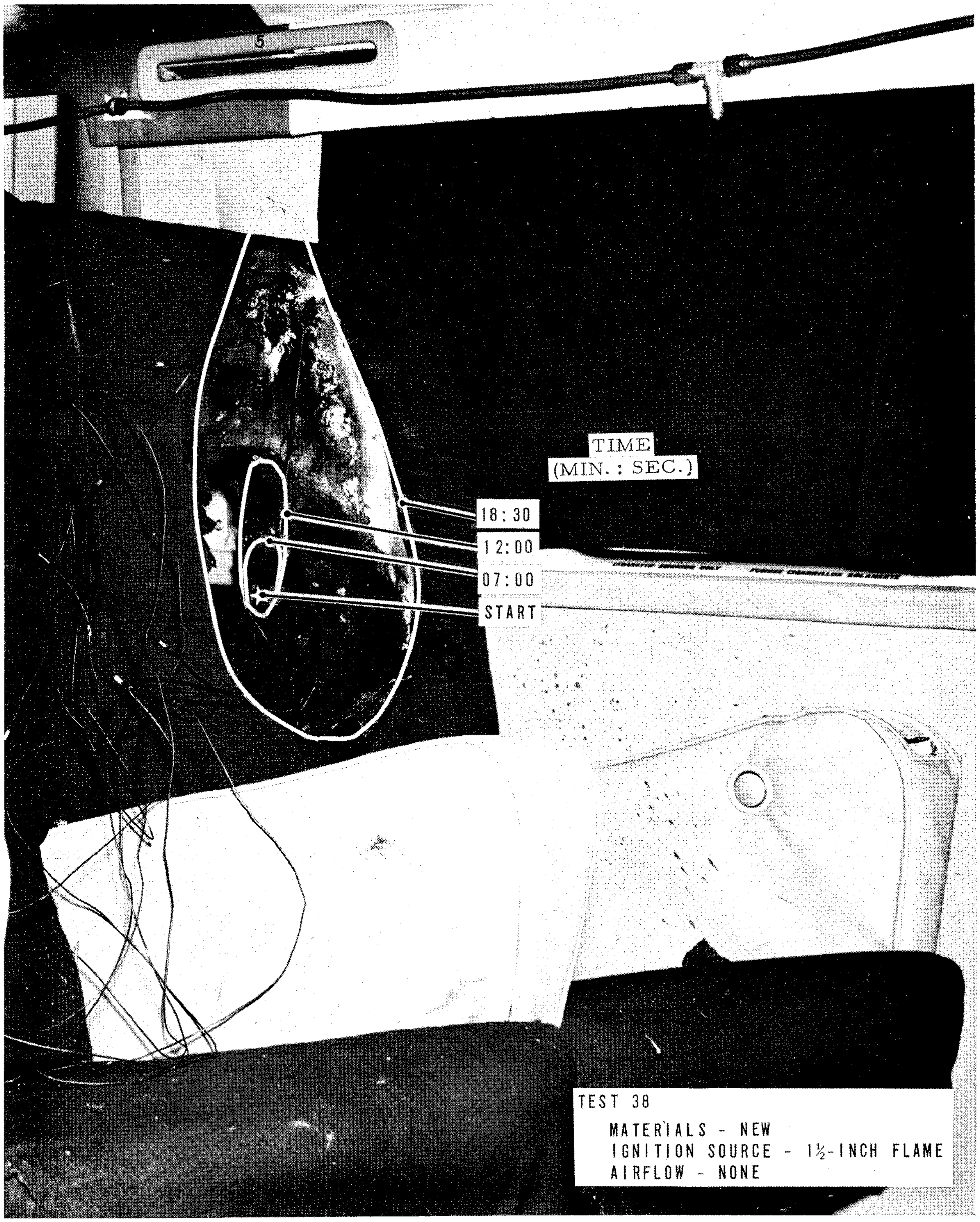


FIG. 7 MODACRYLIC/POLYURETHANE SEAT CUSHION FLAME PATTERN AND FIRE DAMAGE

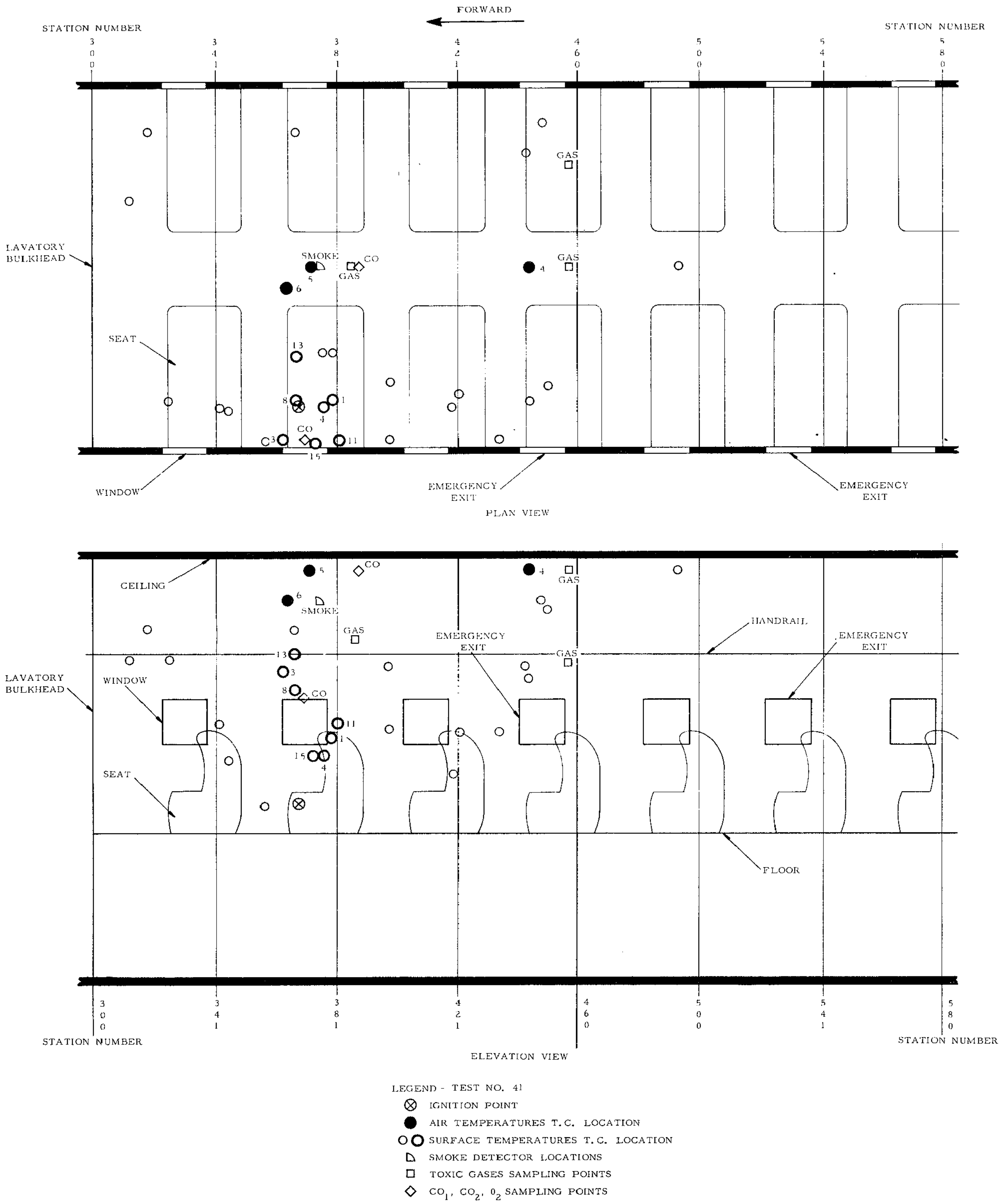
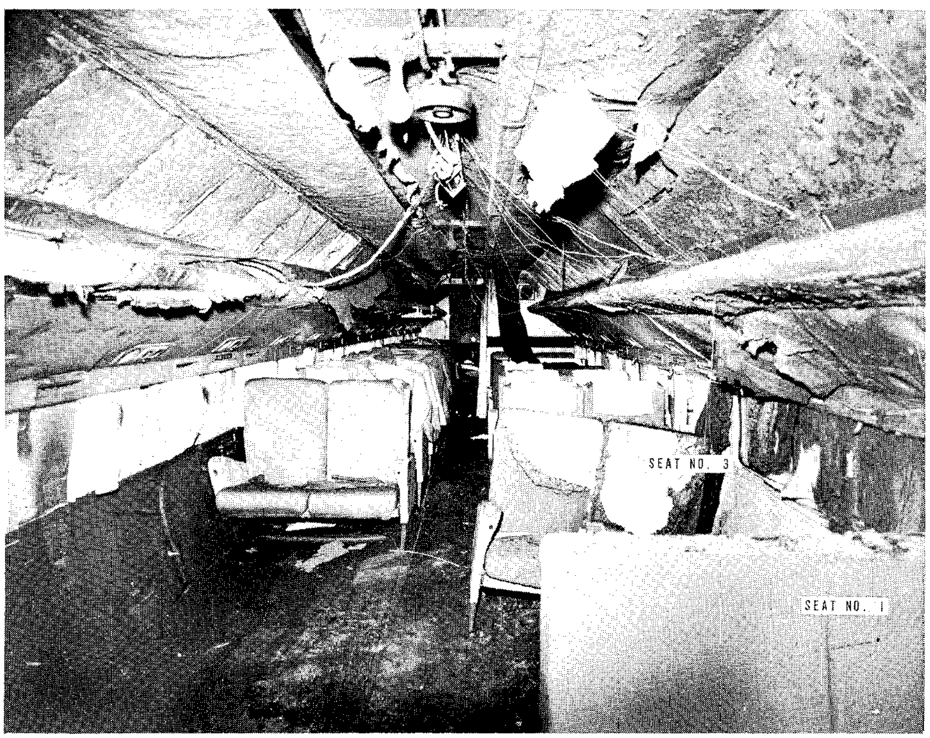


FIG. 9 TEST 41 - TEMPERATURE, SMOKE AND GAS SAMPLING LOCATION POINTS INSIDE AIRPLANE CABIN

TEST NO. 41
BEFORE FIRE



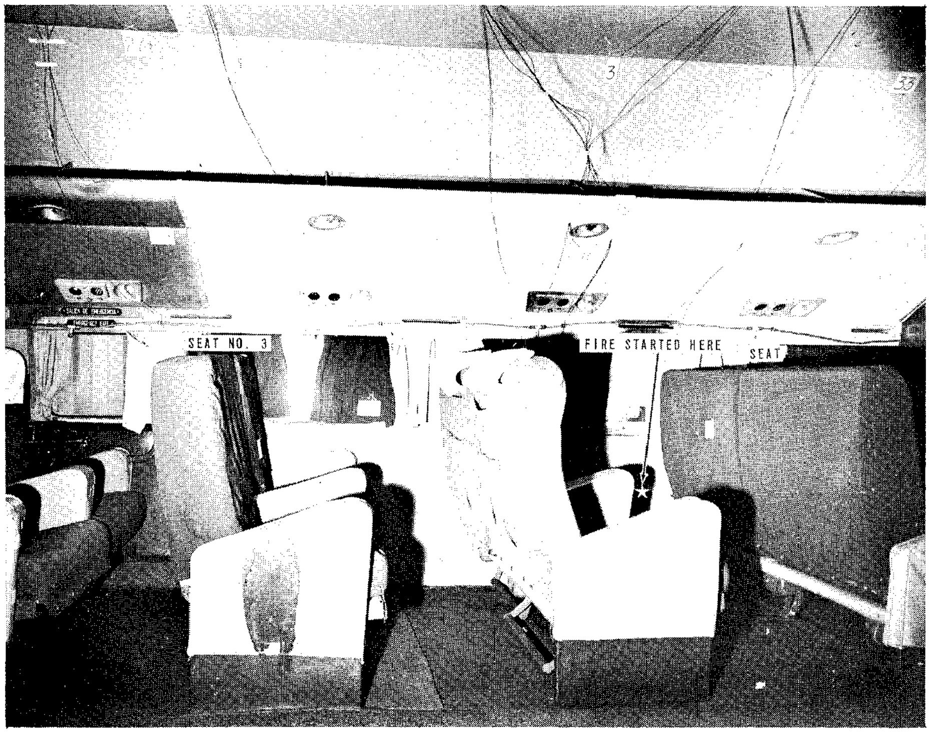
TEST NO. 41
AFTER FIRE

FIG. 10 TEST 41 - REAR VIEW OF CABIN INTERIOR BEFORE AND AFTER LARGE-SCALE FIRE

TEST NO. 41
BEFORE FIRE

TEST NO. 41
AFTER FIRE

FIG. 11 TEST 41 - FRONT VIEW OF CABIN INTERIOR BEFORE AND AFTER LARGE-SCALE FIRE



TEST NO. 41
BEFORE FIRE

TEST NO. 41
AFTER FIRE

FIG. 12 TEST 41 - SIDE VIEW OF CABIN INTERIOR BEFORE AND AFTER LARGE-SCALE FIRE

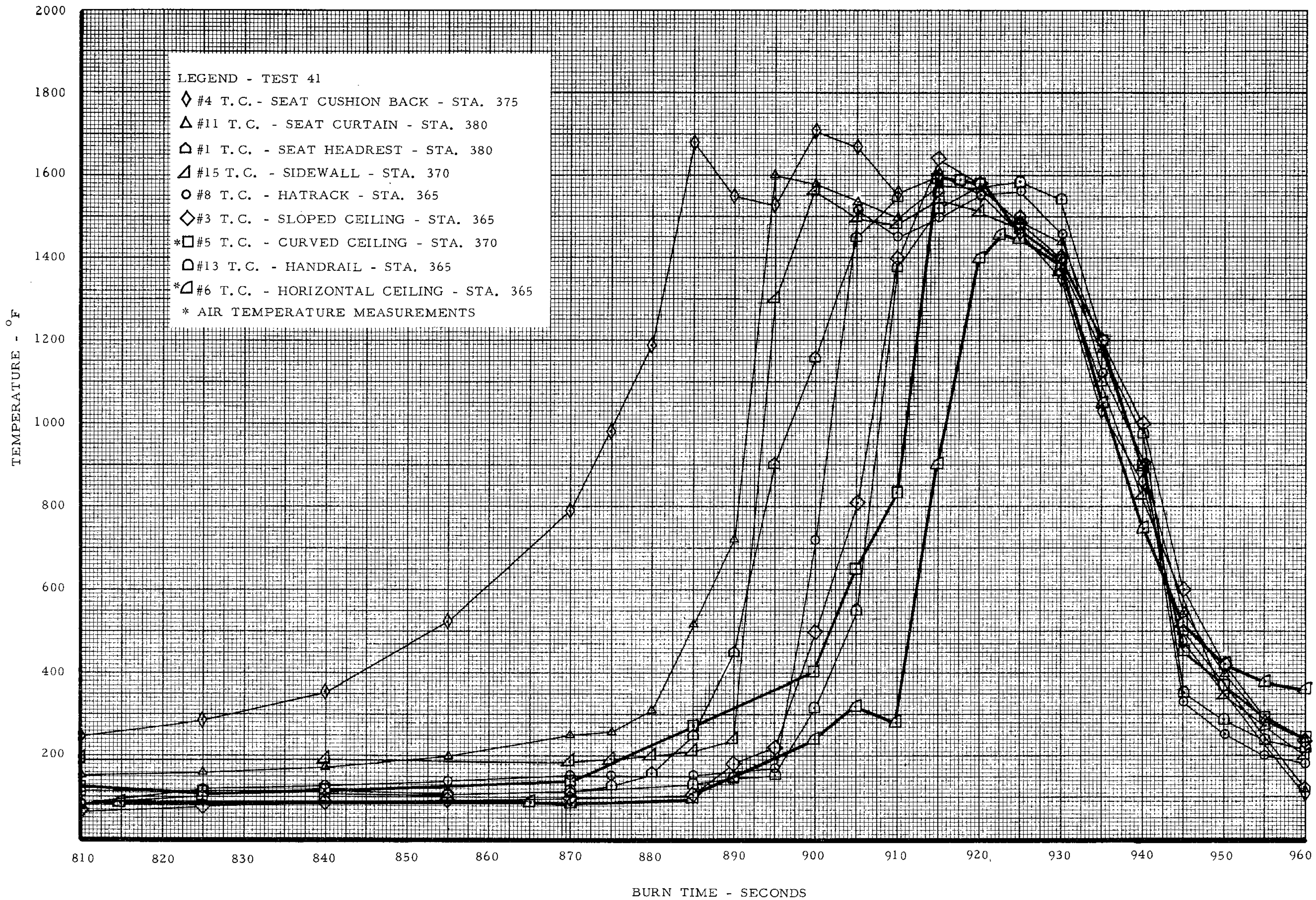


FIG. 13 TEST 41 - TEMPERATURE RECORDING INSIDE CABIN

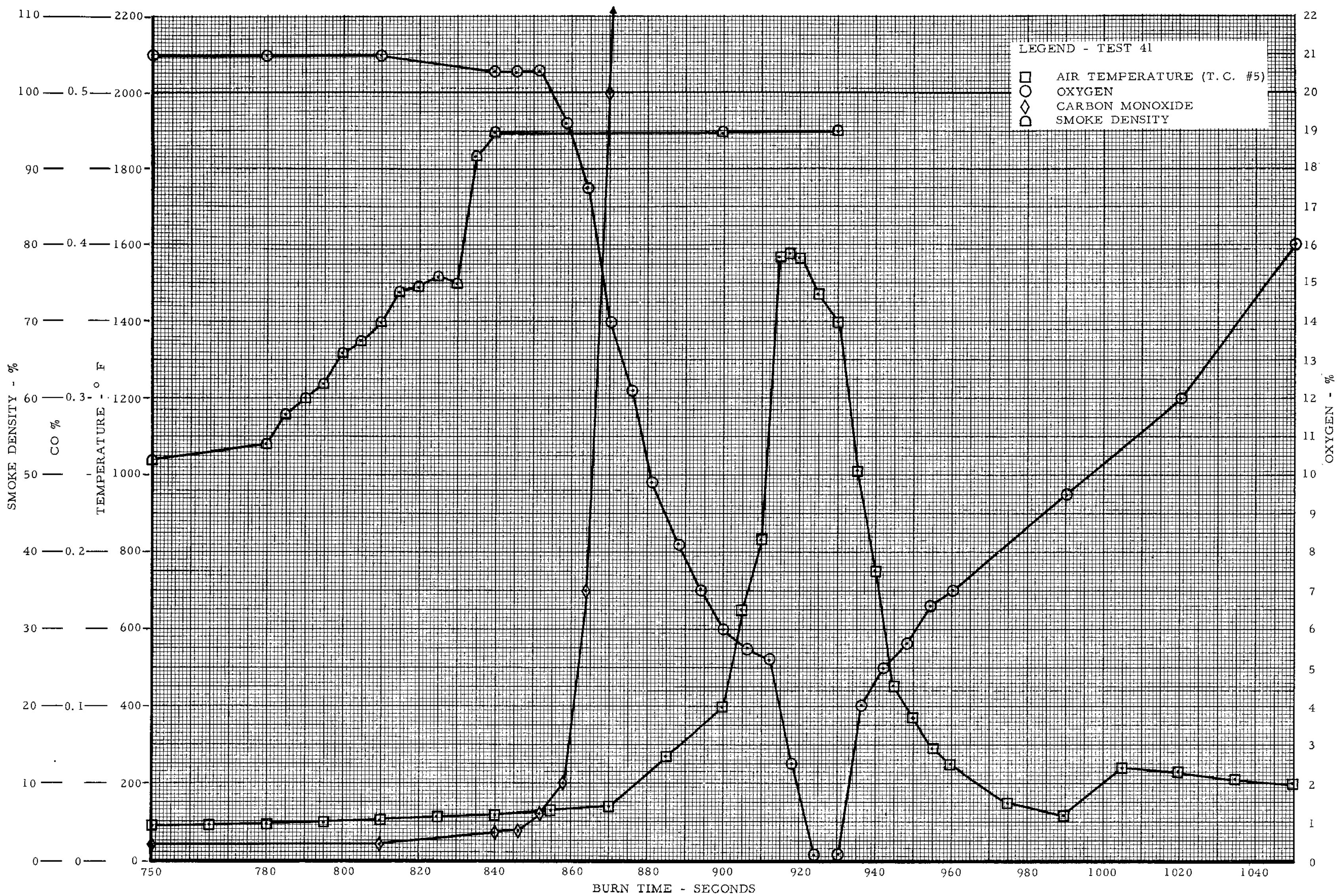


FIG. 14 TEST 41 - TEMPERATURE, SMOKE, CARBON MONOXIDE AND OXYGEN RECORDINGS INSIDE MAIN CABIN

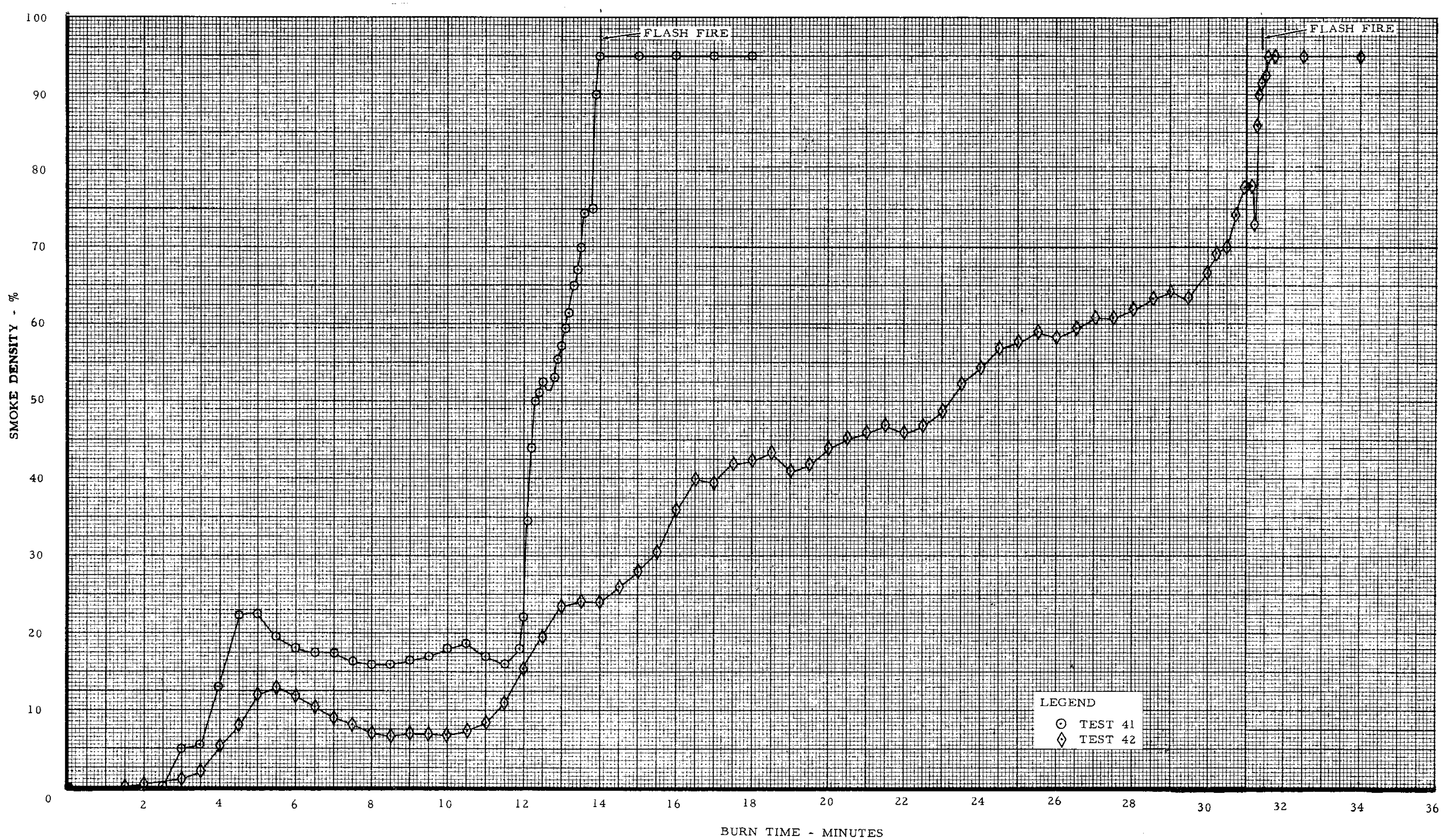


FIG. 15 TESTS 41 AND 42 - SMOKE RECORDING INSIDE CABIN

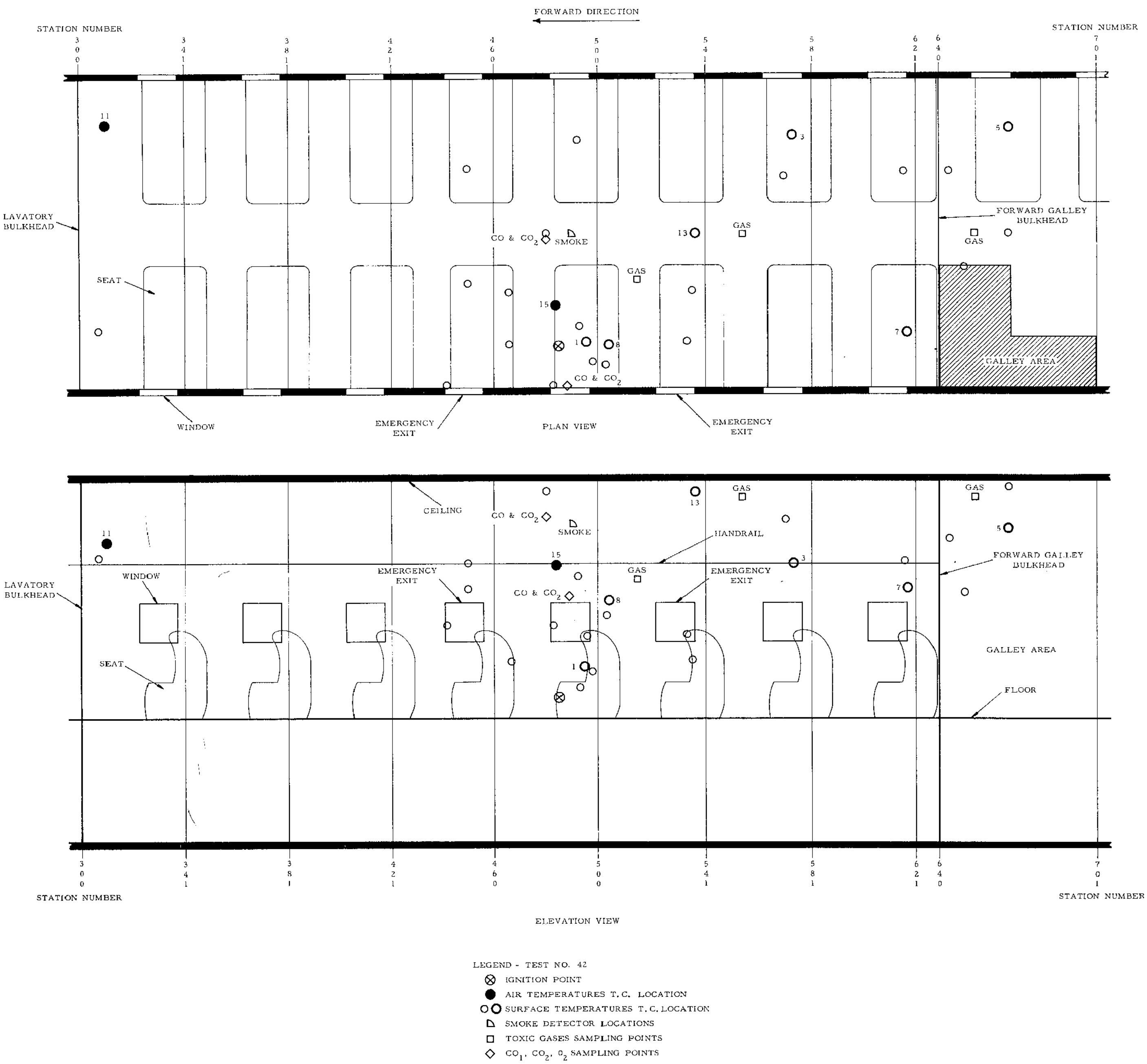
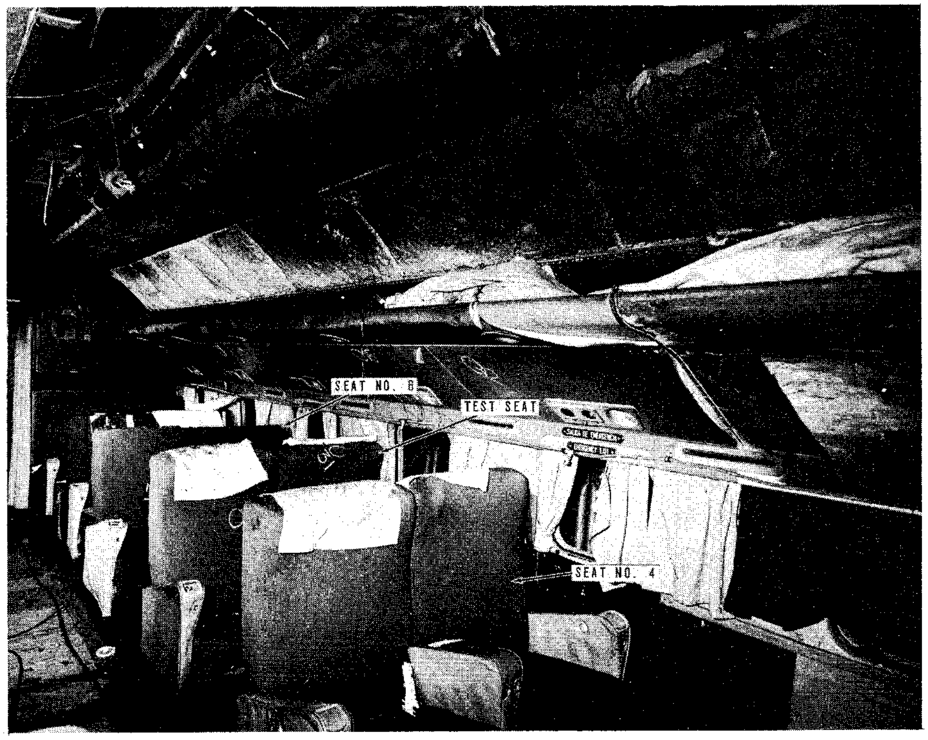


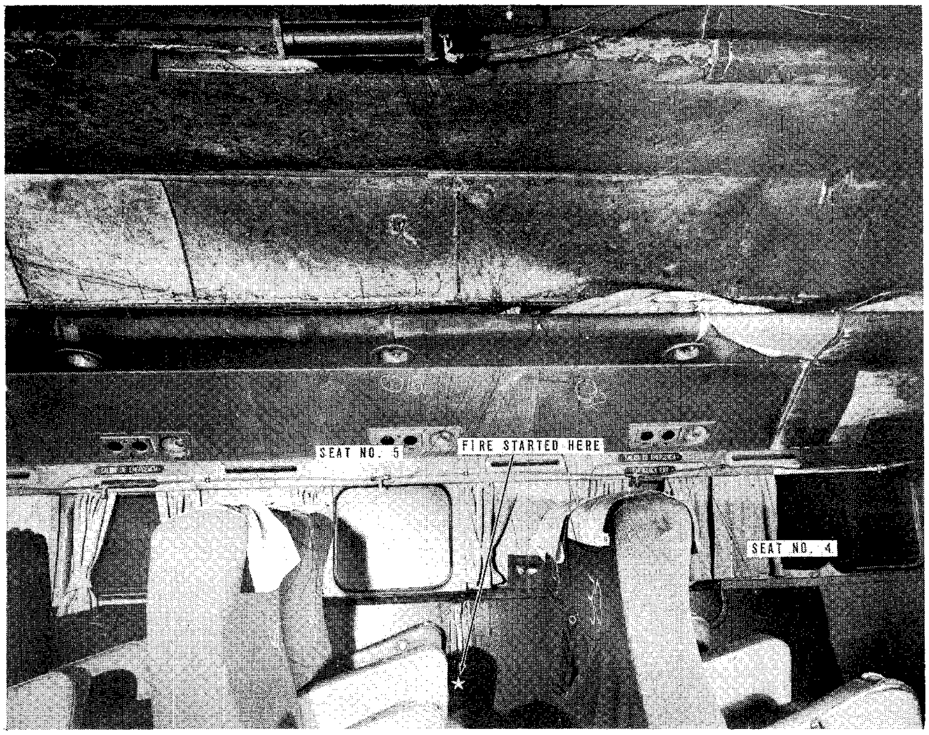
FIG. 16 TEST 42 - TEMPERATURE, SMOKE AND GAS SAMPLING LOCATION POINTS INSIDE AIRPLANE CABIN



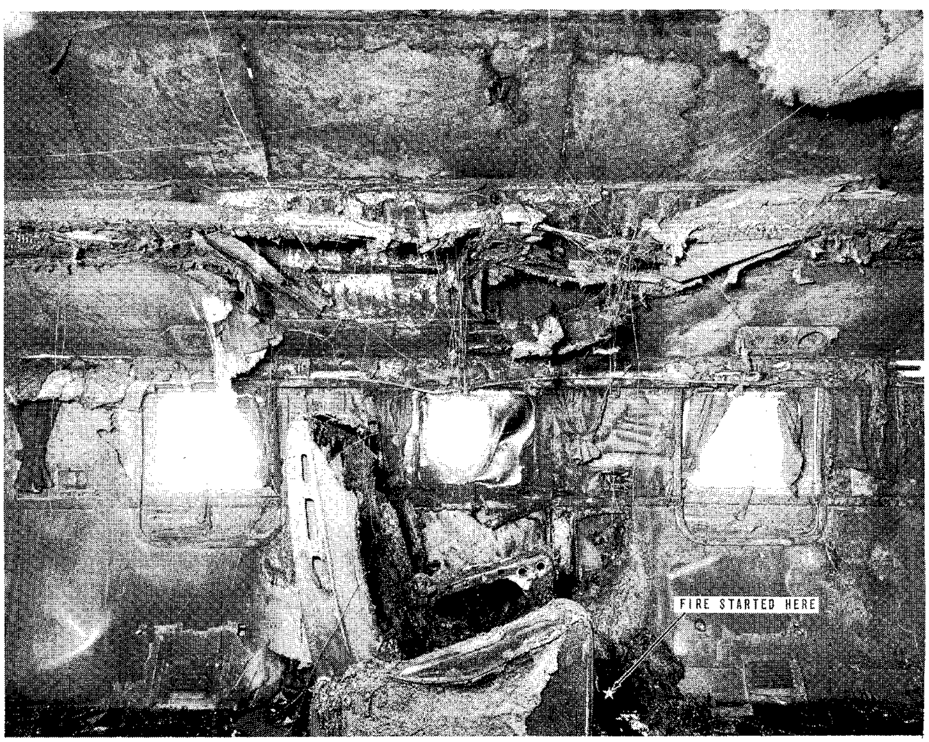
TEST NO. 42
BEFORE FIRE

TEST NO. 42
AFTER FIRE

FIG. 17 TEST 42 - REAR VIEW OF CABIN INTERIOR BEFORE AND AFTER LARGE-SCALE FIRE



TEST NO. 42
BEFORE FIRE



TEST NO. 42
AFTER FIRE

FIG. 18 TEST 42 - SIDE VIEW OF CABIN INTERIOR BEFORE AND AFTER LARGE-SCALE FIRE

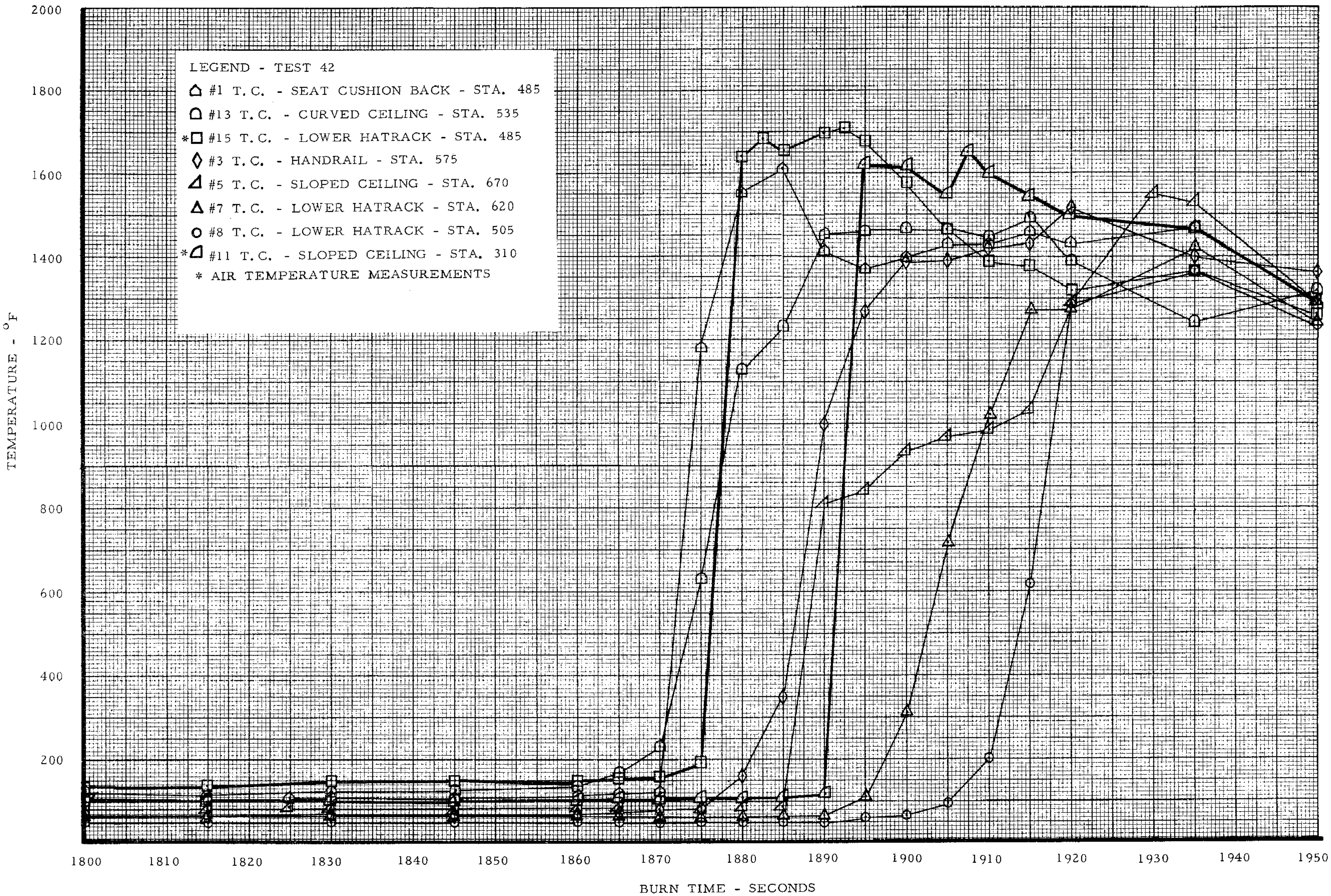


FIG. 19 TEST 42 - TEMPERATURE RECORDING INSIDE CABIN

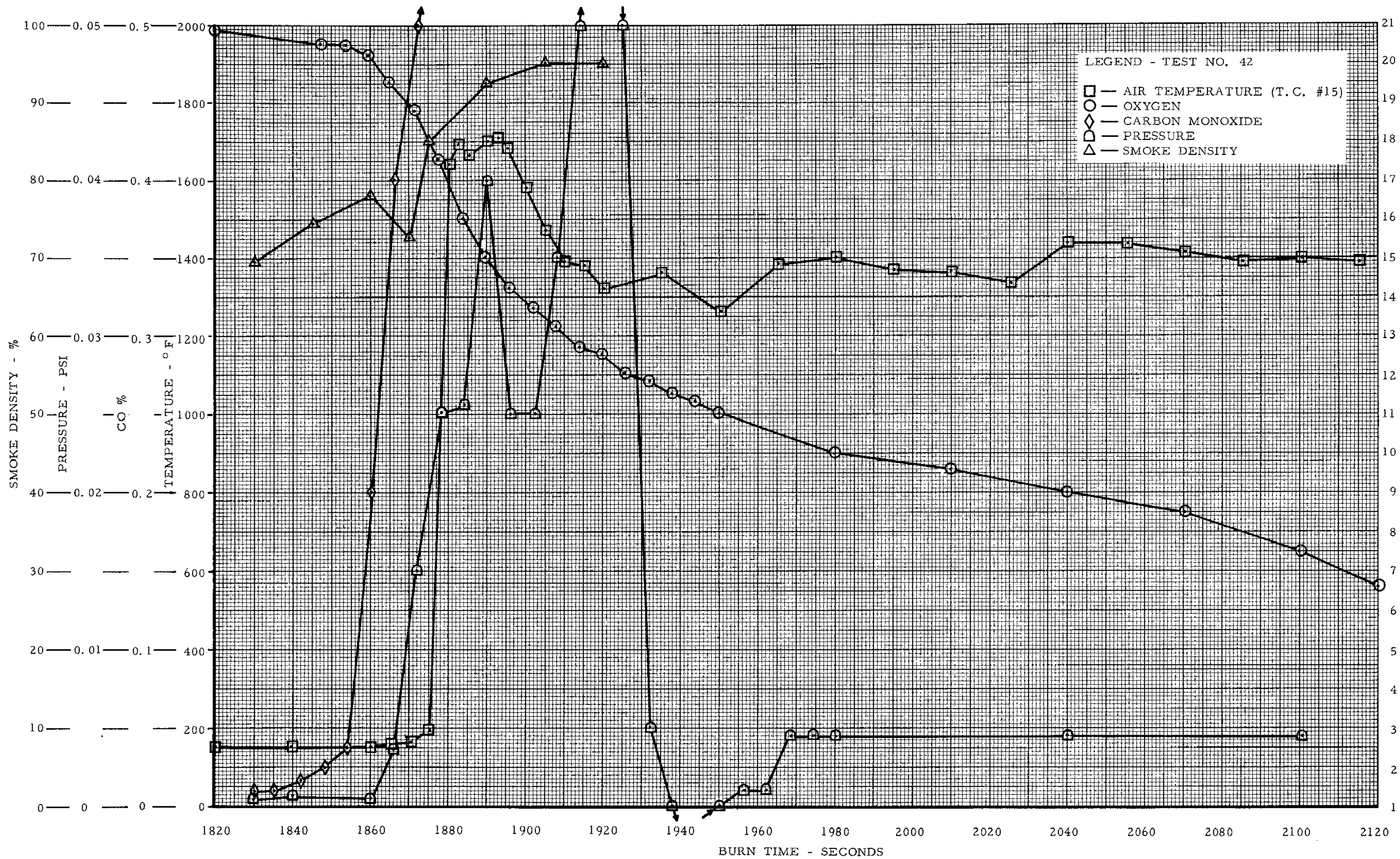


FIG. 20 TEST 42 - TEMPERATURE, SMOKE, CARBON MONOXIDE AND OXYGEN RECORDINGS INSIDE CABIN