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Development of Improved Flammability Criteria for Aircraft Thermal Acoustic Insulation

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16. Abstract

A large number of small-, intermediate-, and full-scale flame propagation tests representative of an in-flight fire were conducted on various thermal acoustic insulation blanket materials. Results indicated that the current Federal Aviation Administration (FAA) vertical Bunsen burner test requirement could not adequately discriminate between poorly performing materials and materials that performed well under realistic fire scenarios. A radiant panel laboratory test was shown to be an effective method for evaluating the in-flight fire resistance qualities of thermal acoustic insulation.

In addition, a new laboratory test was developed for evaluating the postcrash fire burnthrough resistance of thermal acoustic insulation. The test method was based on full-scale tests in which a fuselage structure was subjected to jet fuel fires. Approximately 60 burnthrough tests were conducted on a variety of insulation materials. Insulation materials compliant with the new burnthrough test method will provide a minimum of 4 minutes of protection against a postcrash fuel fire.

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EXECUTIVE SUMMARY

This report discusses the development of new flammability test standards for aircraft thermal acoustic insulation. Currently, a vertical Bunsen burner test is the only Federal Aviation Administration (FAA) requirement for fuselage thermal acoustic insulation materials, including those used to insulate ductwork beneath floors, behind the sidewall, and in the cheek areas. Several in-flight and ramp fires between 1993 and 1995 focused attention on the flammability of the insulation materials. Consequently, a series of tests were conducted which exposed the inability of the vertical Bunsen burner test method to discriminate between materials that allow flame propagation and materials that do not. A test originally developed and used by the aircraft manufacturers, involving the placement of flaming cotton swabs on the film surface, was evaluated. However, large-scale tests and in-service experience indicated that the cotton swab test was not severe enough, prompting additional research to develop a more realistic test. After conducting a variety of mock-up tests in small-, intermediate-, and full-scale test rigs, the flame characteristics of the very thin moisture barrier films were more fully understood, leading to the selection of a radiant panel test apparatus as an appropriate method for determining the in-flight fire resistance characteristics. In addition to fire resistance, the ability of the insulation to resist flame penetration, or burnthrough, by a postcrash fuel fire was also studied. A number of postcrash fire accidents have occurred in which the spillage of jet fuel and the ensuing fire have destroyed aircraft and caused fatalities. A full-scale test rig was developed to evaluate the burnthrough resistance of current materials and to determine if alternate materials could be used to prevent or delay the occurrence of fuselage burnthrough. Test results indicated that significant gains in fuselage burnthrough resistance could be realized by altering or replacing the existing fiberglass-based insulation. Select materials are capable of increasing the fuselage burnthrough resistance by several minutes when exposed to a fully developed fuel fire. Based on the full-scale tests, a laboratory test was developed and numerous insulation material combinations were tested. The new test method employs an oil-fired burner, which is currently used for other flammability tests, including the seat fire-blocking and cargo liner tests. Insulation materials compliant with the new burnthrough test method will provide a minimum of 4 minutes of protection against a postcrash fuel fire.

INTRODUCTION

PURPOSE.

The purpose of this report is to present the test results used in the development of new flammability standards for aircraft thermal acoustic insulation. The new standards include in-flight fire ignition resistance and postcrash fire burnthrough requirements.

BACKGROUND.

The International Aircraft Materials Fire Test Working Group (IAMFTWG), hereafter referred to as the Working Group, was formed in November of 1989 to conduct round-robin testing of the Ohio State University (OSU) and National Bureau of Standards (NBS) smoke chambers, which had been adopted by the Federal Aviation Administration (FAA) as regulatory requirements. Since this approach worked well in providing useful information and needed data to the FAA, the activities of the Working Group were expanded to include any fire test method utilized in aviation. The main objective of the group was to provide a broad base of technical information to the FAA for use in formulating recommendations to the regulatory authorities pertaining to aircraft material fire test methods.

Fiberglass, bat-type insulation is used extensively throughout the fuselage of commercial aircraft. It serves two main purposes: thermal and acoustical insulation. The thermal environment outside an airplane produces fuselage skin temperature extremes ranging from about -60°F in-flight to about 160°F when parked in direct sunlight in the desert. The amount of insulation needed for the air conditioning/heating system to economically produce comfortable cabin temperatures varies with airplane type and location. However, except for a few locations such as the crown area over the aft passenger cabin and the lower fuselage area below the passenger floor, acoustic requirements predominate. Therefore, except for those locations, the amount of insulation required for noise attenuation considerations exceeds that needed for thermal requirements. Outside noise is generated by aerodynamics and engines. Insulation is used to attenuate outside noise to allow reasonable levels of comfort and verbal communication inside the passenger cabin and flight deck. The acoustic attenuation needed varies from airplane to airplane, but it is generally substantial and insulating material of very high acoustic efficiency is used to minimize the amount (weight, volume) required. Fiberglass batting, using a very small fiber diameter, is a highly efficient acoustic attenuator.

Between 1993 and 1995, a number of incidents were reported involving flame propagation on thermal acoustic insulation blankets. In particular, some types of the thin films that encapsulate the fiberglass insulation have been shown to propagate flames under certain conditions. For example, in 1993 an MD-87 experienced smoke in the cabin on final approach to Copenhagen. After landing, an emergency evacuation was ordered as the smoke and eventually flames intensified and caused considerable damage. An electrical arc in or adjacent to the aft lavatory area had ignited the metallized polyester terepthalate (PET) moisture barrier film. The role of this particular film in several other aircraft fires has also been investigated (table 1).

The thermal acoustic insulation and moisture barrier film materials are currently required to meet the FAA vertical Bunsen burner test method. In many instances, the film materials will rapidly

TABLE 1. RECENT INCIDENTS INVOLVING IGNITION OF INSULATION MATERIALS

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	B-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.

shrink away from the flame during this test, causing propagation to cease, as the material is no longer in contact with the burner flame. In addition, minor variations in the test procedure may also result in significant variability in the degree of flame propagation. For this reason, a more realistic test method has been pursued.

The FAA became concerned about the in-flight fire characteristics of thermal/acoustic insulation in 1995 after testing material involved in the MD-87 incident. Work began and was discussed at the Working Group meeting in March of 1996, and round-robin tests were conducted utilizing the cotton swab test, an industry flammability standard for thermal acoustical insulation [1]. Although the test data indicated that this method produced more consistent results than the vertical Bunsen burner test, large-scale tests and in-service experience indicated that the cotton swab test was not severe enough and could not effectively screen materials that were known to propagate fire. In addition, because the ignition source used was limited to a large cotton swab, the test did not simulate other sources of ignition, specifically any other burning material or electrical arcing. As a result, in June 1998, the FAA announced plans to proceed with the development of a new test method, based on larger, more realistic full-scale testing that could replace the existing Bunsen burner test method. Approximately four months later, in October 1998, the FAA Administrator announced the FAA's intention to develop new insulation fire test standards. It was also stated that the FAA would propose making the new standards mandatory, once the new test standards were developed.

In addition to the pursuit of a more realistic test for in-flight ignition, there was also concern over the burnthrough resistance of the fuselage structure from an external postcrash fuel-fed fire. In a majority of survivable accidents accompanied by fire, ignition of the interior of the aircraft is caused by burning jet fuel external to the aircraft. Therefore, the integrity of the aircraft and its ability to provide a barrier against fuel fire penetration may be an important factor related to the survival of aircraft occupants. Fuselage burnthrough resistance becomes particularly important when the fuselage remains intact following a crash, which often occurs in survivable accidents. For example, in 1985 in Manchester, England, a British Airtours 737 aborted a takeoff after debris from an uncontained engine failure ruptured the wing fuel tank. The leaking fuel from the wing erupted into a pool fire adjacent to the aircraft and subsequently burned through the external skin in a short period of time. The rapid burnthrough contributed to the inability of 55 persons to escape the airplane due to the fire. Over the past 20 years, approximately 16 other accidents have occurred in which fuselage burnthrough has been a possible factor in occupant survivability [2].

In 1988, the FAA began a project to investigate fuselage burnthrough. A series of full-scale tests were conducted utilizing a salvaged Convair 880 and a DC-8 to determine the mechanism and time frame for burnthrough [3]. It was determined that the industry-standard fiberglass insulation provided relatively little additional protection after skin burnthrough, perhaps 30-60 seconds. As a result of the initial testing, in 1994 the FAA began construction of a full-scale test rig at the William J. Hughes Technical Center to evaluate potential improvements under more controlled conditions. Testing of thermal acoustic insulation in the full-scale B707 test article began in 1995, at which time the Fire Safety Section developed a cooperative burnthrough program with the UK Civil Aviation Authority (CAA). Work was coordinated through the Working Group with results of all testing presented at various meetings of the group from that time to present. In 1997 the French Direction General de l'Aviation Civile (DGAC) became involved in the testing through the development of a burnthrough test method at Centre d'Essais Aeronautique de Toulouse (CEAT).

From the dozens of full-scale burnthrough tests conducted, the FAA determined that enhancement of the thermal acoustical insulation is the most potentially effective and practical means of achieving a burnthrough barrier [4]. Comparative testing in the full-scale test rig has shown that several alternative thermal acoustical insulation materials/systems are capable of significantly delaying the burnthrough process. As a result, the FAA's announced plans to develop new fire test standards for thermal acoustic insulation included burnthrough resistance.

Because the projected development of a new in-flight ignition resistance standard and a new burnthrough standard impacted the thermal acoustic insulation blankets, there was initially a thrust to combine the two flammability factors into a single test. Industry, in particular the airframe manufacturers and suppliers of insulation products, had expressed interest in the development of a single test in order to simplify the certification process. However, initial efforts in this direction indicated that this approach was not feasible.

OBJECTIVE.

Thermal acoustic insulation is used extensively throughout the aircraft fuselage for the purpose of reducing the noise entering the cabin from external sources and for maintaining comfortable cabin temperatures. Historically, both functions have been provided by fiberglass batting encapsulated in plastic moisture barrier film coverings. Film covering materials consist of PET, polyvinyl fluoride (PVF), and to a lesser degree, polyimide. Both the PET and PVF materials exist in metallized and nonmetallized forms. Although these materials are required to meet the vertical Bunsen burner test, some have been found to propagate fire under certain conditions. The objective of this research was to develop a more stringent in-flight ignition resistance test method. In addition, research on fuselage burnthrough has highlighted the benefits of alternative materials used in combination with or in place of the existing fiberglass-based insulation. Therefore, a secondary objective was to develop a burnthrough standard for the thermal acoustic insulation.

IN-FLIGHT FIRE TESTS

There were a number of materials tested during the research. In order to facilitate the identification of the products, a coding system was established according to the material type, followed by the weight classification, and finally the manufacturer's abbreviation (table 2).

TABLE 2. INSULATION MATERIAL IDENTIFICATION CODE

Material Type (abbreviation)	BMS Weight Classifications Class - (range, oz/yd^2)	Product Manufacturers
polyvinyl fluoride (PVF)	00 - (0 to 0.5)	O
polyethylene terepthalate (PET)	0 - (0.5 to 0.65)	F
Metallized polyvinyl fluoride (mPVF)	1 - (0.65 to 0.9)	J
Metallized polyethylene terepthalate (mPET)	2 - (0.9 to 1.3)	L
Polyimide (PI)	3 - (1.3 to 1.8)	C
fluoropolymer composite (FPC)		

For example, a metallized polyvinyl fluoride material that had a weight per area of 1.1 oz/yd^2 manufactured by company "F" would have the following code: mPVF2-F.

VERTICAL BUNSEN BURNER AND FLAMING COTTON SWAB TEST RESULTS.

Currently, thermal acoustic insulation, insulation covering, and insulation blankets must be tested in accordance with Federal Aviation Regulation (FAR) 25.853. It has been shown that the vertical flammability test requirement can produce inconsistent results and may not be suitable for determining the flammability characteristics of the components used in thermal acoustic insulation. However, the aircraft manufacturers have employed a separate test involving the placement of a flaming cotton swab on the surface of a small blanket test sample that has been shown to be effective in identifying covering materials that propagate flame in a consistent manner. Both the Boeing Commercial Airplane Company and Douglas Aircraft Company, now part of Boeing, added the flaming cotton swab test to their internal material specifications.

As a result of the previously mentioned incidents and a request from the aircraft industry, the Working Group formed an ad hoc task group for the purpose of conducting vertical flammability round-robin testing on thermal acoustic insulation films and blankets and to evaluate the cotton swab test. A total of five films were included in the round-robin testing, which was supported by a total of eight laboratories. The test results indicated that sample shrinkage, not sample burning, caused what was interpreted as burn length for several of the films in the vertical Bunsen burner test. To verify this, three samples each of three different thermoplastic films were cut and weighed to four decimal places. The samples were then subjected to the vertical Bunsen burner test and reweighed (tables 3 through 5). The "burned out" areas of the specimens were then measured, indicating that the area losses were high, while the weight losses were minimal. Since the large discrepancy between the area and weight loss data indicated that shrinkage is a primary mechanism, it appeared that shrinkage was being interpreted as burn length by some of the round-robin participants.

TABLE 3. BUNSEN BURNER TESTS, WEIGHTS AND AREA LOSS (METALLIZED PVF)

Metalized PVF	Preburn Weight (grams)	Afterburn Weight (grams)	Weight Loss (%)	Area Loss (%) Approximate
Sample 1	1.0032	1.0005	0.26	8.8
Sample 2	1.0216	1.0193	0.23	9.2
Sample 3	1.1412	1.1383	0.29	9.1

TABLE 4. BUNSEN BURNER TESTS, WEIGHTS AND AREA LOSS (PET)

PET	Preburn Weight (grams)	Afterburn Weight (grams)	Weight Loss (%)	Area Loss (%) Approximate
Sample 1	0.6071	0.6027	0.72	8.4
Sample 2	0.5877	0.5847	0.51	9.1
Sample 3	0.6012	0.5977	0.58	9.7

TABLE 5. BUNSEN BURNER TESTS, WEIGHTS AND AREA LOSS (PVF)

PVF	Preburn Weight (grams)	Afterburn Weight (grams)	Weight Loss (%)	Area Loss (%) Approximate
Sample 1	1.0639	1.0634	0.04	9.0
Sample 2	1.0388	1.0369	0.19	9.2
Sample 3	1.0517	1.0500	0.17	8.9

In addition to the above conclusion regarding the material shrinkage, seven of the eight labs reported that the front face of the metallized PET blanket samples were totally consumed during the cotton swab test (the eighth laboratory reported that 75% of the front face was consumed). This was in sharp contrast to the vertical flammability test results, which indicated that the metallized PET/fiberglass samples passed most of the time. Hence, the cotton swab test proved itself to be a more reproducible test than the vertical flammability test for this particular film/fiberglass assembly [1]. Moreover, the results indicated that this particular grade of metallized PET film was flammable and could possibly propagate a fire in a realistic situation. Finally, determining the vertical burn length of the thermoplastic films tested, including the metallized PET, is subject to interpretation. This appears to be due to the tendency of the thin films to shrink quickly away from the heat source, causing some labs to report shrinkage as burn length.

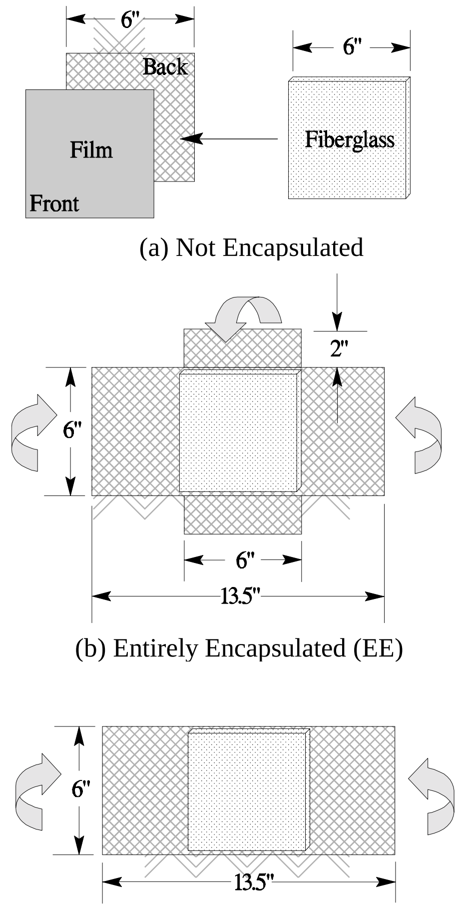
In summary, the round-robin tests pointed to discrepancies in interpreting the burn length data from vertical testing specified in FAR 25.853 and clearly indicated that at least one material meeting these requirements consistently failed the cotton swab test. This conclusion pointed to the inadequacies of the current test method at clearly producing consistent results and effectively screening materials that can propagate fire.

RATE OF HEAT RELEASE TEST RESULTS.

Because of the shortcomings of the vertical Bunsen burner and cotton swab tests, the search for a more realistic flammability test for thin film materials was extended to the rate of heat release. Both the OSU rate of heat release test, a requirement for certain cabin materials, and the cone calorimeter were employed.

In the OSU test, the samples consisted of both the insulation material and film covering. Initially, several methods of constructing the test samples were evaluated (figures 1(a), (b), and (c)). First, a 6- by 6- by 1-inch sample of the insulation material was sandwiched between two layers of the film covering material. Although realistic, this configuration allowed the front surface film material to shrink and pull away from the heat source, resulting in the material clinging to the one of the metal safety wires that spanned the front of the sample holder. When this occurred, the clustered material would eventually ignite, creating an anomalous elevated peak heat release rate. This condition was magnified by differences in material composition. For example, some of the materials quickly shrank away from the heat source while others, the metallized PVF in particular, actually rolled into a cylindrical shape. The time for this event to occur also varied from test to test. A second sample method was tested in which the film material encapsulated the insulation material as shown in figure 1(b). The top and bottom flaps of film material were first folded around the insulation material, then the sides were folded over these and secured using three staples. This configuration produced a test sample that more closely resembled actual encapsulated insulation batting. A third configuration was also evaluated in which the insulation material was not entirely encapsulated, but had the top and bottom of the sample left open (figure 1(c)).

After conducting initial tests under all three sample configurations with a limited array of materials, it appeared that entirely encapsulating the insulation with the film covering produced the most repeatable results. As shown in table 6, both the peak heat release rate and the total heat release over a 2-minute period were less than 50 kW/m^2 and 50 kW/m^2 min, respectively. Because the film covering materials were so thin, there was still a considerable amount of shrinkage on many of the samples, even though the material completely encapsulated the insulation. Other factors were also found to produce differences in the results. For example, the thin, web-like scrim that was laminated to the materials for the purpose of producing a tear-stop appeared to influence the heat release rate. The type of scrim material (either Nylon or polyester) and the yarn count (typically 8 or 10 per inch) played an important role. The higher yarn count resulted in additional combustible material available to increase the total heat release.



(a) Not Encapsulated

(b) Entirely Encapsulated (EE)

(c) Not Entirely Encapsulated (EE)

FIGURE 1. VARIOUS METHODS OF CONSTRUCTING INSULATION TEST SAMPLES FOR OSU TESTING

Similarly, the weight of the film was a factor, as the heavier films produced a larger flame, greater flame propagation, and higher peak heat release rate when forced to burn in the test chamber. The use of fire retardants on the scrim side only, or on both the scrim side and delustered side of the film, also caused marked differences. This can be observed by comparing the class 3 PET results from manufacturers F and L. The L-film has a fire retardant on both sides, while the F-film is treated on the scrim side only. The adhesive system used to bond the scrim to the film also impacts the overall performance, as the older nonwater-based systems appear to yield higher numbers. In addition, the insulation material did not appear to contribute to the heat release of the samples.

The polyimide and fluoropolymer composite samples yielded the lowest peak heat release rate and total heat release, while the metallized PVF and some of the PET yielded the highest results. Interestingly, the metallized PET material that consistently failed the flaming cotton swab test did not produce a high rate of heat release, by comparison.

TABLE 6. OSU RATE OF HEAT RELEASE TEST RESULTS FOR VARIOUS INSULATION MATERIALS

Material	Mass/ Area (g/m^2)	PHRR1 THRR1 WL1	PHRR2 THRR2 WL2	PHRR3 THRR3 WL3	Average PHRR (kW/m^2)	Average THRR (kW/m^2min)	Average Weight Loss (g)	Notes
PI-F	65.5	14.42	12.81	12.39	13.21	12.01	1.93	Initial flaming at about 10 sec. Small flaming 75-100 sec. FG+Film not consumed.
		11.85	12.82	11.35				
		2.2	2.1	1.5				
PI-O	52.2	11.35	5.86	6.47	7.89	8.86	1.43	Small flame size. Persistent upper corner flames; FG+Film not consumed.
		7.67	9.05	9.86				
		1.2	1.6	1.5				
MPET1-F	32.8	26.67	28.24	33.47	29.46	23.80	2.43	Burns slowly, flashing on the core, flames on top until 2 min. FG not consumed.
		23.37	23.04	24.99				
		2.4	2.5	2.4				
PET00-O	17.8	15.36	17.74	14.45	15.85	11.97	1.43	Medium flames, fast ignition, small flashes on the top, FG not consumed.
		11.16	11.06	13.7				
		1.4	1.4	1.5				
PET00-L	18	17.05	21.33	17.92	18.77	12.97	1.50	Medium flames, film shrinks and scrim melts w/FG, then burns; FG not consumed.
		10.87	17.47	10.57				
		1.4	1.3	1.8				
PET1-F	30.1	27.85	26.88	31.51	28.75	19.55	2.20	High flames at beginning, then smaller flames on the top still burning after 1 min.
		18.89	18.38	21.38				
		2.2	2.2	2.2				
PET1-O	27.2	39.07	40.24	35.69	38.33	26.82	2.20	Very high flames, early peak (9 sec); flashing in the core and top (1-2 min).
		23.65	27.9	28.92				
		2	2.4	2.2				
PET2-L	43.1	38.66	36.52	37.43	37.54	27.43	2.90	Peak/high flames at 10 sec, burning in the back (40 sec until 2 min), FG shrinkage.
		29.49	25.73	27.06				
		2.8	3	2.9				
PET3-F	54.6	41.69	39.92	38.05	39.89	30.64	3.30	High flames, 9 sec peak. Back/bottom flames (40-90 sec), FG not consumed.
		32.55	32.61	26.76				
		3.2	3.1	3.6				
PET3-L	57.5	33.81	38.09	29.16	33.69	27.37	3.47	High flames until 30 sec, small flames in top (40 sec to 2 min), FG not consumed.
		25.16	29.18	27.77				
		3.3	3.4	3.7				
MPVF1-O	32.8	40.49	42.76	38.25	40.50	27.72	X	High flames, slow flame propagation at edges; FG consumption/shrinkage.
		29.25	26.32	27.6				
		X	X	X				
MPVF2-F	41.1	49.35	53.77	43.41	48.84	30.95	3.27	Very high flames, burns on the back (2nd peak); flames out (1 min), FG shrinkage.
		30.45	29.43	32.97				
		3.5	3.2	3.1				
PVF2-J	43.6	49.66	44.28	42.95	45.63	29.17	3.03	Late ignition but very high flames. Flames out (40 sec), rapid FG shrinkage.
		26.61	31.4	29.51				
		3	3.1	3				
PTFE3-C	26	13.09	X	X	13.09	9.35	1.20	Small flames at the beginning, neither Film or FG consumed.
		9.35	X	X				
		1.2	X	X				

The testing of the entirely encapsulated insulation samples demonstrated that the films typically shrank away immediately after insertion into the test chamber, which had a significant effect on the test results. One alternative testing concept explored was to use a restraining medium laminated to the back of the films to prevent shrinkage during testing. The concept was developed by the Schneller Corporation, who were successful in laminating a very fine glass woven fabric to several of the films (table 7).

TABLE 7. OSU RATE OF HEAT RELEASE RESULTS USING MATERIALS LAMINATED WITH GLASS FABRIC

Material	Mass/Area (g/m2)	PHRR1 THR1 WL1	PHRR2 THR2 WL2	PHRR3 THR3 WL3	Average PHRR (kW/m2)	Average THR (kW/m2min)	Average Weight Loss (g)	Notes
PI_F	65.5	6.31	9.35	8.13	7.93	2.94	0.97	Small ignition at the beginning, no flame propagation.
		0.72	2.68	5.43				
		1	0.8	1.1				
PI_O	52.2	8.42	8.86	9.47	8.92	3.83	0.63	No flame propagation.
		2.9	4.24	4.36				
		0.5	0.8	0.6				
MPET1_F	32.8	16.21	13.77	24.17	18.05	9.12	0.93	Burns slowly and for long duration at the edges.
		8.09	8.08	11.2				
		0.9	0.8	1.1				
PET00_O	17.8	10.53	10.65	7.5	9.56	5.11	1.00	Small flame propagation, large quantities of smoke.
		5.75	7.02	2.56				
		1.3	0.9	0.8				
PET1_F	30.1	17.5	18.61	16.43	17.51	7.90	1.13	The film burns from the middle, slow flame propagation to the edges.
		8.58	9.61	5.5				
		1.2	1.3	0.9				
PET3_F	54.6	28.37	27.35	23.96	26.56	10.75	1.33	High flames, which terminate at 15 sec.
		10.3	9.87	12.08				
		1.4	1.2	1.4				
PET1_O	27.2	20.77	17.91	29.11	22.60	10.79	1.50	High flames immediately until 25 sec, then small flames for additional 10 sec.
		9.54	12.26	10.57				
		1.7	1.4	1.4				
MPVF1_O	34.9	11.01	9.37	11	10.46	4.60	1.13	Film shrinks and gathers at the wire and edges, pulls away from scrim.
		4	3.34	6.47				
		1	1.1	1.3				
MPVF2_F	44.1	20.61	16.89	24.13	20.54	8.85	1.13	Film shrank very quickly, flashed downward at 10 sec; flames out at 30 sec.
		9.5	6.38	10.67				
		1.2	1	1.2				

As shown in table 7, the laminated films produced drastically lowered heat release rate results compared to the entirely encapsulated tests. In all cases (except for the peak of one of the polyimide materials, which increased very slightly), the reduction in heat release was significant. The peak heat release rate was typically reduced 30% to 70%, while total heat release was reduced by as much as 83% (table 8). A slight reduction in these numbers could be expected, since there was more combustible material in the entirely encapsulated materials. Some technical problems were also encountered with this method of test, as the thin films often delaminated after insertion into the test chamber, and pulled away from the glass fabric. In

TABLE 8. COMPARISON OF INSULATION FILM HEAT RELEASE RATE OF ENTIRELY ENCAPSULATED AND GLASS LAMINATE SAMPLES

	Entirely Encapsulated Method		Restrained Using Glass Fabric		Amount Reduced (%)	
Material	Peak HRR	Total Heat	Peak HRR	Total Heat Release	Peak	Total
PI-F	13.21	12.01	7.93	2.94	40.0	75.5
PI-O	7.89	8.86	8.92	3.83	-13.1	56.8
MPET1-F	29.46	23.8	18.05	9.12	38.7	61.7
PET00-O	15.85	11.97	9.56	5.11	39.7	57.3
PET1-F	28.75	19.55	17.51	7.9	39.1	59.6
PET1-O	38.33	26.82	22.6	10.79	41.0	59.8
PET3-F	39.89	30.64	26.56	10.75	33.4	64.9
MPVF1-O	40.5	27.72	10.46	4.6	74.2	83.4
MPVF2-F	48.84	30.95	20.54	8.85	57.9	71.4

addition, the lamination process used heat and pressure to bond the films to the fabric, which may alter the flammability characteristics. However, the extreme difference in results between the entirely encapsulated and laminated film tests highlighted the sensitivity of heat release to sample configuration.

Another test condition evaluated was the incident heat flux level (other than the current OSU standard of 3.5 W/cm^2). The Boeing Company conducted numerous tests at different heat flux levels; the results are listed in table 9. Boeing's OSU tests were done with 1-inch-thick, 0.60-lb/ft^3 density fiberglass batting (BMS 8-42 Class 2, Grade B). The test samples were initially constructed using a 6- by 6-inch piece of fiberglass sandwiched between two layers of film covering. The layers of film were placed with the heat-sealable side facing inward towards the insulation. A 0.25-inch foil edge was folded on the front edges; the sample was not compressed.

After evaluating the initial results, the sample preparation was simplified. It appeared that the peak heat release rate was the important distinguishing factor, although the time duration was typically only 5 or 6 seconds. The front face of the test sample played a dominant role in the peak heat release rate, as the back face only affected the 2-minute total heat release. At the higher incident heat fluxes, the film would immediately shrink and cling to one or both of the sample holding wires upon insertion into the test chamber, then the sample would smoke and ignite from the upper burners. The revised sample preparation format utilized a 6- by 6-inch piece of aluminum foil placed on the back of the insulation sample, along with a compression spring that applied minimal force to reduce sample compression. The remaining tests were conducted with samples prepared under this simplified format, which may have yielded lower 2-minute heat release totals at the higher heat fluxes, but should not have affected the peak heat release rate values.

As shown in figures 2 and 3, there were some similarities between the films at the various incident heat fluxes. For example, the peak heat release rate and the total heat release increases for all materials as the incident heat flux is increased, although the trend discontinues for some materials at the higher heat fluxes (refer to figures 2 and 3).

TABLE 9. HEAT RELEASE RESULTS AS A FUNCTION OF INCIDENT HEAT FLUX LEVELS

	10 kW/m^2 Incident Heat Flux		15 kW/m^2 Incident Heat Flux		20 kW/m^2 Incident Heat Flux		30 kW/m^2 Incident Heat Flux		35 kW/m^2 Incident Heat Flux		40 kW/m^2 Incident Heat Flux		45 kW/m^2 Incident Heat Flux	
Films	Peak	Total	Peak	Total	Peak	Total	Peak	Total	Peak	Total	Peak	Total	Peak	Total
PI-F	4.8	1.15	NR	NR	6.28	4.42	17.57	9.2	17.08	8.52	31.05	19.42	34.48	14.57
PI-O	NR	NR	6.09	2.69	NR	NR	NR	NR	12.96	8.5	NR	NR	24.85	13.81
MPET1-F	20.92	6.45	19.55	8.72	NR	NR	NR	NR	27.23	14.59	NR	NR	31.22	12.74
PET00-F	NR	NR	10.86	5.09	NR	NR	NR	NR	21.45	8.22	NR	NR	21.57	9.99
PET00-O	NR	NR	5.14	2.56	NR	NR	NR	NR	18.74	7.74	NR	NR	20.72	9.24
PET1-F	2.56	1.06	16.2	6.89	NR	NR	NR	NR	25.42	11.43	NR	NR	26.79	10.56
PET1-O	NR	NR	14.15	4.35	NR	NR	NR	NR	23.32	10.59	NR	NR	24.89	11.13
PET3-F	4.21	0.46	23.98	7.74	33.3	9.37	35.15	11.87	39.68	18.8	38.35	19.99	41.15	16.72
MPVF2-F	3.17	0.44	23.61	8.49	28.44	9	39.45	15.02	43.35	17.67	47.91	19.79	47.21	15.21
MPVF1-O	9.41	NR	15.28	NR	NR	NR	NR	NR	36.07	13.63	NR	NR	35.96	15.42

Peak = Peak Heat Release Rate, kW/m^2

Total = Total Heat Release, kW-min/m^2

NR = Not Recorded

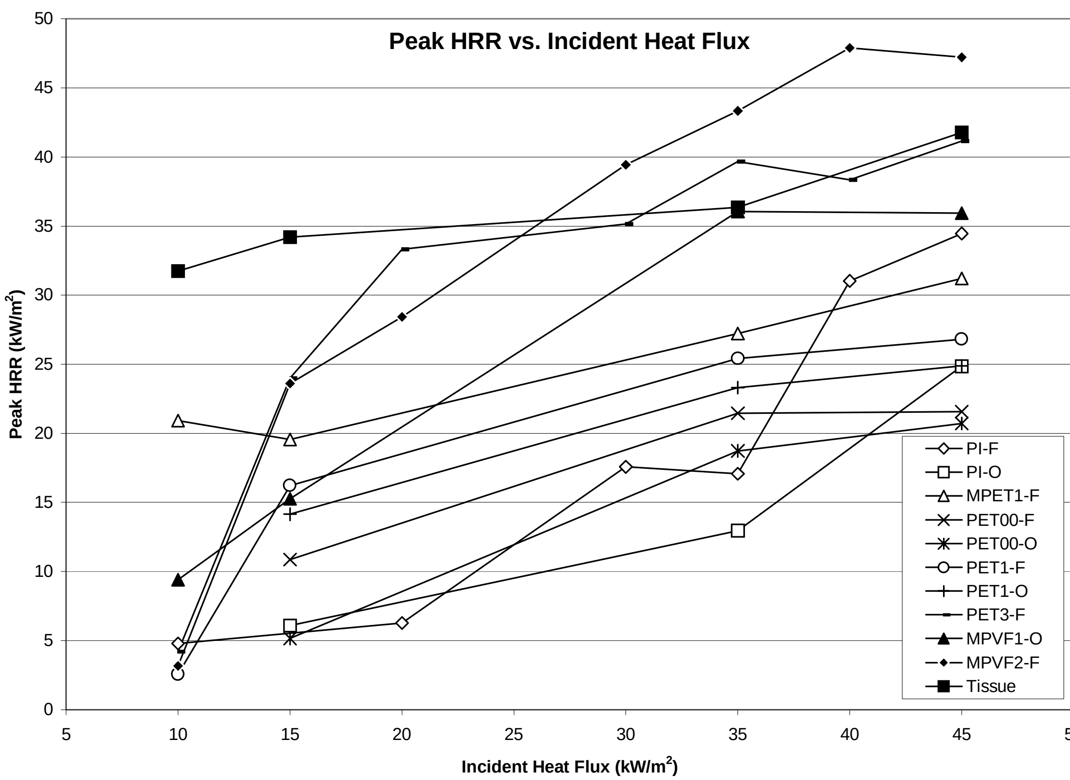


FIGURE 2. PEAK HEAT RELEASE RATE RESULTS AT VARIOUS INCIDENT HEAT FLUX LEVELS

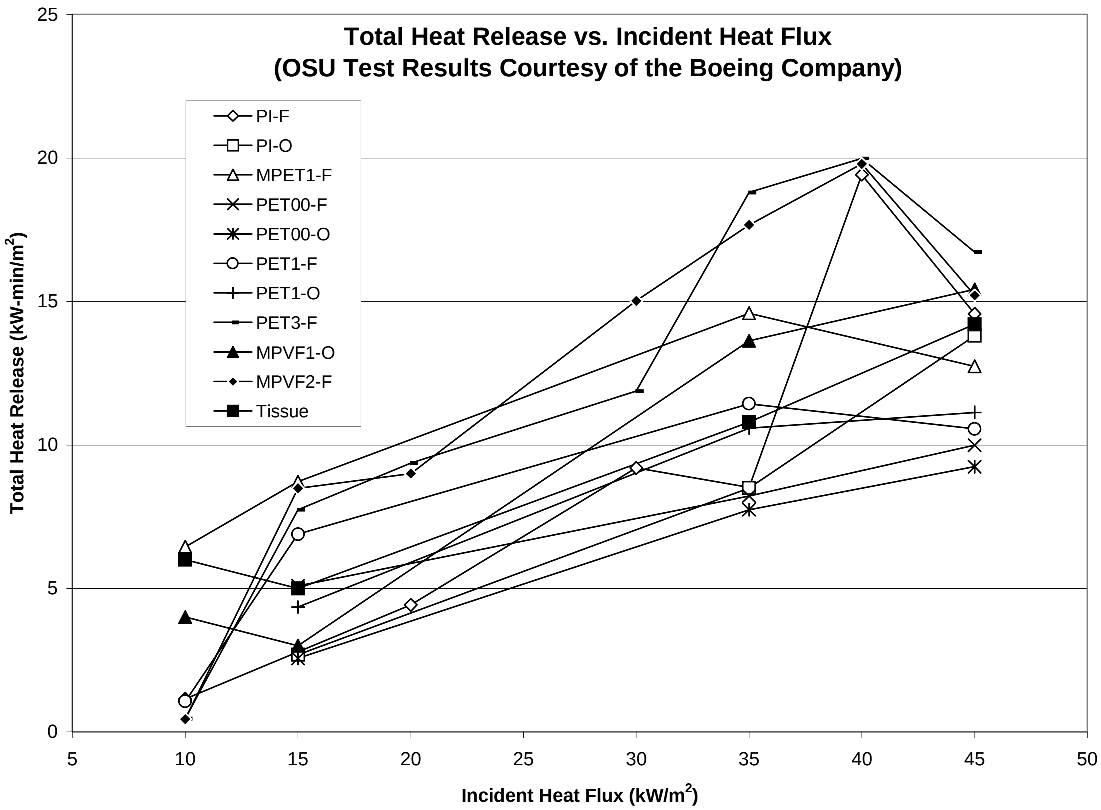


FIGURE 3. TOTAL HEAT RELEASE RESULTS AT VARIOUS INCIDENT HEAT FLUX LEVELS

Additionally, there appeared to be a large increase in both the peak and total heat release for some materials when the incident heat flux increased from 10 to 15 kW/m^2. The peak heat release rate of the class 1 and 3 PET samples escalated sixfold, the class 2 metallized PVF increased eightfold, and the class 1 metallized PVF nearly doubled. This would indicate that below a certain incident heat flux level, the materials behave quite differently.

In general, the OSU results produced a significant amount of scatter. The results were also affected by a number of factors, including the sample preparation, the physical behavior of the films (melting, shrinking, etc.), and the level of incident heat flux.

A limited number of materials were evaluated in the cone calorimeter at various incident heat flux levels for comparison with the OSU test results (table 10). No similar trends, as observed in the OSU tests, were noted amongst the materials tested in the cone calorimeter. As the incident heat flux increased, the peak heat release rate of the metallized PET decreased, while an opposite trend appeared with the class 3 PET material. As the incident heat flux was increased during tests with the PET00 and metallized PVF, the resultant peak heat release rate varied, while it remained fairly consistent with the class 1 PET material (see figure 4). The results obtained for the 2-minute integrated total were much more consistent.

TABLE 10. RESULTS OF CONE CALORIMETER HEAT RELEASE TESTING

Material	Test	25 kW/m^2 Incident Heat Flux		35 kW/m^2 Incident Heat Flux		50 kW/m^2 Incident Heat Flux		60 kW/m^2 Incident Heat Flux	
		Peak (kW/m^2)	Total (kW/m^2 min)	Peak (kW/m^2)	Total (kW/m^2 min)	Peak (kW/m^2)	Total (kW/m^2 min)	Peak (kW/m^2)	Total (kW/m^2 min)
MPET1-F	1	30.20	10.50	35.00	10.50	37.90	15.50	39.00	13.33
	2	41.90	10.50	33.20	10.83	28.00	100.00	20.00	8.33
	Avg	36.10	10.50	34.10	10.67	33.00	57.83	29.50	10.83
PET00-O	1	21.50	7.16	13.30	5.33	25.30	10.00	25.00	9.83
	2	21.10	8.83	14.70	6.00	26.70	11.17	24.00	8.33
	Avg	21.30	8.00	14.00	5.67	26.00	10.67	24.50	9.17
PET1-F	1	28.50	8.00	23.10	7.33	20.70	8.33	26.00	11.00
	2	21.40	7.00	25.50	8.33	23.30	10.83	25.00	9.00
	Avg	25.00	7.50	24.30	7.83	22.00	9.58	25.50	10.00
PET3-F	1	4.20	5.33	35.80	11.67	44.30	17.00	44.00	14.17
	2	34.00	10.33	29.90	10.00	41.50	15.33	43.00	15.33
	Avg	19.00	7.83	32.90	10.83	42.90	16.17	43.50	14.75
MPVF1-O	1	18.20	7.00	10.70	4.00	29.40	11.50	27.00	11.67
	2	4.10	0.00	12.50	7.33	27.70	10.67	25.00	10.50
	Avg	11.20	3.50	11.60	5.67	28.60	11.08	26.00	11.08

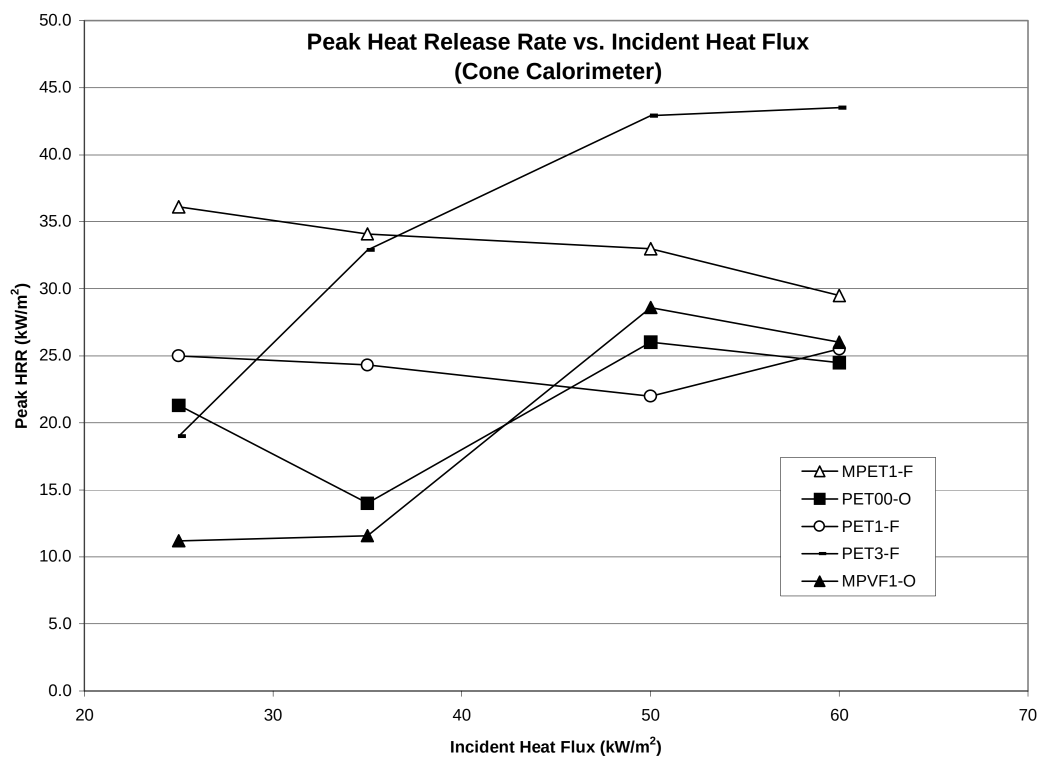


FIGURE 4. PEAK HEAT RELEASE RATE RESULTS USING CONE CALORIMETER

Analysis of the rate of heat release tests conducted in the OSU chamber and the cone calorimeter apparatus highlighted several findings. First, the calculated rate of heat release appeared to be relatively low, which appeared to be a function of the materials' thickness. Because the combustible portion of the test samples (i.e., the films) are extremely thin, they may react differently from one another when ignited. Physical effects, such as shrinkage and rolling, which tend to vary greatly from test to test and are highly dependant on sample configuration, may limit the ability to produce consistent results with thin films in this type of equipment. Secondly, the physical behavior of the materials is difficult to observe since the test samples are placed inside a chamber in the OSU test. Thirdly, and most importantly, the heat release test results are highly dependent on the sample preparation, which is due, in part, because the entire sample area is exposed to heat. The differences in test results between samples that were entirely encapsulated with film with those that were partially encapsulated or simply sandwiched were significant. Other methods aimed at constraining the material to prevent shrinkage and bunching did not produce test results that were more consistent and were less plausible.

ELECTRICAL ARC TEST RESULTS.

Mock-up tests were performed on a variety of insulation materials to determine their ability to propagate fire from an electrical arcing event [5]. Electrical ignition testing was an important part of the test program due to the number of service incidents involving electrical arcing and flame spread on the thermal acoustic insulation. The current vertical Bunsen burner test was intended to represent a small ignition source such as that which results when an electrical arcing event takes place. However, in many instances the film materials will rapidly shrink away from the flame during the Bunsen burner test, causing propagation to cease, as the material is no longer in contact with the burner flame. As a result, many materials can pass the vertical Bunsen burner test but do not meet the intent of the test, which is to determine the ability of materials to propagate fire from small ignition sources.

During testing, a realistic ignition event was created in which an electrical wire was arced against different types of insulation materials to determine their propensity to ignite and spread a fire. Four combinations of materials were used in the fabrication of the insulation blankets, which were installed in the lower sidewall section of a DC-10 fuselage. The fuselage section contained four vertical formers that encompassed three frame sections, each measuring 16 inches in width. Test blankets, 12 feet in length, were placed in the center frame section (figure 5).

The arcing event was caused by contacting the inner side of the vertical former in which the insulation blanket was placed with a hot wire. Electrical power was supplied by a Hobart ground power cart generator, with a 3-phase, 400-cycle output rated at 60 KVA. The generator supplies 208 volts phase to phase and 115 volts phase to ground. Each phase was connected to a 15-amp aircraft style circuit breaker. A 22-guage wire was connected to the load side of each breaker, and the ends of each wire were stripped and used for arc initiation. The test fixture was grounded to the power supply.

During the initial 115-volt electrical arc testing, an insulation blanket was placed between the vertical formers in the test fixture such that it was in contact with both formers. The blanket was then subjected to an electrical arc at 115 volts by bringing one hot wire into contact with the

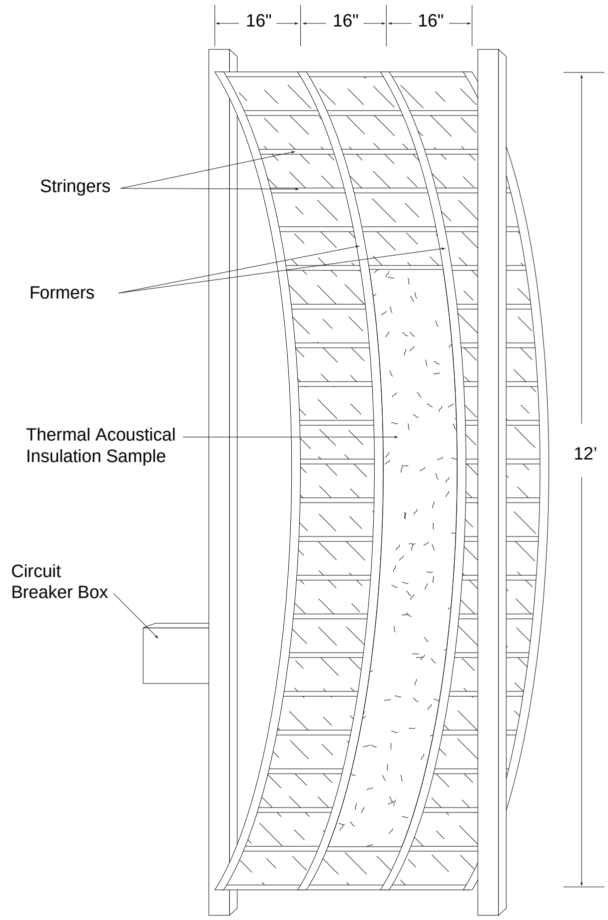


FIGURE 5. ELECTRICAL ARC TEST RIG

grounded test fixture in the vicinity of the blanket. The contact of wire with the structure was made in such a manner as to create ticking faults. Ticking faults are intermittent metal-to-metal events, such as conductor-to-conductor or conductor-to-structure, that result in the discharge of sparks and arcing events. This type of arc initiation was done in order to prevent a dead short circuit (bolted fault) that would have tripped the circuit breaker. While arcing events may be "point" sources of heat, the energy released in the arc may create localized temperatures in excess of 10,000°F.

Additional testing was conducted at 208 volts. During this series, the arcing events were initiated by bringing one hot wire into contact (intermittently) with another hot wire, which was taped to the surface of the blanket (208 volts phase to phase).

The arcing test results are shown in table 11. The polyimide and metallized PVF blankets did not ignite when subjected to multiple arcing events at either 115 or 208 volts. The polyimide film charred in those areas struck by the arcs, but no flaming was observed. Crater-like holes were formed in the fiberglass due to the energy of the arc. The PVF film shrunk away from the intense heat of the arcing, leaving small circular voids in the film cover, and also resulted in crater-like holes in the fiberglass.

TABLE 11. RESULTS OF ELECTRICAL ARC TESTING

Blanket Film Covering	115 Volts	208 Volts	Notes
Polyimide	No ignition	No ignition	Charring of film and crater formation in fiberglass during both voltages.
Metalized PET	Ignition; blanket consumed	Ignition; blanket consumed	Flame propagated and consumed the blanket during both voltages.
PET	Ignition (seam area); self-extinguished	Ignition; self-extinguished	Slightly longer sustained burning in seam area (115 volts) than in middle of blanket (208 volts); shrinkage of film covering, crater formation in fiberglass at both voltages.
Metalized PVF	No ignition	No ignition	Shrinkage of film cover, crater formation in fiberglass at both voltages.

The metallized PET film easily ignited from arcing at both 115 and 208 volts, resulting in uncontrolled flame propagation. The flames spread upward, downward, and horizontally. This multidirectional flame spread behavior had been observed during the flaming cotton swab tests. The plain PET film ignited only after prolonged multiple arcing at both voltages but self-extinguished. At 115 volts, the flaming was confined to the seam area. At 208 volts, the fire was small and self-extinguished in seconds with minimal flame spread, and there was a slightly longer burn length in the seam area than in the middle of the blanket. Polyester film shrinks when exposed to heat, and this was observed at both voltages during testing. In addition, crater-like holes were formed in the fiberglass.

The electrical arc testing of the insulation materials also examined the impact of corrosion inhibiting compounds (CIC) on the surface of the insulation blanket covering materials [5]. Of concern is the transfer of CIC from the aircraft structure to the insulation blanket that may inadvertently occur during maintenance operations or replacement of blankets. AV-8™, a newer CIC that dries hard (not tacky) when compared to older formulations, was sprayed across a 16- by 12-inch area of each test blanket. These blankets were then tested at both 115 volts and 208 volts at approximately 1 1/2 hours after application (dry). The test results are shown in table 12.

TABLE 12. RESULTS OF ELECTRICAL TESTING USING CORROSION INHIBITING COMPOUNDS

Blanket Film Covering	115 Volts	208 Volts
Polyimide	No ignition	No ignition
Metalized PET	Flame spread, blanket ~ 50% consumed.	Flame spread, blanket ~ 75% consumed.
PET	Small flaming area at the seam, self-extinguished.	No ignition
Metalized PVF	No ignition	No ignition

The test results indicate that neither of the polyimide or metallized PVF blankets ignited when tested with an AV-8™ coating at either voltage. Both types of blankets performed in the same manner as they did when tested without AV-8™. When subjected to an electrical arc, the metallized PET film cover sprayed with AV-8™ ignited with flame propagation. At 115 volts, approximately 50% of the blanket was consumed, and at 208 volts, approximately 75% of the blanket was consumed. Comparing the data between tables 11 and 12, it can be seen that the uncoated blankets were totally consumed. The amount of blanket consumed was more likely due to the existence of test variables such as flatness of the film cover, melting, and dripping and not the presence of this particular CIC. The plain PET blanket ignited at the seam when tested at 115 volts and self-extinguished with minimal flame spread. When tested at 208 volts, no ignition occurred.

SMALL-SCALE MOCK-UP TEST RESULTS.

Early attempts to consistently ignite thermal acoustic insulation batting from any one of a number of small ignition sources failed, as the very thin moisture barrier film materials inherently shrunk away from the heat/ignition source, allowing the films to self-extinguish. However, by forming a hollow tube out of the material as shown in figure 6, it was discovered that flame propagation occurred along a significant portion of the batting surface. After forming the tube, an additional piece of film/insulation was placed at one end to block it off, and a crumpled mass of class 3 PET film material was centered in the hollow tube and ignited. This configuration allowed flames to consistently propagate over the inner film surface of the tube and ultimately consume a major portion of the film on the outer surface as well. It appeared that this geometry allowed significant preheating of the inner film surface that was predominant to film shrinkage, thus causing the film to ignite and propagate flame. Once the propagation covered a significant portion of the inner surface, enough heat was generated to preheat the outer surface, which ignited and burned as well. This process was repeated with a variety of films, including metallized PET, various thicknesses of nonmetallized PET and metallized PVF. The results indicated that the effects of preheating the surface of the thin film materials was crucial in sustaining flame propagation. Additional tests were run in a similar manner, some in which the blanket was rolled into a “jellyroll” type configuration, which also allowed the fire to propagate to some degree.

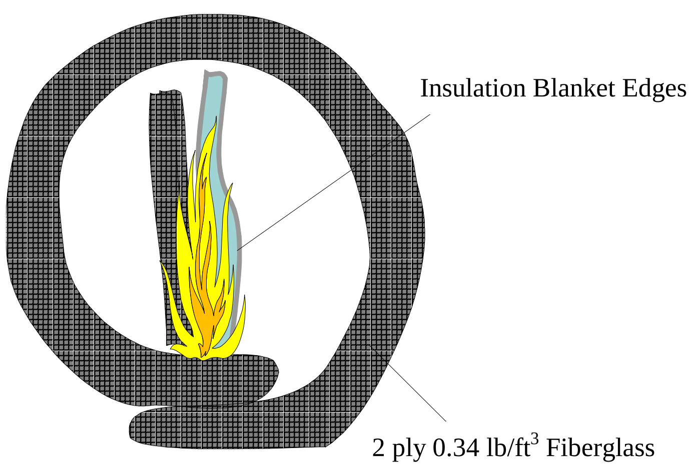


FIGURE 6. HOLLOW INSULATION TUBE TEST CONFIGURATION

SMALL-SCALE TESTS LEADING TO DEVELOPMENT OF INTERMEDIATE-SCALE TEST CONFIGURATION.

As previously discussed, it was initially difficult to achieve sustained flame propagation on any of the insulation films, with the exception of metallized PET, which could usually be ignited. Because of this, numerous attempts were made to initiate ignition using various arrangements of the blankets and fire sources, such as the hollow tube and jellyroll configurations mentioned previously. Most of these arrangements allowed momentary ignition, but the film materials typically would shrink away from the burning material, thus, disrupting or eliminating sustained flame spread. One common element observed during these initial trials was the effect of preheating the material, which seemed to cause the flames to propagate much further along the surface. An attempt to examine the effect of preheating on insulation ignitability is shown in figure 7. A small cabinet was used to house a radiant heater, which preheated a blanket sample clipped in place slightly above it. This configuration enhanced flame propagation in some of the PET films, but the PVF film continued to shrink away after ignition, causing self-extinguishment.

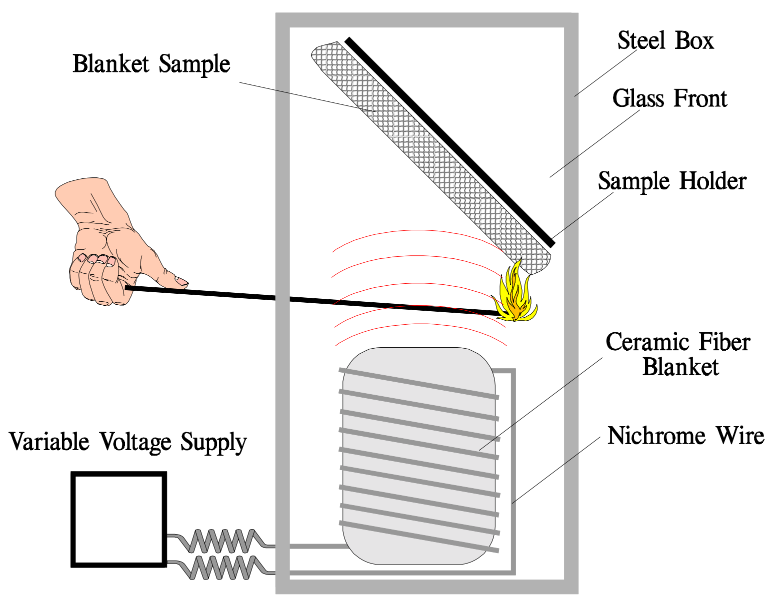


FIGURE 7. CABINET PREHEATING CONFIGURATION

This configuration and the hollow tube tests suggested that a realistic and perhaps high risk environment to assess the flammability of insulation was the attic space above the cabin ceiling. Initial tests were conducted in a simple mock-up, as shown in figure 8. During this scenario, four small trays of heptane were ignited inside an enclosure built around a small section of fuselage with attached insulation blankets. The fuselage section was enclosed with Lexan panels to contain the heat generated by the small heptane fires. The goal was to preheat the insulation blankets with the heptane fires, which were situated so that the flames did not impinge on the insulation blankets in order to enhance flame propagation. After several minutes of preheating, a separate tray of heptane was ignited that impinged on the blankets. During the first attempt, the flames propagated along the “cap strip” of material that is placed over the fuselage rib formers. This area of the insulation blanket differed from the insulation placed between the frames in that there was a doubling or two layers of material in contact with one another. Further attempts were made to create a sustained fire but failed after the initial cap strip material was consumed. Although it was difficult to get fire to propagate, the tests suggested that the multiple layers of insulation materials combined with preheating, tended to promote flame propagation.

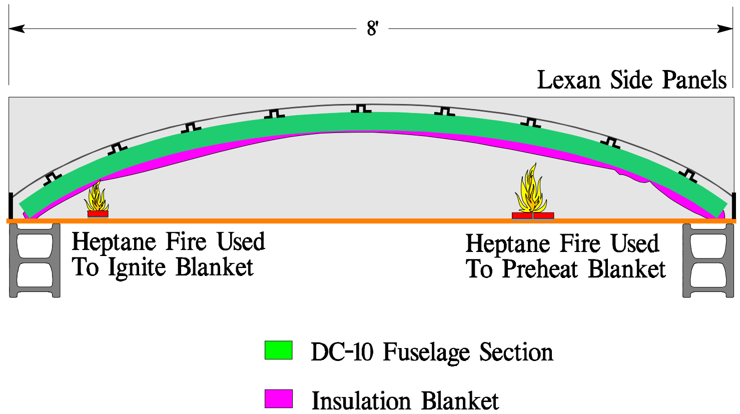


FIGURE 8. MOCK-UP ENCLOSURE USING HEPTANE FUEL FIRE

INTERMEDIATE-SCALE WIDE-BODY MOCK-UP TESTING.

Following these tests, an additional effort was made to scale up the tube enclosure tests by examining flame spread in the space that can be created in between layered blankets. In order to accomplish this, a section of a B747 fuselage was mounted on several concrete blocks (figure 9). Since there seemed to be a relationship between multiple layers of film and the ability of the fire to propagate, a configuration was devised in which double blankets were installed in the test section in a manner similar to that used in some manufactured aircraft. A fire was initiated in the area between the blankets, which formed an enclosure of material similar to the initial hollow tube tests. During the first several trials, a crumpled mass of PET film was ignited in this area. After several attempts, a spreading fire was produced that consumed a large quantity of the film material.

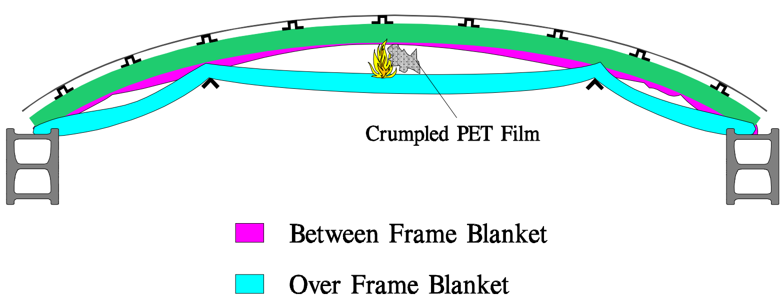


FIGURE 9. INITIAL MOCK-UP TEST CONFIGURATION USING A B747 FUSELAGE SECTION

A similar, but more realistic configuration simulating the attic area above the cabin ceiling was created by using three longitudinally placed heating, ventilation, and air conditioning (HVAC) ducts in the test section (figure 10). Under this configuration the insulation-wrapped ducts created the material enclosure that tended to propagate flames and support combustion. An initial test was run in which a rolled-up quantity of PET film and insulation was placed between two of the ducts and set on fire. Although the test was successful in illustrating the ability of the fire to propagate along the blanket material, a more standardized and repeatable fire source was needed in order to evaluate and compare the performance of other types of films.

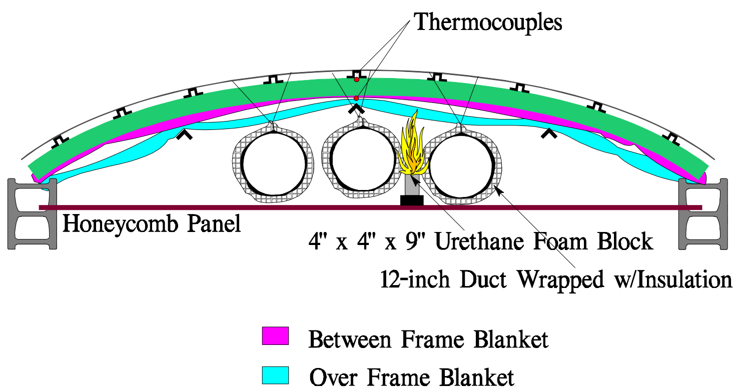


FIGURE 10. FINALIZED MOCK-UP TEST CONFIGURATION USING A B747 FUSELAGE SECTION

During this initial mockup test, the crumpled PET ignition source was variable and incapable of initiating consistent flame propagation; therefore, experimentation with a variety of materials/ignition sources began. An appropriate ignition source was paramount to the mock-up testing, since both the size and duration of the ignition source impacted the test results. This was a difficult task, since an ignition source that was too small would not be capable of spreading the fire to a large enough area, while conversely an overly aggressive ignition source could overwhelm the materials and limit the amount of useful data obtained. In an actual aircraft, the most likely ignition source in an inaccessible area would be an electrical arc. Since an electrical arc had been found inadequate at initiating flame propagation during smaller tests on all virgin films except one, it was hypothesized that contamination on the surface of the films played a role in their ignitibility. Since it would be very difficult, if not impossible, to simulate the contamination that could exist on the film surface, a slightly larger ignition source was used. To simulate what could occur from a small electrical arc in the presence of a contaminated blanket, an argument could be made that most aircraft in service have blankets with varying degrees of surface contamination. While service experience has shown that surface contamination cannot be fully avoided, it would not be appropriate to assume that it exists over a majority of the blankets in an aircraft. If it did, this would be considered a maintenance issue and not an acceptable basis to formulate a test condition to conduct the experiments. Instead, the goal was to develop a realistic condition that could exist in an aircraft, so that insulation materials could be appropriately evaluated. The results would be useful in the development of a suitable test standard that would require the use of more fire-resistant materials to prevent a small fire from propagating on the surface of the blankets.

Initially, a 16-inch-wide by 24-inch-long insulation blanket covered with class 3 PET film was rolled into a tight cylinder and situated over a 12-inch-long pin oriented vertically, with steel safety wire holding it in place. The bottom of the rolled insulation was ignited with a butane lighter, but the fire quickly subsided, resulting in an ignition source that was insufficient in duration. Following this, a piece of woven fiberglass sleeve was soaked in alcohol and placed over the pin. Once ignited, the fire quickly burned off the alcohol fuel, preventing flame duration. Further tests were run using a variety of small blocks of non-fire-retardant urethane foam. In order to promote even ignition of the material, a small quantity of heptane was poured onto the top of the block, providing a rapid and consistent ignition source. Additional trials were conducted using heptane along the edges of the vertically positioned block in an effort to more evenly ignite the sides. After numerous small tests, a finalized arrangement was developed using a 4- by 4-inch block of foam that measured 18 inches in height, with 10 ml of heptane soaked into the bottom end of the foam block to facilitate uniform ignition.

In the finalized attic mock-up (figure 10), the blankets were constructed using two layers of 0.34 lb/ft^3 density Microlite AA fiberglass supplied by Johns-Manville Corporation. The blankets were fabricated by encapsulating two layers of fiberglass with the film material and then heat sealing the edges using a hot-air gun. The between-frame blankets were first installed using the original equipment manufacturer (OEM) plastic piercing-style fasteners that were through-mounted in the fuselage formers. A second layer of double width blankets was then installed over the fuselage formers and held in place using three lengths of 1- by 1-inch-angled steel. All of the seams formed at the union of the double blankets were taped using materials that were compatible with the films (i.e., PET tape was used during tests in which the blankets were constructed with PET film). Blankets fabricated of a single layer of fiberglass encapsulated in identical film material were employed to wrap the 12-inch-diameter mock-up ducts, which were constructed of general purpose galvanized steel duct. The duct insulation blanket was stitched together along a longitudinal seam using steel safety wire. The insulated ducts were then suspended below the double blankets at a specified distance using safety wire. Additionally, honeycomb-style aircraft panels were then placed below the suspended ducts to form the attic space.

A total of seven different film materials were tested, including a baseline test without any film covering material. During a typical test, the heptane-spiked foam block, secured to a mounting pin, was placed on the ceiling panel approximately one-third of the way into the test article, nested between two of the ducts. A long flaming stick was used to light the foam block on fire. Video and still photography monitored the progress of the test. After conducting two tests under this configuration, the consensus was that the ignition source was too severe, so subsequent tests were conducted using a foam block that was half the size, or 9 inches high. During some of the subsequent tests, if little propagation resulted, repeat tests were conducted by situating another foam block at the opposite end of the test rig, nested between the center duct and the noninflicted duct from the previous test. If flame propagation and material consumption was minimal, a third test using a larger ignition source was performed. The results of the mockup tests are tabulated in table 13.

TABLE 13. WIDE-BODY MOCK-UP TESTING RESULTS

Date	Film	BMS Class	Insulation	Ducts	Ignition Source	Result
2/15/99-1	PET3-F	3	2 ply 0.34 lb/ft^3	N	Crumpled PET film	Several attempts made prior to getting propagation.
2/18/99-1	PET3-F	3	2 ply 0.34 lb/ft^3	Y	Crumpled PET film	Large amount of flame propagation, extremely large smoke output.
2/22/99-1	PET3-F	3	2 ply 0.34 lb/ft^3	Y	Crumpled PET film	Large amount of flame propagation, extremely large smoke output.
3/11/99-1	MPET1-F	1	2 ply 0.34 lb/ft^3	Y	4 x 4 x 18-inch Urethane Foam + 10cc Heptane	Film completely consumed, large smoke output.
3/15/99-1	PI-O	1 mil	2 ply 0.34 lb/ft^3	Y	4 x 4 x18-inch Urethane Foam + 10cc Heptane	30%-40% of film charred, propagation ceased once ignition source consumed.
3/15/99-2	PI-O	1 mil	2 ply 0.34 lb/ft^3	Y	4 x 4 x 9-inch Urethane Foam + 10cc Heptane	Small area of film charred, propagation ceased once ignition source consumed.
3/15/99-3	PI-O	1 mil	2 ply 0.34 lb/ft^3	Y	4 x 4 x 9-inch Urethane Foam + 10cc Heptane	Small area of film charred, propagation ceased once ignition source consumed.
3/16/99-1	PET3-F	3	2 ply 0.34 lb/ft^3	Y	4 x 4 x 9-inch Urethane Foam + 10cc Heptane	Large amount of flame propagation, extremely large smoke output.
3/17/99-1	none	N/A	2 ply 0.34 lb/ft^3	Y	4 x 4 x 9-inch Urethane Foam + 10cc Heptane	Minimal flame propagation, no smoke output once ignition source consumed.
3/17/99-2	none	N/A	2 ply 0.34 lb/ft^3	Y	4 x 4 x 9-inch Urethane Foam + 10cc Heptane	Minimal flame propagation, no smoke output once ignition source consumed.
3/17/99-3	none	N/A	2 ply 0.34 lb/ft^3	Y	4 x 4 x 18-inch Urethane Foam + 10cc Heptane	Minimal flame propagation, no smoke output once ignition source consumed.
3/18/99-1	MPVF1-O	1	2 ply 0.34 lb/ft^3	Y	4 x 4 x 9-inch Urethane Foam + 10cc Heptane	Moderate flame propagation, minimal smoke output.
3/18/99-2	MPVF1-O	1	2 ply 0.34 lb/ft^3	Y	4 x 4 x 9-inch Urethane Foam + 10cc Heptane	Moderate flame propagation, minimal smoke output.
3/18/99-3	MPVF1-O	1	2 ply 0.34 lb/ft^3	Y	4 x 4 x 18-inch Urethane Foam + 10cc Heptane	Increased flame propagation, slightly increased smoke output.
3/23/99-1	PET00-O	0-0	2 ply 0.34 lb/ft^3	Y	4 x 4 x 9-inch Urethane Foam + 10cc Heptane	Small to moderate amount of flame propagation, moderate smoke output.
4/19/99-1	PET1-F	1	2 ply 0.34 lb/ft^3	Y	4 x 4 x 9-inch Urethane Foam + 10cc Heptane	Moderate amount of flame propagation, moderate to large smoke output.
5/06/99-1	FPC-C	N/A	2 ply 0.34 lb/ft^3	Y	4 x 4 x 9-inch Urethane Foam + 10cc Heptane	Minimal flame propagation, no smoke output once ignition source consumed.
5/06/99-2	FPC-C	N/A	2 ply 0.34 lb/ft^3	Y	4 x 4 x 18-inch Urethane Foam + 10cc Heptane	Minimal flame propagation, no smoke output once ignition source consumed.
5/06/99-3	FPC-C	N/A	2 ply 0.34 lb/ft^3	Y	(2) 4 x 4 x 18-inch Urethane Foam + 10cc Heptane	Minimal flame propagation, no smoke output once ignition source consumed.

During the mock-up tests, temperatures were measured at both ends of the test rig to provide an estimate of the material's energy release rate (figure 11). Assuming the mass flow rates exiting the ends of the attic space are equivalent, the energy release is approximately proportional to the sum of the average of two thermocouples at each end, or

$$ERR \approx (T1 + T2) / 2 + (T3 + T4) / 2$$

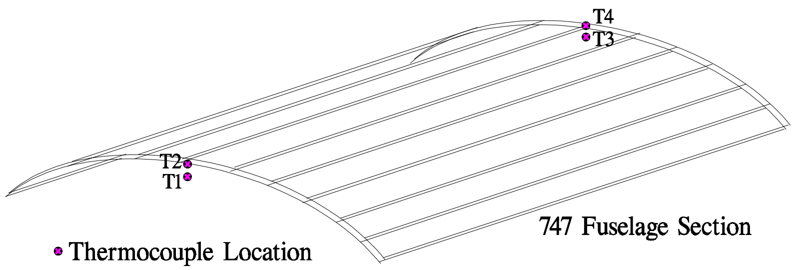


FIGURE 11. PLACEMENT OF TEMPERATURE SENSORS

Since the ability of the thin moisture barrier films, or any combustible materials, to propagate fire is related to energy release rate, this calculation would be a useful indication of the relative fire performance of the insulation films. The estimated energy release rates provided a ranking order of the most flammable films to the least, and the observed burning behavior of the films was found to be consistent with the calculations (figure 12).

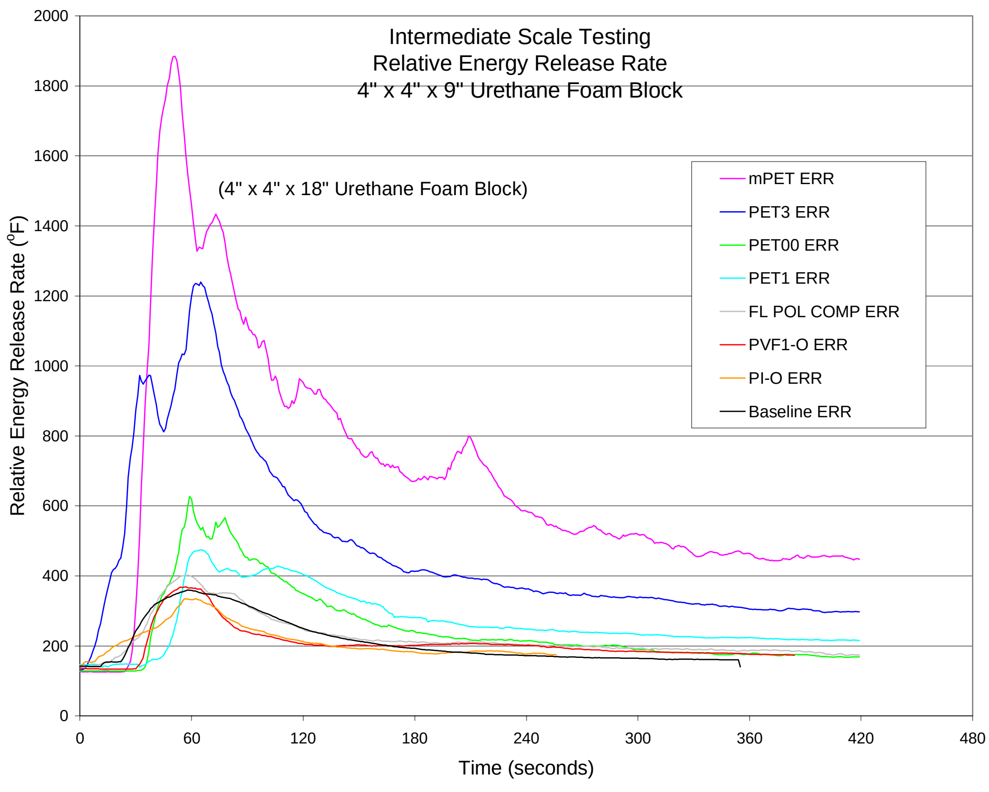


FIGURE 12. RELATIVE ENERGY RELEASE RATE CALCULATION OF MATERIALS USED IN WIDE-BODY TESTS

As shown in figure 12, the metallized PET film produced the highest estimated energy release rate, but this was during a test in which the larger, 18-inch-high foam block was used. However, this material was clearly more flammable than all other materials tested, as the fire propagated long after the ignition source was completely consumed. There were other trends noted from the testing and estimated energy release data. For example, the heavier class 3 PET film produced much more heat, flames, and smoke than the thinner class 00 and class 1 PET materials. This result indicated the propagation of flames along the very thin materials was difficult to sustain, while thicker samples of the identical material were more easily ignited and flame propagation was more likely to occur. Conversely, the polyimide and fluoropolymer composite materials produced very minimal flame spread, resulting in low energy release rate estimates. Also noted was the good performance of the metallized PVF material, which was difficult to ignite and propagate flames due in part to the material's propensity to shrink away from the heat source.

INTERMEDIATE-SCALE NARROW-BODY MOCK-UP TESTS.

After successfully completing a series of mock-up tests using a wide-body fuselage section, further tests were conducted in a smaller, more confined simulated overhead area using a B707 narrow-body fuselage section. The 12-foot-long section of fuselage was positioned on a steel frame as shown in figure 13. The test conditions were similar to those used in the wide-body configuration, with a heptane-spiked foam block used as the ignition source.

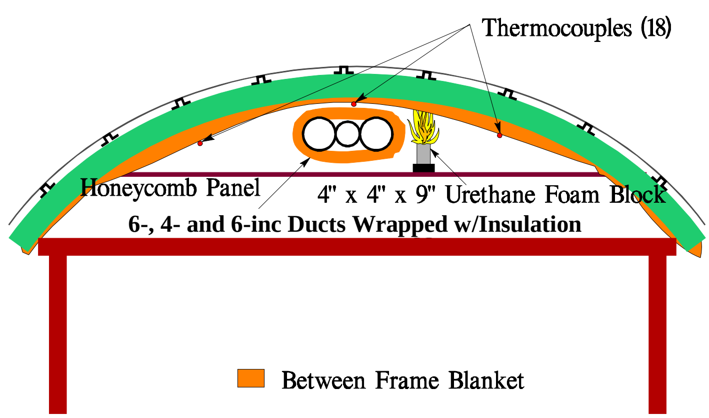


FIGURE 13. NARROW-BODY TEST CONFIGURATION USING A B707 FUSELAGE SECTION

The insulation blankets were constructed using two layers of 0.42 lb/ft^3 density Microlite AA fiberglass supplied by Johns-Manville Corporation. Blankets were fabricated by encapsulating the two layers of fiberglass with the film material and then heat sealing the edges using a hot-air gun. The insulation blankets were first installed between the fuselage frames (formers), and a secondary "cap strip" of insulation was then installed over the fuselage formers and held in place using the plastic OEM-style piercing fasteners, which were through-mounted in the formers. Plastic washers were placed over the fasteners to affix the cap strip insulation. Blankets were then fabricated using a single layer of fiberglass encapsulated in covering film for the purpose of wrapping the central HVAC mock-up duct, which was fabricated from smaller diameter galvanized steel general-purpose ducting that was safety wired together. The insulation blanket was stitched together along a longitudinal seam using steel safety wire. The insulated duct was then suspended below the insulation blankets at a specified distance using safety wire. Additionally, aircraft honeycomb panels were then placed below the suspended duct to enclose the attic space.

A total of five different film materials were tested. During a typical test, the heptane-spiked foam block, secured to the mounting pin, was placed onto the ceiling panel approximately one-third of the way into the test article, adjacent to the central duct. A long flaming stick was used to light the foam block on fire. Measurements of the temperatures were taken at 18 locations along the surface of the insulation blankets and video and still photography were used to monitor the progress of the test (figure 14).

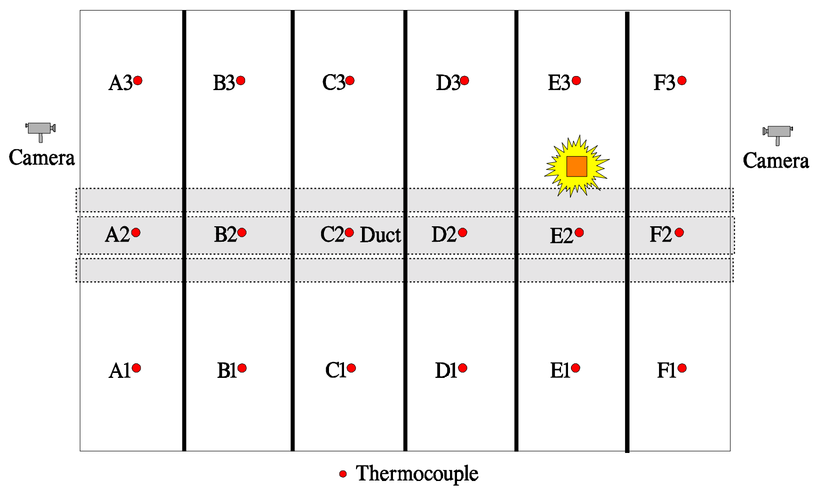


FIGURE 14. NARROW-BODY MOCK-UP TEST INSTRUMENTATION CONFIGURATION

As was the case during the wide-body testing, many of the tests were repeated when very little flame propagation occurred. Table 14 summarizes the results of the duplicate tests conducted with the five film materials. Generally, the relative performance of the films was consistent with observations and measurements from previous tests.

The temperature measurements were employed to estimate the energy release rates (figure 15). As shown, the metallized PET film produced the highest estimated energy release rate. This material was clearly more flammable than all other materials tested, as the film continued to burn long after the ignition source was completely consumed. Other trends that were noted from the estimated energy release data were observed during the testing. For example, the class 00 and class 1 PET films produced more heat, flames, and smoke than either the metallized PVF or the polyimide materials. Also noted was the good performance of the metallized PVF material, which was difficult to burn due to the material’s propensity to shrink away from the heat source.

The temperature data obtained from the thermocouple grid was also used to generate a topographic plot of the temperatures at various points during the test, which enabled a simulation of fire development.

TABLE 14. NARROW-BODY MOCK-UP TEST RESULTS

Date	Film	BMS Class	Insulation	Ignition Source	Result
6/8/99-1	MPVF1-O	1	2 ply 0.42 lb/ft^3	4 x 4 x 9-inch Urethane Foam + 10cc Heptane	Minimal flame propagation, minimal smoke output.
6/8/99-2	MPVF1-O	1	2 ply 0.42 lb/ft^3	4 x 4 x 9-inch Urethane Foam + 10cc Heptane	Minimal flame propagation, minimal smoke output.
6/21/99-1	PI-O	1 mil	2 ply 0.42 lb/ft^3	4 x 4 x 9-inch Urethane Foam + 10cc Heptane	Minimal flame propagation, no smoke output once ignition source consumed.
6/21/99-2	PI-O	1 mil	2 ply 0.42 lb/ft^3	4 x 4 x 9-inch Urethane Foam + 10cc Heptane	Minimal flame propagation, no smoke output once ignition source consumed.
6/22/99-1	PET1-F	1	2 ply 0.42 lb/ft^3	4 x 4 x 9-inch Urethane Foam + 10cc Heptane	Moderate flame propagation, moderate smoke output.
6/22/99-2	PET1-F	1	2 ply 0.42 lb/ft^3	4 x 4 x 9-inch Urethane Foam + 10cc Heptane	Moderate flame propagation, moderate smoke output.
6/23/99-1	PET00-F	0-0	2 ply 0.42 lb/ft^3	4 x 4 x 9-inch Urethane Foam + 10cc Heptane	Small to moderate amount of flame propagation, moderate smoke output.
6/23/99-2	PET00-F	0-0	2 ply 0.42 lb/ft^3	4 x 4 x 9-inch Urethane Foam + 10cc Heptane	Small to moderate amount of flame propagation, moderate smoke output.
6/24/99-1	MPET1-F	1	2 ply 0.42 lb/ft^3	4 x 4 x 9-inch Urethane Foam + 10cc Heptane	Film completely consumed, large smoke output.
6/24/99-2	MPET1-F	1	2 ply 0.42 lb/ft^3	4 x 4 x 9-inch Urethane Foam + 10cc Heptane	Film completely consumed, large smoke output.

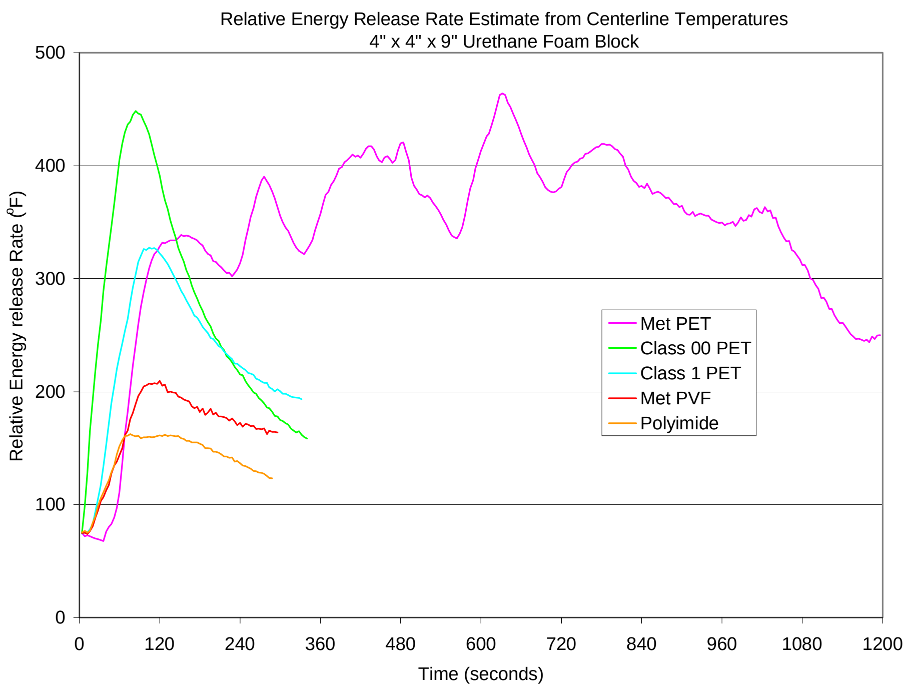


FIGURE 15. RELATIVE ENERGY RELEASE RATE CALCULATION FOR NARROW-BODY TESTS

FULL-SCALE MOCK-UP TESTS IN DC-10 FUSELAGE.

Following the mock-up tests in the wide-body and narrow-body test sections, a series of tests were run under full-scale conditions in the attic area of a DC-10 fuselage aft section. The test section was approximately 18 feet in length, and was outfitted with an array of thermocouples to monitor the growth of the fire. Two layers of thermal acoustic insulation blankets were installed in the test section, consisting of between-frame and over-frame blankets. The insulation blankets were constructed using two layers of 0.34 lb/ft^3 density Microlite AA fiberglass supplied by Johns-Manville Corporation. Blankets were fabricated by encapsulating the two layers of fiberglass with the film material and then heat sealing the edges using a hot-air gun. The between-frame blankets were held in place using five safety wires run longitudinally from one end of the test section to the other. Following this, the over-frame blankets were placed on top of the between-frame blankets, and secured using 10 wire bundles, also run longitudinally from end to end. Each wire bundle contained 20 individual strands of 20 AWG, tin-plated copper conductor wire. The wire insulation was a hybrid construction consisting of a polytetrafluoroethylene (PTFE) outer layer, a polyimide middle layer, and a PTFE layer next to the conductor wire, insulated with cross-linked polymer coating. The wire bundles were attached to the fuselage formers using adel clamps spaced every 40 inches. Once the insulation blankets were installed, all seams were taped using materials common to the film type. Three longitudinal ducts were also installed in the overhead area. The ducts were wrapped in blankets constructed with one layer of 1-inch-thick 0.34 lb/ft^3 density fiberglass batting and wrapped in a film identical to that being used for the general blankets.

Figure 16 is a schematic of the instrumentation locations. Following installation of the blankets, thermocouples were installed in each of the areas between the fuselage formers. Five thermocouples were placed in each between-frame area, for a total of 55. The thermocouples were in contact with the face of the over-frame blankets in order to measure the flame temperature on the blanket surface. In addition, a smokemeter was installed in the overhead area, along with three calorimeters to measure the heat flux. Additional smokemeters were placed in the cabin section at heights of 18, 42, and 66 inches above the floor. Wide-angle video cameras were situated at both ends of the overhead area.

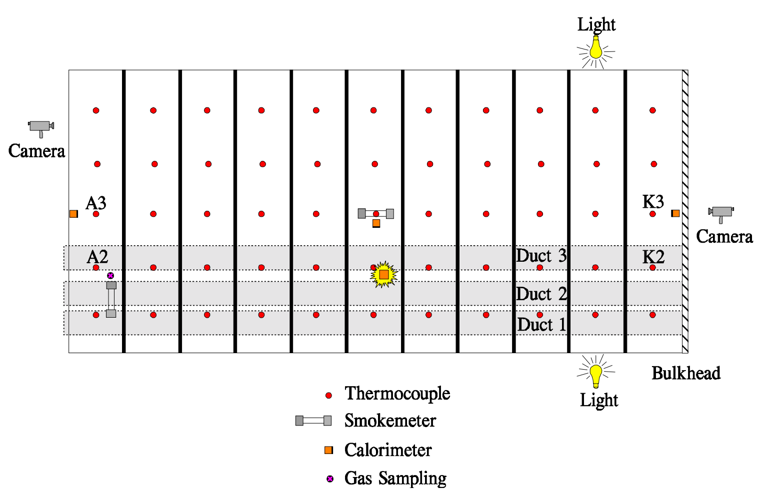


FIGURE 16. FULL-SCALE TEST CONFIGURATION IN DC-10 OVERHEAD

Table 15 tabulates the test results. During the initial test, a class 1 PET film was installed. A 4- by 4- by 9-inch block of heptane-dipped urethane foam was placed in the overhead area between

TABLE 15. RESULTS OF FULL-SCALE MOCK-UP TESTS IN DC-10 OVERHEAD AREA

Date	Film	BMS Class	Insulation	Ignition Source	Result
4/06/99-1	PET1-F	1	2 ply 0.34 lb/ft^3	4x4x9-inch Urethane Foam + 10cc Heptane	Minimal flame propagation, no smoke output once ignition source consumed.
4/06/99-2	PET1-F	1	2 ply 0.34 lb/ft^3	4x4x18-inch Urethane Foam + 10cc Heptane	Moderate flame propagation, minimal smoke output.
4/06/99-3	PET1-F	1	2 ply 0.34 lb/ft^3	4x4x18-inch Urethane Foam + 10cc Heptane	moderate flame propagation, minimal smoke output.
4/20/99-1	PET1-O (AN-47R)	1	2 ply 0.34 lb/ft^3	4x4x18-inch Urethane Foam + 10cc Heptane	Film completely consumed, large smoke output
5/5/99-1	MPET1-F	1	2 ply 0.34 lb/ft^3	4x4x18-inch Urethane Foam + 10cc Heptane	Moderate flame propagation, minimal smoke output.
5/5/99-2	MPET1-F	1	2 ply 0.34 lb/ft^3	small ignition source	Once ignition occurs between double blankets, flame will propagate and produce moderate levels of smoke.
5/19/99-1	MPVF1-O	1	2 ply 0.34 lb/ft^3	4x4x18-inch Urethane Foam + 10cc Heptane	Minimal flame propagation, no smoke output once ignition source consumed.
5/19/99-2	MPVF1-O	1	2 ply 0.34 lb/ft^3	(2) 4x4x18-inch Urethane Foam + 10cc Heptane	Minimal flame propagation, no smoke output once ignition source consumed.

two of the longitudinal ducts (figure 17). After ignition of the block, the fire self-extinguished after a relatively small amount of fire propagation. The test was repeated using a larger 4- by 4- by 18-inch foam block. This test resulted in a slightly larger area of flame propagation along the surface, but the flames subsided shortly after the foam block ignition source was depleted.

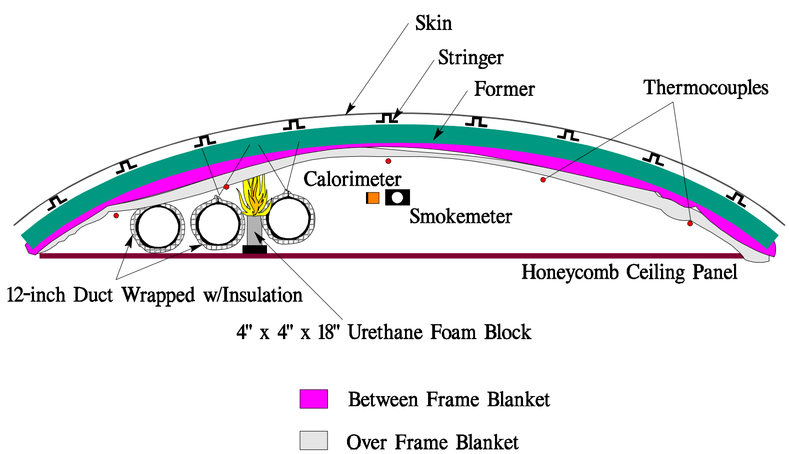


FIGURE 17. FULL-SCALE TEST CONFIGURATION IN DC-10 OVERHEAD

As with earlier testing, additional tests with the same material were conducted if limited flame propagation and film damage resulted, as was the case during the first series. All subsequent tests were conducted using the larger 4- by 4- by 18-inch foam block spiked with 10 ml of heptane. During the next series, a class 1 PET material supplied by a different manufacturer was installed, which utilized a different scrim configuration. The initial material contained a 6 by 6 scrim (6 yarns per inch), whereas the second type of material had a tighter 10 by 10 scrim. During this test, there was widespread flaming along the surface of the material, which continued after the foam block was consumed. A second test was not possible due to the large amount of material consumption. A comparison of the two tests indicated that the effects of the scrim, and possibly the adhesive used to bond the scrim to the film material, probably played a more dominant role in the overall flammability of the material than the virgin film material itself.

Next, metallized PET film blankets were tested. During the initial test, the foam block caused considerable flame propagation to occur along the surface of the suspended ducts, but the propagation appeared to subside several minutes after the foam block was consumed. Based on the results of previous tests, this outcome was somewhat irregular, as the metallized PET material consistently yielded the greatest amount of flame propagation, and usually burned until a majority of the material was consumed. This did not occur during the full-scale test. Additional tests were conducted in which small ignition sources were used to initiate flame propagation on the undamaged insulation in various locations. Attempts to ignite the exposed surface of insulation to produce a sustained, spreading fire were unsuccessful. It appeared that the region of sustained burning was along the concealed surfaces that faced each other between the blankets. Upon removal and inspection, it was observed that the material was designated as type "L", whereas all previous metallized PET material tested in the intermediate-scale configuration were imprinted type "K". No further explanation could be given for the difference in results between the previous intermediate-scale tests in which the material was totally consumed, and full-scale tests in which only moderate propagation occurred.

A final series of full-scale tests were run using a metallized PVF material. Following ignition of the foam block during the first test, the surrounding material shrunk, preventing further burning. A second test was run in which two foam blocks were attached, in an effort to produce an ignition source that was large enough to overcome the physical shrinking of the film and allow sustained propagation to occur. The foam blocks were situated in an area several feet away from the prior test-fire insult and ignited. The resulting flames were noticeably larger, but failed to burn the film with any more severity than the previous test. It was determined that the only flame propagation occurred when the ignition source was in direct contact with the film covering material. As soon as the flames from the ignition source diminished, there was no further propagation, and the film self extinguished.

The recorded temperatures were used to estimate a relative energy release rate of the film covering, similar to previous mock-up tests, by summing the average of thermocouples A2 and A3 with the average of thermocouples K2 and K3. As shown in figure 18, the estimated energy release rates matched the observed conditions. Clearly, the class 1 PET-O material used during the second test series provided the greatest flame propagation along the surface of the blankets. Conversely, the metallized PVF material resulted in very minimal flame propagation and yielded the lowest estimated energy release rate, matching that of the baseline test in which no film was used.

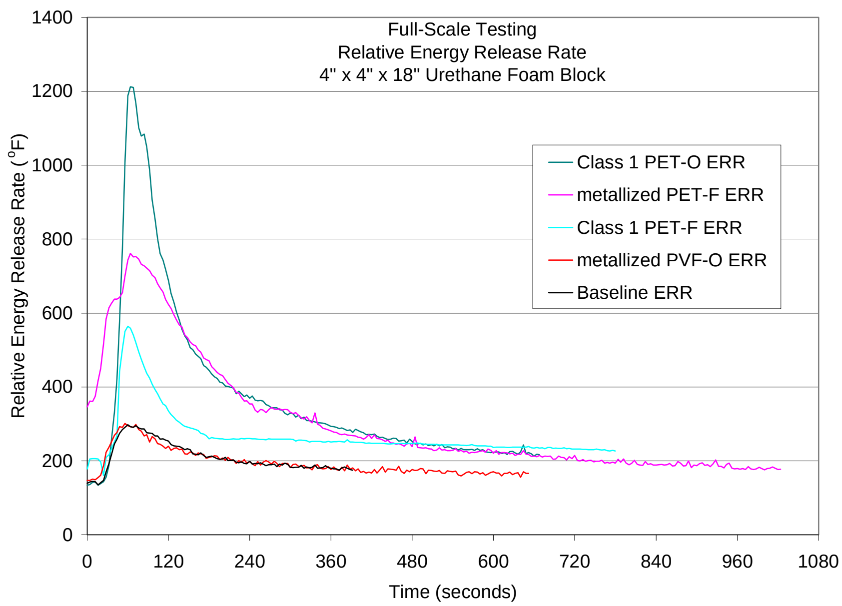


FIGURE 18. RELATIVE ENERGY RELEASE RATE CALCULATION FOR FULL-SCALE TESTS

The temperature data obtained from the thermocouple grid was also used to generate an isotherm plot at various times during the test, which enabled a simulation of fire development. Figure 19 shows a typical isotherm plot resulting from the ignition of a class 1 PET film after 1 minute. A more comprehensive program was later written which allowed a continuous view of all topographic plots generated during the test, which was helpful in visualizing the actual flame spread.

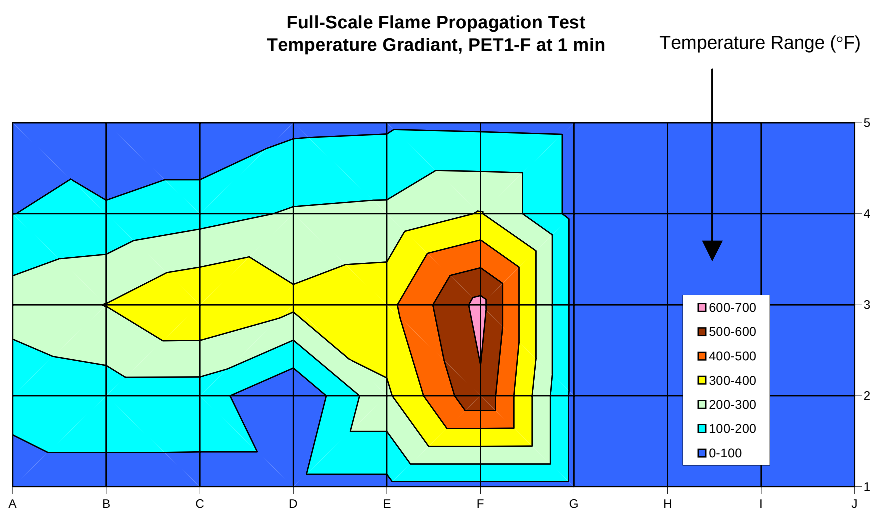


FIGURE 19. TYPICAL ISOTHERM PLOT IN DC-10 OVERHEAD AREA USING THERMOCOUPLE DATA

RADIANT PANEL TEST APPARATUS.

After conducting a variety of mock-up tests in small-, intermediate-, and full-scale test rigs, the flame characteristics and relative fire performance of the thin film coverings became more fully understood. Several conditions appeared to be critical to ignite the film covering surface and create a sustained fire. The influence of preheating the surface of the film was important, although not completely understood. The thickness of the materials was also a factor, as the thicker materials produced greater smoke, heat, and flames than thinner materials of the same type. Other finished film constituents were suspected of playing a role in the overall flammability, in particular, the type and amount of adhesive used to bond the scrim material to the film, the material used in the construction of the scrim, and the yarn count per area. The mock-up tests demonstrated that film coverings manufactured from the same basic material, for example, PET or PVF, could produce drastically different levels of flammability based on the scrim type. Although the heat release data generated from the OSU and cone calorimeter were useful in separating the most flammable materials from the least, they did not rank the fire performance in intermediate- and full-scale tests nor discriminate more subtle differences in the film behavior. Much of the difficulty in predicting actual full-scale flammability characteristics based on laboratory heat release testing was due in part to the small sample size, the difficulty in observing the materials' physical response to the fire source, and the strong dependence on sample configuration. In order to properly evaluate the flammability of the insulation, a more realistic (i.e., more life-like) sized specimen was needed. As a result, a decision was made to run trials using a radiant panel test apparatus that was previously developed to determine the fire resistance of carpet materials and floor coverings. This particular piece of equipment had a more realistic-sized test specimen, a test setup where the performance is less dependent on sample configuration, a more realistic variable preheating condition, and the means to monitor the progress of the test very closely through a large viewing area.

The radiant panel test apparatus that was used for evaluating the flammability of insulation blankets is shown in figure 20. This test equipment was originally used for measuring the critical radiant flux of horizontally mounted floor-covering systems according to ASTM E648, which exposed a test sample to a flaming ignition source in a graded radiant heat energy environment. The critical radiant heat flux can be described as the heat flux level below which flame spread will not occur. This test offers the possibility of recording flame propagation velocity, the time of ignition, and the burn length at different heat fluxes. The test also measures the level of incident radiant heat energy on the covering film at the most distant flameout point, which is defined as the critical heat flux measurement, in Btu/ft^2-sec (kW/m^2).

The relationship between the burn length along the test specimen and the critical radiant heat flux is shown in figure 21. In general, there exists an inverse relationship between the distance of flame propagation and the critical radiant flux of the specimen.

Prior to testing, the radiant panel was calibrated to determine the heat flux as a function of distance from the flaming ignition source. This is referred to as the flux profile. The heat flux was measured using a 0 to 10-mV range heat flux transducer at 10 positions along the horizontal incident surface, at a distance of 2 inches between each position (figure 22).

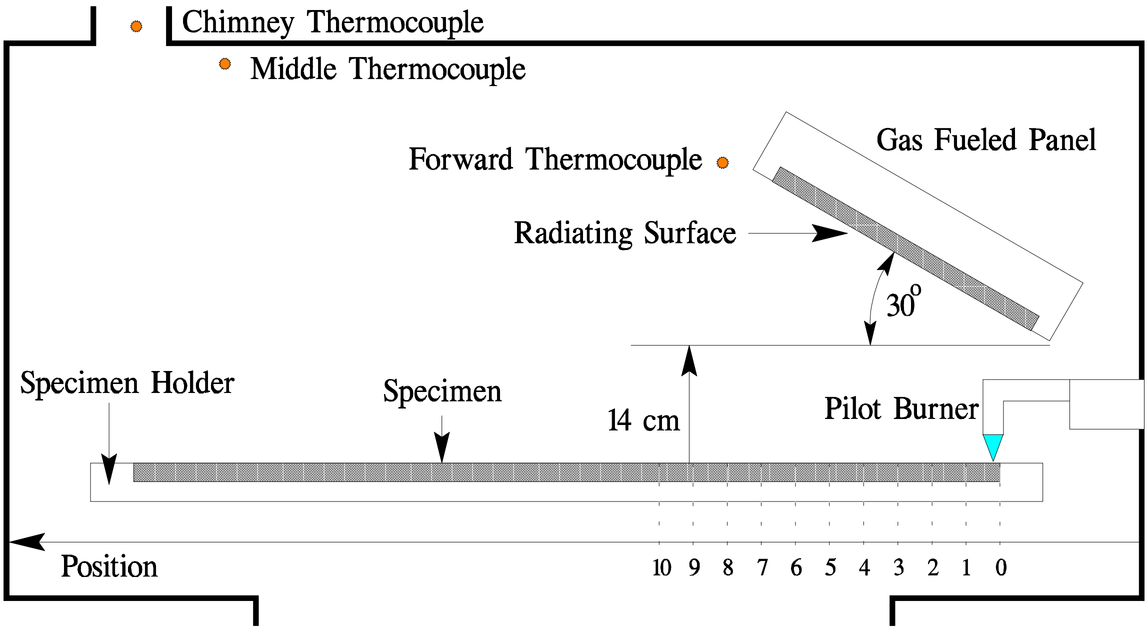


FIGURE 20. RADIANT PANEL TEST APPARATUS

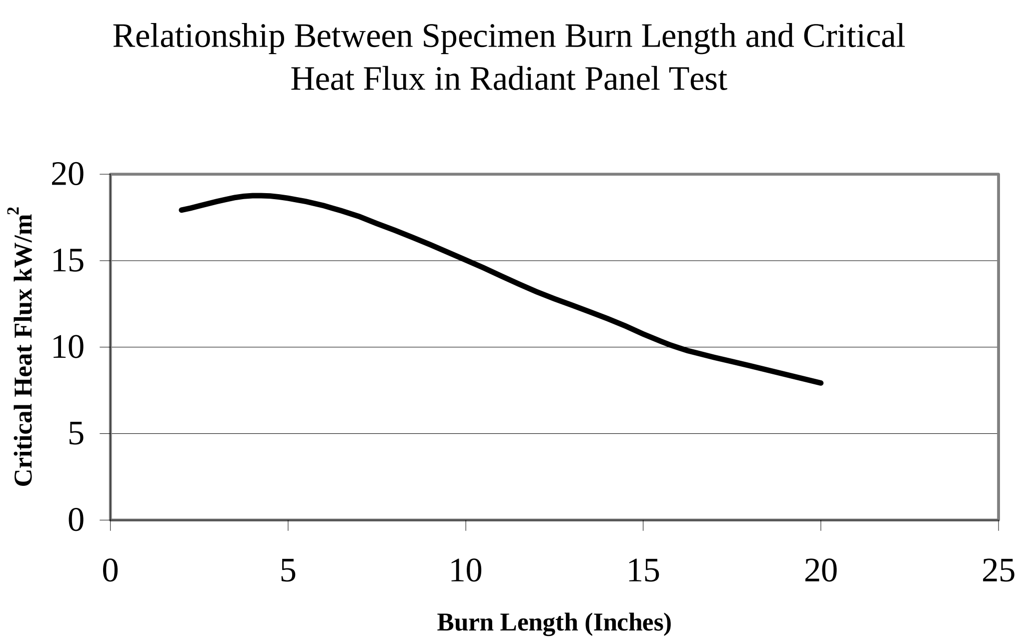


FIGURE 21. INVERSE RELATIONSHIP BETWEEN FLAME PROPAGATION AND CRITICAL RADIANT FLUX

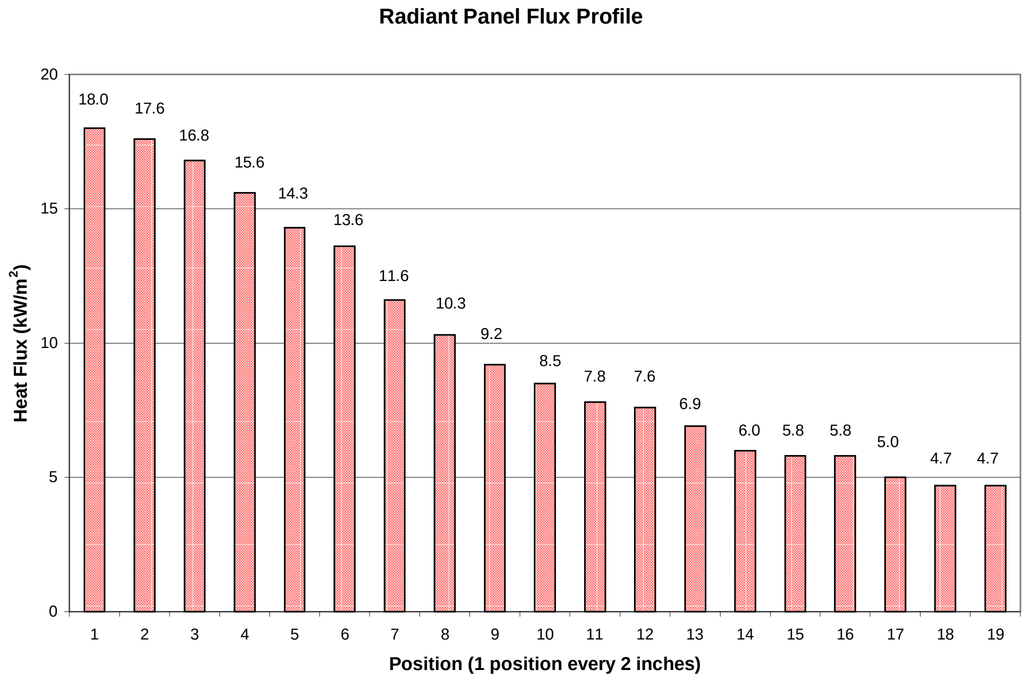


FIGURE 22. RADIANT PANEL FLUX PROFILE

During the test, a 10-inch-wide by 40-inch-long sample is clamped to a sliding platform, with test samples typically consisting of two layers of fiberglass batting with film covering. After the temperatures within the test chamber stabilize, the sample is inserted into the test chamber via the sliding platform, and the chamber door is closed. Simultaneously, the pilot burner flame is brought into contact with the specimen for the prescribed period of 15 seconds. The test is terminated when the material self extinguishes or flames propagate along the entire length. In order to become familiar with the test apparatus, preliminary tests were conducted on a variety of materials. Based on these tests, the radiant panel heat flux level was set to 18 kW/m^2, as measured in the first position, and a number of aircraft films were tested. The results in terms of percentage of burn length are shown in figure 23. Overall, the results were consistent with what was observed during the mock-up, intermediate-, and full-scale fire tests. In addition, physical effects such as melting, contraction, and the behavior of the reinforcing scrim, which play an important role in the flammability of the thin films, can be readily observed and better understood. Finally, the test appeared to be repeatable, which is an important consideration when the output is a proposed requirement.

COMPARISON OF LABORATORY-, INTERMEDIATE-, AND FULL-SCALE TEST RESULTS.

The flammability testing and analysis of insulation materials involved a variety of test methods, each generating a multitude of data. From these tests, observations, and data, the flammability characteristics of film materials were more fully understood. In order to determine the most appropriate test method for measuring insulation flammability, the results of the laboratory, mock-up, and full-scale tests were compared.

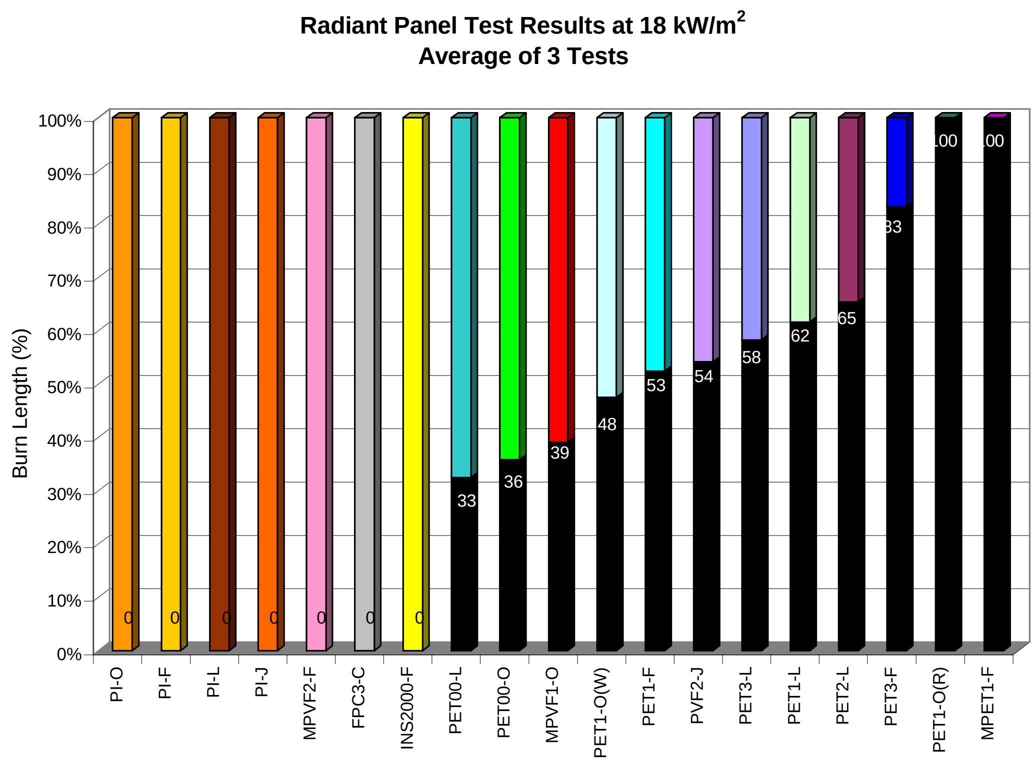


FIGURE 23. INITIAL RESULTS USING RADIANT PANEL TEST APPARATUS

Figure 24 shows the heat release data for all materials tested in the OSU apparatus using the entirely encapsulated method of sample preparation, at an incident heat flux of 3.5 kW/m^2. As shown, the peak heat release rate ranged from approximately 10 to 50 kW/m^2. Although these values are fairly low in comparison to other cabin materials, this can be attributed at least partly to the physical characteristics of the moisture barrier films themselves, as they are typically very thin, thereby offering minimal mass for combustion. The test data generated a material ranking order that provided a basis by which to compare these results to those obtained using other types of tests. As shown, the polyimides, fluoropolymer composite, and ultra thin (class 00) PET produced the lowest peak heat release rates, while the heavier (class 3) PET, PVF, and metallized PVF produced the highest.

Figure 25 shows the same OSU heat release data, however, only the materials that were tested in mock-up and full-scale tests are displayed.

Figures 26 and 27 show the estimated energy release rates obtained during intermediate mock-up and full-scale testing, respectively. These calculations also provided a ranking order of the material performance. Comparing figures 26 and 27, it appears that the metallized PET produced much higher energy release rates than the metallized PVF, which was in agreement with the observed results. However, this result is not supported by the results obtained during OSU heat release trials, where the metallized PVF had the highest heat release. There are several factors that should be considered.

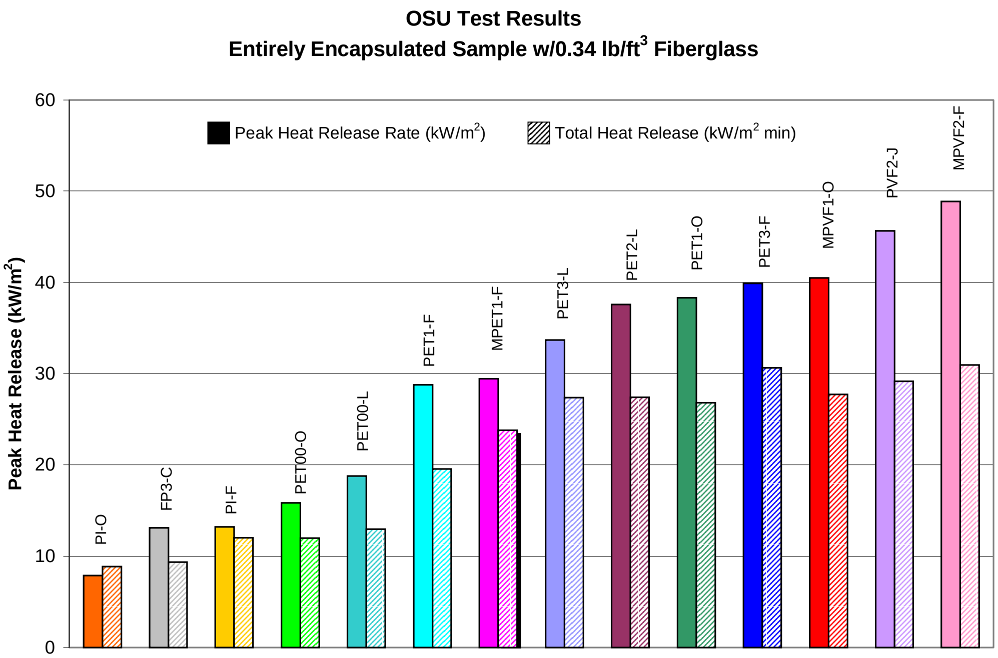


FIGURE 24. OSU TEST RESULTS USING THE ENTIRELY ENCAPSULATED METHOD OF SAMPLE PREPARATION

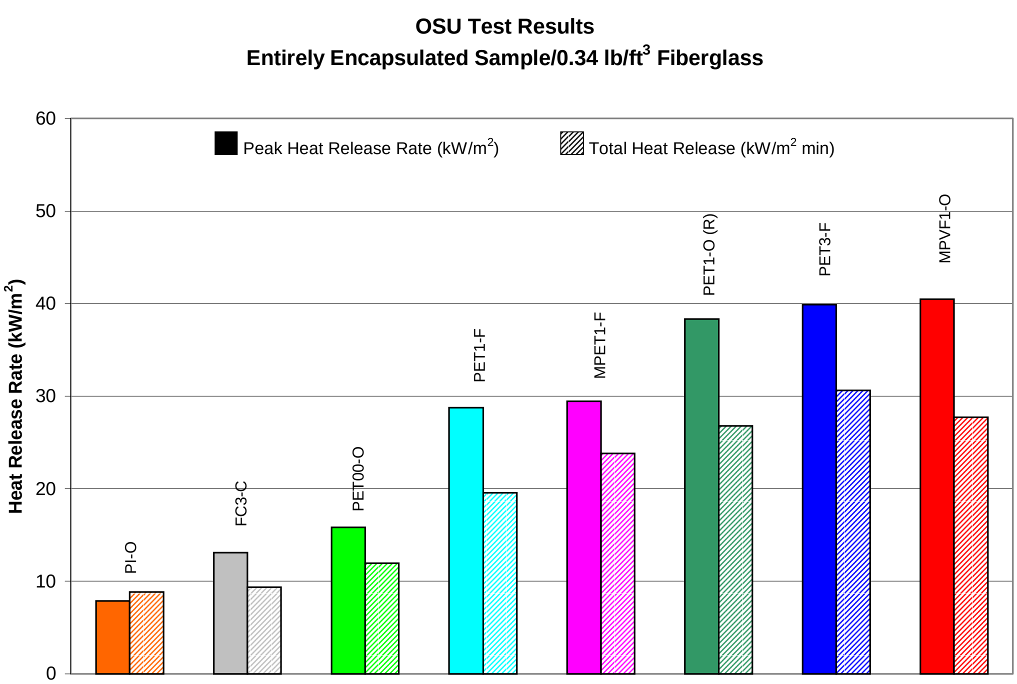


FIGURE 25. OSU TEST RESULTS OF MATERIALS COMMON TO MOCK-UP AND FULL-SCALE TESTING

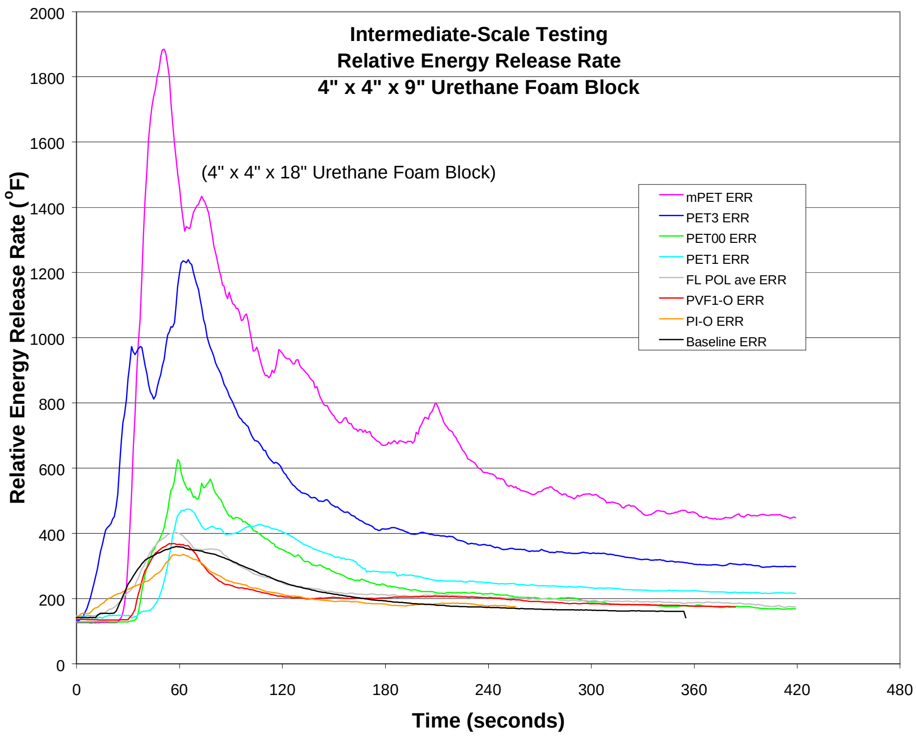


FIGURE 26. ESTIMATED ENERGY RELEASE RATES DURING MOCK-UP INTERMEDIATE-SCALE TESTING

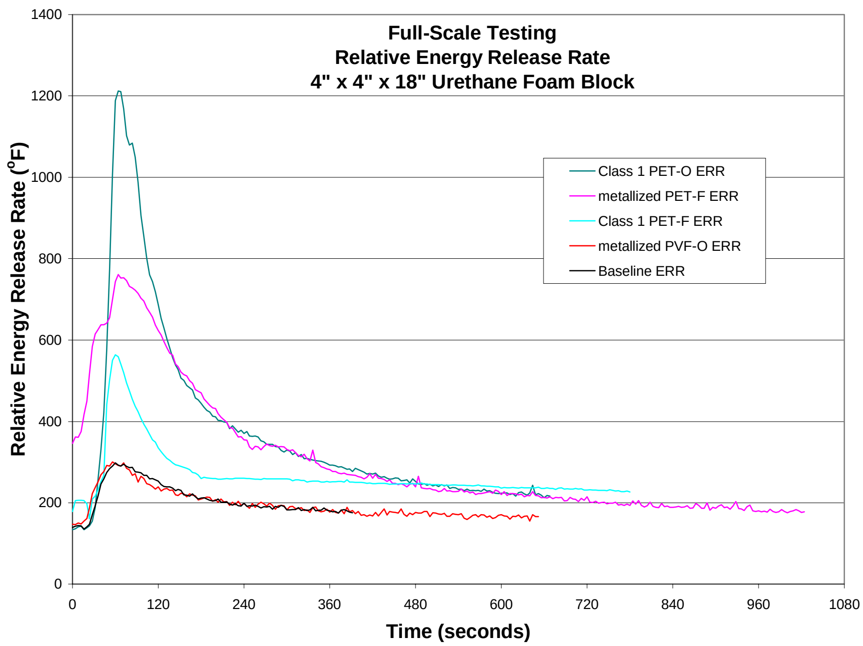


FIGURE 27. ESTIMATED ENERGY RELEASE RATES DURING FULL-SCALE TESTING

First, the scenarios used during the intermediate-scale mock-up tests and full-scale tests represented very realistic conditions. During these trials, the metallized PVF material performed extremely well due in part to its ability to shrink away from the flame ignition source. This performance was repeated during subsequent tests, even when larger ignition sources (i.e., multiple foam blocks) were used. Conversely, the metallized PET showed the ability to readily ignite and propagate fire more than any other film tested. Regardless of ignition source size, this material would continue to spread fire once it was ignited until completely consumed.

Second, when tests were conducted in the OSU rate of heat release apparatus, the material's natural tendency to withdraw from the heat source was significantly reduced, thereby forcing the material to ignite, to a certain extent. This occurred when materials such as the PET and particularly the metallized PVF shrank and rolled into small clusters or "cylinders" near the edges of the specimen holder. Since it was impossible for these clusters to physically escape the heat/ignition source in the test chamber, they continued to melt and burn. This interaction created high heat release rates, which are somewhat misleading, especially with regard to the metallized PVF. Conversely, the metallized PET material did not possess the same tendency to roll into clusters, and generally burned more evenly in the OSU test chamber. This even burning resulted in a much lower peak heat release rate when compared to the metallized PVF, which again, was somewhat misleading considering these materials' performance under more realistic situations. Although heat release testing ranked the metallized PVFs and PETs as poor performers, it is the full-scale performance that is representative of real fire behavior.

Finally, test results from the radiant panel were compared to the mock-up and full-scale test results. The percentage of material burned in length is shown in figure 28, for only those materials that were tested in the intermediate-scale mock-up and full-scale rigs. As shown, the polyimide and fluoropolymer composite allowed no flame propagation. Conversely, the metallized PET and a particular class 1 PET were totally consumed, as flames propagated all the way to the end of the sample. A heavy class 3 PET also allowed flames to consume a majority of the sample. Other materials such as the ultra thin class 00 PET and metallized PVF performed well, as flame propagation was limited to less than half of the sample length. These results correlated well with those obtained during the intermediate-scale mock-up and full-scale testing. Although the ranking order produced by the radiant panel did not match up exactly in all cases, it appeared to be a much better predictor of larger scale test results than the OSU rate of heat release apparatus. For example, the one type of class 1 polyethylene terepthalate, PET1-O(R), yielded considerable flame propagation during the full-scale tests and burned completely in the radiant panel test. However, this particular material was ranked only around the median when considering peak heat release in the OSU. This also holds true for the metallized PET, which exhibited the highest propensity to propagate fire under realistic conditions. Again, the radiant panel results were consistent with mock-up and full-scale test findings, while the peak heat release rate yielded by the OSU chamber for this material was only average compared to the others.

SUMMARY OF FLAMMABILITY TESTING OF INSULATION FILMS.

In response to several incidents/accidents involving the ignition of insulation materials from in-flight or small ignition sources, an evaluation of both the current FAA vertical Bunsen burner test requirement and the industry standard cotton swab test to assess the flammability of thermal

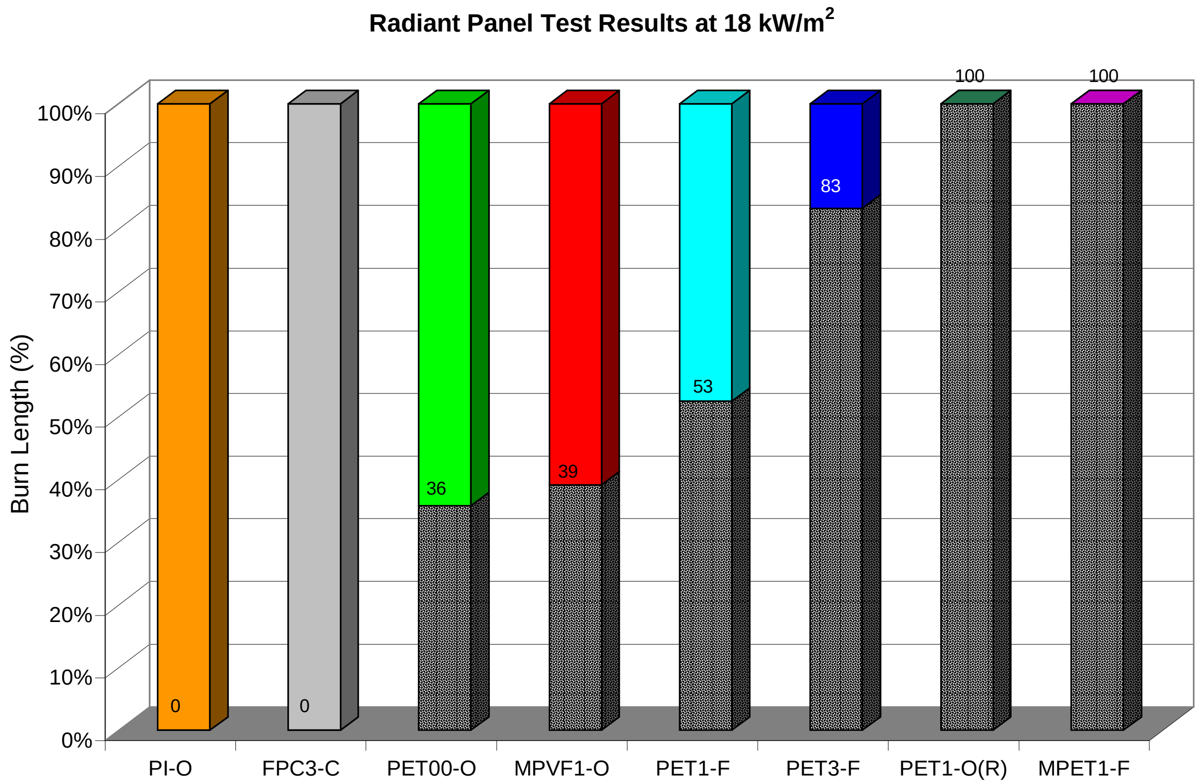


FIGURE 28. RADIANT PANEL TEST DATA FOR MATERIALS COMMON TO MOCK-UP AND FULL-SCALE TESTS

acoustic insulation was conducted. The results of these tests indicated that the cotton swab test did provide better discrimination among materials than did the Bunsen burner test method. However, prior full-scale testing conducted in 1997 and 1998 indicated that there were materials that could pass the cotton swab test but still propagate fire under realistic conditions. In addition, because the ignition source used was limited to a burning cotton swab, the test did not simulate the effects of other sources of ignition, specifically any other burning material or electrical arcing. The main conclusion of this initial testing was that the cotton swab test was not sufficient as a certification standard, and a new test method based on full-scale testing was required.

Consequently, tests were conducted using a wide array of film materials involving a number of test methods, including the OSU rate of heat release apparatus, the cone calorimeter test, a radiant panel test, and small-, intermediate-, and full-scale mock-up tests. The results provided the necessary information regarding the behavior of insulation materials when subjected to representative ignition sources. In general, the radiant panel was capable of creating the conditions required to cause flame propagation observed during intermediate- and full-scale tests representative of a realistic aircraft fire. In addition, flame propagation is not measurable in the OSU chamber. The fire exposure condition in the radiant panel appeared representative and repeatable; also, the test provided the added benefit of allowing the sample to be observed during the test. Finally, the observed physical behavior of the films tested in the radiant panel apparatus were consistent with intermediate/full-scale observations.

After conducting numerous tests in this apparatus, the method was refined to reflect the installation characteristics of the thin films used in aircraft insulation blankets. The recommended pass/fail criteria requires a burn length of less than a 2-inch radius, which essentially prohibits ignition under the specified in-flight fire exposure condition. The proposed test method is described in detail in appendix A.

POSTCRASH FIRE TESTS

FULL-SCALE TESTING.

Fuselage burnthrough refers to the penetration of an external postcrash fuel fire into an aircraft cabin. The time to burnthrough is critical because, in survivable aircraft accidents accompanied by fire, ignition of the cabin materials may be caused by the burnthrough of burning jet fuel external to the aircraft. There are typically three barriers that a fuel fire must penetrate in order to reach the cabin interior: aluminum skin, thermal acoustical insulation, and the interior sidewall and floor panel combination. The burnthrough resistance of aluminum skin is well known, lasting between 30 to 60 seconds, depending on the thickness. Thermal acoustical insulation, typically comprised of fiberglass batting encased in a lightweight moisture barrier, can offer additional protection if the material is not physically dislodged from the fuselage structure. Full-scale testing on surplus aircraft has demonstrated the burnthrough sequence of events as a large external fire penetrates into an aircraft cabin. In many instances, the fire first gains access into the fuselage by melting through the exterior skin around the cheek area, just below the cabin floor. The fire then progresses upward through openings behind the cabin sidewall panels, eventually gaining access into the cabin via return air grills [2].

Additional testing was carried out in a purpose-built, full-scale test article that allowed the major components of a fuselage to be evaluated when exposed to a fuel fire. During a typical test, the steel-framed fuselage structure was outfitted with a large area aluminum skin section, 8 by 12 feet in size. Various types of insulation were installed in the fuselage section behind the skin, allowing an examination of potential replacements. A fuel fire was situated adjacent to the test article to provide a realistic fire threat. The entire test article easily allowed for repeat tests, as the durable steel frame was resistant to warpage, and the realistic skin section could be removed and replaced without significant refurbishment. The tests demonstrated that alternate insulation materials significantly delayed or prevented the penetration of an external fuel fire into an aircraft cabin [3]. The enhanced burnthrough resistance of improved insulation blankets led to the development of a standardized small-scale test method for the purpose of evaluating the burnthrough resistance of thermal acoustic insulation blankets. Over 60 tests were conducted in various-sized test rigs in an effort to establish a repeatable test condition that was representative of the threat likely to occur from a large external fuel fire.

INITIAL LABORATORY-SCALE TESTING USING BOX APPARATUS.

In order to develop a test standard that was repeatable and representative of a postcrash fire threat, an oil-fired burner was chosen. This burner equipment is currently in use for other FAA test methods, such as the seat fire blocking test and the cargo liner flame penetration resistance test. Initially, the burner was situated horizontally to impinge against a steel box measuring 36 by 36 by 36 inches (figure 29).

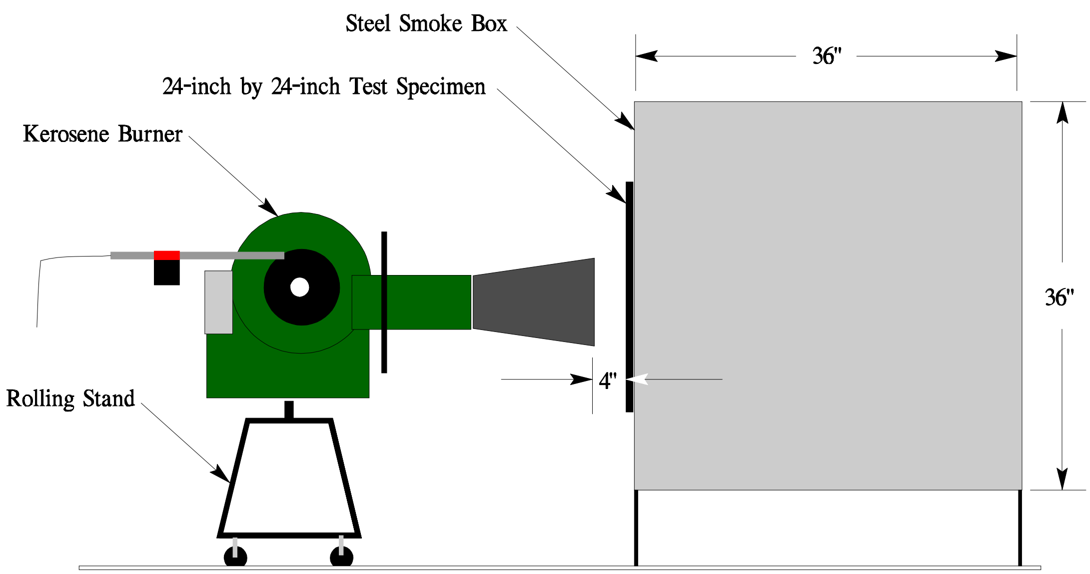


FIGURE 29. INITIAL BURNTHROUGH BOX APPARATUS

On the box side facing the burner, a sample holder was constructed to enable the placement of both thermal acoustic insulation and the aluminum aircraft skin (figure 30). The sample holder was partially closed on the internal side to facilitate holding the insulation sample in place, without the use of clips or other hardware. On the external side of the sample holder, the edge was flanged with holes drilled to allow for placement over the threaded studs located on the test box. The sample holder with insulation was placed into the opening in the test box over the threaded studs, followed by the aircraft skin sample, all of which were secured to the test box using washers and nuts.

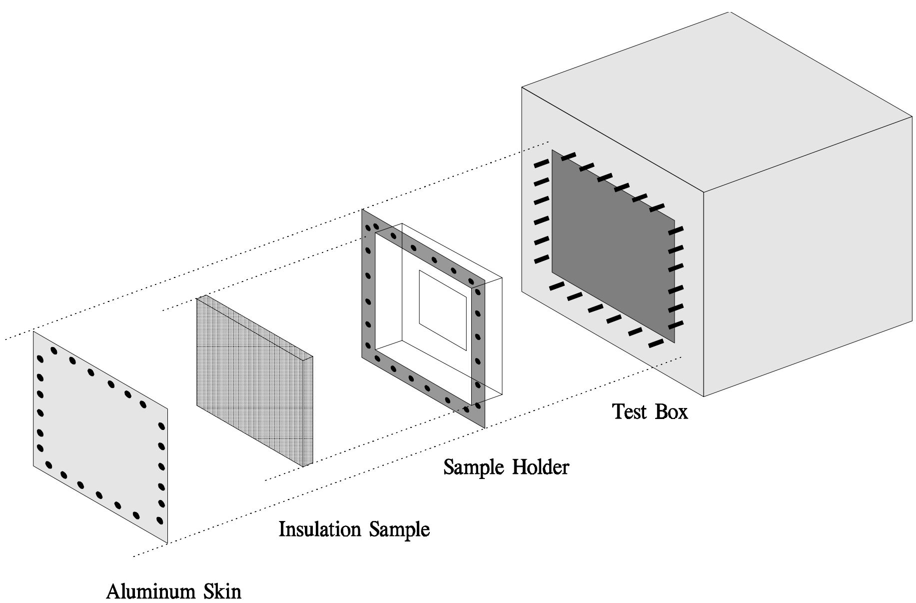


FIGURE 30. BURNTHROUGH BOX SAMPLE HOLDER

Although this configuration clamped the skin to the box securely, it allowed the insulation to remain uncompressed. Several initial tests were run using two layers of 0.42 lb/ft^3 density fiberglass batting encased in a metallized PVF film, which was an assembly that had been tested in the full-scale rig. During these initial trials, after melting through the aluminum skin, it appeared that the burner flames wrapped around the sides of the insulation specimen which would "slump" down slightly. The tests were repeated several times with the same result. An additional test was run using a sample blanket made from heat stabilized, oxidized polyacrylonitrile fibers (OPF), encased in a polyimide film. This combination yielded over 5 minutes of burnthrough protection during full-scale tests, but again lasted less than 2 minutes in the box configuration, with the flames wrapping around the sides of the insulation specimen as before. The initial tests highlighted the inability of the box configuration in evaluating the performance of attachment pins or clips in keeping the insulation blanket in place. Another problem with this configuration related to the size of the test sample. During full-scale testing, the insulation bagging film was observed to ignite and propagate flames during many of the tests. This was of concern, since this flaming propagation on the insulation film could potentially ignite other materials, such as the cabin sidewall or floor panels. For this reason, it would be beneficial to have a larger sized test sample to better observe these effects.

Prior to development of a larger test configuration, the box was used to develop the appropriate flame temperature and size. Trials were run on 24- by 24-inch pieces of 0.063-inch-thick aluminum skin mounted on the test box, without insulation batting. A review of full-scale test data indicated an incident heat flux ranging from 10 to 16 Btu/ft^2-sec, with an average of approximately 13 Btu/ft^2-sec, as calculated by a total heat flux calorimeter that measured both radiant and convective heat flux. This information was supplied to CEAT, the research conglomerate responsible for developing test specifications for passenger aircraft materials in France. CEAT and FAA were collaborating in the development of the laboratory-scale burnthrough test. From this data, CEAT proposed the use of a 7-gallon-per-hour (GPH) fuel flow rate to produce the desired flame output, and the FAA test burner was adjusted accordingly.

A further review of the data and video taken during the full-scale tests was made, in particular the tests in which 0.063-inch-thick Alclad 2024 T3 skin was evaluated without insulation backing. These tests indicated the 8 by 10 foot fully developed fuel fire required 55 seconds to burn through the skin, which became the goal for the laboratory-scale tests in order to achieve correlation. As shown in table 16, the relative distance between the exit plane of the burner cone and the aluminum skin sample was varied, along with the burner intake air velocity in an attempt to reproduce this burnthrough time.

As shown from the results, it was difficult to reproduce the full-scale outcome. During the laboratory tests, a very small hole would develop in the test sample, as viewed from a camera mounted on the back of the test box. Once this occurred, there was a significant amount of time delay, in some cases 60–70 seconds, before a majority of the test sample was consumed by the burner flames. When viewed from the box-mounted camera, the skin appeared fluid-like, yet remained in place. One possibility for this difference was that the full-scale fuel fire was so large that natural air currents were dominant enough to force the molten skin out of place. Although the test burner had a reasonable amount of airflow being directed at the sample, it may not have been enough to immediately force the skin open. Although the box-test configuration did not

TABLE 16. ALUMINUM SKIN BURNTHROUGH TESTS

Test No.	Material Type	Material Thickness (in)	Initial Flame Penetration Time (sec)	Final Flame Penetration Time (sec)	Distance Between Test Specimen and Burner Cone	Air Inlet Velocity (ft/min)
1	Alclad 2024 T3	0.063	35	106	6	1740
2	Alclad 2024 T3	0.063	27	46	3	1740
3	Alclad 2024 T3	0.063	27	94	4	1740
4	Alclad 2024 T3	0.063	46	83	6	2040
5	Alclad 2024 T3	0.063	23	52	4	2040
6	Alclad 2024 T3	0.063	21	31	3	2040
7	Alclad 2024 T3	0.063	23	61	6	2245
8	Alclad 2024 T3	0.063	33	72	8	2245
9	Alclad 2024 T3	0.063	22	44	4	2245
10	Alclad 2024 T3	0.063	34	45	3	2245
11	Alclad 2024 T3	0.063	31	50	6	2380
12	Alclad 2024 T3	0.063	39	68	8	2380
13	Alclad 2024 T3	0.063	33	53	4	2380
14	Alclad 2024 T3	0.063	36	44	4	2380
15	Alclad 2024 T3	0.063	43	65	7	2380
16	Alclad 2024 T3	0.063	41	66	7	2380
17	Alclad 2024 T3	0.063	45	70	8	2380
18	Alclad 2024 T3	0.063	35	67	6	2380
19	Alclad 2024 T3	0.063	40	69	7	2380
20	Alclad 2024 T3	0.063	42	62	5	2040
21	Alclad 2024 T3	0.063	39	73	5	2040
22	Alclad 2024 T3	0.063	21	68	6	2040
23	Alclad 2024 T3	0.063	36	51	3	2040
24	Alclad 2024 T3	0.063	27	63	4	2040
25	Alclad 2024 T3	0.063	33	52	5	2040
26	5054 Aluminum	0.05	43	99	4	2040
27	5054 Aluminum	0.031	24	45	4	2040
28	5054 Aluminum	0.05	34	104	3	2040

replicate the full-scale arrangement satisfactorily, it served as a good starting point in the development of a more appropriate test configuration.

DEVELOPMENT OF A CURVED LABORATORY-SCALE BURNTHROUGH TEST RIG.

Because of the problems associated with the sample holder and the attachment process in the initial box tests, a larger surface area rig was constructed to more closely resemble a generic aircraft structure. The new steel rig incorporated curved “Z” section formers oriented vertically and hat-shaped lateral stringer pieces (figure 31). This enabled the attachment of the insulation to the test rig using in-service type fasteners. The entire test frame was capable of being rotated to produce a variety of impact angles by the burner flame. Since an actual crash fire situation could result in an infinite number of possibilities regarding the location of the fire with respect to

FIGURE 31. CURVED TEST RIG

the fuselage, this flexibility would allow a determination of the critical, or most severe angle from a burnthrough standpoint.

An initial test at 7-GPH fuel flow rate produced a result that did not correlate well with previous full-scale tests. Blankets comprised of OPF insulation encased in a polyimide film, which had typically provided a minimum of 5 minutes protection during full-scale tests, failed at approximately 150 seconds. For this reason, subsequent tests were conducted at reduced burner outputs in an effort to achieve better correlation. As shown in table 17, a reduced fuel flow rate of 2 GPH produced similar early burnthrough results with the OPF insulation. Surprisingly, standard fiberglass batting materials yielded equivalent times, in the range of 120 seconds for two layers of insulation. These results were similar to those obtained from full-scale tests in which aluminum skin and two layers of fiberglass typically lasted 1.5-2 minutes, although the correlation did not exist with respect to the OPF tests.

Although initial indications pointed to a very good correlation with full-scale results when using fiberglass, it was difficult to determine the reason for the anomaly when testing OPF insulation. The greatest difference between the full-scale and laboratory-scale tests appeared to be the method used to attach the insulation to the respective test rig. In the full-scale rig, the insulation was held firmly to the steel rig using steel spring clips. In the laboratory-scale rig, an OEM-style configuration was initially used in which between-frame blankets were attached using plastic clips with washers, along with narrow "cap strips" of insulation that were placed over the vertical

TABLE 17. TEST RESULTS USING CURVED TEST RIG

Run No.	Test Date	Burner Fuel Flow Rate (gal/hr)	Burner Air Velocity (ft/min)	Burner Distance (inches)	Skin Material (inches)	Insulation Material	Film	Cap Strip Insulation/ Film	Burnthrough Time (sec)
1	11/13/98	7	2245	3	0.063 Alclad	1 ply OPF	KN-80	FG/KN-80	150
2	12/1/98	2	1820	4	0.063 Alclad	2 ply OPF	AN-18R	FG/AN-18R	120
3	12/2/98	2	1820	4	0.050 Aluminum	1 ply 0.60 lb/ft^3 Fiberglass	AN-18R	FG/AN-18R	80
4	12/2/98	2	1820	4	0.050 Aluminum	2 ply 0.60 lb/ft^3 Fiberglass	AN-49W	FG/AN-49W	124
5	12/2/98	2	1820	4	0.050 Aluminum	2 ply 0.60 lb/ft^3 Fiberglass	AN-49R	FG/AN-49R	121
6	12/2/98	2	1820	4	0.050 Aluminum	1 ply 0.60 lb/ft^3 Fiberglass	AN-49R	FG/AN-49R	86

formers. Under this configuration, there appeared to be a weakness in which the fire could penetrate the system along the seam area where the two field blankets butt the vertical former (figure 32). A more complete discussion of the method of attachment will follow.

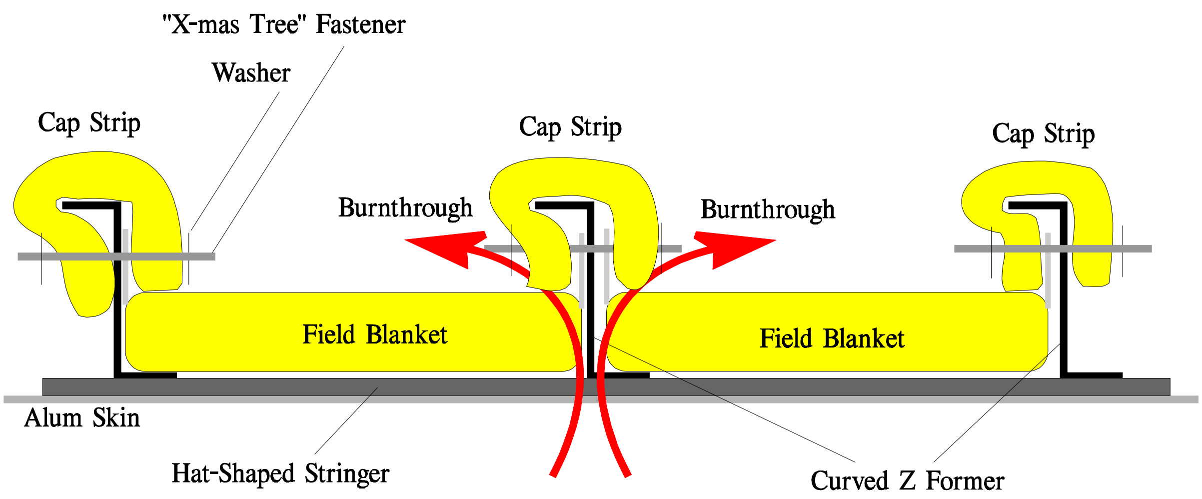


FIGURE 32. OEM STYLE OF BLANKET ATTACHMENT TO THE TEST RIG

BURNER PLACEMENT.

In addition to the seam problems, it appeared that the placement of the burner flame with respect to the test frame had a major influence on the test outcome. Since the 2-GPH burner produced a flame that did not entirely encompass the test area, it was possible to direct a majority of the flame at either the vertical seam area or the between-frame area. Initial tests indicated that by directing the burner flame between two of the vertical formers into the field blanket area, the entire system of blanket and attachment clips were not being exposed. In addition, the adjustability of the test frame angle produced virtually infinite testing possibilities. In an effort to reduce the variables, a test configuration deemed most likely to occur in a crash fire scenario was developed.

IMPROVED LABORATORY-SCALE BURNTHROUGH TEST RIG.

Because this test would likely become an FAA standard, steps were taken to make the rig more easy to reproduce. The initial curved rig would be costly and difficult to construct, so the rig was modified using noncurved Z-frames for the formers. In addition, the new flat rig incorporated two panel surfaces, one vertical and another oriented 30^{o} with respect to vertical, to better simulate the area of a fuselage that would typically be impacted during a post crash fuel fire. The improved test rig incorporated three steel Z-frame vertical formers that were spaced 20 inches on center. A total of nine horizontal hat-shaped stringers were welded into place as shown in figure 33. The upper section of the rig was covered with a 48-inch-wide piece of steel with a 0.0625-inch thickness. This configuration allowed the installation of two between-frame blankets that could be tested for burnthrough resistance on the lower section, and upward flame propagation on the backface of the upper section. The test burner was oriented on a 30^{o} angle aimed at the center of the lower angled section of the test frame.

INITIAL BASELINE TESTS ON IMPROVED LABORATORY-SCALE TEST RIG.

In order to develop a test condition that was most representative of full-scale conditions, several tests were performed using Alclad aluminum skin identical to that used in the full-scale tests. During full-scale tests, the 0.063-inch-thick Alclad 2024 T3 melted in approximately 55 seconds, which was the target for the laboratory-scale testing device. During the first two trials, the burner fuel flow rate was set at 2 GPH, which produced a flame temperature in the area of 1900°F and a heat flux of approximately 8.5 Btu/ft^2-sec. The first test required over 480 seconds to burn through the 0.050-inch 5052 aluminum skin (0.063-inch Alclad material was unavailable at the time of these tests). The lengthy burnthrough time was attributed to the 5-inch distance of the sample from the exit plane of the burner, which allowed the flames to rotate upward so as not to directly impinge against the sample. A subsequent test in which the sample was placed 2 inches from the burner provided better results. However, the same condition resulted as had taken place during the initial trials with the aluminum skin mounted on the test box. A small breach would occur, then a period of time typically greater than 30 seconds would elapse prior to a significant burnthrough. Another test was run in which the burner output was increased in an effort to penetrate the skin more forcibly, with a fuel flow rate of 4 GPH and the air velocity increased to 2000 feet per minute (FPM). The burner distance was set at 4 inches, which resulted in a lengthy 120-second burnthrough time. However, the burnthrough was significant and did not occur over a period of time, but rather instantaneously. This failure mode more closely resembled the results of the full-scale test, so the burner output was again increased to 6 GPH, again at a distance of 4 inches. This configuration yielded a failure at exactly 55 seconds, precisely the time required for burnthrough during the full-scale test. This configuration was repeated with an identical result (table 18).

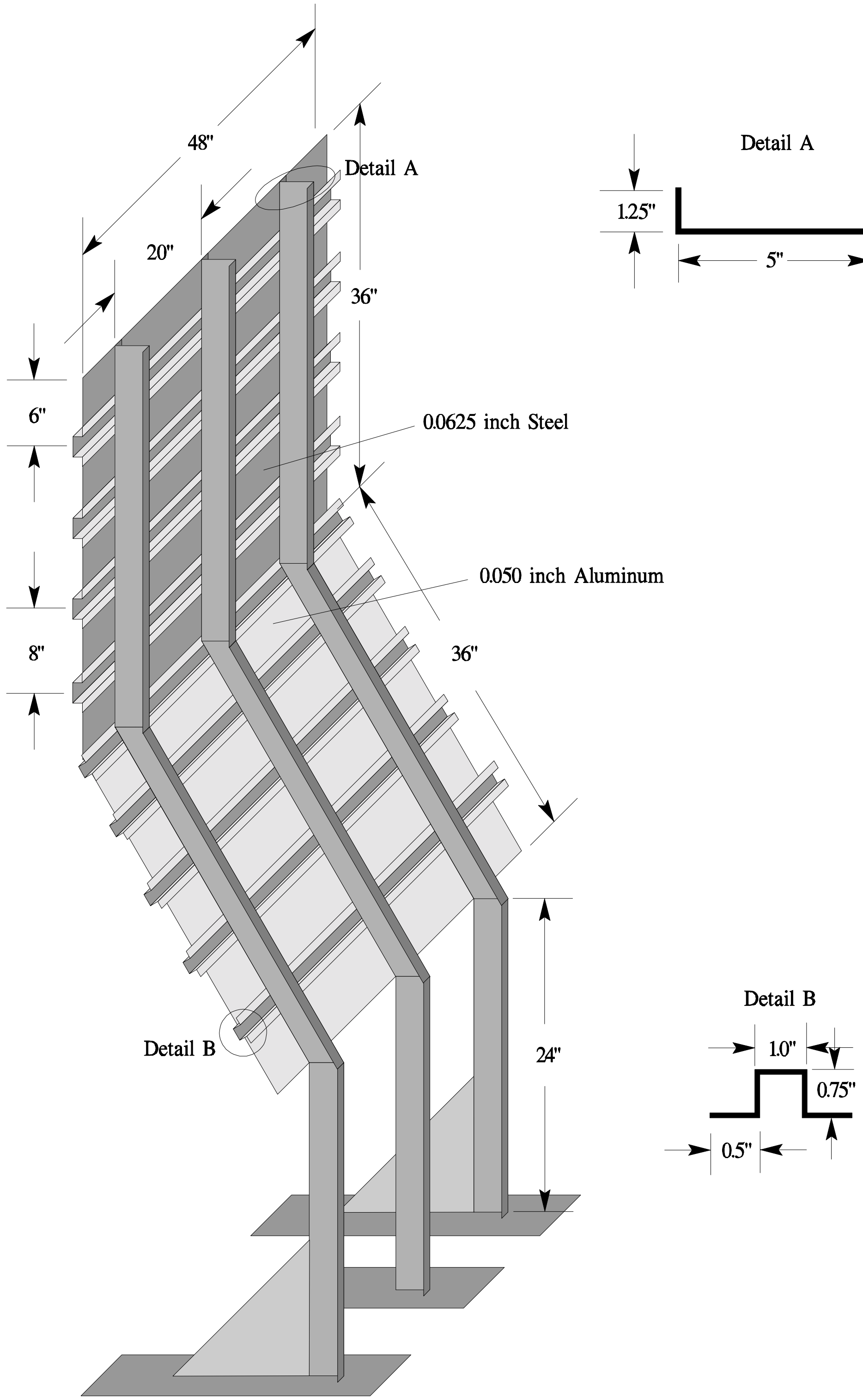


FIGURE 33. IMPROVED LABORATORY-SCALE BURNTHROUGH RIG USING FLAT SURFACES

TABLE 18. ALUMINUM SKIN TESTS WITH IMPROVED APPARATUS AT VARIOUS BURNER SETTINGS

Test Date	Burner Fuel Flow Rate (gal/hr)	Burner Air Velocity (ft/min)	Burner Distance (inches)	Skin Material	Skin Thickness (inches)	Burnthrough Time (seconds)
12/8/98	2	1800	5	5052 Aluminum	0.05	480 +
12/8/98	2	1800	2	5052 Aluminum	0.05	45 to 80
12/8/98	4	2000	4	5052 Aluminum	0.05	120
12/9/98	6	2200	4	5052 Aluminum	0.05	55
12/9/98	6	2200	4	5052 Aluminum	0.05	55

MODIFICATIONS TO IMPROVED TEST RIG.

During initial burner correlation trials using the 48-inch-wide piece of aluminum skin, the samples were bolted to the test frame's lower section using nuts and washers attached to the frame-mounted studs. Although this produced a very realistic condition, it was difficult to remove and replace the nuts from the studs. Because of the intense heat, small pieces of molten aluminum were becoming lodged into the threads of the studs, causing the nuts to eventually bind and strip. As a result of this difficulty, a 48-inch-wide piece of 0.125-inch-thick steel was placed on the test frame's lower section, with a 24- by 24-inch opening to simulate the melted aluminum skin (figure 34).

During two initial tests with the 24- by 24-inch void in the lower steel panel section, insulation batting was attached to the test rig using OEM fasteners. In both cases the failure location was along the center vertical former, typically at the seam. These initial results again focused attention on the method of attachment of the insulation blankets. As shown in figure 35, the OPF insulation blankets failed in less than 60 seconds with the OEM attachment method, which was very atypical for this material. Subsequent to this test, the insulation blankets were attached directly to the test frame structure, without the use of a center cap strip (figure 36). Seven additional tests were run using a variety of insulation materials. The test results correlated well with previous full-scale results, as the OPF insulation encased in a polyimide film offered approximately 5 minutes of protection, without the aluminum skin.

In addition to the attachment modification, the 48-inch-wide steel panel with the void was completely removed from the lower section after this initial series of nine tests, since the periphery of the steel had no influence on the test outcome (figure 37).

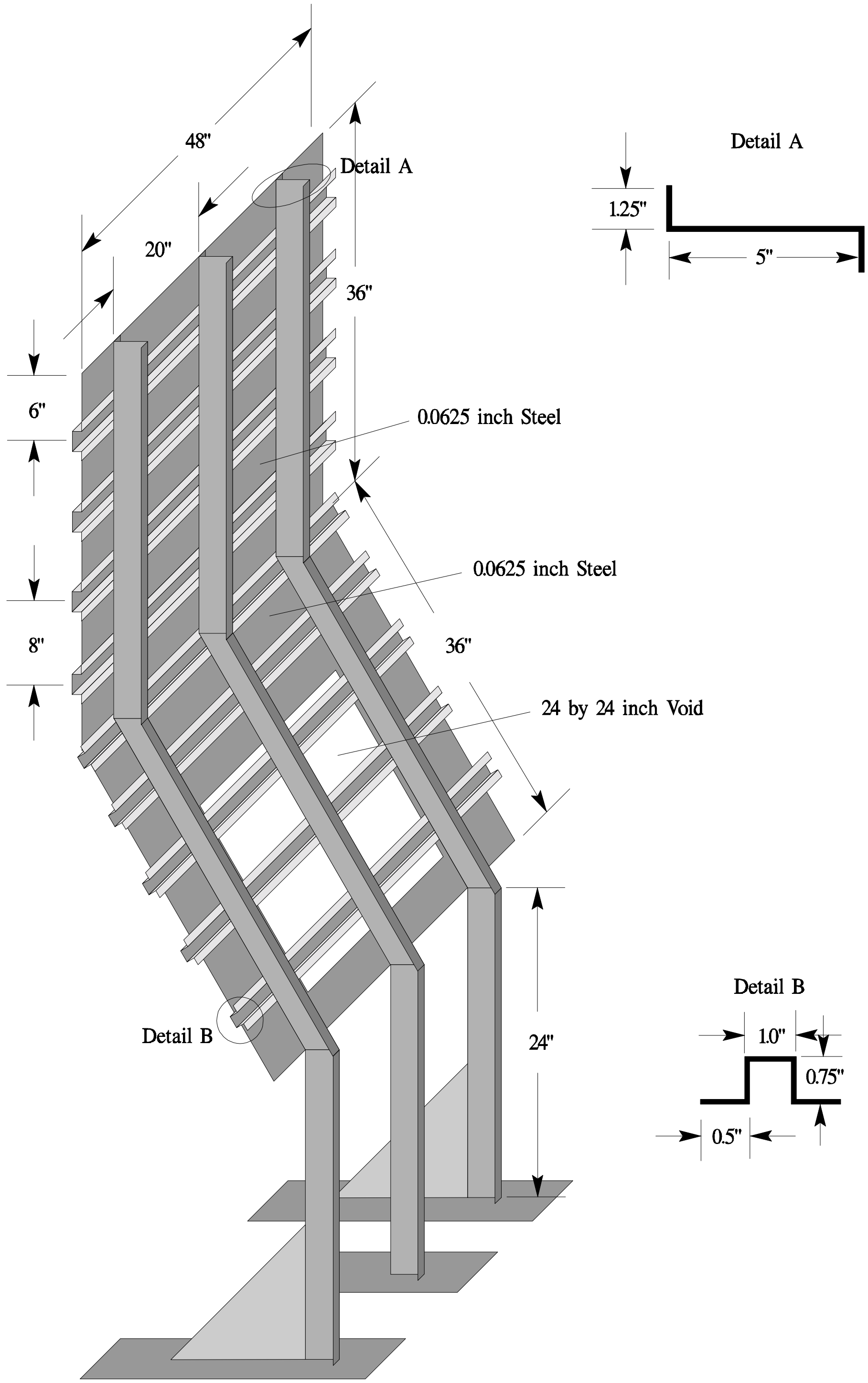


FIGURE 34. IMPROVED TEST RIG WITH 24- BY 24-INCH VOID MODIFICATION TO THE LOWER SECTION

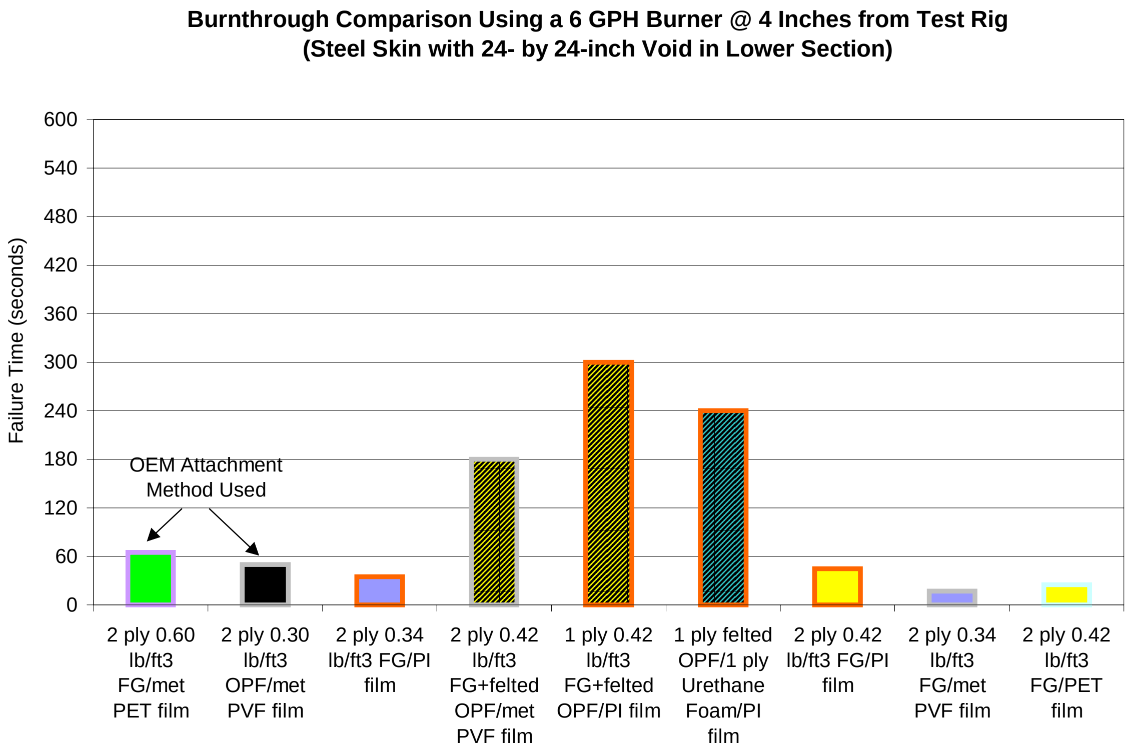


FIGURE 35. BURNTHROUGH TEST RESULTS USING THE TEST RIG WITH A 24- BY 24-INCH VOID IN LOWER SECTION

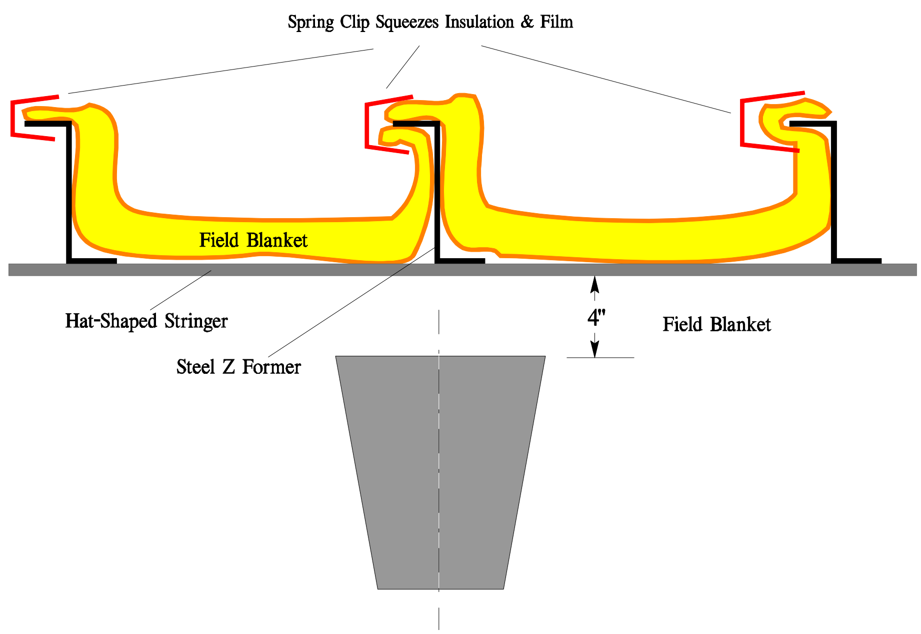


FIGURE 36. IMPROVED INSULATION BLANKET TEST SPECIMEN ATTACHMENT METHOD

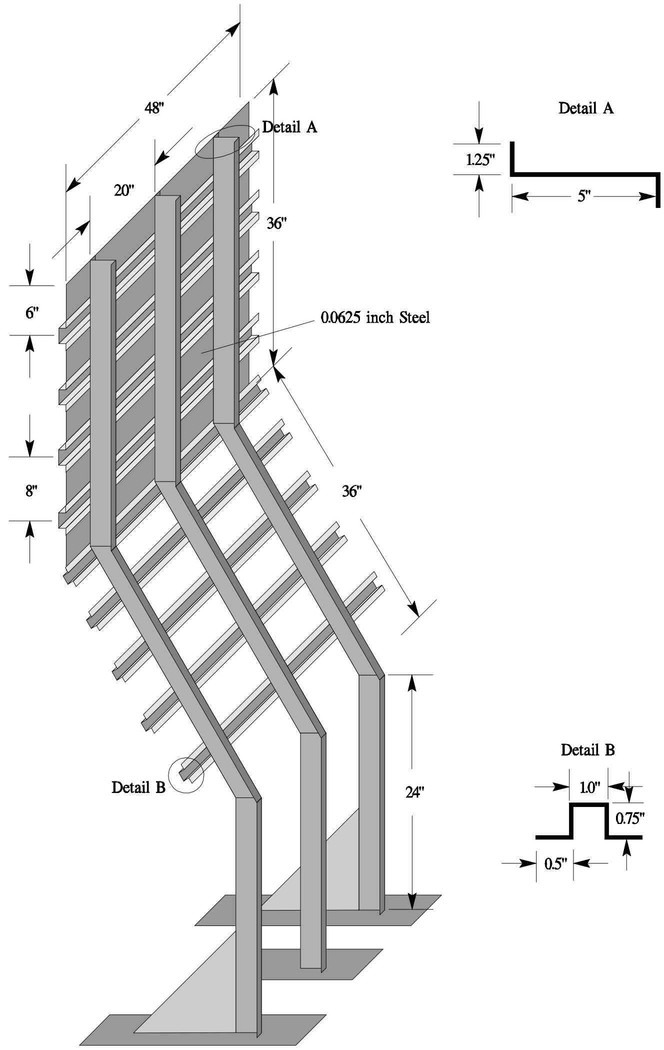


FIGURE 37. TEST RIG WITH LOWER STEEL PANEL REMOVED

Additional testing was conducted on the modified test rig with favorable results, as shown in figures 38, 39, and 40. Typically, the fiberglass insulation, depending on density, thickness, and type of film covering used, would generally fail between 20 and 90 seconds. In most instances when a polyimide film covering was not used, the failure occurred in less than 60 seconds. This result correlated well with previous full-scale results using fiberglass, in which failure occurred in approximately 80 to 100 seconds. Considering the full-scale tests were conducted using an exterior aluminum Alclad skin, which was known to require approximately 50 seconds to fail, the contribution from the fiberglass insulation would be in the area of 30 to 50 seconds, or very close to the laboratory-scale findings. Moreover, other materials that were tested in both the full- and laboratory-scale apparatus showed excellent correlation, such as the OPF insulation and the ceramic paper barrier. Each of these materials prevented burnthrough for a minimum of 5 minutes under full-scale conditions, and they exhibited similar results during laboratory tests, failing in the 5 to 6 minute range and beyond (figure 38).

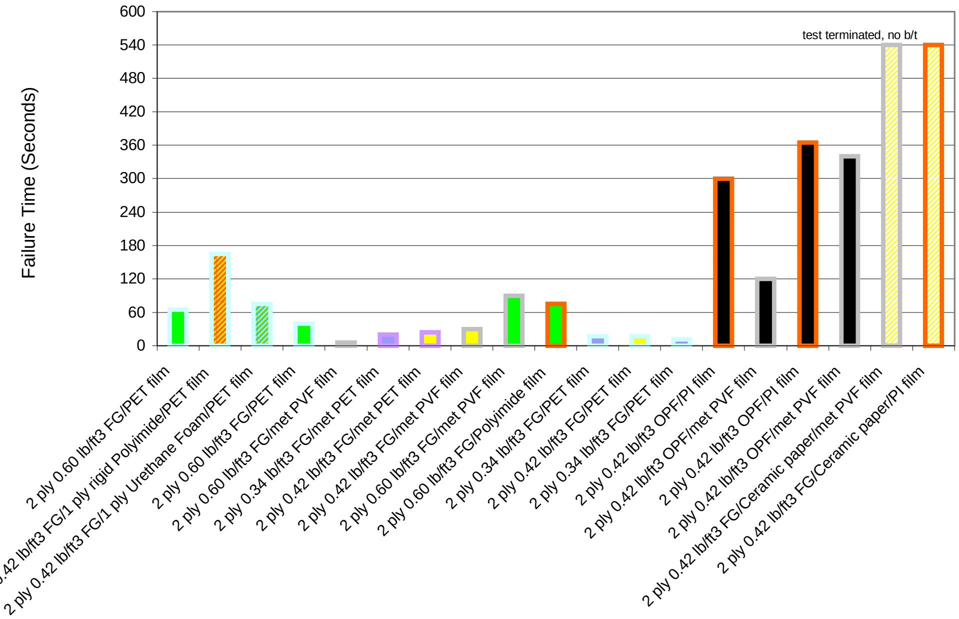


FIGURE 38. BURNTHROUGH TEST COMPARISON USING A 6-GPH BURNER AT 4 INCHES FROM THE TEST RIG

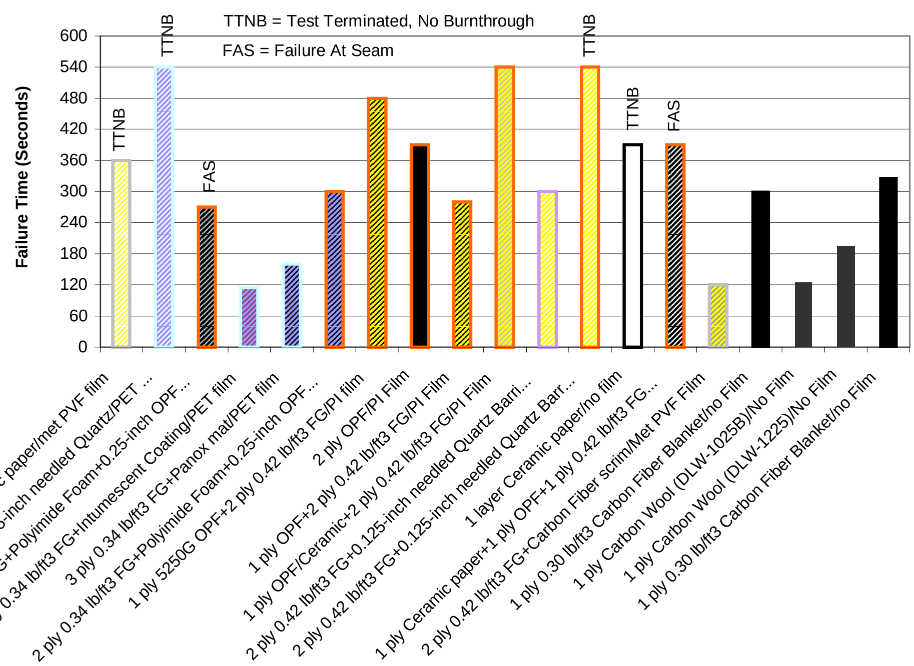


FIGURE 39. BURNTHROUGH TEST COMPARISON USING A 6-GPH BURNER AT 4 INCHES FROM THE TEST RIG

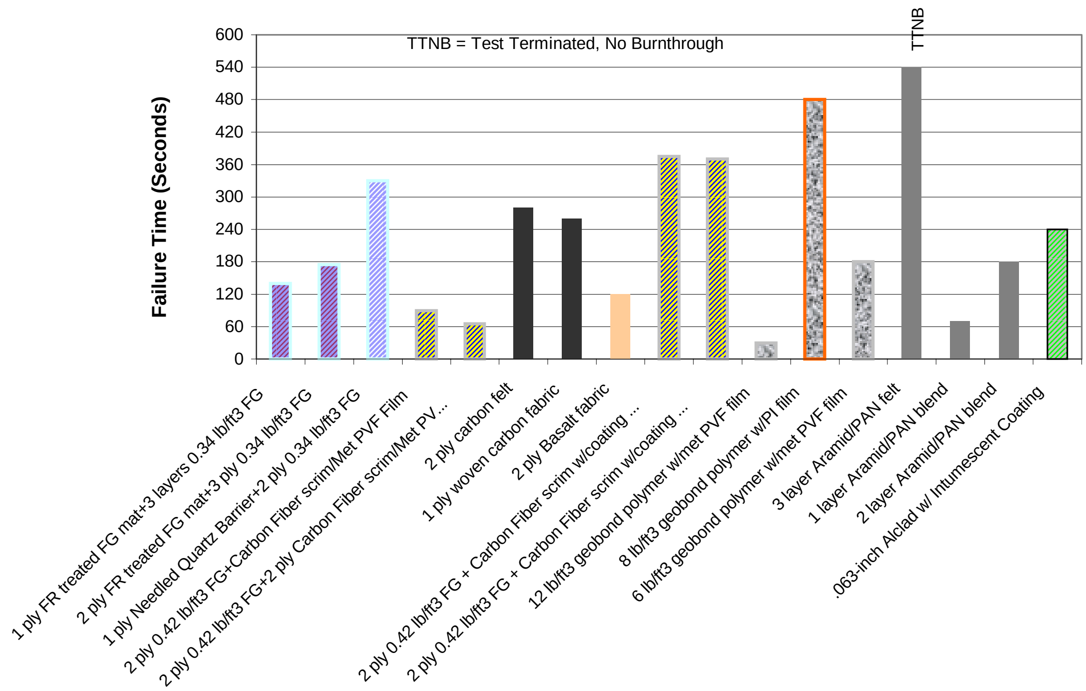


FIGURE 40. BURNTHROUGH TEST COMPARISON USING A 6-GPH BURNER AT 4 INCHES FROM THE TEST RIG

Some of the materials tested prevented flame penetration for extended periods of time, but allowed considerable heat to radiate through to the cold side of the test rig. These materials acted as flame arresters that did not physically break down or fail, but eventually allowed enough heat to pass through that could lead to a failure point. For this reason, a back face (cold side) maximum allowable heat flux requirement was conceived. A heat flux transducer was positioned behind the center vertical former, pointed directly at the center of the burner along an imaginary axis. The heat flux transducer measured both the radiant and convective heat flux penetrating the specimen. Since the burnthrough failures were observed to occur on either side of the vertical former, the proposed test eventually included 2 transducers mounted behind each of the blanket samples.

A multitude of tests were conducted, indicating that materials were available that could meet the proposed standard. The test method was also refined slightly, as additional modifications to the test burner and sample holder were performed in an effort to make the test more repeatable and representative. For example, the vertical upper section of the specimen holder was removed completely, as this section was initially installed early in the development to evaluate flame propagation on the backface of the insulation specimen. There was an initial preference from industry to develop a singular test that could evaluate both the flammability and burnthrough resistance of insulation blankets, however this approach was abandoned as limited testing proved the methodology unsuccessful. Since the sole purpose of this apparatus was for the evaluation of insulation burnthrough resistance, and all failures had occurred in the lower section, the upper section was not necessary. Additional modest refinements were made to the burner equipment to ensure consistent exposure in other laboratories.

FINALIZED TEST APPARATUS AND CORRELATION WITH FULL-SCALE TEST RESULTS.

The finalized test apparatus is shown in figure 41. As discussed previously, the proposed test subjects the insulation blanket specimen to an intense oil-fired burner flame for a period of 4 minutes (appendix B). The burner intensity is adjusted to produce a flame temperature of 1900°F and heat flux of 16.0 Btu/ft^2-sec. The burner cone exit plane is situated 4 inches from the face of the test frame, at an angle of 30^o with respect to horizontal. Although this configuration yielded results that correlated well with previous full-scale tests using identical materials, a final comparison was made with the test equipment.

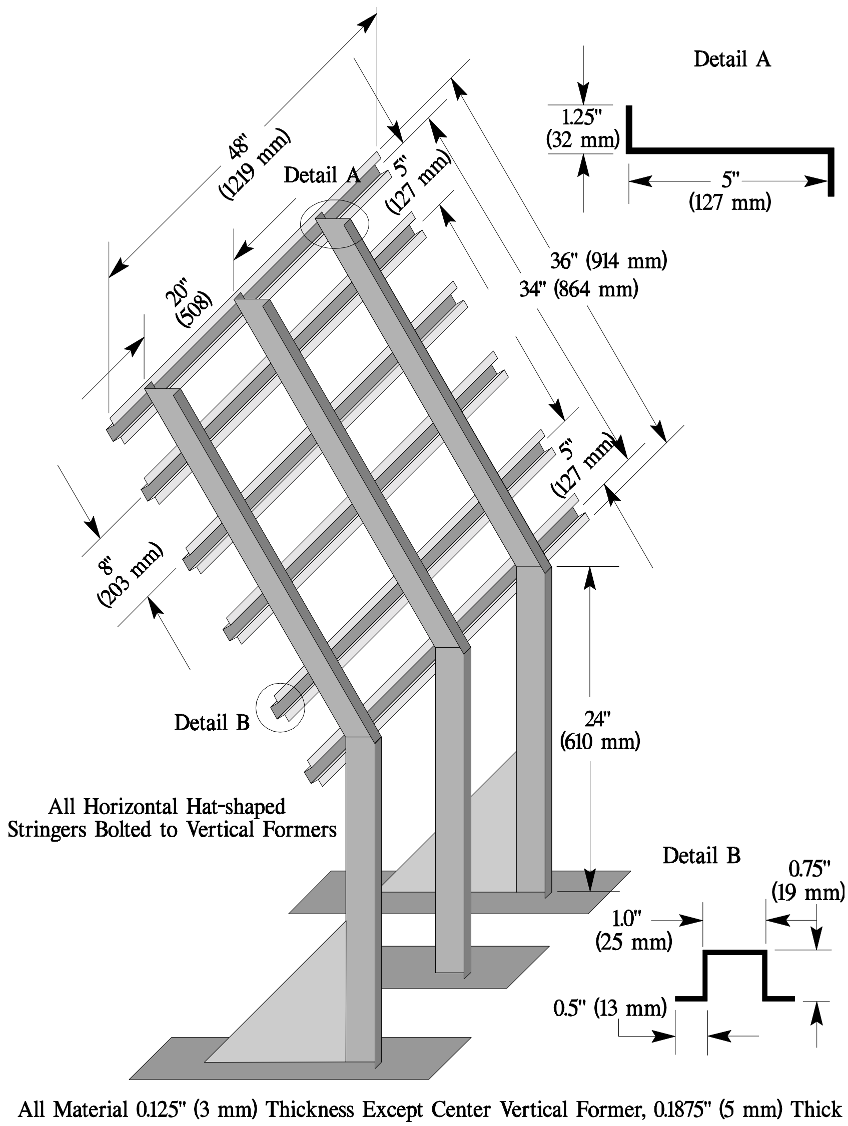


FIGURE 41. FINALIZED BURNTHROUGH TEST RIG (BURNER NOT SHOWN)

In order to provide a direct comparison to the full-scale testing, the proposed burnthrough apparatus was outfitted with a 0.063-inch-thick aluminum skin identical to that used in the original full-scale tests, Alclad 2024 T3. The skin was bolted to the test apparatus around the sample periphery, so as not to produce bolt holes that could provide a weak area for burnthrough to occur prematurely. Since OPF, ceramic paper, and the most common type of fiberglass insulation identical to that used in previous full-scale tests were unavailable, another type of fiberglass insulation was chosen for the comparison tests. “Aerocor,” an older style of fiberglass insulation manufactured by Owens-Corning, was tested substantially in the full-scale rig. Since this material was abundantly available, it was used for this comparison. Test samples were fabricated with the Aerocor insulation encased in a heat-sealable class 1 PET film barrier.

During the first test series, the burner intake air velocity was set at 2000 ft/min. Under this condition, a burnthrough occurred at 98 seconds for a three-layer insulation sample, and 134 seconds for a four-layer sample. These results compared reasonably well with the full-scale results, although it appeared this burner setting was somewhat less severe (figure 42). The three- and four-layer insulation samples required 14 and 38 seconds additional time, respectively, to fully penetrate.

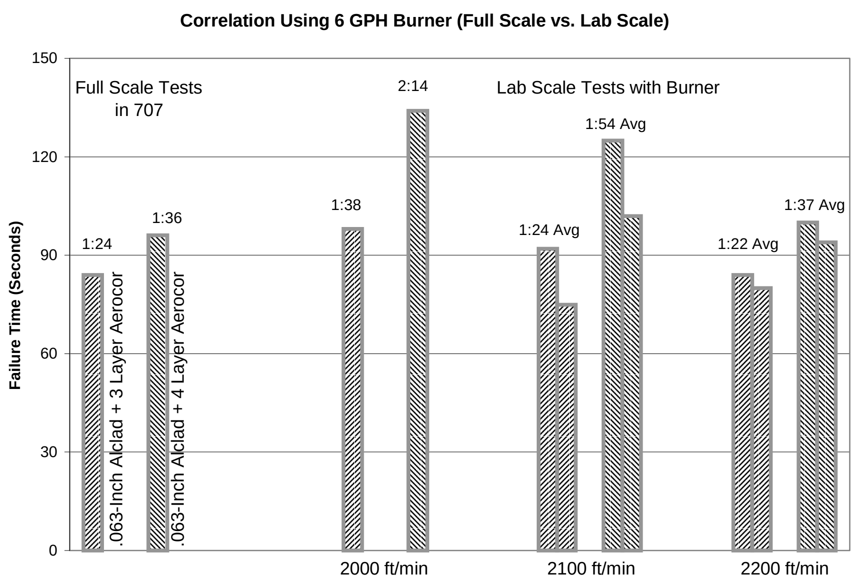


FIGURE 42. CORRELATION TEST RESULTS USING THE PROPOSED 6-GPH BURNER

A second series of tests were run using a greater amount of airflow through the burner. The intake air velocity was set at 2100 ft/min, which produced a slightly leaner flame. During this series, two tests each were run for the three- and four-layer configurations. The three-layer configuration yielded an average failure time of 84 seconds, identical to that achieved during the full-scale test. However, the four-layer configuration yielded an average failure time of 114 seconds, or an additional 18 seconds over the full-scale result of 96 seconds. The results of this series indicated the proposed test configuration was very close, but slightly less severe, at least for the four-layer test configuration.

A final series of tests were run at yet a higher airflow. For this series, the intake air velocity was set at 2200 ft/min, producing an even cleaner flame than previously. Again, 2 tests each were run for the three- and four-layer sample configurations. The three-layer configuration yielded an average failure time of 82 seconds, nearly identical to the full-scale result, and the four-layer configuration was breached in an average of 97 seconds, only 1 second different than the full-scale. From this result, it was clear that the burner intensity yielded nearly identical results to those obtained in full-scale when the intake air velocity was between 2100 and 2200 ft/min.

SUMMARY OF BURNTHROUGH TESTING.

The finalized laboratory burnthrough test method evolved from an extensive series of tests. Eventually, the use of aluminum skin on the exterior side of the test rig was found unnecessary. As a result, the proposed arrangement subjects only the insulation materials to the oil-burner flame, and the initial goal of a 5-minute requirement for the combined skin/insulation materials was simplified and reduced to 4 minutes for the insulation only.

During testing, it was also determined that the method of attaching the insulation to the test rig structure had a critical effect on the effectiveness of the insulation material. In particular, one OEM-style of insulation placement on the test rig allowed premature failures along the vertical former seams. Since the benefit of burnthrough resistant materials can only be realized if they remain fully attached to the aircraft structure, research continues on the development of newer, more fire resistant attachment clips and installation techniques to maintain an integrated barrier to fire in the event of an accident.

In addition, the composition of the insulation bagging material, normally a thermoplastic film, was not an important factor in preventing burnthrough with burnthrough resistant insulation materials. However, the use of polyimide film was capable of extending the burnthrough time of fiberglass insulation by as much as 40 seconds over thermoplastic films.

A number of fiberglass insulation modifications and new insulation materials were shown to be effective in varying degrees. In particular, a heat-treated, OPF insulation encased in a polyimide bagging material prevented burnthrough for over 6 minutes. Also, a thin paper-like dot-printed ceramic barrier, when used in conjunction with fiberglass, was capable of preventing burnthrough failure for over 8 minutes. Although very effective, this particular material highlighted the need for a backside heat flux criteria, as the fiberglass insulation used in conjunction with the barrier eventually melted away, leaving a red hot area on either side of the center vertical former. This material and others that act as flame arresters rather than flame blockers, allow substantial heat to progress inward once the main batting (typically fiberglass) was depleted. As a result, a maximum allowable heat flux was established on the back face (cold side) of the test rig, at a distance of 12 inches from the test rig front face.

Once the test apparatus and conditions were refined, a series of correlation tests were performed to evaluate the final configuration. By outfitting the test rig with aluminum skin and insulation, the burnthrough times were compared against full-scale results, and the intensity of the burner was adjusted accordingly. Test trials at various settings revealed that an air intake velocity of between 2100 and 2200 ft/min produced the best correlation with full-scale results. At this setting, the flame temperature is approximately 1900°F and the heat flux is 16.0 Btu/ft^2-sec.

Approximately 60 tests were conducted on a wide variety of materials, including lofted insulation types that could replace the existing fiberglass, as well as barrier materials that could be used in conjunction with the fiberglass. The results of materials tested in both the proposed apparatus and previously in the full-scale burnthrough apparatus correlated well. Several materials have been identified that can meet the proposed test method.

CONCLUSIONS

Thermal acoustic insulation is used extensively throughout the aircraft fuselage for the purpose of reducing noise and for maintaining comfortable cabin temperatures. Historically, both functions have been provided by fiberglass batting usually encapsulated in thermoplastic moisture barrier film coverings. Although these materials are required to meet the FAA vertical Bunsen burner test, several in-flight fires and ramp fires have shown that some of these materials can propagate fire under certain conditions. A review of the Bunsen burner test method and the flaming cotton swab test used by certain segments of industry revealed that the cotton swab test provided better discrimination among materials than the Bunsen burner test method. However, additional testing also showed that there were materials that could pass the cotton swab test, but still propagate flames under realistic conditions. Based on these results, it was concluded that the cotton swab test was not sufficient as a certification standard, and a new test method was needed. Flammability testing was conducted on a wide array of materials spanning in size and realism, from small-scale laboratory tests such as the cone calorimeter, OSU rate of heat release, and radiant panel test, to intermediate-scale mock-up tests, culminating in realistic full-scale tests. These tests provided the necessary data to develop a test method for evaluating the flammability of the thin films. A radiant panel test showed the best correlation with intermediate- and full-scale mock-up tests. This equipment, originally used to evaluate the flame propagation of flooring materials, provided a graduated radiant heat source, in addition to a small pilot ignition source. The equipment and test methodology were refined slightly to accommodate the testing of the extremely thin moisture barrier films.

The resultant test proposes a less-than-2-inch radius of flame propagation on the blanket surface, which essentially requires no ignition or flame propagation. The implementation of this more stringent flame spread requirement will reduce the occurrence of fire from in-flight ignition sources.

In addition, research on fuselage burnthrough has determined that improved thermal acoustic insulation will significantly extend the time before an external fire penetrates the fuselage. Earlier research findings indicated that improved thermal acoustical insulation can delay the entry of a postcrash fuel fire by several minutes, thus prolonging the time available for escape. Conversely, the absence of thermal acoustic insulation can allow rapid entry of a fire into the fuselage. Although other factors affect fuselage burnthrough (e.g., fuselage skin, the floor/sidewall characteristics, return grills, etc.), research demonstrated that the simplest and most effective approach to enhanced burnthrough resistance was to improve the fire resistance of the insulation. Consequently, a burnthrough test standard for thermal acoustic insulation was developed. The burnthrough test employs an oil-fired burner, similar to that used in other existing FAA flammability tests. Standard and alternative insulation materials were evaluated in a variety of specimen holders and configurations, and a finalized method was developed. The testing highlighted the importance of securing the insulation to the fuselage such that the benefits of the fire resistant materials can be fully realized. Correlation tests using materials previously tested under full-scale conditions demonstrated that the chosen method was representative of full-scale results. Materials meeting the proposed burnthrough standard can significantly reduce the occurrence of rapid fire penetration into an aircraft cabin in the event of a postcrash fire.

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2. R.G.W. Cherry & Associates, Ltd., "Fuselage Hardening for Fire Suppression: Safety Benefit Analysis based on Past Accidents," DOT/FAA/AR-99/57, September 1999.

3. Webster, H., "Fuselage Burnthrough From Large Exterior Fuel Fires," DOT/FAA/CT-90/10, July 1994.

4. Marker, T.R., "Full-Scale Test Evaluation of Aircraft Fuel Fire Burnthrough Resistance Improvements," DOT/FAA/AR-98/52, January 1999.

5. Cahill, P., "Electrical Arc Testing of Thermal Acoustic Insulation Materials," DOT/FAA/AR-00/20, April 2000.

APPENDIX A—PROPOSED IN-FLIGHT FLAMMABILITY TEST STANDARD FOR AIRCRAFT THERMAL ACOUSTIC INSULATION

This test method is used to evaluate the flammability and flame propagation characteristics of thermal/acoustic insulation when exposed to both a radiant heat source and a flame.

DEFINITIONS.

THERMAL ACOUSTIC INSULATION. Thermal/acoustic insulation is defined as a material or system of materials used to provide thermal and/or acoustic protection. Examples include a film-covering material encapsulating a core material such as fiberglass or other batting material and foams.

RADIANT HEAT SOURCE. The radiant heat source is an air-gas fueled radiant heat energy panel or equivalent.

TEST APPARATUS.

(The test apparatus is schematically shown in figure A-1).

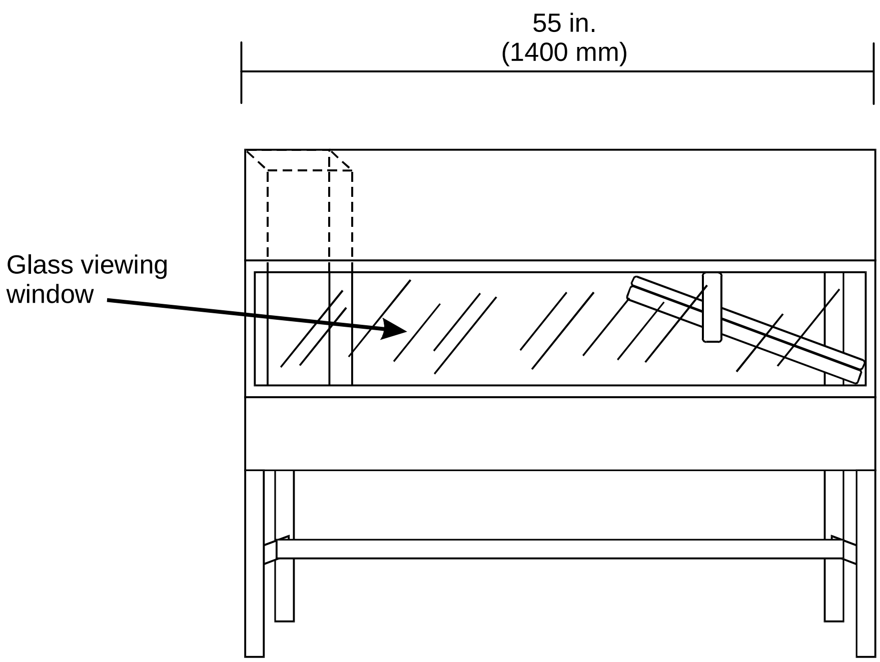

FIGURE A-1. RADIANT PANEL TEST CHAMBER

RADIANT PANEL TEST CHAMBER. Tests shall be conducted in a radiant panel test chamber (see figure A-1). The test chamber shall be located under an exhaust hood to facilitate clearing the chamber of smoke after each test. The radiant panel test chamber shall consist of an enclosure 55 inches (1400 mm) long by 19.5 (500 mm) deep by 28 (710 mm) to 30 inches (maximum) (762 mm) above the test specimen. The sides, ends, and top shall be insulated with a fibrous ceramic insulation such as Kaowool M™ board. The front side shall be provided with an approximately 52- by 10-inches (1321- by 254-mm) draft-free, high-temperature, glass observation window to facilitate viewing the sample during testing. Below the window is a door, which provides access to the movable specimen platform holder. The bottom of the test chamber shall consist of a sliding steel platform, which has provisions for securing the test specimen holder in a fixed and level position. The chamber shall have an internal chimney with exterior dimensions of 5.1 inches (129 mm) wide, by 16.2 inches (411 mm) deep by 13 inches (330 mm) high at the opposite end of the chamber from the radiant energy source. The interior dimensions are 4.5 inches (114 mm) wide by 15.6 inches (395 mm) deep. The chimney extends to the top of the chamber (see figure A-2).

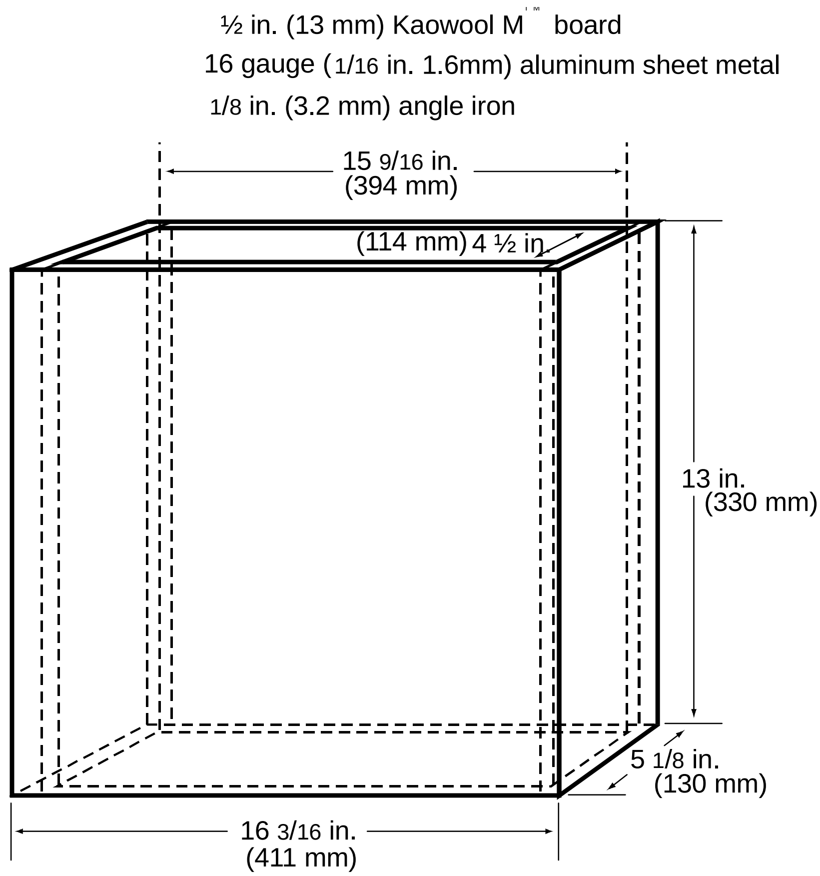

FIGURE A-2. INTERNAL CHIMNEY

RADIANT HEAT SOURCE. The radiant heat energy source shall be a panel of porous refractory material mounted in a cast iron frame or equivalent. The panel shall have a radiation surface of 12 by 18 inches (305 by 457 mm). The panel shall be capable of operating at temperatures up to 1500°F (816°C). See figure A-3. An equivalent panel must satisfy the calibration conditions and produce test results equivalent to the air-gas panel for any material tested.

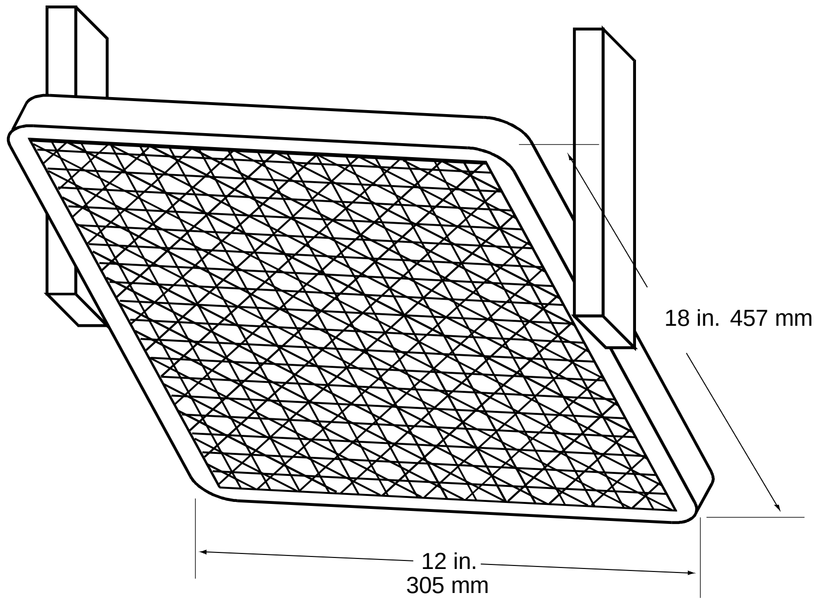

FIGURE A-3a. AIR-PROPANE RADIANT PANEL

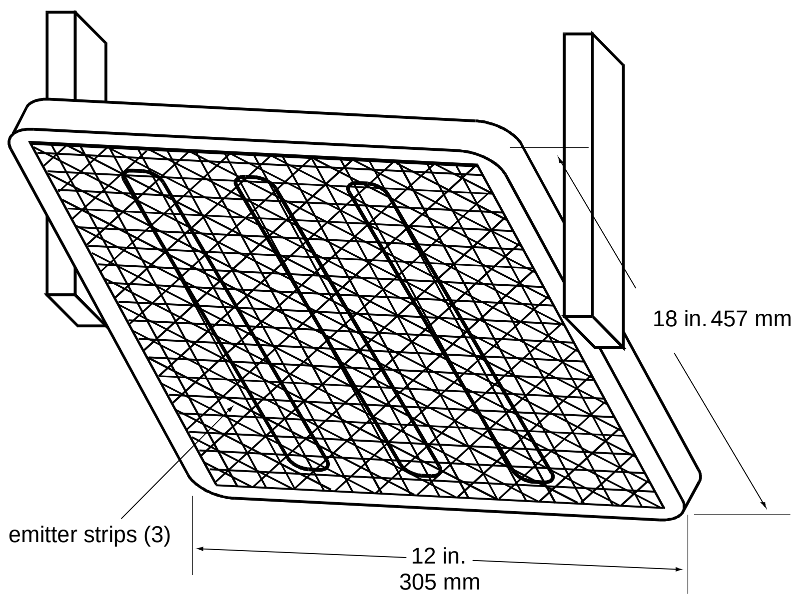

FIGURE A-3b. ELECTRIC PANEL

Radiant Panel Heating System. The radiant panel fuel shall be propane (liquid petroleum gas – 2.1 UN 1075). The panel fuel system shall consist of a venturi-type aspirator for mixing gas and air at approximately atmospheric pressure. Suitable instrumentation will be necessary for monitoring and controlling the flow of fuel and air to the panel. Instrumentation shall include an air flow gauge, an air flow regulator, and a gas pressure gauge.

Radiant Panel Placement. The panel shall be mounted in the chamber at 30º to the horizontal specimen plane.

SPECIMEN HOLDING SYSTEM. The sliding platform serves as the housing for test specimen placement. Brackets may be attached (via wing nuts) to the top lip of the platform in order to accommodate various thicknesses of test specimens. A sheet of refractory material may be placed and supported by the lip in the open bottom (base) of the sliding platform for samples that do not require height compensation. The refractory material may be placed on the bottom of the brackets to hold the test specimen (for height requirement) if necessary. See figure A-4.

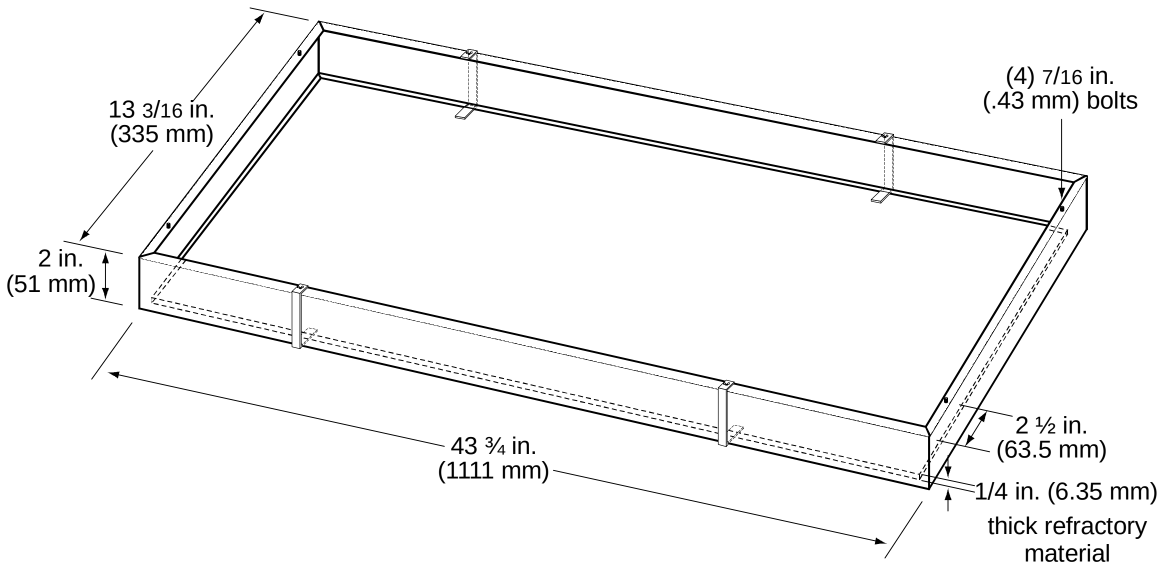

FIGURE A-4. SLIDING PLATFORM

A 1/2-inch (13-mm) piece of Kaowool M™ board or other high-temperature material measuring 41 1/2 by 8 1/4 inches (1054 by 210 mm) shall be attached to the backside of the platform. This board will serve as a heat retainer and will protect the test specimen from excessive preheating. The height of this board must not be too high such that it impedes the sliding platform movement (in and out) of the test chamber.

The test specimen shall be placed horizontally on the refractory base (or brackets). A stainless steel retaining frame (AISI Type 300 UNA-NO8330), or equivalent, having a thickness of 0.078 inch (1.98 mm) and overall dimensions of 44 3/4 by 12 3/4 inches (1137 by 320 mm) with a specimen opening of 40 by 7 7/8 inches (1016 by 140 mm) shall be placed on top of the test specimen. The retaining frame shall have two 1/2-inch (12.7-mm) holes drilled at each end for positioning the frame to the two stud bolts at each end of the sliding platform. See figure A-5.

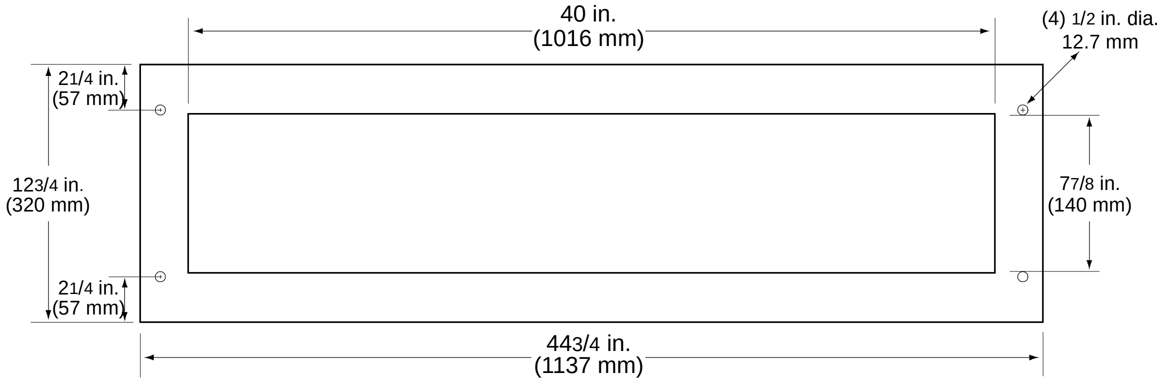

FIGURE A-5. RETAINNG FRAME

A securing frame (acting as a clamping mechanism) constructed of mild steel may be placed over the test specimen. The securing frame overall dimensions are 42 1/2 by 10 1/2 inches (1080 by 267 mm) with a specimen opening of 39 1/2 by 7 1/2 inches (1003 by 190 mm). Hence, the exposed area of test specimen exposed to the radiant panel is 39 1/4 by 7 1/4 inches (996 by 184 mm). See figure A-6. It is not necessary to physically fasten the securing frame over the test specimen due to the weight of the frame itself.

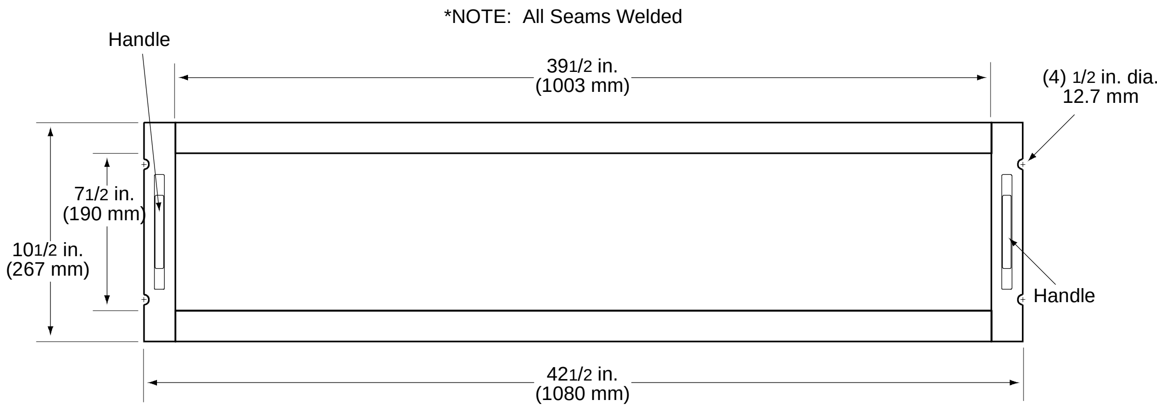

FIGURE A-6. SECURING FRAME

PILOT BURNER. The pilot burner used to ignite the specimen is a Bernzomatic™ commercial propane venturi torch with an axially symmetric burner tip having a propane supply tube with an orifice diameter of 0.006 inch (0.15 mm). The length of the burner tube is 2 7/8 inches (71 mm). The propane flow is adjusted via gas pressure through an in-line regulator to produce a blue inner cone length of 3/4 inch (19 mm). A 3/4-inch (19-mm) guide (such as a thin strip of metal) may be spot welded to the top of the burner to aid in setting the flame height. There shall be a means provided to move the burner out of the ignition position so that the flame is horizontal and at least 2 inches (50 mm) above the specimen plane. See figure A-7.

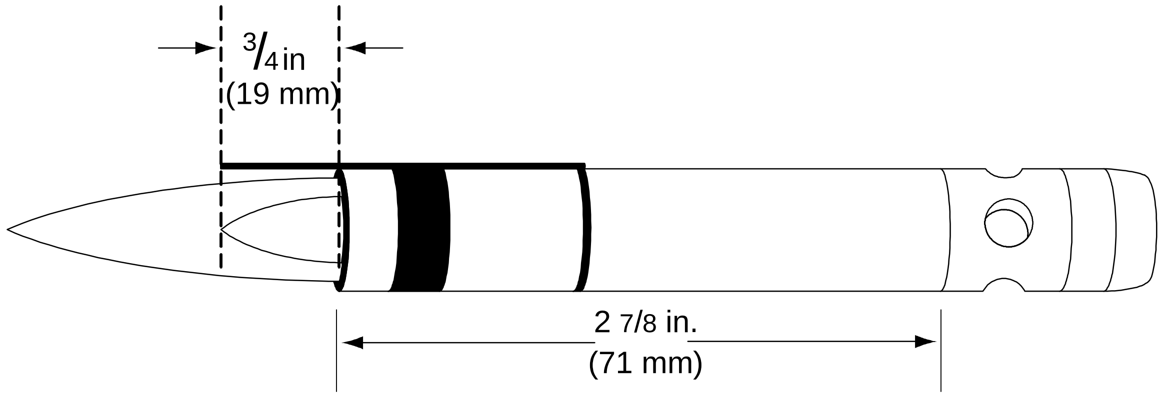

FIGURE A-7. PROPANE PILOT BURNER

THERMOCOUPLES. A 24 American Wire Gauge (AWG) Type K (Chromel-Alumel) thermocouple shall be installed in the test chamber for temperature monitoring. It shall be inserted into the chamber through a small hole drilled through the back of the chamber. The thermocouple shall be placed such that it extends 11 inches (279 mm) out from the back of the chamber wall, 11 1/2 inches (292 mm) from the right side of the chamber wall, and is 2 inches (51 mm) below the radiant panel. The use of other thermocouples is optional.

CALORIMETER. The calorimeter shall be a one inch cylindrical water-cooled, total heat flux density, foil-type Gardon Gage that has a range of 0 to 5 Btu/ft^2- second (0 to 5.6 Watts/cm^2).

CALORIMETER CALIBRATION SPECIFICATION AND PROCEDURE.

- Calorimeter Specification
  - Foil diameter shall be 0.25 ±0.005 inch (6.35 ±0.13 mm).
  - Foil thickness shall be 0.0005 ±0.0001 inch (0.013 ±0.0025 mm).
  - Foil material shall be thermocouple grade Constantan.
  - Temperature measurement shall be a Copper Constantan thermocouple.
  - The copper center wire diameter shall be 0.0005 inch (0.013 mm).
  - The entire face of the calorimeter shall be lightly coated with “Black Velvet” paint having an emissivity of 96 or greater.

- Calorimeter Calibration

  – The calibration method shall be by comparison to a like standardized transducer.

  – The standardized transducer shall meet the specification given in this appendix.

  – It shall be calibrated against a primary standard by the National Institute of Standards and Technology (NIST).

  – The method of transfer shall be a heated graphite plate.

  – The graphite plate shall be electrically heated, have a clear surface area on each side of the plate of at least 2 by 2 inches (51 by 51 mm) and be 1/8 inch ±1/16 inch thick (3.2 ±1.6 mm).

  – The two transducers shall be centered on opposite sides of the plates at equal distances from the plate.

  – The distance of the calorimeter to the plate shall be no less than 0.0625 inch (1.6 mm), nor greater than 0.375 inch (9.5 mm).

  – The range used in calibration shall be at least 0-3.5 Btus/ft^2 second (0-3.9 Watts/cm^2) and no greater than 0-5.6 Btus/ft^2 second (0-5 Watts/cm^2.

  – The recording device used must record the two transducers simultaneously or at least within 1/10 of each other.

<u>CALORIMETER FIXTURE</u>. With the sliding platform pulled out of the chamber, install the calorimeter holding frame. The frame is 13 1/8 inches (333 mm) deep (front to back) by 8 inches (203 mm) wide and rests on the top of the sliding platform. It is fabricated of 1/8 inch (3.2 mm) flat stock steel and has an opening that accommodates a 1/2-inch (12.7-mm) -thick piece of Kaowool M™ board, which is level with the top of the sliding platform. The board has three 1-inch (25.4-mm) -diameter holes drilled through the board for calorimeter insertion. The distance from the outside frame (right side) to the centerline of the first hole ("zero" position) is 1 7/8 inches (47 mm). The distance between the centerline of the first hole to the centerline of the second hole is 2 inches (51 mm). It is also the same distance from the centerline of the second hole to the centerline of the third hole. See figure A-8.

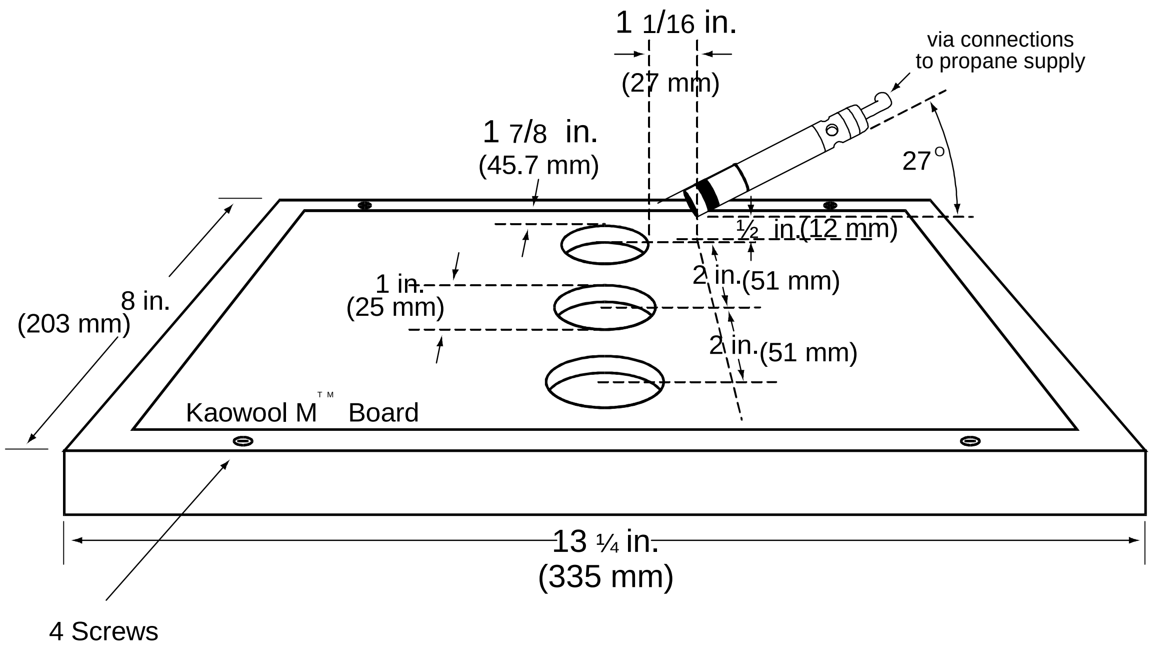

FIGURE A-8. CALORIMETER HOLDING FRAME

INSTRUMENTATION. A calibrated recording device with an appropriate range or a computerized data acquisition system shall be provided to measure and record the outputs of the calorimeter and the thermocouple. The data acquisition system must be capable of recording the calorimeter output every second during calibration.

TIMING DEVICE. A stopwatch or other device, accurate to ±1 second/hour, shall be provided to measure the time of application of the pilot burner flame.

TEST SPECIMENS.

SPECIMEN PREPARATION. A minimum of three test specimens shall be prepared and tested.

CONSTRUCTION. Test specimens shall include all materials used in construction of the insulation (including batting, film, scrim, tape, etc.) Cut a piece of core material such as foam or fiberglass, 43 inches long (1092 mm) by 11 inches (279 mm) wide. Cut a piece of film cover material (if used) large enough to cover the core material. There are a number of ways to prepare the sample. These include stapling the film cover around the ends (as the ends are not exposed to the radiant heat source), wrapping the core material and taping it at the bottom, and heat sealing the sample. The specimen thickness must be of the same thickness as installed in the airplane.

SPECIMEN CONDITIONING. The specimens shall be conditioned at 70° ±5°F (21° ±2°C) and 55% ±10% relative humidity, for a minimum of 24 hours prior to testing.

CALIBRATION.

1. With the sliding platform out of the chamber, install the calorimeter holding frame. Push the platform back into the chamber and insert the calorimeter into the first hole ("zero" position). See figure A-8. Close the bottom door located below the sliding platform. The centerline of the calorimeter is 1 7/8 inches (46 mm) from the end of the holding frame. The distance from the centerline of the calorimeter to the radiant panel surface at this point is 7.5 inches ±1/8 (191 mm ±3). Prior to igniting the radiant panel, ensure that the calorimeter face is clean and that there is water running through the calorimeter.

2. Ignite the panel. Adjust the fuel/air mixture to achieve 1.5 Btus/ft^2-second ±5% (1.8 Watts/cm^2 ±5%) at the zero position. If using an electric panel, set the power controller to achieve the proper heat flux. Allow the unit to reach steady state (this may take up to 1 hour). The pilot burner is off during this time.

3. After steady-state conditions have been reached, move the calorimeter 2 inches (51 mm) from the zero position (first hole) to the second position and record the heat flux. Move the calorimeter to the third position and record the heat flux. Allow enough time at each position for the calorimeter to stabilize.

4. Open the bottom door, remove the calorimeter and holder fixture. Use caution as the fixture is very hot.

TEST PROCEDURE.

1. Ignite the pilot burner. Ensure that it is at least 2 inches (51 mm) above the top of the platform. The burner must not contact the specimen until the test begins.

2. Place the test specimen in the sliding platform holder. Ensure that the test sample surface is level with the top of the platform. At zero point, the specimen surface is 7 1/2 inches ±1/8 inch (191 mm ±3) below the radiant panel.

3. With film/fiberglass assemblies, it may be necessary to puncture small holes in the film cover to purge any air inside. This allows the operator to maintain the proper test specimen position (level with the top of the platform). The holes should be made in the sides and/or the corners of the test specimen using a needle-like tool.

4. Place the retaining frame over the test specimen. The securing frame may be used if the samples have been stapled and tend to shrink away from the radiant heat source. It may be necessary (due to compression) to adjust the sample (up or down) in order to maintain the distance from the sample to the radiant panel (7 1/2 inches ±1/8 inch (191 mm ±3) at zero position).

5. Immediately push the sliding platform into the chamber and close the bottom door.

6. Bring the pilot burner flame into contact with the center of the specimen at the zero point and simultaneously start the timer. The pilot burner shall be at a 27º angle with the sample and be 1/2 inch (12 mm) above the sample. See figureA-8. A stop, as shown in figure A-9, allows the operator to position the burner in the correct position each time.

7. Leave the burner in position for 15 seconds and then remove to a position at least 2 inches (51 mm) above the specimen.

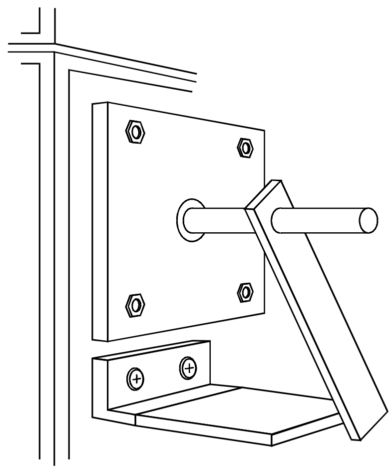

FIGURE A-9. PROPANE BURNER STOP

REPORT.

1. Identify and describe the specimen being tested.
2. Report any shrinkage or melting of the test specimen.
3. Report the flame time.
4. Report the after-flame time.

REQUIREMENTS.

1. No flaming beyond 2 inches (51 mm) to the left of the centerline of the point of pilot flame application is allowed.

2. Of the three specimens tested, only one specimen may have an after flame. That after flame may not exceed 3 seconds.

APPENDIX B—PROPOSED POSTCRASH BURNTHROUGH TEST STANDARD FOR AIRCRAFT THERMAL/ACOUSTIC INSULATION MATERIAL

The following test method is used to evaluate the burnthrough resistance characteristics of aircraft thermal/acoustic insulation materials when exposed to a high intensity open flame.

DEFINITIONS.

BURNRNTHROUGH TIME. The burnthrough time is measured at the inboard side of each of the insulation blanket specimens. The burnthrough time is defined as the time required, in seconds, for the burner flame to penetrate the test specimen, and/or the time required for the heat flux to reach 2.0 Btu/ft^2 sec on the inboard side, a distance of 12 inches from the front surface of the insulation blanket test frame, whichever is sooner.

SPECIMEN SET. A specimen set consists of two insulation blanket specimens. Both specimens must represent the same production insulation blanket construction and materials, proportioned to correspond to the specimen size.

INSULATION BLANKET SPECIMEN. The insulation blanket specimen is one of two specimens positioned in either side of the test rig, at an angle of 30° with respect to vertical.

APPARATUS. The arrangement of the test apparatus is shown in figures B-1 and B-2 and shall include swinging the burner away from the test specimen during warm-up.

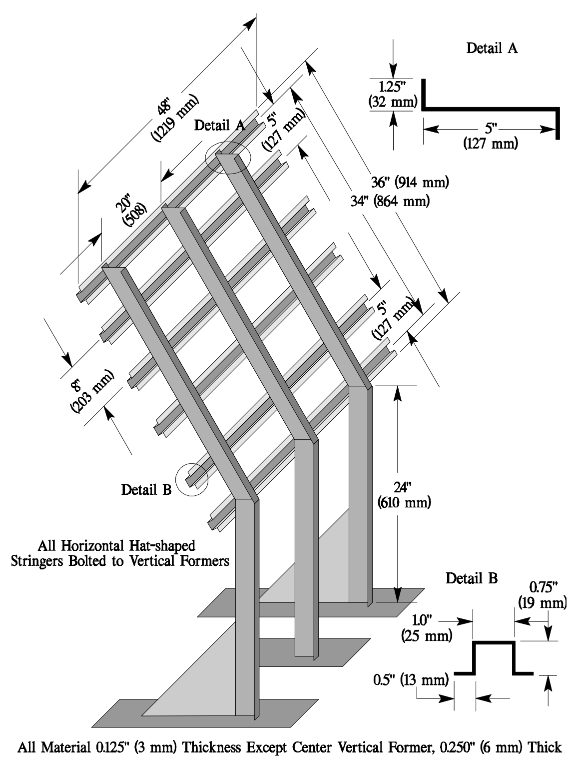

FIGURE B-1. BURNTHROUGH TEST APPARATUS SPECIMEN HOLDER

TEST BURNER. The test burner shall be a modified gun-type such as the Park Model DPL 3400. Flame characteristics may be enhanced with the optional use of a static disc turbulator or a temperature compensation fuel nozzle.

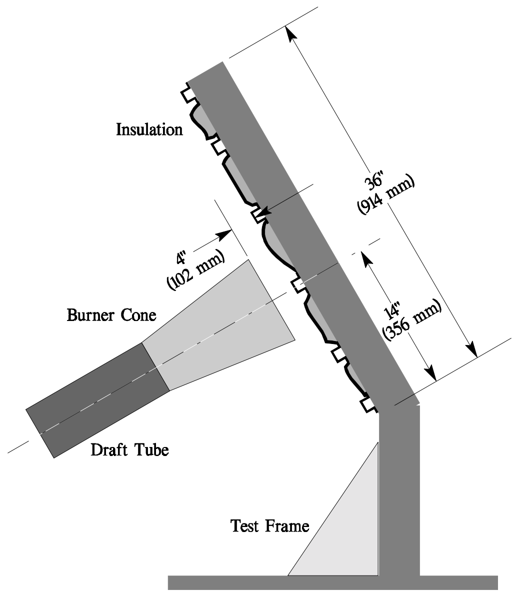

FIGURE B-2. BURNTHROUGH TEST APPARATUS

Nozzle. A nozzle is required to maintain the fuel pressure to yield a nominal 6.0 gal/hr (0.378 L/min) fuel flow. A Monarch manufactured 80°. PL (hollow cone) nozzle nominally rated at 6.0 gal/hr at 100 lb/in^2 (0.71 MPa) has been found to deliver a proper spray pattern. Minor deviations to the fuel nozzle spray angle, fuel pressure, or other similar parameters are acceptable if the nominal fuel flow rate and temperature and heat flux measurements conform to the requirements of this appendix.

Burner Cone. A 12 ±0.125-inch (305 ±6-mm) burner extension cone shall be installed at the end of the draft tube. The cone shall have an opening 6 ±0.125 inch (152 ±6 mm) high and 11 ±0.125 inch (280 ±6 mm) wide (figure B-3).

Fuel. JP–8, Jet A, or their international equivalent has been found to satisfactorily deliver a 6.0 ±0.2 gal/hr flow rate. If this fuel is unavailable, ASTM K2 fuel (Number 2 grade kerosene) or ASTM D2 fuel (Number 2 grade fuel oil or Number 2 diesel fuel) are acceptable if the nominal fuel flow rate, temperature, and heat flux measurements conform to the requirements of this appendix.

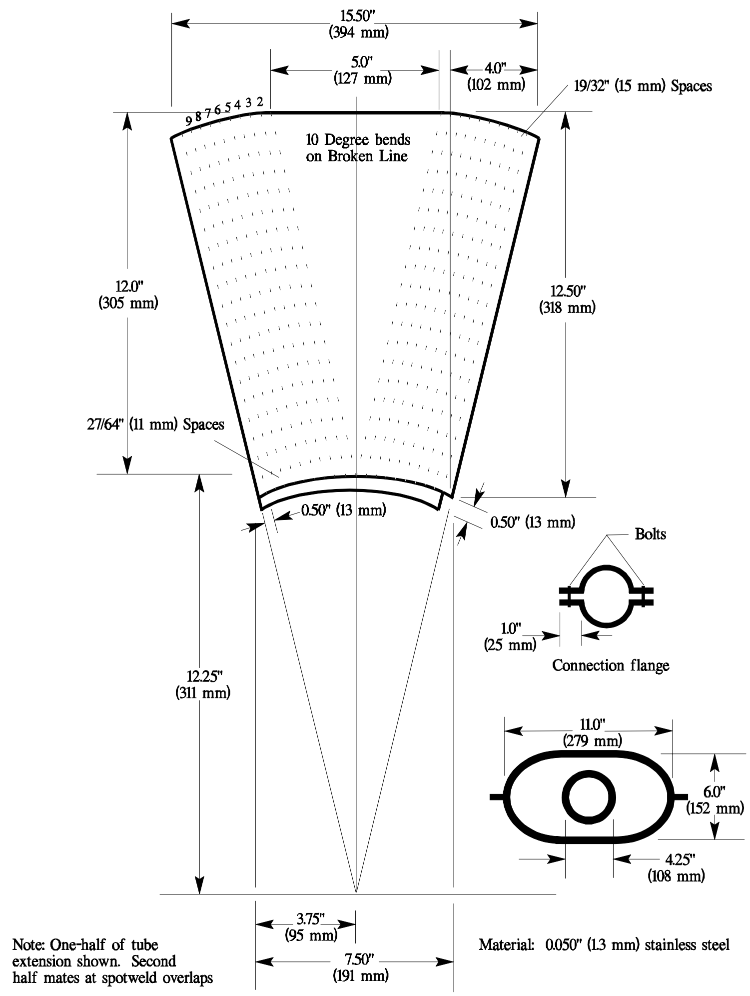

FIGURE B-3. BURNER DRAFT TUBE EXTENSION CONE

Fuel Pressure Regulator. A fuel pressure regulator, adjusted to deliver 6.0 gal/hr (0.378 L/min) nominal, shall be provided. An operating fuel pressure of 100 lb/in^2 for a 6.0 gal/hr 80° spray angle nozzle (such as a PL type) has been found to be satisfactory to deliver 6.0 ±0.2 gal/hr (0.378 L/min).

CALIBRATION RIG AND EQUIPMENT. A calibration rig shall be constructed to incorporate a calorimeter and thermocouple rake for the measurement of both heat flux and temperature. A combined temperature and heat flux calibration rig enables a quick transition between these devices, so that the influence of air intake velocity on heat flux and temperature can be analyzed

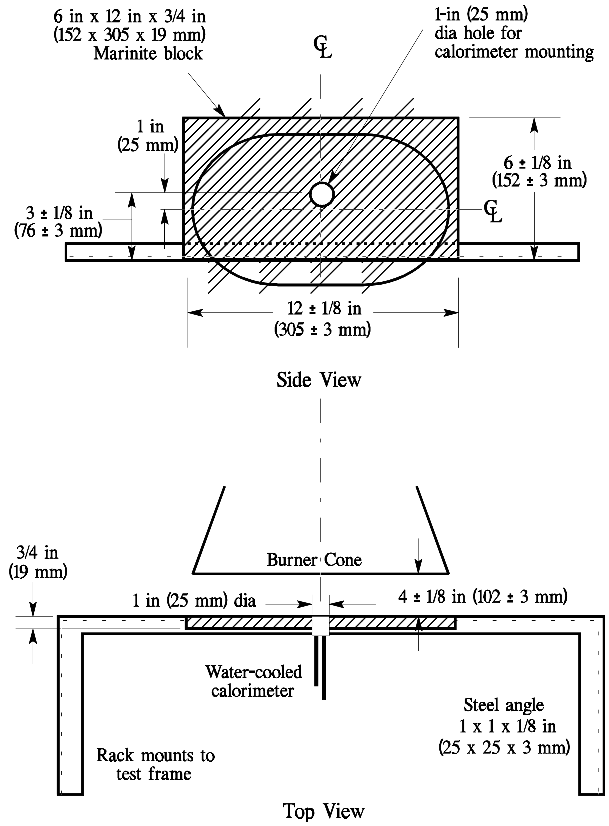

FIGURE B-4. CALORIMETER POSITION RELATIVE TO BURNER CONE

without necessitating removal of the calibration rig. Individual calibration rigs are also acceptable.

Calorimeter. The calorimeter shall be a total heat flux, foil-type Gardon Gage of and appropriate range such as 0-20 Btu/ft^2-sec (0-22.7 W/cm^2), accurate to ±3% of the indicated reading. The heat flux calibration method shall be in accordance with appendix A.

Calorimeter Mounting. The calorimeter shall be mounted in a 6- by 12- ±0.125-inch (152- by 305- ±3-mm) by 0.75 ±0.125-inch (19 ±3-mm) -thick insulating block which is attached to a calibration rig for attachment to the test rig during calibration (figure B-4). The insulating block shall be monitored for deterioration and replaced when necessary. The mounting shall be adjusted as necessary to ensure that the calorimeter face is parallel to the exit plane of the test burner cone.

Thermocouples. Seven 1/8-inch ceramic packed, metal sheathed, type K (Chromel-alumel) grounded junction thermocouples with a nominal 24 American Wire Gauge (AWG) size conductor shall be provided for calibration. The thermocouples shall be attached to a steel angle bracket to form a thermocouple rake for placement in the calibration rig during burner calibration (figure B-5).

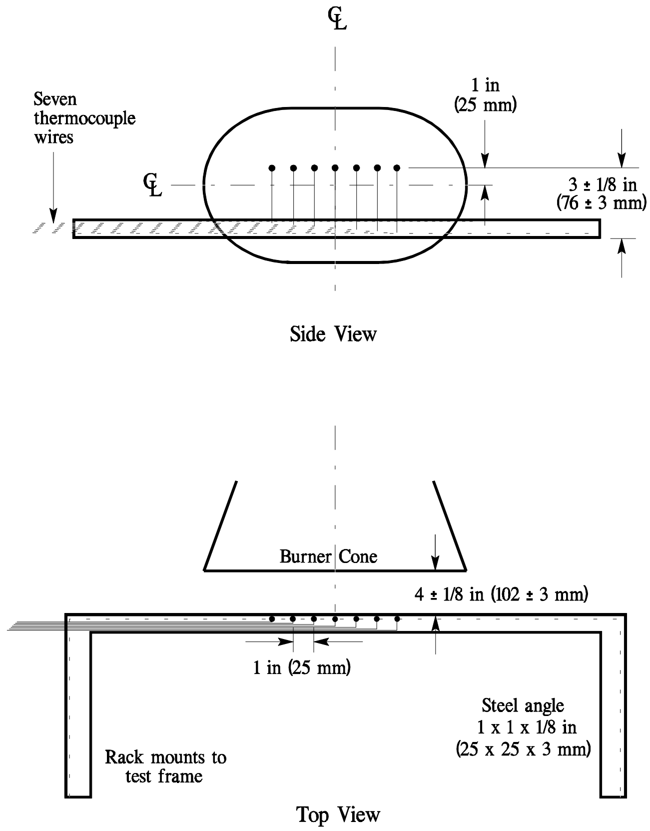

FIGURE B-5. THERMOCOUPLE RAKE POSITION RELATIVE TO BURNER CONE

Air Velocity Meter. A vane-type air velocity meter must be used to calibrate the velocity of air entering the burner. An Omega Engineering Model HH30A has been shown to be satisfactory. A suitable adapter used to attach the measuring device to the inlet side of the burner is required to prevent air from entering the burner other than through the device, which would produce erroneously low readings.

TEST SPECIMEN MOUNTING FRAME. The mounting frame for the test specimens shall be fabricated of 1/8-inch-thick steel as shown in figure B-1, except for the center vertical former, which should be 1/4 inch thick to minimize warpage. The specimen mounting frame stringers (horizontal) should be bolted to the test frame formers (vertical) such that the expansion of the stringers will not cause the entire structure to warp. The mounting frame shall be used for mounting the two insulation blanket test specimens as shown in figure B-2.

BACKFACE CALORIMETERS. Two total heat flux Gardon-type calorimeters shall be mounted above the insulation test specimens on the back side (cold) area of the test specimen mounting frame as shown in figure B-6. The calorimeters must be positioned

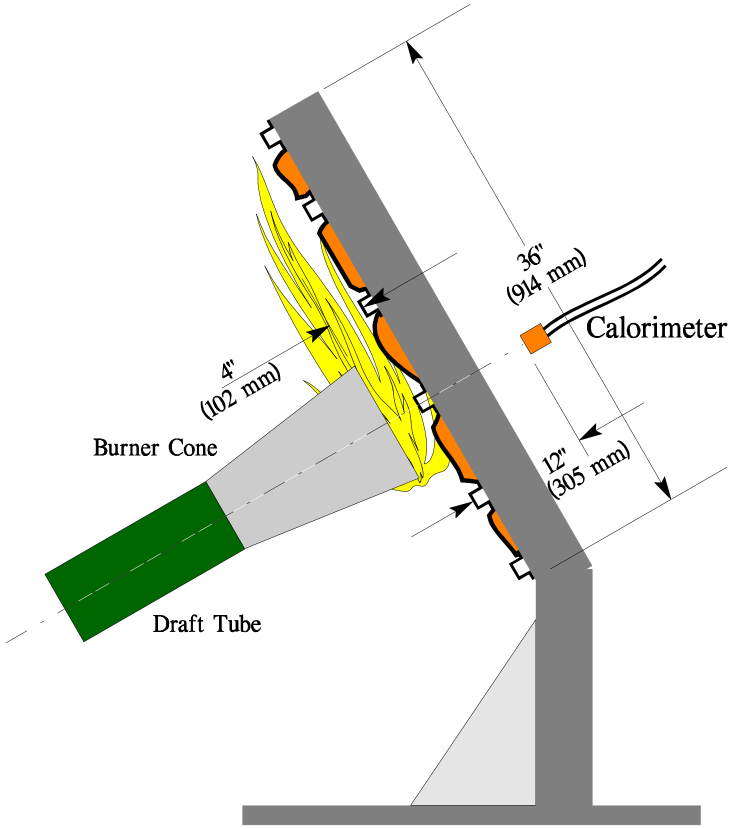

FIGURE B-6. POSITION OF BACKFACE CALORIMETERS RELATIVE TO TEST SPECIMEN FRAME

along the same plane as the burner cone centerline, at a distance of 4 inches from the centerline of the test frame. The heat flux calibration shall be in accordance with appendix A.

<u>INSTRUMENTATION</u>. A recording potentiometer or other suitable calibrated instrument with an appropriate range shall be provided to measure and record the outputs of the calorimeter and the thermocouples.

<u>TIMING DEVICE</u>. A stopwatch or other device, accurate to ±1%, shall be provided to measure the time of application of the burner flame and burnthrough time.

<u>TEST CHAMBER</u>. Tests should be performed in a suitable chamber to reduce or eliminate the possibility of test fluctuation due to air movement. The chamber must have a minimum floor area of 10 by 10 feet.

<u>Ventilation Hood</u>. The test chamber must be provided with an exhausting system capable of removing the products of combustion expelled during tests.

TEST SPECIMENS.

SPECIMEN PREPARATION. A minimum of three specimen sets of the same construction and configuration shall be prepared for testing.

THE INSULATION BLANKET TEST SPECIMEN. For batt-type materials such as fiberglass, the constructed, finished blanket specimen assemblies shall be 32 inches wide by 36 inches long, exclusive of heat sealed film edges.

For rigid and other nonconforming types of insulation materials, the finished test specimens shall fit into the test rig in such a manner as to replicate the actual in-service installation.

CONSTRUCTION. Each of the specimens tested shall be fabricated using the principal components (i.e., insulation, fire barrier material if used, and moisture barrier film) and assembly processes (representative seams and closures).

Fire Barrier Material. If the insulation blanket is constructed with a fire barrier material, the fire barrier material shall be placed in a manner reflective of the installed arrangement (e.g., if the material will be placed on the outboard side of the insulation material, inside the moisture film, it must be placed accordingly in the test specimen).

Insulation Material. Blankets that utilize more than one variety of insulation (composition, density, etc.) shall have specimen sets constructed that reflect the insulation combination used. If, however, several blanket types use similar insulation combinations, it is not necessary to test each combination if it is possible to bracket the various combinations.

Moisture Barrier Film. If a production blanket construction utilizes more than one type of moisture barrier film, separate tests must be performed on each combination. For example, if a polyimide film is used in conjunction with an insulation in order to enhance the burnthrough capabilities, the same insulation with a polyvinyl fluoride must also be tested.

Installation on Test Frame. The blanket test specimens must be attached to the test frame using 12 steel spring type clamps as shown in figure B-7. The clamps must be used to hold the blankets in place in both of the outer vertical formers as well as the center vertical former (4 clamps per former). Place the top and bottom clamps 6 inches from the top and bottom of the test frame, respectively. Place the middle clamps 8 inches from the top and bottom clamps.

Note: For blanket materials that cannot be installed in accordance with figure B-7, the blankets must be installed in a manner approved by the FAA.

Conditioning. The specimens shall be conditioned at 70° ±5°F (21°. ±2°C) and 55% ±10% relative humidity for a minimum of 24 hours prior to testing.

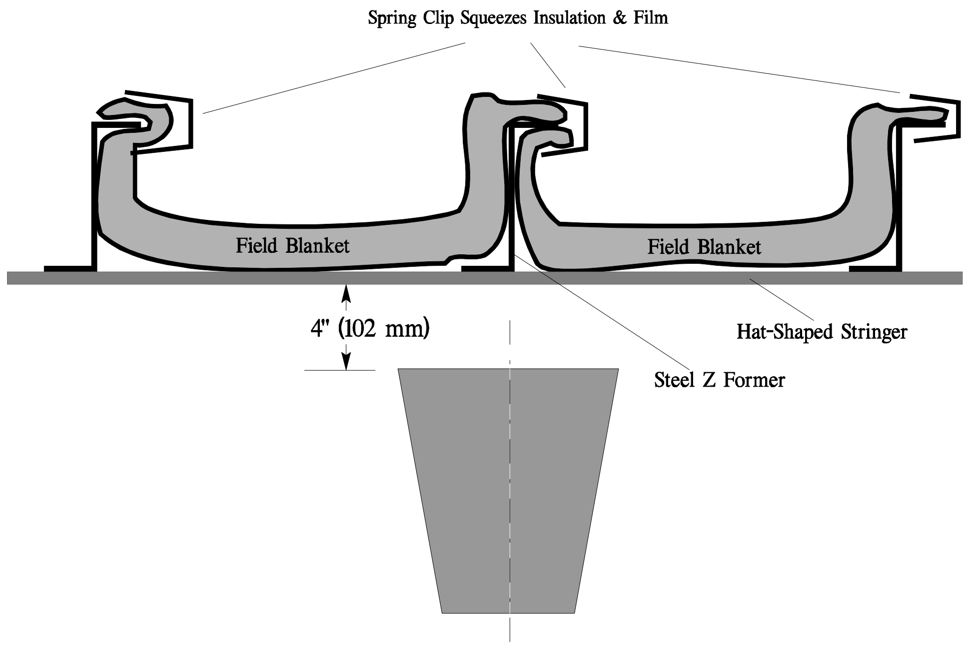

FIGURE B-7. TEST SPECIMEN INSTALLATION ON TEST FRAME

PREPARATION OF APPARATUS.

1. Level and center the frame assembly to ensure alignment of the calorimeter and/or thermocouple rake with the burner cone.

2. Turn on the ventilation hood for the test chamber. Do not turn on the burner blower. Measure the airflow of the test chamber using a vane anemometer or equivalent measuring device. The vertical air velocity just behind the top of the upper insulation blanket test specimen shall be 100 ±50 ft/min. The horizontal air velocity at this point shall be less than 50 ft/min.

3. If a calibrated flow meter is not available, measure the fuel flow rate using a graduated cylinder of appropriate size. Turn on the burner motor/fuel pump after insuring that the igniter system is turned off. Collect the fuel via a plastic or rubber tube into the graduated cylinder for a 2-minute period. Determine the flow rate in gallons per hour. The fuel flow rate shall be 6.0 ±0.2 gallons per hour.

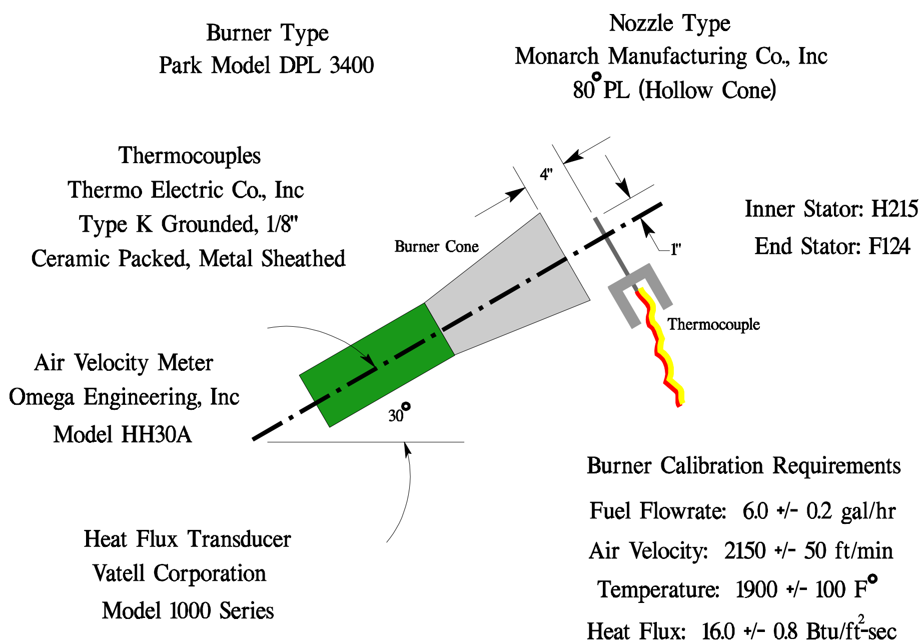

FIGURE B-8. BURNER INFORMATION AND CALIBRATION SETTINGS

CALIBRATION.

Secure the calibration rig to the test specimen frame. Position the burner so that it is centered in front of the calibration rig, and the vertical plane of the burner cone exit is at a distance of 4 ±0.125 inch (102 ±3 mm) from the calorimeter face. Ensure that the horizontal centerline of the burner cone is offset 1 inch below the horizontal centerline of the calorimeter (figure B-8). Without disturbing the burner position, slide the thermocouple rake portion of the calibration rig in front of the burner, such that the middle thermocouple (number 4 of 7) is centered on the burner cone. Ensure that the horizontal centerline of the burner cone is also offset 1 inch below the horizontal centerline of the thermocouple tips*. If individual calibration rigs are used, swing the burner to each position to ensure proper alignment between the cone and the calorimeter and thermocouple rake.

Position the air velocity meter in the adapter, making certain that no gaps exist where air could leak around the air velocity measuring device. Turn on the blower/motor while ensuring that the fuel solenoid and igniters are off. Adjust the air intake velocity to a level of 2150 ft/min, then turn off blower /motor.

Rotate the burner from the test position to the warm-up position. Prior to lighting the burner, ensure that the calorimeter face is clean of soot deposits, and there is water running through the

*The calibration rig must incorporate ‘‘detents’’ that ensure proper centering of both the calorimeter and the thermocouple rake with respect to the burner cone so that rapid positioning of these devices can be achieved during the calibration procedure.

calorimeter. Examine and clean the burner cone of any evidence of buildup of products of combustion, soot, etc. Soot buildup inside the burner cone may affect the flame characteristics and cause calibration difficulties. Since the burner cone may distort with time, dimensions should be checked periodically.

While the burner is still rotated out of the test position, turn on the blower/motor, igniters, fuel flow, and light the burner. Allow it to warm up for a period of 2 minutes. Move the burner into the test position and allow 1 minute for calorimeter stabilization, then record the heat flux once every second for a period of 30 seconds. Turn off burner, rotate out of position, and allow to cool. Calculate the average heat flux over this 30-second duration. The average heat flux should be 16.0 ±0.8 Btu/ft^2 sec.

Position the thermocouple rake in front of the burner. After checking for proper alignment, rotate the burner to warm-up position, turn on the blower/motor, igniters, fuel flow, and light the burner. Allow it to warm up for a period of 2 minutes. Move the burner into the test position and allow1 minute for thermocouple stabilization, then record the temperature of each of the seven thermocouples once every second for a period of 30 seconds. Turn off burner, rotate out of position, and allow to cool. Calculate the average temperature of each thermocouple over this 30-second period of record. The average temperature of each of the seven thermocouples should be 1900° ±100°F.

If either the heat flux or the temperatures are not within the specified range, adjust the burner intake air velocity and repeat the procedures of the previous two paragraphs to obtain the proper values. Ensure that the inlet air velocity is within the range of 2150 ft/min ±50 ft/min.

Calibrate prior to each test until consistency has been demonstrated. After consistency has been confirmed, several tests may be conducted with calibration conducted before and after a series of tests.

<u>TEST PROCEDURE</u>.

1. Secure the two insulation blanket test specimens to the test frame. The insulation blankets should be attached to the test rig center vertical former using four spring clamps positioned as shown in figure B-7 (according to the criteria in Installation on Test Frame or Alternative Installation Method of this part of this appendix).

2. Ensure that the vertical plane of the burner cone is at a distance of 4 + 0.125 inches from the outer surface of the horizontal stringers of the test specimen frame, and that the burner and test frame are both situated at a 30° angle with respect to vertical.

3. When ready to begin the test, direct the burner away from the test position to the warm-up position so that the flame will not impinge on the specimens. Turn on and light the burner and allow it to stabilize for 2 minutes.

4. To begin the test, rotate the burner into the test position and simultaneously start the timing device.

5. Expose the test specimens to the burner flame for 4 minutes and then turn off the burner. Immediately rotate the burner out of the test position.

6. Determine (where applicable) the burnthrough time, or the point at which the heat flux exceeds 2.0 Btu/ft^2-sec.

REPORT.

1. Identify and describe the specimen being tested.

2. Report the number of insulation blanket specimens tested.

3. Report the burnthrough time (if any), and the maximum heat flux on the back face of the insulation blanket test specimen and the time at which the maximum occurred.

REQUIREMENTS.

1. Neither of the two insulation blanket test specimens shall allow fire/flame penetration in less than 240 seconds

2. Neither of the two insulation blanket test specimens shall allow more than 2.0 Btu/ft^2-sec on the cold side of the insulation specimens at a point 12 inches from the face of the test rig.