3/12/65

FIRE, SMOKE, AND TOXIC GASES HAZARDS IN A ~~LARGE~~ LARGE AIRPLANE ~~DC-7~~ PASSENGER CABIN

TECHNICAL REPORT
ADS-

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APRIL ~~MARCH~~ 1965

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

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FEDERAL AVIATION AGENCY

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SUMMARY

A study of the combustion characteristics of interior cabin materials was made to establish the relative fire hazards inherent in the use of such materials in passenger air transport~~s~~. Standard laboratory tests were conducted on the interior materials used in the DC-7 passenger cabin to determine, separately, the flammability, smoke and toxic characteristics of each of the materials. In addition to the laboratory tests, a series of fire ~~five~~ tests were conducted in situ inside the DC-7 fuselage at different locations to determine the relative ease by which the materials may be ignited and burned. In these tests, time for self-ignition, rapidity of flame spread, extent of burned area, smoke and toxic gases concentrations were obtained for various sizes of ignition sources, both with and without rated cabin airflow.

The study revealed that the most important factor affecting the degree of fire hazard present inside an aircraft cabin was that of 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 the DC-7 cabin are subject to a flash fire. Heat, smoke, and toxic gases generated by the fire up to the time of the flash fire did not exceed human survival limits as determined by test data.

INTRODUCTION

The project was established primarily for the purpose of providing a better understanding of the nature and extent of the fire problem within the large passenger cabins of modern air transports for both the safety of the aircraft and its occupants. Present regulations contained in CAR 4b recognize the fire hazard inherent in the use of combustible interior materials in the furnishings and construction of the airplane cabins. In recognition of this danger, some attempt was made in the past, by limiting the flammability of the interior materials, to reduce the incidence and damage of fire to levels that would still be considered acceptable risks.

Recent fire experience aboard large jet transports would seem to indicate that the possibility of widespread fire among interior materials in cabins is perhaps much greater than that originally thought possible. This has raised the question as to whether present safeguards are adequate, and if not, what improvements, such as more stringent requirements for less flammable materials should be considered by the Agency.

BACKGROUND

A series of small cabin fires, ~~reported routinely in the press~~, have continued to plague the aircraft industry during recent years. The type and number of such fire incidents provides ~~should be~~ a good indication of the severity of the fire problem in airline operation. These fires involving the safety of passengers in flight have, up to the present time, been discovered in sufficient time to be easily extinguished without harm to passengers or, for that matter, much damage to the aircraft itself. Most of these fires can be traced to the carelessness of passengers smoking, and involved most frequently 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 the pressurized airflow. 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 the latest fire of this type involving an American Airlines Convair 990 (Newark Airport, May 1963), the entire fuselage was destroyed by fire. The fire problem, as implied by the use of large quantities of combustible material in aircraft interiors, has received only minor attention until recently. The only safeguard for limiting the fire hazard was that of FSS Release 259, dated August 26, 1948, which specified the use of flame-resistant interior cabin materials for aircraft. This regulation established both a fire test method for evaluating materials and a maximum burn rate in the horizontal position not exceeding 4 inches per minute. The event that has sparked renewed interest in the problem of adequate fire protection in this area has been the occurrence of the TWA Boeing 707 fire in San Francisco in February of 1961 (Reference 1) which gutted the interior of this transport aircraft which was then unoccupied and parked on the ground at the time. Tests by Boeing Co. on a mockup of this airplane, in an attempt to simulate the conditions believed responsible for the fire, demonstrated the vulnerability of the interior materials to a large-scale fire.

Subsequent to the Boeing tests, a comprehensive test program was instituted by this Agency to review present requirements for interior materials in respect to the existing fire experience. A report (Reference 2) covering the first phase of the project has already been 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 present 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 (References 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 more equivalent to normal operations and use. The test article made available for the test program consisted of an American

Airlines DC-7 fuselage with complete cabin furnishings and interior decor. At the time, it was fortunate that this airplane was being phased out of airline operation, and therefore could be obtained at reasonably low cost. It should be noted, that although this particular airplane was 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 DC-7 airplane, have been replaced in large part by the synthetics and plastics typical of the more modern jet transport. Of even greater significance to the fire hazard, is the use of latex foam padding in the seats instead of polyurethane or other foamed plastics, which seems to have generally replaced this material. Although the materials may have changed, it is believed that the conclusions obtained from a study of the test results should still be generally valued and applicable to present-day transports.

Materials differ markedly in their ability to ignite, burn, and withstand the affects of exposure to fire. There are two main categories of materials, namely, combustible and non-combustible. Interior materials generally belong to the first group which includes both the natural and synthetic fibers used in fabric, leather and, an ever increasing number of plastics. In certain applications, such as in aircraft construction, safety requires that the materials either withstand fire for a specified time limit, or else if ignited, not burn at more than 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, (4) flash-resistant. The particular classification which applies to the interior materials is that of flame-resistance. At present, Federal regulations require that materials meeting this classification shall not propagate flame at a rate greater than 4 inches per minute in the horizontal position. However, recent laboratory tests (Reference 2) on some 100 materials selected at random and representative of the materials now being used on large jet transports have shown that the materials in the majority of cases far exceed present requirements. As a result, ~~consideration was given to revising~~ revision of the present standares to require that materials be self-extinguishing (zero burn rate) has been proposed. In addition to the self-flaming characteristics of materials, there are other important factors that should be considered. Some of these are: (1) flash-point temperature, (2) self-ignition temperature, (3) flame-spread index, (4) potential heat, and (5) tendency of the material to smoulder, smoke, and produce toxic combustion products, as these affect visibility and survival. All these factors, which are related to the general fire problem, are of concern to aviation and were considered in this report from the viewpoint of both laboratory and full-scale tests on the materials.

EQUIPMENT DESCRIPTION

Laboratory Tests

1. 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).

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

3. 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).

4. 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).

Full-Scale Tests

1. Test Article: This consisted of a pressurized DC-7 fuselage with complete cabin furnishings. All fire tests were conducted in the main passenger cabin. Tests were performed on both the original equipment and on replacement new materials with improved flame-resistant qualities.

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

3. <u>Flame and Fire Propagation Recording</u>: 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.

4. <u>Smoke Recording</u>: 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 VR photocell at the other end, which measured the absorption of light by smoke through a distance of one foot.

5. <u>Carbon Monoxide, Carbon Dioxide, and Oxygen Concentrations Recording</u>: This was accomplished by infrared and paramagnetic type gas analyzers connected to continuous potentiometer recorders. Gases were sampled continously through two 1/4 inch copper tubes located both at the ceiling and directly above the window 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%.

6. <u>Trace Toxic Gases Concentration Recording</u>: 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

Laboratory

1. 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 replacement of DC-7 original equipment, were likewise tested.

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

3. Radiant Heat Tests: The back cushion assembly of a DC-7 seat was subjected to the heat of seven 375-watt infrared lamps. Temperature at which the material became self-flaming and the rapidity of flamespread at elevated temperatures were measured.

Full- Scale in a DC-7 Cabin

1. Fifteen Second Fire Exposure Test Series: A Bunsen Burner attached to a 3-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 15 seconds. The flame was adjusted with no air 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 determinedl

2. <u>Continuous Fire Expesure Test Series</u>: Test s were performed utilizing the same burner as described previously. The burner flame was held in a rigid position in contact with various parts of the cabin until the material subjected to the fire would either start to flame or else 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 ~~falem~~ flame of its own accord, after removal of the ignition source, (2) time that flaming persisted until extinguished, (3) cabin temperature and humidity, (4) smoke density,and (5) carbon monoxide, carbon dioxide, and oxygen concentrations. When a severe fire condition developed that threatened to get out of control and endanger test personnel, the fire was extinguished with either water or preferably with a CO_2 bottle.

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

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, the floor materials in some tests were ~~locate~~d heated electrically (800 watts) from underneath. In addition, in a few tests hexamethyl mine powder was spread on the floor and burned.

Fire tests,in most cases, were conducted with no airflow. However, the cabin was provided with rated pressurized airflow of 1100 CFM. Airflow velocity was ~~low an~~d without apparent effect on the smaller fires at most locations, except near the air return grilles (up to 100 FPM) and near the ventilation outlets above the windows (up to 520 FPM).

TEST RESULTS AND ANALYSES

Laboratory Tests

The tests were conducted on sample pieces of the materials ~~and~~ subjected to standard laboratory tests. Both used materials, which were part of the original DC-7 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 1. 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 2, 3, and 4. 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 to be not self-extinguishing. Aside from these materials and the latex and polyurethane foams, all the other materials were considered to have good flame resistance. It should be noted that All the materials tested, ~~with the exception of the two foam materials~~, surpassed the present regulations requiring a burn rate not to exceed 4 inches per minute.

Improvements in the flame resistance of the curtains and seats, ~~as~~ is shown in test data by the substitution of Verel (Reference 10) for wool, of vinyl fiberglas for vinyl cotton (Naugahyde), and vinyl foam (References 11 and 12) for latex foam. These new materials are seen to be self-extinguishing in both 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 radian t panel tests are given in Table 4, together with data on the relative amounts of smoke produced by the burning materials. Flammability of the materials, it should be noted, increases with the flamespread index number. This index is based on a scale where a non-combustible is rated at zero and red oak rated at 100.

The test data show that the present seat cushion in the original DC-7 equipments has a very high flamespread index of 670, compared to a very low 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, Verel, a modified acrylic plastic, does not show an y visible flaming when exposed to radiant heat. However, this 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 beneficial use of fiberglas fabric covering material in reducing significantly the flame-spread index figures for the sidewall, hatrack and headcovers 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 DC-7 cabin witht with the original materials and with all the new materials appear to be directly related to the difficulty of setting fire to the cabin interior, as experienced later in the full-scale fire tests.

Test data on the ignition, burning, and smoke characteristics of the materials used in the DC-7 cabin are given in Table 5. The data show that the flash-point temperature of latex foam at 324°F is considerably lower than that of any of the other materials tested. The corresponding temperature for vinyl foam is 741°F, or more than twice as high. The material with the lowest self-ignition temperature at 675°F, was the vinyl cotton fabric (Naugahyde) used in the armrest covering, as original material. The densest smoke was produced by the foam padding material, as was also recorded in the radiant panel fire tests.

Test data on the relative concentrations of gases (References 13 and 14) liberated during the pyrolysis of the sample materials at a temperature of 1150°F in the laboratory tests are proven in Table 6. Also shown in the table are the concentrations of gases obtained during the large-scale fire tests inside the cabin. The MAC figure (Reference 15), or maximum allowable concentration for an 8-hour exposure, for each of the suspected gases, is also listed in the table. 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 were the large concentrations of hydrogen chloride, hydracyanic acid, unsaturated hydrocarbons and halogenated hydrocarbons (Groups B and D) obtained with the Verel fabric. Also to be noted, was the large arsine concentrations obtained with the plywood material, which exceeded 100 times the MAC value. In general, carbon monoxide proved to be the most significant toxic gas. For the majority of materials, the concentrations shown in the table greatly exceed the recommended MAC figures for carbon monoxide.

The fire tests, both in the laboratory and in the DC-7 cabin, were conducted on the materials essentially at room temperature. However, a separate investigation was undertaken to determine the increase in flammability with pre-heating 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 subjected to the standard 1 1/2 omcj birmer 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 break out rapidly in flames. This test would tend to confirm the very low flash-ignition temperature obtained for latex foam in the laboratory tests, as shown in Figure 5.

DC-7 CABIN FIRE TESTS

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 15 seconds, then removed. This is consistent with current interpretation of FSS Release 453 laboratory test requirements. The only material that was not self-extinguishing, and continued to burn after 15 seconds, was the wool curtain material. Repeating this test with a paper safety match, the material developed a self-sustaining flame in less than 10 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.

Fire Tests Nos. 1 to 40

The conditions under which the main series of 42 fire tests were conducted are shown in Table 7. Also, listed in this table are the locations of the tests within the cabin. The actual location of the tests are shown pin-pointed in Figure 1. Of the 42 tests conducted, only in the last two tests 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 6.

For the first group of 40 tests, the data show that in only 7 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. The severe fire condition in the sidewall developed only after being pressurized with rated airflow, which caused failure to the weakened air duct.

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 the table. Also shown in the table is the time flaming persisted after removal of the burner. Duration of the fire test varied from as low as 4 minutes to 30 minutes. The test was stopped only after it was established that continued burner application would either increase the size of the fire or else that allowing the fire to continue burning could cause excessive damage to the interior and endanger test personnel. The flame-spread with time for the larger size fires and the damage inflicted are shown by the photographs in Figures 2 to 8. The data for the contour mapping of the flame propagation were obtained from color motion picture film. The figures show the relatively slow increase initially in the size of the fire in contrast to the very rapid build-up in fire which occurred just prior to the extinguishment of the fire to limit its further damage.

A comparison of the flammability afforded by the new materials, as compared to the original equipment, is shown in the test data. No serious fire hazard is seen to exist, from an ignition source the size and intensity of a 10-inch burner flame, when the more flame-resistant materials are used in the cabin interior.

The floor materials resisted fire exposure better than that of any other part of the cabin. In an attempt to increase the combustibility of the flooring, the materials were heated electrically from underneath by a series of strip heaters. Chemical powder was also ignited on top the flooring to provide a more severe ignition source.

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 a fresh air supply are prevented, by the fiberglas fabric, from reaching the backing material. Latex foam was seen to heat up very slowly and smoulder as long as the seat upholstery material remained relatively intact. However, once the covering material is destroyed, the foam padding will burn rapidly with an open flame.

Only with latex foam, was difficulty encountered in extinguishing the fire, which then required total immersion in water to be effective.

Polyurethane foam burned more rapidly than either latex or vinyl foam, but unlike latex, did not smoulder. Of the three foam materials, only vinyl foam could not be ignited to a self-sustaining fire.

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

Concentrations of smoke, carbon monoxide, carbon dioxide, and oxygen are presented in the tables. 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.

Fire Test No. 41

Test No. 41 was conducted in the forward section, left-side area, of the DC-7 cabin, which had been in part retrofitted for this test with new materials of a more flame-resistant type. Instrumentation within the cabin is shown in the plan drawing (Figure 9). The test area, before and after the fire, is shown by the photographs of 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 bottom 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 for this test with Verel, fiberglas and vinyl foam.

A self-sustaining fire over the forward cape 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 seat back cushion 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.

It is of utmost significance to note, that test personnel did not experience any discomfort from heat or difficulty in seeing through the smoke while inside the cabin. The occurrence of the flash fire followed evacuation of the cabin by less than two minutes. 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 ~~Afger~~ the flash fire, which endured for only ~~for~~ about one minute, was smothered by lack of oxygen, the only fire that continued to burn was that of a deep-seated fire inside the latex foam cushions of the test seat. This seat had to be removed bodily 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, & 12 ~~of the~~ fire. The test seat is shown missing in the photographs after the fire.

Between the seats are shown Verel and wool curtains. The Verel curtains were completely charred by the fire, while the wool curtains were only partially charred.

The hat rack portion directly above the fire was severely damaged. However, the vinyl fiberglas fabric, for the most part, resisted ~~was not damaged~~ by flame penetration and provided considerable protection to the hatrack.

The Verel fabric used on Seats Nos. 1 and 3, adjacent to the seat that was set on fire (Seat No. 2) was severely charred, as shown in the photographs. However, the exposed back of the cushion of Seat No. 1 was only slightly charred, as shown in the photographs. The Verel fabric on the front side of Seat No. 3 was likewise completely charred. It is of interest to note that the vinyl foam for this seat protected by a fiberglas cover, underneath the Verel fabric, showed no signs of fire damage.

The wood paneling only experienced a skuggt slight charring near the ceiling level.

No damage, other than a slight puckering of the doorway near the test fire, was noticed. However, there was no discoloration of the material from heat. The wool carpet did not show any visible signs of fire damage.

The plexiglas windows in the immediate fire area had been protected by a thin aluminum sheet and only showed a light damage (frosting).

Smoke damage was extensive throughout the cabin. A greasy film was found on the surfaces left undamaged by fire, especially the metal surfaces and floor.

Air and surface temperatures of the interior of the cabin are shown by the series of curves in Figure 13. Only continuous recordings were plotted. Other temperature data was only of limited use because of too low scanning speeds. Of major signifiaant interest to the fire hazard was the very slow increase in temperature over a comparatively long period of time, followed by an abrupt and extremely rapid rise which was then accompanied by an equally rapid drop in temperature. Such a behaviour pattern for the cabin fire would appear to be more closely related to a ClassB fire (gases and liquid fuels) than to a ClassA fire (~~solid hydrocarbon materials~~). The rapidity of flame-spread from the center of the back cushion (Thermocouple No. 4) of the test seat set on fire, to engulf the entire interior of the cabin, occurred in only about 30 seconds. Extinguishment of the flash fire, as shown by the curves, was even more rapid. After the extinguishment of the fire, the temperature returned to almost normal, which implied that open flaming had ceased. The short duration of the fire was also indicative of the small amount of heat liberated during a flash fire of this type.

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 flamespread along the ceiling as being approximately 68 feet per minute.

Of ~~equal surprise~~, was the 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 against temperature rise and the curves are reproduced in Figure 14. The curves also show the very abrupt rise in carbon monoxide concentration from a relatively safe level of 100 PPM. This ~~is shown~~ accompanied by a sudden rise in temperature after about 30 seconds. Decrease in oxygen content in 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 by the curves in Figure 15. Nevertheless, about 1-1/2 minutes before the flash fire the smoke density was found to suddenly increase very rapidly.

From the test results for the particular fire incidence repressnted by the curves, it was concluded that from a safety viewpoint, heat exposure, rather than carbon monoxide inhalation, would be the primary danger to life. Smoke during the early part of the fire would likely be sufficient tocause serious discomfort and panic before the more serious effects of carbon monoxide and heat were felt.

Concentrations of toxic gases shown in Table 6 are generally low compared to [illegible] their respective MAC values. However, caution is needed in the interpretation of such test data. The synergestic effect of combining toxic gases on the health hazard could not be cnnsidered in this limited study of the problem (Reference 16). Although the percent concentration of each of the toxic gases may be low as compared to their MAC number, the total effect of all the gases reported in the test data can only be surmised.

Fire Test No. 42

Test No. 42 was conducted in the mid-section left-side area of the DC-7 cabin. Instrumentation within the cabin is shown in the plan 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 Seats Nos. 5, 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 the sense of smell in less than one minute. Due to more humid conditions, 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 cushions. The back cushion of the test seat was observed outside the cabin window to ignite only after 31 minutes. This was followed within two minutes, 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 occurrence of 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 to dumping CO_2, a flash fire, more violent than the first flash fire, suddenly occurred without warning. Flames were seen to shoot out of the camera openings in the plexiglas windows. This experience demonstrated very vividly the danger of admitting fresh air to a confined smouldering fire, as was the case in the test fire.

Both cardox and water were used in large quantities to extinguish the fire. Only after about two hours time, was it possible to ~~safety~~ safely re-enter the cabin to remove seats that were still smouldering.

Fire damage was much more extensive than in the previous test, as seen by the photographs ~~of fire damage~~. 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 Verel and wool curtains were completely charred by the fire. Seat upholstery utilizing Verel and wool likewise sustained almost complete destruction in the center area of the fire.

Wood paneling showed extensive charring ~~above the handrail~~ over the upper part of the sidewalls 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 plexiglas windows showed some frosting due to heat melting the material. The window next to the fire burned through one layer of plexiglas, although protected by an aluminum sheet. Adjacent unprotected windows did not suffer any burn throughs.

The portion of the hatrack and ~~sidx~~ sidewall reupholstered with vinyl fiberglas fabric did not show any further deterioration from that in Test No. 41.

Again, very little damage, if any, 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. Seats shown missing in the photographs were removed from the cabin to better control the still smouldering fire in the latex foam.

The seat, behind the test seat, shows the destruction of the Verel upholstery. However, the fiberglas covering for the back cushion, as shown in the same photograph, ~~is~~ remained virtually intact and the vinyl foam padding was not affected by fire. (Note: Damage shown resulted from previous fire tests).

Continuous recordings of temperature inside the cabin are reproduced in the curves 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 to 500~~ about 400°F was about five minutes. It should be noted that the more readily combustible ceiling materials normally present in cabins were absent in this re-run test.

The curves relating the build-up in temperature, smoke, carbon monoxide, oxygen and pressure with one another are shown in Figure 20. The curves differ mainly 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 in time to that of the air temperature. Pressure ~~frop~~ 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 an American Airlines configured DC-7 passenger cabin, 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 DC-7 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, are valuable in predicting the degree of fire hazard present within a given aircraft cabin.

3. Low flammable materials are available which are capable of greatly reducing the extent of the fire damage which may arise from the majority of fire incidents typical of 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 an ignition of the seat cushion is slow to develop during an initial stage of 15 to 20 minutes. However, once the flames have reached ~~a height~~ the top of the seat of about 2 feet,further progress of the fire is greatly ~~increased~~ accelerated. Thus, from a relatively small fire that may considered at first to be harmless, a flash fire may be expected to develop within a few minutes.

6. The most hazardous furnishings in the cabin interior are the wool curtains which are capable of being set on fire ~~with one~~ even ordinary paper safety match.

7. Damage to the interior of the cabin by a flash fire is extensive with most damaged areas occurring above the window level and 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. Survival limits for exposure to heat and carbon monoxide inside the cabin are not exceeded up to within a few minutes of the occurrence of the flash fire.

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

11. The flash point temperature for latex foam is considerably less than that for any other cabin magerial.

12. The self-ignition temperature for the Naugahyde armrest material is the lowest for all the cabin materials.

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

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

15. Fire is extinguished following the flash fire by oxygen starvation, except for deep-seated smouldering fires inside latex foam cushions.

16. Low flammable rated materials are capable of very rapid flame propagation and burning when subject to radiant heat from a large cabin fire.

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

18. Smouldering fires inside the cabin may produce a flash fire when fresh air is admitted during fire-fighting operations.

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ILLUSTRATIONS

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ABSTRACT

FAA ADS
Federal Aviation Agency

A study of the combustion characteristics of interior cabin materials used in air transport was made. Standard laboratory tests were conducted on both the original materials used on ~~the~~ a DC-7 cabin and on new replacement materials of a more flame-resistant type.

In the laboratory tests, ignition time, flaming time, flash ignition temperature, self-ignition temperature, burn length, burn rate, flame spread index, smoke and toxic gas concentrations were measured for each material.

Materials tested in the laboratory were ignited insitu inside the DC-7 cabin at different locations by a Bunsen burner flame in a series of 42 tests. Flame propagation, smoke, carbon monoxide, carbon dioxide and oxygen concentrations were recorded.

The major fire hazard in the DC-7 cabin resulted from materials used in the curtains and seat cushions. The ability of the more flame-resistant materials to contain and resist the spread of fire was demonstrated. In the two large fire tests conducted, recordings of cabin temperature, smoke, and carbon monoxide showed that survival limits were not exceeded up to about the time of the occurrence of a flash fire.

Descriptors:

~~Aircraft~~ Fires — Fire Safety

~~Fire Safety~~ — Survival

~~Smoke~~ — Smoke

~~Toxic Gases~~ — Toxicit

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