DOT/FAA/TC-24/33

Federal Aviation Administration
William J. Hughes Technical Center
Aviation Research Division
Atlantic City International Airport
New Jersey 08405

Development of a Revised Test Method for Evaluating the Performance of Evacuation Slide Materials during Exposure to Radiant Heat

October 2024

Final report

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/TC-24/33		
4. Title and Subtitle Development of a Revised Test Method for Evaluating the Performance of Evacuation Slide Materials During Exposure to Radiant Heat		5. Report Date October 2024 6. Performing Organization Code ANG-E212
7. Author(s) Steven Rehn, Dung Do, Timothy R. Marker, Tina Emami		8. Performing Organization Report No.
9. Performing Organization Name and Address FAA William J. Hughes Technical Center Airport and Aircraft Research and Development Division - Fire Safety Branch Atlantic City International Airport, NJ 08405		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation - Federal Aviation Administration Air Traffic Organization Operations Planning Office of Aviation Research and Development Washington, DC 20591		13. Type of Report and Period Covered Technical Report 14. Sponsoring Agency Code ANG-E2
15. Supplementary Notes		

16. Abstract

This report summarizes the research effort undertaken by the Federal Aviation Administration (FAA) to develop an improved test methodology for determining the performance of aircraft evacuation slide materials when exposed to radiant heat. A laboratory-scale test method was previously developed by the FAA circa 1983, which used a pressurized cylinder apparatus on which a sample of evacuation slide material is mounted. The slide sample material was exposed to an electrically powered radiant heat source that simulated the heat flux typical of a fully-developed jet fuel fire. The purpose of the test was to determine the ability of an evacuation slide to maintain pressurization when the material was exposed to radiant heat, as past aircraft accidents had shown that evacuation slides were losing pressure prematurely during exposure to jet fuel fires.

An adjustable voltage regulator was used to set the level of heat flux of the radiant heater before the test, as measured by the calorimeter. Once the heat flux was set, a test was conducted in which the slide material was exposed to the radiant heat source. During a test, it was possible for normal supply voltage fluctuations to increase or decrease the previously-set heat flux level of the radiant heater resulting in poor test repeatability.

An improved test method in which the electrical power input to the radiant heater was continuously monitored and adjusted for the duration of the test. This ensures that fluctuations in supply voltage are accounted for, to prevent any variability in the heat flux level generated by the heater. In addition to the adjustable voltage regulator, the improved methodology also requires a digital amp meter to measure the amount of electrical current entering the radiant heater.

Numerous trials were conducted to determine the repeatability of different radiant heaters and heat flux gauges to potentially improve the calibration method. The heat flux gauges proved to be much more consistent and require yearly recalibration making them essential for proper calibration of the evacuation slide test apparatus.

17. Key Words	18. Distribution Statement
Aircraft Fire Safety--Radiant Heat Aircraft Fire Safety--Evacuation Slide Aircraft Fire Safety--Electrical Power Aircraft Fire Safety--Postcrash Survivability	This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161. This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages
Unclassified	Unclassified	72

Contents

Figures

Tables

Acronyms

Acronym	**Definition**
AC	Alternating current
ASTM	American Society of Testing and Materials
Btu/ft^{2}s	Unit of heat flux, British Thermal Unit per foot-squared per second
calorimeter	Gardon-style heat flux gauge
EAM	Eastern Aero Marine
FAA	Federal Aviation Administration
HFC	Heat flux gauge
ID	Inside diameter
NPT	National Pipe Thread
Nylon®	Registered trademark of Dupont
OD	Outside diameter
SAE	Society of Automotive Engineers
TSO	Technical Standard Order
variac	adjustable voltage regulator

Executive summary

The primary means of egress from a commercial aircraft during an emergency evacuation is via the inflatable passenger slides. Inflatable slides have improved greatly since their introduction into service over 60 years ago. The FAA developed a Technical Standard Order (TSO) that specified a performance test for the materials used in the manufacture of evacuation slides. TSO-C69a was implemented in 1983. This TSO uses a sample of evacuation slide material mounted on a pressurized cylinder apparatus. The slide sample material is exposed to a radiant heat source that simulates the heat flux typical of a fully-developed jet fuel fire.

The purpose of the test was to determine the ability of an evacuation slide to maintain pressurization when the material was exposed to radiant heat. In the past, aircraft accidents showed that evacuation slides were losing pressure prematurely during exposure to jet fuel fires. Premature loss of pressure and slide deflation could result in loss of evacuation slide function, making emergency evacuation difficult or impossible. The original TSO-C69a was revised in August 1988 (TSO-C69b), in which the required inflation time decreased from 10 seconds to 6 seconds after actuation of the inflation controls begins. A final revision, TSO-C69c was issued in August of 1999, which required the pressure holding materials in the device to meet a 90-second minimum time-to-failure requirement and a 180-second average time to failure requirement during the radiant heat resistance tests.

The original test methodology in the TSOs used an electrically-powered radiant heater to simulate the heat flux of a large jet fuel fire. This was calibrated using a Gardon-style heat flux gauge, also referred to as a calorimeter. An adjustable voltage regulator (variac) was used to set the level of heat flux of the radiant heater before the test, as measured by the calorimeter. Once the heat flux was set, a test was conducted where the slide material was exposed to the radiant heat source. During a typical 3-minute test, it was possible for normal supply voltage fluctuations to increase or decrease the previously-set heat flux level of the radiant heater.

The improved test method requires the electrical power input to the radiant heater to be continuously monitored and adjusted for the duration of the test. This ensures that fluctuations in supply voltage are accounted for, to prevent any variability in the heat flux level generated by the radiant heater. In addition to the adjustable voltage regulator, the improved methodology also requires a digital amp meter to measure the amount of electrical current entering the radiant heater.

Numerous trials were conducted to determine the repeatability of different radiant heaters and heat flux gauges to potentially improve the calibration method. The heat flux gauges proved to

be much more consistent and require yearly recalibration making them essential for proper calibration of the evacuation slide test apparatus.

1 Introduction

1.1 Purpose

This report describes the research undertaken by the Federal Aviation Administration (FAA) to develop an improved test methodology for measuring the thermal resistance of evacuation slide materials. Among other improvements, the new methodology monitors and controls the amount of electrical power input to the radiant heater used in the test after calibration. By controlling the input power to the heater, better accuracy is maintained throughout the test by eliminating increases or decreases in heater intensity caused by supply voltage fluctuations.

1.2 Background

The primary means of egress from a commercial aircraft during an emergency evacuation is via the inflatable passenger slides. Inflatable slides have improved greatly since their introduction into service over 60 years ago (Brown & Nicholas, 1981). The original TSO, TSO-C69 in 1961, created minimum performance standards for emergency evacuation slides in commercial aircraft, including a flammability standard consisting of testing the slide material in the horizontal Bunsen burner test (Federal Aviation Agency, 1961). However, several subsequent accidents showed that some slides lost pressure prematurely during exposure to jet fuel fires. The fire and accompanying intense radiant heat during an accident can cause an overpressure, subsequent seam rupture, resulting in pressure loss in the slide. Premature pressure loss and deflation could result in loss of function, making emergency evacuation difficult or impossible. One such example occurred during an accident on March 1, 1978, at Los Angeles International airport where a number of slides were rendered unusable due to the external fuel fire. Following this accident, a review of the fire-induced failure modes of evacuation slide materials was initiated at the FAA William J. Hughes Technical Center (formerly the National Aviation Facilities Experimental Center, NAFEC). Among other findings, the study concluded that, “the low resistance of evacuation slide materials to radiant heat produced by a free-burning fuel fire can cause early deflation of the escape slides” (Geyer, Brown, Neri, & O'Niell, 1978).

Subsequent to the studies, the FAA updated the TSO that specified a performance test for the materials used in the manufacture of evacuation slides. TSO-C69a was implemented in 1983, which specifies a test apparatus that consists of a sample of evacuation slide material mounted on a pressurized cylinder apparatus . The slide sample material is exposed to a radiant heat source that simulates the heat flux typical of a fully developed jet fuel fire (Federal Aviation Administration, 1983). The purpose of the test was to determine the ability of an evacuation slide to maintain pressurization when the material was exposed to radiant heat. TSO-C69a was revised in August 1988, TSO-C69b, which reduced the time allowable for a slide to inflate from 10 seconds to 6 seconds, once actuation of the inflation controls begins (Federal Aviation Administration, 1988). A final revision, TSO-C69c, was issued in August of 1999, requiring the pressure holding materials in the device to meet a 90-second minimum time-to-failure requirement and a 180-second average time-to-failure requirement during the radiant heat resistance test (Federal Aviation Administration, 1999). The test method was also included in Chapter 9 of the Aircraft Materials Fire Test Handbook (Federal Aviation Administration, 2000).

The electrically-powered radiant heater used in the test to simulate typical fuel fire heat flux levels is calibrated using a calorimeter. A variac is used to set the level of heat flux before the test, as measured by the calorimeter. Once the heat flux is set, a test was conducted in which the slide material is exposed to the radiant heat source. During a typical 3-minute test, it is possible for normal supply voltage fluctuations to increase or decrease the previously set heat flux level of the radiant heater. Interlab studies using identically prepared materials often yield test results that do not correlate well between various laboratories.

To limit radiant heater fluctuation during tests, an improved test method, in which the electrical power input to the radiant heater is continuously monitored and adjusted for the duration of the test. This ensures that fluctuations in supply voltage are accounted for, to prevent any variability in the heat flux level generated by the radiant heater. In addition to the adjustable voltage regulator, the improved methodology also requires a digital amp meter to measure the amount of electrical current entering the radiant heater.

Following the development of this new methodology, numerous trials were conducted to determine the amount of electrical power required to energize the radiant heater to produce the correct 1.5 Btu/ft^{2}s heat flux level at a 2-inch distance from the face of the heater, which was the specified heat flux level required in the original test method. Testing was completed to determine whether measuring the power input to the heater would be a more repeatable method to calibrate the evacuation slide test apparatus compared to measuring the heat flux.

2 Experiments

2.1 Overview

The evacuation slide test consists of 7-inch diameter pressurized cylinder to hold the test sample and a 3-inch diameter electric furnace as the radiant heat source. An overview of the test apparatus is shown in Figure 1. To run a test, the electric heater must first warm up for 30 to 45 minutes. The calorimeter is rotated into place, centered, and positioned 1.5 inches from the front of the furnace. The voltage of the electric furnace is adjusted until the heat flux reaches 2.0 Btu/ft^{2}s. Then the calorimeter slides further away until the heat flux reads 1.5 Btu/ft^{2}s. The surface of the test sample is placed in this position for testing. The calorimeter is then rotated out of position to make room for the pressure cylinder.

The test sample is placed at the open end of the pressurized cylinder and held in place by an aluminum ring with eight bolts and sealed with a neoprene gasket on each side of the sample. Next, the cylinder is pressurized and must hold its pressure for 3 minutes before being rotated in front of the furnace to ensure there are no leaks. The pressurized cylinder is rotated in front of the furnace to begin the test. During testing, the pressure is monitored, and the first observed pressure loss is the point of failure. If the pressure never drops, the test is ended after 5 minutes.

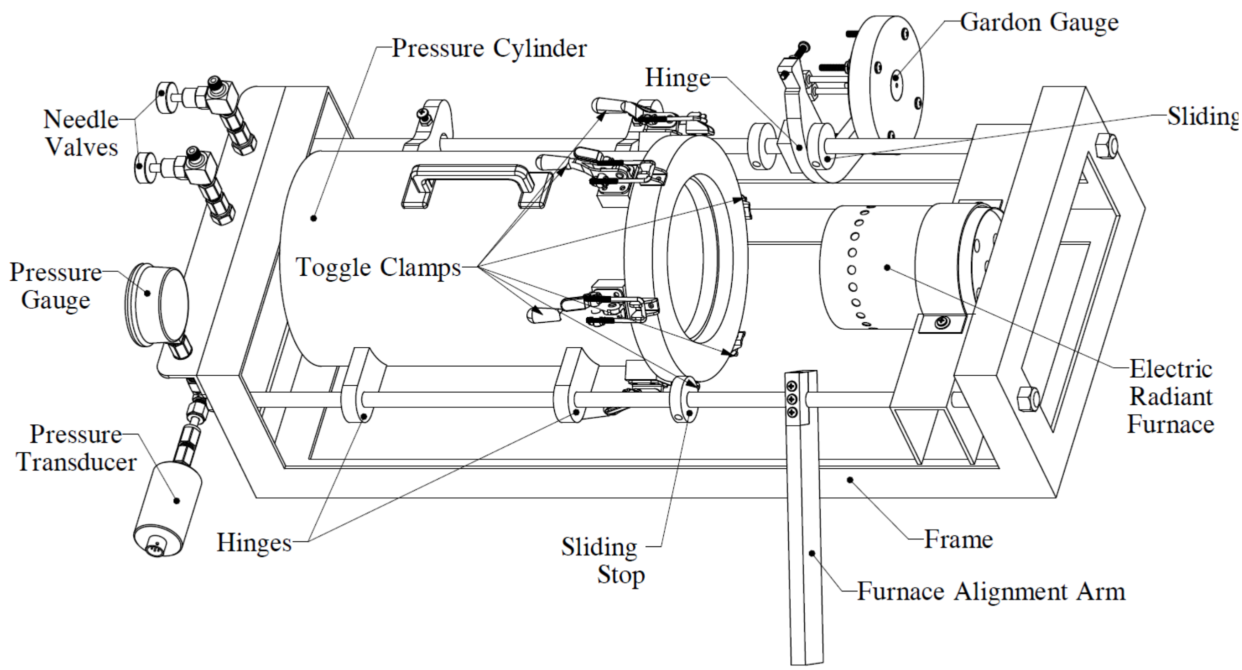

Figure 1. Overview of the evacuation slide test apparatus

2.2 Early interlab tests using heat flux gauge calibration

Before conducting any tests with the other participating labs, the FAA performed its own testing with three different furnaces. They were all manufactured by Newport Scientific, Inc. and were identified as an old wire coil, new wire coil, and new solid coil furnaces. A picture is shown in Figure 2. Three materials, identified as Mustard/Mustard, Yellow/Gray, and Blue/Gray, were tested using each furnace. The materials were donated by the Goodrich Company(now Collins

Aerospace) and are summarized in Table 1. All testing was done using the standard handbook chapter 9 test method.

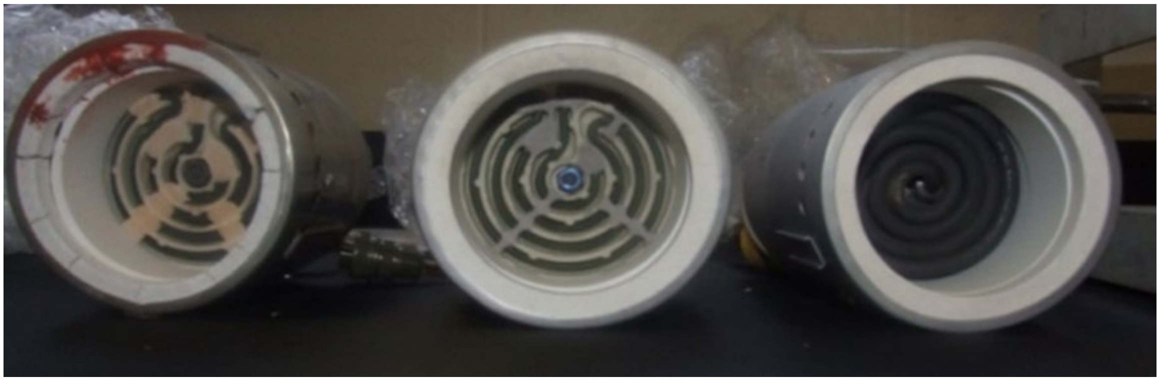

Figure 2. Different furnace types (from left to right, old wire coil, new wire coil, solid coil)

Table 1. Summary of three different material types

Mustard/Mustard	Two ply Neoprene coated nylon fabric
Yellow/Gray	A single ply, polyurethane coated, not quite square woven, nylon fabric, gray side is the fine aluminum flake mixed into the polyurethane raw material
Blue/Gray	A single ply, polyurethane coated, square woven, nylon fabric, gray side is the fine aluminum flake mixed into the polyurethane raw material

The Mustard/Mustard material used an initial pressure of 2.5 PSI and failed every test. The time-to-failure for each is shown in Figure 3. The results were similar for each, with the old wire coil failing the material at an average of 37.7 seconds, new wire coil at 38.7 seconds, and solid coil at 33.3 seconds. The solid coil had the shortest time-to-failure, but the sample size is likely too small to reach any conclusions.

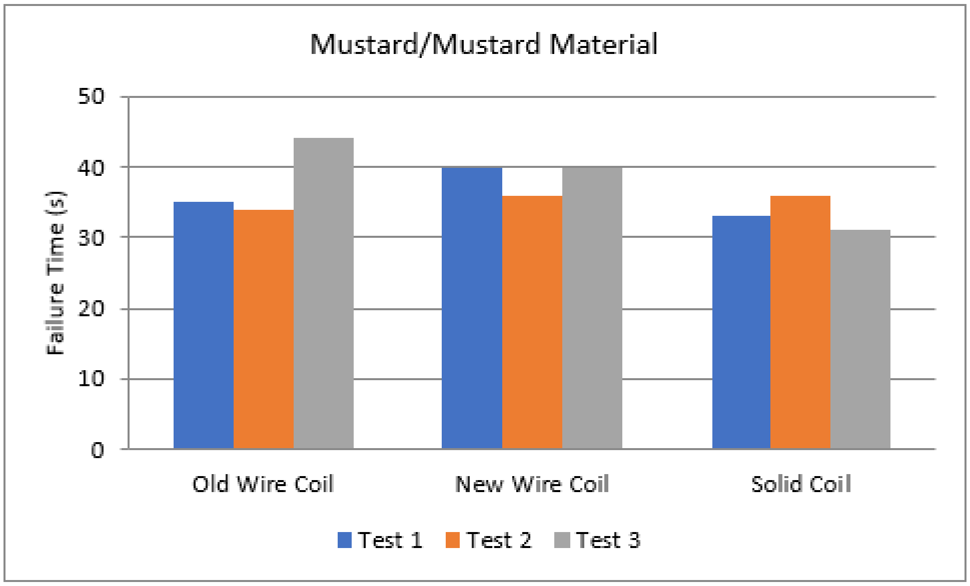

Figure 3. Test results of Mustard/Mustard material with three different furnace types

The Yellow/Gray and Blue/Gray materials passed every test. Figure 4 and Figure 5 show the pressure readings at the start of the test, after 90 seconds, 180 seconds, 240 seconds, and 300 seconds. The gray side faced the heat source for both materials and provided excellent resistance to melting because of its aluminized coating. All the test results showed little to no difference between the two wire coils and solid coil. A picture of the Yellow/Gray and Mustard/Mustard materials from before and after the tests is shown in Figure 6.

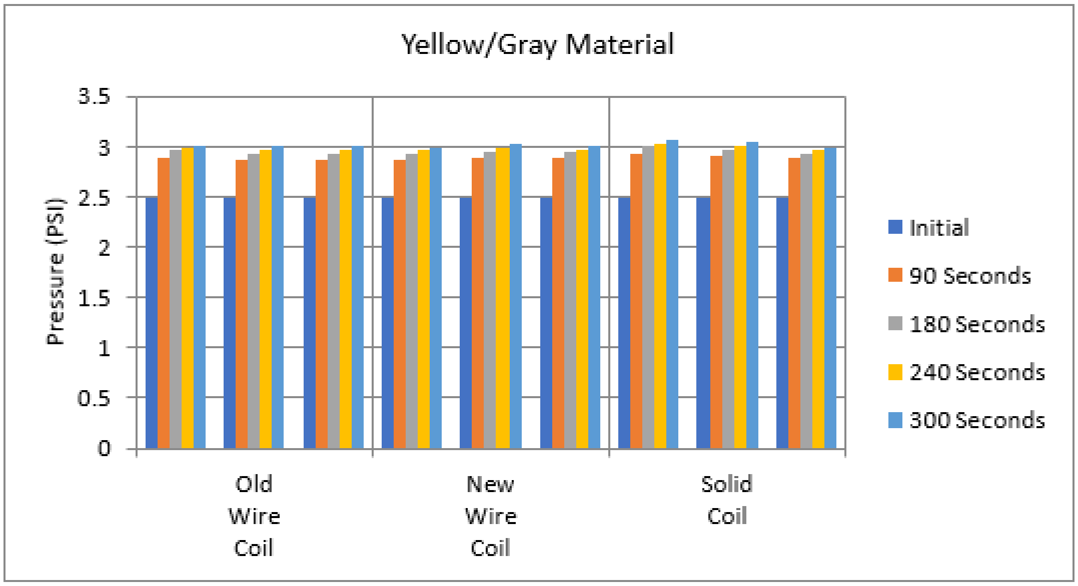

Figure 4. Test results of Yellow/Gray material with three different furnace types

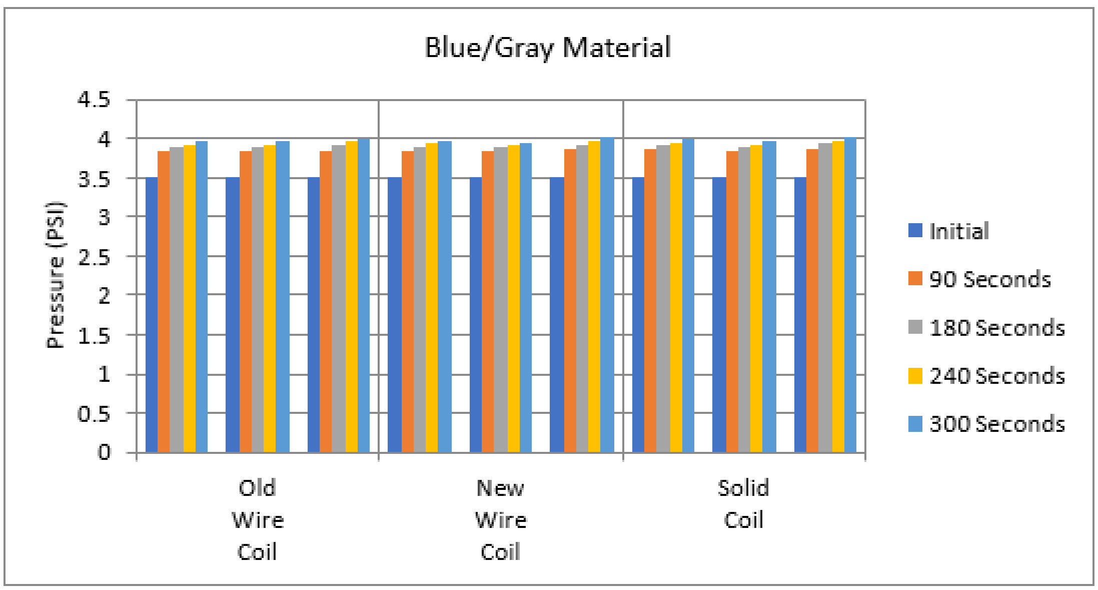

Figure 5. Test results of Blue/Gray material with three different furnace types

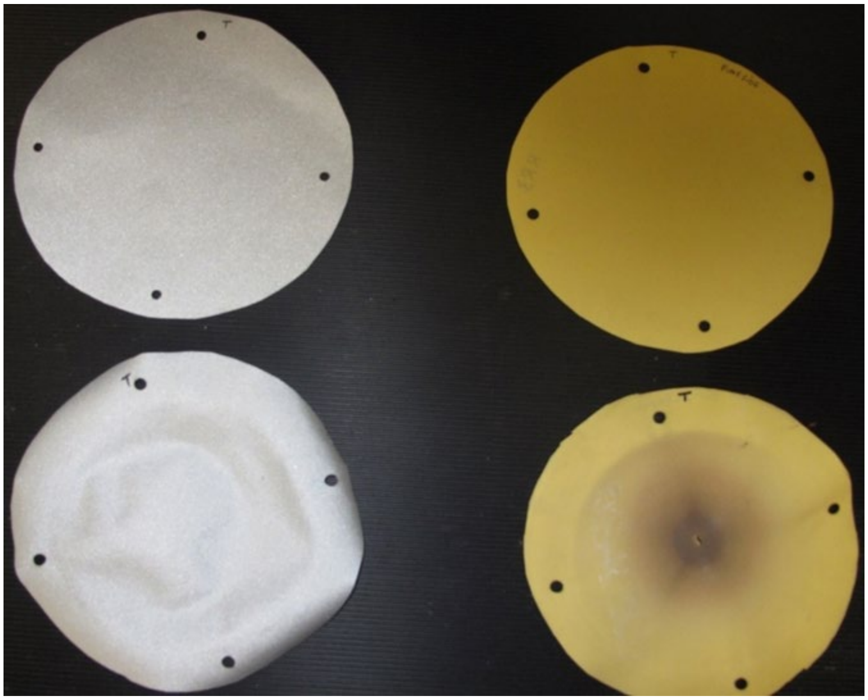

Figure 6. Yellow/Gray (left) and Mustard/Mustard materials (right) before and after a test

2.3 Round robin 1

After this initial testing, one other lab (Lab A) joined in for a round robin using the same materials. The FAA and Lab A both used the solid coil furnace in their respective testing apparatus for this test. Before testing, Lab A sent their calorimeter to the FAA Technical Center for calibration to ensure that the calorimeter calibrations would not result in errors in the test data. The FAA also used Lab A’s calorimeter along with their own to compare results. The results for the Mustard/Mustard material are shown in Figure 7. This material failed in an average of 36.0 seconds for the FAA with their calorimeter, 34.8 seconds for the FAA with Lab A’s calorimeter, and 34.9 seconds for Lab A with their own calorimeter. These results show very good agreement between both labs.

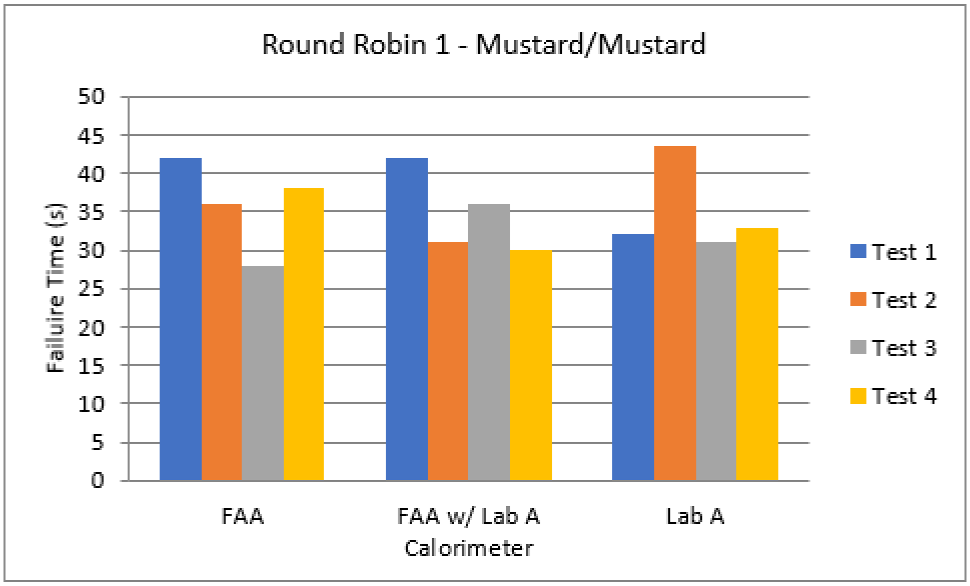

Figure 7. Mustard/Mustard test results from round robin 1

The Yellow/Gray and Blue/Gray materials were tested as well. They passed every test and their pressure data are shown in Figure 8 and Figure 9. Lab A did not report their pressure data but saw no loss in pressure during these tests. Overall, this round robin showed very good agreement between the two labs.

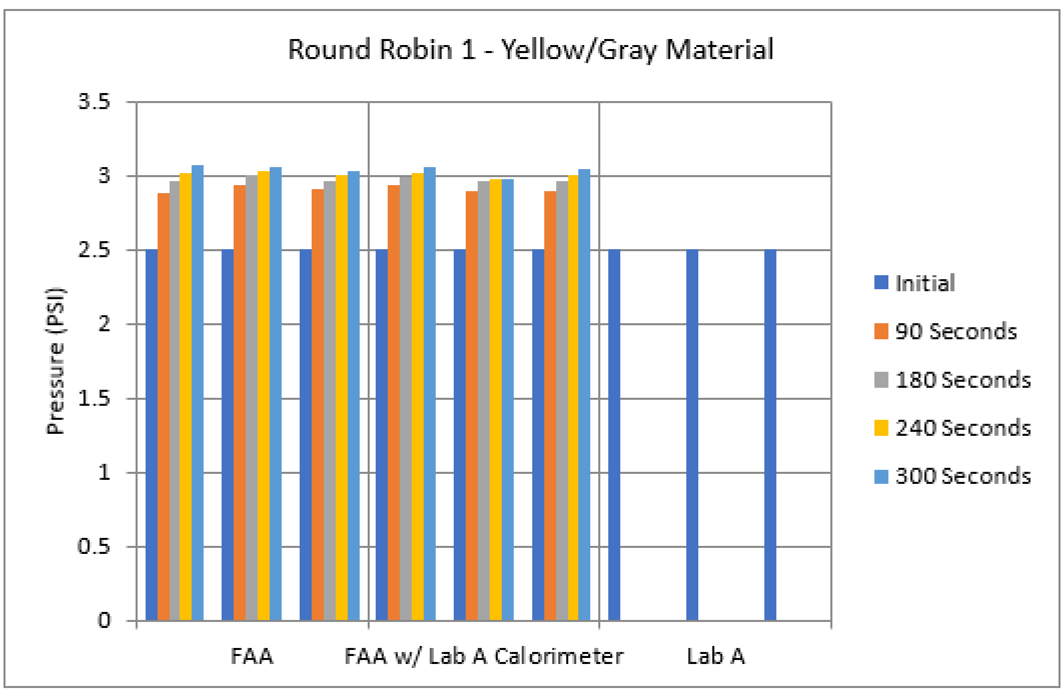

Figure 8. Yellow/Gray test results from round robin 1

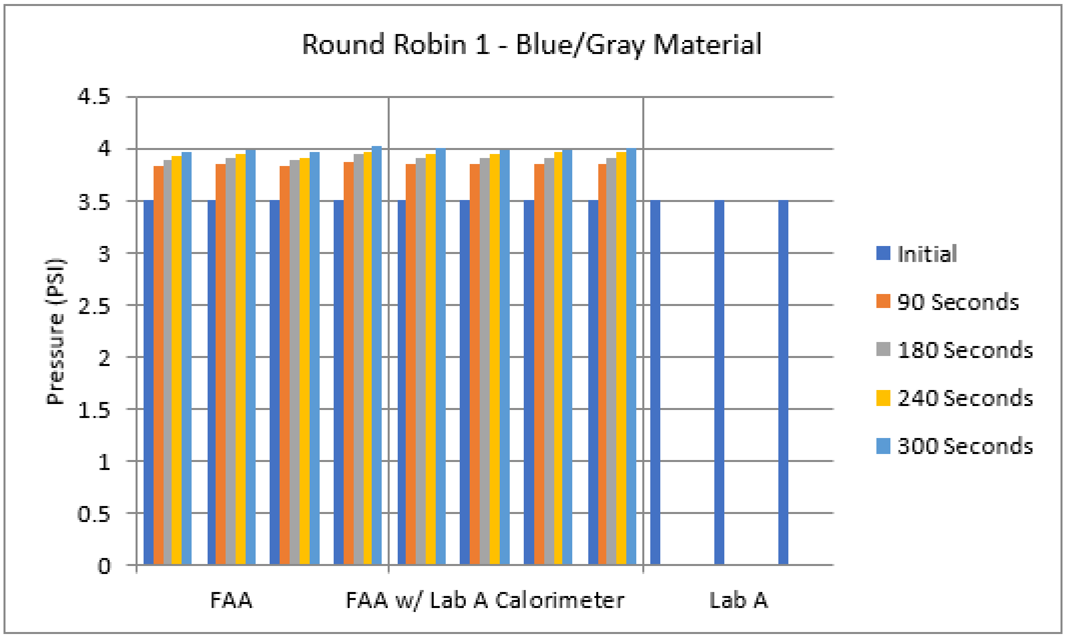

Figure 9. Blue/Gray test results from round robin 1

2.4 Round robin 2

Round robin 2 had much better participation than the first. The FAA was joined by four other labs for testing–Air Cruiser, Uretek, Goodrich and Boeing. Three materials were used were donated by Goodrich and Air Cruiser and each lab tested three samples of each material. Labs A, B, and E used solid coil furnaces and labs C and D used wire coil furnaces. They each used their own calibration for the calorimeters. All tests used an initial pressure of 2.5 PSI.

The first material tested was the same Mustard/Mustard material as the previous tests. The test results for failure time are shown in Figure 10. The average time-to-failure for each lab is shown in Table 2. Most of the samples failed at around 30 seconds for all labs except Lab D. Lab B and Lab E each seemed to have one outlier that increased and decreased their averages, respectively, but there was too small of a sample size to know definitively. Lab D, however, had much shorter average failure times than the other labs, with an average of 12 seconds.

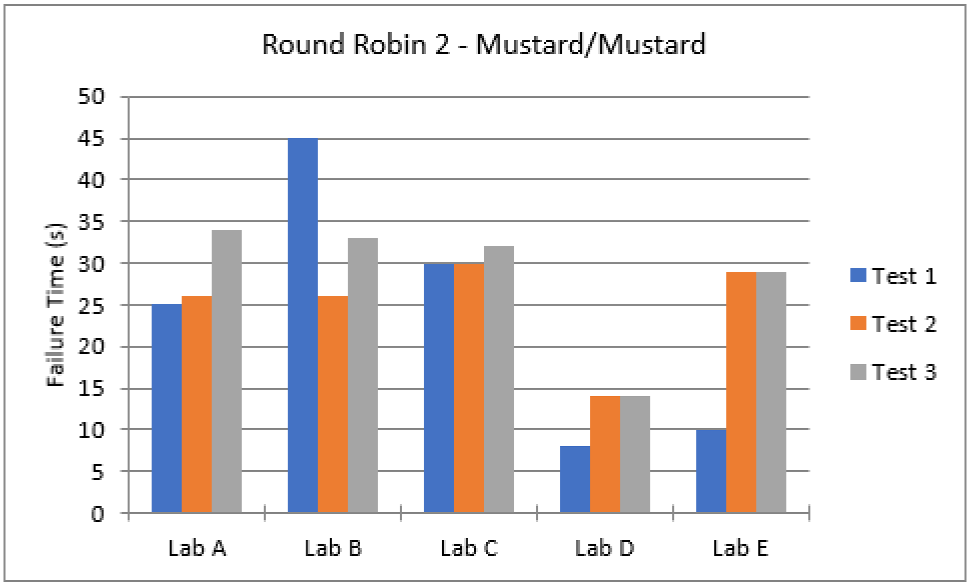

Figure 10. Mustard/Mustard test results from round robin 2

Table 2. Average failure time of Mustard/Mustard material

	Average Failure Time (s)
Lab A	28.3
Lab B	34.7
Lab C	30.7
Lab D	12.0
Lab E	22.7

The next material tested was the Yellow/Gray material used in previous tests. The time-to-failure data is shown in Figure 11. All labs passed every sample of this material except Lab D. They had very short failure times, with an average of 28.3 seconds.

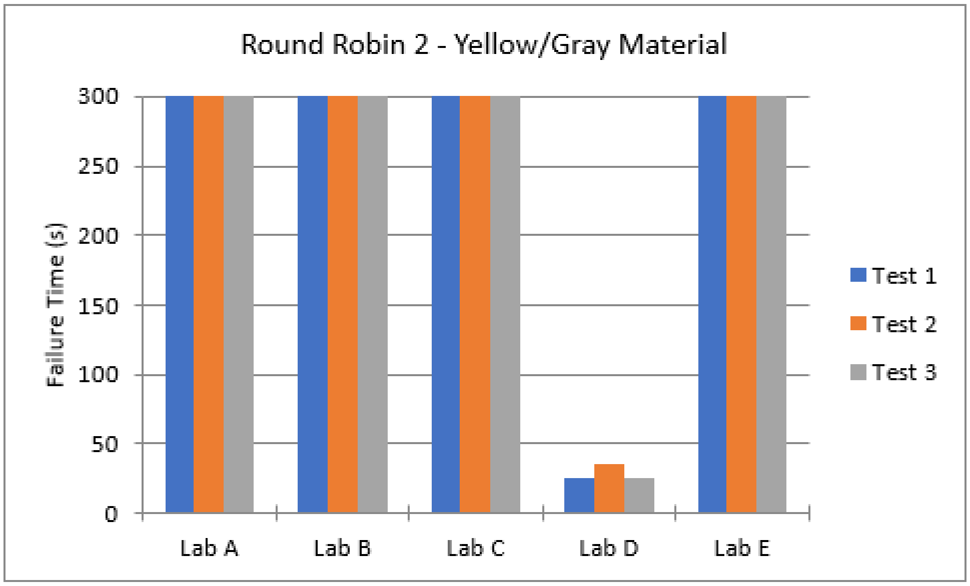

Figure 11. Yellow/Gray test results from round robin 2

The final material tested was a new Yellow/Light Gray material. The time-to-failure data is shown in Figure 12. The results were very similar to the Yellow/Gray material in that all labs passed the samples except Lab D. They had an average failure time of 22.3 seconds. Based on the data from the three materials tested, it appears that Lab D's testing apparatus was running much hotter than the other labs, which otherwise all had good agreement with each other.

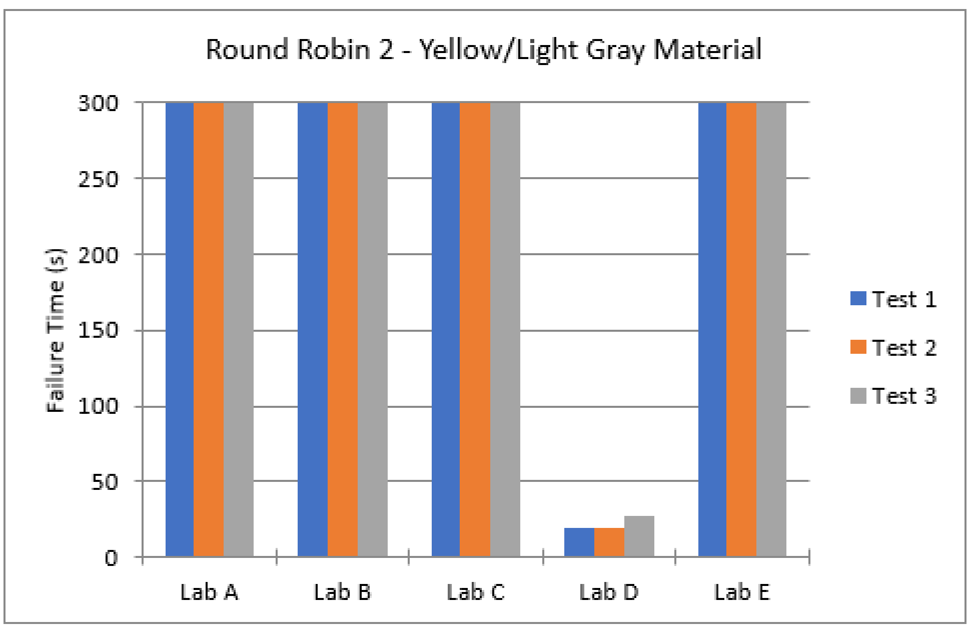

Figure 12. Yellow/Light Gray test results from round robin 2

After this round robin, a task group meeting was held at the FAA Technical Center to discuss the results. A few possible explanations were given as to why Lab D's test results did not line up with the other labs. The radiant heater may have been too close to the sample causing the heat to be more intense and allowing the material samples to fail much more quickly. The early failures may have been from air leaking around the edge of the samples. The bolts holding the sample may not have been tightened well enough causing air to leak as the pressure increased from the heat. This is why it is vital that the test specimen must be able to hold its pressure for 3 minutes before the test begins. It was also discussed that the time-to-failure is when the pressure first decreases and then continues to decrease. If the pressure has a small decrease and then continues to increase again, that is likely from noise in the pressure transducer signal, not a leak.

The FAA also demonstrated three alignment tools to easily ensure that all the critical dimensions in the test apparatus are set up correctly. The first tool was used to align the center point of the calorimeter to the center point of the furnace. The second tool was used to align the center of the test cylinder with the center of the furnace. The third tool ensured the distance from the front of the furnace to the expanded surface of the test sample was the same as the distance from the front of the furnace to the calorimeter. Drawings and more detailed explanations of these alignment tools are given in Appendix B.

2.5 Round robin 3

The participants in round robin 3 were FAA, Uretek, and Goodrich, along with two new labs, Lamcotec and Eastern Aero Marine (EAM). Goodrich and EAM supplied three different materials for testing, and each lab tested the standard three samples of each material. Labs A, B, and C used solid coil furnaces while Labs D and E used wire coil furnaces. The Ivory/Gray and Yellow/Gray materials passed for all labs, while the Mustard/Mustard material failed for all labs. The pressure data for the Ivory/Gray and Yellow/Gray materials are shown in Figure 13 and Figure 14 and the failure times for the Mustard/Mustard material are shown in Figure 15. The average failure times for this material are in Table 3.

The failure times for the Mustard/Mustard material had more variation compared to previous tests. Only Labs A and D had failure times around 30 seconds, which was typical in previous testing. Two of Lab C's samples were close to that time, but they had one outlier at 160 seconds. The test results of Labs B and E had failure times that were about 10 seconds higher and lower, respectively, than the expected result.

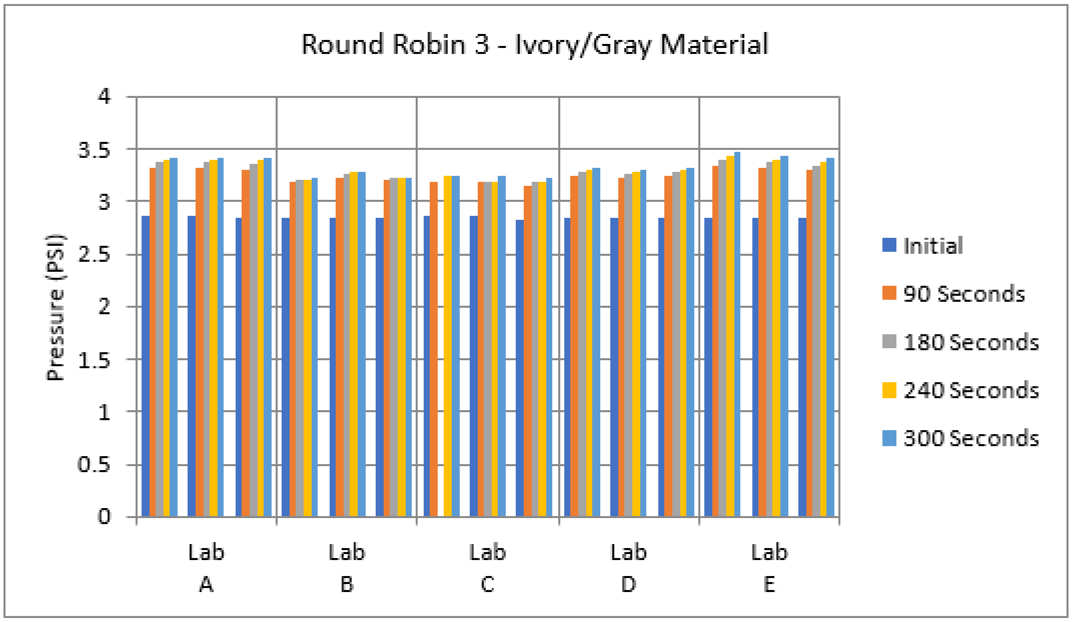

Figure 13. Ivory/Gray test results from round robin 3

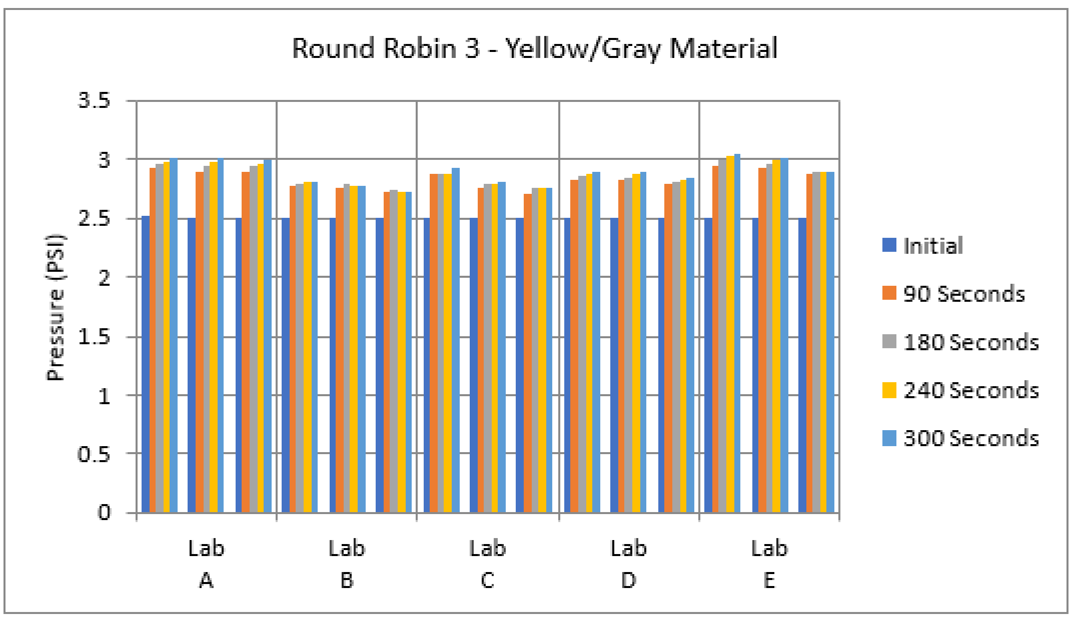

Figure 14. Yellow/Gray test results from round robin 3

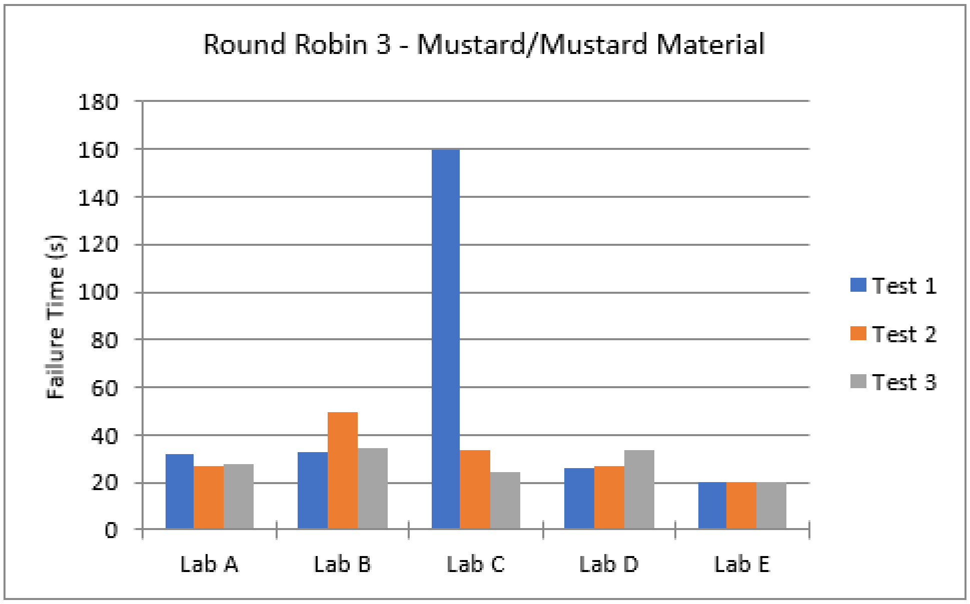

Figure 15. Mustard/Mustard test results from round robin 3

Table 3. Average failure times of Mustard/Mustard material

	Average Failure Time (s)
Lab A	29.0
Lab B	38.9
Lab C	72.7
Lab D	29.0
Lab E	20.0

2.6 Round robin 4

The next task group meeting was in December 2013 and discussed ways to improve this test method to make it more repeatable across all testing labs. It was discussed that the 1.5 Btu/ft^{2}s heat flux calibration was typically found at 2 inches in front of the heater. The FAA and other members of the task group decided to try out a new test method in which the calorimeter was placed at a distance 2 inches from the front of the heater and the voltage was adjusted to reach the 1.5 Btu/ft^{2}s heat flux value. Then another round robin was held to compare this test method to the original test method.

Only one material was used in this experiment, a Yellow/Gray material. It did not show any difference between the results of the two test methods. It did however save the operator a lot of time in calibrating the equipment because it was not necessary to find the proper distance between the furnace and the calorimeter. The results are shown in Figure 16.

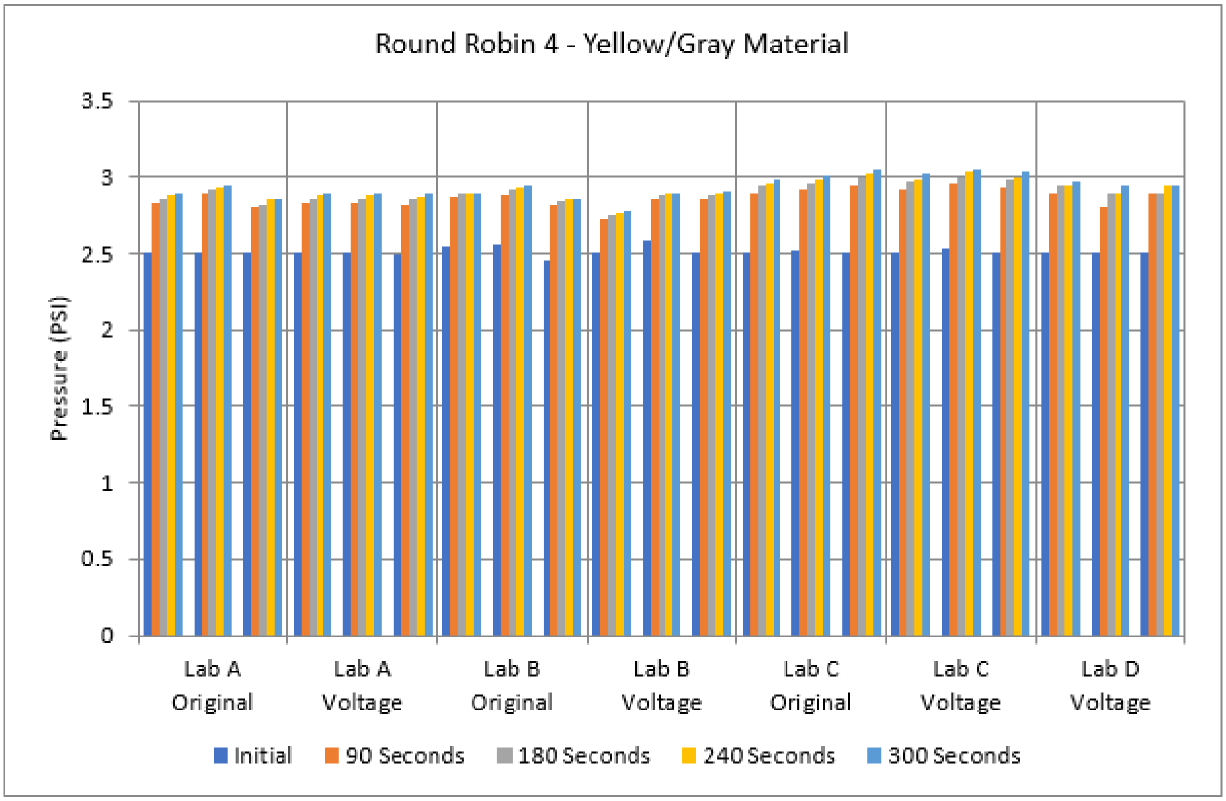

Figure 16. Yellow/Gray test results from round robin 4

2.7 Updated test method with voltage and current monitors

The FAA then conducted several tests where the current and the voltage input going into the furnace were measured when calibrating at a heat flux of 1.5 Btu/ft^{2}s at 2 inches away from the heater. A voltage regulator and current sensor were used to measure and record the power going into the furnace. A diagram of the test setup is shown in Figure 17. It showed that the power input (voltage × current) never changed when calibrating at the same heat flux. Three calibration tests were conducted to compare the power input of the furnace to the heat flux output. The results are shown in Table 4. This test used a solid coil furnace with a distance of 1.625” from the coil to the opening of the furnace.

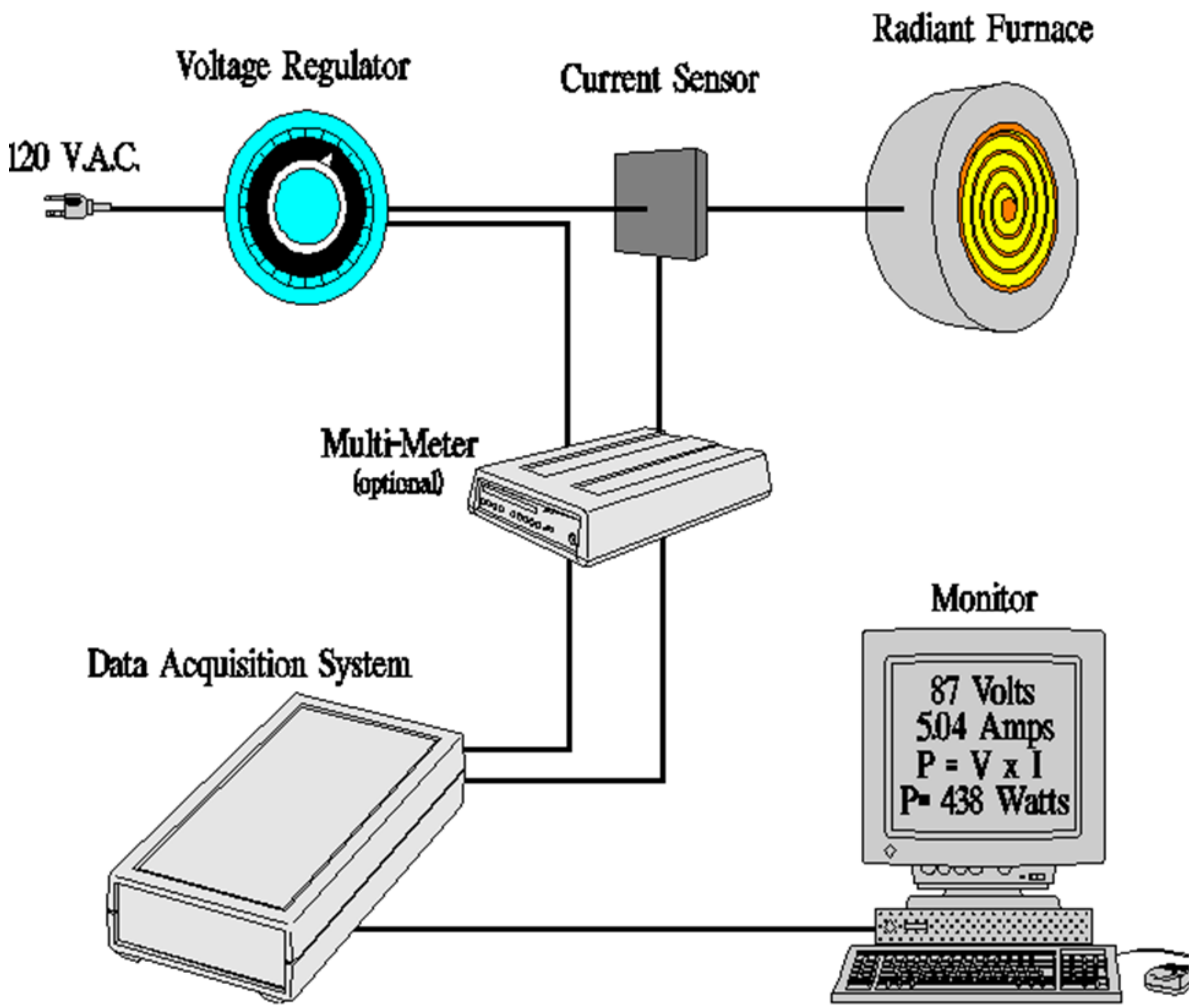

Figure 17. Diagram of test setup used to measure input voltage and current

Table 4. Measured input power to the furnace compared to heat flux measurement

Voltage (AC volts) of the furnace	**Current (Ampere) of the furnace**	**Power (Watts) of the furnace**	**Heat Flux (Btu/ft^{2}sec) of calorimeter**
86-87	5.04	438 to 440	1.49 to 1.51
87	5.04 to 5.10	438 to 448	1.50 to 1.53
86-87	5.04 to 5.10	438 to 448	1.51 to 1.52

This test showed that a power input of about 440 watts was needed to produce a heat flux of 1.5 Btu/ft^{2}s 2 inches from the furnace. Calibration was achieved much more quickly using the power method than the original calorimeter method. The required power input was adjusted and set in a few seconds after the heater warmed up compared to about 20 minutes to calibrate using the calorimeter.

Material tests were then conducted with the Yellow/Gray material and Mustard/Mustard material. The Yellow/Gray material passed every test and did not show any pressure differences between the two methods. The results are shown in Figure 18 and Figure 19. The Mustard/Mustard material all failed and had very similar failure times for both methods, with an average of 26.0 seconds for the calorimeter method and 27.3 seconds for the power method.

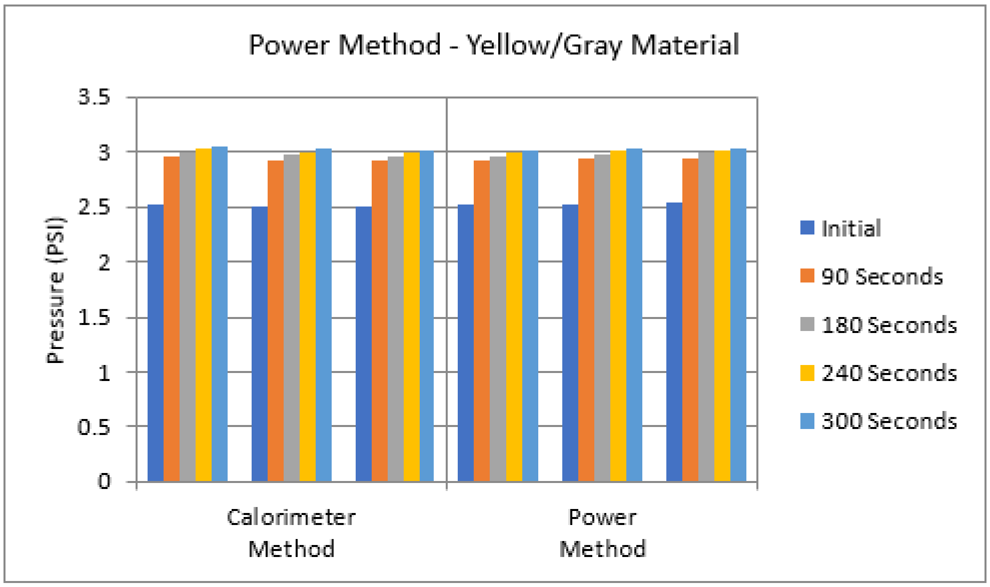

Figure 18. Original test method vs. power method testing Yellow/Gray material

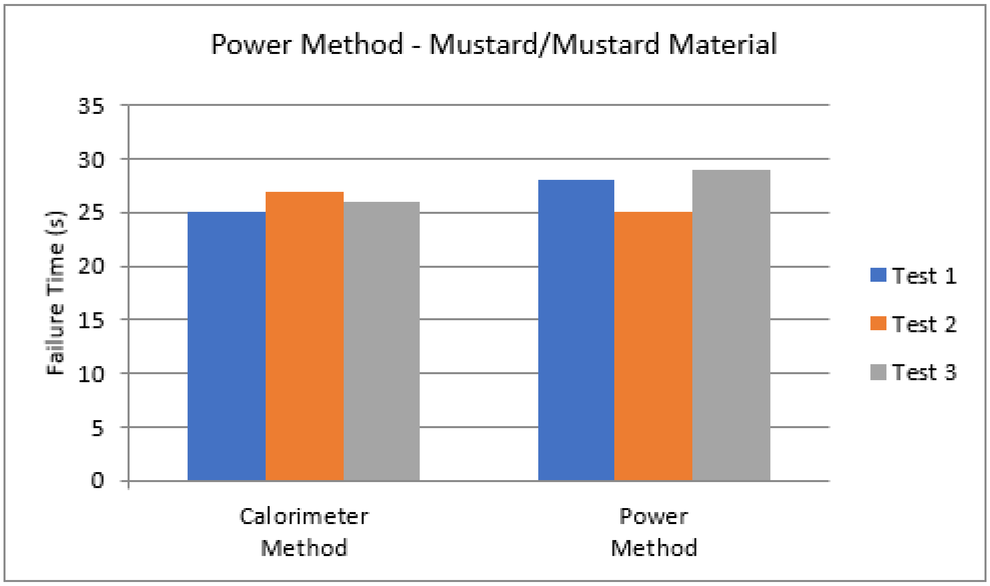

Figure 19. Original test method vs. power method testing Mustard/Mustard material

The FAA then tested three different furnaces (all manufactured by Newport Scientific, Inc.) to determine if they would produce the same heat flux output given the same power input. Two of the heaters used a solid coil, and the third used a wire coil. The distance from the opening of the furnace to the surface of the coil was 1.625 inches in the first solid coil and the wire coil heaters, and 1.5 inches in the second solid coil. The 1.5-inch distance was tested and then adjusted to 1.625 inches and tested again. The depth of the coil is easily adjusted by loosening a screw on the outside of the furnace and sliding the outside cover as necessary, as shown in Figure 20.


Figure 20. Adjustment screw on the outside of the furnace used to change coil depth

Each heater was tested 3 times and the results for the power input and heat flux are summarized in Table 5. The first solid coil needed a power input of about 440 watts to achieve the 1.50 Btu/ft^{2}s heat flux 2 inches from the furnace. Running the second solid coil at about the same power produced a heat flux of about 1.54 Btu/ft^{2}s. However, the coil was 0.125 inches closer to the calorimeter, so this distance was adjusted to match the first coil and produced about the same results. The wire coil only needed about 388 watts to achieve the desired 1.50 Btu/ft^{2}s heat flux and produced a much higher heat flux when given a power input closer to the solid coil.

Table 5. Power and heat flux measurements of 3 different furnaces

Test #	**Furnace**	**AC voltage**	**Current (ampere)**	**Power input (watts)**	**Heat Flux (Btu/ft^{2}s)**	**Distance from the opening surface of the furnace to the coil (inch)**
1	Solid Coil 1	86 - 87	5.04	438 - 440	1.49 – 1.51	1.625
2	Solid Coil 1	87	5.04 - 5.10	438 – 448	1.50 – 1.53	1.625
3	Solid Coil 1	86 - 87	5.04 – 5.10	438 - 448	1.51 – 1.52	1.625
4	Solid Coil 2	89	4.92	438 - 439	1.54	1.5
5	Solid Coil 2	89	4.92	438	1.53 – 1.54	1.5
6	Solid Coil 2	89	4.92	438	1.53 – 1.54	1.5
7	Solid Coil 2	89	4.86	435 - 437	1.51 – 1.52	1.625
8	Solid Coil 2	90	4.86	437 - 438	1.51 – 1.52	1.625
9	Solid Coil 2	90	4.86	437 - 438	1.52	1.625
10	Wire Coil	108	3.6	389 - 390	1.51 – 1.52	1.625
11	Wire Coil	108	3.6	387 - 388	1.48 - 1.50	1.625
12	Wire Coil	110	3.72	411	1.58 – 1.60	1.625

Tests with the Mustard/Mustard and Yellow/Gray materials were conducted with both solid coils. Both coils were set back 1.625 inches from the front of the furnace. The failure times for the Mustard/Mustard material were very close for both solid coils. It failed at an average of 27.3 seconds for Solid Coil 1 and 27.0 seconds for Solid Coil 2. The results are shown in Figure 21. The results for the Yellow/Gray material were very similar as well. None of the samples failed and their pressure increases were very consistent. These results are shown in Figure 22.

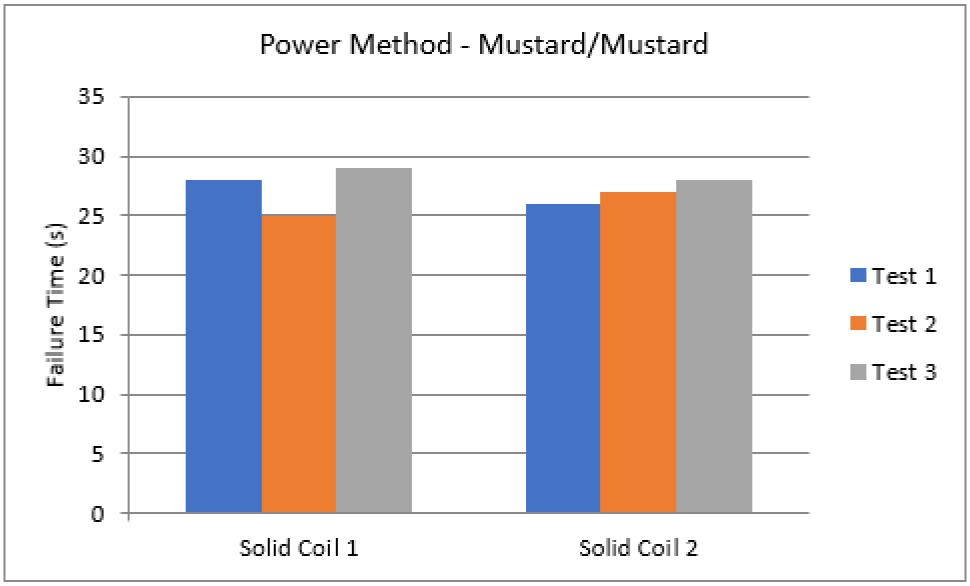

Figure 21. Comparing two solid coils using Mustard/Mustard materia

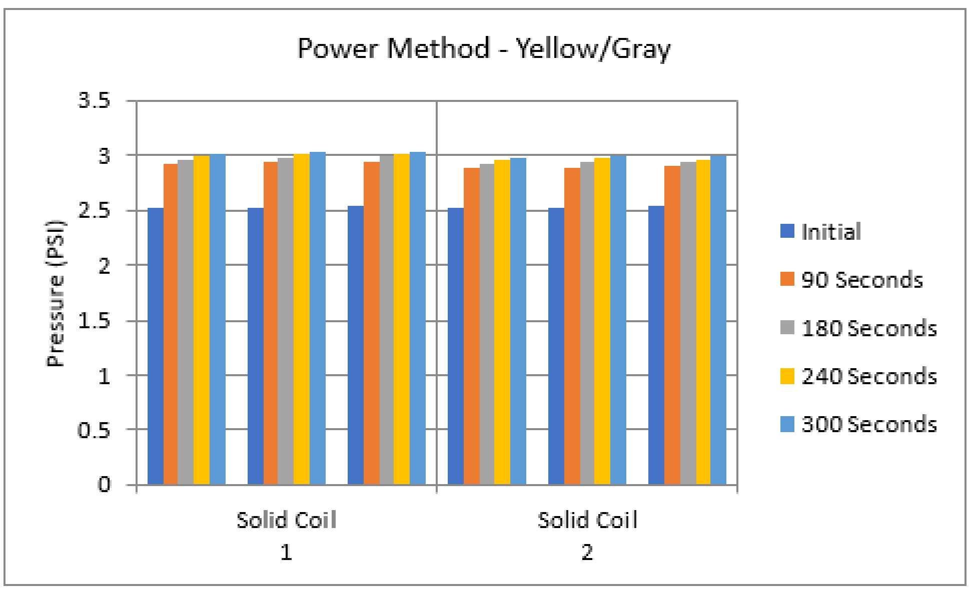

Figure 22. Comparing two solid coils using Yellow/Gray material

In a further comparison between these two solid coil furnaces, each of them was tested using three different calorimeters. All were calibrated by adjusting the voltage regulator to achieve a heat flux as close to 1.50 Btu/ft^{2}s as possible. The power input for each test was in the range of 440 ± 5 watts. The results for each test are shown in Figure 23. Combining all these tests, furnace 1 required an average of 438.7 watts and produced an average heat flux of 1.51 Btu/ft^{2}s, and furnace 2 required an average of 436.3 watts to produce the same 1.51 Btu/ft^{2}s average heat flux. The results were repeatable across both heaters and all three calorimeters.

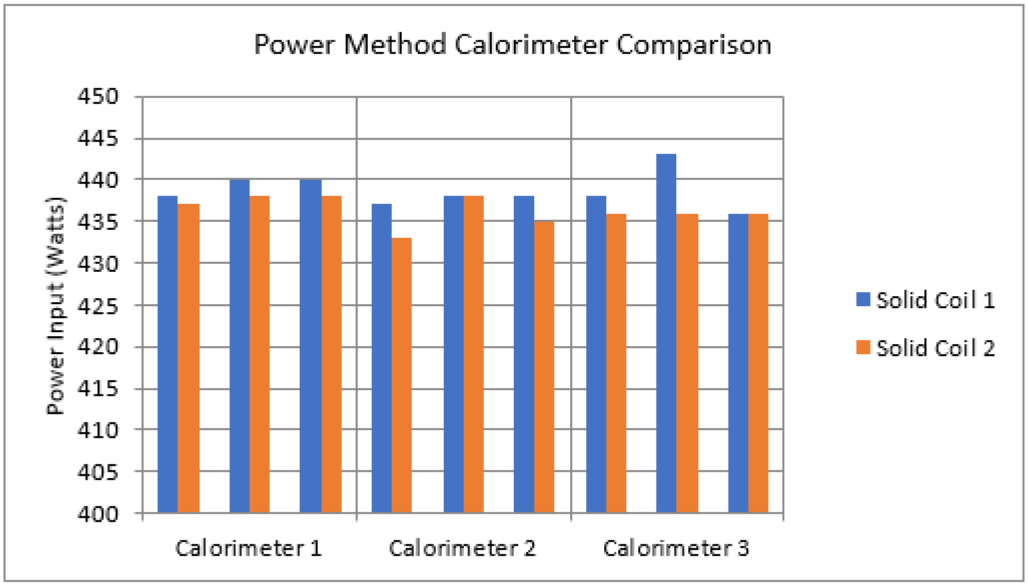

Figure 23. Two solid coils power input when calibrated with three different calorimeters

Upon seeing the differences in the distance between the opening of the furnace and the surface of the coil on the heaters in the FAA's furnaces, the other labs were asked to measure this same distance on their furnaces. They resulted with either 1.5 inches, 1.5625 inches, and 1.625 inches. Therefore, the FAA conducted calibration tests to find the power input required to reach 1.5 Btu/ft^{2}s for each of these distances. Three trials were run at each distance and the power input required for each test is shown in Figure 24. The average power required, and average heat flux measurements are shown in Table 6. As expected, the heating coil required more power to reach the required heat flux as it was moved further away from the calorimeter.

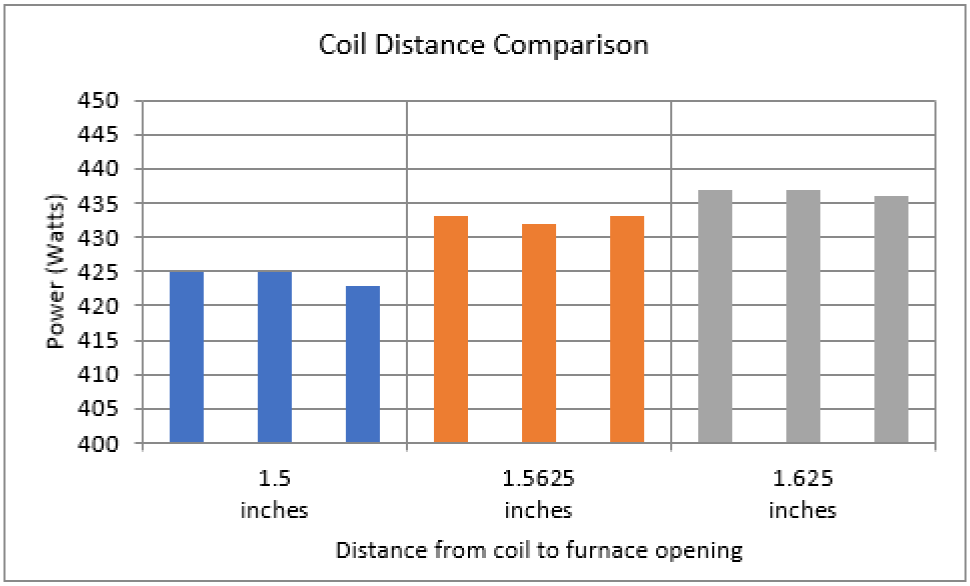

Figure 24. Power input required to reach calibration at three different coil depths

Table 6. Average power input and heat flux measurements at three different coil depths

Distance from the coil to the opening of Furnace	**Average power input (Watts)**	**Average heat flux (Btu/ft^{2}s)**
1.5 inches	424.3	1.51
1.5625 inches	432.7	1.51
1.625 inches	436.7	1.52

2.8 Follow-up interlab studies using revised methodology

On October 18, 2015, the FAA met with Uretek, Air Cruiser, and Lamcotec to discuss the revised test method of controlling the power input to the furnace rather than adjusting the furnace to reach a desired heat flux value. Achieving calibration with the revised test method takes less time and is easier to accomplish. The power input could also be monitored during the material testing, which could not be done using the original test method. The FAA also demonstrated that the distance from the opening of the furnace to the surface of the coil was critical in having a repeatable heat flux for a given power input. After discussion, it was decided to set this distance to 1.5 inches because the majority of furnaces were manufactured that way.

Following this meeting, the FAA and Uretek did a small comparison test. Both labs used the same furnace (Newport Scientific part number 68086038000) with the 1.5-inch distance from the opening of the furnace to the surface of the coil. Each lab conducted a calibration comparing the power input to the measured heat flux, which is shown in Table 7. Both labs required about the same power to reach calibration. They also had similar results in testing one of each of the Mustard/Mustard and Yellow/Gray materials, as shown in Figure 25 and Figure 26. Based on these and previous tests, the revised test method would use this solid coil heater with a power input between 425 and 433 watts, and the sample placed 2 inches from the furnace.

Table 7. Power input and heat flux measured at two different labs

Lab	**Heat flux (Btu/ft^2s)**	**Power input (Watts)**
FAA	1.51	429
Uretek	1.48	431

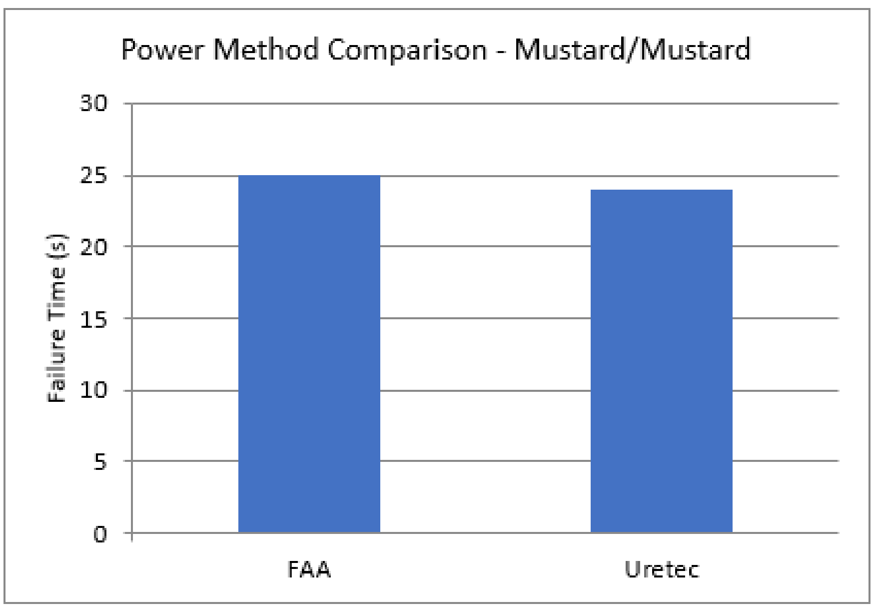

Figure 25. Mustard/Mustard material tested using power method

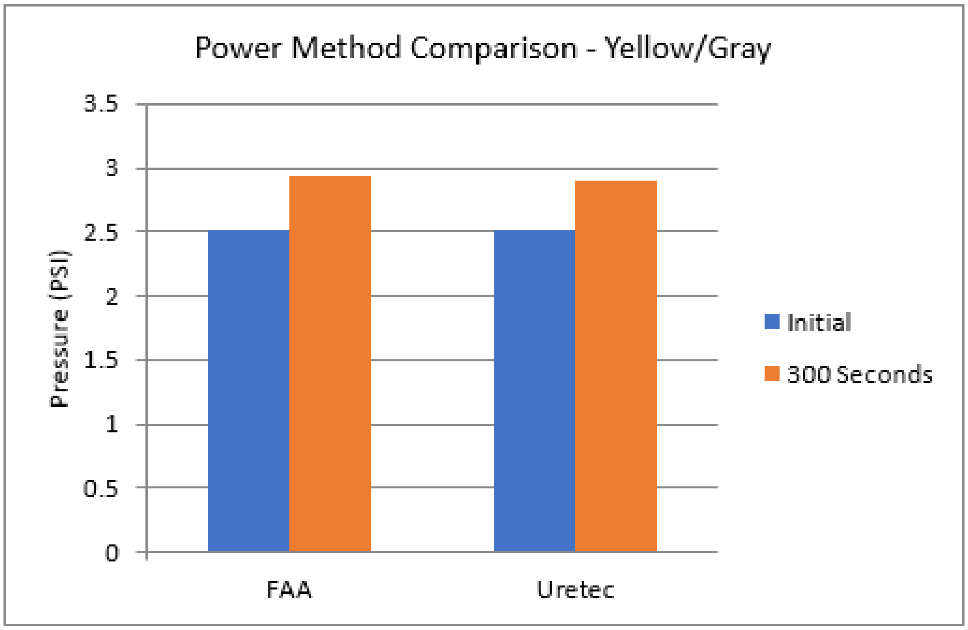

Figure 26. Yellow/Gray material tested using power method

2.9 Round robin 5

Using the same test method, round robin 5 was held between the FAA and Uretek. The FAA used two furnaces for testing (both part number 68086038000) and Uretek used one furnace of the same part number. The furnace was allowed to warm up for 30 to 45 minutes, then the power was adjusted to input between 425 and 433 watts. The heat flux was measured and tests were done with the Mustard/Mustard and Yellow/Gray materials. Each lab conducted each test three times. The calibration was repeatable between furnaces and labs and is shown in Table 8.

Table 8. Round robin 5 power and heat flux measurements

Test #	**Furnace #**	**AC voltage**	**Current (Ampere)**	**Power input (Watts)**	**Heat flux (Btu/ft^2s)**
1	FAA Furnace 1	88.2	4.86	429	1.51
2	FAA Furnace 1	88.2	4.86	429	1.52
3	FAA Furnace 1	88.2	4.86	429	1.5
4	FAA Furnace 2	86	5	430	1.5
5	FAA Furnace 2	86	5	430	1.49
6	FAA Furnace 2	86	5	430	1.5
7	Uretek			431	1.48
8	Uretek			431	1.48
9	Uretek			431	1.48

The FAA tested the Mustard/Mustard material with both heaters, but Uretek did not report the results from this material. This material failed in furnace 1 at an average of 44 seconds, and furnace 2 at an average of 54 seconds. The failure times are longer than previous testing with this material due to a change in the material itself, not the test method. However, it took this material 23% longer on average to fail with furnace 2 compared to furnace 1. The data for the tests are shown in Figure 27.

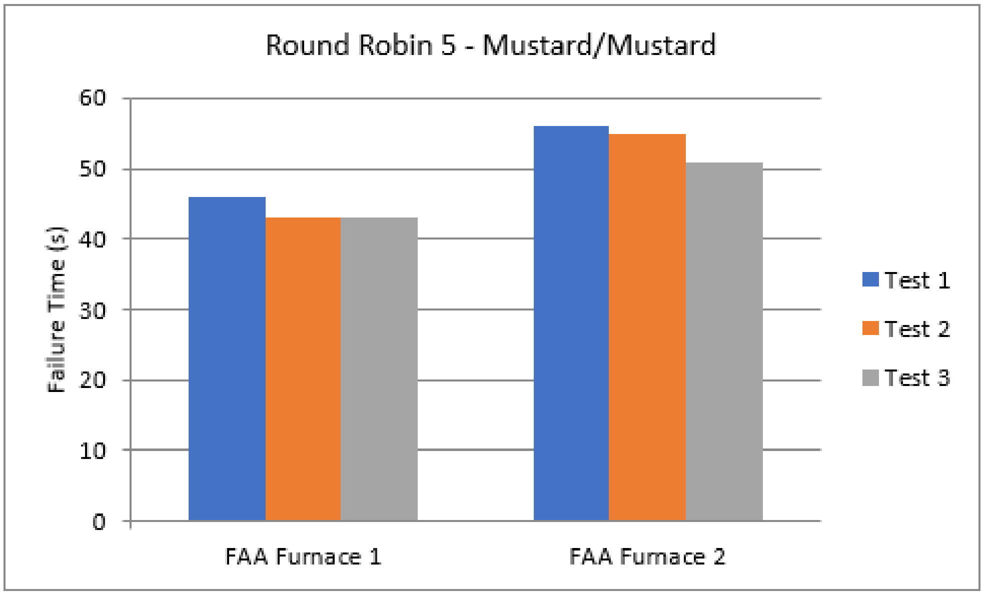

Figure 27. Round robin 5 Mustard/Mustard material tests

The Yellow/Gray material was tested with both FAA furnaces and Uretek. All the test samples passed as expected, but the final pressure did not increase as much at Uretek as it did at the FAA. However, both FAA furnaces were consistent with each other. The results are shown in Figure 28.

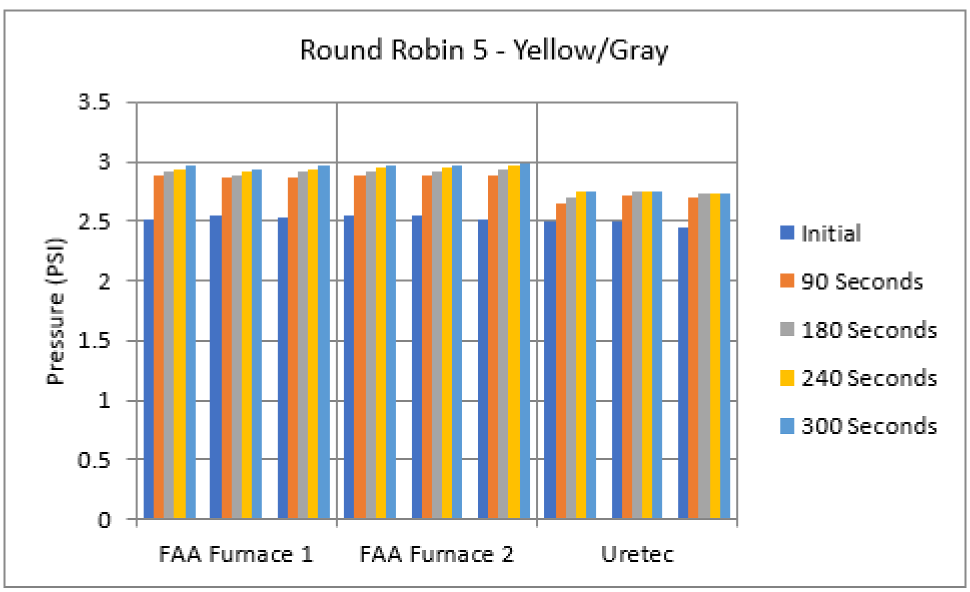

Figure 28. Round robin 5 Yellow/Gray material tests

In observing different labs conducting this test, the orientation of the furnace was not the same from lab to lab. The manufacturer placed a marking on top of each furnace indicating how to place the furnace in the holder. Other labs did not follow this marking so the furnaces in the field were rotated at different angles compared to each other. Therefore, the FAA conducted calibration testing at four different angular orientations (0°, 90°, 180°, and 270°) to see if this had any effect on test results. A diagram is shown in Figure 29.

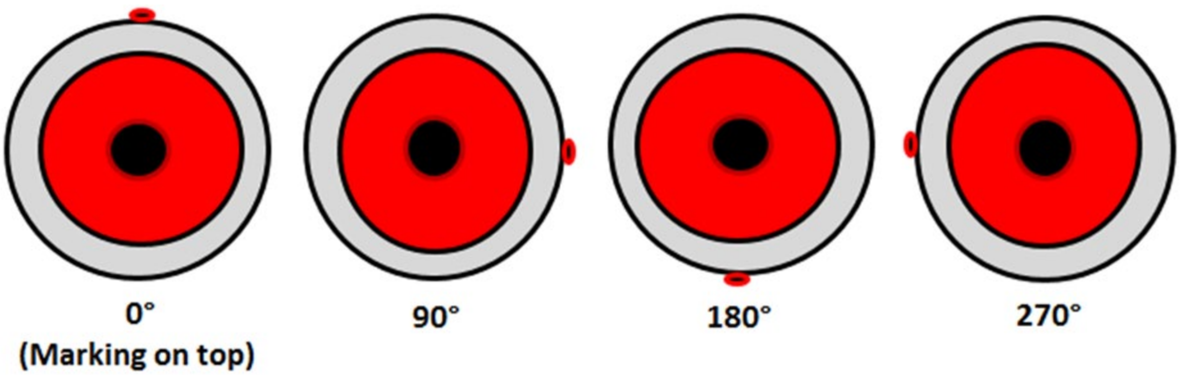

Figure 29. Four angular orientations of the furnace used in this test

Each position was tested with the heater running at 425 and 433 watts to test the top and bottom of the allowable range. Heat flux readings were taken 10, 20, and 30 minutes after the furnace was turned on. The data is shown in Figure 30, with the black lines indicating the allowable heat flux range to reach calibration. The heat flux at all orientations and power levels of the furnace fell within the allowable range of 1.50 ± 0.03 Btu/ft^{2}s. The angular orientation of the heater made little to no impact on test results.

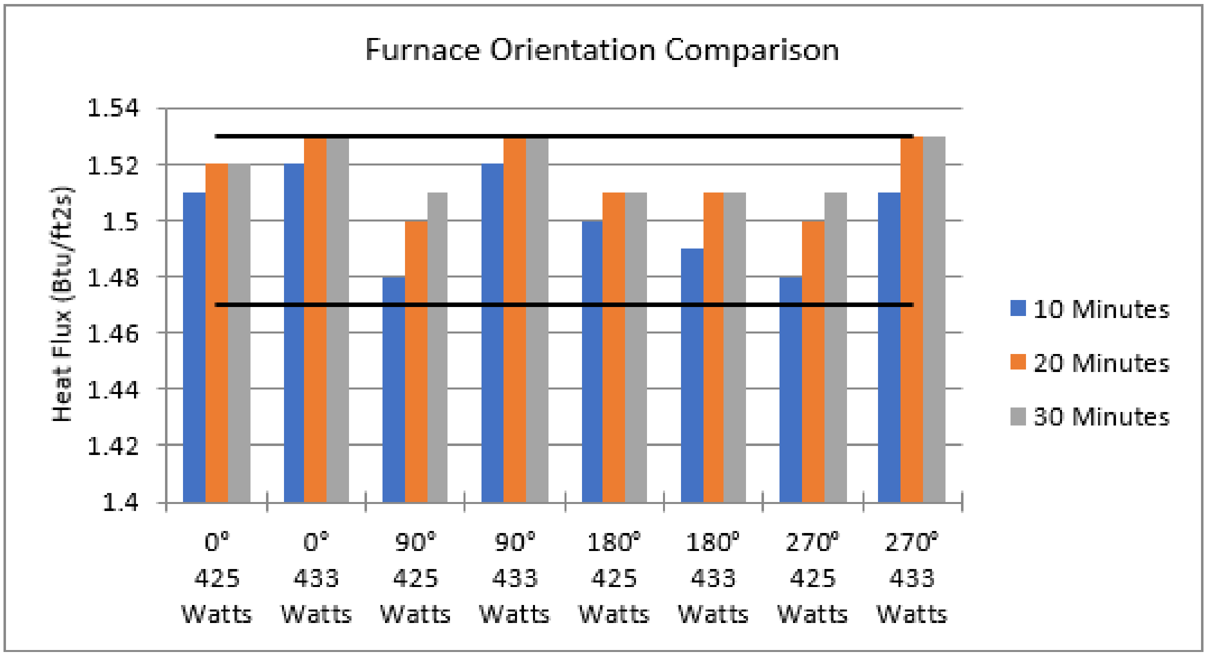

Figure 30. Power and heat flux comparison of furnace tested at four angular orientations

2.10 Testing an alternate power source

An alternate power source for the radiant heater was tested as well. The Keysight 6802A Basic AC Power Source was used in place of the Powerstat Variable Autotransformer 3PN116B. The two power sources are shown in Figure 31. The Keysight power source is programmable and has been used in the development of the Vertical Flame Propagation test with good results and provides consistent power to the radiant heater.

The Powerstat Variable Autotransformer uses a large, imprecise dial for setting the voltage. This requires a separate voltmeter to get an accurate reading and sometimes needs to be adjusted during testing to maintain the voltage at a constant level. By contrast, the Keysight AC Power Source sets the voltage digitally to the nearest 0.1V and maintains it at this level automatically. It also measures the current internally to produce an accurate power reading.

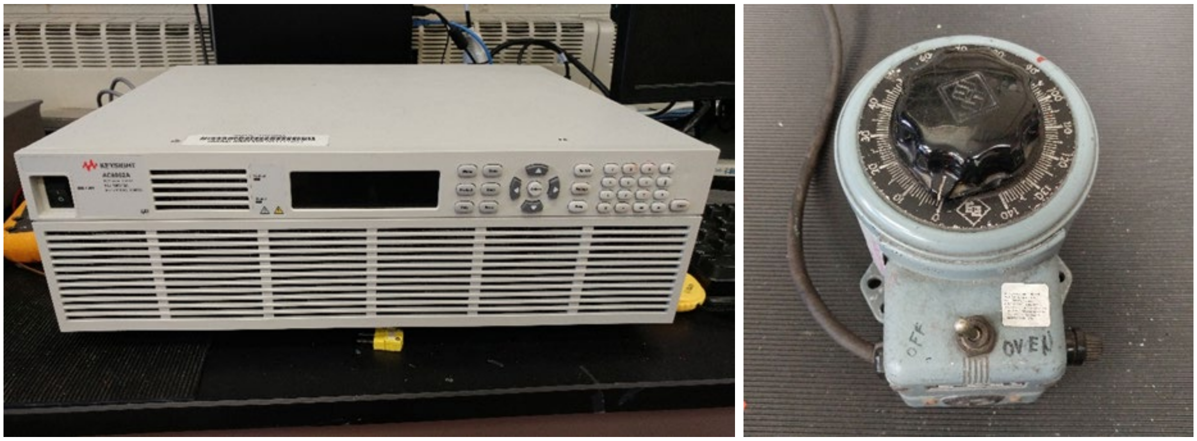

Figure 31. Keysight 6802A AC Power Source and Powerstat Variable Autotransformer

Both power sources were compared using three different heat flux gauges and the same radiant heater. The three heat flux gauges were all recalibrated before testing. The measured power and heat flux were averaged over a 5-minute period for each test. The power was measured by a separate power meter for both power sources and did not rely on the internal measurements of the Keysight Power source to keep the measurement devices the same. The results are shown in Figure 32. There was a minimal difference between the two power sources in the power required to reach 1.50 Btu/ft^{2}s in calibration testing when using the same heat flux gauge. There was a bigger difference when changing heat flux gauges.

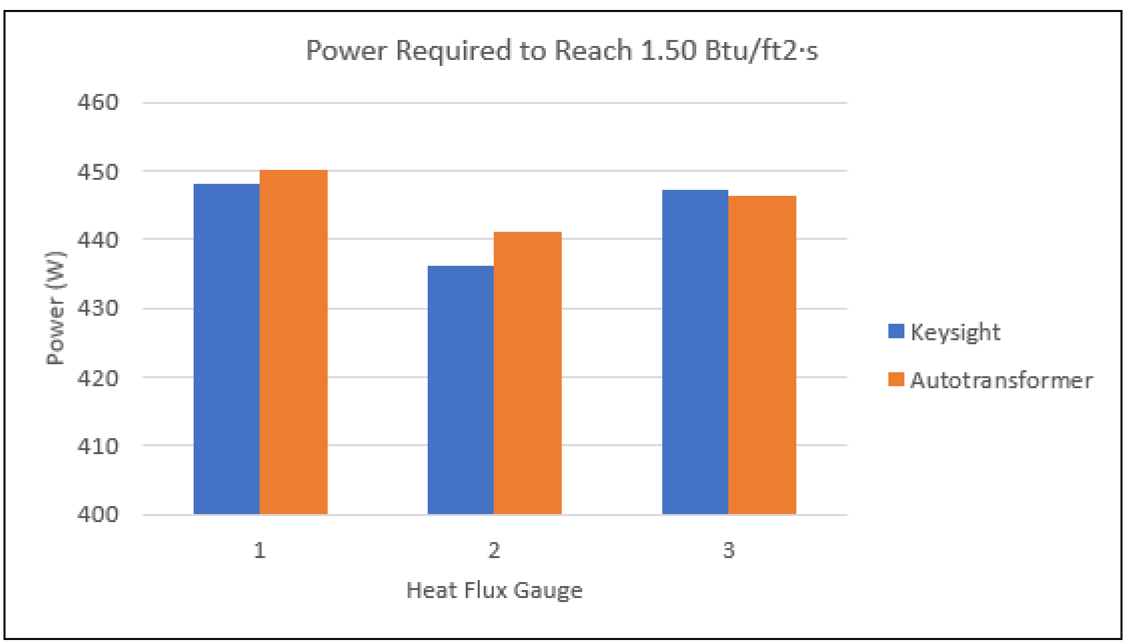

Figure 32. Comparing power sources with three different heat flux gauges

The heat flux and power measurements fluctuated over the course of the 5-minute measurement period for both power sources. The instantaneous values for the heat flux and power for both power sources using heat flux gauge number 3 are shown in Figure 33 and Figure 34, respectively. Both power sources had about the same average power and heat flux, but the instantaneous measurements of the Autotransformer varied a little more over the course of the 5-minute measurement period.

The standard deviation for each measurement was calculated and averaged across all tests. For the heat flux measurement, the average standard deviation for the Keysight was 0.0096 Btu/ft^{2}s compared to 0.0119 Btu/ft^{2}s for the Autotransformer. For the power measurement, the average standard deviation for the Keysight was 0.655W compared to 0.919W for the Autotransformer. The Keysight AC Power Source was then used for all subsequent tests because of its better results and ease of use.

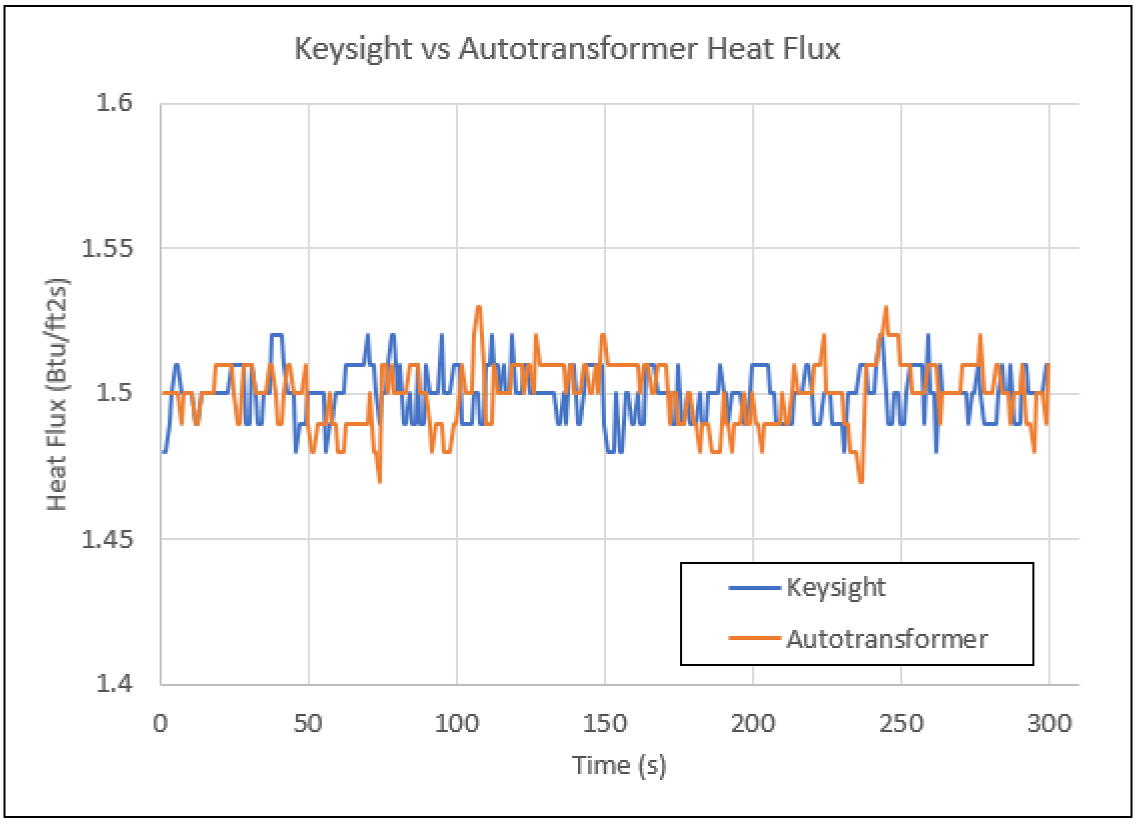

Figure 33. Instantaneous heat flux measurement of each power source using calorimeter 3

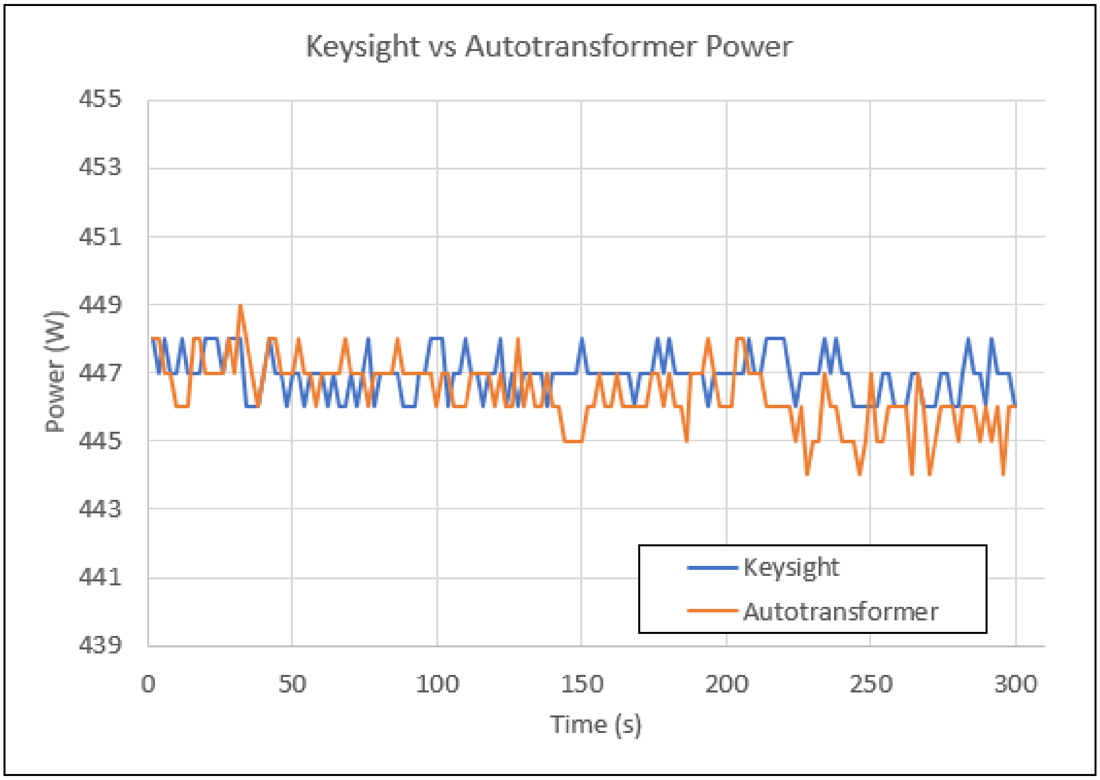

Figure 34. Instantaneous power measurement of each power source using calorimeter 3

2.11 Heat flux gauge comparison

As shown in the previous testing and Figure 32, the variation between the heat flux gauges was too large for what are supposed to be identical gauges. The power required to reach 1.50 Btu/ft2s for the three heat flux gauges ranged from 436.3W to 448.3W though they were all recalibrated before testing and all used the same heater and power source. In observing the gauges, the condition of the black paint on the surface varied on each gauge, as shown in the picture in Figure 35. Heat flux gauge (HFG) 2 looked the most like the flat black paint is supposed to look, while HFG 1 looked shinier and more scratched and HFG 3 looked more gray.

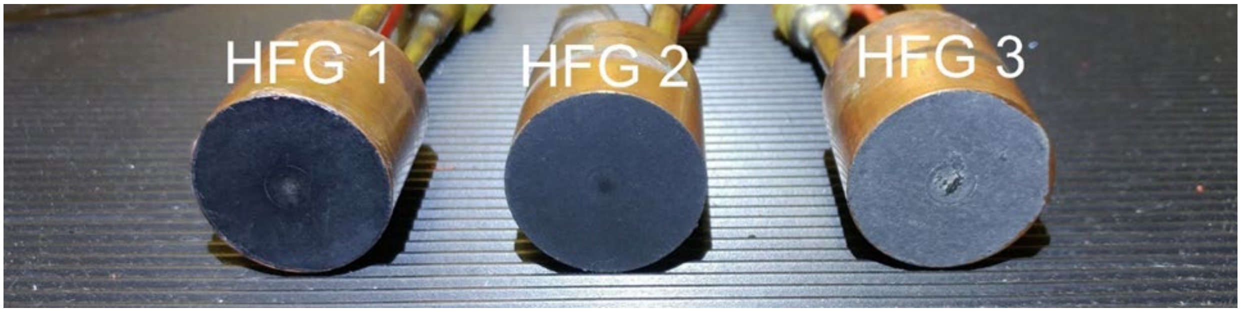

Figure 35. Heat flux gauges 1, 2, and 3 before repainting

The heat flux gauges were repainted, recalibrated, and the previous tests were repeated. The surfaces of the three gauges looked basically identical after painting, as shown in Figure 36. All had a high quality flat black finish without any scratches. The measurements of the power required to reach 1.50 Btu/ft^{2}s are shown in Figure 37. The results are much improved and there was very little variation between gauges. The overall readings were lower with the repainted gauges, but the power only ranged from 431.5W to 432.1W compared to 436.1W to 448.3W previously.

Figure 36. Heat flux gauges 1, 2, and 3 after repainting

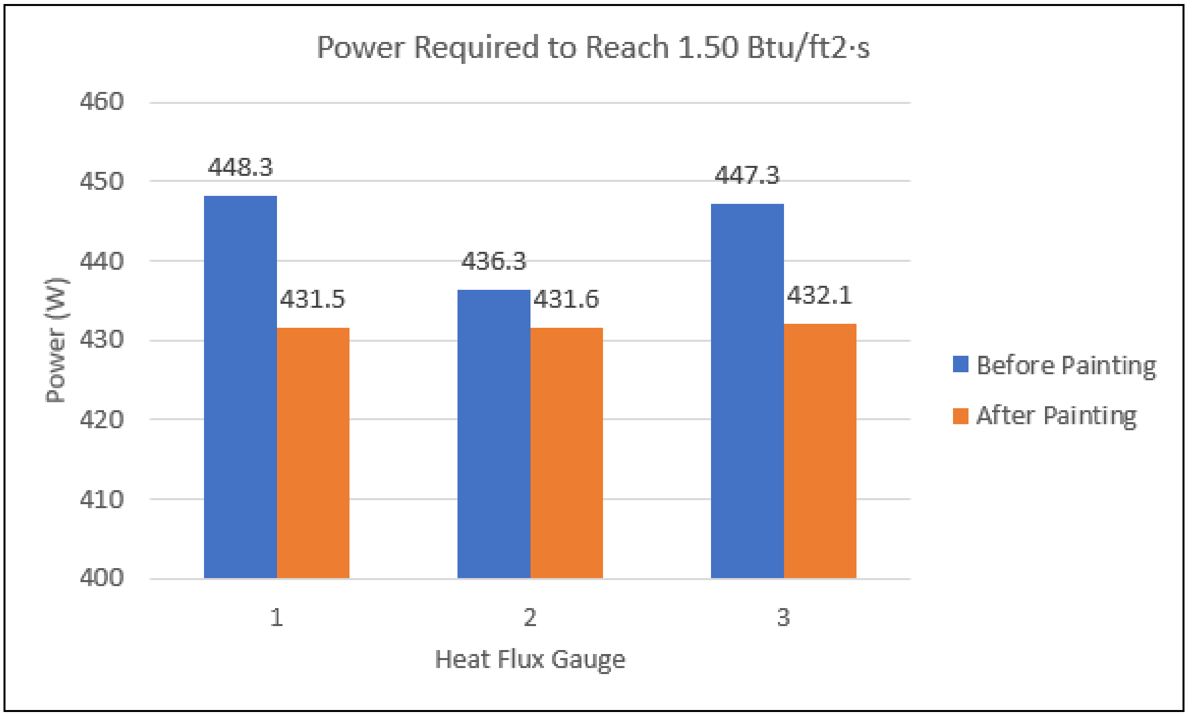

Figure 37. Comparison of heat flux gauges before and after repainting

2.12 Comparing calibration methods

The FAA had six radiant heaters in their possession to test if it would be more accurate to calibrate the evacuation slide test by setting the power or measuring the heat flux. The depth of the coils in the six heaters were all set to 1.5 inches. The heaters were each calibrated to 1.50 Btu/ft^{2}s at 2 inches away using each of the three repainted heat flux gauges from the previous section and their power measurements were compared. Of the six heaters, four were the solid coil type, and two were the wire coil type.

At least three individual 5 minute averages of the power and heat flux were recorded for each of the 18 combinations of heater and heat flux gauge. These three recordings were averaged for each heater and heat flux gauge and the results for the power required to reach 1.50 Btu/ft^{2}s are shown in Figure 38. There was a much bigger difference when changing heaters compared to changing heat flux gauges. The biggest difference in heaters was from Solid Coil 2 to Wire Coil 1 using HFG 3, which was 448.2W to 404.6W. The biggest difference in heat flux gauges was from HFG 2 and HFG 3 when tested with Solid Coil 4, which was 409.9W to 420.4W.

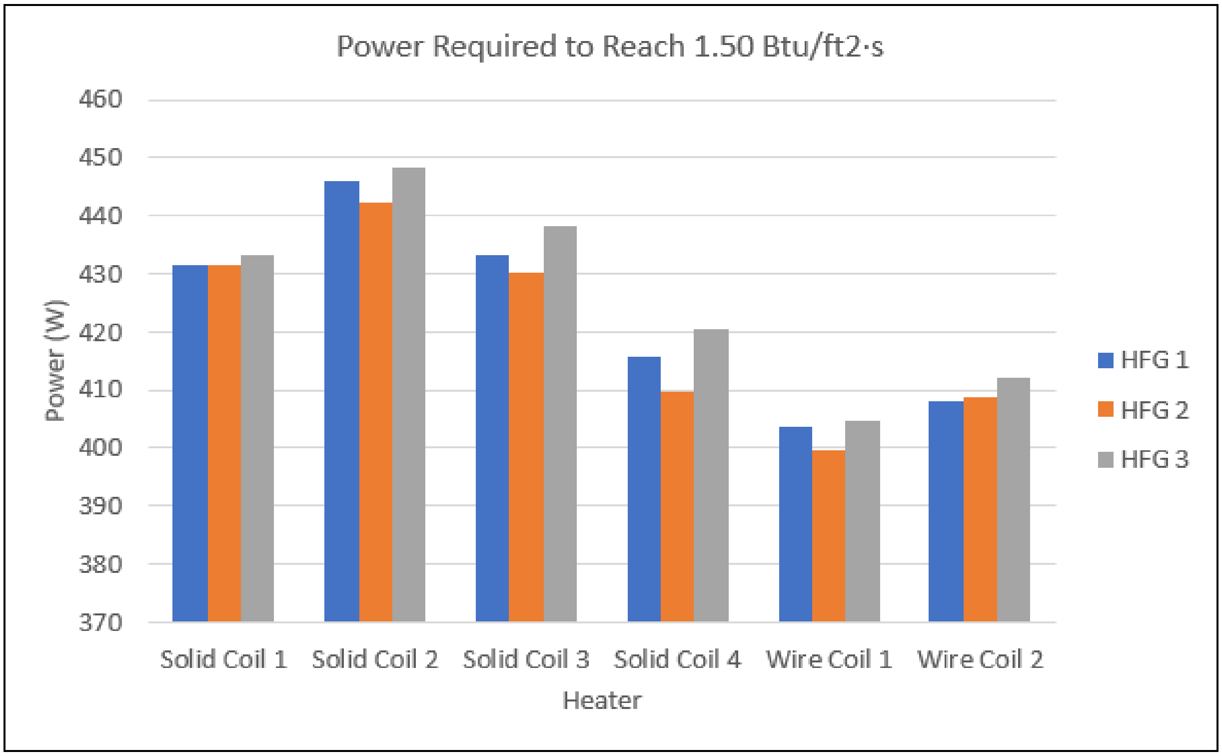

Figure 38. Comparison of six heaters and three heat flux gauges

Simplifying the comparison to just comparing same model heaters, averaging the power for each solid coil heater across the three heat flux gauges varied from 415.3W on Solid Coil 4 to 445.5W on Solid Coil 2. Using the same data, averaging the power for each heat flux gauge across the four solid coil heaters varied from 428.5W on HFG 2 to 435.0W on HFG 3. Both graphs are shown in Figure 39.

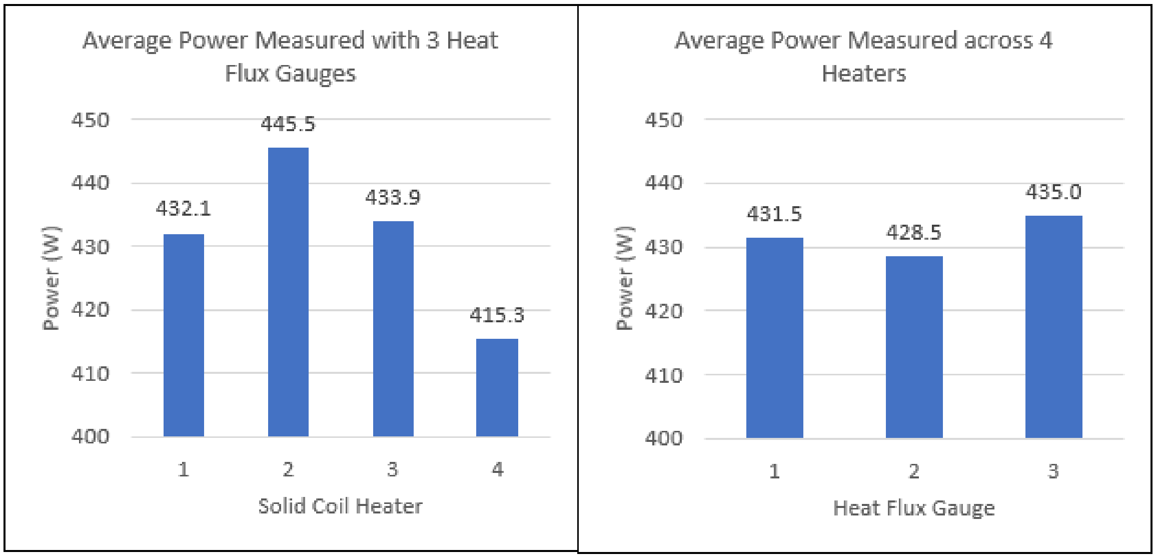

Figure 39. Comparison of solid coil heaters and heat flux gauges

A similar comparison with the two wire coil heaters was performed as well. Averaging the power for each wire coil heater across the three heat flux gauges varied from 402.7W on Wire Coil 1 to 409.6W on Wire Coil 2. Averaging the power for each heat flux gauge across the two wire coil heaters varied from 404.1W on HFG 2 to 408.4W on HFG 3. Both graphs are shown in Figure 40. Even with only two wire coil heaters, they still varied more than the three heat flux gauges.

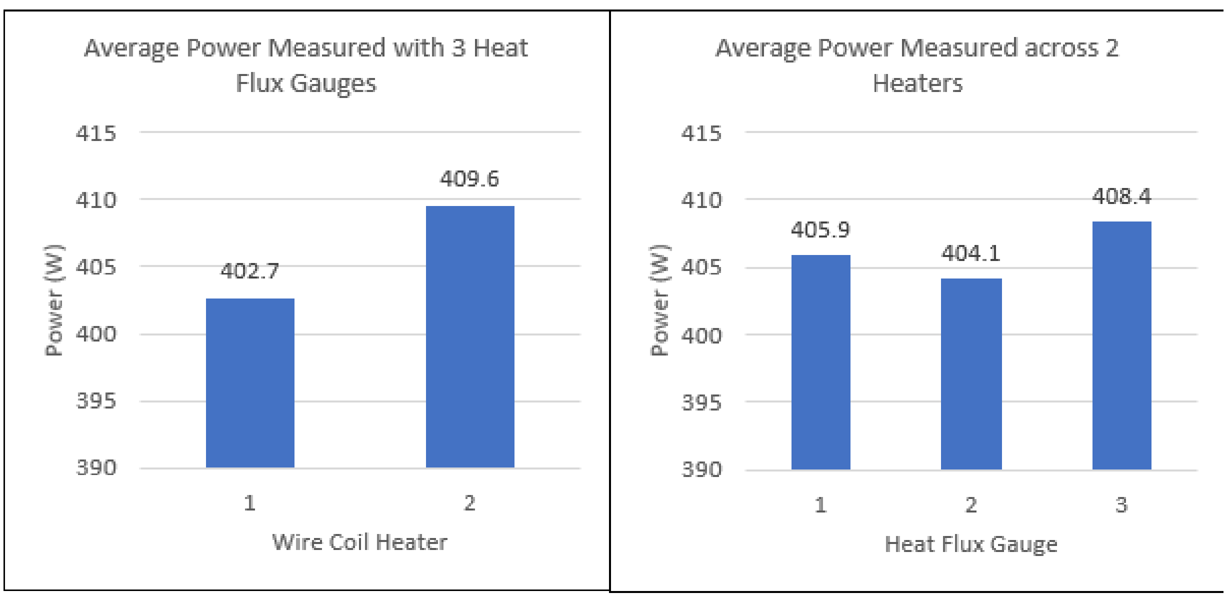

Figure 40. Comparison of wire coil heaters and heat flux gauges

Achieving the correct heat flux calibration was much more repeatable when changing heat flux gauges compared to changing radiant heaters. Some analysis was done to determine possible reasons why the heaters were not consistent. The coil depth inside the heater was set to 1.5

inches; however, the coils on the heater are not all on the same plane. A difference as high as 0.2 inches was measured from the surface of one coil to the next. The condition of the surface could affect the test results as well. The surface of the coils of the different heaters were not the same color or reflectivity which could affect the emissivity of the coils. The internal resistance of the coils was different as well, ranging from 16.89 Ω to 18.14 Ω in the solid coil heaters and 4.33 Ω to 28.59 Ω in the wire coil heaters. A graph of resistance versus. power required to reach 1.50 Btu/ft^{2}s is shown in Figure 41.

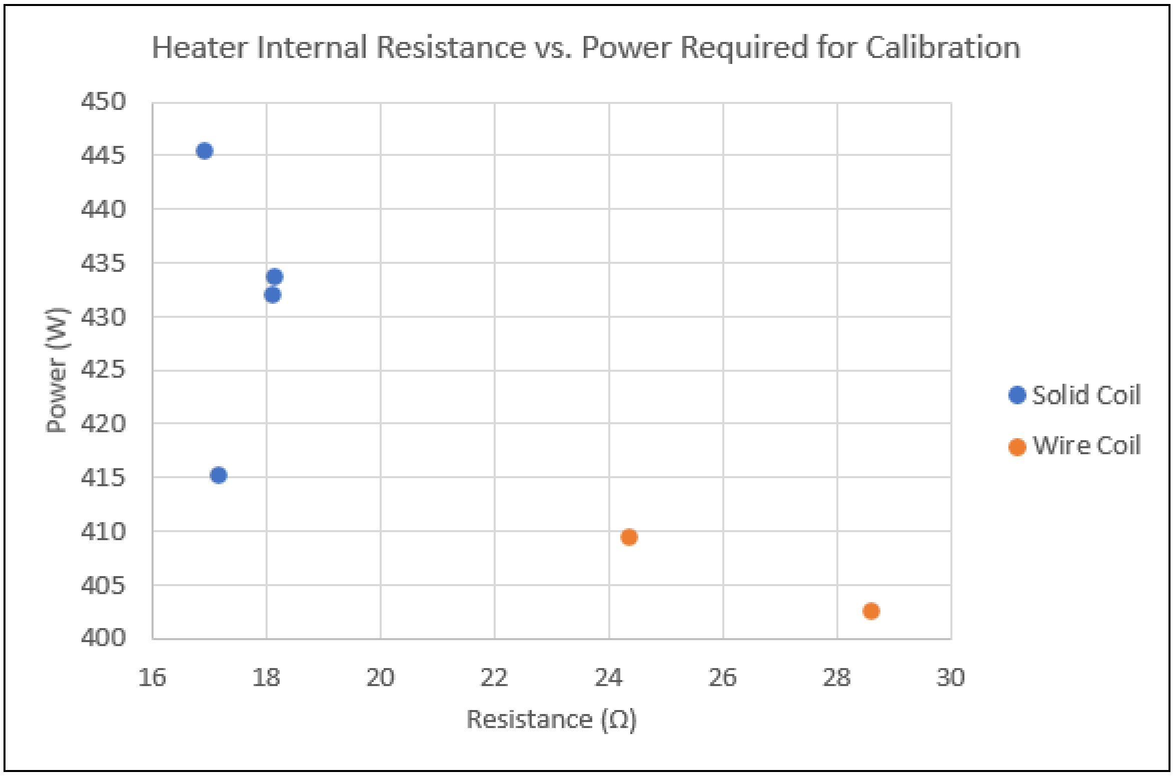

Figure 41. Resistance vs. Power for calibration for each heater

3 Summary of results

The purpose of this testing was to improve the repeatability of the evacuation slide, ramp, and raft radiant heat test. Round robin testing showed a disparity in test results among certain labs testing the same materials. Several variables were identified that may have caused this variation: the distance from the heater to the test sample, different calorimeter calibrations, leaks around the edge of the test sample, and variations in the voltage supplying the radiant heater.

Changes were made to the original test method to simplify the operation of this test method and to make the test results more repeatable. The distance from the surface of the test sample to the front of the furnace was changed to 2 inches, instead of being variable based on the heat flux measurement. That eliminated the distance variable and made the test simpler to operate.

Monitoring the power input to the radiant heater made the test more repeatable by keeping the heat flux more constant. The voltage from the analog voltage regulator can drift over time causing the heat flux to change along with it. Monitoring and adjusting the voltage as necessary keeps the heat flux constant and test results more repeatable. A self-regulating digital power supply was also tested and proved to be more consistent and easier to operate.

Further testing was done with six different radiant heaters and three different heat flux gauges. There was a much larger variation in power required to reach 1.50 Btu/ft^{2}s when changing heaters than changing heat flux gauges. This large disparity in the heaters means the heat flux gauge cannot be eliminated when calibrating this test apparatus. The heat flux gauge must be used for calibration and then the power must be monitored to ensure it stays constant.

4 Conclusions

Several changes were made to the radiant heat test method of evacuation slides, ramps, and rafts to eliminate variables and simplify operation. The center points of the calorimeter assembly and pressurized cylinder can now be aligned with the center point of the furnace much more easily using positioning tools. The inflated surface of the test sample must always be placed 2 inches from the front of the furnace, eliminating that distance as a variable and potential source of error. After the sample is installed and cylinder is pressurized, it must hold its pressure for 3 minutes before being rotated in front of the furnace to ensure there are no leaks that would cause erroneous test results. The power must be continually monitored and kept constant throughout testing to ensure that the heat flux does not change once set at 1.50 Btu/ft^{2}s. Older analog voltage regulators can drift over time and may need to be adjusted to maintain the initially set voltage. A self-regulating AC power source can maintain the initial voltage automatically and was shown to maintain tighter tolerances.

Testing was completed with six different radiant heaters and three different heat flux gauges, and the heat flux gauges proved to be much more repeatable than the heaters. There was a much smaller difference in the power required to reach 1.50 Btu/ft^{2}s when changing heat flux gauges compared to changing heaters, meaning that a correctly calibrated heat flux gauge is still the best method for calibrating this test apparatus.

5 References

Brown, L. J., & Nicholas, E. B. (1981). *Effect of Thermal Radiation on the Integrity of Pressurized Aircraft Evacuation Slides and Slide Materials.* FAA-CT-81-28: Department of Transportation, Federal Aviation Administration.

Federal Aviation Administration. (1983). *Technical Standard Order TSO-C69a Emergency Evacuation Slides, Ramps, and Slide/Raft Combinations.*

Federal Aviation Administration. (1988). *Technical Standard Order TSO-C69b Emergency Evacuation Slides, Ramps, and Slide/Raft Combinations.*

Federal Aviation Administration. (1999). *Technical Standard Order TSO-C69c Emergency Evacuation Slides, Ramps, and Slide/Raft Combinations.*

Federal Aviation Administration. (2000). *DOT/FAA/AR-00/12 Aircraft Materials Fire Test Handbook.*

Federal Aviation Agency. (1961). *Technical Standard Order TSO-C69 Emergency Evacuation Slides.* Washington D.C.: FAA.

Geyer, G. B., Brown, L. J., Neri, L. M., & O'Niell, J. H. (1978). *Preliminary Assessment of the Integrity of Aircraft Evacuation Slide Material When Exposed to thermal Radiation.* NA-78-41-LR: Department of Transportation, Federal Aviation Administration.

A Revised test method measuring the heat resistance of evacuation slides

A.1 Scope

Test method
This test method evaluates the ability of an evacuation slide material to resist heat and maintain pressure when subjected to a radiant heat source that simulates a large jet fuel fire. This test method is also used to show compliance with Technical Standard Order (TSO) C69A.

A.2 Definitions

Time-to-failure
The time-to-failure is the time between first application of heat to the sample and the first decrease in pressure below the maximum pressure attained in the test cylinder during the test.

Test sample
A test sample must replicate the material used in the pressurized portion of an evacuation slide vessel.

A.3 Test Apparatus

Pressure cylinder sample holder
The pressure cylinder consists of a 12-inch long (314 mm) aluminum cylinder with a 7-inch (178 mm) outside diameter (OD) and a 6.5-inch (165 mm) inside diameter (ID) and is used to hold the test sample in place and under pressure in front of the radiant heat source. Figure A-1 shows an overview diagram of the test apparatus. Refer to Appendix B for more details on the pressure cylinder and supporting parts.

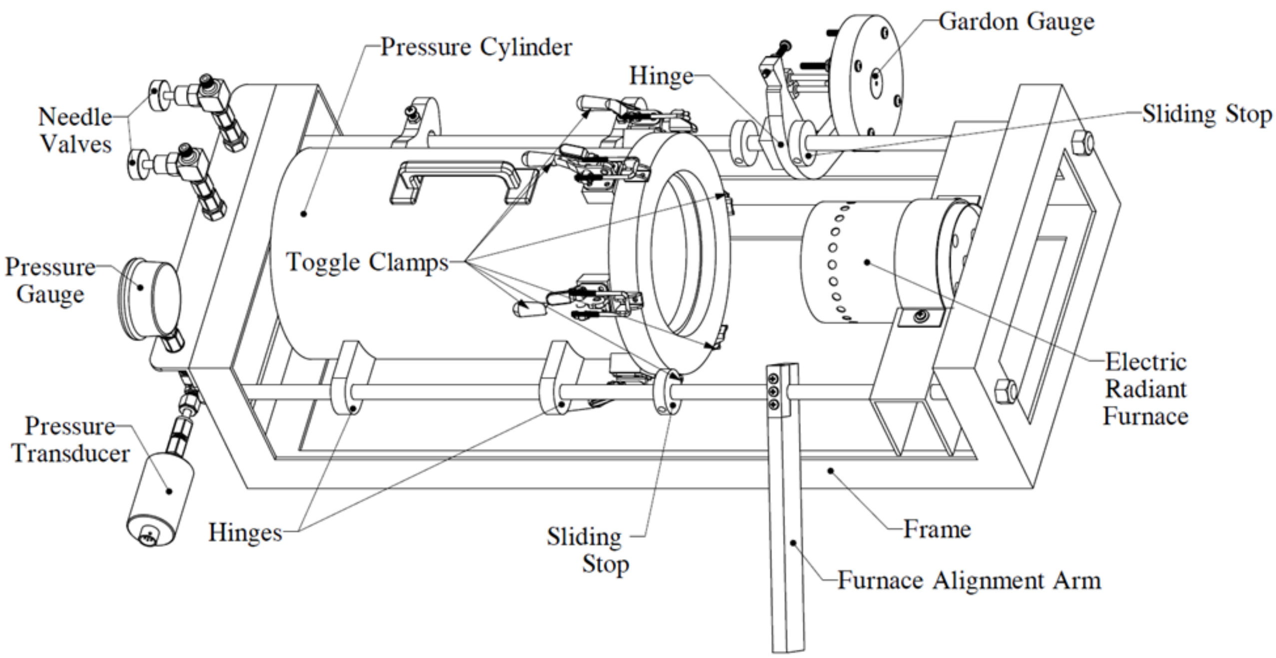

Figure A-1. Overview of evacuation slide material test apparatus

Electric furnace

An electric radiant furnace with a 3-inch (76-mm) diameter opening, as shown in Figure A-4, must be used to supply a constant irradiance on the sample surface. The diameter of the spiral element is nominally 3 inches. It is an 875-Watt, 120-Volt alternating current (AC) element with an internal resistance of approximately 17 ohms. It is shown to the right of the pressure cylinder in Figure A-1. Refer to Appendix B for more details on the electric furnace.

Furnace voltage control

A variable voltage control unit, 115-volt, 600-watt minimum, is connected to the electric furnace power supply to adequately control the heat flux from the furnace. The furnace control system must be capable of maintaining the irradiance level under steady-state conditions for a minimum of 20 minutes.

Voltmeter

The voltmeter is used to measure the input AC voltage going to the furnace and must have a range capable of measuring the maximum AC voltage produced by the input circuitry (typically 0–120 volts or 0–240 volts).

Ammeter

The ammeter is used to measure the input AC current going to the furnace and must have a minimum range of 0–7.5 amperes.

Apparatus framework

Pressure supply and equipment

Compressed air is supplied to the pressure cylinder through a needle valve attached to the end of the framework. A tee-manifold on the outlet side of the valve provides for a 0–5 psig pressure gauge, a transducer, a flexible tube to supply air to the rear plate of the pressure cylinder, and a bleed valve, as shown in Figure A-2.

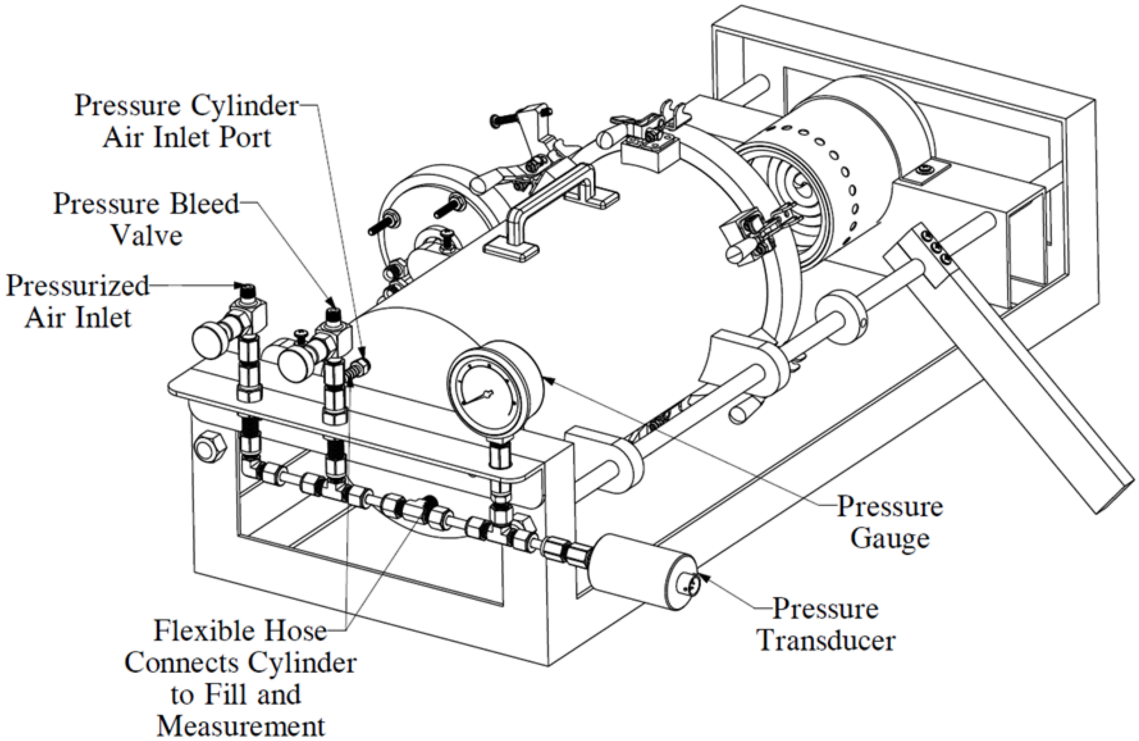

Figure A-2. Evacuation slide test apparatus in test position

Heat flux gauge

A 0 to 4.4 Btu/ft^{2}s (0 to 5 W/cm^2) water-cooled, Gardon-type heat flux gauge (HFG) must be used to measure the heat flux from the furnace. The calorimeter is mounted in a 4.5 inch (114 mm)-diameter by 0.75 inch (19 mm)-thick insulating block, such as calcium-silicate millboard, with the surface of the calorimeter flush with the surface of the insulating block. The HFG is hinged to one of the sliding bars of the framework and centered with the furnace, as shown in Figure A-1. The surface of the HFG must be 2 inches from the front edge of the radiant heater, as shown in Figure A-3. The HFG cooling water temperature, pressure, and flow must be maintained within the manufacturer's recommendations. Ensure no condensation occurs on the gauge surface at any time (often caused by cooling water being too cold).

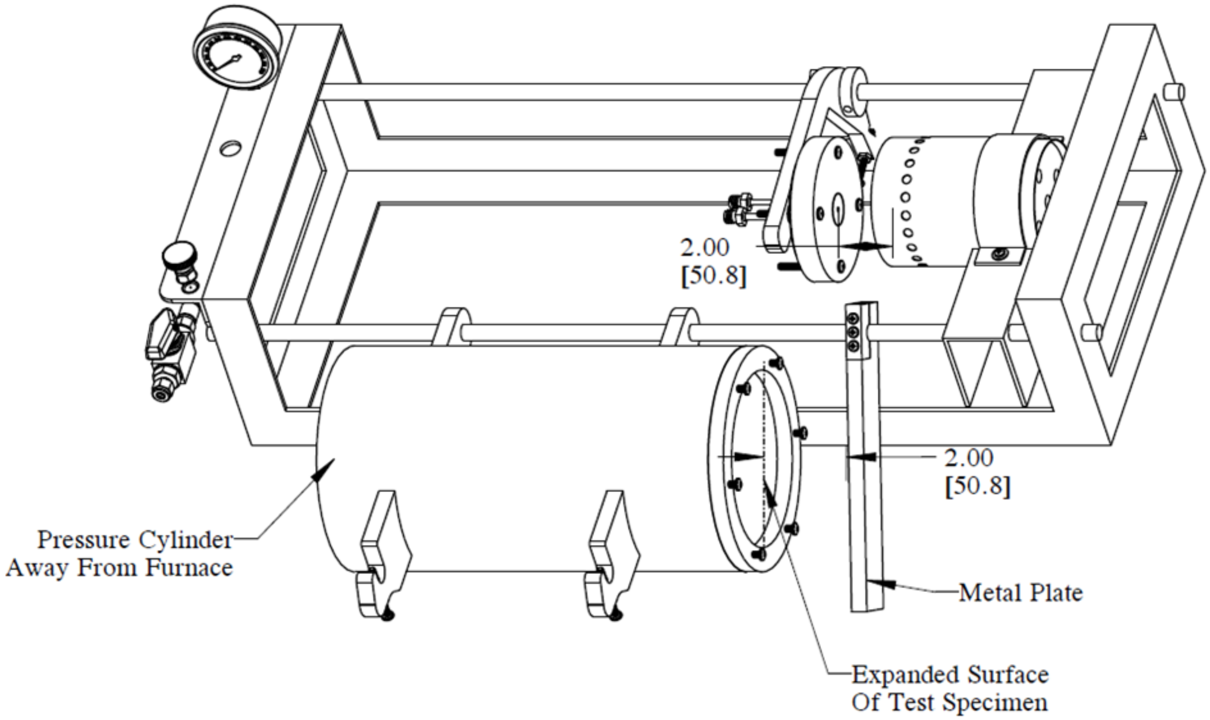

Figure A-3. Sample and heat flux gauge to furnace distance measurements

Instrumentation

Data acquisition

A calibrated recording device or a computerized data-acquisition system with an appropriate range must be used to measure and record the heat flux, the power input of the furnace, and pressure transducer reading. If a voltmeter is used, it requires a resolution of 0.01 V and an accuracy of 0.3%.

Timing device

A stopwatch or other device, accurate to within +/-1 second per 8 hours (+/-3 sec/day), must be used to measure the time of application of the burner flame and the test sample ignition and extinguishment times.

A.4 Apparatus configuration

Power measurement hardware

The source voltage (typically from a wall outlet) must first go to the voltage regulator to control the voltage input to the furnace. The output of the voltage regulator connects to the ammeter, which then connects to the furnace. The voltmeter is connected between the positive and negative leads going to the furnace. The voltage and current readings must be recorded during testing by a computerized data-acquisition system or other calibrated recording device. The data-acquisition system is connected to the voltmeter and ammeter to record the data and calculate the power input. Figure A-4 shows a schematic of this configuration.

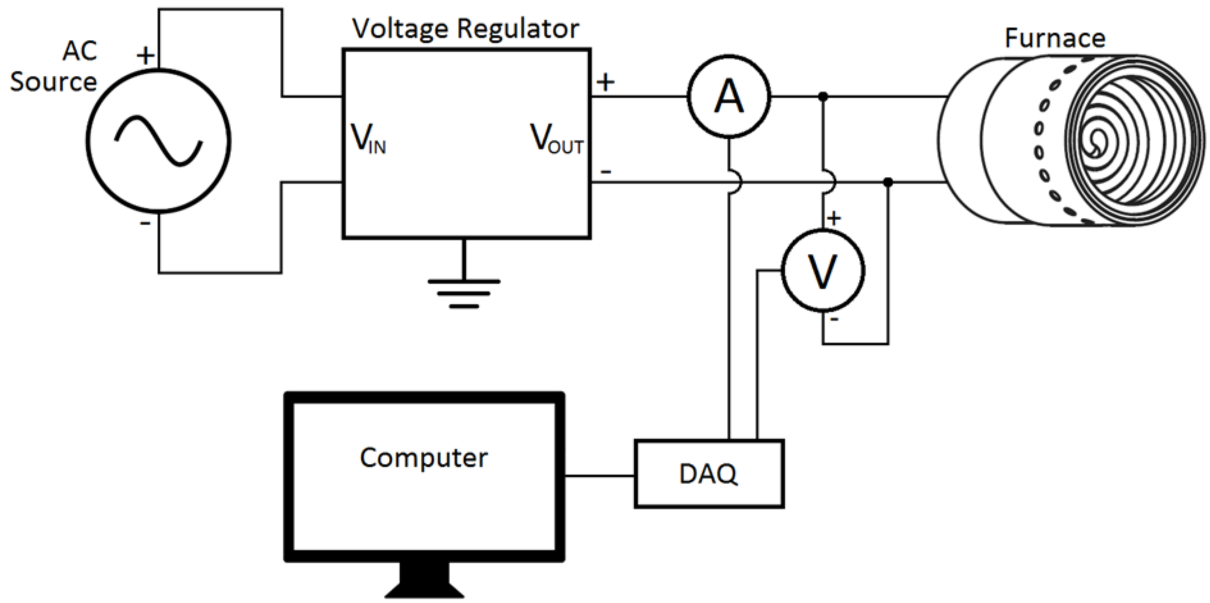

Figure A-4. Schematic of power measurement hardware

A.5 Test samples

Sample selection

Samples tested must be either cut from a fabricated slide as installed in the aircraft or cut from a section simulating a fabricated slide (e.g., cut from a flat sheet of material that simulates the fabricated slide). The sample may be cut from any location in the fabricated slide; however, the surface exposed to the burner must not consist of the finished or protected edge of the sample.

Sample directionality

For slides that may have different flammability characteristics in different directions (e.g., textiles), separate sets of samples cut from each direction showing the greatest difference (e.g., warp and fill) must also be tested.

Sample representation

If the evacuation slide (pressure holding material) has any exposed surfaces that are marked, overlay material, seams, or altered in any other manner that affects radiant heat resistance, each different surface must be tested as a separate sample set.

Sample number

Each separate set of samples prepared for testing must consist of at least three test samples.

Sample size

The test sample must be 7 inches (178 mm) in diameter with eight 0.25-inch (6-mm) holes punched in the material to match the studs in the pressure cylinder.

Test sample operating pressure

Nominal operating pressure is the pressure that the slide generally achieves when deployed under normal operating conditions. Each evacuation slide material has its own nominal operating pressure for the test. The nominal test pressure is the midpoint pressure between the highest and lowest normal deployment range pressures.

Test sample conditioning

Condition test samples at 70° ± 5°F (21° ± 3°C) and 55% +/- 10% relative humidity for a minimum of 24 hours before testing.

A.6 Furnace calibration

1. Conduct the calibration in a draft-free room or enclosed space.
2. Level the pressure cylinder and the furnace. Make certain that the center line of the pressure cylinder lines up with the center of the furnace when positioned in front of it.
3. Position the heat flux gauge in front of the furnace. Make certain that the center line of the heat flux gauge lines up with the center of the furnace and is positioned 2 inches from the front face of the furnace.
4. Turn on the heat flux gauge cooling water pump, radiant heat furnace, and other required instrumentation, and allow 30 to 45 minutes to stabilize the heat output and instrumentation.
5. Adjust the transformer voltage such that the heat flux is 1.50 Btu/ft^{2}s at steady-state. Record the power input to the furnace. This power level must be maintained throughout testing.

   NOTE: To prolong the life of the furnace, increase the voltage slowly.
6. Do not turn off the furnace. Use this radiant heat output for the test. Rotate the heat flux gauge out of position.

A.7 Procedure

1. Conduct the test in a draft-free room or enclosed space. It is recommended that tests be conducted under a hood or other means to remove potentially hazardous gases from the test area.

2. Mount the test sample with the reflective surface of the material facing the furnace on the open end of the cylinder. A neoprene gasket or comparable gaskets, such as silicone, must be positioned on each side of the test sample. Place the aluminum ring on the studs and tighten the nuts to 30 inch-pounds so that an airtight seal is achieved.

   NOTE: It is acceptable to use Toggle clamps instead of nuts and bolts (see Figure A-1) as a method to secure the test sample in place between the aluminum ring holder and the pressure cylinder.

3. Pressurize the cylinder to the correct operating pressure for the test sample material and check for leakage. The nuts must be torqued before and after the cylinder is pressurized to prevent air leakage from the cylinder. Ensure that the test sample holds the pressure for at least 3 minutes before testing. During this time, place a sheet of insulation board in front of the sample, while avoiding contacting the sample, to block any radiant heat from the furnace before the test starts (see Figure A-5).

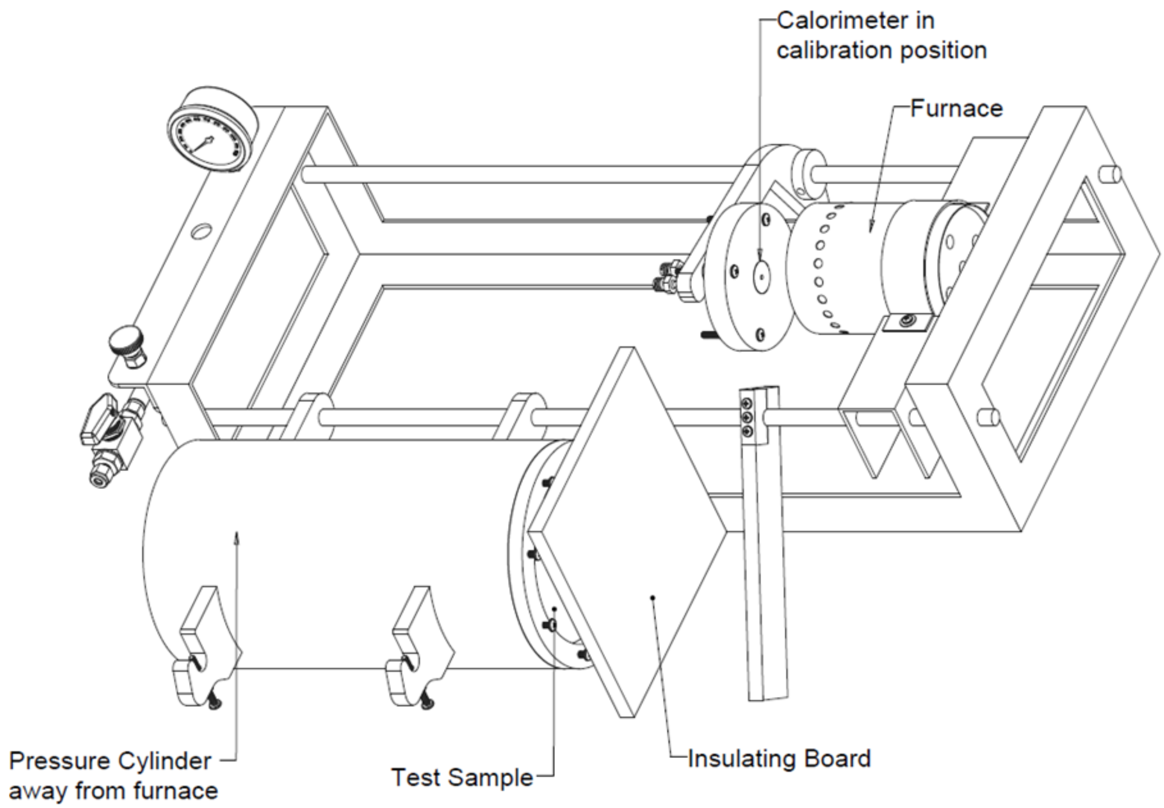

Figure A-5. Insulating board placed in front of sample during 3-minute waiting period

4. Using the sample distance measuring tool, check the distance from the center of the expanded surface of the test sample to the furnace. Ensure that this distance is 2 inches once the pressure cylinder with test sample is rotated into test position (see Figure A-3).
5. Check and ensure the power input is the same as measured during calibration.
6. Rotate the pressurized cylinder with the test sample in front of the radiant heat furnace. Simultaneously start the timer.
7. Monitor the pressurized cylinder from the time the test sample is placed in front of the furnace until the first observed pressure loss.
8. Record time-to-failure in seconds.
9. The duration of the test is 180 seconds.

A.8 Report

Report material description and full identification of the sample. This may include type of fabric and coating, manufacturer, manufacturer style number, weight, thickness, color, and any alterations, if applicable.

- Report the starting pressure for each of the three samples.
- Report any observations of the material's behavior during the test and times of the occurrence.
- Report the time-to-failure for each of the test samples.

A.9 Requirement

A minimum of three samples must be tested. At least 80% of the test samples must maintain the correct pressure for a minimum of 180 seconds.

B Evacuation slide radiant heat test apparatus

B.1 Scope

Applicability

This test apparatus is intended for use in determining the ability of a material to resist heat and maintain pressure when subjected to a radiant heat source that simulates a large jet fuel fire.

B.2 Definitions

Radiant heat source

The radiant heat source is a 3-inch diameter circular electric furnace with a spiral tubular heating element.

Time-to-failure

The time-to-failure is the time between first application of heat to the sample and the first decrease in pressure below the maximum pressure attained in the test cylinder during the test.

Test sample

A test sample is a flat, 7-inch diameter circle that must replicate a material installed on an aircraft.

B.3 Test apparatus

Pressure cylinder sample holder

The pressure cylinder consists of a 12.375-inch-long (314 mm) aluminum cylinder with a 7-inch (178 mm) outside diameter (OD) and a 6.5-inch (165 mm) inside diameter (ID), as shown in Figure B-1 and Figure B-2.

1. An aluminum plate 0.5-inches (13 mm) thick must be welded to one end of the cylinder and must be drilled and tapped near its upper edge for a 0.25-inch (6.4-mm) National Pipe Thread (NPT) pipe to facilitate the installation of air pressure and pressure recording equipment.
2. An aluminum ring 7 inches (178 mm) OD, 5.5 inches (140 mm) ID, and 0.5 inch (13 mm) thick must be welded to the other end of the cylinder. The ring must have eight evenly spaced 10-32 bolt holes on the circle, 0.3125 inch (8 mm) from the ring's inner edge. The diameter of this circle is 6.125 inches (156 mm) and the adjacent bolt holes are 2.3125 inches (59 mm) apart (see figure A2-2 for detail dimensions). A 10-32 steel bolt 0.875 inches (22 mm) long will be placed into each of the holes.
3. Another aluminum ring, 6.75 inches (171 mm) OD, 5.5 inches (140 mm) ID, and 0.5 inch (13 mm) thick, with two neoprene or comparable (e.g., silicone rubber) gaskets with similar clearance holes to fit over the bolts, must provide a means for clamping and sealing the test sample in place. Hinges and adjustable stops will be welded to the sides of the cylinder, as shown Figure B-1 and Figure B-2.

   NOTE: It is acceptable to use toggle clamps instead of nuts and bolts (see Figure B-1*) as a method to secure the test sample in place between the aluminum ring holder and the pressure cylinder.*

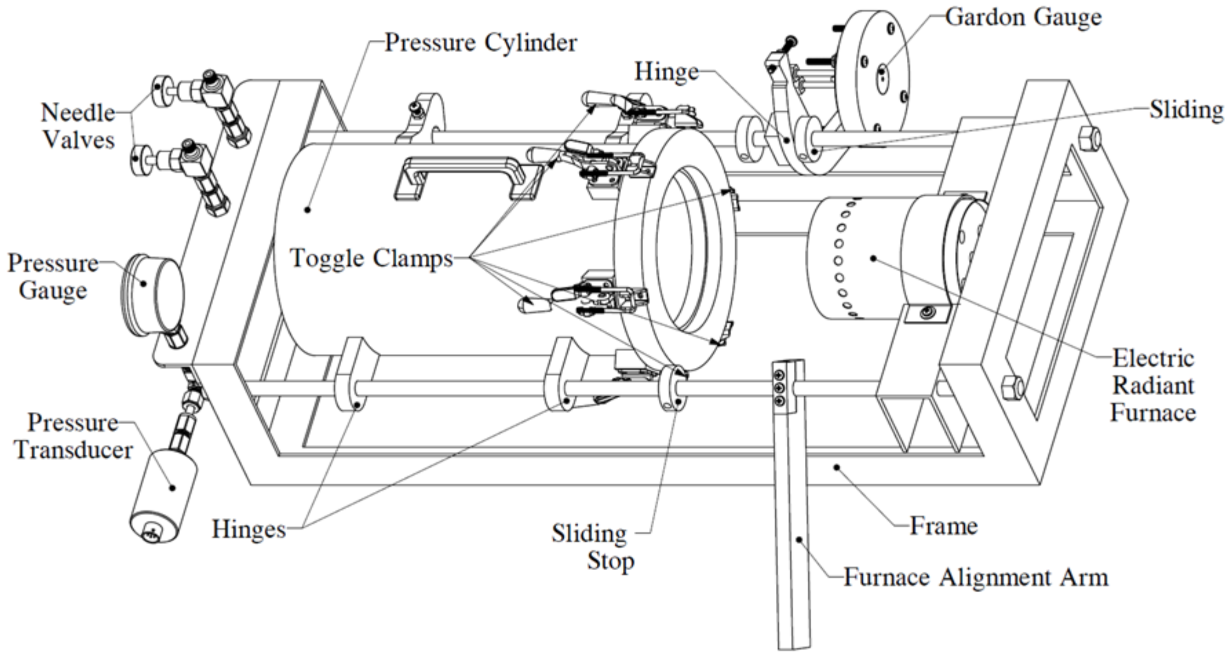

Figure B-1. Overview of evacuation slide material test apparatus

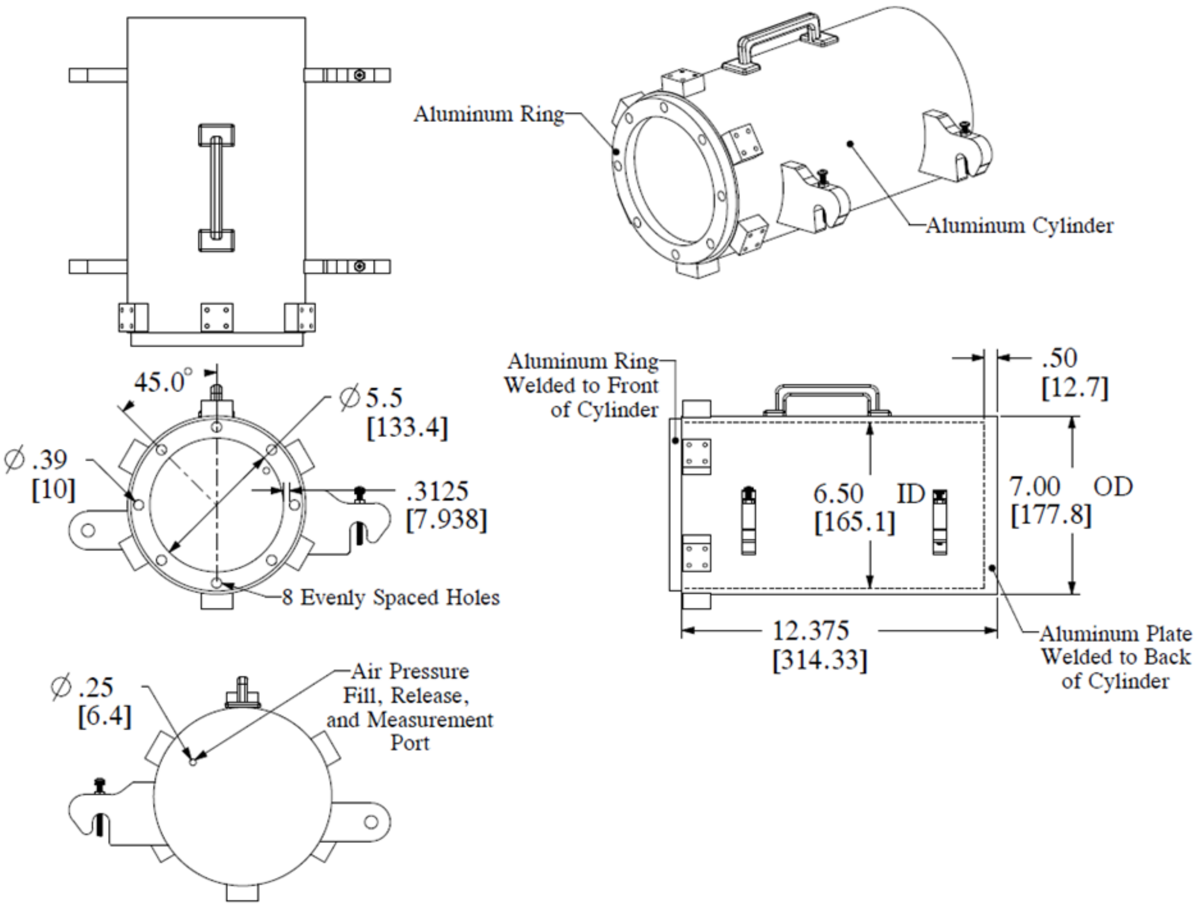

Figure B-2. Dimensioned drawing of the pressure cylinder

Test apparatus frame

The test apparatus frame must be able to support the electric furnace, pressure cylinder sample holder, and heat flux gauge. The furnace is fixed in place at one end but the pressure cylinder and heat flux gauge must be able to rotate into and out of test position and translate toward and away from the furnace. The dimensions of the frame are not critical, but an example is shown in Figure B-3.

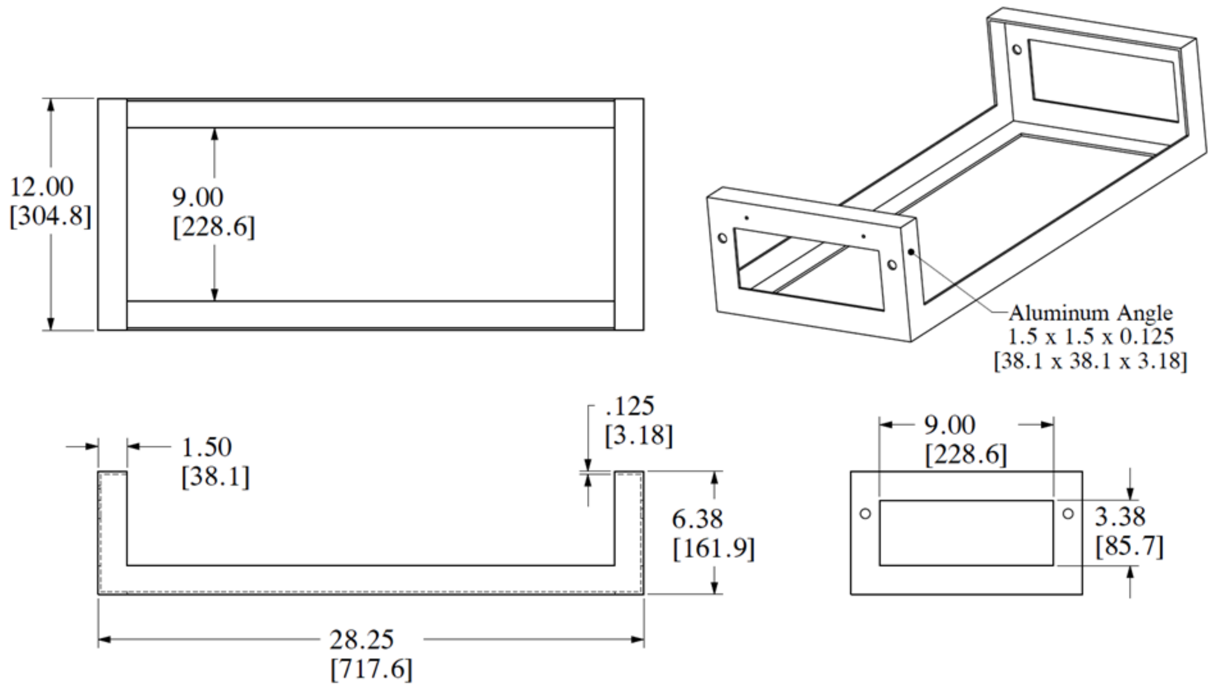

Figure B-3. Dimensioned drawing of the frame

Electric furnace

An electric radiant furnace with a 3-inch (76-mm) diameter opening, as shown in Figure B-4, must be used to supply a constant irradiance on the sample surface. The radiant furnace uses a spiral tubular heating element with a 0.260-inch Inconel sheath diameter as the heat source. The diameter of the spiral element is nominally 3 inches. It is an 875-Watt, 120-Volt alternating current (AC) element with an internal resistance of approximately 17 ohms. The front half of the furnace housing is constructed from rolled sheet metal with an outer diameter (OD) of 4 inches (102 mm) and inside diameter (ID) of 3.938 inches (100 mm). The back half has an OD of 3.875 inches (98 mm) and an ID of 3.813 inches (97 mm). The face of the furnace coil is recessed 0.0938 inch (2.4 mm) from the edge of the front housing. Ceramic insulating rings are placed inside the housing to fill the space between the heating coil and the housing.

NOTE: A suitable 875-Watt electric furnace is manufactured by Newport Scientific Inc. of Jessup, MD, 301-498-6700. Part numbers 68086038000 and 68086040400 are both acceptable. This is the same furnace used in the NBS Smoke Density Chamber.

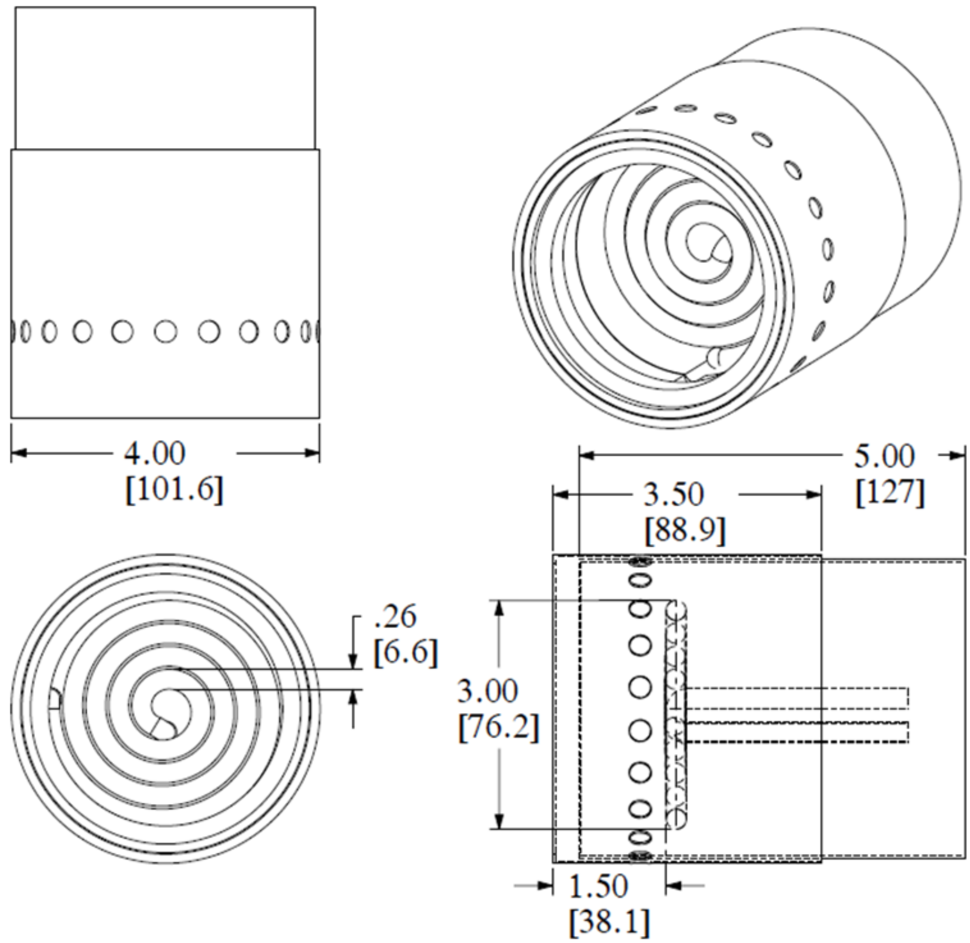

Figure B-4. Dimensioned drawing of the electric radiant furnace

Heating element orientation

The heating element must be oriented as shown in Figure B-5. This orientation minimizes interlab differences, as results have shown that orientation influences the shape of the heat profile impacting the test sample.

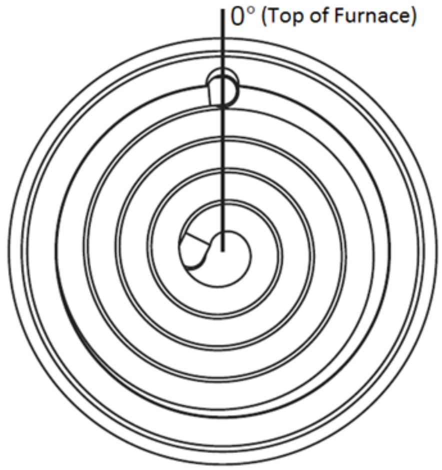

Figure B-5. Heating element orientation

Heating element position

The location of the heat element must be 1.5 inches from the open face of the furnace.

Furnace power control

A variable voltage or power control unit—115-Volt, 600-Watt minimum—is connected to the electric furnace power supply to adequately control the heat flux from the furnace. The furnace control system must be capable of maintaining the irradiance level under steady state conditions for a minimum of 20 minutes.

NOTE: A suitable power control unit is manufactured by Keysight Technologies of Santa Rosa, CA. Model AC6802 Basic AC Power Source rated at 1000 VA is acceptable.

Voltmeter

The voltmeter is used to measure the input AC voltage going to the furnace and must have a range capable of measuring the maximum AC voltage produced by the input circuitry (typically 0–120 Volts or 0–240 Volts).

Ammeter

The ammeter is used to measure the input AC current going to the furnace and must have a minimum range of 0–7.5 amperes.

Apparatus framework

Pressure supply and equipment

Compressed air is supplied to the pressure cylinder through a needle valve attached to the end of the framework. A tee-manifold on the outlet side of the valve provides for a 0 to 5 psig pressure gauge, a transducer, a flexible tube to supply air to the rear plate of the pressure cylinder, and a bleed valve, as shown in Figure B-6.

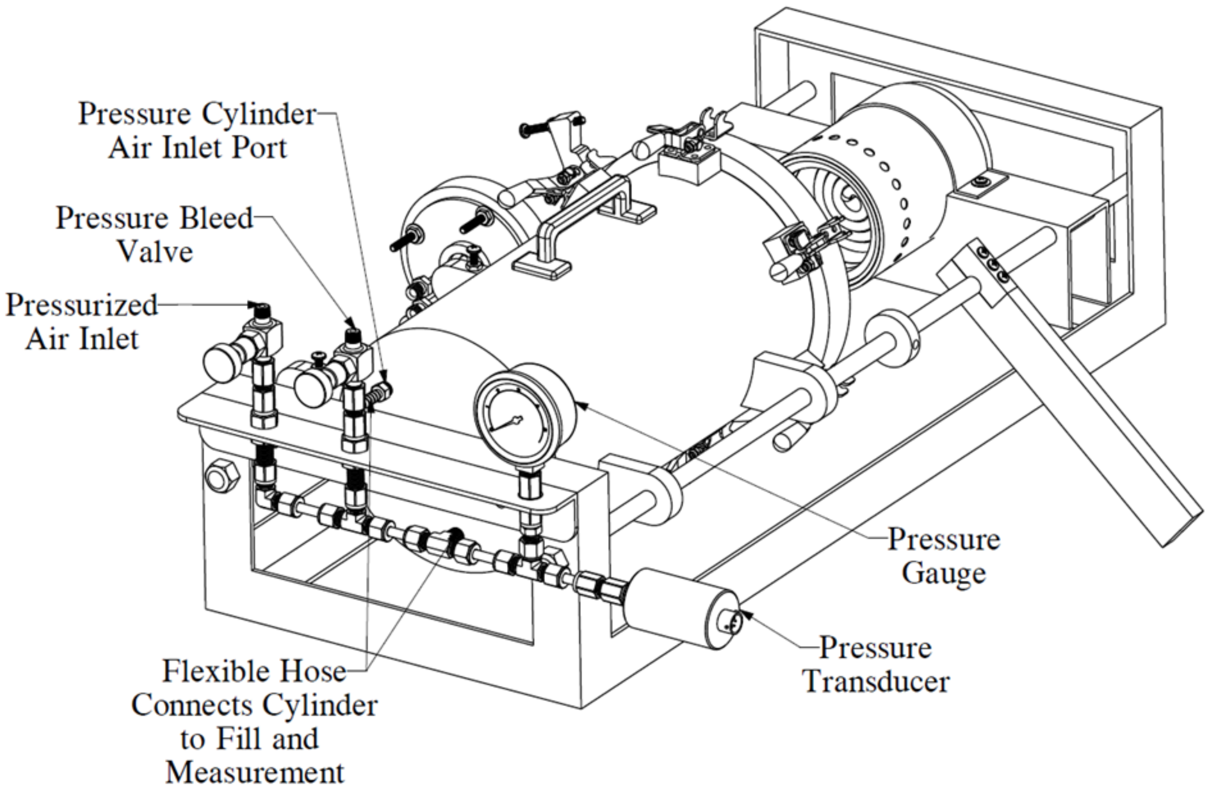

Figure B-6. Evacuation slide test apparatus in test position

Heat flux gauge

A 0 to 4.4 Btu/ft^{2}s (0 to 5 W/cm^2) water-cooled, Gardon-type HFG must be used to measure the heat flux from the furnace. The HFG is mounted in a 4.5 inch (114 mm)-diameter by 0.75 inch (19 mm)-thick insulating block, such as calcium-silicate millboard, with the surface of the HFG flush with the surface of the insulating block. The HFG is hinged to one of the sliding bars of the framework and centered with the furnace, as shown in Figure B-1. The surface of the HFG must be 2 inches from the front edge of the radiant heater, as shown in Figure B-7. The HFG cooling water temperature, pressure, and flow must be maintained within the manufacturer's recommendations. Ensure no condensation occurs on the gauge surface at any time (often caused by cooling water being too cold).

The HFG must have a thin, full-faced, opaque coating of high-temperature, high-emissivity, ultra-flat black paint. The sensitivity of the gauge is a function of the surface condition. Changes in the coating may cause drift in the overall characteristics of the gauge. Regularly inspect the measuring surface for physical damage or dust particles that may have accumulated. Cleaning is accomplished by gently wiping a soft, water-dampened sponge across the sensor face. Damage done to the coating during the cleaning process affects the measurement accuracy of the sensor. To maintain accuracy, the measuring surface must be recoated at regular intervals, followed by annual recalibration. See Appendix A for full details on the HFG and its required calibration.

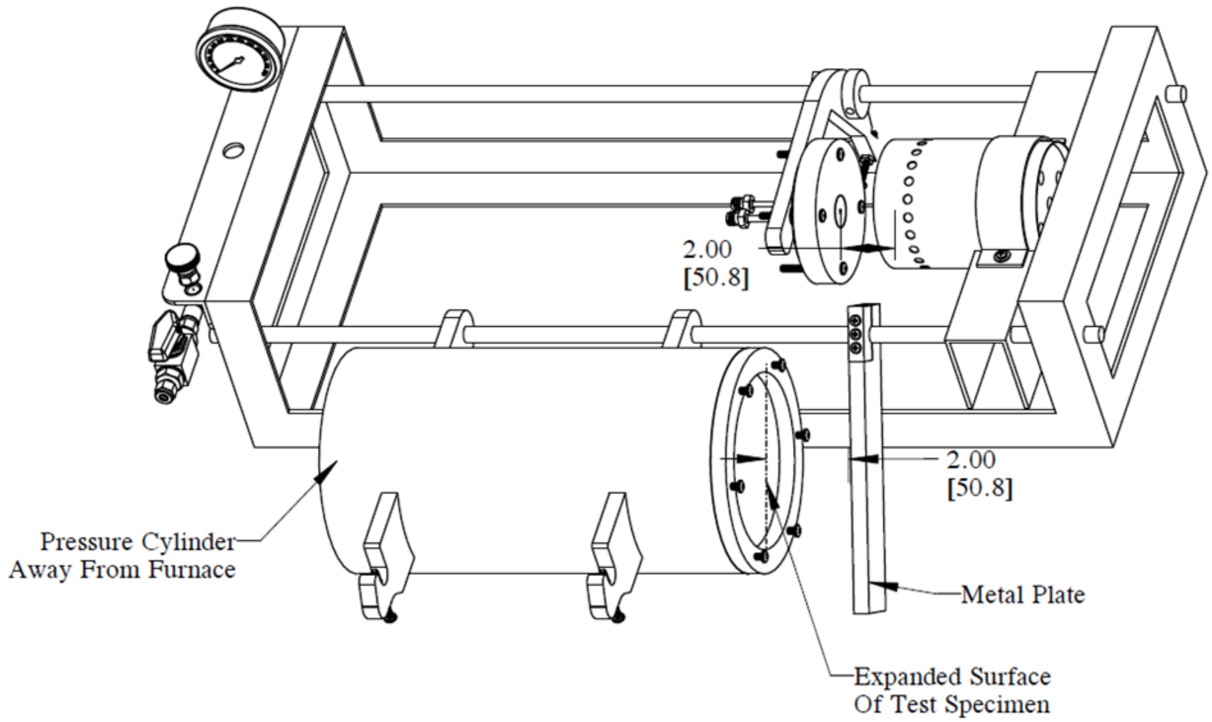

Figure B-7. Sample and heat flux gauge to furnace distance measurements

Alignment tools

Before performing the calibration and test procedures, the center points of the HFG and pressure cylinder must each align with the center point of the furnace. Use two tools to easily perform and periodically inspect these alignments.

Various methods of mounting the furnace are in practice and some include methods which may be prone to unintentional misalignment. The frequency of alignment inspection is dictated by the rigidity of fixture, i.e., if the fixtures are rigid and do not easily allow misalignment. Align fixture monthly and each time the HFG is replaced.

Pressure cylinder alignment tool

It is recommended that a tool be used to align the center of the furnace with the pressure cylinder. The tool must be a round disk with a 4-inch hole in the center and designed to either be bolted to the pressure cylinder or fit with the toggle clamps. An example of a tool that can be bolted is a 6.75-inch diameter disk with 8 evenly spaced holes placed 3.0625-inch from the center (see Figure B- 8). An example of a tool to fit a pressure cylinder with clamps has a 5.5-inch diameter lip to fit inside the inside diameter of the pressure cylinder (see Figure B- 9.

No matter which design is used, it must be mounted on the front of the pressure cylinder and slid in front of the furnace. Then adjustments must be made to align the 4-inch inner diameter of the tool with the 4-inch outer diameter of the furnace (see Figure B- 10).

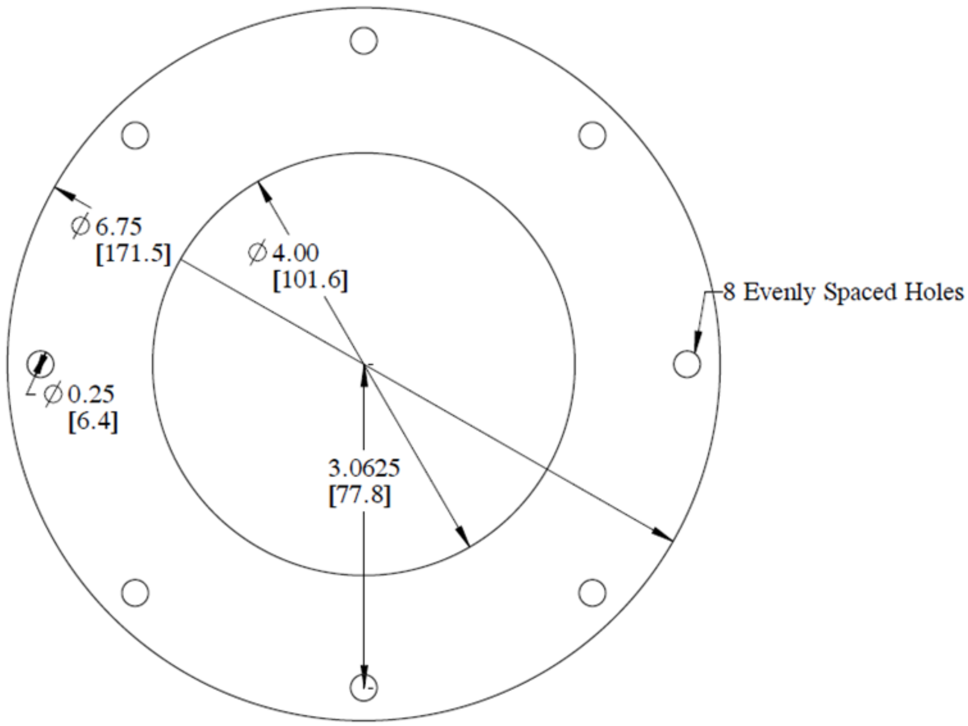

Figure B- 8. Pressure cylinder alignment tool for bolted desig

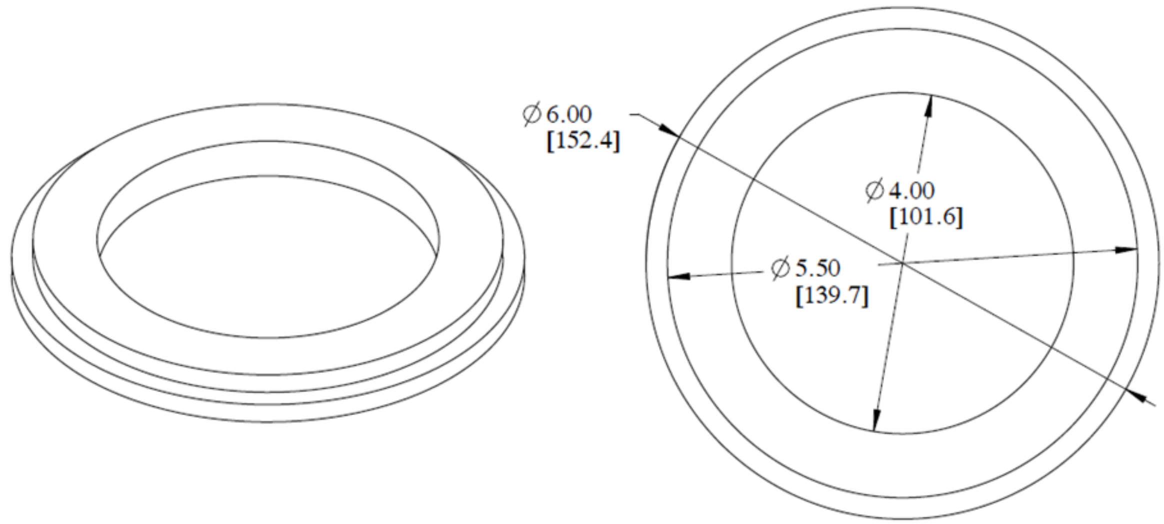

Figure B- 9. Pressure cylinder alignment tool for toggle clamps

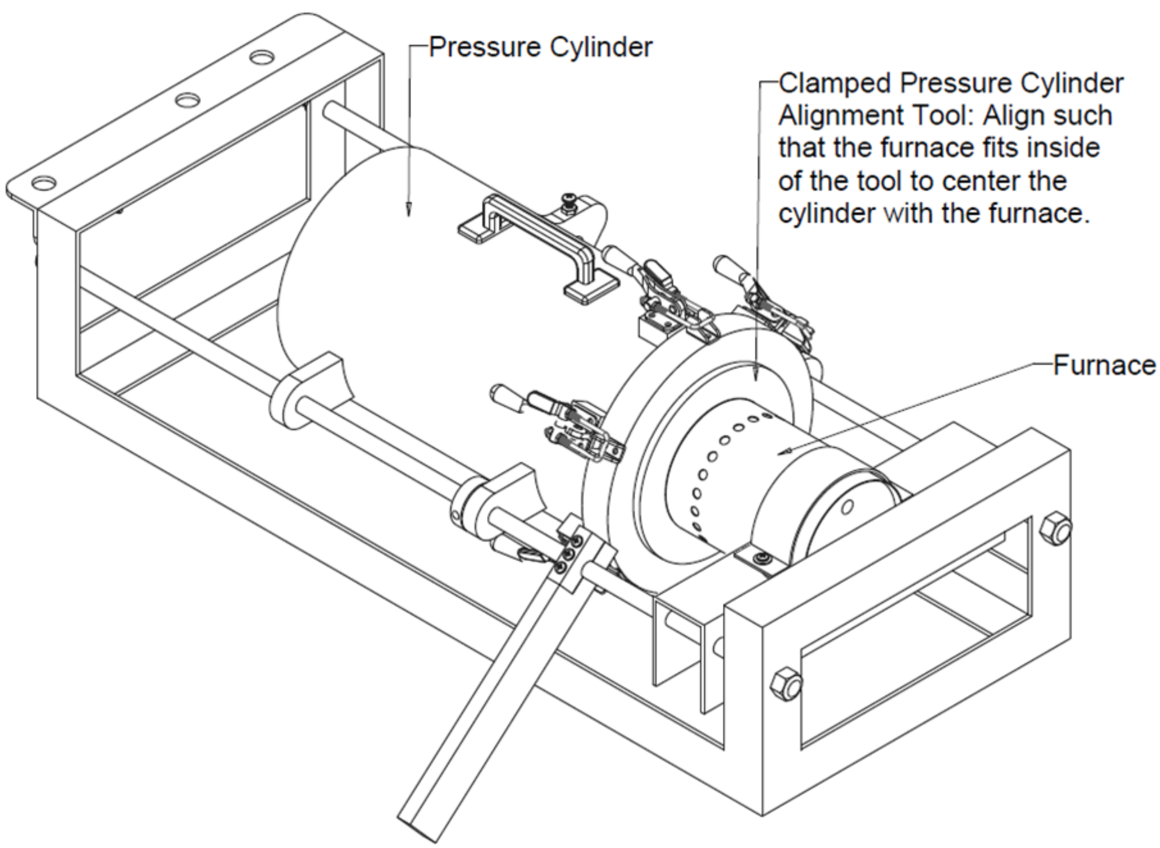

Figure B- 10. Clamped cylinder alignment tool in place

Heat flus gauge alignment tool

The tool used to align the center of the HFG with the center of the furnace is a 4-inch diameter disk with a 1-inch diameter hole in the center, as shown in Figure B- 11. The disk is placed such that the 1-inch hole fits around the 1-inch diameter HFG. Then the HFG assembly and disk is slid over to match up with the front of the furnace. The 4-inch outer diameter of the disk needs to align with the 4-inch outer diameter of the furnace. Make the necessary adjustments until HFG and furnace are aligned, as shown in Figure B- 12.

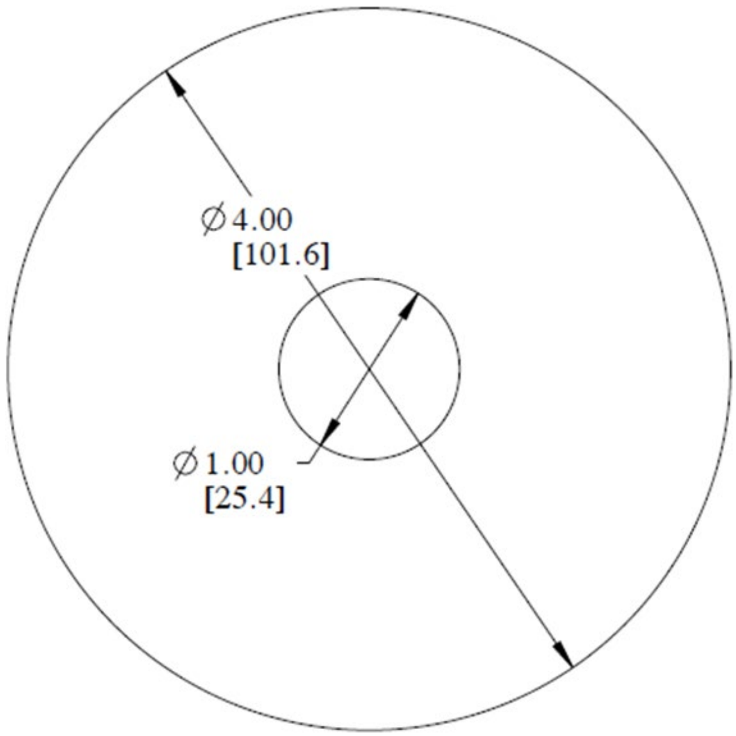

Figure B- 11. Heat flux gauge alignment tool

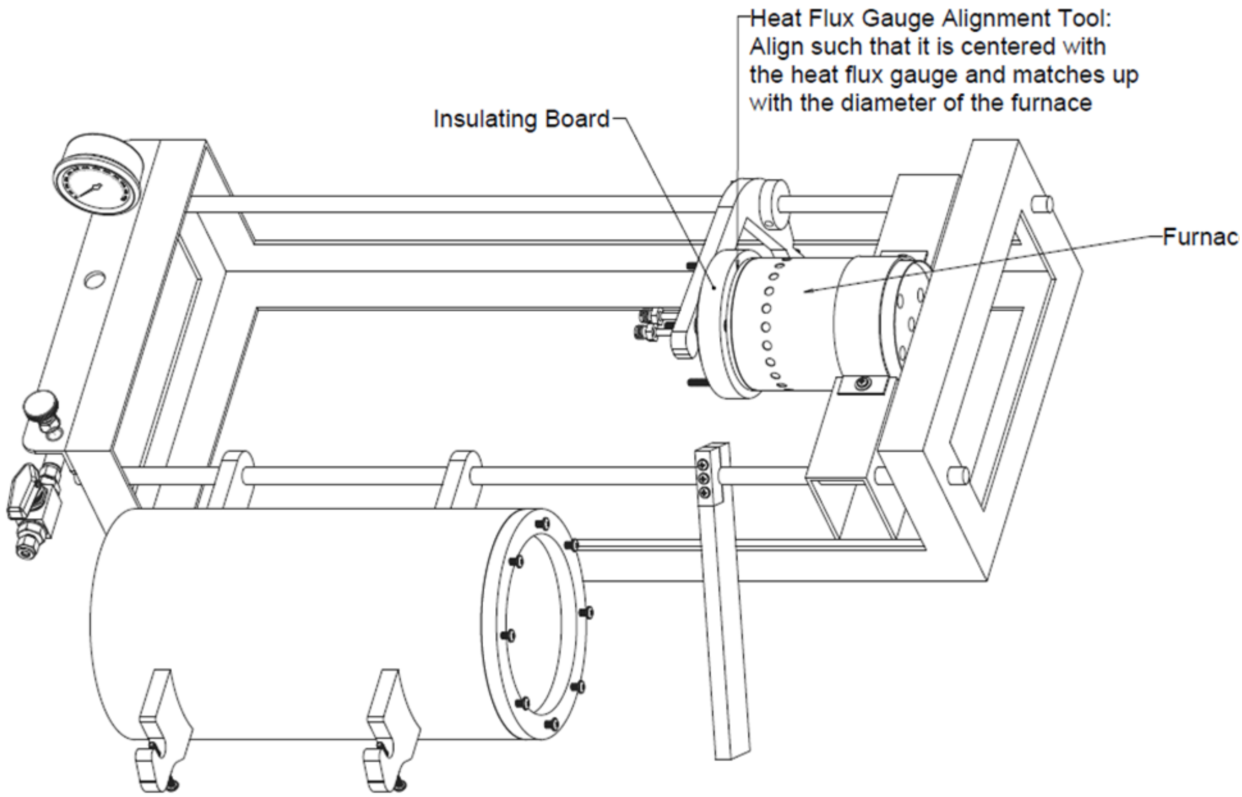

Figure B- 12. HFG alignment tool placed between HFG and furnace

Test sample to furnace distance measurement tool

After pressurizing the pressure cylinder with a test sample in place, the surface of the sample expands outward. The farthest edge of this surface must be placed 2 inches from the front of the furnace. This must be measured when the pressure cylinder is away from the furnace to not expose the sample to its radiant heat. Therefore, a metal plate that aligns with the front of the furnace is placed in front of the pressure cylinder when it is rotated out of position (see Figure B-13). To reach the correct position, slide the pressure cylinder until the expanded surface of the test sample is 2 inches from the metal plate and tighten the sliding stop to hold that position.

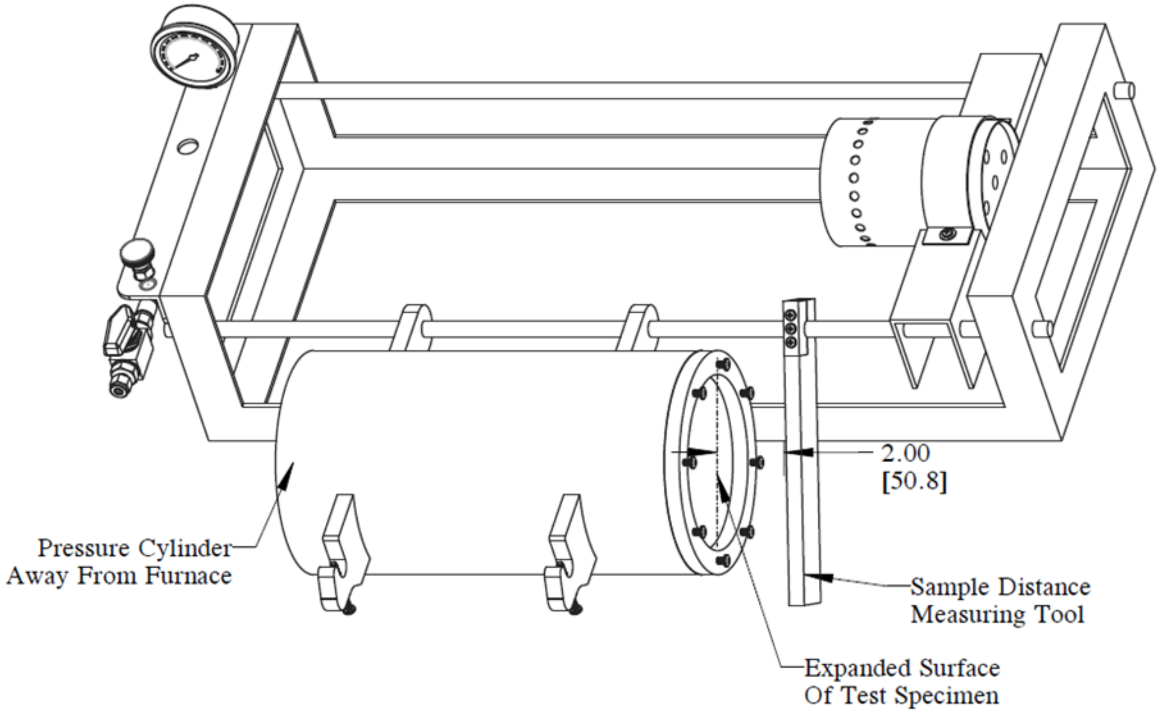

Figure B-13. Sample to furnace distance measurement

Instrumentation

Data acquisition

A calibrated recording device or a computerized data-acquisition system with an appropriate range must be used to measure and record the power input of the furnace and pressure transducer. If a voltmeter is used, it requires a resolution of 0.01 V and an accuracy of 0.3%.

Timing device

A stopwatch or other device, accurate to within +/-1 second per 8 hours (+/-3 sec/day), must be used to measure the time of application of the burner flame, and the test sample ignition and extinguishment times.