DEVELOPMENT OF IMPROVED FIRE TEST CRITERIA FOR AIRCRAFT THERMAL ACOUSTICAL INSULATION

Richard Hill
Timothy Marker
Patricia Cahill
Severine Fiorletta*
Constantine P. Sarkos

Fire Safety Section
Federal Aviation Administration
William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405
USA

*Ecole Nationale De L'Aviation Civile
France

ABSTRACT

The United States Federal Aviation Administration (FAA) recently developed new fire test criteria for aircraft thermal acoustical insulation. Aircraft insulation is attached to the fuselage structure to provide a noise and thermal barrier. Generally, the lightweight insulation blankets are comprised of fiberglass encased in a film bagging material. The new fire test criteria provide improvements in both postcrash fuel fire resistance and in-flight fire protection. Full-scale fire tests have shown that available fire-resistant blanket materials or fire barriers can significantly prolong the time for fuselage burnthrough and thereby provide additional time for passengers to survive a postcrash fuel fire. A new small-scale fire test method and criteria for insulation blanket burnthrough resistance has been developed and finalized. Similarly, intermediate- and full-scale fire tests were conducted to evaluate the behavior of the thin bagging material films during a hidden in-flight fire. It was observed that the films exhibit a range in fire behavior, depending on the chemical composition, thickness, and type of scrim (tear stopper). A new small-scale fire test method and criteria that measures the flammability of insulation blankets subjected to an in-flight fire was also developed to compliment the proposed burnthrough test standard. On August 12, 1999, the FAA proposed to require the operators of 699 aircraft to replace certain insulation blankets within four years. Replacement materials must meet the new in-flight fire flammability test method. Moreover, the FAA plans to propose an even higher standard for testing insulation that will include burnthrough resistance as well as in-flight fire flammability.

INTRODUCTION

Background. Aircraft thermal acoustical insulation consists of lightweight fiberglass encased in a thin film bagging material. Practically the entire fuselage is layered with insulation blankets to deaden noise and insulate against heat or cold. Also, heating and air conditioning ducts, in some cases, may be covered with fiberglass blankets. The film bagging material holds the insulation together and is intended to also act as a moisture barrier. Currently, FAA flammability requirements for thermal acoustical insulation, as prescribed in Federal Aviation Regulation (FAR) 25.853a, consist of a vertical Bunsen burner test method (ref. 1).

Insulation blankets may be a factor in the prevention of in-flight fires or the mitigation of postcrash fires. In the past, fatal in-flight fires – although relatively rare events – have originated in hidden or inaccessible areas of the aircraft. The preponderance of insulation makes it a likely target for an in-flight ignition fire source and/or as a path for flame propagation and fire growth. With regard to postcrash fire, insulation blankets can provide a barrier against penetration of the fuselage shell by an external fuel fire, commonly referred to fuselage burnthrough. Extending the time for fuselage burnthrough improves survivability by providing additional time for passengers to escape during a postcrash fire.

Incidents and Accidents. Concern over the fire performance of thermal acoustical insulation was initially raised by a number of incidents in the mid-1990's (table 1). In spite of the Bunsen burner "self-extinguishing" requirements, these incidents revealed surprising flame spread along the insulation film bagging material. In all cases, the ignition source was relatively modest and, in most cases, was electrical in origin; e.g., electrical short circuit, arcing caused by chafed wiring, ruptured ballast case, etc. More recently, two separate incidents in the United States, involving insulation fires beneath the floor, have highlighted concern with a particular type of film – metallized polyethyleneteraphalate (PET). In the latest incident, an MD-88 experienced smoke in the cabin while on climb out. The airplane returned safely to Cincinnati/Northern Kentucky Airport where an emergency evacuation was performed. Preliminary information indicates that the fire originated near the alternate static port heater and consumed the metallized PET film on three blankets. In all of these incidents (table 1) there was no loss in life.

Concern with the flammability of thermal acoustical insulation has been raised by the Transportation Safety Board (TSB) of Canada during their ongoing investigation of the fatal Swiss Air MD-11 in-flight fire accident (9/2/98, 229 fatalities). TSB investigators have revealed that the fatal fire appears to have been confined to the area above the cockpit and forward cabin ceiling, and involved the insulation blankets. TSB has issued interim insulation fire safety recommendations related to the development of improved fire test standards and the replacement of a certain type of film bagging material. Independently, the FAA was pursuing a similar course of action.

Table 1. Recent Incidents/Accidents Involving Ignition of Thermal Acoustical Insulation

Incident/ Accident Date	Location	Aircraft Type	Insulation Film Type	Condition
11/24/93	Copenhagen, Denmark	MD-87	metallized PET	smoke/fire on insulation blankets as result of arcing wires near aft lavatory
10/10/94	Beijing, China	B-737-300	metallized PVF	fire on insulation blanket in E/E bay as result of arcing wires
9/6/95	Capital Airport, China	MD-11	metallized PET	fire on insulation blankets in E/E bay as result of arcing wires
11/13/95	Yunan Airlines Maintenance, China	737-300	metallized PVF	fire on insulation blanket under floor as result of hot metal chips from air drill
11/26/95	Turin Airport, Italy	MD-82	metallized PET	fire on insulation blankets in ceiling area as result of ruptured lighting ballast
11/8/98	Atlanta, GA	MD-11	metallized PET	cargo pallet inadvertently dragged across wire bundle that was being serviced, causing arcing and subsequent flame spread across insulation blanket
9/17/99	Covington, KY	MD-88	metallized PET	electrical arc in connector for right alternate static port heater element wire caused flame spread on insulation blankets

Fuselage burnthrough was a factor in occupant survivability in at least 17 accidents over the period 1966 to 1993 (ref. 2). It was also determined that fuselage hardening against burnthrough could save, on the average, as many as 10 lives per year in worldwide accidents involving postcrash fire. Perhaps the most cited reference of an accident in which fuselage burnthrough was a critical factor impacting passenger survival was the Air Tours 737 accident in Manchester, England (8/22/85, 55 fire fatalities) (ref. 3). In this accident, the aircraft takeoff was aborted following an engine failure, which caused fuel tank damage, spilled jet fuel, and an ensuing fuel fire. When the airplane was stopped, a pool fire was created on the ground that was driven against the fuselage by the prevailing wind. Accident investigators estimated that the fuel fire penetrated into the passenger cabin in approximately one minute (ref. 3). Based on an in-depth analysis of the Manchester fire, it was determined that 40 of the 55 fire fatalities may have been prevented by an effective burnthrough barrier (ref. 2).

Bunsen Burner Round-Robin Tests. Following the previously referenced early incidents involving insulation fires, the FAA sponsored round robin tests employing the Bunsen burner test method and an industry standard referred to as the "cotton swab" test (ref. 4). Eight laboratory members of the FAA's International Aircraft Material Fire Tests Working Group participated in the study. The round-robin tests revealed that metallized PET films were very sensitive to whether the film was tested separately or in combination with fiberglass. Some laboratories failed this particular type of film while other laboratories passed the film, depending on how the test was conducted. Also, when the metallized PET was tested with the "cotton swab" method, ALL laboratories failed the material which almost always was completely consumed. It was apparent that the performance of some insulation films, such as metallized PET, is very sensitive to configurational changes when the thin films are subjected to a small flaming ignition source (ref. 4).

Initiation of New Test Development. FAA policy with regard to the adequacy of current fire test requirements for thermal acoustical insulation (Bunsen burner test method, FAR 25.853a), was made public on October 14, 1998. In a press release, Administrator Jane Garvey stated that the "FAA will develop – within six months – a new test specification for insulation that will result in increasing fire safety on aircraft." It was also stated that the FAA would "propose requiring the use of improved insulation once the new test standard is developed." Except for the full-scale burnthrough fire tests and early work to develop a small-scale burnthrough fire test method, the following describes research activities subsequent to the Administrator's announcement.

FUSELAGE BURNTHROUGH RESISTANCE

Fuselage burnthrough resistance may be viewed as the time interval for a fuel fire to penetrate three fuselage members: (1) aluminum skin, (2) thermal acoustical insulation, and (3) sidewall/cabin flooring. In terms of occupant survivability, fuselage burnthrough resistance becomes particularly important when the fuselage remains intact following a crash, which occurs in many survivable accidents. Based on past full-scale fire tests, wherein surplus aircraft were subjected to large external fuel fires, it appears that the likely pathway for fire penetration is through the "cheek" area of the fuselage beneath the cabin floor (ref. 5). Once the fire burns through the lower fuselage area, earliest penetration of flames into the cabin will occur through the path of least resistance, such as air return grills or wall seams/joints. Of the three fuselage members involved in the burnthrough process, the FAA has focused research on the thermal acoustical insulation as being the most practical and cost-effective approach for creating a barrier against fuselage burnthrough.

Full-Scale Fire Tests. In order to realistically evaluate and develop thermal acoustical insulation improvements regarding burnthrough resistance, a reusable fuselage section was designed and constructed. As shown in figure 1, the 20-foot-long test rig was constructed of steel framing, to allow for repeated use, and inserted in the aft section of an existing B707 fuselage test article. In preparation for a test, the insulation blankets are securely fastened to the steel framing. Afterward, aluminum sheeting representative of the fuselage skin is riveted to the steel framing. The test area is subjected to an 8-foot by 10-foot fuel fire.

Dozens of full-scale tests have demonstrated that materials are available to act as highly effective burnthrough barriers (ref. 6). The approach that can be taken is to replace the current fiberglass insulation or to employ a lightweight barrier in conjunction with the existing insulation. It has been shown that both approaches can be effective (ref. 6). For example, fig. 2 compares test results with existing fiberglass blankets and a replacement fibrous material, in this case, heat stabilized oxidized polyacrylonitrile fiber (OPF). The fiberglass blankets (and aluminum skin) withstand flame penetration for only slightly more than 2 minutes. Conversely, the OPF insulation prevented flame penetration for over 5 minutes. During these tests it was also shown that in order to gain the full protection that can be provided by the improved insulation materials, it is

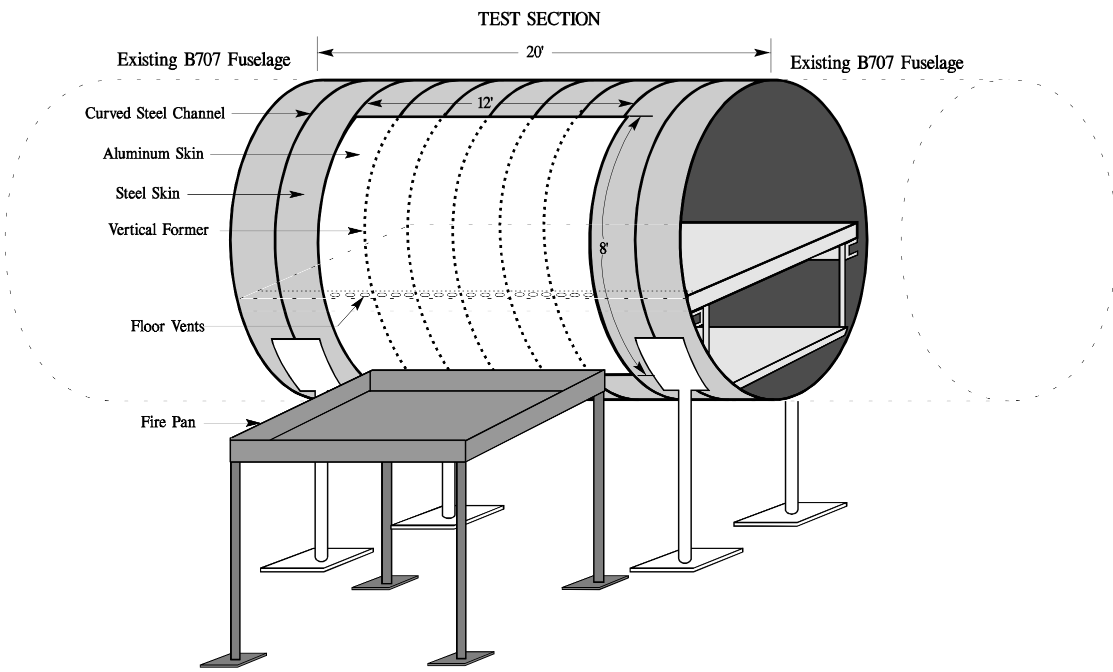

Figure 1. Full-Scale Burnthrough Test Rig Positioned in Aft B707 Fuselage

necessary to properly secure the blankets to the fuselage framing so they remain in place during fire exposure, preventing the creation of any openings between the insulation and framing. In essence, the thermal acoustical insulation system must be essentially continuous in order to achieve its full burnthrough protection capability.

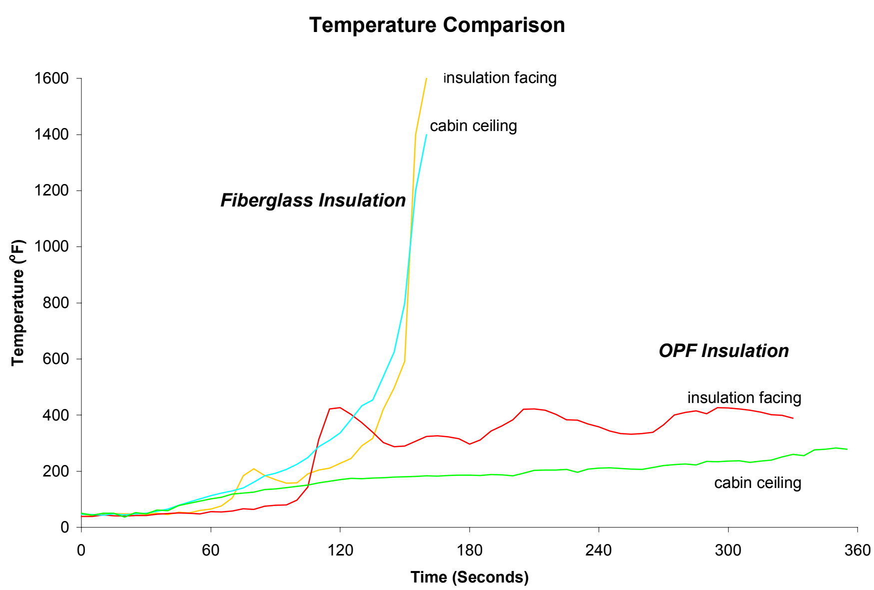

Figure 2. Temperature Comparison of Current and Alternative Materials

Small-Scale Test Method. A small-scale test was developed to evaluate the burnthrough resistance of insulation systems and to be the basis for a proposed regulatory requirement, developed by the FAA, which is currently undergoing review and approval within the U.S. Government. Because of its potential application as a regulatory requirement, the new test method was designed to be relatively simple for use in a laboratory environment, yet also realistic in order to produce data consistent with full-scale test results.

A schematic of the new proposed burnthrough test method is shown in fig. 3. It is comprised of two main components: (1) a large burner that simulates a jet fuel fire and (2) a sample holder representative of the fuselage structural framing. The kerosene burner is similar to the type used for cargo liner and seat cushion test requirements, but operates at higher fuel flow rates in order to generate a more intense and larger flame. Initial development of the burner was conducted by Centre d'Essais Aeronautique de Toulouse (CEAT) in France (ref. 7). The burner operates at 6 gal/hr, generating an 1850°F flame having a heat flux of 15.0 Btu/ft^2-sec. The burner flame conditions were set so that the melting time of aluminum sheeting would coincide with full-scale test results. The 3-foot-square specimen holder consists of representative fuselage formers (vertical) and stringers (horizontal).

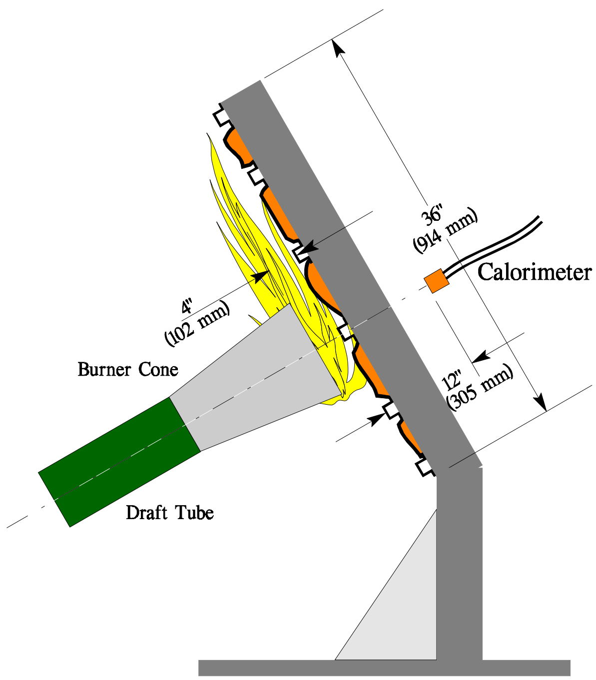

Figure 3. Proposed Burnthrough Test Apparatus

The test specimen consists of two layers of insulation which are installed in the sample holder in a manner similar to that used in service. In order to simplify the test procedure and improve its repeatability, the tests are conducted without the aluminum skin because its thickness changes with location in an actual aircraft. However, the burnthrough protection provided by the aluminum skin (melting time) can be accounted for. Based on past accident experience and analysis (ref. 2), the required pass/fail criteria for the insulation specimen was set at 4 minutes, because very limited benefit would accrue beyond this period (i.e., approximately 5 minutes factoring in the skin melting time). The burnthrough time is based on visual observation and measured heat flux through the specimen back face for three replicate tests.

The FAA has tested numerous samples submitted by industry in the new small-scale burn through test method. Fig. 4 shows a sample of burnthrough time test data. The majority of the samples passed the proposed 4-minute criteria. Of those compliant specimens, noteworthy is the new insulation system comprised of 2-ply Curlon™ (OPF) fiber and polyimide (PI) film and in-use 2-ply 0.42 1b/ft ^{3} fiberglass insulation employing a Nextel™ paper barrier and metalized polyvinyl fluoride (PVF) film. Both insulation systems were also effective burnthrough barriers during full-scale fire tests (ref. 6).

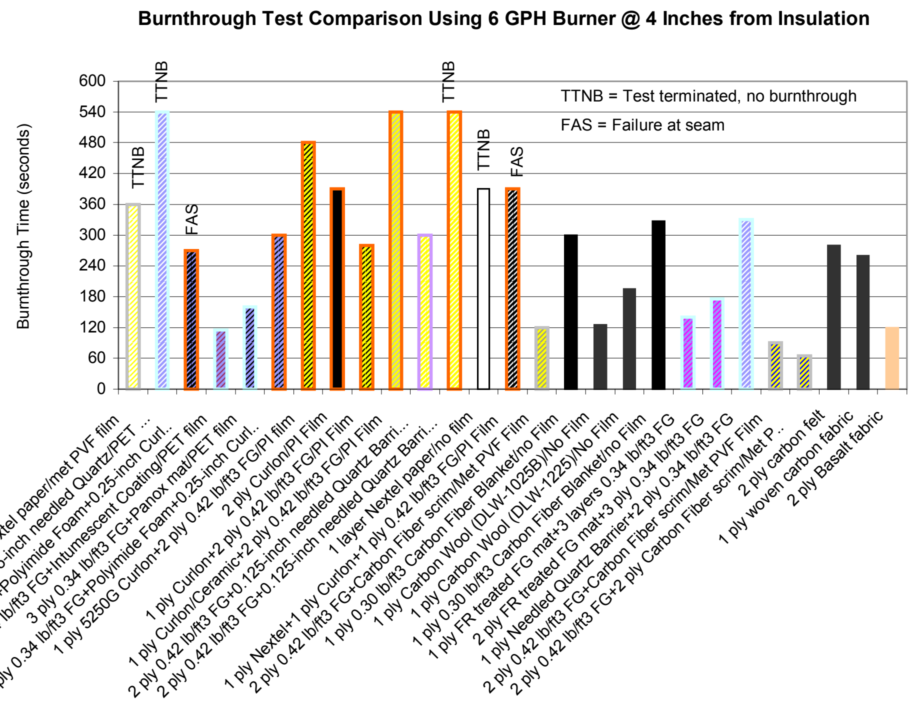

Figure 4. Preliminary Test Results Using Various Material Combinations

As previously discussed, the method of insulation system attachment to the fuselage framing has a critical effect on burnthrough protection. In the data shown in fig. 4, the method of attachment was not a variable; therefore, the data reflects the inherent burnthrough resistance of the insulation materials. Work is underway in the U.S. and United kingdom (UK) to evaluate and develop practical and effective insulation blanket methods of attachment. For example, it has been shown that adjacent insulation blankets require 100 mm (or possibly 50 mm, depending on the failure criteria) of overlap in order to realize the inherent burnthrough resistance of the superior insulation blankets (ref. 8).

IN-FLIGHT FIRE RESISTANCE

As previously discussed, past incidents involving modest ignition sources, such as electrical arcs and shorts, have raised questions about the fire performance of thermal acoustical insulation bagging materials. Moreover, inter-laboratory comparison of the Bunsen burner test method requirement for insulation films revealed a number of deficiencies. One film material, metallized polyethyleneteraphalate (PET), was shown to produce variable test results, with some laboratories passing and others failing this material, and was sensitive to reasonable, minor variations in test conditions. The metallized PET also ignited and propagated flames when subjected to a small flaming ignition source ("cotton swab test method"). The aforementioned concerns and deficiencies was the impetus for an accelerated program to develop new fire test criteria for insulation films which directly relate to in-flight fire resistance.

Materials. Film materials are selected primarily based on consideration of impermeability, durability, weight, and cost. The most common types are metallized PET, non-metallized PET, metallized PVF, and polyimide (PI). A bonded scrim made of nylon or polyester mesh provides tear resistance and strength to the assembly. The films are extremely lightweight and thin. For example, the lightest type weighs approximately ½ oz/yd^2. Because of their low weight and thermoplastic nature (except for the PI thermoset), they melt and contract in unusual ways when exposed to a flame; often making it difficult to ignite a sample or assessing their overall flammability behavior.

Large-Scale Fire Tests. A series of large-scale fire tests were conducted in a mock-up of the attic area above the passenger cabin ceiling. This scenario was selected because small-scale tests demonstrated that insulation films would ignite and propagate flame in a confined space. By contrast, it is very difficult to ignite a thermoplastic film with a stationary flame in an open space because the films melt and shrink away from the flame before their surface temperature can be raised to the ignition point. However, in a confined space ignition and flame propagation may occur because of more extensive radiative heating and containment of melted film/scrim. It is apparent that the attic area offers a number of confined spaces covered with insulation that may be prone to ignition and flame spread.

Figure 5 is a schematic of the mock-up of the cabin attic area. The open-ended, 15-foot-long mock-up consisted of an insulated fuselage crown section, insulated air ducts, and cabin ceiling. During the mock-up tests, temperatures were recorded at both ends of the test rig to provide an estimate of the materials heat release rate. The calculated heat release rate reflects the degree of flame propagation across the films and was consistent with the observed burning behavior. It also provided a rank order of the flammability of different types of films under realistic in-flight fire conditions.

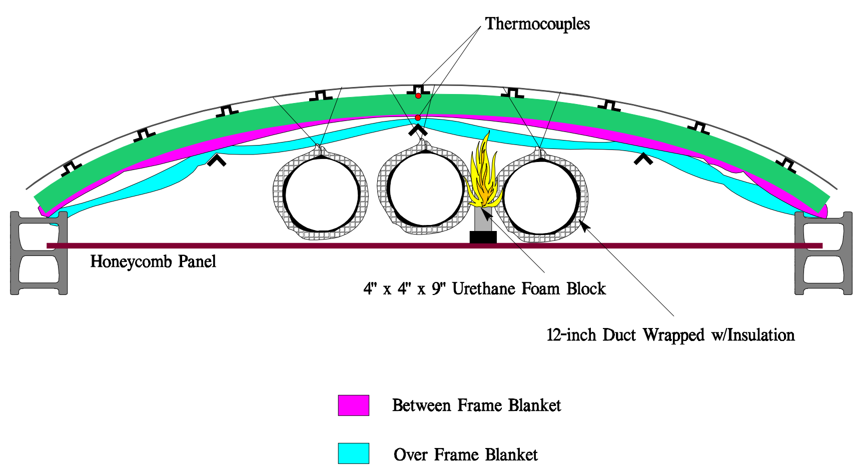

Figure 5. Large-Scale Test Configuration for Measuring Flammability of Insulation Blankets

Mock-up temperature (and heat release) histories are shown in fig. 6 for a number of different types of insulation films (ref. 9). The most flammable film was the metallized PET, whereas the least flammable were PI, metallized PVF, and a fluoropolymer not used in aircraft. The non-metallized PET performance was in between these extremes. The superior performance of the PI and fluoropolymer films was consistent with their well known fire resistance; however, the performance of this particular type of metallized PVF was somewhat surprising since PVF is not as fire resistant as either PI or the fluoropolymer. The metallized PVF tends to shrink and roll up on itself when exposed to a fire and very little burning occurs. Thus, the actual fire performance of insulation films depends on their inherent flammability and their physical behavior as well. Another trend which could be expected is that heavier films have a higher heat release due to their greater mass.

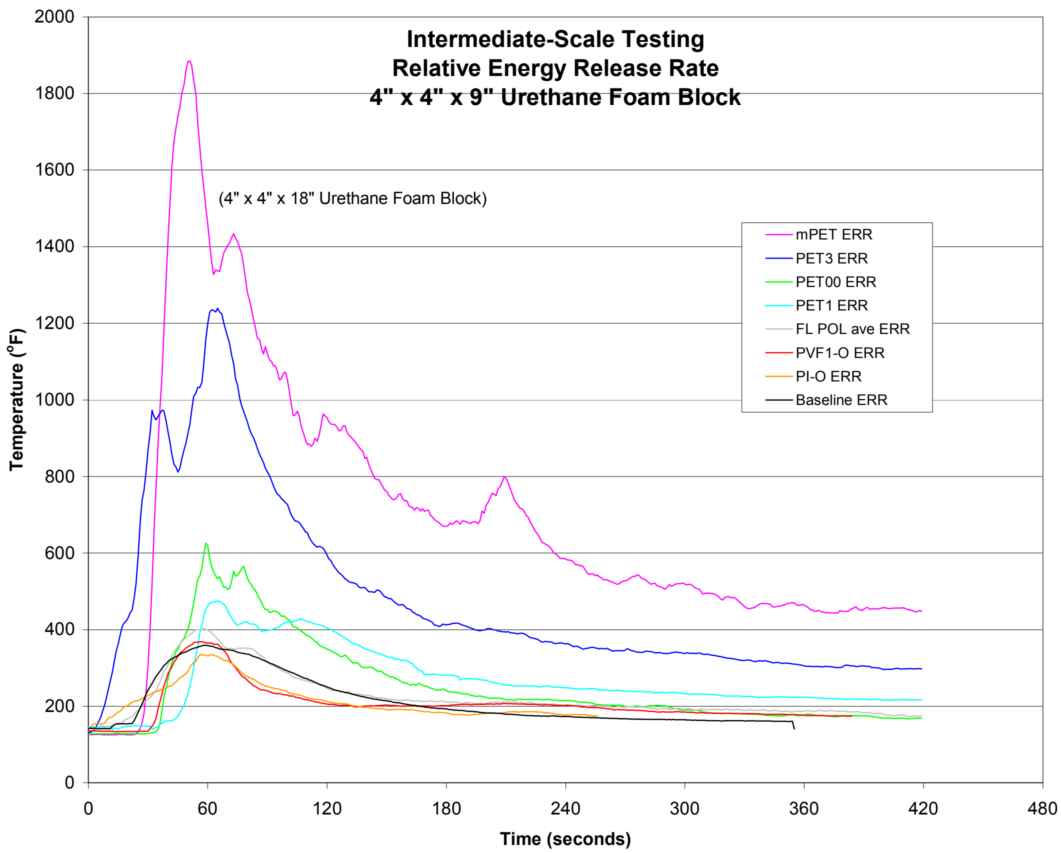

Figure 6. Temperature Profiles of Various Film Materials

Small-Scale Test Method. In seeking a new fire test method for insulation films, several candidate tests were considered and evaluated. The cotton swab test produced more consistent results and was more severe than the current Bunsen burner test (ref. 4). However, the cotton swab test did not identify all flammable materials. The Ohio State University (OSU) Rate of Heat Release Apparatus, a regulatory requirement for large surface area cabin materials, was also examined. Heat release rate is a widely accepted indicator of relative fire hazard. Unfortunately, analysis of the results of tests conducted with a number of insulation films uncovered a number of deficiencies. Foremost was the lack of a consistent correlation with large-scale fire test results. Additionally, the results were highly dependent on sample configuration (completeness of film encapsulation over fiberglass), appeared to lack repeatability and the heat release values were relatively low.

A test method that gives a good correlation with large-scale fire test data is the critical radiant panel test standard developed a number of years ago by the American Society for Testing and Materials (ASTM) for flooring materials (ref. 10). It subjects a material to a pilot flame while the material is being heated by a radiant panel. Fig. 7 is a schematic of the radiant panel test. Its basic components are a propane-fired radiant panel angled at 30° with the horizontal specimen, a pilot flame and a 10- by 42-inch specimen holder. The pilot flame is applied for 15 seconds at one end of the specimen, while it is subjected to a graded level of radiant heat. The proposed criteria is, essentially, that the specimen <u>not</u> ignite, which is specified by not allowing any flaming beyond a 2-inch radius at the point of flame application, or any flaming after removal of the pilot flame.

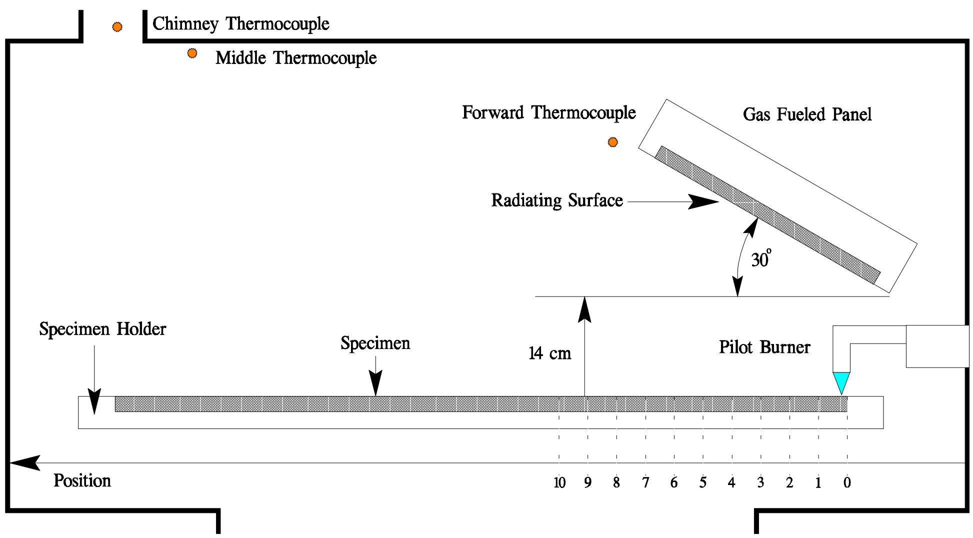

Figure 7. Schematic of Radiant Panel Test Apparatus

Table 2 contains radiant panel test data for a series of insulation films. Again, the radiant panel test results are consistent with the large-scale fire test data shown in fig. 6. Also, it is evident that the data can vary widely for a particular type of film. For example, the PVF films tested exhibited the full spectrum of flaming behavior ranging from no flame propagation to total consumption of the specimen. It has become evident that the behavior of a particular type of film (chemical composition) will depend on a number of variables, including the scrim type and pitch, thickness (weight), scrim adhesive, and use of flame retardants. Another advantage of the radiant panel test is that the effect of some of these variables on the materials flammability can be easily observed during the conduct of a test. Also, as shown in table 2, the radiant panel results are fairly repeatable.

Table 2. Results of Radiant Panel Test Using Various Film Materials

Films Tested With 0.34 lb/ft^3 Fiberglass	Supplier Product Designation	Mass per Area (g/m^2)	Burn Length (inches)	Burn Length (inches)	Burn Length (inches)	Burn Length Average (inches)	Critical Heat Flux (kW/m^2)
Polyethylene terpthalates							
PET00_L	8273	18.0	13.0	15.0	11.0	13.0	12.0
PET00_O	Orcofilm AN-36W	17.8	15.0	12.0	16.0	14.3	10.5
PET1_L	8234	29.6	24.5	25.0	24.5	24.7	7.5
PET1_F	Insulfab 240	30.1	21.0	20.0	22.0	21.0	7.5
PET1_O(R)	Orcofilm AN-47R	27.2	TC	TC	TC	TC	<4
PET1_O(W)	Orcofilm AN-47W	30.4	19.0	17.0	21.0	19.0	8.5
PET2_L	8271	43.1	27.5	26.5	24.5	26.2	7.0
PET3_L	8272	57.5	28.0	22.5	19.5	23.3	7.3
PET3_F	Insulfab 260	54.6	30.5	34.5	35.0	33.3	5.2
MPET1_F	Insulfab 350	32.8	TC	TC	TC	TC	<4
Polyvinyl fluorides							
MPVF1_O	Orcofilm AN-18R	32.8	14.5	17.0	15.5	15.7	10.0
MPVF2_F	Insulfab 330	44.1	NFP	NFP	NFP	NFP	>18
PVF2_J	Terul 14	47.6	19.0	22.0	24.0	21.7	8.5
PVF2_J	Terul 9 Lab 13H	45.5	NFP	NFP	NFP	NFP	>18
Polyimides							
PI_F	Apical 100JL	65.5	NFP	NFP	NFP	NFP	>18
PI_O	Orcofilm KN-80	52.2	NFP	NFP	NFP	NFP	>18
PI_L	10313	49.5	NFP	NFP	NFP	NFP	>18
PI_J	Terimide9 Lab06E	52.5	NFP	NFP	NFP	NFP	>18
Others							
INS2000_F	Insulfab 2000	103.8	NFP	NFP	NFP	NFP	>18
FPC3_C	Chemfilm	61.0	NFP	NFP	NFP	NFP	>18

FPC= Fluoropolymer Composite
TC= Totally Consumed
NFP= No Flame Propagation

REGULATORY ACTIVITES

On August 12, 1999, the FAA issued a proposed airworthiness directive (AD) that would require the replacement of metallized PET, which was employed in insulation blankets on over 700 aircraft. This particular type of film is no longer being installed in commercial transports. It was proposed that the replacement film comply with the new radiant panel test criteria. In addition, the FAA has prepared a Notice of Proposed Rulemaking (NPRM) that would impose new fire test criteria for thermal acoustical insulation based on both the radiant panel test (in-flight fire) and the burnthrough test method (postcrash fire). The draft NPRM is undergoing review and approval within the U.S. Government. Finally, under the auspices of the FAA-sponsored International Aircraft Material Fire Test Working Group, interested laboratories will be conducting round-robin tests with the new proposed insulation fire test methods to examine and improve, if necessary, intra-laboratory repeatability and inter-laboratory reproducibility. This activity will support the utilization of these new fire test methods as a regulatory requirement.

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