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Effectiveness of Seat Cushion Blocking Layer Materials against Cabin Fires

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ABSTRACT

Materials are available for preventing or retarding aircraft cabin fires involving urethane foam seat cushions. Realistic fire tests performed in a wide-body test article demonstrate that some in-flight and ramp fires can be prevented, and that the allowable time for safe evacuation can be significantly extended during a survivable postcrash fuel fire, when the urethane foam seat cushion is covered by a "blocking layer" material.

OBJECTIVE

The main objective of this paper is to describe the effectiveness of aircraft seat cushion blocking layer materials when subjected to various realistic cabin fire conditions.

BACKGROUND

The flammable nature of foamed plastics, in general, has focused attention on protecting or replacing urethane foam in such widespread residential applications as household insulation, upholstery furniture, and mattresses (reference 1). In transport aircraft, the large number of passenger seats constitute the major application for flexible urethane foam. Accordingly, the Special Aviation Fire and Explosion Reduction (SAFER) Advisory Committee, convened by the Federal Aviation Administration (FAA) to "examine the factors effecting the ability of aircraft cabin occupants to survive in the postcrash environment and the range of solutions available," made the following recommendation: "Develop for aircraft seats, fire blocking layers (e.g., fire barriers) for polyurethane foam cushioning material, in order to retard fire spread" (reference 2). This paper describes FAA test results on candidate blocking layer materials evaluated in wide-body cabin test article under various realistic fire conditions. The effectiveness of the blocking layer material is judged by comparing seat test results, with and without blocking layer protection, under identical fire test conditions.

Aircraft cabin fires may be categorized as follows: ramp, in-flight, and postcrash. The characteristics of each are sufficiently distinct to require separate analysis. Ramp fires occur when an aircraft is parked at the ramp, usually in an unattended condition, but on less frequent occasions during servicing. Past ramp fire experience has resulted in loss of property but not loss of life. For example, a 727 was extensively damaged as a result of a fire originating from discarded smoking material placed inside a plastic disposal bag located adjacent to a passenger seat (reference 3). The loss was estimated at $3,200,000. The elapsed time before discovery of the fire, approximately 50 minutes, is consistent with the ability of polyurethane foam to support smoldering combustion for long periods of time, before transitioning to open flaming. Most in-flight fires occur in accessible areas, such as a galley, and are detected and extinguished promptly. On rare occasions in-flight fires become uncontrollable, leading to large loss of life. The most recent example was an L-1011 in-flight cargo compartment fire over Saudi Arabia, eventually claiming all 301 occupants onboard the airplane (reference 4). The fire became life threatening when flames penetrated through the cabin floor, involving seats and other interior materials. In the United States all fatalities attributable to fire

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occur in postcrash fire accidents (reference 5). Most postcrash cabin fires are accompanied by a large fuel spill fire. Burning interior materials may effect the survivability of cabin occupants in those accidents with a predominantly intact fuselage and a fuel fire adjacent to a fuselage opening, such as a rupture or door opening (references 6 and 7). Under these conditions, seats near a fuselage rupture or door opening will be subjected to intense thermal radiation and/or flames from the fuel fire.

DISCUSSION

BLOCKING LAYER MATERIALS - Over the past 20 years or more, the aircraft industry has constructed aircraft seat cushions from urethane foam, which possesses low weight and excellent comfort, resiliency and durability. In applications where weight is not a consideration, neoprene foam is a viable replacement for urethane foam when improved fire performance becomes a requirement (reference 8). However, neoprene foam is approximately 3 to 4 times as dense as urethane foam, and would create a prohibitive weight penalty in aircraft seating. A thin, lightweight blocking layer material, encapsulating the urethane foam to prevent or retard fire involvement of the urethane, is an attractive protective measure for aircraft seating. The blocking layer material is an interliner between the upholstery cover and foam cushion. In some cases it can also function as a ticking.

Table 1 is a list of candidate blocking layer materials for aircraft seating evaluated in this paper. There are two basic types of blocking layer materials; (1) foams, and (2) aluminized fabrics. The foam blocking layers are neoprene (polychloroprene), which is glued to the urethane foam. Upon exposure to heat or flame, neoprene foam blocking layers produce a relatively stable char, which acts as an insulator and reduces the rate of heat transfer to the urethane foam. Of the two foams listed, only Vonar® is marketed as a blocking layer; LS-200 is normally used as a full cushion. The lightest Vonar blocking layer has a cotton scrim and weighs 23.5 oz/yd^2.

A more recent blocking layer consideration is the aluminized fabrics, used primarily in protective clothing against heat or fire. These materials were identified by the National Aeronautics and Space Administration (NASA) as a possible alternate to a Vonar blocking layer at approximately 1/2 the weight (reference 9). Fabric blocking layers are designed to cover the urethane foam in the same manner as an upholstery cover, with the open end being sewn or fastened in some manner to completely cover the urethane. Fabric blocking layers are composed of high-temperature synthetic fibers, and an aluminized outer coating to reflect heat. The aluminized coating may also impart some degree of protection by preventing or delaying the the formation of urethane drippings on the floor which, if ignited, can contribute to the spread of fire (reference 10).

Table 1. Materials Tested

Material	Chemical Composition
Baseline	
(1) Wool (90%)/Nylon (10%) Fabric	-
(2) FR Urethane foam	-
Foam Blocking Layer	
(3) Vonar®, 3/16 in. thick	FR polychloroprene
(4) LS-200, 3/8 in. thick	FR polychloroprene
Fabric Blocking Layer	
(5) Norfab®, 13 oz/yd^2	Blend of predominatly aromatic polyamide fibers wrapped around a fiberglass fire core, aluminized outer surface.
(6) Preox®, 11 oz/yd^2	Heat stabilized polyacrylonitrile, aluminized outer surface.

(1) Type of seat upholstery cover used in all tests
(2) Fire-retardant
(3) Registerd Trademark, DuPont Co., Wilmington, Delaware
(4) Product of Toyad Corporation, Latrobe, Pa.
(5) Registerd Trademark, Norfab Corporation, Norristown, Pa.
(6) Registerd Trademark, Gentex Corporation, Carbondale, Pa.

TEST ARTICLE

The test article was a C-133 aircraft, modified to resemble a wide-body cabin interior, as shown in figure 1 and in reference 11. The cross sectional area is similar to, although slightly smaller than, a wide-body cabin. An interior volume of 13,200 ft^3 is representative of a wide-body jet.

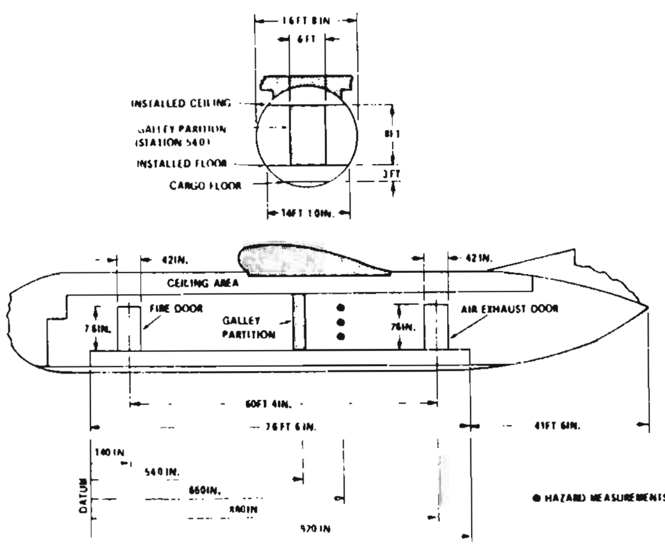


Figure 1. Schematic of C-133 Wide-Body Cabin Fire Test Article

All combustible materials installed in the original cargo aircraft were removed and the new floor, sidewall and ceiling surfaces are composed of noncombustible materials. A CO_2 total flooding system allows for the selective termination of a test. These protective measures have resulted in a durable test article, which has withstood hundreds of tests with only minor damage and thus allowed for the conduct of parametric studies with different materials or different fire test conditions.

The test article is extensively instrumented to measure the major hazards produced by a cabin fire as a function of time at various cabin locations. The following measurements are routinely taken: temperature, heat flux, smoke density, carbon dioxide (CO_2), carbon monoxide (CO), oxygen (O_2), acid gases (e.g., hydrogen fluoride (HF), hydrogen chloride (HCl)), and organic gases (e.g., hydrogen cyanide (HCN)). Video and photographic coverage documents the visual progress of the fire.

The C-133 test article was utilized to evaluate candidate blocking layer materials under test conditions representative of the three major types of cabin fires. Figure 2 illustrates the installation of interior materials in the forward part of the test article. The furnished test section is centered at the fuselage opening (test station 140) adjacent to an external fuel fire used in postcrash studies. For the postcrash test condition, an additional opening is provided at test station 880 (figure 1). A large fan behind the fire pan can be employed to simulate ambient wind and create penetration of fuel flames through the forward opening. Under both the ramp and in-flight test conditions, all fuselage openings are closed. For the in-flight condition, a ducting system was designed and installed in the test article to simulate ceiling air intake and baseboard air exhaust from a cabin environmental control system. One cabin air change occurs approximately every 3 minutes. No ventilation was used under the ramp fire condition.

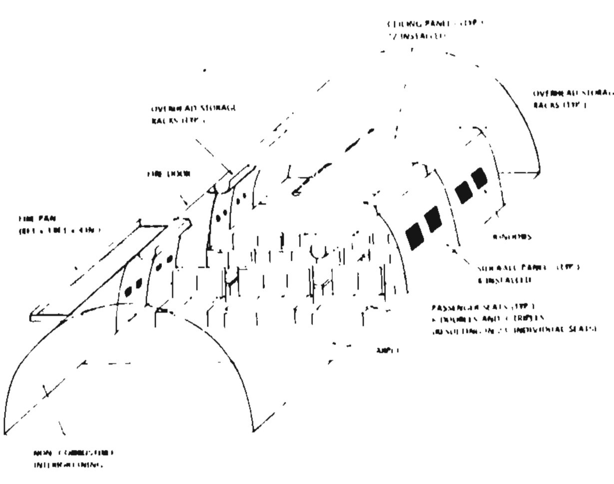


Figure 2. Installation of Wide-Body Materials Inside C-133 Test Article

During some of the tests only aircraft seats were subjected to the fire conditions (e.g., ramp and in-flight tests). This was necessary because of the great expense of the ceiling and sidewall panel materials and stowage bins. The seating configuration was always centered at test station 140.

IGNITION SOURCES

Table 2 lists the ignition sources used to evaluate the effectiveness of the candidate blocking layer materials. The plastic trash bag used in the ramp fire test was suggested by the 727 ramp fire discussed previously. Various ignition source intensities possible during an in-flight fire were employed, ranging from the relatively weak cigarette ignition to the more intense flight bag or gasoline fire. The burning flight bag ignition source, which was located underneath a seat, was also representative of floor burn through from a lower compartment. The most severe ignition source was the 80-square-foot fuel fire adjacent to a 76-inch by 42-inch fuselage opening, used to simulate a postcrash fire condition. Previous work had demonstrated that the intensity of the thermal radiation passing through an opening of this size was approximately 80 percent of the level produced by an infinitely large fuel fire under zero wind conditions (references 7 and 12).

Table 2. Test Ignition Sources

Type of Fire	Ignition Source
Ramp	• Plastic trash bag filled with approximately 18 ounces of paper towels and newspaper
In-Flight	• Cigarette • Newsprint (4 double sheets) • Gasoline (1 print) • Simulated nylon flight bag (contents 2 shirts and 2 double sheets of newsprint approximately 22 ounces)
Postcrash	• Jet fuel (80-square-foot pan containing 50 gallons of fuel)

TEST RESULTS

RAMP FIRE - In the ramp fire tests, three rows of triple aircraft seats, with each row containing two sets of triple seats and a section of carpet under the center row, were installed in the test article. The trash bag was placed adjacent to an outer seat in the middle row and ignited with a match. Figure 3 compares results for a test with unprotected cushions and a test with cushions protected with an LS-200 blocking layer. The results demonstrated that the use of a foam blocking material on seat cushions can prevent a ramp fire which would become out of control in 3 to 5 minutes, if the seats were not protected.

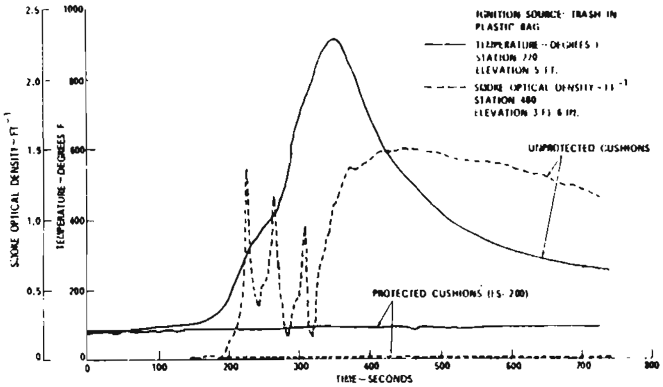


Figure 3. Seat Cushion Blocking Layer Benefit-- Ramp Fire Scenario

Figure 3 indicates that the target seat became significantly involved in fire in about 3 to 3 1/2 minutes. By almost 6 minutes oxygen depletion caused the flames to subside and the fire to transition to a smouldering stage, evidenced by the temperature peak and subsequent decrease in temperature and by the persistent increase in smoke level. Although not shown in the figure, the seats reignited into a flaming mode when a door to the test article was opened, because the supply of oxygen in the cabin was replenished. Eventually, all 6 sets of triple seats were consumed by fire.

IN-FLIGHT FIRE (C-133) - The in-flight fire test setup was identical to that used in the ramp fire tests with two exceptions: (1) simulated cabin air ventilation was employed, and (2) the ignition source was placed under (versus adjacent to) the target seat (same seat location). Figure 4 compares the temperature history slightly

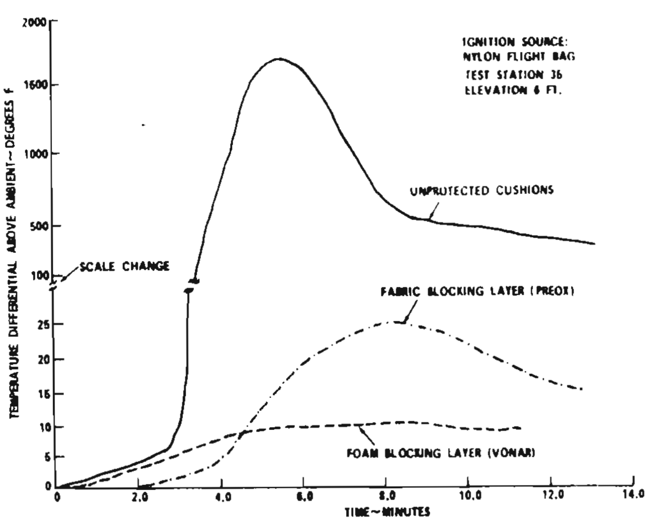


Figure 4. Seat Cushion Blocking Layer Benefit-- In-Flight Scenario

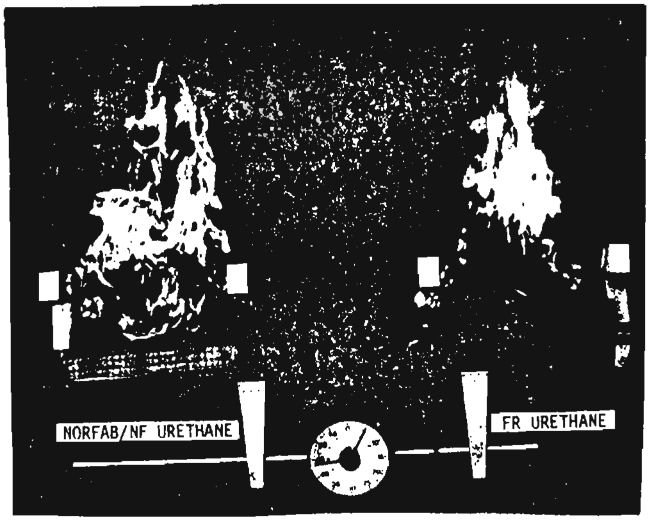
forward of the fire origin in tests with foam blocking layer protection, fabric blocking layer protection and no seat protection. Both types of blocking layer materials prevented a fire which would have spread uncontrolably without seat protection. Based on the peak temperatures, the foam blocking layer was more effective than the fabric blocking layer, although both types of material prevented fire spread beyond the vicinity of the ignition source.

The ramp and in-flight test results were similar in terms of the time interval from ignition to a significant increase in cabin temperature — approximately 3 minutes in both cases. This finding was probably due to the weights of the ignition sources being nearly equivalent. However, the in-flight ignition source was observed to continue burning for a longer time than the ramp fire ignition source. From figure 4, it appears that the in-flight source fire persisted for 8 minutes, apparently because of the slower-burning clothing materials.

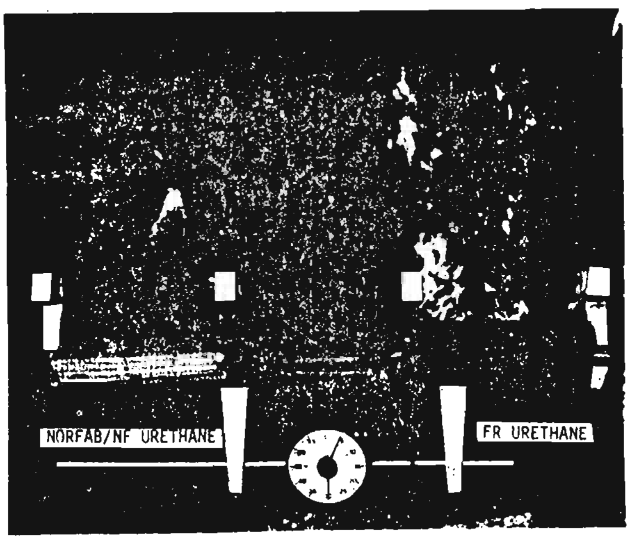
From a practical viewpoint, the time interval before significant seat involvement, without blocking layer protection, under most circumstances would be adequate for cabin crewmembers to extinguish the fire with hand-held extinguishers. Fires of this nature can be extinguished in 5 to 10 seconds under optimum fire-fighting conditions (e.g., immediate agent application, unobstructed access to base of fire, etc.). However, extenuating circumstances such as panic, or perhaps the fire origin being beneath the cabin floor, suggest the potential benefits of additional protection.

EFFECT OF FLAME RETARDANT IN URETHANE - In this period of unpredictable fuel costs, airplane operators continually strive for weight reduction. When a blocking layer material is employed, an increase in seat weight will be incurred. One method of minimizing the potential weight penalty of fire blocking layers is to utilize a nonfire-retardant (NF) urethane foam cushion, which is about 20 percent lighter than fire-retardant (FR) urethane foam. A series of tests were performed to determine if the use of a blocking layer over NF urethane foam presented any greater in-flight fire hazard than presently used FR urethane foam. Tests were also performed to study and compare the behavior of FR cushions with various blocking layers.

The tests were conducted in an open test bay area using a single aircraft triple seat (reference 13). The middle seat cushions were removed and the outer seats were configured in accordance to the comparison under study; e.g., in one test, both seats were protected with a foam blocking layer, but an NF foam was used in one seat and an FR foam in the other. For a given test, each seat was subjected to an identical ignition source. Figure 5 shows test results with newspaper ignition on the seat, with one seat comprised of an NF urethane foam protected with a fabric blocking layer and the other seat comprised of unprotected FR urethane foam. At 90 seconds, the protected seat had self-extinguished, while the unprotected seat fire was essentially out of control.



(t = 15 seconds)



(t = 90 seconds)

Figure 5. Seat Performance Against Newspaper Fire

Table 3 is a generalization of the in-flight ignition source results. It is apparent that either foam or fabric blocking layers over NF urethane cushions can prevent in-flight fires, which if left uncontrolled, can spread beyond the ignition source when the cushion is simply FR urethane. Moreover, when a blocking layer material is utilized, the presence or not of fire retardants in the urethane foam cushion will not have a bearing on the ultimate result, which is self-extinguishment of the seat fire. During replicate tests with blocking layer materials, the time to self-extinguishment depended on whether other seat components (e.g., armrest, tray back) were ignited. If these components were not involved, the fire was essentially out after the ignition source was consumed. When the seat components became involved, the fire burned, appreciably longer before self-extinguishing. During this latter kind of behavior, the fire intensity and growth was subdued compared to the burning of an unprotected seat. Thus, blocking layer materials were effective even when seat components other than the cushions were ignited.

Table 3. Generalization of Small Ignition Source Results

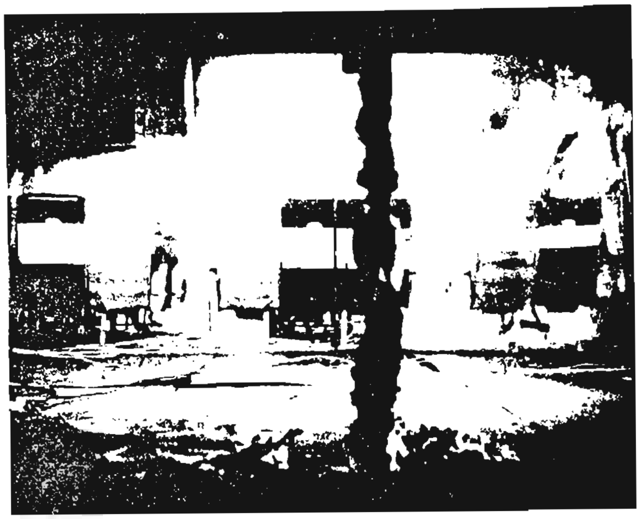
	Blocking Layer Type				
	None	Foam		Fabric	
	Urethane Foam Treatment				
Ignition Source	FR	FR	NF	FR	NF
Cigarette	Self-Extinguished	Self-Extinguished	Self-Extinguished	Self-Extinguished	Self-Extinguished
Newspapers on Seat	Destroyed Seat	Self-Extinguished	Self-Extinguished	Self-Extinguished	Self-Extinguished
Newspapers under Seat	Destroyed Seat	Self-Extinguished	Self-Extinguished	Self-Extinguished	Self-Extinguished
Gasoline (1 pint)	Destroyed Seat	Self-Extinguished	Self-Extinguished	Self-Extinguished	Self-Extinguished

FR - Fire-Retardant
NF - [illegible]

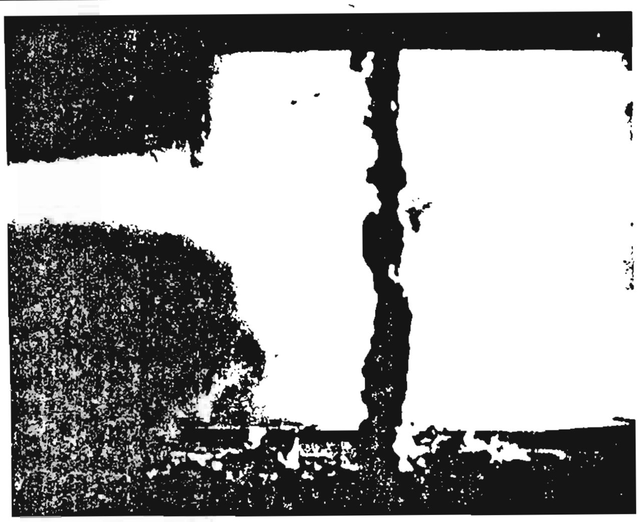
POSTCRASH FIRE (FULL-SCALE TESTS) - The postcrash fire tests were the most realistic undertaken. In these tests, a section of the C-133 test article was realistically lined and furnished with surplus or new wide-body materials, as illustrated in figure 2 and reference 7. The main objective was to examine the postcrash fire benefit of seat cushion blocking layer materials within the context of the remaining interior materials. The materials were subjected to a zero wind fuel fire adjacent to a large (22 ft^2) fuselage opening. Prior testing had demonstrated that a zero wind condition would produce minimal cabin hazards from the fuel fire; therefore, any hazards detected with interior materials installed could be attributed to the burning materials. Four full-scale tests were conducted with the only variable being the cushion makeup. The following cushions were tested: (1) unprotected (FR urethane) cushion, (2) FR urethane cushion with foam (Vonar) blocking layer, (3) FR urethane cushion with fabric (Norfab®) blocking layer, and (4) noncombustible (ceramic fiber glass) cushion.

In each of the tests, the fuel fire ignited the interior and produced a condition called "flashover," which occurred at a different point in time in each test. Flashover corresponds to a rapid growth of the fire from an area in the immediate vicinity of the fuel fire to the remaining cabin interior.

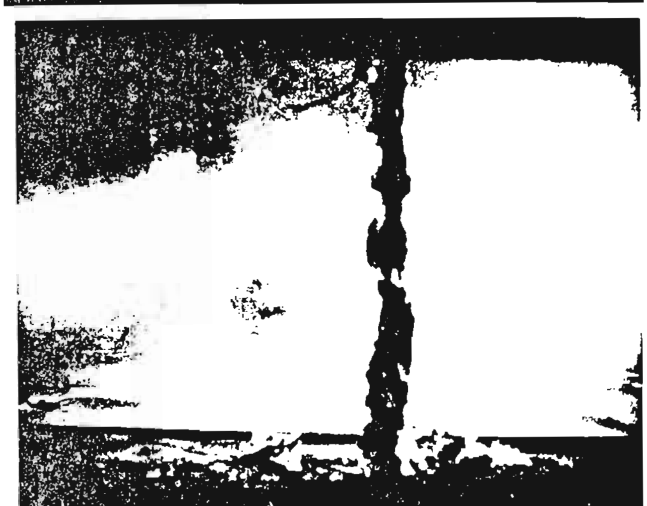
Figure 6 is a set of photographs taken at 5-second intervals, evidencing the onset of flashover in the test with unprotected cushions.



(a) 2:05



(b) 2:10

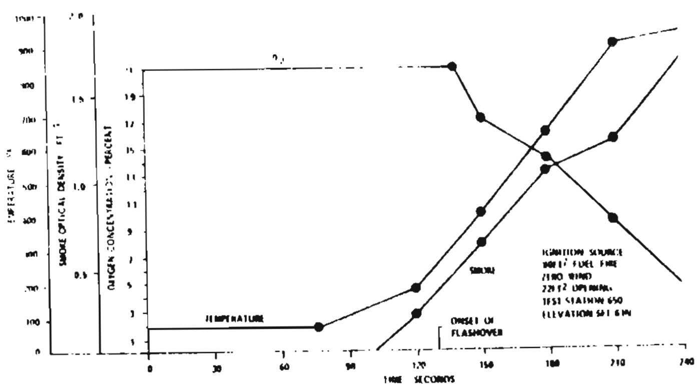


(c) 2:15

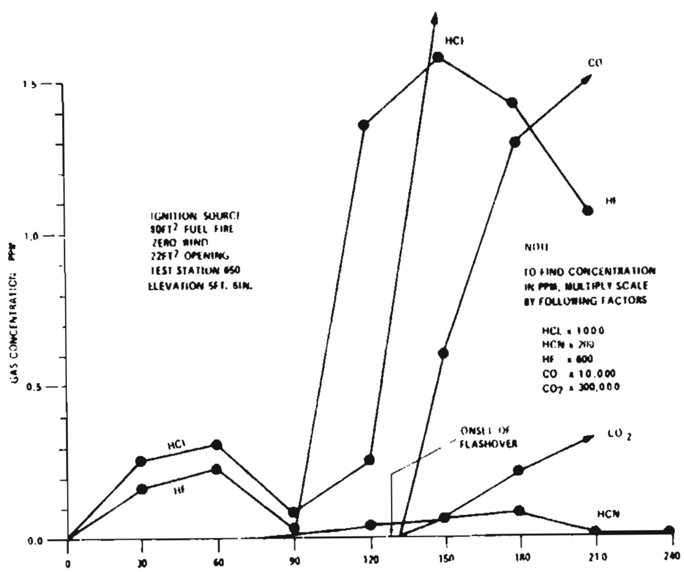
Figure 6. Photographic Documentation of Flashover

In a cabin fire, flashover seems to be caused by ignition of the hot smoke layer in the upper part of the cabin and of any materials nearby, leading to increased thermal radiation upon, and ignition of, materials in the lower cabin, and by burning ceiling panels which happen to fall upon and ignite seats.

In the C-133 test article, measurements are taken of what are believed to be the major fire hazards. Figure 7 contains these measurements as a function of time at an aft location for the test with unprotected cushions. Reference 7 contains an analysis which concludes that the various hazards are survivable before the onset of flashover, although widely accepted data does not exist for the incapacitation tolerance limits of the irritant gases HCl and HF. After flashover the various hazards increase markedly, and the analysis in reference 7 indicates that the tolerance limit is exceeded for five of the hazards. Thus, the occurrence of flashover indicates that conditions will rapidly become nonsurvivable throughout the cabin.



(a) During a Postcrash Fire



(b) During a Postcrash Fire

Figure 7. Hazards in Aft Cabin Produced by Burning Interior Materials

In order to quantitate the hypothetical survival time, a simple human survival model was developed which considers the effects of elevated temperature, CO_2, CO, HCN, HF, and HCl (reference 7). The major assumptions were that the hazards are additive and that a classical hyperbolic relationship exists between gas concentration and time of incapacitation. The model is hypothetical, and was developed as a tool for reducing a number of somewhat abstract hazard measurements into a single, cogent parameter-survival time.

The model was applied to analyze the survivability associated with the four full-scale fire tests with different cushion makeups. In the model, a variable called the mixture fractional effective dose (FED) is defined. It is calculated at each time increment analyzed, and is essentially the sum of the ratios for each hazard of measured dose to the incapacitation dose. Thus, the hypothetical survival time corresponds to that point in time when FED = 1.0.

Figure 8 is a plot of the calculated FED versus time in the aft cabin for the four full-scale fire tests. This plot indicates the safety benefit, in terms of increase in survival time, associated with seat blocking layer materials under the postcrash fire condition tested. The calculated FED does not include the effect of HCl in any of the tests because a malfunction in the analysis of HCl in one of the tests. The safety benefit of Vonar and Norfab blocking layer materials — 60 and 43 seconds, respectively — is considered significant, especially since the benefit is incurred within the context of the remaining interior materials. In addition, the results indicate that the amount of protection provided by Vonar is nearly equivalent to that of a noncombustible cushion, under the fire conditions studied. (Note that the improvement in survival time with the noncombustible cushions was only 8 seconds better than with the Vonar protected cushions.) The shape of the FED profiles indicate to some degree the rapidity by which conditions become nonsurvivable after the onset of flashover. In fact, the calculated safety benefit (survival time increase) for each of the protected cushion tests corresponds to the increase in time before the onset of flashover relative to the unprotected cushion test. Figure 8 also indicates that FED = 0 throughout the time framework of interest when the interior is noncombustible. This finding indicates that potential safety benefits exist, beyond that provided by seat blocking layers, by making improvements in the fire performance of other important interior materials; e.g., ceiling panels and overhead stowage bins.

Smoke was not a component of the human survival model. However, the impact of visibility obscuration resulting from smoke was calculated (reference 7). Figure 9 is a plot of cabin visibility in the aft cabin versus time for the four full-scale material tests. The most striking feature of the curves is the rapidity by which visibility becomes obscured, e.g., in some cases visibility was reduced from the length of the cabin to less than the width of the cabin in approximately 15 seconds. Also, by comparing figures 8 and 9, it is apparent that smoke becomes an important factor anywhere from 30 to 60 seconds before survival is no longer theoretically possible. This comparison also reveals that the ranking of results from best to worst for visibility loss was identical to the rankings for loss in survival time (i.e., noncombustible cushions > Vonar > Norfab > unprotected cushions).

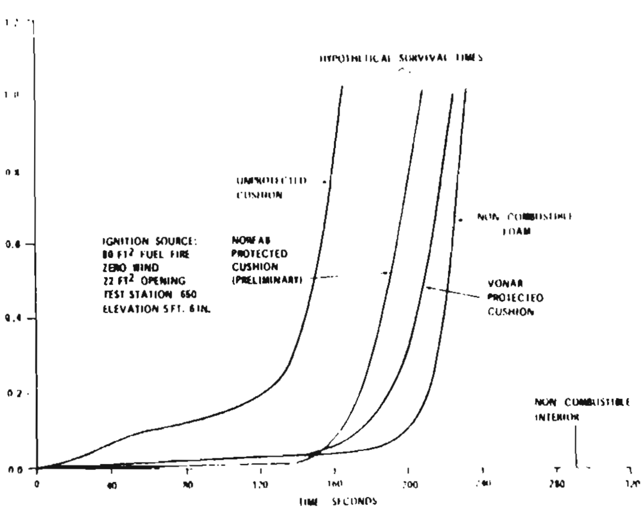


Figure 8. Effect of Cushioning Protection on Calculated Survival time Under Full-Scale Postcrash Fire Conditions

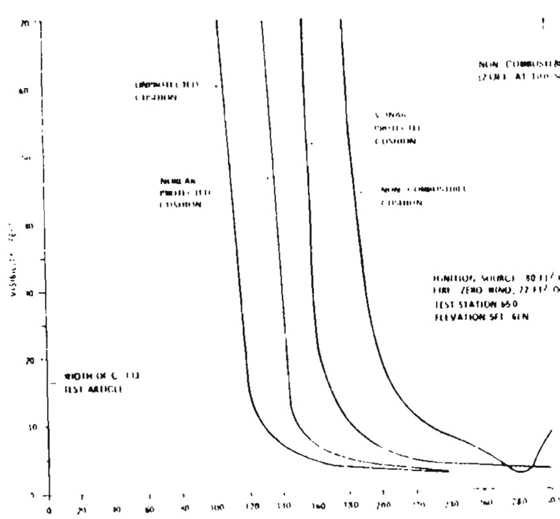


Figure 9. Effect of Cushioning Protection on Calculated Visibility Through Smoke Under Full-Scale Postcrash Fire Conditions

POSTCRASH FIRE (OTHER SCENARIOS) - The postcrash fire scenario discussed above was conceived for the purpose of creating a realistic impact-survivable fire situation wherein burning cabin materials have a dominant, if not controlling, effect on survivability. Obviously, a large number of other, and, perhaps more likely survivable postcrash fire conditions are possible. Another condition studied was a 2-foot-square opening, simulating a small fuselage rupture above the cabin floor, adjacent to the large external fuel fire. Because of the small rupture area, a simulated 3 miles per hour (mph) wind was utilized to intensify the cabin exposure conditions. Four double seats — three outboard and one inboard — symmetrically placed about the small rupture, were tested under these conditions. No other materials were placed in the test article. Figure 10 displays the cabin temperature history for three types of seating materials and for the fuel fire without seats. The results exhibit data crossover and small discrimination in the performance of different materials. For these reasons, this scenario was not utilized except for the above tests. The data also demonstrates that wind conditions created significant fuel-fire hazards inside the cabin. Under the conditions tested, approximately 50 percent of the cabin hazards were caused by the fuel fire.

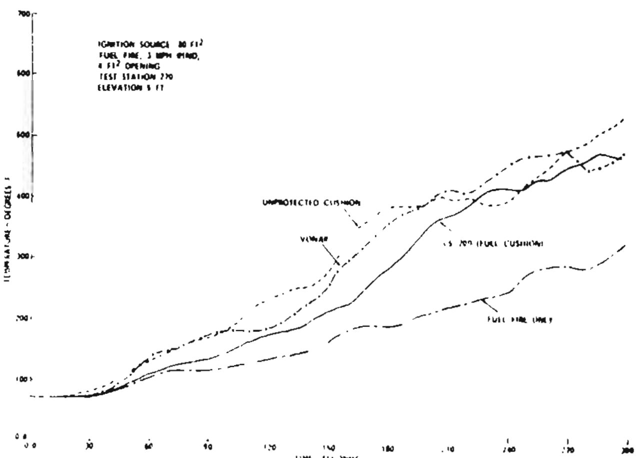


Figure 10. Postcrash Fire Test Results With Small Fuselage Opening and Wind

Another possible postcrash fire scenario consists of an intact fuselage with a door opening adjacent to a large external fuel fire. This scenario was also studied briefly, and is very similar to a past accident (reference 14). In these tests, a single triple outboard seat was located fore and aft of the type A door opening, and a 1.5 mph simulated wind was employed to create slight flame penetration into the cabin. Figure 11 compares temperature and smoke histories in tests with Vonar protected cushions and with unprotected cushions. In the test with protected cushions, the seat fire damage was minor and confined to the seat upholstery cover and various seat components; the flammable urethane foam did not become involved. By contrast, in the test with unprotected cushions, the fire became out of control in 3 to 4 minutes.

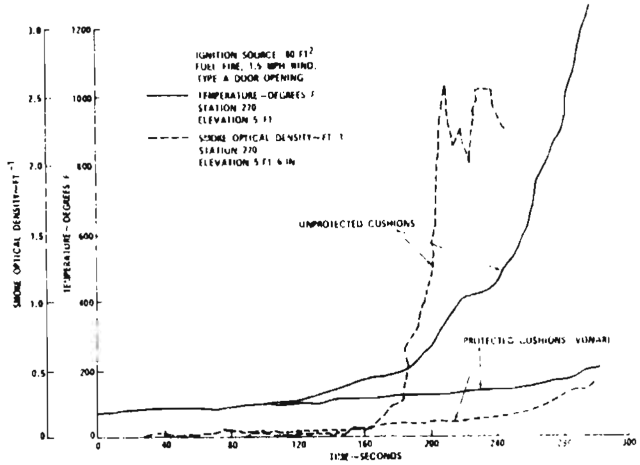


Figure 11. Seat Cushion Blocking Layer Benefit--Postcrash Fuel Fire Adjacent to Open Door

Thus, under this fire scenario, the benefit of seat cushion blocking layers is significant. An analysis of the results acquired for the three postcrash fire scenarios, as presented in figures 8, 10, and 11, demonstrate that potential benefits of seat cushion fire blocking layer materials are highly dependent upon fire scenario.

SUMMARY OF SIGNIFICANT FINDINGS

Based on the realistic cabin fire tests and analysis described in this paper, and on the seat cushion blocking layer materials evaluated and the types of fire test conditions employed, the following are the significant findings:

(1) Seat cushion fire blocking layer materials such as neoprene foam or aluminized high-temperature fabrics can prevent ramp and in-flight fires which become out of control when initiated at an unprotected seat and left unattended.

(2) Seat cushion fire blocking layer materials can significantly increase the safe time available for evacuation during specific types of postcrash cabin fire scenarios.

(3) Under severe fire conditions, such as a postcrash fuel fire, neoprene foam materials are more effective seat cushion blocking layers than aluminized high-temperature fabrics.

(4) Fire-retardant urethane foam can be replaced by nonfire-retardant urethane foam in aircraft seat cushions covered with a blocking layer material without essentially any loss in in-flight fire protection.

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