Development of a Laboratory Scale Burnthrough Test for Thermal Acoustic Insulation

Abstract. This report summarizes the research and laboratory-scale tests undertaken by the Federal Aviation Administration (FAA) to develop a standardized test method for evaluating the postcrash fire burnthrough resistance of transport category aircraft thermal-acoustic insulation. Over sixty laboratory scale tests were conducted in various test rig configurations on a variety of insulation materials in an effort to establish a repeatable test condition that was representative of the threat likely to occur from a large external fuel fire. The finalized test apparatus utilizes an oil-fired burner adjusted to produce a flame temperature of 1900^{o}F and accompanying heat flux of 16.0 Btu/ft^{2}sec. The burner output cone was situated 4 inches from the plane of the specimen holder frame, at an angle of 30^{o} with respect to horizontal. This configuration yielded results that correlated with previous full-scale tests using identical materials.

A number of fiberglass insulation modifications and new insulation materials were shown to be effective in varying degrees. A heat-treated, oxidized polyacrylonitrile fiber (OPF) encased in a polyimide bagging material prevented burnthrough for over 6 minutes, while a dot-printed ceramic paper in conjunction with 2 layers of fiberglass batting was capable of preventing burnthrough for over 8 minutes. Other technologies exist that are equally as effective. During the testing, it was also determined that the method of attaching the insulation blankets to the test specimen structure had a critical impact on the effectiveness of the insulation material. In addition, the insulation bagging material, normally a thermoplastic film, was not an important factor in delaying the burnthrough, although a polyimide film provided additional protection.

In order to better evaluate the repeatability of the test apparatus worldwide, a number of "round robin" test series were conducted. During the typical round robin, several different types of insulation blanket test samples were identically prepared and shipped to participating labs for testing. Test results were tabulated, compared, and analyzed to determine the degree of fluctuation or "scatter" of data from the labs. The standard deviation of test results from four round robins has shown that the data scatter has been reduced during each test series, indicating the test apparatus is repeatable.

KEY WORDS: Postcrash, Burnthrough, Thermal-acoustic Insulation batting, Heat-treated oxidized polyacrylonitrile fiber (OPF), Dot-printed Ceramic paper, Polyimide film, Flame Enhancement Tab.

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EXECUTIVE SUMMARY

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 burnthrough from burning jet fuel external to the aircraft. There are typically three barriers that a fuel fire must penetrate in order to burnthrough to 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 either a polyvinyl fluoride (PVF) or polyethylene terephthalate (PET) moisture barrier, can offer an additional 1 to 2 minutes protection if the material is not physically dislodged from the fuselage structure.

Full-scale testing using surplus aircraft has confirmed the burnthrough sequence of events as a large external fire penetrates into an aircraft cabin. Subsequent tests performed in a purpose-built test rig have also highlighted the effectiveness of alternate insulation materials at significantly delaying or preventing the penetration of an external fuel fire into an aircraft cabin. Although other technologies exist by which fuel fire penetration could be delayed, replacing or modifying the existing thermal-acoustic insulation appears to be the most effective and economically feasible means. As a result of this research, a standardized small-scale test method for evaluating the burnthrough resistance of thermal acoustic insulation was developed. 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. Materials previously tested in the full-scale rig were also evaluated in the small-scale apparatus, producing similar results. In particular, a heat-treated, oxidized polyacrylonitrile fiber (OPF) encased in a polyimide bagging material prevented burnthrough for over 6 minutes, while a dot-printed ceramic paper in conjunction with currently-in-use fiberglass prevented burnthrough for over 8 minutes.

The detailed specification for the proposed test method was prepared, describing the apparatus, instrumentation, calibration, conduct of test, and reporting of data. The test method utilizes an oil-fired burner adjusted to produce a flame temperature of 1900^{o}F and heat flux of 16.0 Btu/ft^{2}sec. The burner output cone is situated 4 inches from the plane of the test frame specimen holder, at an angle of 30^{o} with respect to horizontal. This configuration yields results that correlate well with previous full-scale tests using identical materials. During the testing, it was determined that the method of attaching the insulation to the test rig structure had a critical effect on the capability of the insulation material. In addition, the type of insulation bagging material, normally a thermoplastic film, was not an important factor in prolonging burnthrough, although a polyimide film provided additional protection.

INTRODUCTION

PURPOSE.

The purpose of this report is to describe the research and laboratory-scale tests undertaken to develop a standardized testing apparatus used to evaluate the burnthrough resistance of transport category aircraft thermal-acoustical insulation.

BACKGROUND.

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 as a result of fuel tank damage during impact. One important factor to occupant survivability is the integrity of the fuselage during an accident. There are typically two possibilities which exist in an aircraft accident: (1) an intact fuselage or (2) direct impingement of external fuel fire flames on the cabin materials through a crash rupture or an emergency exit opening. Based on a consideration of past accidents, experimental studies, and fuselage design, it is apparent that the fuselage rupture or opening represents the worst case condition and provides the most significant opportunity for fire to enter the cabin [1]. Past Federal Aviation Administration (FAA) regulatory actions governing interior material flammability were based on full-scale tests employing a fuel fire adjacent to an opening in an otherwise intact fuselage. This scenario, in which the cabin materials were directly exposed to the intense thermal radiation emitted by the fuel fire, represented a severe but survivable fire condition and was used to develop improved standards for cabin materials. However, in some crash accidents, the fuselage remained completely intact and fire penetration into the passenger cabin was the result of a burnthrough of the fuselage shell [2]. A number of transport accidents involving burnthrough have occurred in the last 20 years. Rapid fire penetration of the fuselage was a primary focus of fire accident investigations: Los Angeles 1972, Malaga 1982, Calgary 1984, Manchester 1985, and Anchorage 1987.

There are typically three barriers that a fuel fire must penetrate in order to burnthrough to 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 passenger compartment by melting through the exterior skin around the cheek area, just below the cabin floor. The fire then progresses upward through openings beneath the cabin sidewall panels, eventually gaining access into the cabin via return air grills [3].

Additional full-scale testing was carried out in a purpose-built test article that allowed the major components of a transport category fuselage to be mocked-up and evaluated [4]. During a typical test, a large-area aluminum skin section, 8 by 12 feet in size, was riveted to the steel-framed fuselage structure. Various types of insulation were tested in the fuselage section behind the skin to examine of potential improvements. A fuel fire was situated adjacent to the test article to provide a realistic fire threat. This test configuration 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 a number of replacement insulation blanket materials could be used to significantly delay the occurrence of burnthrough into the passenger cabin [4]. Although other burnthrough protection technologies exist, such as the use of a sandwich-style aluminum/composite skin, replacing or modifying the existing thermal-acoustic insulation appears to be the most effective and economic means of delaying burnthrough. Delaying burnthrough provides passengers additional time to evacuate an aircraft, thus reducing fatalities. As a result of this research, a standardized small-scale test method for evaluating the burnthrough resistance of thermal acoustic insulation was developed. Over 60 tests were conducted in various sized laboratory scale test rigs and configurations in an effort to establish a repeatable test condition representative of the threat likely to occur from a large external fuel fire.

OBJECTIVE

The primary objective of this research was to develop a realistic and repeatable laboratory scale test standard for evaluating the burnthrough resistance of thermal-acoustic insulation. The test standard was based on the results of previous full-scale tests conducted on identical materials.

DISCUSSION

INITIAL LABORATORY SCALE TESTING USING BOX APPARATUS

In order to develop a test fire that was repeatable and representative of a post crash fire threat, an oil-fired burner was chosen. The burner 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, adjacent to a steel box measuring 36 by 36 by 36 inches (figure 1).

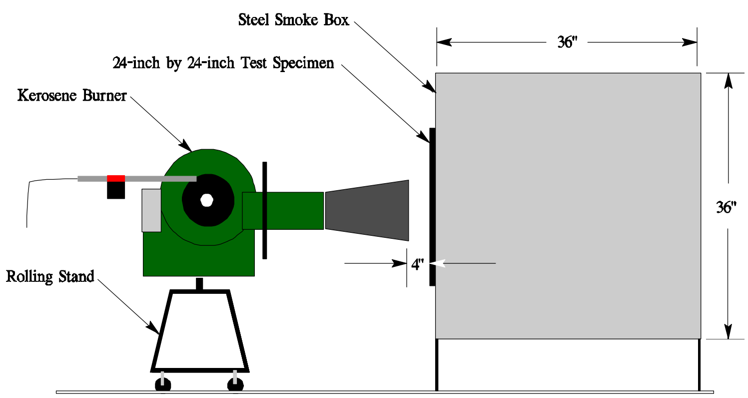

Figure 1. Initial Burnthrough Box Apparatus

On the box side facing the burner, a steel sample holder was constructed for both the thermal acoustic insulation and the aluminum aircraft skin. 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, a flange along the edge had 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 2).

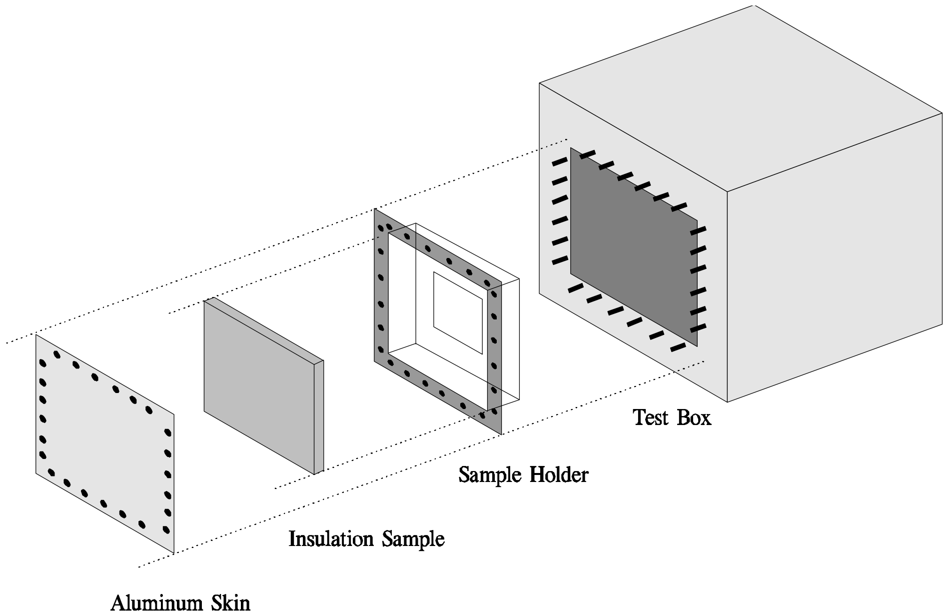

Figure 2. Burnthrough Box Sample Holder

Although this configuration clamped the skin to the box securely, it allowed the insulation to remain uncompressed. Several initial tests were run using 2 layers of 0.42 lb/ft^3 density fiberglass batting encased in a metallized polyvinyl fluoride film (PVF), 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 did not correlate well with full-scale test results and highlighted the inability of the box configuration at evaluating the performance of attachment pins or clips at 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.

BURNER FLAME TEMPERATURE AND SIZE DETERMINATION

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 Alclad aluminum skin mounted on the test box, without insulation batting. The 0.063-inch Alclad 2024 T3 material was used exclusively during the full-scale tests, representing an actual aircraft skin of a median thickness. A review of full-scale test data indicated an incident heat ranging from 10 to 16 Btu/ft^2 sec resulted from the fuel fire, with an average of approximately 13 Btu/ft^2 second as calculated by a total heat flux calorimeter that measured both radiant and convective heat flux contributions. 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 flowrate 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 the 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 lab scale tests in order to achieve correlation. As shown in table 1, 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.

Table 1. Aluminum Skin Burnthrough Tests

Test #	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

As shown from the results, it was difficult to reproduce the full-scale outcome. During the lab 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 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 3). 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 the fuselage, this flexibility would allow a determination of the critical, or most severe angle from a burnthrough standpoint.

Figure 3. Curved Test Rig

An initial test at 7 GPH fuel flowrate 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 2, a reduced fuel flowrate 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 2 layers of insulation. These results were similar to those obtained from full-scale tests in which aluminum skin and 2 layers of fiberglass typically lasted 1.5-2 minutes, although the correlation did not exist with respect to the OPF tests.

Table 2. Test Results Using Curved Test Rig

Test Date	Burner Fuel Flowrate (gal/hr)	Burner Air Velocity (ft/min)	Burner Distance (inches)	Skin Material	Skin Thickness (inches)	Insulation Material	Film Material	Cap Strip Insulation	Burnthrough Time (sec)
11/13/98	7	2245	3	Alclad 2024	0.063	1 ply OPF	polyimide	FG	150
12/1/98	2	1820	4	Alclad 2024	0.063	2 ply OPF	metallized PVF	FG	120
12/2/98	2	1820	4	Alum 5052	0.050	1 ply 0.60 PCF FG	metallized PVF	FG	80
12/2/98	2	1820	4	Alum 5052	0.050	2 ply 0.60 PCF FG	polyethylene teraphthalate	FG	124
12/2/98	2	1820	4	Alum 5052	0.050	2 ply 0.60 PCF FG	polyethylene teraphthalate	FG	121
12/2/98	2	1820	4	Alum 5052	0.050	1 ply 0.60 PCF FG	polyethylene teraphthalate	FG	86

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 lab-scale tests was 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 lab-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 formers. Under this configuration, there appeared to be a weakness in which the fire could penetrate the system along the seam area where the 2 field blankets butt the vertical former (figure 4). A further review of the videotape taken during the initial tests confirmed this. In all cases, the burner flames penetrated the seam area first, causing the initial failure.

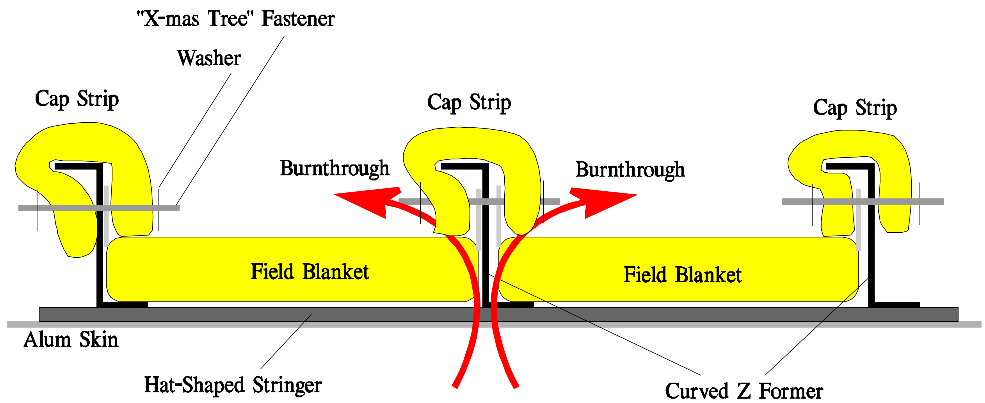

Figure 4. OEM Style of Blanket Attachment to Test Rig

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 easily reproduced. The initial curved rig would be costly and difficult to construct, so the rig was modified using non-curved Z-frames for the formers. In addition, the new flat rig incorporated 2 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 5. 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.

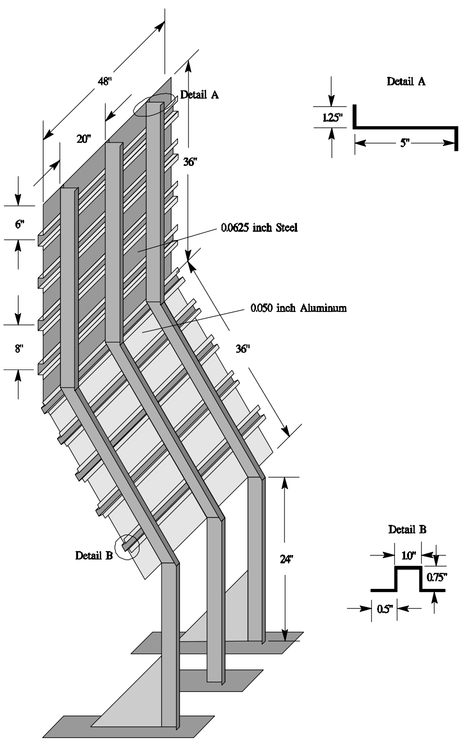

Figure 5. Improved Laboratory Scale Burnthrough Rig Using Flat Surfaces

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 aluminum skin similar 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 lab-scale testing device. During the first 2 trials, the burner fuel flowrate was set at 2 GPH, which produced a flame temperature in the area of 1900^{o}F with a heat flux of approximately 10.5 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 flowrate 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 3).

Table 3. Aluminum Skin Tests With Improved Apparatus at Various Burner Settings

Test Date	Burner Fuel Flowrate	Burner Air Velocity	Burner Distance	Skin Material	Skin Thickness	Burnthrough Time
12/8/1998	2 GPH	1800 FPM	5 inches	5052Aluminum	0.050 inch	480 seconds +
12/8/1998	2 GPH	1800 FPM	2 inches	5052Aluminum	0.050 inch	45 to 80 seconds
12/8/1998	4 GPH	2000 FPM	4 inches	5052Aluminum	0.050 inch	120 seconds
12/9/1998	6 GPH	2200 FPM	4 inches	5052Aluminum	0.050 inch	55 seconds
12/9/1998	6 GPH	2200 FPM	4 inches	5052Aluminum	0.050 inch	55 seconds

ATTEMPT TO DEVELOP A COMBINED BURNTHROUGH AND FLAME PROPAGATION TEST RIG

The postcrash fire burnthrough research, initially directed to show the benefits associated with the use of improved insulation systems, ultimately lead to the development of a representative laboratory scale test. However, a parallel effort was underway to develop an improved in-flight fire test standard for thermal-acoustical insulation to replace the existing Bunsen burner test method, which could not effectively identify poor performing materials. In particular, some of the insulation moisture barrier films were shown to be flammable under certain conditions, and one type of film was shown to propagate fire from an ignition source as small as an electrical arc. The ignitibility of films was also observed during the full-scale burnthrough tests. When OPF insulation was tested in a PVF moisture film, the film would eventually ignite from a combination of the intense radiant heat through the blanket and small flames around the periphery of the blanket. In comparison, this did not occur when the OPF was encased in a polyimide film blanket. Since the postcrash/in-flight flammability issues associated with thermal acoustic insulation were somewhat related, an effort was made to combine the research. In addition, industry appeared to prefer a singular test method that could screen for postcrash fire burnthrough and in-flight fire surface ignition/flame propagation in order to reduce the number of required tests.

Although the concept of a single fire test for insulation had its merits, the development proved to be difficult. As shown during earlier burnthrough tests using the improved test rig (figure 5), the flammability of the insulation surface was directly related to the blankets' burnthrough resistance. If a highly burnthrough resistant insulation material was tested and little or no flames penetrated the sample, there was a reduced likelihood that propagation would occur along the back surface of the test sample. Conversely, when the same film was used in conjunction with a material that allowed rapid burnthrough, there was an increased likelihood that propagation would occur along the back surface of insulation. In order to separate these 2 events in the same apparatus, the upper test frame section was separated slightly from the lower section to produce a slotted area (figure 6).

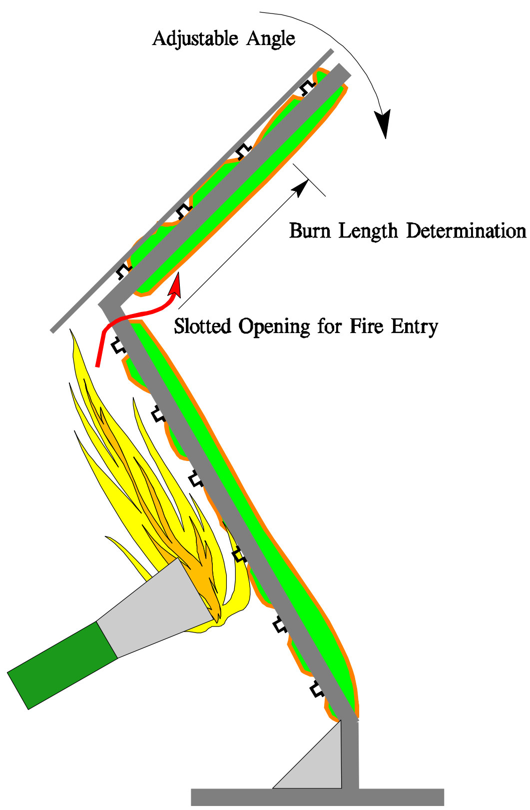

Figure 6. Combined Test Apparatus for Determining Flame Propagation and Burnthrough

As shown, the intent of the slotted area was to allow a small portion of the intense burner flame to impinge the lower surface of the upper insulation blanket in order to measure ignition/flame propagation. Simultaneously, the majority of the intense burner flames impacted the lower insulation sample, to measure the burnthrough resistance. Several tests were run but the results had a high degree of scatter, as it was difficult to control the amount of flames entering the slotted area to impact the sample. It appeared that a smaller, more consistent flame was required to fully evaluate the ignition/flame propagation qualities of the insulation. The large, fluctuating flame produced by the oil-burner was not suitable for this application. As a result, this approach was abandoned in favor of 2 separate tests.

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 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, the frame-mounted studs would warp, and 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 decision was made to replace the aluminum skin with a 48-inch wide piece of 0.125-inch thick steel skin, and simulate the burnthrough area by placing a 24 by 24-inch opening in the steel. The opening represented the typical burnthrough area that resulted when the aluminum was in place, which was slightly larger than the burner flame area (figure 7).

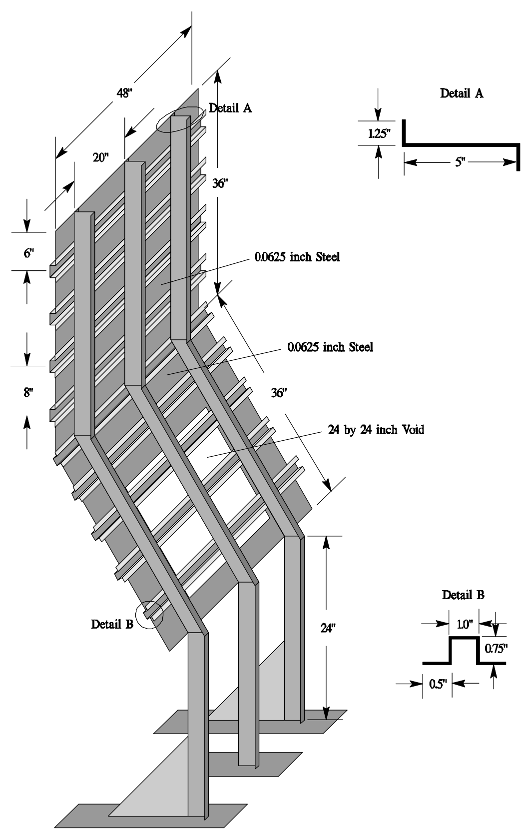

Figure 7. Improved Test Rig with 24 by 24-Inch Opening in Lower Steel Section

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 8, 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 9). 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.

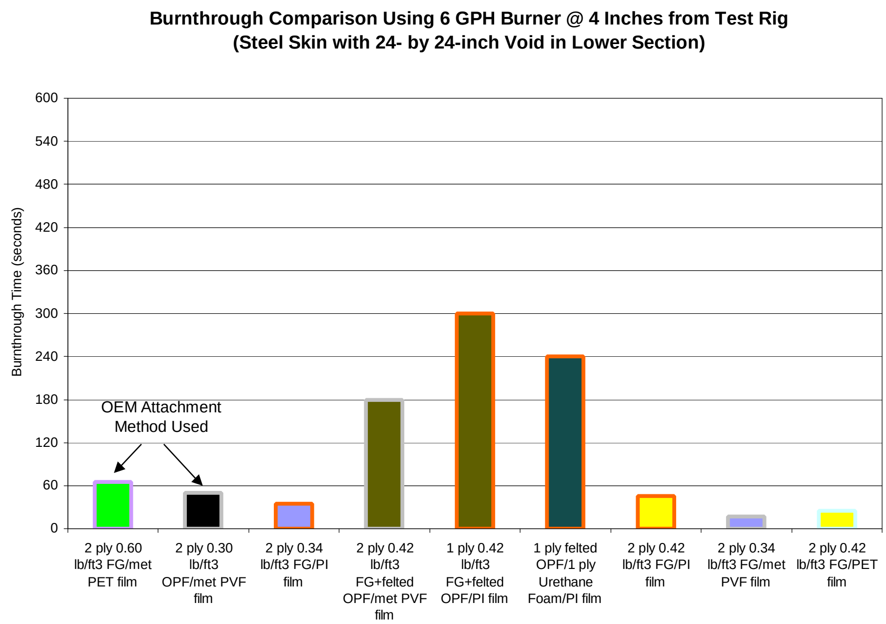

Figure 8. Burnthrough Test Results Using Test Rig with 24 by 24 Void in Lower Section

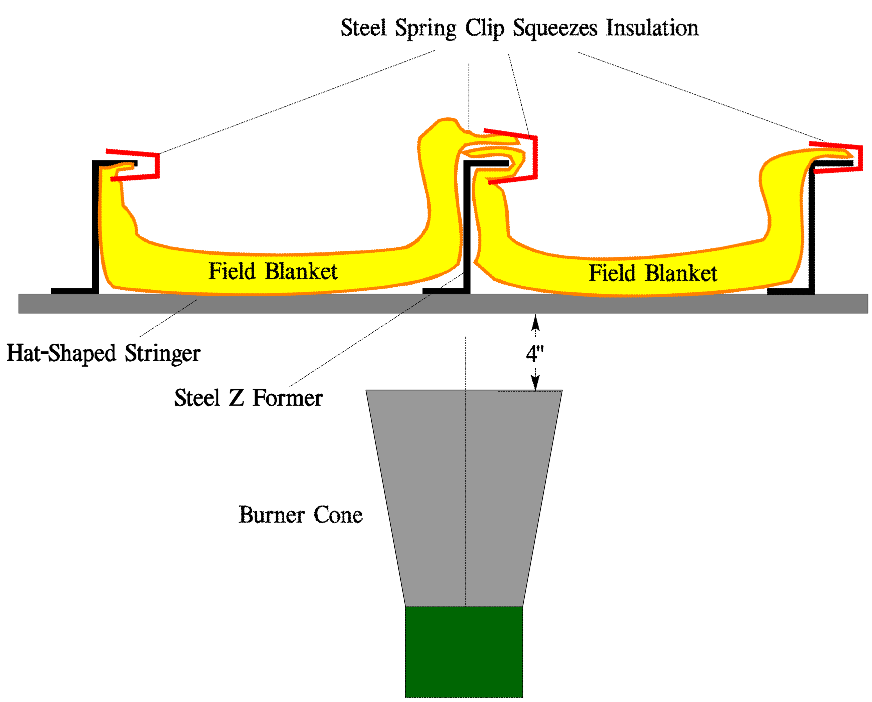

Figure 9. Improved Insulation Blanket Test Specimen Attachment Method

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 9 tests, since the periphery of the steel had no influence on the test outcome (figure 10). In all cases, the failures occurred on either side of the center vertical former.

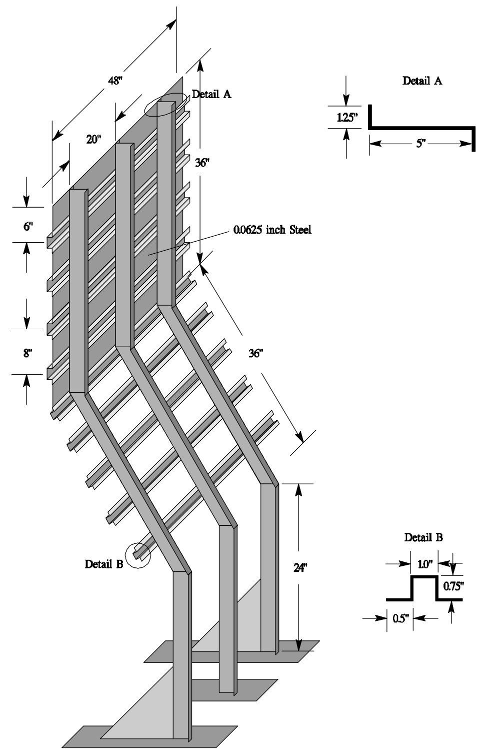

Figure 10. Test Rig with Lower Steel Panel Removed

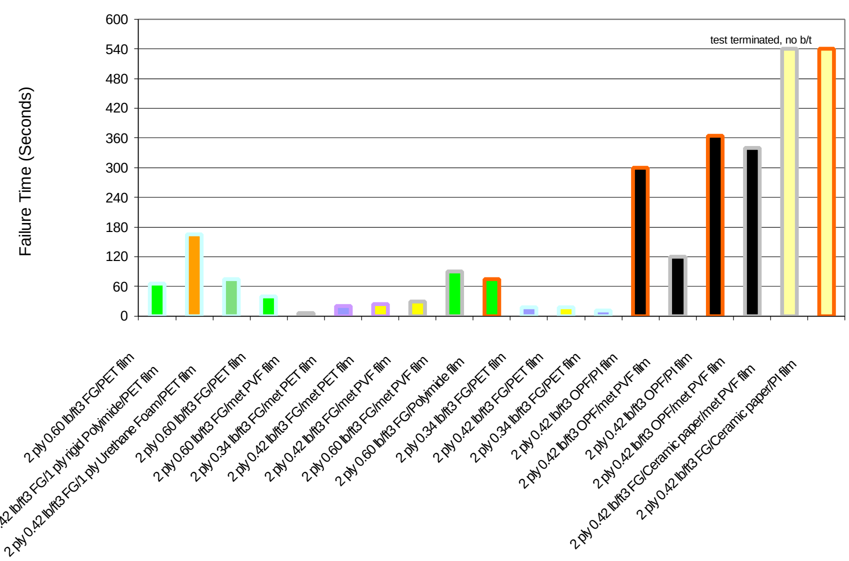

Figure 11. Burnthrough Test Comparison Using 6 GPH Burner @ 4 Inches from Test Rig

Additional testing was conducted on the modified test rig with favorable results, as shown in figures 11, 12, and 13.

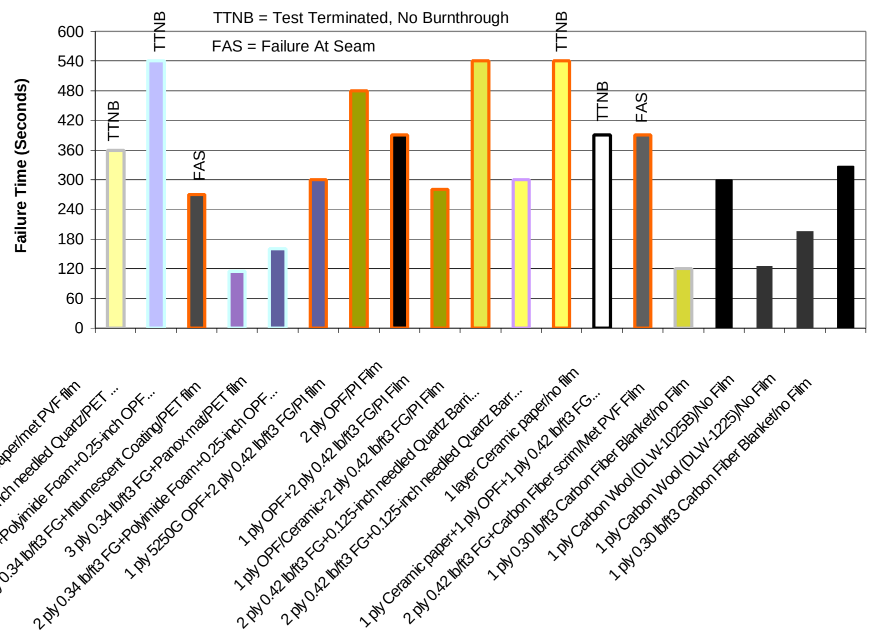

Figure 12. Burnthrough Test Comparison Using 6 GPH Burner @ 4 Inches from Test Rig

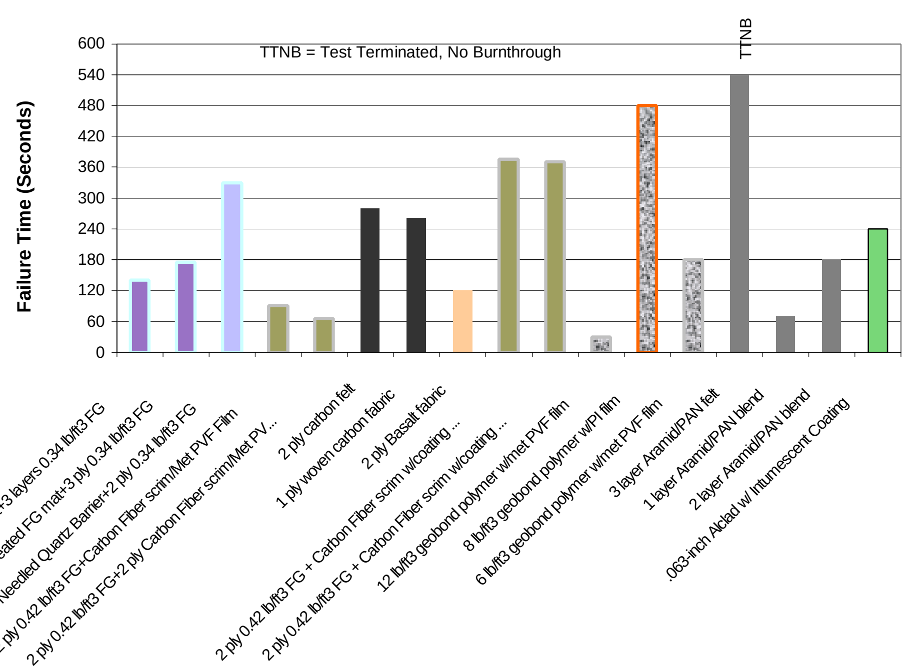

Figure 13. Burnthrough Test Comparison Using 6 GPH Burner at 4 Inches from Test Rig

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 failed in approximately 50 seconds, the contribution from the fiberglass insulation would be in the area of 30 to 50 seconds, or in proximity of the lab-scale findings. Moreover, other materials that were tested in both the full- and lab-scale apparatus showed excellent correlation, such as the OPF insulation and the ceramic dot-printed paper barrier. Each of these materials prevented burnthrough for a minimum of 5 minutes under full-scale conditions, and they exhibited similar results during lab tests, failing in the 5 to 6 minute range and beyond (figure 11).

DEVELOPMENT OF A BACK SIDE HEAT FLUX REQUIREMENT

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. A back face (cold side) maximum allowable heat flux requirement was conceived. In order to accomplish this, 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. Since the burnthrough failures were observed to occur on either side of the vertical former, the proposed test was changed to include 2 transducers mounted behind each of the blanket samples (figure 14).

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. Since limited testing proved this methodology unsuccessful, and the sole purpose of this apparatus was for the evaluation of insulation burnthrough resistance, the upper section was not necessary. Additional modest refinements were made to the burner equipment to ensure consistent test conditions in other laboratories.

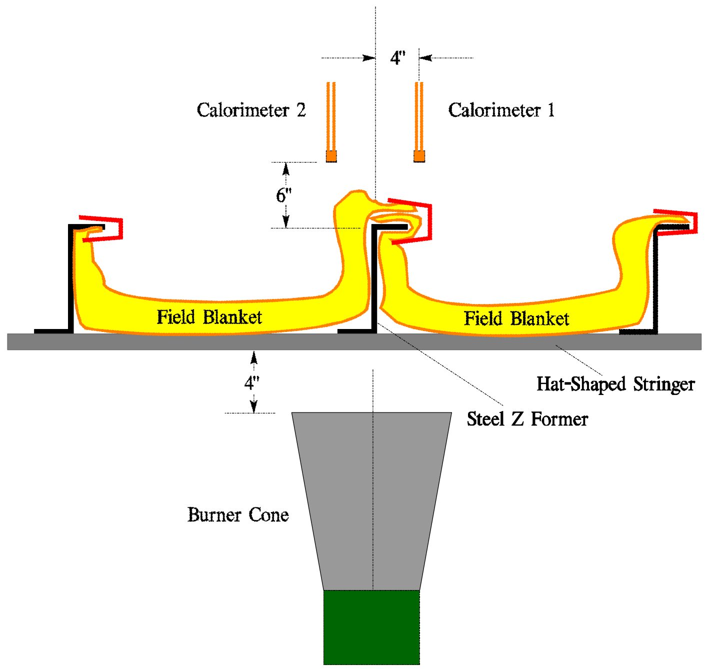

Figure 14. Placement of Heat Flux Transducer Used to Measure Backface Heat Flux

FINALIZED BURNTHROUGH TEST APPARATUS

The finalized test apparatus is shown in figure 15. As discussed previously, the proposed test subjects the insulation blanket specimen to an intense, oil-fired burner flame for a period of 4 minutes. The burner intensity is adjusted to produce a flame temperature of 1900^{o}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.

Figure 15. Finalized Burnthrough Test Rig

REFINEMENTS TO CALIBRATION AND TEST PROCEDURES

In order to ensure that the proposed test conditions are replicated in other laboratories, specific calibration and test procedures were implemented. Parameters such as the type of thermocouple (closed junction vs. open junction), and the size of the thermocouple were found to influence the measurement of the burner flames during calibration. In general, the open bead-type thermocouples have a much faster response than the closed-bead type, which results in higher recorded temperatures. Conversely, the larger thermocouples have a greater mass and essentially respond slower, thus producing lower recorded temperatures since the temperature peaks are not always fully realized.

In addition, the amount of time that the thermocouples and calorimeter were allowed to stabilize prior to recording values also affected the results, as did the method of averaging the values obtained. As shown in figure 16, the heat flux measurement is substantially reduced over a period of time due to the build-up of soot on the face of the calorimeter. Regardless of the amount of air flowing through the burner, a substantial drop-off in measured heat flux resulted after approximately 60-90 seconds of exposure.

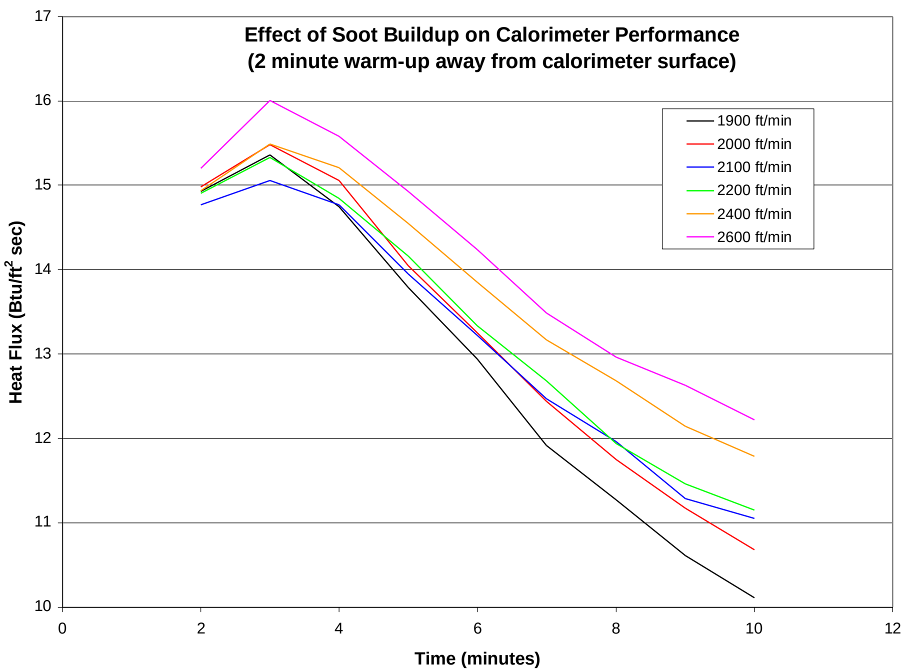

Figure 16. Effect of Soot Build-up on Calorimeter Performance

Similarly, the thermocouples required a period of time to fully stabilize, as shown in figure 17. Following a warm-up period, the burner is swung into place in front of the thermocouple rake. Testing determined that a 1-minute stabilization period was required to allow for accurate measurement of the burner flame.

The method of data collection and subsequent calculation of the temperatures and heat flux was then specified, since a variety of methods were found to produce dissimilar results. The prescribed method calls for a 2-minute warm-up of the burner, at which point it is positioned in front of either the thermocouple rake or calorimeter. After a 1-minute stabilization period, data collection begins for a 30-second period, once per second. This group of 30 data points is then averaged to yield a final number.

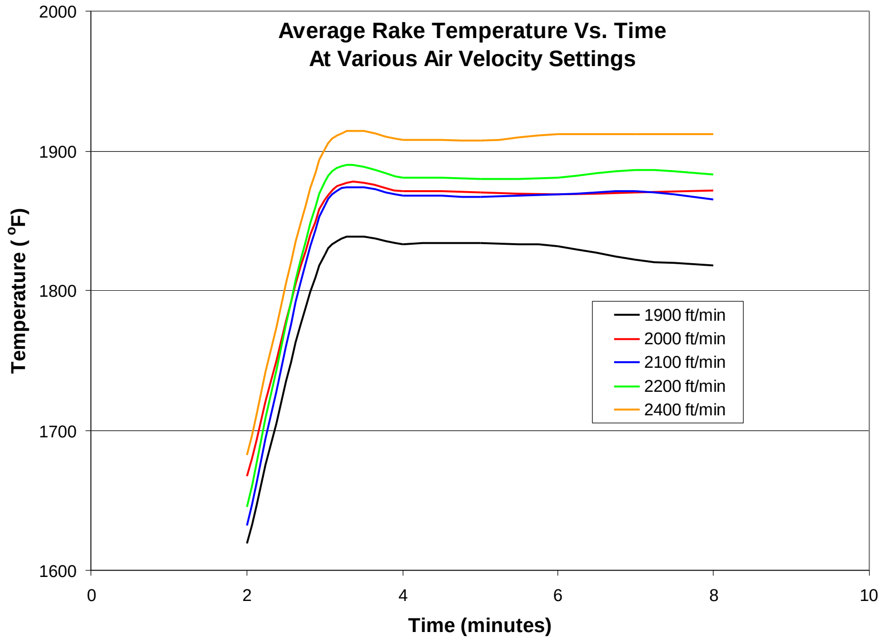

Figure 17. Average Rake Temperature Versus Time At Various Airflow Settings

There were also minor differences in the way that the actual test could be set up and executed, such as the technique for clamping the blankets onto the test frame. In order to assist in the proper conduct of a burnthrough test, a calibration/test guideline document was assembled and circulated to burnthrough labs. Although this document was for guidance only, it allowed the tester the opportunity to investigate many parameters that can influence the calibration and test outcome.

REFINEMENTS TO BURNER APPARATUS

In addition to the specific calibration and test procedures that were instituted, many tolerances were placed on the burner settings, as well as other critical dimensions and measurements. For example, the fuel and intake air velocity into the burner were specified as 6.0 +/- 0.2 GPH and 2150 +/- 50 FPM, respectively. These 2 parameters had the greatest influence on the size/intensity of the burner flames, particularly the air flowrate. However, the testing also highlighted several other parameters that influenced the calibrated flame temperature and heat flux, and therefore the outcome of the tests. In particular, the type of stators located in the middle and end of the draft tube used to swirl and diffuse the air entering the combustion cone were extremely important. It was determined that a variety of stator components were supplied with the Park burner equipment, depending on when it was purchased. As shown in figure 18, there were 2 distinct types of end stators. The F-124 (upper left) had a 2.75-inch inside diameter, while the F-124A (upper right) had a 2.625-inch inside diameter. Similarly, the H215 mid stator (lower left) measured 4 inches in diameter, while the other stator (lower right) measured 3.875 across. To further complicate the matter, each of these mid stators swirled the airflow in opposite directions.

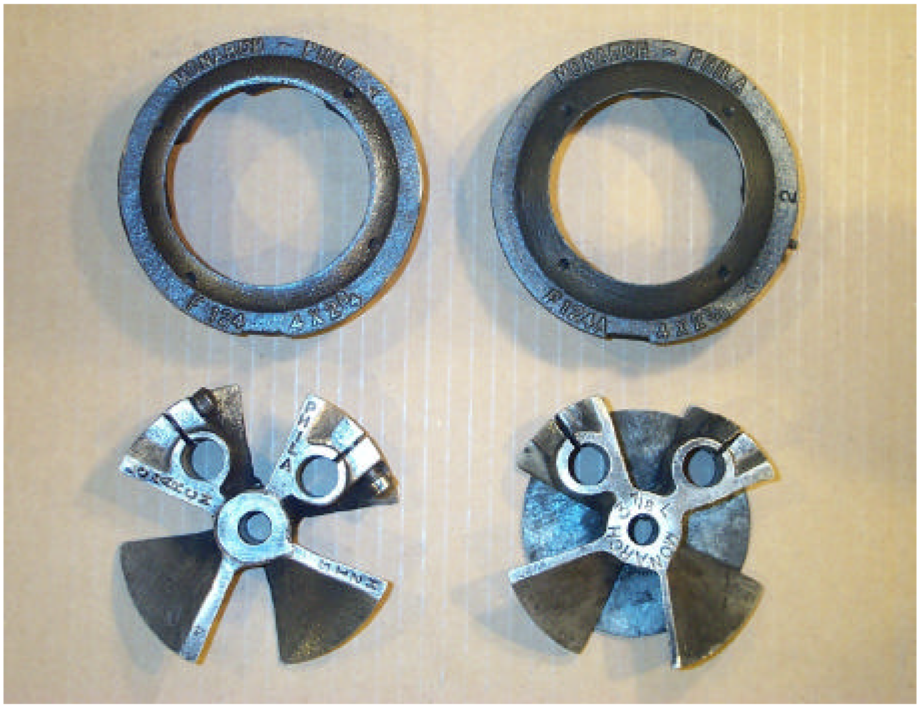

Figure 18. Various Stator Components Supplied with Test Burner

Several burners also included a "static disc" that was intended to stabilize the burner flame, while other units were not supplied with it (figure 19).

Figure 19. Static Disc Mounted to Mid Stator

An exhaustive study found that only one combination of stator types was capable of producing a consistent and even flame (Monarch H215 mid stator without static disc, and Monarch F124 end stator).

The switch from a semi-solid conical-spray patterned fuel nozzle to a hollow cone nozzle also aided in the evening of the flame profile. In addition, many parameters including the temperature of the fuel and air entering the burner, the position of the igniters, and the position of the stator in the draft tube also affected the flame profile. It was determined that in order to achieve the best calibration, the igniters needed to be set at approximately 10 o'clock when viewed from the draft tube end (figure 20).

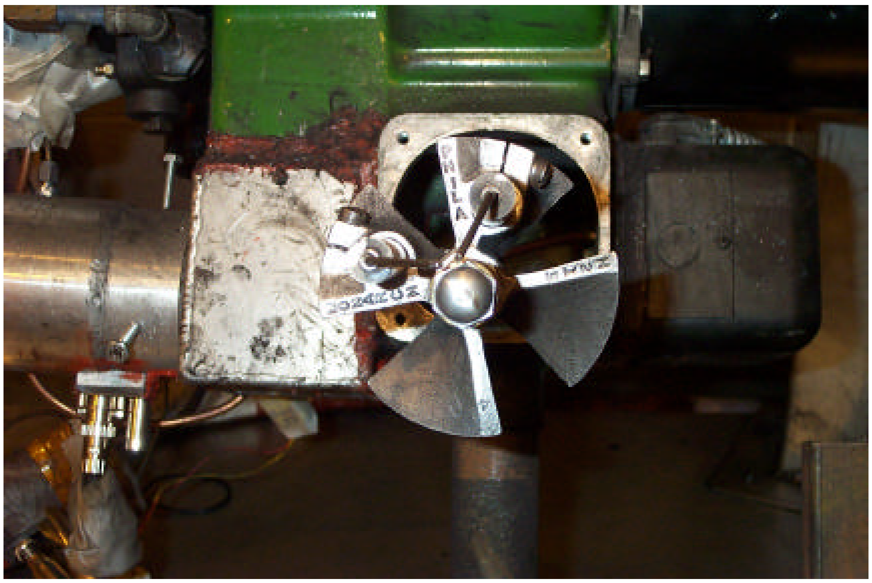

Figure 20. Preferred Position of Igniters to Achieve Calibration

<u>MEASUREMENT OF INTAKE AIR VELOCITY</u>

As mentioned previously, testing had determined that one of the most critical parameters in the burner set-up was the amount of air entering the intake. The amount of air affects not only the combustion characteristics of the fuel, but also the amount of force impacting the test sample. Since a majority of the insulation test samples are very light (i.e. "lofted") materials, higher airflows will cause quicker failures. For this reason, a very strict method for measuring the intake airflow was devised. The Park DPL oil burner used in the development testing did not have a flanged intake area that would allow for the precise fitting of an air velocity instrument (figure 21). As shown, an adapter plate with a cut-out designed to accept the air velocity instrument was first used at the intake opening. Although this approach allowed for reasonably accurate air velocity readings, clearance problems often limited the movement/adjustment of the damper plate. For this reason, an intake airbox was constructed and mounted to the burner to allow insertion of the air velocity meter. This configuration allowed for both constant air velocity monitoring and unlimited adjustment of the damper plate (figures 22 and 23). The air velocity measurements were obtained using an Omega HH-30A vane-type air velocity meter that yielded instantaneous measurements (figure 24). The cross-sectional area of the meter, 0.0376 ft^2, permitted the conversion of all air velocity measurements to volumetric flowrate, in ft^3/min (CFM).

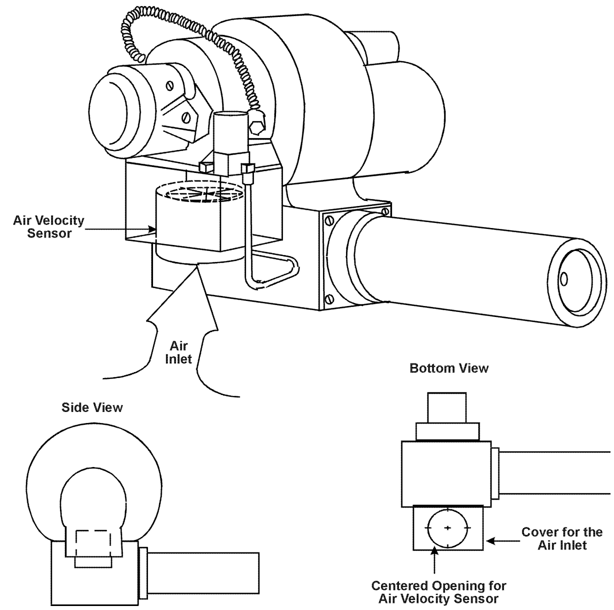

Figure 21. Park DPL Burner Air Intake

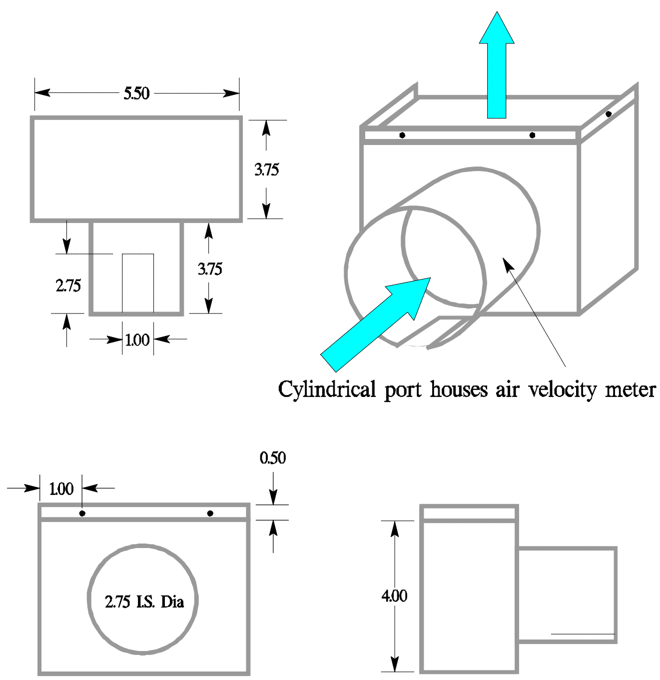

Figure 22. Schematic of Intake Airbox Used to Hold Air Velocity Meter

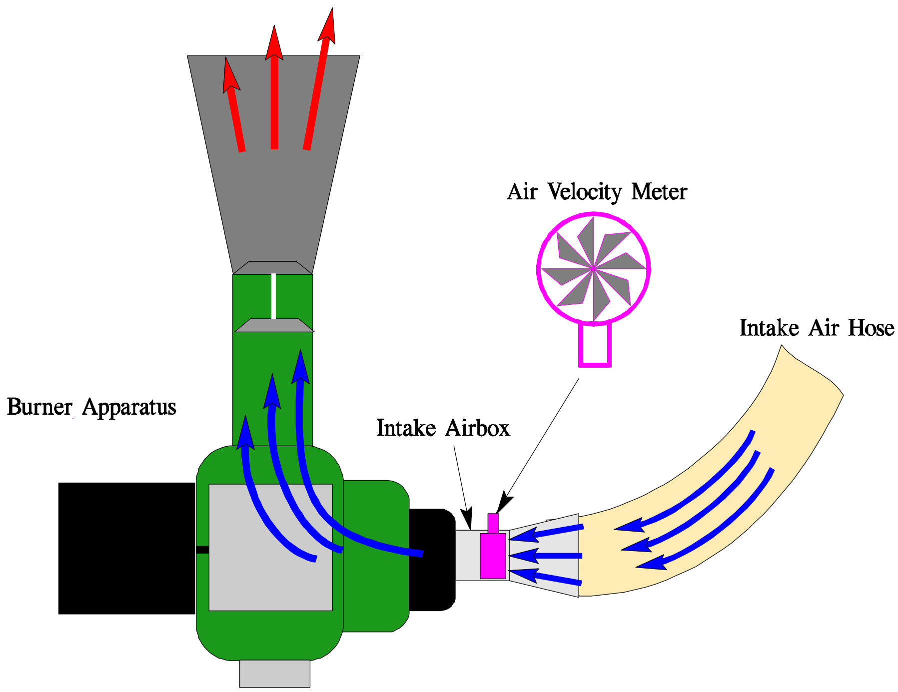

Figure 23. Schematic of Intake Air Velocity Measuring System

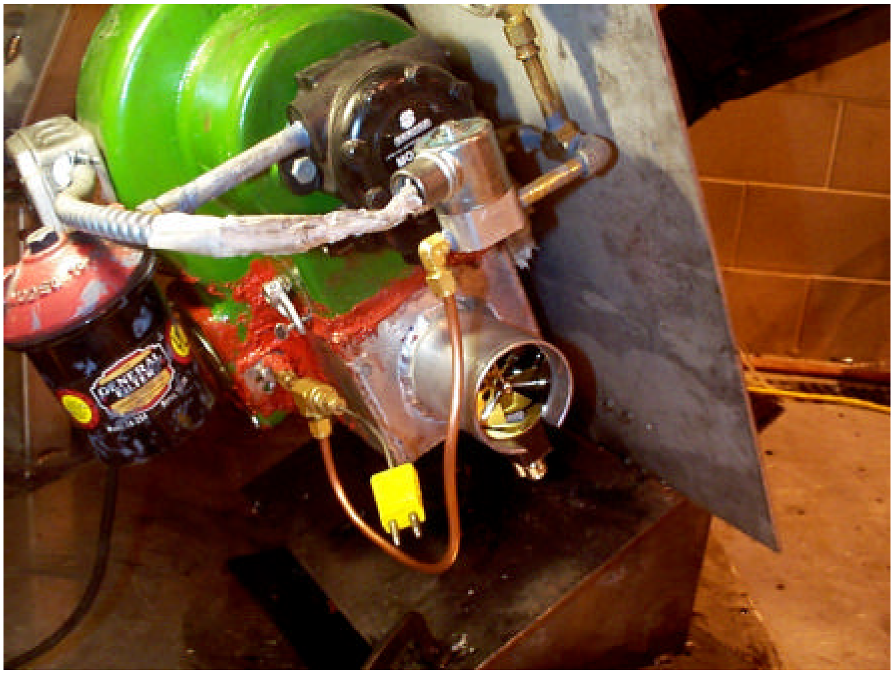

Figure 24. Intake Airbox Housing Omega HH-30A Velocity Meter

BURNER CORRELATION WITH FULL-SCALE TEST RESULTS

Although the refined burner configuration yielded results that correlated well with previous full-scale tests using identical materials, an additional comparison was made using the test equipment. To provide a direct comparison to the full-scale testing, the proposed burnthrough apparatus was outfitted with 0.063-inch Alclad 2024 T3 aluminum skin, identical to that used in the original full-scale tests. The skin was bolted to the test apparatus around the sample periphery, so as not to produce bolt holes that could weaken the skin area for burnthrough to occur prematurely. Since samples of 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 previously 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.

For the comparison testing, the fuel flowrate was held constant at 6 GPH, while the air flowrate going into the burner was varied slightly. All other adjustments and modifications to the burner and calibration procedures were made according to latest guidelines prior to running the test.

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 3-layer insulation sample, and 134 seconds for a 4-layer sample. These results compared reasonably well with the full-scale results, although it appeared this burner setting was somewhat less severe (figure 25). The 3 and 4 layer insulation samples required 14 and 38 seconds additional time, respectively, for the burner flames to fully penetrate.

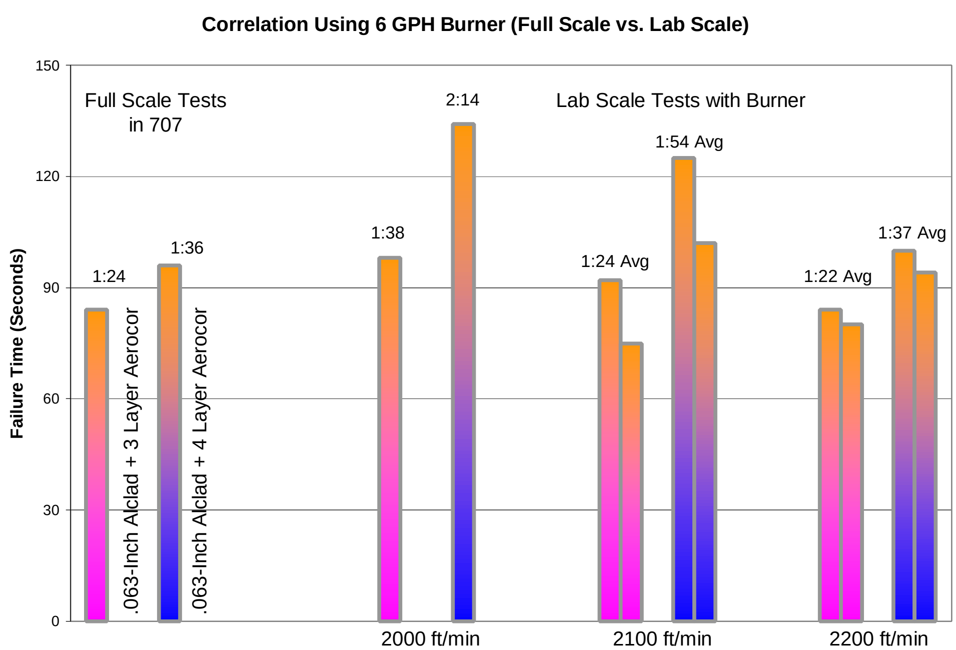

Figure 25. Correlation Test Results Using Proposed 6 GPH Burner

A second series of tests were run using a higher airflow through the burner. The intake air velocity was set at 2100 ft/min, which produced a slightly leaner flame. During this series, 2 tests each were run for the 3 and 4 layer configurations. The 3-layer configuration yielded an average failure time of 84 seconds, identical to that achieved during the full-scale test. However, the 4-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 4-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 FPM, producing an even leaner flame than previously. Again, 2 tests each were run for the 3 and 4 layer sample configurations. The 3-layer configuration yielded an average failure time of 82 seconds, nearly identical to the full-scale result, and the 4-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 full-scale when the intake air velocity was between 2100 and 2200 FPM.

Although it appeared the 6 GPH burner configuration yielded excellent correlation with full-scale results, several labs participating in the development of the new standard were having difficulty obtaining similar results. Some labs suggested that since the 6 GPH burner configuration was severely over-rich (i.e., insufficient combustion air for the amount of fuel being delivered through the nozzle) that small differences in the burner configuration would result in significant differences in the test results. For this reason, the FAA Technical Center agreed to run a series of tests at a reduced fuel flowrate to determine if leaner, less fuel-rich burner configurations could also yield results similar to full scale. To accomplish this, the fuel nozzle was changed to a 4 GPH, 80-degree spray angle unit with a PLP (semi-solid) spray pattern, identical to the original 6 GPH unit.

For the initial test, the intake airflow was adjusted to 2000 FPM. The flame was visibly less sooty, but significantly smaller in size. For the 3-layer insulation configuration with skin, the average failure time was 96 seconds, slightly longer than the full-scale result of 84 seconds (figure 26). Additional tests were run using the 4-layer configuration, which yielded an average failure time of 102 seconds, again slightly longer than the full-scale result of 96 seconds.

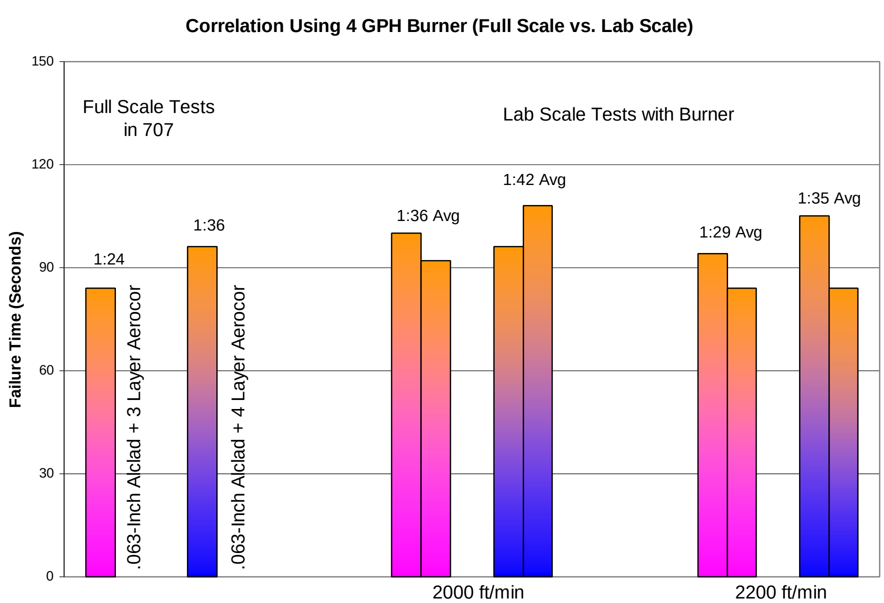

Figure 26. Correlation Test Results Using 4 GPH Arrangement

A following series of tests were run using a slightly higher intake air velocity of 2200 FPM, which leaned the flame out even more. This burner configuration yielded an average of 89 seconds for the 3-layer configuration, and 95 seconds for the 4-layer configuration. Although these results correlated well with the full-scale results, the burnthrough area was noticeably smaller than that achieved during the 6 GPH tests. It appeared that the leaner flame was more intense over a smaller area, resulting in a similar failure time using less fuel.

Since the primary objective of the research was not only to develop a test that was representative of full-scale conditions, but also repeatable for other laboratories conducting the test worldwide, the reduced fuel flowrate tests invoked interest. Following these tests, it was theorized that a variety of burner configurations could yield burnthrough times similar to full-scale, but only a small percentage of those configurations were representative of actual conditions. As a result, it was agreed that all future development on the test method would remain at the 6 GPH fuel flowrate. In addition, a series of comparison or “round robin” tests would be conducted by 10 laboratories using various standardized materials at the 6 GPH fuel flowrate.

ROUND ROBIN TESTING

The primary goal of round robin testing is to determine the amount of variation from lab to lab. This is accomplished by testing identically prepared samples at various participating labs, all of which must conduct the test according to a stringent set of guidelines. During the first burnthrough round robin, 10 labs participated, and a total of 8 different types of materials were tested; for each material type, 6 tests were conducted for a total of 48 tests per lab.

An analysis of the test results obtained during the first round robin indicated a fairly high degree of scatter existed between the labs. However, the initial round robin was the first attempt at formally conducting the test for most of the participants. In addition, many of the labs had not yet implemented the agreed-upon techniques and components used for refining the burner calibration and conduct of the test, which likely influenced the results. As shown in figure 27, a histogram of the failure times for 0.60 lb/ft^3 density fiberglass indicates that a majority of the failures were recorded in a specific range, while some of labs recorded failures that were obviously askew. This existed for all of the materials tested during the first round robin, which indicated that the skewed data was not due to a material anomaly, but rather due to the substantially contradictory results recorded by one lab. If this portion of the data is omitted, the modified data forms a more traditional bell curve distribution, with a substantial reduction in the standard deviation (figure 28).

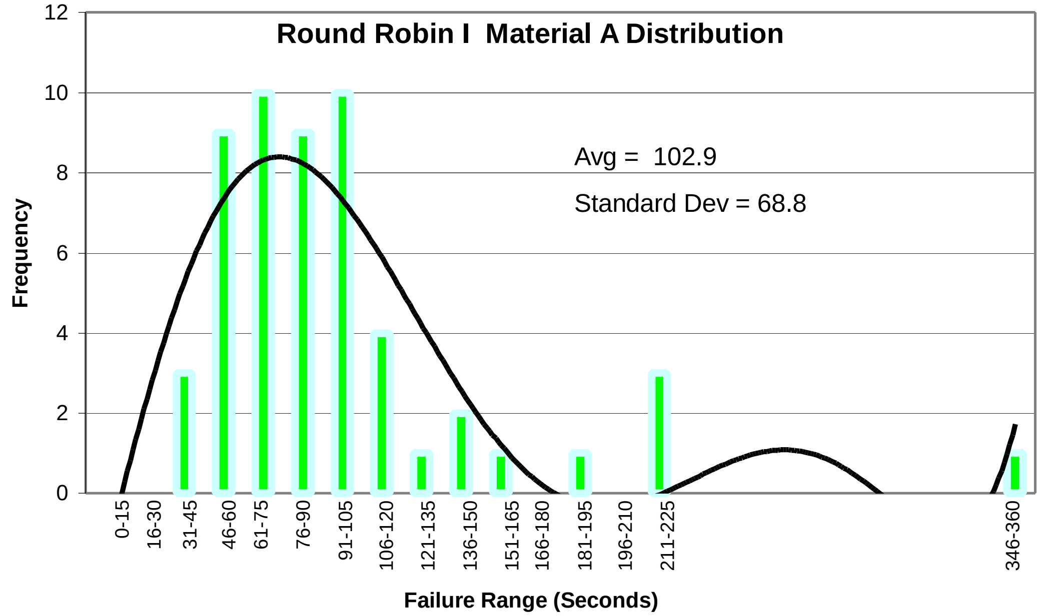

Figure 27. Round Robin I Histogram for 0.60 lb/ft^3 Density Fiberglass

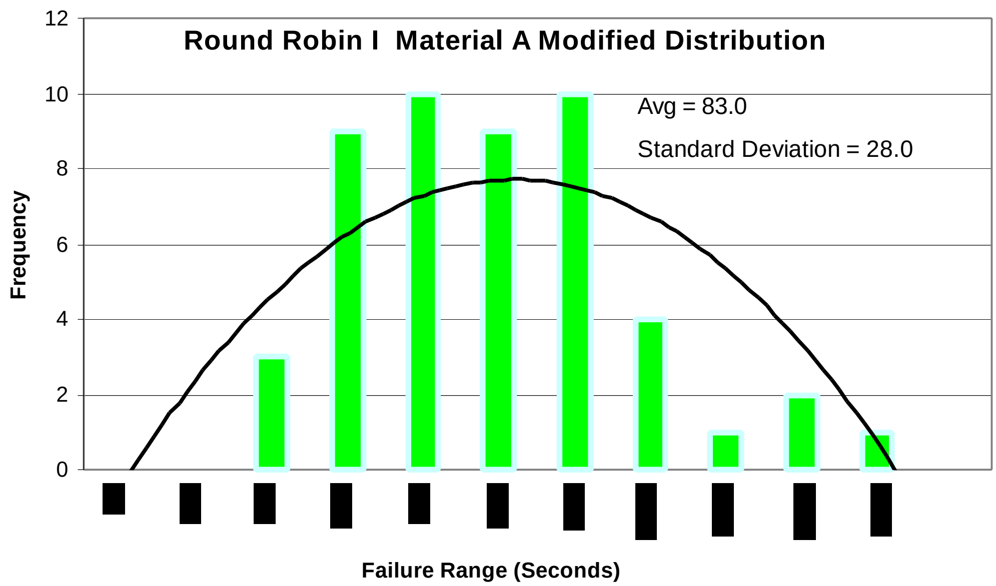

Figure 28. Round Robin I Modified Histogram for 0.60 lb/ft^3 Density Fiberglass

Although modification of the data resulted in a substantially reduced standard deviation, it was far too scattered for the test to be considered repeatable from lab to lab. In light of this, another round robin was arranged using the same fuel flowrate conditions, only with fewer materials to reduce the amount of testing. The second round robin included only 4 material types, each of which were tested only 4 times (16 tests total).

The second round robin test results indicated a reduced amount of scatter compared to the first round robin, which was likely due to the implementation of the refined calibration guidelines. However, the results highlighted a problem that existed with regard to one set of recorded failure times. As shown in figure 29, while a majority of the failures occurred within a specific range, there were still recorded failures well outside the expected range. These failure times were all recorded by one particular lab. As with the previous round robin, the data was modified to omit all failures outside the expected values, which greatly reduced the standard deviation (figure 30).

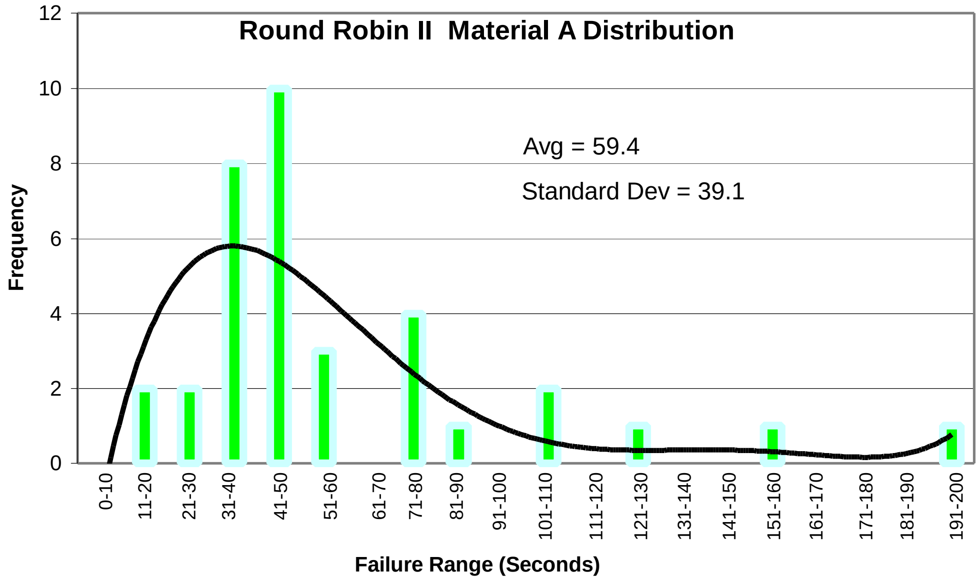

Figure 29. Round Robin II Histogram for 0.60 lb/ft^3 Density Fiberglass

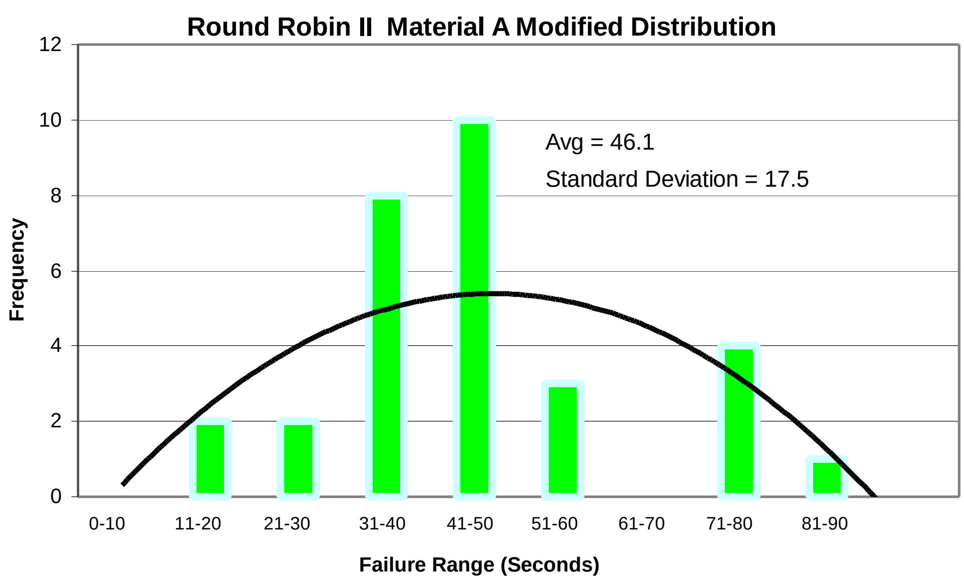

Figure 30. Round Robin II Modified Histogram for 0.60 lb/ft^3 Density Fiberglass

As discussed previously, many factors can influence the output of the burner, including the method of calibration, and the actual burner set-up. Although the method of calibration was refined, it was discovered that several different components were supplied with the burners used in the round robins. Most notably was the variety of internal stators used, which can significantly affect the burner flame characteristics (table 4 top). This problem was not fully realized until after the second round robin was completed. In an effort to eliminate the burner equipment as the cause of the data scatter, all burners were upgraded to contain the proper stators and fuel nozzles, and all static discs and flame enhancement tabs were removed. This resulted in all labs having an identical burner apparatus (table 4 bottom).

Table 4. Various Burner Components Used in Round Robins I and II

Round Robin I & II									
Lab Code (A-J)	Internal Turbulator Rotation	Internal Turbulator O.D. (inches)	Internal Turbulator Type	End Turbulator Rotation	End Turbulator I.D. (inches)	End Turbulator Type	Static Disc Used (Y/N)	Tabs Used (Y/N)	Nozzle Type
A	CCW	4.000	Monarch H215	CW	2.75	Monarch F124	Y	Y	Hago 6.00
B	CW	4.000	Monarch 4L	CW	2.75	Monarch F124	Y	Y	?
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	CW	4.000	Monarch 4 1/2 L	CW	2.75	Monarch F124	Y	Y	Monarch 2.00
E	CW	4.000	Monarch 4 1/2 L	CW	2.75	Monarch F124	Y	Y	Monarch 6.00 80° PLP
F	CW	3.875	Monarch 3 7/8L	CW	2.625	Monarch F124A	Y	Y	Monarch 6.00 80° PLP
G	CCW	4.000	Monarch H215	CW	2.75	Monarch F124	Y	Y	?
H	CCW	4.000	Monarch H215	CW	2.75	Monarch F124	Y	Y	Monarch 6.00 80° PLP
I	CCW	4.000	Monarch H215	CW	2.75	Monarch F124	Y	Y	Monarch 6.00 80° PLP
J	CCW	4.000	Monarch H215	CW	2.75	Monarch F124	Y	N	Monarch 6.00 80° PLP

Round Robin III & IV									
Lab Code (A-J)	Internal Turbulator Rotation	Internal Turbulator O.D. (inches)	Internal Turbulator Type	End Turbulator Rotation	End Turbulator I.D. (inches)	End Turbulator Type	Static Disc Used (Y/N)	Tabs Used (Y/N)	Nozzle Type
A	CCW	4.000	Monarch H215	CW	2.75	Monarch F124	N	N	Monarch 6.00 80° PL
B	CCW	4.000	Monarch H215*	CW	2.75	Monarch F124	N	N	Monarch 6.00 80° PL
C	CCW	4.000	Monarch H215	CW	2.75	Monarch F124	N	N	Monarch 6.00 80° PL
D	CCW	4.000	Monarch H215*	CW	2.75	Monarch F124	N	N	Monarch 6.00 80° PL
E	CCW	4.000	Monarch H215*	CW	2.75	Monarch F124	N	N	Monarch 6.00 80° PL
F	CCW	4.000	Monarch H215	CW	2.75	Monarch F124	N	N	Monarch 6.00 80° PL
G	CCW	4.000	Monarch H215	CW	2.75	Monarch F124	N	N	Monarch 6.00 80° PL
H	CCW	4.000	Monarch H215	CW	2.75	Monarch F124	N	N	Monarch 6.00 80° PL
I	CCW	4.000	Monarch H215	CW	2.75	Monarch F124	N	N	Monarch 6.00 80° PL
J	CCW	4.000	Monarch H215	CW	2.75	Monarch F124	N	N	Monarch 6.00 80° PL

*replicate burner component

correct burner component

Following the effort to correct the differences in the burner equipment, two subsequent round robin test series were conducted that showed further reduction in the data scatter, indicating better inter-lab correlation was possible. As shown in figure 31, the standard deviation was reduced to 12 seconds for the 0.60 lb/ft^3 density fiberglass. By comparison, the standard deviation was 69 and 39 seconds for round robins I and II, respectively. Round robin III was also the first series in which the data did not require modification to produce the traditional bell curve distribution. The standard deviation was further reduced in round robin IV, indicating many of the earlier problems with the equipment had been corrected (figure 32). Many of the labs had more experience operating the equipment at this point, which also helped reduce the amount of fluctuation in test results between labs.

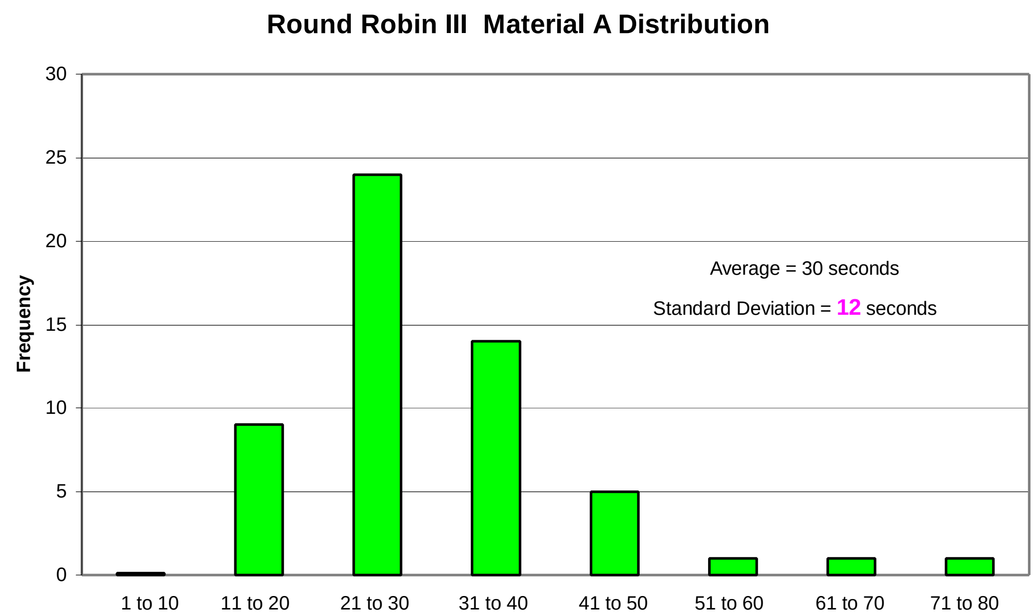

Figure 31. Round Robin III Histogram for 0.60 lb/ft^3 Density Fiberglass

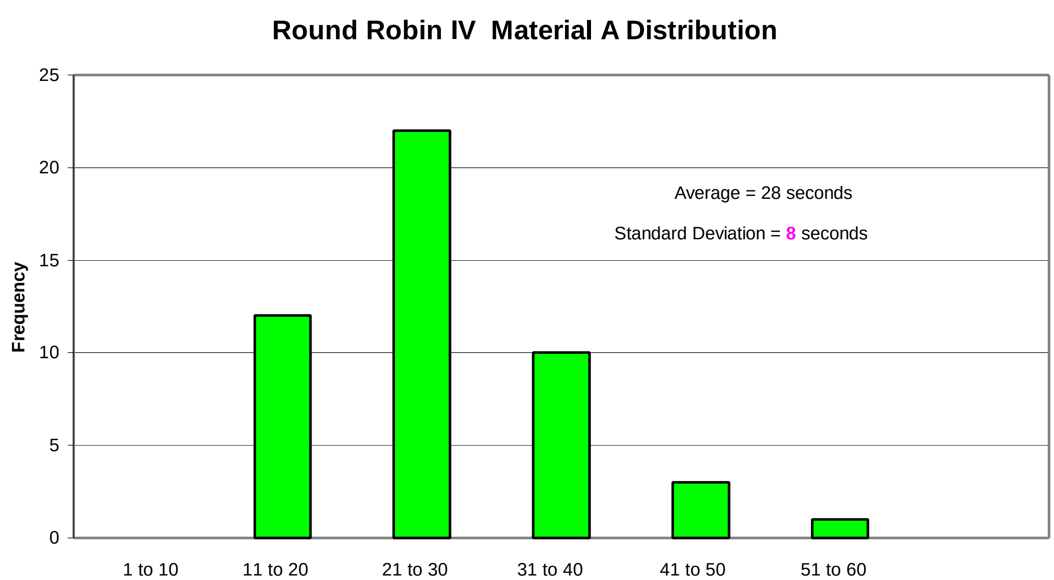

Figure 32. Round Robin IV Histogram for 0.60 lb/ft^3 Density Fiberglass

During the four round robin test series, there were many different types of materials used in an effort to fully exploit any deficiencies with the test equipment. For this reason, it was not possible to examine the trend in standard deviation for a variety of materials, with the exception of the 0.60 lb/ft^3 fiberglass, which was used in all four test series; variants of an oxidized polyacrylonitrile fiber were used in the three of the four studies. As shown in figure 33, the trend in standard deviation decreases over the course of the four studies, indicating the test method is repeatable.

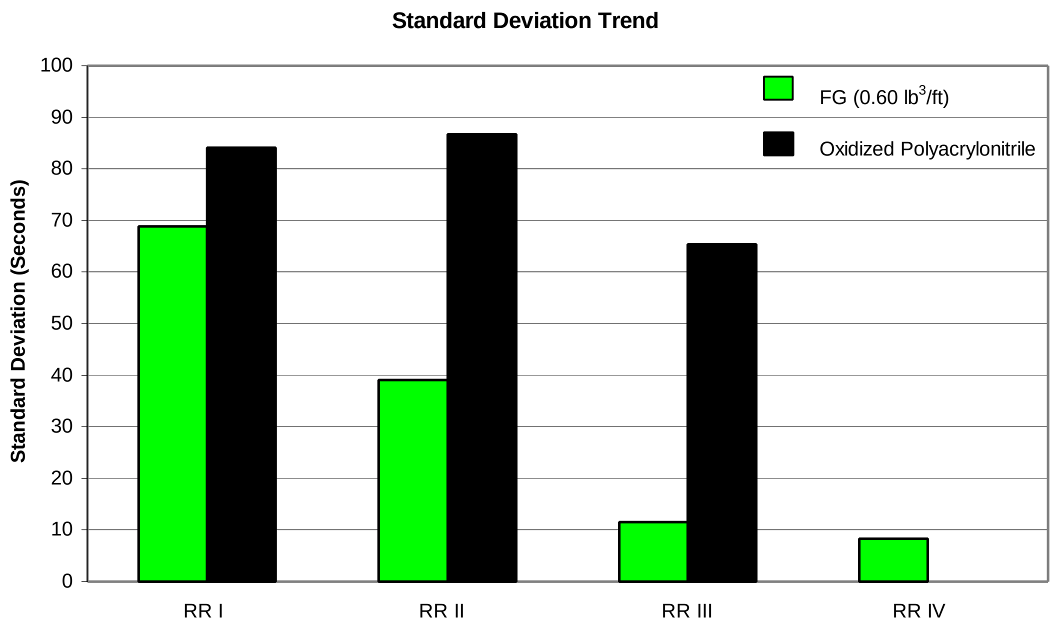

Figure 33. Standard Deviation Trend, Round Robin I through IV

SUMMARY OF BURNTHROUGH TESTING

During the development of the test method, many variations of the proposed test rig were evaluated. Early in the development phase, a singular test for measuring burnthrough and ignition/flame propagation was sought, but this approach was abandoned, and separate tests were pursued. The burnthrough test apparatus was also simplified greatly, as 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 flames, and the initial goal of a 5-minute requirement for the combined skin/insulation materials was reduced to 4 minutes for the insulation only.

During testing, it was 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 type of insulation exhibited premature failures along the vertical former seams. In addition, the composition of the insulation bagging material, normally a thermoplastic film, was not an important factor in preventing burnthrough. However, the use of polyimide film was capable of extending the burnthrough time of fiberglass insulation by as much as 40 seconds over other thermoplastic materials.

Approximately 60 trial tests were conducted on a wide variety of materials, 80% of which were conducted using the finalized apparatus. The trial tests included lofted insulation types that could replace the existing fiberglass, as well as barrier materials that could be used in conjunction with the fiberglass. In particular, a heat-treated, oxidized polyacrylonitrile fiber (OPF) insulation encased in a polyimide bagging material prevented burnthrough for over 6 minutes, while a thin paper-like, dot-printed ceramic barrier was capable of preventing burnthrough failure for over 8 minutes when used in conjunction with fiberglass. 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. Materials that act as flame arresters, rather than flame blockers, allow substantial heat to progress inward once the main batting (typically fiberglass) is depleted. As a result, a maximum allowable heat flux of 2.0 Btu/ft^2 sec was established on the back face (cold side) of the test rig, at a distance of 12 inches from the test rig front face. The trial test results correlated well with previous full-scale burnthrough test results, and several materials were identified that could meet the proposed test method.

Once the test method had exhibited correlation to the full-scale results, refinements were made to increase the test repeatability. The initial refinements focused on the calibration and test procedures. Testing had shown that following the burner warm-up period, the amount of time that the calorimeter and thermocouple rake were exposed to the burner flames was critical. Since the equipment operates in an overly fuel rich condition to best simulate an actual fuel fire, soot typically builds up on the face of the calorimeter within 90 seconds of flame application. After this period, the accuracy of the instrument is significantly reduced, and therefore important to take measurements within this 90-second period. The method of collecting data and averaging it to produce a final number was also important, since various methods were determined to yield differing results. After refining the calibration process, the focus shifted to refinement of the burner equipment. An investigation revealed that a variety of burner components were supplied with the Park style burner used in the proposed test, so an effort was undertaken to standardize all burner components. This included the internal and external stators, the removal of static discs, and the use of a common fuel nozzle.

The measurement of the intake air velocity was also critical in the test repeatability. Since the installation of a semi-permanent air velocity instrument at the intake of the original Park style burner was not feasible, the construction of an intake airbox was performed to facilitate its installation. This allowed continuous and consistent air velocity readings, which greatly improved the ability to calibrate the equipment.

Once the proposed test apparatus and conditions were refined, a mock-up series of correlation tests were performed to evaluate the finalized 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. Test trials at various settings revealed that an air intake velocity of between 2100 and 2200 FPM produced the best correlation to full-scale results. At this setting, the flame temperature was approximately 1900^{o}F with a heat flux of 16.0 Btu/ft^2 sec. Additional correlation tests were also run at a reduced fuel flowrate of 4 GPH to determine if a less fuel-rich burner flame could provide similar results. Although the correlation was good, the burnthrough failure area was much smaller and confined compared to the result obtained during the 6 GPH trials.

An initial “round robin” test series between various laboratories was conducted with an array of standardized materials. The results indicated a moderate amount of scatter existed between the labs, necessitating that an additional series be undertaken in an effort to reduce the scatter. A second round robin test series was conducted using fewer materials, and the results showed the level of scatter was significantly reduced. After making further refinements to the calibration and test methods, two additional round robin series were conducted with even more favorable results. These results indicated a high level of inter-lab correlation was possible using the proposed test equipment.

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