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FIRE-RESISTANT MATERIALS FOR AIRCRAFT PASSENGER SEAT CONSTRUCTION

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SUMMARY

This study describes the thermal response characteristics of fabric and fabric-foam assemblies. The various aspects of the ignition behavior of contemporary aircraft passenger seat upholstery fabric materials relative to fabric materials made from thermally stable polymers are evaluated. The role of the polymeric foam backing on the thermal response of the fabric-foam assembly is also ascertained. The optimum utilization of improved fire-resistant fabric and foam materials in the construction of aircraft passenger seats is suggested.

INTRODUCTION

The evaluation and selection of fire-safe materials for the construction of aircraft passenger seats is a difficult and complex problem. In a previous study (ref. 1) basic selection criteria were established for evaluating candidate materials for improved seats. Those materials were evaluated on the basis of FAA-airworthiness burn and smoke generation tests, colorfastness, limiting oxygen index (LOI), and animal toxicity testing based on the animal's response to the material's volatile products of decomposition. All materials tested or evaluated in this study passed the FAR 25.853 burn and smoke tests (ref. 1). The performance life and characteristics of the materials were also ascertained, based on their physical, mechanical, and aesthetic properties. Materials that had been proved to be fire resistive in our testing program (ref. 1) generally had improved thermal responses to various thermal loads corresponding to reasonable fire threats as they relate to in-flight fire situations.

The variety of passenger carry-on items — such as newspapers, matches, lighter fluid, and souvenirs (table 1) — represents a source of potentially combustible materials whose introduction on-board a commercial passenger aircraft would be difficult to control. The alternative is to increase the fire-hardness or fire-resistivity of the nonmetallic materials used in the construction of aircraft passenger seats. Nonmetallic materials, when categorized by their fire-resistivity properties can be grouped into two classes: fire retarded (FR) and thermally stable (TS).

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Fire-retardant treated materials have been and are currently being used in the construction of aircraft passenger seats. Such contemporary components as the polyurethane foam cushioning and upholstery fabrics have been treated with fire-retardant chemicals. As a result of such treatments, fire-retardant treated materials have varying degrees of resistance to ignition, burning rates, and smoke production. Fire-retardant treated materials tend to propagate a fire by flames once a sufficient thermal load, or flux, has been applied and the burning process has begun. Such a burning process is accompanied generally with an increase in the generation of smoke or toxic gas, or both, due to the fact that the material's normal mode of thermal degradation has been altered (ref. 2).

The development and utilization of thermally stable (TS) polymeric materials seems to be the desirable route to the solution of the problem of thermal stability, smoke, and toxic gas generation. A considerable interest has developed in recent years in fibers from thermally stable polymers for use in upholstery fabrics. Thermally stable fabrics have been reviewed by several investigators (refs. 3-5); some of the fabrics have been manufactured on a commercial scale. Fabric materials from such polymers as polyimide, aromatic polyamide, phenolics, and polybenzimidazoles (table 2) have had a considerable effect on the material options available to aircraft seat manufacturers. Polyimide fibers are promising as thermally stable polymers (ref. 6) that have excellent mechanical properties (ref. 7). Polyamide-polyimide mixtures have been blended with wool; they are commercially available in Europe. The future commercial availability of polyimide fabrics is still uncertain. Aromatic polyamides, on the other hand, are readily available commercially as Aramid. The manufacture and properties of aromatic polyamides are described in reference 8. Polyamides have been modified to enhance their thermal stability and other properties; these changes are reported in reference 9.

Phenolic fibers classed generically as "Novoloid" (personal communication from R. Jackson, Celanese Research Company, to authors, 19 March 1975) are commercially available, although in limited amounts. These phenolic fibers are made by the familiar condensation polymerization of phenol and formaldehyde. Polybenzimidazole (PBI) fiber (produced by Celanese Research Company) has excellent thermal stability and mechanical properties (ref. 10). A flight suit made from this material affords the pilot maximum protection in a fire. However, PBI is not yet available commercially.

In addition to fire resistivity and mechanical property requirements, upholstery fabric materials for aircraft passenger seats must comply with criteria such as appearance, weight range, wear life, and in-use performance. Fabric performance properties and some minimal acceptable levels are summarized in table 3. Properties related to the flammability level of fabric materials (contemporary and advanced) are summarized in table 4.

The concept of the fire-blocking layer, or heat barrier, between foam cushioning material and upholstery fabric is a design alternative for aircraft seats; it could be used immediately to improve the fire safety of aircraft passenger seats.

EXPERIMENTAL METHOD

Using the apparatus shown in figure 1, samples were placed in a vertical plane and subjected to an external point-source radiative heat flux. The sample materials used in this study are described in table 1. The fabric samples were pressed tightly against the foam samples (fig. 1) in order to minimize or prevent fabric shrinkage, which would result in areas of foam directly exposed to the radiant flux which would result in erroneous thermal responses. The actual sample area exposed to the radiant flux was 12.9 cm^2. The polyurethane foam was 10.20 cm thick; the neoprene foam was 5.08 cm thick. All tests were conducted at ambient temperature (25° C and 67% relative humidity). The heat flux was obtained by focusing radiation from a 500-W lamp onto the fabric sample, using an ellipsoidal reflector (fig. 1). Such an arrangement results in an axisymmetric radiant flux that decreases rapidly with distance normal to the reflector axis (fig. 2). Heat flux measurements were made by two methods: (1) a 1-cm-diameter heat sensor and (2) a 1-cm water-cooled slug calorimeter. The results are reported as a function of the peak heat fluxes, measured at the center of the heated region (radius = 0, fig. 2).

The samples were exposed to a heat flux range of 3 to 21 W/cm^2, as measured using a slug calorimeter at various heights and distances, The time at which smoke was emitted or when there was ignition and melting was measured.

RESULTS AND DISCUSSION

When fabrics are exposed to a sufficient thermal load they exhibit several observable changes, such as smoke evolution, melting, charring, and ignition. The exposure times at which such changes occurred were measured under peak heat fluxes in the range of 5 to 21 W/cm^2, for wool-nylon, PBI, Kynol, and cotton fabrics (figs. 3-5). The "no ignition" points (fig. 5) indicate that ignition did not occur even after a lengthy exposure at that particular heat flux. Quantitative comparisons of the thermal responses of the fabric samples tested are not possible because the samples varied in weight, construction, finish, weave, etc.; however, qualitative comparisons are sufficient to identify differences that can be attributed to the fiber composition of the materials. The exposure time required to produce observable thermophysical or thermally-induced chemical changes, such as smoke production, charring or melting, and/or ignition decreases with increasing heat flux for all materials tested (figs. 3-5). These materials were comparable in their behavior in regard to smoking and charring-melting but their ignition behaviors varied significantly. At high heat fluxes (>10 W/cm^2), cotton and wool-nylon fabrics ignite. Kynol and polybenzimidazole (PBI) do not exhibit ignition at higher thermal fluxes due to an inherent thermal stability that derives from their chemical structures (ref. 3). These results are consistent with results obtained by other methods and by various investigators (ref. 3) in the evaluation of the flammability characteristics of these materials.

Thermal responses of various fabric-foam combinations — wool-nylon, PBI, and Kynol fabrics — are shown in figures 6-8. The figures show the exposure times required, for the fabric alone and the fabric in combination with polymeric foam backing (polyurethane or modified neoprene foam), to produce smoking, charring, melting, or ignition. The densities of the polyurethane and modified neoprene foams were 0.86 kg/m^3 and 3.36 kg/m^3, respectively.

The effect of the foam backing on the fabric exposure times that produced smoke, charring, or melting was dependent on the magnitude of the imposed heat flux (negligible above 10 W/cm^2). At the higher thermal flux, large temperature gradients develop within the fabric-foam assembly. The fabric may smoke and char or melt before the foam senses the imposed thermal flux and therefore the influence of the foam on the thermal response of the fabric is negligible. At low thermal flux, large temperature gradients do not develop in the fabric-foam assembly, and the foam backing participates in the thermal response of the assembly. Once the foam backing is involved, its effects on the response of the fabric become somewhat unpredictable due to the complex thermal and fluid mechanical interactions between these materials.

The effect of the foam cushion backing on ignition is shown in figures 7 and 8. The urethane-PBI and urethane-Kynol assemblies ignite at heat fluxes at which Kynol or PBI will not ignite when tested individually. The neoprene-PBI and neoprene-Kynol assemblies (figs. 7, 8) did not ignite. Ignition test results for all fabric-foam combinations tested are shown in figure 9. The results indicate that the neoprene-fabric assembly is less likely to ignite as the result of a thermal load than a urethane-backed fabric. These qualitative results demonstrate the importance of the polymeric foam cushioning material in the overall thermal response of the fabric-foam combinations to an imposed thermal load. Therefore, the foam is an important consideration in the selection of materials and designs for fire-resistant aircraft passenger seats.

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TABLE 1.- AIRLINE TRASH SURVEY FOR WIDE-BODY JET TRANSPORT

	Bag 1	Bag 2	Bag 3	Bag 4	Bag 5	Bag 6
Aircraft origin	Chicago	Chicago	Chicago	London	London	London
Seat no./ location	22K and L/coach	5K/first class	12D/coach	Unknown	12B/coach	28F/coach
Location relative to seat	On floor under and behind seat	On floor behind seat	On floor under seat	Unknown	In pocket on back of seat	On floor in front of seat
Items collected	Newspaper — 7 sections and ads	Headphone bag Used cigarette packs Newspaper	2 newspapers — 1 with 6 sections, 1 with 4 sections	2 newspapers	2 headset bags 1 airsick bag 1 napkin (cocktail size) 1 airline magazine	Newspaper — 8 sections
Weight of items[a]	654 g	681 g	976 g	690 g	204 g	568 g

[a]Average weight of items: 628.8 g.

TABLE 2.- FIBERS FROM THERMALLY STABLE POLYMERS

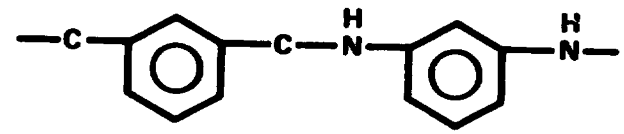
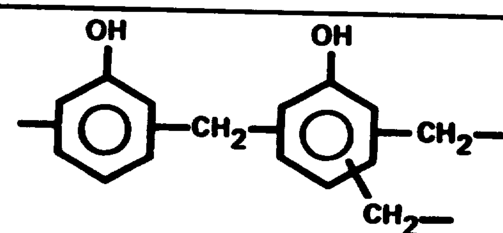
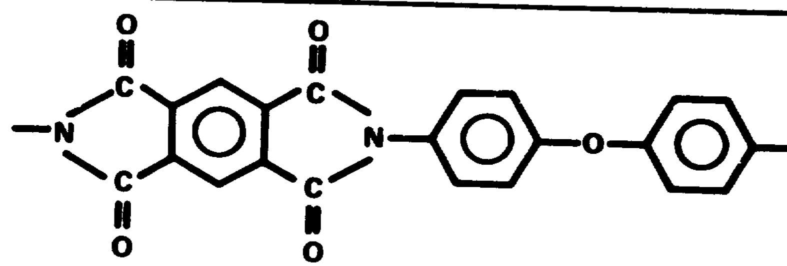
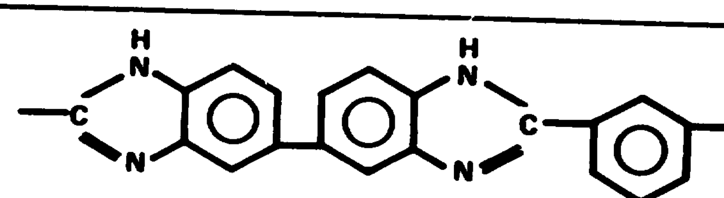
CLASS	EXAMPLE	STRUCTURE
AROMATIC POLYAMIDE	NOMEX	
PHENOLIC	KYNOL	
POLYIMIDE	KAPTON	
POLYBENZIMIDAZOLE	PBI	

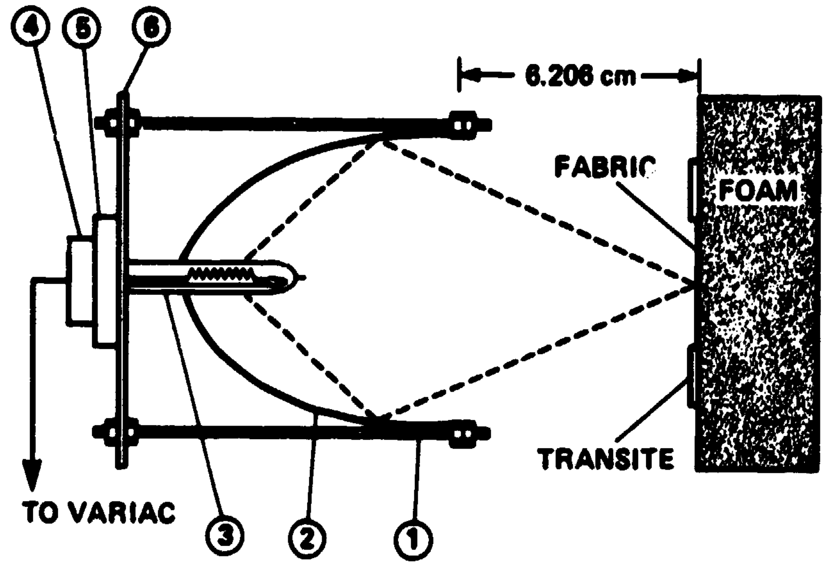
TABLE 3.- PERFORMANCE REQUIREMENTS OF FABRIC MATERIALS

Property	Minimum acceptable value
Tensile strength	31.8 kg
Tear strength	0.9 kg
Abrasion resistance (stoll flex)	1,000 cycles
Dimensional stability (dry cleaning)	2% shrinkage
Color fastness (to light, crocking, perspiration)	Must pass
Sewability and seam strength	Good
Cleanability	Good
Flame resistance (FAR 25.853(b))	Must pass

TABLE 4.- PROPERTIES RELATED TO FIRE HAZARD—QUALITATIVE ASSESSMENT

	Cotton	Polyester	Nomex	Kynol	PBI
Ingition in air[a]					
Calrod temp °C	<550	---	871	788	927
Time, sec	Inst.		1	---	6
Flame impingement					
Heat flux-protection	Nil	(Melt)	Good	Good	Good
Char yield characteristics	Low ---	(Melt) ---	High, friable	High, strong	High, strong
Smoke	Moderate	Low	Moderate	Low	Low
Off-gases (toxicity)	---	---	Toxic	CO_2/H_2O predom.	CO_2/H_2O predom.
Thermal stability					
Temp. degradation, °C	---	---	437	---	590-680
Approx. wt. loss 900° C, %	---	---	60	40	30
Oxygen index, % O_2	16-18	20-21	27-29	29-30	38-43

[a]From reference 11.



(1) THREE 0.145 cm THREADED RODS AND NUTS

(2) ELLIPSOIDAL REFLECTOR No. 4085-A, RESEARCH INC., MINNEAPOLIS, MINNESOTA

(3) QUARTZ LIGHT BULB, 500 W, GENERAL ELECTRIC No. Q500CL/DC

(4) BULB SOCKET

(5) TRANSITE SPACER

(6) 0.317 cm ALUMINUM PLATE

Figure 1.- Schematic diagram of experimental apparatus.

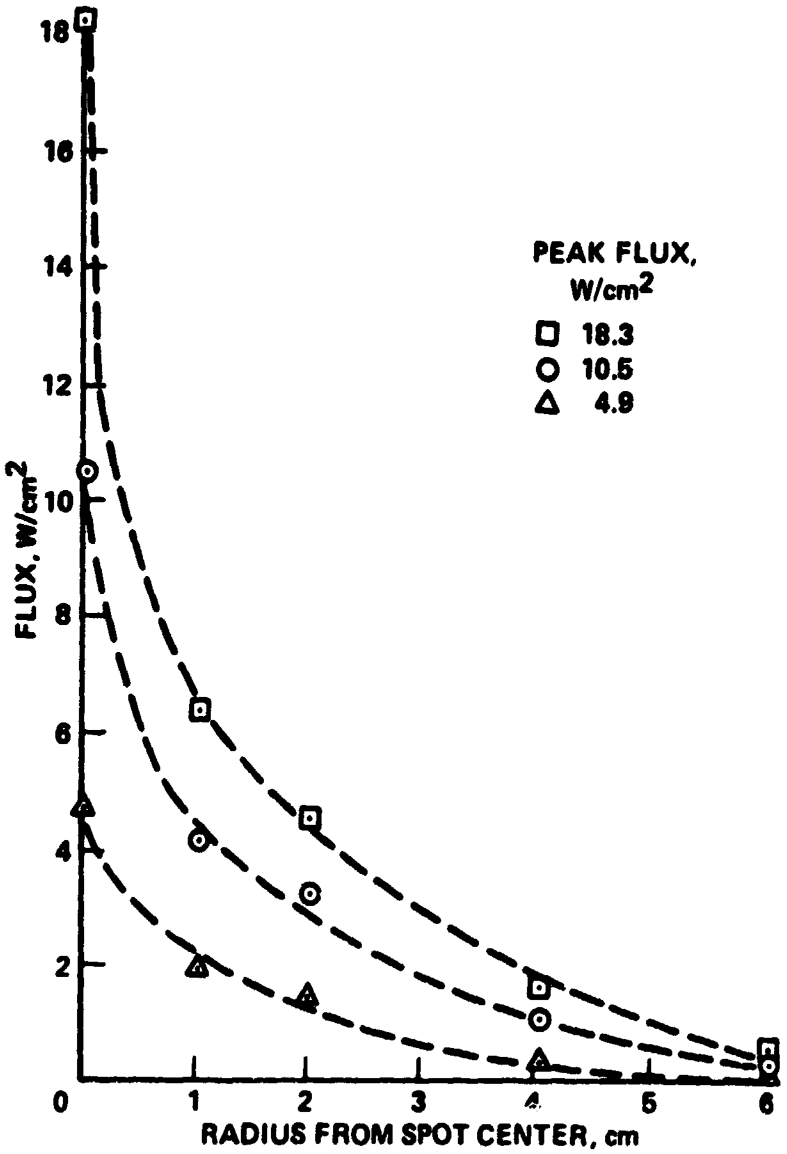


Figure 2.- Imposed heat flux as function of radius from center.

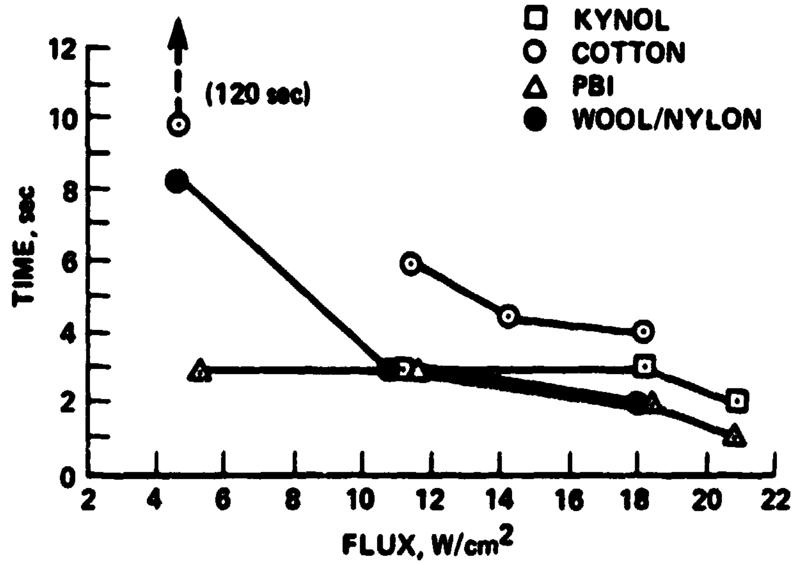


Figure 3.- Time to smoke vs imposed heat flux.

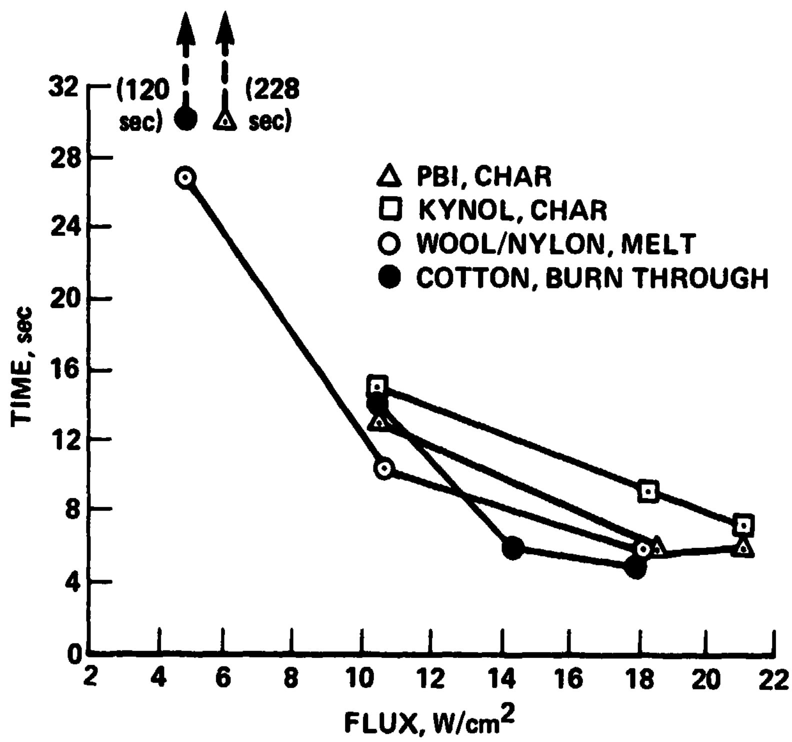


Figure 4.- Time to char, burn through, or melt vs heat flux.

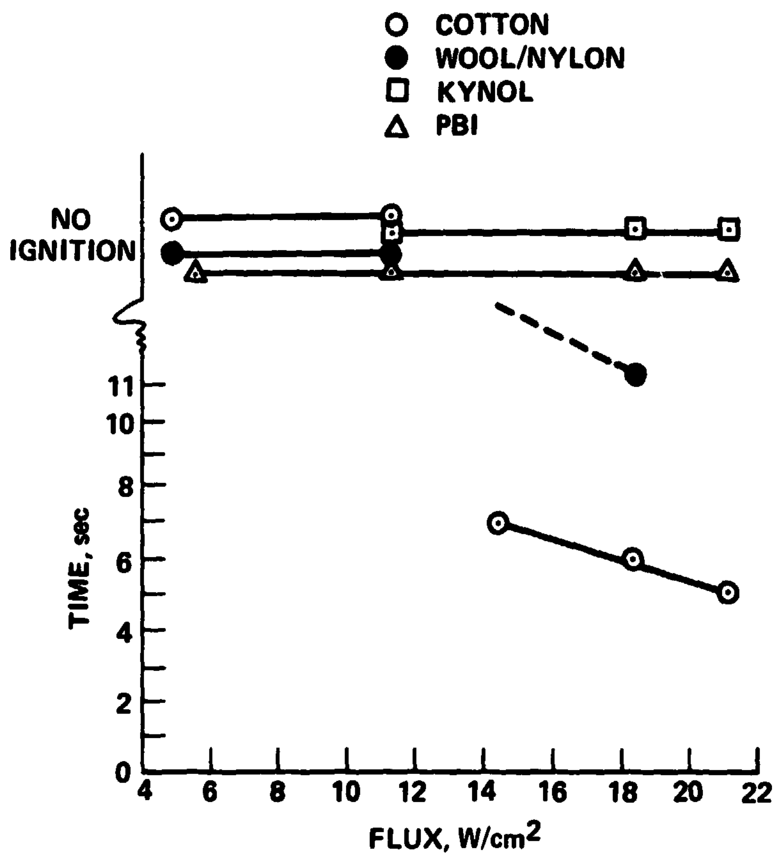


Figure 5.- Ignition times for fabric materials.

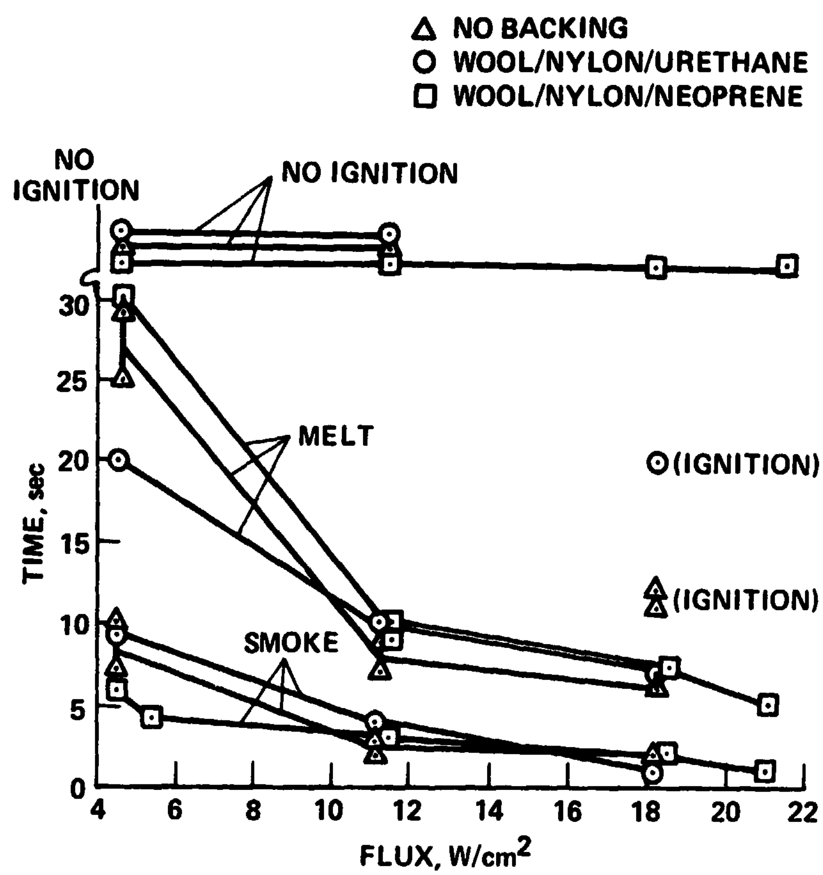


Figure 6.- Times to smoke, melt, or ignition for wool/nylon.

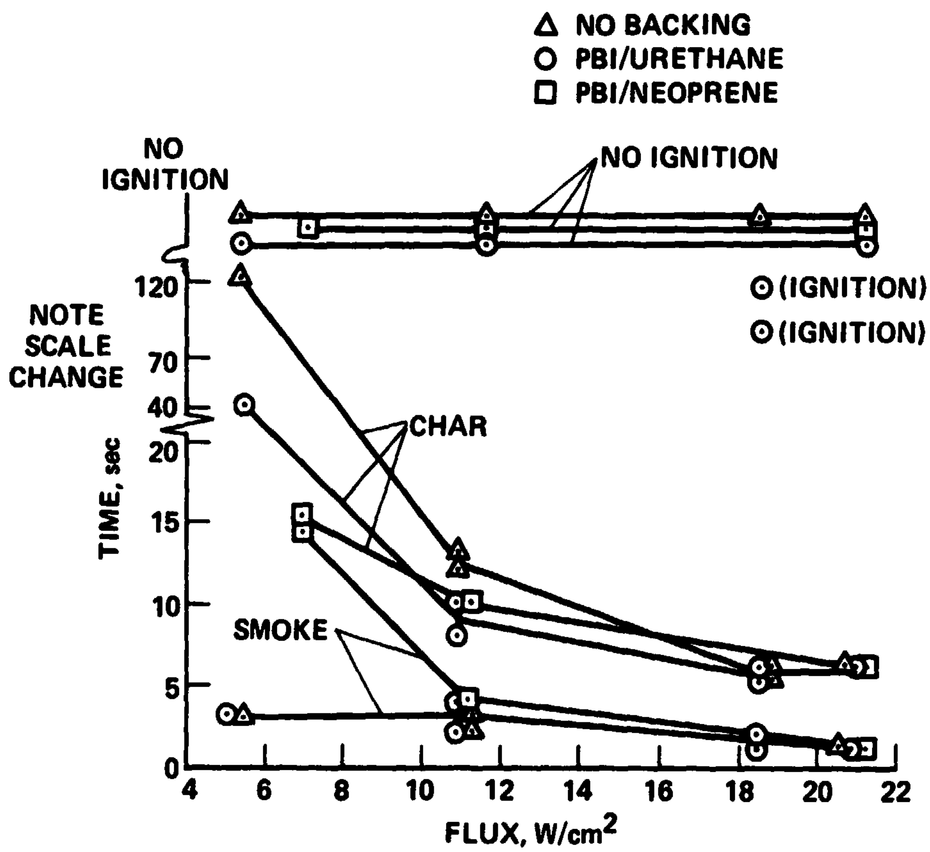


Figure 7.- Times to smoke, char, or ignition for PBI.

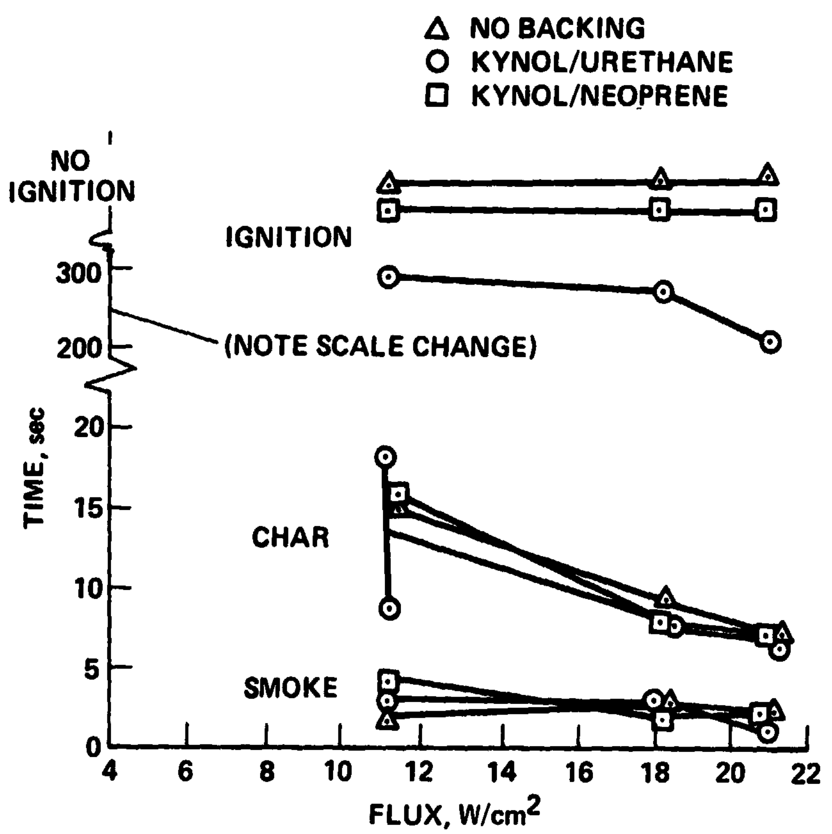


Figure 8.- Times to smoke, char, or ignition for Kynol.

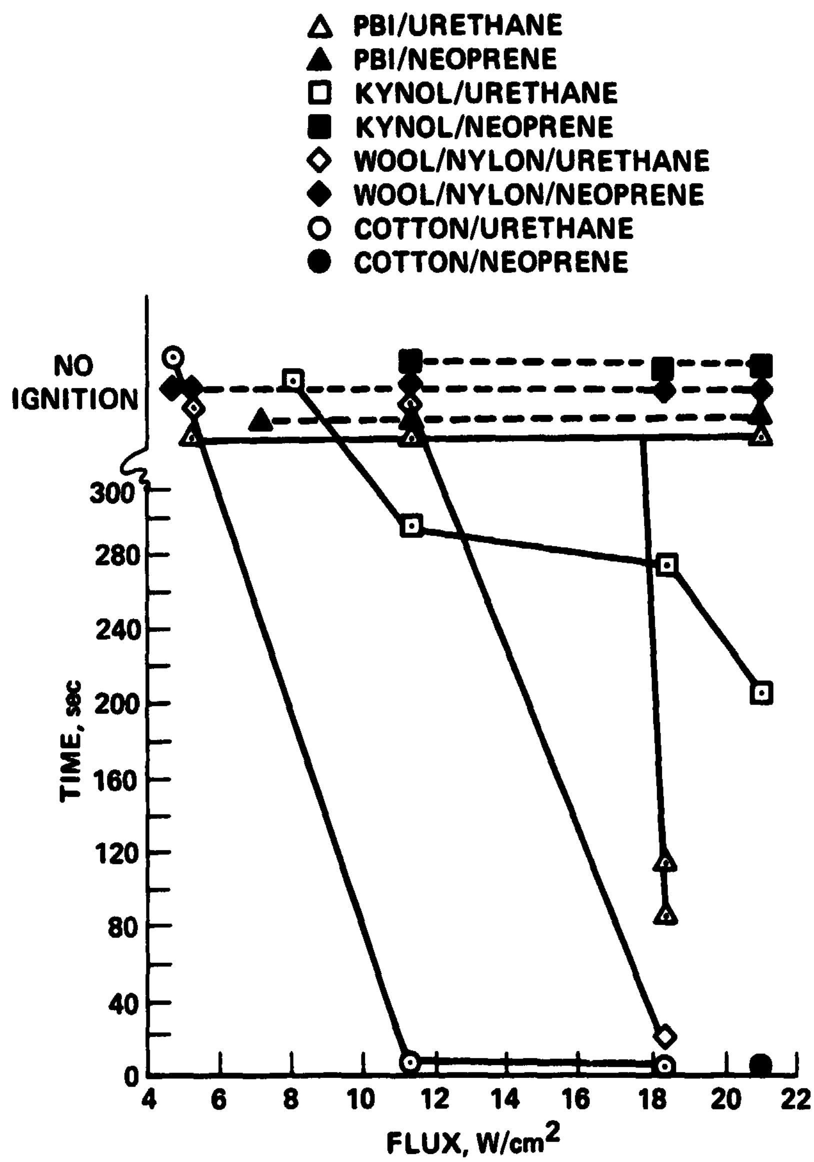


Figure 9.- Ignition times for fabric-foam assemblies.

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15. Supplementary Notes

16. Abstract

This study describes the thermal response characteristics of fabric and fabric-foam assemblies. The various aspects of the ignition behavior of contemporary aircraft passenger seat upholstery fabric materials relative to fabric materials made from thermally stable polymers are evaluated. The role of the polymeric foam backing on the thermal response of the fabric-foam assembly is also ascertained. The optimum utilization of improved fire-resistant fabric and foam materials in the construction of aircraft passenger seats is suggested.

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